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ENGINEERING DESIGN HANDBOOK

GUNS SERIES

AUTOMATIC WEAPONS

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ENGINEERING DESIGN HANDBOOK
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Paragraph		Page
	LIST OF ILLUSTRATIONS	vi
	LIST OF TABLES	viii
	LIST OF SYMBOLS	x
	PREFACE	xviii
	CHAPTER 1. INTRODUCTION	
1-1	SCOPE AND PURPOSE	1-1
1-2	GENERAL	1-1
1-3	DEFINITIONS	1-1
1-4	DESIGN PRINCIPLES FOR AUTOMATIC WEAPONS	1-1
	CHAPTER 2. BLOWBACK WEAPONS	
2-1	GENERAL	2-1
2-2	SIMPLE BLOWBACK	2-3
2-2.1	SPECIFIC REQUIREMENTS	2-3
2-2.2	TIME OF CYCLE	2-4
2-2.2.1	Recoil Time	2-5
2-2.2.2	Counterrecoil Time	2-6
2-2.2.3	Total Cycle Time	2-7
2-2.3	EXAMPLE OF SIMPLE BLOWBACK GUN	2-8
2-2.3.1	Specifications	2-8
2-2.3.2	Computed Design Data	2-8
2-2.3.3	Case Travel During Propellant Gas Period	2-10
2-2.3.4	Sample Problem of Case Travel	2-10
2-2.3.5	Driving Spring Design	2-11
2-3	ADVANCED PRIMER IGNITION BLOWBACK	2-12
2-3.1	SPECIFIC REQUIREMENTS	2-12
2-3.2	SAMPLE CALCULATIONS OF ADVANCED PRIMER IGNITION	2-13
2-3.2.1	Firing Rate	2-13
2-3.2.2	Driving Spring Design	2-15
2-4	DELAYED BLOWBACK	2-17
2-4.1	SPECIFIC REQUIREMENTS	2-17
2-4.2	DYNAMICS OF DELAYED BLOWBACK	2-18
2-4.3	SAMPLE PROBLEM FOR DELAYED BLOWBACK ACTION	2-24
2-4.3.1	Specifications	2-24
2-4.3.2	Design Data	2-24
2-4.4	COMPUTER ROUTINE FOR COUNTERRECOILING BARREL DYNAMICS	2-33
2-4.5	SPRINGS	2-37
2-4.5.1	Driving Spring	2-37
2-4.5.2	Barrel Spring	2-39
2-4.5.3	Buffer Spring	2-39
2-5	RETARDED BLOWBACK	2-40
2-5.1	SPECIFIC REQUIREMENTS	2-40

TABLE OF CONTENTS (Con't.)

Paragraph		Page
2–5.2	DYNAMICS OF RETARDED BLOWBACK	2–40
2–5.2.1	Kinematics of the Linkage	2–40
2–5.2.2	Equations of Dynamic Equilibrium	2–43
2–5.2.3	Digital Computer Program for the Dynamic Analysis	2–44
2–6	RATING OF BLOWBACK WEAPONS	2–47

CHAPTER 3. RECOIL-OPERATED WEAPONS

3–1	GENERAL	3–1
3–2	LONG RECOIL DYNAMICS	3–1
3–3	SAMPLE PROBLEM – LONG RECOIL MACHINE GUN	3–1
3–3.1	SPECIFICATIONS	3–1
3–3.2	DESIGN DATA	3–1
3–4	SHORT RECOIL DYNAMICS	3–9
3–5	SAMPLE PROBLEM – SHORT RECOIL MACHINE GUN	3–9
3–5.1	SPECIFICATIONS	3–9
3–5.2	DESIGN DATA	3–9
3–6	ACCELERATORS	3–15
3–7	SAMPLE PROBLEM – ACCELERATOR	3–17
3–7.1	SPECIFICATIONS	3–17
3–7.2	DESIGN DATA	3–17
3–8	RATING OF RECOIL-OPERATED GUNS	3–21

CHAPTER 4. GAS-OPERATED WEAPONS

4–1	GENERAL REQUIREMENTS	4–1
4–2	TYPES OF GAS SYSTEMS	4–1
4–3	CUTOFF EXPANSION SYSTEM	4–1
4–3.1	MECHANICS OF THE SYSTEM	4–1
4–3.1.1	Gas Filling Period	4–6
4–3.1.2	Bolt Locking Cam	4–9
4–3.1.3	Cam Curve	4–15
4–3.2	SAMPLE PROBLEM FOR CUTOFF EXPANSION SYSTEM	4–17
4–3.2.1	Specifications	4–17
4–3.2.2	Design Data, Computed	4–17
4–3.2.3	Counterrecoil Computed Data	4–19
4–3.2.4	Counterrecoil Time	4–20
4–3.2.5	Recoil Time	4–23
4–3.2.5.1	Recoil Time, Decelerating	4–23
4–3.2.5.2	Recoil Time, Accelerating	4–24
4–3.3	DIGITAL COMPUTER ROUTINE FOR CUTOFF EXPANSION	4–28
4–3.3.1	Gas Dynamics Before Cutoff	4–28
4–3.3.2	Gas Dynamics After Cutoff	4–29
4–3.3.2.1	Bolt Unlocking During Helix Traverse	4–29
4–3.3.2.2	Bolt Unlocking During Parabola Traverse	4–29
4–3.3.2.3	Bolt Unlocked, Bolt Traveling With Operating Rod	4–31

TABLE OF CONTENTS (Con't.)

Paragraph		Page
4–3.3.3	Dynamics After Gas Cylinder Operations	4–32
4–3.3.3.1	Recoil Dynamics	4–32
4–3.3.3.2	Counterrecoil Dynamics	4–35
4–3.3.3.3	Bolt Locking Dynamics	4–36
4–3.3.3.4	Firing Rate	4–37
4–3.4	SPRINGS	4–37
4–3.4.1	Driving Spring	4–37
4–3.4.2	Buffer Spring	4–37
4–4	THE TAPPET SYSTEM	4–38
4–4.1	SAMPLE PROBLEM	4–38
4–4.1.1	Specifications	4–38
4–4.1.2	Preliminary Design Data	4–38
4–4.1.3	Design Data, Computed	4–38
4–4.1.4	Spring Design Data	4–45

CHAPTER 5. REVOLVER-TYPE MACHINE GUNS

5–1	SINGLE BARREL TYPE	5–1
5–1.1	PRELIMINARY DYNAMICS OF FIRING CYCLE	5–2
5–1.1.1	Sample Problem of Preliminary Firing Rate Estimate	5–7
5–1.1.2	Analysis of Cam Action	5–8
5–1.1.2.1	Sample Calculation of Cam Action	5–14
5–1.1.2.2	Driving Spring	5–18
5–1.2	FINAL ESTIMATE OF THE COMPLETE FIRING CYCLE	5–18
5–1.2.1	Control of Recoil Travel During Propellant Gas Period	5–20
5–1.2.2	Operating Cylinder Design	5–23
5–1.2.3	Dynamics of Simultaneous Adapter-operating Cylinder Action	5–31
5–1.2.4	Sample Calculation for Complete Firing Cycle	5–32
5–1.2.4.1	Counterrecoil Time of Recoiling Parts	5–33
5–1.2.4.2	Digital Computer Analyses of Barrel-drum Dynamics	5–37
5–1.2.4.3	Firing Rate Computation	5–39
5–2	DOUBLE BARREL TYPE	5–46
5–2.1	FIRING CYCLE	5–46
5–2.1.1	Cam Function	5–46
5–2.1.2	Loading and Ejecting	5–48
5–2.1.3	Ammunition Feed System	5–48
5–2.2	DYNAMICS OF FIRING CYCLE	5–49
5–2.2.1	Cam Analysis	5–50
5–2.2.2	Energy Concept	5–52
5–2.2.3	Digital Computer Program for Firing Cycle	5–52

CHAPTER 6. MULTIBARREL MACHINE GUN

6–1	GENERAL	6–1
6–2	BOLT OPERATING CAM DEVELOPMENT	6–1
6–2.1	CAM ACTION	6–1
6–2.1.1	Cam Kinematics	6–3
6–2.1.2	Definition of Symbols	6–4
6–2.1.3	Cam Forces	6–5
6–2.1.4	Locking Angle	6–6

TABLE OF CONTENTS (Con't.)

Paragraph		Page
6–2.2	ROTOR KINEMATICS	6–7
6–2.3	ILLUSTRATIVE PROBLEM	6–9
6–2.3.1	Cam Analysis During Feed, Rotor at Constant Velocity	6–9
6–2.3.2	Cam Analysis During Ejection, Rotor at Constant Velocity	6–11
6–2.3.3	Cam Analysis During Rotor Acceleration	6–12
6–2.3.4	Digital Computer Program for Gun Operating Power	6–13
6–3	RATING OF GAS-OPERATED AND EXTERNALLY POWERED GUNS	6–14

CHAPTER 7. COMPONENT DESIGN

7–1	GENERAL	7–1
7–2	FEED MECHANISM DESIGN	7–1
7–2.1	MAGAZINES	7–2
7–2.1.1	Box Magazines	7–2
7–2.1.2	Box Feed System	7–4
7–2.1.2.1	Flat Tape Spring	7–5
7–2.1.2.2	Rectangular Coil Spring	7–5
7–2.1.3	Example Problems	7–6
7–2.1.3.1	Flat Tape Spring	7–7
7–2.1.3.2	Rectangular Coil Spring	7–8
7–2.2	BOLT-OPERATED FEED SYSTEM	7–9
7–2.3	ROTATING FEED MECHANISM	7–10
7–2.3.1	Recoil-operated Feed Mechanism	7–10
7–2.3.2	Electrically Driven Feed Mechanism	7–12
7–2.4	LINKLESS FEED SYSTEM	7–14
7–2.4.1	Power Required	7–19
7–2.4.2	Example Problem for Power Required	7–21
7–3	EXTRACTORS, EJECTORS, AND BOLT LOCKS	7–24
7–3.1	EXTRACTORS	7–24
7–3.2	EJECTORS	7–27
7–3.2.1	Ejector Dynamics	7–27
7–3.2.2	Sample Problem of Ejector Dynamics	7–27
7–3.3	BOLT LOCKS	7–30
7–4	FIRING MECHANISM	7–32
7–4.1	COMPONENTS, TYPES, AND ACTION	7–32
7–4.1.1	Trigger Pull	7–37
7–4 1.2	Firing Pin Design	7–39
7–5	LINKS	7–39
7–5.1	TYPES OF LINK	7–40
7–5.2	DESIGN REQUIREMENTS	7–40
7–6	MOUNTS	7–44
7–6.1	GEOMETRY AND RESOLUTION OF FORCES	7–44
7–6.2	SAMPLE PROBLEM	7–48

CHAPTER 8. LUBRICATION OF MACHINE GUNS

8–1	GENERAL CONCEPT	8–1
8–2	EXAMPLES OF LUBRICANTS	8–1
8–3	CASE LUBRICANT	8–2

TABLE OF CONTENTS (Con't.)

APPENDIXES

No.	Title	Page
A–1	Flow Chart for Delayed Blowback	A–1
A–2	Listing for Delayed Blowback Program	A–4
A–3	Flow Chart for Retarded Blowback	A–6
A–4	Listing for Retarded Blowback Program	A–9
A–5	Flow Chart for Cutoff Expansion	A–12
A–6	Listing for Cutoff Expansion Program	A–15
A–7	Flow Chart for Operating Cylinder	A–20
A–8	Listing for Operating Cylinder Program	A–22
A–9	Flow Chart for Cam and Drum Dynamics During Recoil	A–26
A–10	Listing for Cam and Drum Dynamics During Recoil	A–30
A–11	Flow Chart for Cam and Drum Dynamics During Counterrecoil	A–35
A–12	Listing for Cam and Drum Dynamics During Counterrecoil	A–38
A–13	Flow Chart for Double Barrel Machine Gun	A–43
A–14	Program Listing for Double Barrel Machine Gun	A–46
A–15	Flow Chart for Multibarrel Power	A–52
A–16	Program Listing for Multibarrel Power	A–59
B	Automatic Control of Rounds in a Burst for Weapon Effectiveness	B–1
	GLOSSARY	G–1
	REFERENCES	R–1

LIST OF ILLUSTRATIONS

Fig. No.	Title	Page
2–1	Typical Pressure-time Curve	2–1
2–2	Schematic of Simple Blowback Mechanism	2–3
2–3	Allowable Case Travel	2–4
2–4	Pressure-time Curve of Cal .45(11.42 mm) Round	2–8
2–5	Schematic of Advanced Primer Ignition System	2–13
2–6	Locking System for Delayed Blowback	2–18
2–7	Pressure-time Curve of 20 mm Round	2–25
2–8	Schematic of Retarded Blowback Linkage	2–40
2–9	Kinematics of Retarded Blowback Linkage	2–41
2–10	Dynamics of Bolt and Linkage	2–42
3–1	Schematic of Long Recoil System	3–2
3–2	Schematic of Short Recoil System	3–2
3–3	Accelerator Geometry	3–16
4–1	Impingement System	4–1
4–2	Cutoff Expansion System	4–2
4–3	Rotating Bolt Lock and Activating Cam	4–11
4–4	Force System of Bolt Cam	4–12
4–5	Pressure-time Curve of 7.62 mm Round	4–18
4–6	Operating Distances of Moving Parts	4–19
4–7	Tappet System	4–38
4–8	Pressure-time Curve of 7.62 mm Carbine Round	4–40
5–1	Schematic of Single Barrel Revolver-type Machine Gun	5–1
5–2	Two Stage Ramming	5–2
5–3	Force Diagram of Recoiling Parts and Slide	5–3
5–4	Schematic of Cam Geometry	5–5
5–5	Cam-slide Force Diagrams	5–9
5–6	Single Barrel Drum Loading Diagram	5–10
5–7	Single Barrel Drum Dynamics	5–11
5–8	Interior Ballistics of 20 mm Revolver-type Gun	5–19
5–9	Extractor Assembly With Antidouble Feed Mechanism	5–35
5–10	Extractor Cam Assembly	5–36
5–11	Location of Basic Operations	5–47
5–12	Schematic of Double Barrel Drum-cam Arrangements	5–47
5–13	Schematic of Ammunition Feed System	5–48
5–14	Schematic of Ammunition Magazine	5–49
5–15	Double Barrel Cam Force Diagrams	5–50
5–16	Double Barrel Drum Loading Diagram	5–51
5–17	Double Barrel Drum Dynamics	5–51
5–18	Force-time Curve of 20 mm Revolver-type Gun	5–53
5–19	Geometry of Cam Actuating Lever	5–55
6–1	Cam Contour of Multibarrel Gun	6–2
6–2	Loading Diagram of Bolt and Cam During Acceleration	6–2
6–3	Feed Portion of Cam	6–3
6–4	Loading Diagram of Bolt and Cam During Deceleration	6–7
6–5	Bolt Position Diagram for Computer Analysis	6–13

LIST OF ILLUSTRATIONS (Con't.)

Fig. No.	Title	Page
7–1	Initial Contact of Bolt and Cartridge Case Base	7–1
7–2	Chamber-projectile Contact	7–2
7–3	Box Magazine	7–2
7–4	Lip Guides	7–3
7–5	Lip-cartridge Case Orientation	7–4
7–6	Geometry of Double Row Stacking	7–4
7–7	Box Magazine Follower	7–4
7–8	Flat Tape Spring and Loading Analogy	7–5
7–9	Rectangular Coil Spring and Loading Characteristics	7–7
7–10	Schematic of Feed System, End View	7–10
7–11	Feed System Illustrating Mechanics of Operation	7–11
7–12	Recoil-operated Rotating Feed Mechanism	7–13
7–13	Feed Wheel and Operating Lever Units	7–14
7–14	Electrically Operated Rotating Feed Mechanism	7–15
7–15	Outer Drum	7–16
7–16	Inner Drum Helix	7–16
7–17	Conveyor Elements	7–17
7–18	Schematic of Linkless Feed System	7–18
7–19	Path of Rounds in Single End System	7–19
7–20	Extractors	7–25
7–21	Extractor Loading Diagrams	7–26
7–22	Ejectors	7–28
7–23	Ejector Loading Diagram	7–29
7–24	Sliding Breech Lock	7–31
7–25	Tipping Bolt Lock	7–32
7–26	Firing Mechanism for Recoil Machine Gun	7–33
7–27	Firing Mechanism for Gas-operated Machine Gun	7–34
7–28	Three-position Firing Mechanism	7–36
7–29	Triggering Mechanism Loading	7–38
7–30	Ammunition Link, Cal .50 Round	7–41
7–31	Nose Fanning Flexibility, 7.62 mm Link	7–42
7–32	Base Fanning Flexibility, 7.62 mm Link	7–43
7–33	Geometry of Base Fanning	7–44
7–34	Helical Flexibility, 7.62 mm Link	7–45
7–35	Total Folding 7.62 mm Ammunition Belt	7–46
7–36	Partial Folding 7.62 mm Ammunition Belt	7–46
7–37	Loading Link With RADHAZ Shield	7–47
7–38	Loading Diagram of Mount	7–47
B–1	Hit Probability vs Number of Rounds in a Burst	B–2

LIST OF TABLES

Table No.	Title	Page
2–1	Case Travel of Cal .45(11.42 mm) Gun	2–11
2–2	Recoil Travel of 20 mm Gun	2–26
2–3	Symbol-code Correlation for Delayed Blowback Program	2–36
2–4	Input for Delayed Blowback Program	2–37
2–5	Counterrecoil Dynamics of Delayed Blowback Gun	2–38
2–6	Symbol-code Correlation for Retarded Blowback	2–46
2–7	Input Data for Retarded Blowback	2–47
2–8	Retarded Blowback Dynamics	2–48
3–1	Recoil Travel of 20 mm Gun	3–3
3–2	Spring Design Data of Recoil-operated Guns	3–8
3–3	Recoil Travel of 20 mm Gun Equipped With Accelerator	3–17
4–1	Computed Dynamics of Gas Cutoff System	4–25
4–2	Gas Expansion Time Calculations	4–29
4–3	Symbol-code Correlation for Cutoff Expansion	4–30
4–4	Input for Cutoff Expansion Program	4–31
4–5	Computed Dynamics Before Gas Cutoff	4–32
4–6	Computed Dynamics After Gas Cutoff Bolt Unlocking During Helix Traverse	4–33
4–7	Computed Dynamics After Gas Cutoff Bolt Unlocking During Parabola Traverse	4–33
4–8	Computed Dynamics After Gas Cutoff Bolt and Rod Unit Recoiling After Cam Action	4–34
4–9	Computed Dynamics, Counterrecoil Bolt Locking During Parabola Traverse	4–35
4–10	Buffer Spring Design Data	4–39
4–11	Dynamics of Tappet	4–43
4–12	Critical Pressure Time Requirements	4–46
5–1	Free Recoil Data of 20 mm Revolver-type Machine Gun	5–21
5–2	Preliminary Recoil Adapter Data	5–22
5–3	Revised Preliminary Recoil Adapter Data	5–24
5–4	Operating Cylinder Data for 0.12 $in.^2$ Orifice (Critical Pressure)	5–26
5–5	Operating Cylinder Data for 0.12 $in.^2$ Orifice	5–27
5–6	Operating Cylinder Data for 0.09 $in.^2$ Orifice	5–28
5–7	Operating Cylinder Data for 0.06 $in.^2$ Orifice	5–29
5–8	Symbol-code Correlation for Operating Cylinder	5–37
5–9	Symbol-code Correlation for Cam Dynamics	5–38
5–10	Input Data for Drum Dynamics During Recoil	5–38
5–11	Input Data for Drum Dynamics During Counterrecoil	5–39
5–12	Computed Recoil and Operating Cylinder Data for Orifice Area of 0.042 $in.^2$	5–40
5–13	Cam and Drum Dynamics During Recoil	5–41
5–14	Cam and Drum Dynamics During Counterrecoil	5–42
5–15	Symbol-code Correlation for Double Barrel Machine Gun	5–56
5–16	Input Data for Double Barrel Machine Gun	5–56
5–17	Double Barrel Machine Gun Dynamics	5–59

LIST OF TABLES (Cont'd)

Table No.	Title	Page
6–1	Symbol-code Correlation of Variables for Multibarrel Gun	6–14
6–2	Symbol-code Correlation and Input for Gun Operating Power	6–15
6–3	Cam Dynamics	6–16
6–4	Gun Operating Power	6–17
7–1	Power Required for Linkless Belt Feed System	7–24
7–2	Firing Pin Dynamics	7–40

LIST OF SYMBOLS

A = coefficient in equation defining the tube recoil travel

A_b = bore area

A_c = peripheral surface contact area between case and chamber; operating cylinder piston area

A_l = differential area under pressure-time curve

A_o = orifice area

A_{pt} = area under pressure-time curve

$A_1, A_2, \ldots A_n$ = coefficients of x in a series

a = general expression for linear acceleration; major axis of elliptical cam; length of short segment of rectangular coil spring

a_a = average linear acceleration

a_c = acceleration of chutes

a_{cr} = counterrecoil acceleration

a_{crc} = major axis of counterrecoil portion of elliptical cam

a_d = tangential acceleration of cam roller on cam path

a_e = entrance unit acceleration; exit unit acceleration

a_n = normal acceleration of cam roller on cam path

a_r = recoil acceleration; retainer acceleration

a_{rec} = major axis of recoil portion of elliptical cam; slide travel during slide deceleration

a_s = slide acceleration

a_t = acceleration of transfer unit

B = coefficient in equation defining recoil travel; collective term in defining time during polytropic expansion of gas

b = minor axis of an elliptical cam; length of long segment of rectangular coil spring; spring width

b_{cr} = minor axis of counterrecoil section of elliptical cam

b_r = minor axis of recoil section of elliptical cam

C = orifice coefficient

C_r = end clearance of round

D = mean coil diameter

D_b = bore diameter

D_r = horizontal distance between trunnion and rear support

D_c = diameter of cartridge case base

D_d = drum diameter

d = wire diameter

d_c = gas cylinder diameter

d_p = gas port diameter; piston diameter of operating cylinder

dt = differential time

dx = differential distance

E = modulus of elasticity; energy

E_a = energy of ammunition belt

E_b = bolt energy; combined energy of buffer and driving springs

E_{bc} = counterrecoil energy of buffer spring

x

LIST OF SYMBOLS (Con't.)

E_c = modulus of elasticity of case; energy at gas cutoff

E_{cr} = counterrecoil energy

E_{cs} = energy needed to bring slide up to speed

E_{crb} = counterrecoil energy of barrel at end of buffer action

E_{cri} = counterrecoil energy at beginning of increment

E_{crt} = maximum counterrecoil energy of barrel

E_d = energy of rotating parts, drum energy

E_{dcr} = counterrecoil energy of drum

E_{ds} = energy of drum-slide system

E_e = ejection energy of case

E_i = input energy of each increment; total energy at any given increment

E_o = energy of operating rod

E_{oi} = energy of operating rod at gas cutoff

E_r = energy of recoiling parts; energy to be absorbed by mount

E_{rb} = recoil energy of bolt

E_s = energy transferred from slide to driving spring; driving spring energy

E_{sc} = total work done by all springs until start of unlocking of bolt

E_{scr} = slide counterrecoil energy

E_{sr} = slide recoil energy

E_{ss} = energy transferred from driving spring to slide

E_t = barrel energy

E_{to} = barrel energy when bolt is unlocked

E_{ζ} = energy loss attributed to spring system

E_{μ} = total energy loss caused by friction

$E_{\mu d}$ = energy loss in drum

$E_{\mu s}$ = energy loss in slide

e = base of natural logarithms

F = general expression for force; driving spring force; spring force at beginning of recoil

F_a = general expression for average force; average driving spring force; axial inertial force

F_{ab} = average force of spring-buffer system

F_{as} = average force of spring system

F_b = buffer spring force

F_c = operating cylinder force

F_{ca} = average operating cylinder force

F_{cr} = counterrecoil force

F_e = general expression for effective force, exit force, entrance force, maximum extractor load to clear cartridge case

F_{eb} = effective force on barrel

F_{es} = load when cartridge is seated

F_g = residual propellant gas force; propellant gas force

F_i = initial spring force

F_L = transverse force on locking lug; reaction on bolt

F_m = maximum spring force; spring force at end of recoil

LIST OF SYMBOLS (Con't.)

F_{mb} = maximum force of spring-buffer system

F_{ms} = maximum force of barrel and driving spring

F_{mt} = maximum force of barrel spring; of adapter

F_o = minimum spring force; minimum operating load

F_{ob} = initial buffer spring system force

F_{obs} = initial buffer spring force

F_{ot} = initial force of barrel spring; of adapter

F_p = cam roller pin load

F_r = average force during recoil

F_s = sear spring force; centrifugal force of cartridge case or round

F_{sh} = horizontal component of safety spring force

F_{sv} = safety spring force

F_t = force of barrel spring; of adapter; vertical reaction of trigger spring pin

$\bar{F}_t$ = average adapter force for time interval dt

F_{tb} = barrel spring force at end of propellant gas period

F_x = resultant force of x-axis

F_y = resultant force of y-axis

$F_{\mu s}$ = frictional force

Fdt, $F\Delta t$ = general expressions for differential impulse

f_r = rate of fire

$f(T_c/T)$ = function of the ratio of compression time to surge time

G = torsional modulus; shear modulus

g = acceleration due to gravity

H = command height

HP = horsepower

H_s = solid height of spring

h = depth of magazine storage space

h_t = distance between trunnion and pintle-leg intersection

I = area moment of inertia; general term for mass moment of inertia

I_b = mass moment of inertia of bolt

I_d = mass moment of inertia of drum; mass moment of inertia of all rotating parts

I_{de} = effective mass moment of inertia of drum

J = area polar moment of inertia

K = spring constant, general; driving spring constant

K_a = coefficient in gas flow equation

K_b = combined spring constant during buffing

K_{bs} = buffer spring constant

K_s = combined constant of barrel and driving springs

K_t = spring constant of barrel spring, of adapter

K_w = coefficient in the rate of gas flow equation

K_x = directional coefficient in F_x equation

K_y = directional coefficient in F_y equation

k = ratio of specific heats; radius of gyration; bolt polar radius of gyration

L = general expression for lengths; length of recoil; bolt travel; length of flat spring

LIST OF SYMBOLS (Con't.)

L_b = length of buffer spring travel

L_{bt} = length of total bullet travel in barrel

L_c = axial length of cam; length of slide travel; total peripheral length of cam

L_d = decelerating distance prior to buffer contact; operating distance of operating rod spring; length of drum; driving spring travel

L_e = extractor length

L_f = length of front pintle leg

L_p = location of gas port along barrel

L_r = length of round; length of rear pintle leg

L_t = tappet travel; barrel spring operating deflection

M = mass, general; mass of accelerating parts; bending moment

M_a = mass of round; mass of ammunition unit

M_{ae} = effective mass of ammunition

M_b = mass of bolt

M_{cc} = mass of cartridge case

M_d = mass of drum

M_{de} = effective mass of drum and ammunition belt; effective mass of rotating drum

M_e = effective mass, general; of extractor unit

M_{ee} = effective mass of extractor unit

M_{ej} = mass of ejector

M_g = mass of propellant gas

M_n = momentum of recoiling or counterrecoiling parts

M_o = mass of operating rod; bending moment at first bend of flat tape spring

M_p = mass of projectile

M_r = mass of recoiling parts

M_{re} = effective mass of recoiling parts

M_s = mass of slide; mass of spring

M_t = mass of barrel

N = number of coils; normal reaction on cam curve; normal force on roller; number of rounds; number of active segments in flat spring

N_a = axial component of normal force; number of links of ammunition

N_c = number of chambers in drum

N_r = number of retainer partitions

N_t = transverse component of normal force

N_μ = cam tangential friction force

P = general term for power

P_f = power required to drive feed system

P_t = trigger pull

p = pressure, general; pressure in reservoir; general term for space between rounds (pitch)

p_a = average pressure; average bore pressure

p_b = bore pressure

p_c = average gas cylinder pressure

p_{cr} = critical pressure

p_d = pitch of double helix drive

LIST OF SYMBOLS (Cont'd.)

p_i = interface pressure

p_{in} = propellant gas pressure as bullet leaves muzzle

F_L = component of pressure that dilates cartridge case

p_1 = initial pressure

p_2 = final pressure

R = radius of bolt outer surface

R_a = reaction of rear support; radius to CG of round

R_b = reaction of front support

R_c = cam radius

R_{ch} = radius of chamber centers of drum

R_d = distance from cam contact point to drum axis

R_L = radius of locking lug pressure center

R_r = roller radius; track reactions due to rotational forces

RT = specific impetus

R_t = track reactions due to tipping forces; trigger reaction on sear

R_y = horizontal reaction on drum shaft

r = mean radius of case

$\bar{r}$ = distance from tipping point on rim to CG of case

r_b = cam radius to contact point on bolt

r_e = extractor radius

r_s = striker radius

r_t = cam radius to contact point on barrel

s = travel distance

s_a = accelerating distance

s_b = bore travel; distance of bolt retraction during recoil

s_c = cutoff distance

s_{cr} = cam follower travel during counterrecoil

s_d = dwell distance

s_n = travel distance of operating unit at given time

s_o = initial distance

s_{ocr} = straight length of cam during counterrecoil

s_{or} = straight length of cam during recoil; position where slide contacts gas operating unit

s_r = cam follower travel during recoil; operating rod travel before bolt pickup

s_1 = travel component due to change in velocity

s_2 = travel component due to velocity

T = surge time of spring; absolute temperature; torque about gun axis; applied torque of trigger spring

T_c = compression time of spring

T_d = required drum torque

T_g = torque due to friction on drum bearing and case

T_L = locking lug torque

T_r = required retainer torque

T_1, T_2 = applied torques

LIST OF SYMBOLS (Con't.)

$\bar{T}_\alpha$ = accelerating torque

T_μ = resisting torque

T_θ = applied torque

t = time

t'' = time to complete counterrecoil of slide

t_b = buffer time

t_{bc} = buffer time during counterrecoil

t_c = time of firing cycle

t_{cr} = counterrecoil time

t_{crb} = time of buffer counterrecoil

t_{crt} = counterrecoil time of barrel after buffer action

t_{ct} = counterrecoil time of barrel

t_d = decelerating time of bolt before buffer is contacted

t_e = time of gas expansion

t_g = duration of propellant gas period

t_i = time interval of dwell between counterrecoil and recoil

t_r = recoil time of bolt

t_{rb} = bolt decelerating time during recoil

t_{rs} = counterrecoil time after buffer action

t_{rt} = recoil time of barrel during pressure decay after bolt unlocking

t_s = thickness of spring

t_{scr} = counterrecoil time of slide

t_t = barrel spring compression time

t_r = accelerating time of rotor

V_b = bore volume

V_c = gas volume in operating cylinder

V_{ch} = chamber volume

V_{co} = operating cylinder displacement

V_e = equivalent gas volume

V_{ec} = equivalent bore volume

V_m = chamber volume plus total bore volume

V_o = initial volume of gas operating cylinder

V_s = vertical component of spring load

V_1 = initial volume in gas equations

V_2 = final volume in gas equations

v = velocity, general

v_a = average velocity; axial velocity

v_b = buffer velocity during recoil

v_{bc} = bolt velocity during counterrecoil

v_c = linear velocity of cam follower along cam; velocity of chutes; linear ejected velocity of cartridge case

v_{cr} = counterrecoil velocity

v_{crb} = counterrecoil velocity of buffer

v_d = peripheral velocity of drum

v_{dm} = maximum peripheral velocity of drum

v_e = extractor velocity; maximum ejection velocity

v_f = velocity of free recoil

v_i = impact velocity

v_m = muzzle velocity of projectile

LIST OF SYMBOLS (Con't.)

v_o = initial velocity, general term

v_{ot} = initial velocity of barrel

v_r = recoil velocity

v_s = slide velocity

v_{sa} = velocity of recoiling parts at end of accelerating travel

v_{scr} = counterrecoil velocity of slide

v'_{scr} = slide velocity before impact

v_{sm} = maximum slide velocity

v_t = barrel velocity; tangential velocity of cartridge case at ejection, velocity of transfer unit

W = general term for weight; wall ratio; work

W_a = weight of round

W_b = bolt weight

W_c = wall ratio of case; weight of gas in cylinder; weight of propellant charge

W_{cc} = weight of cartridge case; weight of empty case

W_{ce} = weight of gas at critical pressure

W_d = weight of drum

W_e = equivalent weight of moving parts

W_g = total weight of propellant or propellant gas

W_o = weight of moving operating cylinder components

W_{os} = combined weight of components and slide

W_p = weight of projectile

W_r = weight of recoiling parts

W_s = work needed to compress spring; slide weight; weight of spring

W_{se} = equivalent weight of spring in motion

W_{sr} = weight of slide with 2 rounds

W_{srp} = weight of slide, 2 rounds, and gas operating unit

W_t = barrel weight

w = rate of gas flow; width of magazine; width of flat spring

w_c = width of cam

x = recoil travel, general; case travel; distance in x-direction

$\ddot{x}$ = axial acceleration of bolt

x_b = bolt travel

x_{bo} = bolt travel at end of propellant gas period

x_m = axial length of parabola

x_r = recoil distance during propellant gas period; recoil travel of drum and barrel assembly

x_{rm} = recoil travel during impulse period

x_{ro} = counterrecoiling travel during impulse period

x_s = slide travel; relative axial travel between cam follower and drum

x_{rd} = travel of recoiling parts during cam dwell period

x_t = barrel travel with respect to gun frame

x_{tf} = barrel travel during free recoil

x_{to} = barrel travel during propellant gas period; after buffer engagement; recoil travel during cam dwell period

LIST OF SYMBOLS (Con't.)

y = distance in y-direction, spring deflection

y_a = peripheral length of constant slope of cam

y_e = shear deflection

y_m = peripheral width of parabola; moment deflection

GREEK LETTERS

α = angular acceleration, general; angular acceleration of bolt; angular acceleration of rotor

α_d = angular acceleration of drum

β = cam angle

β_l = cam locking angle

β_o = slope of cam helix

γ = correction factor

Δt = time differential

Δv = velocity differential

Δx = distance differential

Δy = differential deflection; relative deflection of one spring segment

ϵ = efficiency of spring system

ϵ_b = efficiency of buffer system

ϵ_r = efficiency of recoil adapter

θ = angular displacement, general; angular displacement of rotor; angle of elevation; angular deflection in rectangular coil spring

θ_a = rotor travel for constant cam slope

θ_e = angular shear deflection

θ_m = angular moment deflection

λ = angle of bolt locking cam; slope of lug helix

μ = coefficient of friction

μ_i = index of friction

μ_r = coefficient of rolling friction

μ_s = coefficient of sliding friction

μ_t = coefficient of friction of track

ν = Poisson's ratio

ρ = ratio of spring energy to drum energy

Σ = summation

σ_t = tensile stress

σ_w = working stress of spring

τ = static stress of spring

τ_d = dynamic stress of spring

ϕ = angle of double helix drive

ω = angular velocity

ω_d = angular velocity of drum

PREFACE

This handbook is one of a series on Guns. It is part of a group of handbooks covering the engineering principles and fundamental data needed in the development of Army materiel, which (as a group) constitutes the Engineering Design Handbook Series. This handbook presents information on the fundamental operating principles and design of automatic weapons and applies specifically to automatic weapons of all types such as blowback, recoil-operated, gas-operated, and externally powered. These include single, double, multibarrel, and revolver-type machine guns and range from the simple blowback to the intricate M61A1 Vulcan and Navy 20 mm Aircraft Gun Mark II Mod 5 Machine Guns. Methods are advanced for preparing engineering design data on firing cycle, spring design, gas dynamics, magazines, loaders, firing pins, etc. All components are considered except tube design which appears in another handbook, AMCP 706-252, *Gun Tubes*.

This handbook was prepared by The Franklin Institute, Philadelphia, Pennsylvania, for the Engineering Handbook Office of Duke University, prime contractor to the U.S. Army, and was under the technical guidance and coordination of a special subcommittee with representation from Watervliet Arsenal, Rock Island Arsenal, and Springfield Armory.

The Handbooks are readily available to all elements of AMC including personnel and contractors having a need and/or requirement. The Army Materiel Command policy is to release these Engineering Design Handbooks to other DOD activities and their contractors, and other Government agencies in accordance with current Army Regulation 70-31, dated 9 September 1966. Procedures for acquiring these Handbooks follow:

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Department of the Army
Washington, D. C. 20310

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Comments and suggestions on this handbook are welcome and should be addressed to Army Research Office–Durham, Box CM, Duke Station, Durham, N. C. 27706.

CHAPTER 1

INTRODUCTION*

1–1 SCOPE AND PURPOSE

This handbook presents and discusses procedures normally practiced for the design of automatic weapons, and explores the problems stemming from the functions of each weapon and its components. It is intended to assist and guide the designer of automatic weapons of the gun type, and to contain pertinent design information and references.

1–2 GENERAL

The purpose of the handbook is (1) to acquaint new personnel with the many phases of automatic weapon design, and (2) to serve as a useful reference for the experienced engineer. It does not duplicate material available in other handbooks of the weapon series. Those topics which are presented in detail in other handbooks are discussed here only in a general sense; consequently, the reader must depend on the referenced handbook for the details. Unless repetitive, the text – for cyclic analyses. time-displacement (T-D) curves, chamber design, strength requirements, springs, cams, and drive systems – includes mathematical analyses embodying sketches, curves, and illustrative problems. Topics such as ammunition characteristics, lubrication, handling and operating features, and advantages and disadvantages are generally described more qualitatively than quantitatively.

Appendix B is included to merely introduce the idea of the automatic control of a burst of rounds for weapon effectiveness in the point fire mode – a facet which the gun designer may wish to consider.

1–3 DEFINITIONS

An automatic weapon is a self-firing gun. To be fully automatic, the weapon must load, fire, extract, and eject continuously after the first round is loaded and fired – provided that the firing mechanism is held unlocked. Furthermore, the automatic weapon derives all its operating energy from the propellant. Some weapons have external power units attached and, although not automatic in the strictest sense, are still classified as such.

There are three general classes of automatic weapons, all defined according to their system of operation, namely: blowback, gas-operated, and recoil-operated[1]**

a. Blowback is the system of operating the gun mechanism that uses propellant gas pressure to force the bolt to the rear; barrel and receiver remaining relatively fixed. The pressure force is transmitted directly by the cartridge case base to the bolt.

b. Gas-operated is the system that uses the propellant gases that have been vented from the bore to drive a piston linked to the bolt. The moving piston first unlocks the bolt, then drives it rearward.

c. Recoil-operated is the system that uses the energy of the recoiling parts to operate the gun.

Each system has variations that may borrow one or more operational features from the others. These variations, as well as the basic systems, are discussed thoroughly in later chapters.

1–4 DESIGN PRINCIPLES FOR AUTOMATIC WEAPONS

The automatic weapon, in the process of firing a round of ammunition, is essentially the same as any other gun. Its basic difference is having the ability to continue firing many rounds rapidly and automatically. An outer stimulus is needed only to start or stop firing, unless the latter occurs when ammunition supply is exhausted. The automatic features require major effort in design and development. The design philosophy has been established, then the gun is to fire as fast as required without stressing any component to the extent where damage and therefore malfunction is imminent.

An extremely short firing cycle being basic, the designer must exploit to the fullest the inherent properties of each type of automatic weapon. Generally, each type must meet certain requirements in addition to

*Prepared by Martin Regina, Franklin Institute Research Laboratories, Philadelphia, Pennsylvania.

**References are identified by a superscript number and are listed at the end of this handbook.

being capable of operating automatically. These requirements or design features are:

1. Use part of the available energy of the propellant gases without materially affecting the ballistics.

2. Fire accurately at a sustained rate compatible with the required tactics.

3. Use standard ammunition.

4. Be light for easy handling.

5. Have a mechanism that is:

   a. simple to operate

   b. safe

   c. easy to maintain

   d. economical with respect to manufacturing.

6. Have positive action for feeding, extracting, ejecting.

7. Insure effective breech closure until the propellant gas pressure has dropped to safe limits.

All successful automatic weapons meet these requirements but to a degree normally limited by type of weapon. Conflicting requirements are resolved by compromise.

CHAPTER 2

BLOWBACK WEAPONS

2-1 GENERAL

Controlling the response of the cartridge case to the propellant gas pressure is the basic design criterion of blowback weapons. The case responds by tending to move rearward under the influence of the axial force generated by the gas pressure on its base. Meanwhile, because of this same pressure, the case dilates to press on the inner wall of the chamber. The axial force tends to push the bolt rearward, opposed only by the resistance offered by the bolt inertia and the frictional resistance between case and chamber wall. The question now arises as to which response predominates, the impending axial motion or the frictional resistance inhibiting this motion.

Time studies resolve the problem. Fig. 2-1 is a typical pressure-time curve of a round of ammunition.

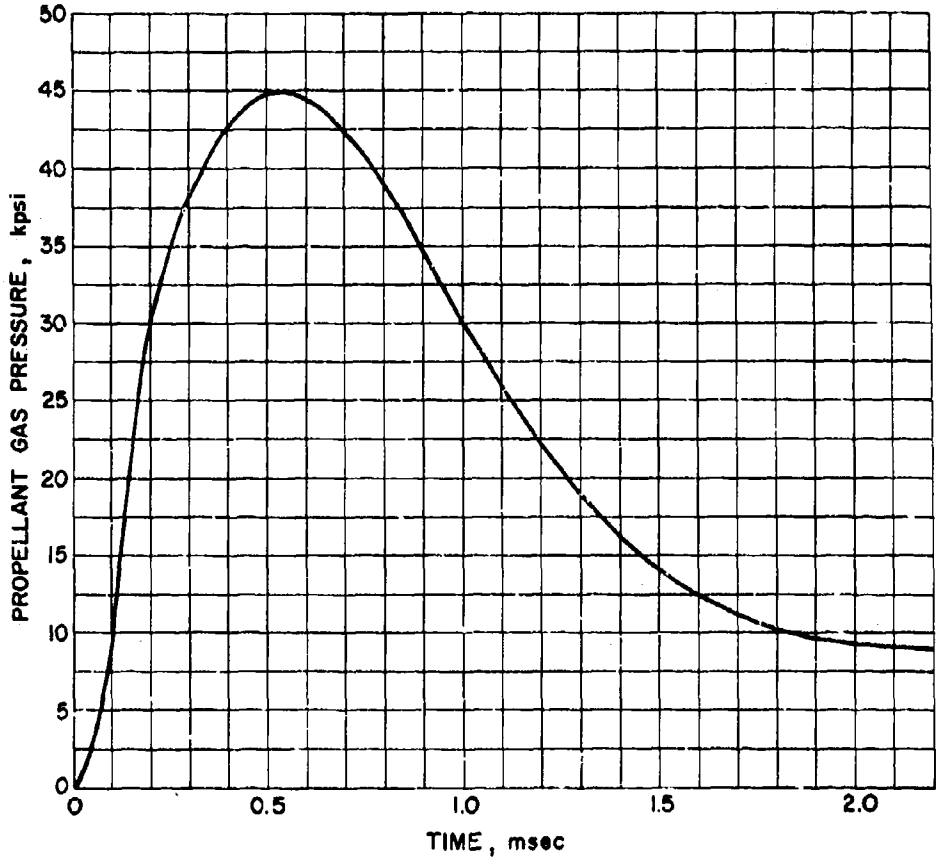


Figure 2-1. Typical Pressure-time Curve

For simplicity, assume unity for bore area and bolt weight. According to Fig. 2–1, the maximum pressure of 45,000 psi develops in 0.0005 sec. Again for simplicity, assume that the pressure varies linearly from $t = 0$ to $t = 0.0005$ sec. The pressure p at any time during the interval

$$p = \left(\frac{45000}{0.0005}\right) t = 9 \times 10^7 t \text{ lb/in.}^2 \qquad (2-1)$$

The corresponding force F driving the cartridge case and bolt rearward is

$$F = A_b p = 9 \times 10^7 tA \text{ lb} \qquad (2-2)$$

where A_b = bore area in square inches

but, by assumption, $A_b = 1.0$ in.^{2}, therefore

$$F = 9 \times 10^7 t = Kt. \qquad (2-3)$$

From mechanics

$$F = M_b a \qquad (2-4)$$

where a = bolt acceleration

M_b = mass of bolt.

According to an earlier assumption $M_b = \frac{W}{g} = \frac{1.0}{g}$

Solve for a in Eq. 2–4

$$a = \frac{F}{M_b} = Kgt \qquad (2-5)$$

but

$$a = \frac{d^2s}{dt^2} = Kgt. \qquad (2-6)$$

Integration of Eq. 2–6 yields

$$v = \int \frac{d^2s}{dt^2} = \frac{ds}{dt} + C = \frac{1}{2} Kgt^2 + C_1 \qquad (2-7)$$

when $t = 0, v = 0$, therefore $C_1 = 0$.

Integration of Eq. 2–7 yields

$$s = \int \frac{ds}{dt} = \frac{1}{6} Kgt^3 + C_2 \qquad (2-8)$$

when $t = 0, s = 0$, therefore, $C_2 = 0$.

Assume that the limiting clearance between case and chamber is equal to the case dilation as it reaches the ultimate strength, and assume further that the cartridge case has a nominal outside diameter of 1.5 in., a wall thickness of 0.05 in., and an ultimate strength of 50,000 psi. Then, according to the thin-walled pressure vessel formula, the pressure at which failure impends and which presses the case firmly against the chamber wall is p_u.

$$p_u = \frac{\sigma_t t_c}{r} = \frac{50{,}000 \times 0.05}{0.725} = 3440 \text{ psi} \qquad (2-9)$$

where

$r = 0.725$ in., mean radius of case

$t_c = 0.05$ in., wall thickness

$\sigma_t = 50{,}000$ lb/in.^{2}, tensile stress

From Eq. 2–1, t is the time elapsed to reach this pressure.

$$t = \frac{p_u}{9 \times 10^7} = 3.83 \times 10^{-5} \text{ sec} \qquad (2-10)$$

From Eq. 2–8, s is the distance that the case and bolt travel during this time, i.e., when only the inertia of the system is considered.

$$s = \frac{1}{6} Kgt^3$$

$$= \frac{1}{6} \times 9 \times 10^7 \times 386 \times 56 \times 10^{-15} < 0.001 \text{ in.}$$

This analysis indicates that when optimum conditions prevail, the cartridge case scarcely moves before frictional resistance begins to take effect. Motion will continue until Eq. 2–11 is satisfied.

$$A_b p = \mu A_c p_l \qquad (2-11)$$

where

A_b = bore area

A_c = peripheral surface contact area between case and chamber

p = propellant gas pressure

p_i = interface pressure of case and chamber

μ = coefficient of friction

With no initial clearance between the case and chamber, an approximate interface pressure p_i may be determined by equating the inside deflection of the chamber, due to this pressure, to the outside deflection of the cartridge case, due to both interface and propellant gas pressure, when both case and chamber are considered cylindrical. Solve for the interface pressure.

$$p_i = \frac{\frac{2p}{W_c^2 - 1}}{\frac{E_c}{E}\left(\frac{(W^2+1)}{(W^2-1)} + \nu\right) + \left(\frac{W_c^2+1}{W_c^2-1} - \nu\right)} \qquad (2-12)$$

where

E = modulus of elasticity of chamber

E_c = modulus of elasticity of case

W = wall ratio of chamber

W_c = wall ratio of case

ν = Poisson's ratio (assumed to be equal for both materials)

Spot checks indicate that those pressures which dilate unsupported cartridge cases to the limit of their strength are reasonably close to the difference in propellant gas pressure and computed interface pressure. Thus

$$p_u \approx p - p_i \qquad (2-13)$$

Ample clearance between case and chamber is always provided but is never so large that barrel recovery exceeds case recovery after gas pressures subside; otherwise, interference develops, i.e., clamping the case to the chamber wall and rendering extraction difficult[2].

2–2 SIMPLE BLOWBACK

Simple blowback is the system wherein all the operating energy is derived from blowback with the inertia of the bolt alone restraining the rearward movement of the cartridge case.

2–2.1 SPECIFIC REQUIREMENTS

Being restricted to low rates of fire because massive bolts are needed for their inertial properties, simple blowback systems are suitable only for low impulse, relatively low rate of fire weapons[3].

The restraining components of a simple blowback mechanism are the bolt and driving spring. Fig. 2–2 is a schematic of an assembled unit. Immediate resistance to case movement offered by the return spring is usually negligible. This burden falls almost totally on the bolt. It begins to move as soon as the projectile starts but at a much lower acceleration so that the cartridge case is still supported by the chamber until propellant gas pressure becomes too low to rupture the case. To realize a low acceleration, the bolt must be considerably heavier than needed as a load-supporting component. In high impulse guns, bolt sizes can be ridiculously large. The large mass, being subjected to the same impulse as that applied to propellant gas and projectile, will develop the same momentum; consequently, its velocity and corresponding kinetic energy will be comparatively low. The slowly moving bolt confines the gun to a low rate of fire.

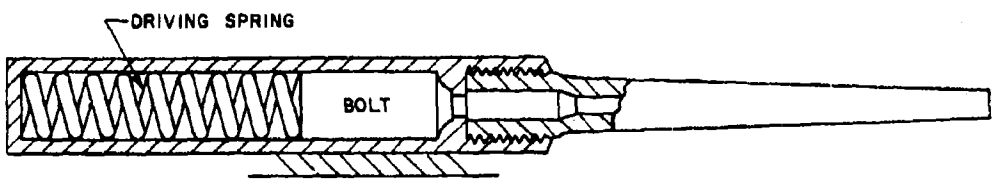


Figure 2–2. Schematic of Simple Blowback Mechanism

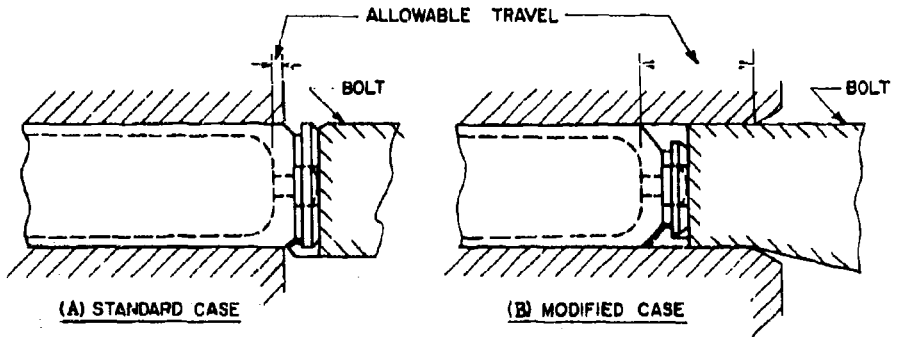


Figure 2–3. Allowable Case Travel

Although the bolt moves slowly, it still permits the case to move. The permissible travel while gas pressures are still high enough to rupture an unsupported case is indicated by Fig. 2–3(A) for a standard cartridge case. Fig. 2–3(B) illustrates how a modified case can increase the permissible travel. The geometry of chamber and cartridge case are also involved. A slight taper or no taper at all presents no problem but, for a large taper, an axial displacement creates an appreciable gap between case and chamber, thereby, exposing the case to deflections verging on rupture. Therefore, for weapons adaptable to simple blowback operation, chamber and case design takes on special significance if bolt travel is reasonable while propellant gases are active. For high-powered guns, exploiting this same advantage gains little. How little effect an increase in travel has on reducing bolts to acceptable sizes is demonstrated later.

The driving spring has one basic function. It stores some of the energy of the recoiling bolt, later using this energy to slam the bolt back into firing position and in the process, cocks the firing mechanism, reloads, and trips the trigger to repeat the firing cycle. That the driving spring stores only some of the energy of the recoiling bolt when firing semiautomatic shotguns, rifles, and pistols is indicated by the forward momentum not being perceptible during reloading whereas the kick during firing is pronounced.

2–2.2 TIME OF CYCLE

The time of the firing cycle is determined by the impulse created by the propellant gases, and by the bolt and driving spring characteristics. The impulse $\int F dt$ is computed from the area beneath the force-time curve. It is equated to the momentum of the bolt assembly, i.e.,

$$\int_{t_1}^{t_2} F_g dt = M_b v_f \qquad (2\text{–}14)$$

where

F_g = propellant gas force

M_b = mass of bolt assembly

v_f = velocity of free recoil

dt = time differential

The mass of the bolt assembly includes about one-third the spring as the equivalent mass of the spring in motion. However, the effect of the equivalent spring mass is usually very small and, for all practical purposes, may be neglected. After the energy of free recoil is known, the recoil energy E_r and the average driving spring force become available

$$E_r = \frac{1}{2} M_b v_f^2 \qquad (2\text{–}15)$$

The average force F_a depends on the efficiency of the mechanical system

$$F_a = \frac{\epsilon E_r}{L} \qquad (2\text{–}16)$$

where L = length of recoil or bolt travel

ϵ = efficiency of system

2-2.2.1 Recoil Time

The bolt travel must be sufficient to permit ready cartridge loading and case extraction. The initial spring force F_o is based on experience and, when feasible, is selected as four times the weight of the recoiling mass. The maximum spring force F_m, when the bolt is fully recoiled, is

$$F_m = 2F_o - F_o \tag{2-17}$$

The spring force at any time of recoil is

$$F = F_o + Kx \tag{2-18}$$

where K = spring constant

x = recoil distance at time t

At time t the energy remaining in the recoiling mass is

$$\frac{1}{2} M_b v_r^2 = \frac{1}{2} M_b v_f^2 - \frac{1}{\epsilon}\left(F_o x + \frac{1}{2} Kx^2\right) \tag{2-19}$$

where ϵ is the efficiency of the spring system. An inefficient system helps to resist recoil by absorbing energy.

But $v_r = \frac{dx}{dt_r}$, therefore

$$\frac{dx}{dt_r} = \sqrt{\frac{2}{M_b}} \sqrt{\frac{M_b}{2} v_f^2 - \frac{1}{\epsilon} F_o x - \frac{1}{2\epsilon} Kx^2} \tag{2-20}$$

Solve for dt_r.

$$dt_r = \frac{\sqrt{\frac{M_b}{2}}\, dx}{\sqrt{\frac{M_b}{2} v_f^2 - \frac{1}{\epsilon} F_o x - \frac{1}{2\epsilon} Kx^2}} \tag{2-21}$$

Set $v_o = v_f$, the initial velocity at time zero, and integrate.

$$t_r = \left(\sqrt{\frac{\epsilon M_b}{K}}\ \mathrm{Sin}^{-1}\ \frac{F_o + Kx}{\sqrt{F_o^2 + \epsilon K M_b v_o^2}}\right)\Bigg]_{x=0}^{x=L} \tag{2-22}$$

This computed time does not include the time while propellant gases are acting. The exclusion provides a simple solution without serious error. Since $Mv_o^2 = \frac{L}{e}(F_m + F_o)$ and, by definition,

$$K = \frac{F_m - F_o}{L} \text{ and } \sqrt{F_o^2 + eKMv_o^2} = F_m.$$

Therefore, the time elapsed during recoil t_r from $x = 0$ to $x = L$ is

$$t_r = \sqrt{\frac{eM_b}{K}}\left(\frac{\pi}{2} - \text{Sin}^{-1}\frac{F_o}{F_m}\right) = \sqrt{\frac{eM_b}{K}}\ \text{Cos}^{-1}\frac{F_o}{F_m}. \tag{2-23}$$

2-2.2.2 Counterrecoil Time

The counterrecoil time is determined by the same procedure as that for recoil, except that the low efficiency of springs deters rapid counterrecoil. The energy of the counterrecoiling mass of the bolt assembly at any time t_{cr} is

$$E_{cr} = \frac{1}{2}M_b v_{cr}^2 = \frac{1}{2}M_b v_o^2 + e\left(F_m x - \frac{1}{2}Kx^2\right) \tag{2-24}$$

where v_o = initial velocity

v_{cr} = counterrecoil velocity at any time

Since $v_{cr} = \frac{dx}{dt_{cr}}$

$$dt_{cr} = \frac{\sqrt{\frac{M_b}{2}}\,dx}{\sqrt{\frac{M_b}{2}v_o^2 + eF_m x - \frac{e}{2}Kx^2}} \tag{2-25}$$

Integrating

$$t_{cr} = \sqrt{\frac{M_b}{eK}}\left(\text{Sin}^{-1}\frac{Kx - F_m}{\sqrt{F_m^2 + \frac{K}{e}M_b v_o^2}} - \text{Sin}^{-1}\frac{-F_m}{\sqrt{F_m^2 + \frac{K}{e}M_b v_o^2}}\right) \tag{2-26}$$

When the initial velocity is zero, the time t_{cr} to counterrecoil the total distance is

$$t_{cr} = \sqrt{\frac{M_b}{eK}}\left(\text{Sin}^{-1}\frac{-F_o}{F_m} - \frac{3\pi}{2}\right) = \sqrt{\frac{M_b}{eK}}\ \text{Cos}^{-1}\frac{F_o}{F_m} \tag{2-27}$$

2–2.2.3 Total Cycle Time

The mass of the bolt assembly and the bolt travel are the controlling elements of a simple blowback system. Large values will decrease firing rate whereas the converse is true for small values. The driving spring characteristics are determined after mass and travel are established. The total weapon weight limits, to a great extent, the weight and travel of the bolt.

Because of the efficiency of the spring system, counterrecoil of the bolt will always take longer than recoil. The time t_c for the firing cycle is

$$t_c = t_r + t_{cr} + t_l \qquad (2-28)$$

where t_l is time elapsed at the end of counterrecoil until the bolt mechanism begins to move in recoil. Since the firing rate is specified, t_c is

$$t_c = \frac{60}{f_r} \text{ , sec/round} \qquad (2-29)$$

where f_r = firing rate in rounds/min.

Initial approximations of blowback parameters may be computed by relating average spring forces and acceleration to the recoil energy. The average spring force F_a needed to stop the recoiling mass is

$$F_a = \frac{\epsilon E_r}{L} = \frac{\epsilon M_b v_f^2}{2L} \qquad (2-30)$$

where, according to Eq. 2–15, $E_r = \frac{1}{2} M_b v_f^2$. Since $F_a = \epsilon M_b a_r$

$$a_r = \frac{F_a}{\epsilon M_b} = \frac{v_f^2}{2L}. \qquad (2-31)$$

From the general expression for computing distance in terms of time and acceleration, $L = \frac{1}{2} a_r t_r^2$, the recoil time becomes

$$t_r = \sqrt{\frac{2L}{a_r}} = \sqrt{\frac{4L^2}{v_f^2}} = \frac{2L}{v_f}. \qquad (2-32)$$

During counterrecoil, the effectiveness of the spring force is reduced by the inefficiency of the system. This force is

$$F_{cr} = \epsilon F_a = M_b a_{cr} \qquad (2-33)$$

where a_{cr} is the counterrecoil acceleration. According to Eq. 2–30

$$\epsilon F_a = \frac{\epsilon^2 M_b v_f^2}{2L} = M_b a_{cr}. \qquad (2-34)$$

Proceed similarly as for recoil

$$t_{cr} = \sqrt{\frac{2L}{a_{cr}}} = \sqrt{\frac{4L^2}{\epsilon^2 v_f^2}} = \frac{2L}{\epsilon v_f}. \qquad (2-35)$$

The approximate time of the firing cycle becomes

$$t_c = t_r + t_{cr} = \frac{2L}{v_f}\left(1 + \frac{1}{\epsilon}\right). \qquad (2-36)$$

By knowing the required cycle time and the computed velocity of free recoil, the distance of bolt travel can be determined from Eq. 2–36. This computed distance will be less than the actual because the accelerations are not constant thereby having the effect of needing less time to negotiate the distance in Eq. 2–36. In order to compensate for the shorter time, the bolt travel is increased until the sum of t_r and t_{cr} from Eqs. 2–23 and 2–27 equals the cycle time.

$$t_c = t_r + t_{cr} = \left(\sqrt{\frac{\epsilon M_b}{K}} + \sqrt{\frac{M_b}{\epsilon K}}\right) \text{Cos}^{-1} \frac{F_o}{F_m}. \qquad (2-37)$$

Substitute $2F_a - F_m$ for F_o and rewrite Eq. 2–37

$$\cos \frac{t_c}{\sqrt{\epsilon M_b} + \sqrt{\frac{M_b}{\epsilon}}} \sqrt{K} = \frac{2F_a - F_m}{F_m}. \qquad (2-38)$$

F_a is computed from Eq. 2–30. Note that

$$t_c \Big/ \left(\sqrt{\epsilon M_b} + \sqrt{\frac{M_b}{\epsilon}}\right)$$

is a constant for any given problem. Now by the judicious selection of L (using Eq. 2–36 for guidance) and K, the spring forces may be computed by iterative procedures so that (1) when substituted into Eq. 2–37 the specified time is matched, and (2) then into Eq. 2–17 to check whether F_a corresponds with the computed value obtained earlier from Eq. 2–30.

The actual firing rate is determined from the final computed cycle time.

$$f_r = \frac{60}{t_c} \text{ rounds/min} \qquad (2-39)$$

2–2.3 EXAMPLE OF SIMPLE BLOWBACK GUN

2–2.3.1 Specifications

Gun: 11.42 mm (Cal .45) machine gun

Firing Rate: 400 rounds per minute

Interior Ballistics: Pressure vs Time (Fig. 2–4)
Velocity vs Time (Fig. 2–4)

Weight of moving bolt assembly: 3 lb

2–2.3.2 Computed Design Data

The area beneath the pressure-time curve of Fig. 2–4 represents an impulse of

$$\int F_g dt = 0.935 \text{ lb-sec.}$$

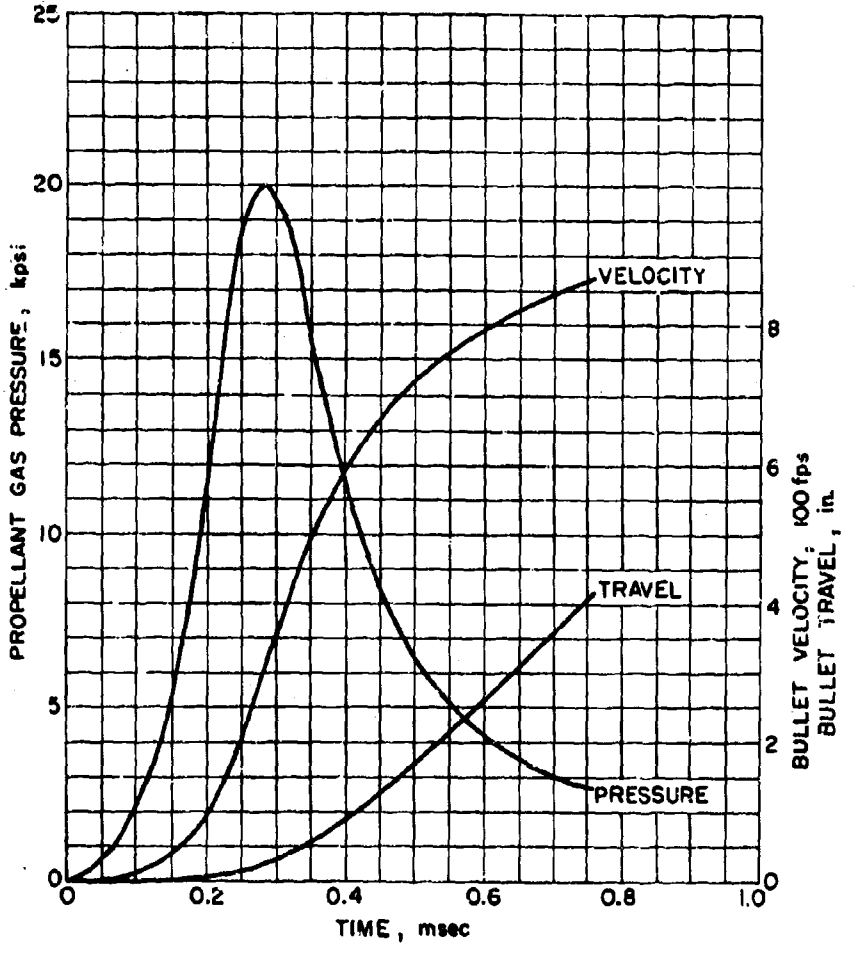


Figure 2–4. Pressure-time Curve of Cal .45 (11.42 mm) Round

The velocity of free recoil according to Eq. 2–14 is

$$v_f = \frac{\int F_g dt}{M_b} = \frac{0.935 \times 386.4}{3} = 120.4 \text{ in./sec.}$$

The recoil energy from Eq. 2–15 is

$$E_r = \frac{1}{2} M_b v_f^2 = \frac{1}{2} \times \frac{3}{386.4} \times 14500 = 56.3 \text{ in.-lb.}$$

The time of the firing cycle for 400 rpm is

$$t_c = \frac{60}{400} = 0.15 \text{ sec.}$$

From Eq. 2–36, the approximate bolt travel is

$$L = \frac{1}{2} t_c v_f \left(\frac{\epsilon}{\epsilon + 1} \right) = \frac{1}{2} \times 0.15 \times 120.4 \left(\frac{0.40}{0.40 + 1.0} \right) = 2.58 \text{ in.}$$

where $\epsilon = 0.40$, the efficiency of system.

$K = 1.0$ lb/in. is selected as practical for the first trials. This value may be revised if the bolt travel becomes excessive or other specifications cannot be met. From Eq. 2–30 the average spring force

$$F_a = \frac{eE_r}{L} = \frac{0.40 \times 56.3}{2.58} = 8.72 \text{ lb.}$$

From Eqs. 2–17 and 2–18 the minimum and maximum spring forces are

$$F_o = F_a - \frac{1}{2} KL = 8.72 - 1.29 = 7.43 \text{ lb}$$

$$F_m = F_o + KL = 7.43 + 2.58 = 10.01 \text{ lb.}$$

Compute the characteristics of Eq. 2–37.

$$\sqrt{\epsilon M_b} = \sqrt{\frac{0.4 \times 3}{386.4}} = \sqrt{0.003106} = 0.0557 \text{ lb-sec}^2/\text{in.}$$

$$\sqrt{\frac{M_b}{\epsilon}} = \sqrt{\frac{3}{0.4 \times 386.4}} = \sqrt{0.01941} = 0.1393 \text{ lb-sec}^2/\text{in.}$$

The time of the firing cycle for $K = 1$ lb/in. is

$$t_c = \left(\sqrt{\frac{\epsilon M_b}{K}} + \sqrt{\frac{M_b}{\epsilon K}} \right) \text{Cos}^{-1} \frac{F_o}{F_m} = (0.0557 + 0.1393) \frac{1}{\sqrt{1}} \text{Cos}^{-1} \frac{7.43}{10.01}$$

$$= 0.195 \text{ Cos}^{-1} \ 0.74226 = 0.195 \left(\frac{42.08}{57.3} \right) = 0.143 \text{ sec.}$$

This cycle time gives a rate of fire of almost 420 rounds per minute which is probably acceptable since firing is the final test. However, attempts will be made to approach the specified rate of 400 rounds/min more closely. The spring constant of $K = 1$ appears acceptable; therefore, to have $t_c = 0.15$ sec, $\text{Cos}^{-1} \frac{F_o}{F_m} = 0.76923$ rad and cos 0.76923 rad = 0.7185 so that

$$\frac{F_o}{F_m} = \frac{F_o}{F_o + KL} = 0.7185.$$

Since $K = 1$, $\frac{F_o}{F_o + L} = 0.7185$ and $F_o = 2.552L$.

Also, since $\frac{1}{e} F_a L = \frac{(F_o + F_m)L}{2e} = E_r = 56.3$ in.-lb

$$2F_o + L = 2F_a = \frac{2(0.40 \times 56.3)}{L} = \frac{45.04}{L}.$$

Therefore

$L^2 = 7.379$ in.^{2} $\quad L = 2.72$ in.

$F_o = 6.94$ lb $\quad F_m = 9.62$ lb

The spring work $W_s = \frac{1}{2}(F_o + F_m)L = 22.52$ in.-lb, which matches the input. The time t_c of the firing cycle for $K = 1$

$$t_c = \left(\sqrt{\frac{eM_b}{K}} + \sqrt{\frac{M_b}{eK}} \right) \text{Cos}^{-1} \frac{F_o}{F_m}$$

$$= (0.557 + 0.1393)\ \text{Cos}^{-1} \frac{6.94}{9.62}$$

$$= 0.195\ \text{Cos}^{-1}\ 0.7214 = 0.195 \left(\frac{43.83}{57.3} \right)$$

$$= 0.15 \text{ sec.}$$

2–2.3.3 Case Travel During Propellant Gas Period

Case travel while propellant gas pressures are active is found by numerically integrating the interior ballistics pressure-time curve and the velocity-time curve of the spent cartridge case. If increments of time are taken small enough, the accuracy is within acceptable limits. In addition, the velocity-time curve need not be drawn for integrating purposes. The integrations are readily performed by arranging all items in a table as indicated:

t	Δt	A_l	$F_g \Delta t$	Δv	v	v_a	Δx

t = time, abscissa of pressure-time curve

$\Delta t = t_n - t_{n-1}$, differential time

A_l = differential area under pressure-time curve

$F_g \Delta t = A_b A_l$, differential impulse

A_b = bore area

$\Delta v = F_g \Delta t / M_b$, differential velocity

M_b = mass of bolt

$v = \Sigma \Delta v$ velocity at end of each time increment

$v_a = \frac{1}{2}(v_n + v_{n-1})$ average velocity for each time increment

$\Delta x = v_a \Delta t$, differential distance of case travel

$x = \Sigma \Delta x$, case travel during propellant gas period

2–2.3.4 Sample Problem of Case Travel

The distance that the case is extracted as the projectile leaves the bore is determined by numerically integrating the pressure-time curve of Fig. 2–4.

$A_b = \frac{\pi}{4} D_b = \frac{\pi}{4} \times 0.45^2 = 0.159$ in.^{2}, bore area

$$\Delta v = F_g \Delta / M_b = \frac{32.2 \times 12\, F_g \Delta t}{3} = \frac{386.4\, F_g \Delta t}{3}$$

$$= 128.8\, F_g \Delta t$$

$\Delta x = 0.053$ in., the case travel distance when the projectile leaves the muzzle. This unsupported distance of the case is still within the allowable travel illustrated in Fig. 2–3.

TABLE 2-1. CASE TRAVEL OF CAL .45 (11.42 mm) GUN

t msec	Δt, msec	A_f, lb-sec/in.^{2}	$F_g \Delta t$, lb-sec	Δv, in./sec	v, in./sec	v_a, in./sec	Δx, in.
0.1	0.1	0.07	0.011	1.4	1.4	0.70	0.00007
0.2	0.1	0.56	0.089	11.4	12.8	7.10	0.00071
0.3	0.1	1.73	0.275	35.4	48.2	30.50	0.00305
0.4	0.1	1.60	0.255	32.8	81.0	64.60	0.00646
0.5	0.1	0.88	0.140	18.0	99.0	90.00	0.00900
0.6	0.1	0.52	0.083	10.7	109.7	104.35	0.01043
0.7	0.1	0.36	0.057	7.3	117.0	113.35	0.01134
0.76	0.06	0.16	0.025	3.2	120.2	118.60	0.01186
Σ	0.76	5.88	0.935	120.2			0.05292

2-2.3.5 Driving Spring Design

Driving springs must be compatible with operation and with the space available for their assembly, two factors that limit their outside diameter, and assembled and solid heights. The driving springs must also be designed to meet the time and energy requirement of the firing cycle and still have the characteristics that are essential for maintaining low dynamic stresses. The criteria for dynamic stresses have been established by Springfield Armory[4]. The procedures in the subsequent analyses follow these criteria.

The spring design data developed for the firing cycle calculations are

K = 1.0 lb/in., spring constant

F_o = 6.94 lb, spring force at assembled height

F_m = 9.62 lb, static spring force at end of recoil

L = 2.72 in., bolt travel

t_c = 0.15 sec, time of firing cycle

$t_r = \left(\frac{0.0557}{0.195}\right) t_c$ = 0.0428 sec, time of recoil (see par. 2-2.3.2)

v_f = 120.4 in./sec, spring velocity of free recoil

According to the theory of surge waves in springs, the dynamic stress increases only slightly over the static stress if the following conditions exist:

$$1.67 < \frac{T_c}{T} < 2.0 \text{ when } 25 < v_i < 50 \text{ fps} \quad \text{(Ref. 4)}$$

$$3.33 < \frac{T_c}{T} < 4.0 \text{ when } 20 < v_i < 25 \text{ fps} \quad \text{(Ref. 4)}$$

$$5.0 < \frac{T_c}{T} < 6.0 \text{ when } v_i < 20 \text{ fps} \quad \text{(Ref. 4)}$$

where T = surge time

T_c = compression time of spring

v_i = impact velocity, ft/sec

The impact velocity of 50 ft/sec should not be exceeded, neither should the velocity be less than the lower limit of each range, however, the limits of the ratio $\frac{T_c}{T}$ need not necessarily be restricted to the two lower ranges. For instance, if speeds are less than 20 ft/sec, the limits of $\frac{T_c}{T}$ may be shifted to the upper range which varies between 3.33 and 4.0, or even to the first range of limits 1.67 to 2.0. For speeds between 20 and 25 ft/sec, the limits of the ratio may be shifted to the upper range that varies between 1.67 and 2.0.

The surge time, in terms of spring characteristics is[5]

$$T = 35.5 \times 10^{-6} \left(\frac{D^2}{d}\right) N \qquad (2\text{-}40)$$

where d = wire diameter

D = mean coil diameter

N = number of coils

Refer to the spring design data.

$T_c = t_r = 0.0428$ sec, compression time of spring

Select $\frac{T_c}{T} = 3.8$, or

$$T = \frac{T_c}{3.8} = \frac{0.0428}{3.8} = 0.01125 \text{ sec}$$

$$K = \frac{Gd^4}{8D^3N} \quad \text{or} \quad N = \frac{Gd^4}{8D^3K} \text{ (Ref. 6) (2–41)}$$

where G = torsional modulus (11.5×10^6 lb/in.^{2} for steel)

K = spring constant

Substitute the expression for N of Eq. 2–41 into Eq. 2–40, insert know n values, and solve for d

$$d = 0.27 \sqrt[3]{DKT} \qquad (2–42)$$

When $D = 0.5$ in., and $K = 1.0$ (from spring data)

$$d = 0.27 \sqrt[3]{0.5 \times 1.0 \times 0.01126} = 0.048 \text{ in.}$$

From Eq. 2–41

$$N = \frac{Gd^4}{8D^3K} = \frac{11.5 \times 10^5 \times 530 \times 10^{-8}}{8 \times 0.125 \times 1.0} = 61 \text{ coils}$$

$H_s = Nd = 61 \times 0.048 = 2.93$ in., solid height.

The static torsional stress τ is[6]

$$\tau = \frac{8F_mD}{\pi d^3} = \frac{8 \times 9.62 \times 0.5}{111 \times 10^{-6}\,\pi} = 110{,}000 \text{ lb/in.}^2 \qquad (2–43)$$

According to Eq. 34 in Ref. 4, the dynamic torsional stress is

$$\tau_d = \tau \left(\frac{T}{T_c}\right)\left[f\left(\frac{T_c}{T}\right)\right] \qquad (2–44)$$

$$\tau_d = 110{,}000\left(\frac{1}{3.8}\right)4 = 116{,}000 \text{ lb/in.}^2$$

This stress is acceptable since the recommended maximum stress for music wire is 150,000 lb/in.^{2} In Eq. 2–44, $f\left(\frac{T_c}{T}\right)$ is the next largest even whole number larger than the value of $\frac{T_c}{T}$ if this ratio is not an even whole number

2–3 ADVANCED PRIMER IGNITION BLOWBACK

Timing the ignition so that the new round is fired just before the bolt seats gives the first part of the impulse created by the propellant gas force opportunity to act as a buffer for the returning bolt. The rest of the impulse provides the effort for recoiling the bolt. The system that absorbs a portion of the impulse in this manner is called Advanced Primer Ignition Blowback. This system has its artillery counterpart in the out-of-battery firing system, i.e., the firing of the artillery weapon being initiated during counterrecoil but with the breechblock closed.

2–3.1 SPECIFIC REQUIREMENTS

By virtue of its ability to dispose of the early influence of propellant gas force on recoil, the advanced primer ignition system is much more adaptable to high rates of fire than the simple blowback system. Reducing the effectiveness of the impulse by fifty percent alone reduces the bolt weight by a factor of two with a substantial increase in firing rate.

The restraining components may be considered as real and virtual; the real being the bolt and driving spring; the virtual, the momentum of the returning bolt. Fig. 2–5 is a schematic of the advanced primer ignition system. The firing cycle starts with the bolt latched open by a sear and the driving spring compressed. Releasing the sear, frees the bolt for the spring to drive it forward. The

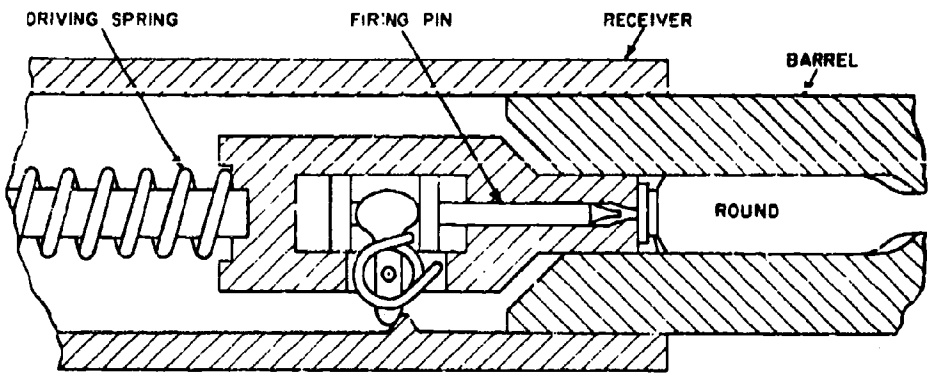


Figure 2–5. Schematic of Advanced Primer Ignition System

moving bolt picks up a round from the feed mechanisms and pushes it into the chamber. Shortly before the round is seated, the firing mechanism activitates the primer. The firing mechanism is so positioned and timed that the case is adequately supported when propellant gas pressures reach case-damaging proportions. The case and bolt become fully seated just as the impulse of the propellant gas force equals the momentum of the returning bolt. This part of the impulse is usually approximately half the total, thus establishing the driving spring characteristics.

As soon as forward motion stops, the continuously applied propellant gas force drives the bolt rearward in recoil. During recoil, the case is extracted and the driving spring compressed until all the recoil energy is absorbed to stop the recoiling parts. If the sear is held in the released position, the cycle is repeated and firing continues automatically. Firing ceases when the sear moves to the latched position.

2–3.2 SAMPLE CALCULATIONS OF ADVANCED PRIMER IGNITION

2–3.2.1 Firing Rate

To illustrate the effectiveness of advanced primer type performance, start with the same initial conditions as for the simple blowback problem with the added provision that half the impulse of the propellant gas is used to stop the returning bolt just as the cartridge seats. Thus,

$$\int F_g dt = \frac{0.935}{2} = 0.4675 \text{ lb-sec}$$

Eqs. 2–14 through 2–39 are again used. Since only half the impulse is available to drive the bolt in recoil, its mass must be reduced by half in order to retain the 120.4 in./sec velocity of free recoil. Thus the weight of this bolt assembly is specified as 1.5 lb and

$$v_f = \frac{\int F_g dt}{M_b} = \frac{0.4675 \times 386.4}{1.5} = 120.4 \text{ in./sec}$$

$$E_r = \frac{1}{2} M_b v_f^2 = \frac{1}{2} \times \frac{1.5}{386.4} \times 14500$$

$$= 28.2 \text{ in.-lb.}$$

According to Eq. 2–36, the approximate bolt travel is the same (2.58 in.) as that for the simple blowback gun in the preceding problem. Again, as in the earlier problem, the 2.58 in. bolt travel does not yield totally compatible results and must be modified to meet the rate of fire of 400 rounds per minute or the cycle time of $t_c = 0.15$ sec.

Since the initial dynamic conditions, impulse and energy of recoil are half as much as those of the preceding problem, the spring constant must also be half in order to have the same bolt travel. Eq. 2–37 shows the firing cycle time to be

$$t_c = \left(\sqrt{\frac{eM_b}{K}} + \sqrt{\frac{M_b}{eK}} \right) \cos^{-1} \frac{F_o}{F_m},$$

Since $K = 0.5$ lb/in., $e = 0.40$, $M_b = \frac{1.5}{386.4}\ \frac{\text{lb-sec}^2}{\text{in.}}$, and $t_c = 0.15$ sec.

$$\frac{F_o}{F_m} = \frac{F_o}{F_o + 0.5L} = \cos\left[\left(\frac{0.15}{0.195}\right)57.3^\circ\right]$$

$$= \cos 44^\circ 04' = 0.7185$$

Solve for F_o

$$F_o = 1.2762\,L.$$

Also

$$2F_o + KL = 2F_o + 0.5L = 2F_s = \frac{2eE_r}{L}$$

$$= \frac{2 \times 0.4 \times 28.2}{L}.$$

Substitute for F_o and collect terms

$$L^2 = \frac{22.56}{3.0524} = 7.39\ \text{in.}^2$$

$$L = 2.72\ \text{in.}$$

$$F_o = 3.47\ \text{lb}$$

$$F_m = 4.83\ \text{lb}$$

Recompute the time for the firing cycle

$$t_c = \left(\sqrt{\frac{eM_b}{K}} + \sqrt{\frac{M_b}{eK}}\right)\text{Cos}^{-1}\frac{F_o}{F_m}$$

$$= 0.195\ \text{Cos}^{-1}\left(\frac{3.47}{4.83}\right) = 0.195 \times 0.769 = 0.15\ \text{sec}$$

Another approach illustrates the advantage of increasing the firing rate by incorporating the advanced primer technique. The length of recoil in the preceding problems was selected to balance the dynamics of the problem and is not necessarily the ideal minimum distance. Suppose that the ideal bolt travel is 1.5 in. and that the recoil force of the simple blowback gun is acceptable. The mass of the bolt is adjusted to suit the requirements.

$\int F_g dt = 0.4675$ lb-sec

$F_o = 7.49$ lb, minimum spring load, simple blowback

$F_m = 10.08$ lb, maximum

$$K = \frac{F_m - F_o}{L} = \frac{2.59}{1.5} = 1.727\ \text{lb/in.}$$

$e = 0.40$, efficiency of spring system

The work W_s done to compress the springs is

$$W_s = \frac{1}{2}(F_o + F_m)L = 8.785 \times 1.5 = 13.18\ \text{in.-lb.}$$

The velocity v_f of free recoil is

$$v_f = \frac{\int F_g dt}{M_b} = \frac{g\int F_g dt}{W_b}.$$

The recoil energy $E_r = \frac{1}{2}M_b v_f^2 = \frac{1}{2}\left(\frac{W_b}{g}\right)v_f^2$.

Substitute for v_f

$$E_r = \frac{1}{2}(\int F_g dt)^2 \frac{g}{W}.$$

When the efficiency of the system is considered, the spring work is

$$W_s = 0.4E_r \quad \text{or} \quad E_r = 2.5W_s.$$

Substitute for E_r and solve for W_b, the weight of the bolt

$$2.5W_s = \frac{1}{2}(\int F_g dt)^2 \frac{g}{W_b}$$

$$32.95 = \frac{1}{2} \times 0.2185\left(\frac{386.4}{W_b}\right)$$

$$W_b = \frac{42.214}{32.95} = 1.281\ \text{lb.}$$

The velocity of free recoil becomes

$$v_f = \frac{g\int F_g dt}{W_b} = \frac{386.4 \times 0.4675}{1.281} = 141\ \text{in./sec}$$

The recoil energy $E_r = \frac{1}{2}\left(Mv_f^2\right) = \frac{1}{2}\left(\frac{1.281}{386.4}\right)19880 = 32.95$ in.-lb.

The time of a firing cycle is

$$t_c = \left(\sqrt{\frac{eM_b}{K}} + \sqrt{\frac{M_b}{eK}}\right) \text{Cos}^{-1}\frac{F_o}{F_m} = 0.6970 \times 0.733 = 0.071 \text{ sec}$$

where

$$\sqrt{\frac{eM_b}{K}} = \sqrt{\frac{0.40 \times 1.281}{1.727 \times 386.4}} = \sqrt{0.000768} = 0.0277$$

$$\sqrt{\frac{M_b}{eK}} = \sqrt{\frac{1.281}{0.40 \times 1.727 \times 386.4}} = \sqrt{0.00480} = 0.0693$$

$$\text{Cos}^{-1}\frac{F_o}{F_m} = \text{Cos}^{-1}\left(\frac{7.49}{10.08}\right) = 42° = 0.733 \text{ rad}$$

The firing rate is

$$f_r = \frac{60}{t_c} = \frac{60}{0.071} = 845 \text{ rounds/min.}$$

2–3.2.2 Driving Spring Design

The driving spring for the advanced primer ignition blowback gun has been assigned the following characteristics to comply with the requirements of the firing cycle for the simple blowback gun:

$K = 0.5$ lb/in., spring constant

$F_o = 3.48$ lb, spring force at assembled height

$F_m = 4.85$ lb, spring force at end of recoil

$L = 2.73$ in., bolt travel

$t_r = T_c = 0.0428$ sec, compression time of spring

$v_f = v_i = 120.4$ in./sec, velocity of free recoil, spring impact velocity

Select $\frac{T_c}{T} = 3.8$. Therefore, $T = \frac{0.0428}{3.8} = 0.1126$ sec.

When $D = 0.5$ in., according to Eq. 2–42

$$d = 0.27\sqrt[3]{DKT} = 0.27\sqrt[3]{0.5 \times 0.5 \times 0.01125} = 0.038 \text{ in.}$$

From Eq. 2–41

$$N = \frac{Gd^4}{8D^3K} = \frac{11.5 \times 10^6 \times 208 \times 10^{-8}}{8 \times 0.125 \times 0.5} = 48 \text{ coils}$$

$$H_s = Nd = 48 \times 0.038 = 1.83 \text{ in., solid height.}$$

The static torsional stress, Eq. 2–43, is

$$\tau = \frac{8F_mD}{\pi d^3} = \frac{8 \times 4.85 \times 0.5}{54.8 \times 10^{-6}\pi} = 113{,}000 \text{ lb/in.}^2$$

Eq. 2–44 has the dynamic stress of

$$\tau_d = \tau\left(\frac{T}{T_c}\right)\left[f\left(\frac{T_c}{T}\right)\right] = 113000\left(\frac{1}{3.8}\right)4 = 119{,}000 \text{ lb/in.}^2$$

The driving spring for the advanced primer ignition when the recoil force is equal to that of the simple blowback gun has the following characteristics:

$K = 1.727$ lb/in., spring constant

$F_o = 7.49$ lb, spring force at assembled height

$F_m = 10.08$ lb, spring force at end of recoil

$L = 1.5$ in., bolt travel

$t_r = T_c = 0.0203$ sec, compression time of spring

$v_f = v_i = 141$ in./sec, velocity of free recoil

Select $\frac{T_c}{T} = 3.8$. Therefore, $T = \frac{0.0203}{3.8} = 0.00535$ sec.

When $D = 0.5$, according to Eq. 2-42

$$d = 0.27 \sqrt[3]{DKT} = 0.27 \sqrt[3]{0.5 \times 1.727 \times 0.00535} = 0.045 \text{ in.}$$

From Eq. 2-41

$$N = \frac{Gd^4}{8D^3K} = \frac{11.5 \times 10^6 \times 41 \times 10^{-7}}{8 \times 0.125 \times 1.727} = 27.3 \text{ coils}$$

$$H_s = Nd = 27.3 \times 0.045 = 1.23 \text{ in., solid height.}$$

The static torsional stress, Eq. 2-43, is

$$\tau = \frac{8F_mD}{\pi d^3} = \frac{8 \times 10.08 \times 0.5}{91.1 \times 10^{-6}\pi} = 141{,}000 \text{ lb/in.}^2$$

The dynamic stress, Eq. 2-44, is

$$\tau_d = \tau \left(\frac{T}{T_c}\right)\left[f\left(\frac{T_c}{T}\right)\right] = 141{,}000 \left(\frac{1}{3.8}\right)4 = 148{,}500 \text{ lb/in.}^2$$

2-4 DELAYED BLOWBACK

Delayed blowback is the system that keeps the bolt locked until the projectile leaves the muzzle. At this instant an unlocking mechanism, responding to some influence such as recoil or propellant gas pressure, releases the bolt thereby permitting blowback to take effect.

2-4.1 SPECIFIC REQUIREMENTS

Since the tremendous impulse developed by the propellant gases while the projectile is in the bore is not available for operating the bolt, the recoiling mass – including driving, buffing, and barrel springs – need not be nearly so heavy as the two types of blowback discussed earlier. The smaller recoiling mass moves relatively faster and the rate of fire increases correspondingly.

Delayed blowback guns may borrow operating principles from other types of action, e.g., the piston action of the gas operating gun or the moving recoiling parts of the recoil operating gun. In either case, only unlocking activity is associated with these two types, the primary activity involving bolt action still functions according to the blowback principle. Fig. 2-6 shows a simple locking system.

Like any other automatic gun, bolt action is congruous with timing particularly with respect to unlocking time. If recoil operated, distance also becomes an important factor. For this type gun, the barrel must recoil a short distance before the moving parts force open the bolt lock. Sufficient time should elapse to permit the propellant gas pressure to drop to levels below the bursting pressure of the cartridge case but retain enough intensity to blow back the bolt.

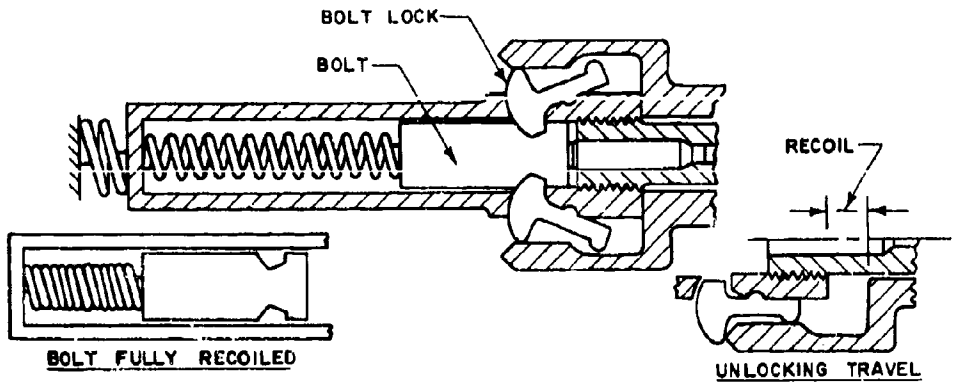


Figure 2–6. Locking System for Delayed Blowback

The stiffness of the springs should not be so great as to interfere unduly with early recoil. Therefore, a system consisting of three springs is customarily used: (1) a barrel spring having an initial load slightly larger than the recoiling weight to insure almost free recoil and still have the capacity to hold the barrel in battery, (2) a buffer spring to stop the recoiling parts and return them, and (3) a bolt driving spring to control bolt activity. Before the bolt is unlocked, all moving parts recoil as one mass with only the barrel spring resisting recoil but this spring force is negligible compared to the propellant gas force and may be neglected during recoil. After the bolt becomes unlocked, the barrel spring combines with the buffer spring to arrest the recoiling barrel unit.

The unlocked bolt continues to be accelerated to the rear by the impetus of the decaying propellant gas pressure whose only resistance now is the force of the driving spring, a negligible resistance until the propellant gas pressure becomes almost zero. Thereafter, the spring stops the bolt and later closes it. Normally the barrel unit has completed counterrecoil long before the bolt has fully recoiled to provide the time and relative distance needed for extracting, ejecting, and loading. After the barrel unit is in battery, the bolt unit functions as a single spring unit.

2–4.2 DYNAMICS OF DELAYED BLOWBACK

While the complete unit is recoiling freely and later while all springs are operating effectively, the dynamics of the system are readily computed by an iterative process. Given the pressure-time curve, by knowing the size of the masses in motion, the dynamics at any given time are determined by the summations of computed values for all preceding increments of time. The impulse during each increment is

$$F\Delta t = A_b A_i \qquad (2\text{–}45)$$

where A_b = bore area

A_i = area under Δt of pressure-time curve

Δt = time increment

When the impulse is being determined during low pressure periods due consideration should be given to the resistance offered by the driving spring. $F_s\Delta t$ should be adjusted after the driving spring and gas pressure forces become relatively significant. During each increment, the differential velocity is

$$\Delta v = \frac{F_s \Delta t}{M_r} \qquad (2\text{–}46)$$

where M_r = mass of the recoiling parts influenced by $F\Delta t$.

The velocity of recoil at the end of each increment becomes

$$v = v_{(n-1)} + \Delta v \qquad (2\text{–}47)$$

where $v_{(n-1)}$ = velocity at the preceding increment

The distance traveled by the bolt with respect to the gun frame during the increment is

$$\Delta x = v_a \Delta t = \left(v_{(n-1)} + \frac{1}{2}\Delta v\right)\Delta t \qquad (2\text{–}48)$$

where v_a = average velocity for the increment.

The total distance at the end of each increment is

$$x = \Sigma \Delta x. \qquad (2\text{–}49)$$

When the propellant gas pressures cease to be effective, the behavior of the barrel and bolt units depend entirely on springs. One such instance involving the buffer spring occurs when the bolt is unlocked. Although the gas pressure continues its effective action on the bolt, it can no longer influence the barrel unit except secondarily through the driving spring. Rewrite Eq. 2–19 for the isolated barrel unit and include the influence of the driving spring. Thus, the energy remaining in the recoiling mass is

$$\frac{1}{2}\left(M_t v_t^2\right) = \frac{1}{2}\left(M_t v_{ot}^2\right) - \frac{1}{e_b}\left[F_{ob}x_t + \frac{1}{2}\left(K_b x_t^2\right)\right] + \frac{1}{e}\left(F x_t\right) \qquad (2\text{–}50)$$

where F = drive spring force

F_{ob} = initial buffer spring force

K_b = spring constant of combined buffer and barrel springs

M_t = mass of barrel unit

v_{ot} = initial velocity of barrel unit

v_t = final velocity of barrel unit

x_t = travel of barrel with respect to gun frame

e = efficiency of drive spring unit

e_b = efficiency of buffer spring unit which includes the barrel spring

The buffer spring performs in unison with the barrel spring. During counterrecoil, at the end of buffer spring travel, the barrel spring continues to accelerate the barrel unit in its return to battery. During recoil, the propellant gas force is so much larger than the barrel spring force as to render the latter practically ineffective. Except for the last millisecond or two, the bolt driving spring also offers a negligible resistance to the propellant gas force. However, it does contribute a small force opposing the buffer spring and is represented in Eq. 2–50 by the expression $\frac{1}{e}\left(Fx_t\right)$, the effective force of the driving spring. The actual spring force F may be assumed to be the driving spring force at the time when the bolt is unlocked. Preliminary estimates should provide reasonable approximations at this stage of the design study.

An equation can be derived for the recoil time of the barrel unit by developing Eq. 2–50 by the same procedure used for Eq. 2–19. The recoil time for the barrel after bolt unlocking until pressure becomes zero is

$$t_{rf} = \sqrt{\frac{e_b M_t}{K_b}} \left[\sin^{-1} \frac{K_b x_{to} + F_{ob} - \left(\frac{e_b}{e}\right) F}{\sqrt{F_{ob} - \left(\frac{e_b}{e}\right) F^2 + e_b K_b M_t v_{ot}^2}} - \sin^{-1} \frac{F_{ob} - \frac{e_b}{e} F}{\sqrt{F_{ob} - \left(\frac{e_b}{e}\right) F^2 + e_b K_b M_t v_{ot}^2}} \right] \quad (2\text{–}51)$$

where x_{to} = barrel travel from time of buffer engagement to end of propellant gas period

All values are known except x_{to}. Since t_{rf} is the time elapsed from bolt unlocking to pressure effectiveness reaching zero, this distance may be computed from Eq. 2–51. It represents the buffer spring deflection. The total barrel travel with respect to the frame is

$$x_t = x_{to} + x_{tf} \quad (2\text{–}52)$$

where x_{tf} = barrel travel during free recoil.

The amount that the driving spring is compressed, while the barrel traverses x_t, is the relative travel distance between barrel and bolt, thus

$$x_b = x - x_t \quad (2\text{–}53a)$$

In terms of differential values, the equation becomes

$$\Delta x_b = \Delta x - \Delta x_t \quad (2\text{–}53b)$$

On the assumption that the recoil velocity of the bolt has been computed at the time corresponding to x_{to}, the energy of the bolt can be computed and converted to the potential energy of the driving spring from which the spring forces may be determined. The average driving spring force over the remaining distance, Eq. 2–16, is

$$F_a = \frac{eE_b}{L_b - x_b} \quad (2\text{–}54)$$

where E_b is calculated according to Eq. 2–15 and $L_b - x_b$ is the spring deflection remaining at the end of free recoil of the bolt.

For the remainder of the buffer stroke and for the time that the barrel unit is counterrecoiling, the dynamics of the system may be computed by dividing the time into convenient intervals, and by use of the relationship existing between impulse and momentum, computing the dynamics for each corresponding increment of travel. Both recoil and counterrecoil of the barrel take place while the bolt is recoiling which changes the effective buffer spring forces for the two directions. The expression of the driving spring effective force does not change since the bolt travel direction does not change. The force of the driving spring at the end of each increment of travel is

$$F = F_{(n-1)} + K\Delta x_b \quad (2\text{–}55)$$

where

$F_{(n-1)}$ = driving spring force at beginning of increment

K = driving spring constant

Δx_b = incremental driving spring deflection

The buffer spring force at the end of its increment of travel is

$$F_b = F_{b(n-1)} + K_b \Delta x_t \quad (2\text{–}56)$$

where

$F_{b(n-1)}$ = buffer spring force at beginning of increment

K_b = buffer spring constant which includes the barrel spring

Δx_t = incremental buffer spring deflection

The effective spring force on the bolt while it is recoiling is

$$F_e = \frac{F + F_{(n-1)}}{2e}. \tag{2-57}$$

The effective spring force on the barrel while it is recoiling is

$$F_{eb} = \frac{F_b + F_{b(n-1)}}{2\epsilon_b} - F_e. \tag{2-58}$$

According to the relationship of impulse and momentum, $Fdt = Mv$, the general expression for differential velocity is

$$\Delta v = \frac{F\Delta t}{M}. \tag{2-59}$$

Based on this expression, the bolt travel during each increment is derived in a sequence of algebraic expressions. Thus

$$\Delta x = v_{(n-1)}\Delta t - \frac{1}{2}\left(\Delta v \Delta t\right) = v_{(n-1)}\Delta t - \frac{F_e \Delta t^2}{2M_b} \tag{2-60a}$$

$$\Delta x = v_{(n-1)}\Delta t - \frac{F_{(n-1)}\Delta t^2}{2eM_b} - \left(\frac{K\Delta t^2}{4eM_b}\right)\Delta x_b. \tag{2-60b}$$

But $\Delta x_b = \Delta x - \Delta x_t$ (see Eq. 2-53b). Substituting this expression and collecting terms, the incremental travel of the bolt becomes

$$\Delta x = \frac{4eM_b}{4eM_b + K\Delta t^2}\left[v_{(n-1)}\Delta t - \frac{F_{(n-1)}\Delta t^2}{2eM_b} + \left(\frac{K\Delta t^2}{4eM_b}\right)\Delta x_t\right]. \tag{2-60c}$$

The incremental travel for the barrel is a similar expression

$$\Delta x_t = v_{t(n-1)}\Delta t - \frac{1}{2}\left(\Delta v_t \Delta t\right) = v_{t(n-1)}\Delta t - \frac{F_{eb}\Delta t^2}{2M_t} \tag{2-61a}$$

$$\Delta x_t = v_{t(n-1)}\Delta t - \frac{\Delta t^2}{2M_t}\left[\frac{F_{b(n-1)}}{\epsilon_b} + \frac{K_b \Delta x_t}{2\epsilon_e} - \frac{F_{(n-1)}}{\epsilon} - \frac{K\Delta x_b}{2\epsilon}\right]. \tag{2-61b}$$

Again substituting $\Delta x - \Delta x_t$ for Δx_b and collecting terms, the incremental travel of the barrel in recoil is

$$\Delta x_t = \frac{4\epsilon\epsilon_b M_t}{4\epsilon\epsilon_b M_t + \epsilon K_b \Delta t^2 + \epsilon_b K \Delta t^2}\left[v_{t(n-1)}\Delta t - \frac{F_{b(n-1)}\Delta t^2}{2\epsilon_b M_t} + \frac{F_{(n-1)}\Delta t^2}{2\epsilon M_t} + \left(\frac{K\Delta t^2}{4\epsilon M_t}\right)\Delta x\right]. \tag{2-61c}$$

While the barrel is counterrecoiling, and the bolt recoiling, the effective spring force on the barrel is

$$F_{eb} = \epsilon_b F_b - F_e = \epsilon_b F_{b(n-1)} - \left(\frac{\epsilon_b}{2}\right)K_b \Delta x_t - \frac{F_{(n-1)}}{\epsilon} - \frac{K\Delta x_b}{2\epsilon}. \tag{2-62}$$

The incremental travel of the barrel now becomes

$$\Delta x_t = v_{t(n-1)}\Delta t + \frac{1}{2}\left(\Delta v_t \Delta t\right) = v_{t(n-1)}\Delta t + \frac{F_{eb}\Delta t^2}{2M_t} \tag{2-63a}$$

$$\Delta x_t = v_{t(n-1)}\Delta t + \frac{\epsilon_b F_{b(n-1)}\Delta t^2}{2M_t} - \left(\frac{\epsilon_b K_b \Delta t^2}{4M_t}\right)\Delta x_t - \frac{F_{(n-1)}\Delta t^2}{2\epsilon M_t} - \left(\frac{K\Delta t^2}{4\epsilon M_t}\right)\Delta x_b. \tag{2-63b}$$

Substitute $\Delta x - \Delta x_t$ for Δx_b, collect terms and solve for Δx_t

$$\Delta x_t = \frac{4\epsilon M_t}{4\epsilon M_t + \epsilon\epsilon_b K_b \Delta t^2 - K\Delta t^2}\left[v_{t(n-1)}\Delta t + \frac{\epsilon_b F_{b(n-1)}\Delta t^2}{2M_t} - \frac{F_{(n-1)}\Delta t^2}{2\epsilon M_t} - \left(\frac{K\Delta t^2}{4\epsilon M_t}\right)\Delta x\right]. \tag{2-63c}$$

While both bolt and barrel are counterrecoiling, the effective spring force on the bolt is

$$F_e = \epsilon(F + F_{n-1})/2 = \epsilon F_{(n-1)} - \epsilon K \Delta x_b/2. \tag{2-64a}$$

Now, substitute for F_e and expand Eq. 2-60a so that

$$\Delta x = v_{(n-1)}\Delta t - \left[\frac{\epsilon F_{(n-1)}}{2M_b} - \left(\frac{\epsilon K}{4M_b}\right)\Delta x_b\right]\Delta t^2. \tag{2-64b}$$

But, according to Eq. 2-53b, $\Delta x_b = \Delta x - \Delta x_t$, therefore

$$\Delta x = v_{(n-1)}\Delta t - \left[\frac{\epsilon F_{(n-1)}}{2M_b}\right]\Delta t^2 + \left(\frac{\epsilon K}{4M_b}\right)\Delta t^2\,\Delta x - \left(\frac{\epsilon K}{4M_b}\right)\Delta t^2\,\Delta x_t. \tag{2-64c}$$

Collect terms and solve for Δx

$$\Delta x = \frac{4M_b}{4M_b - \epsilon K \Delta t^2}\left[v_{(n-1)}\Delta t - \frac{\epsilon F_{(n-1)}\Delta t^2}{2M_b} - \left(\frac{\epsilon K \Delta t^2}{4M_b}\right)\Delta x_t\right]. \tag{2-64d}$$

The effective force on the barrel during this period is

$$F_{eb} = \epsilon_b F_b - F_e = \epsilon_b\left[F_{b(n-1)} - \frac{K_b \Delta x_t}{2}\right] - \epsilon\left[F_{(n-1)} - \frac{K\Delta x_b}{2}\right]. \tag{2-65a}$$

The incremental barrel travel is, according to Eq. 2-63a

$$\Delta x_t = V_{t(n-1)}\Delta t + \frac{F_{eb}\Delta t^2}{2M_t}. \tag{2-65b}$$

Substitute the expression for F_{eb} of Eq. 2-65b, $\Delta x - \Delta x_t$ for Δx_b, and collect terms. The incremental barrel travel now becomes

$$\Delta x_t = \frac{4M_t}{4M_t + (\epsilon K + \epsilon_b K_b)\Delta t^2}\left\{v_{t(n-1)}\Delta t + \left[\frac{\epsilon_b F_{b(n-1)}}{2M_t}\right]\Delta t^2 - \left[\frac{\epsilon F_{(n-1)}}{2M_t}\right]\Delta t^2 + \frac{\epsilon K}{4M_t}\,\Delta t^2 \Delta x\right\}. \tag{2-65c}$$

To avoid repetition, general expressions are used to complete the analysis. The distinction between bolt and barrel activities will be demonstrated later in the sample problem. The spring force at the end of each increment is computed by Eqs. 2–55 and 2–56. The total energy absorbed by a spring system over a distance Δx is

$$\Delta E = \left[\frac{F_{(n-1)} + F}{2e} \right] \Delta x. \qquad (2\text{–}66a)$$

The energy released by a spring system over a distance Δx is

$$\Delta E = e \left[\frac{F_{(n-1)} + F}{2} \right] \Delta x. \qquad (2\text{–}66b)$$

The total energy at the end of the increment is found by adding the incremental energy to the total at the end of the preceding increment when energy is released, or subtracting when it is being absorbed.

$$E = E_{(n-1)} \pm \Delta E \qquad (2\text{–}66c)$$

$$v = \sqrt{\frac{2E}{M}} \qquad (2\text{–}66d)$$

2–4.3 SAMPLE PROBLEM FOR DELAYED BLOWBACK ACTION

2–4.3.1 Specifications

Gun: 20 mm machine gun

Firing rate: corresponding to minimum bolt travel

Interior ballistics: Pressure vs Time, Fig. 2–7

A_b = 0.515 in.^{2}, bore area

2–4.3.2 Design Data

L = 10 in., minimum bolt travel

W_b = 10 lb, weight of bolt unit

W_t = 50 lb, weight of barrel unit

x_{to} = 0.5 in., recoil distance to unlock bolt

e = 0.5, efficiency of driving spring unit

e_b = 0.3, efficiency of combined buffer and barrel spring system

e_t = 0.5, efficiency of barrel spring unit

Table 2–2 has the numerical integration for a recoiling weight of 60 lb. In Table 2–2, the area A_l is measured under the pressure-time curve, Fig. 2–7

$$F_g \Delta t = A_b A_l = 0.515 A_l \text{ lb-sec}$$

$$\Delta v = \frac{F_g \Delta t}{M_r}$$

$$= 6.44\ F \Delta t \text{ in./sec when } t \leq 0.003252 \text{ sec}$$

where

$$M_r = \frac{W_r}{g} = \frac{60}{386.4}$$

$$\Delta v = \frac{F_g \Delta t}{M_b}$$

$$= 38.64\ F_g \Delta t \text{ in./sec when } t > 0.003252 \text{ sec}$$

where

$$M_b = \frac{W_b}{g} = \frac{10}{386.4}$$

$$\Delta x = v_a \Delta t = \left[\frac{v_{(n-1)} + v}{2} \right] \Delta t, \text{ in.}$$

When the bolt is unlocked at t = 3.252 msec, the velocity attained by the recoiling parts is 232.3 in./sec (see Table 2–2).

The energy of the barrel unit at this velocity is

$$E_{to} = \frac{1}{2} \left(M_t v_t^2 \right) = \frac{1}{2} \left(\frac{50}{386.4} \right) 53960$$

$$= 3491 \text{ in.-lb.}$$

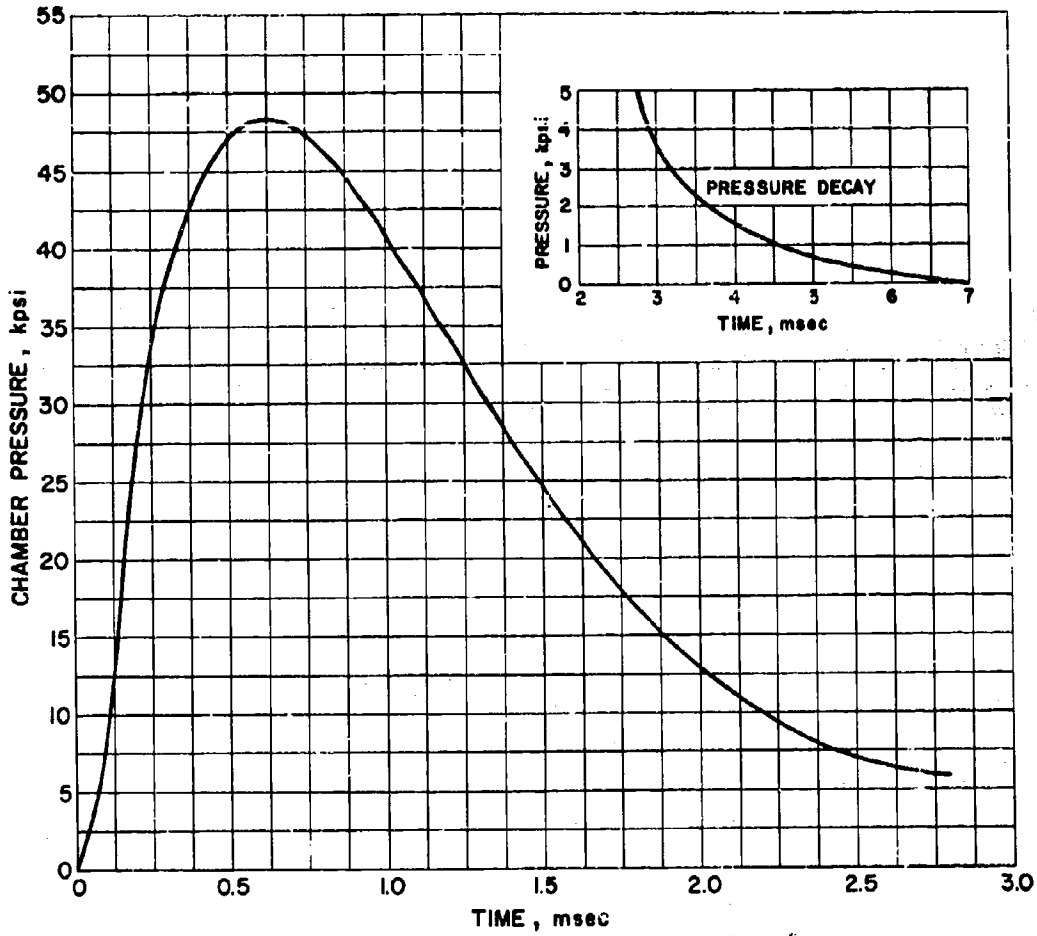


Figure 2–7. Pressure-time Curve of 20 mm Round

The velocity attained by the bolt at the end of the pressure period, v = 285 in./sec (see Table 2–2). The energy of the bolt is

$$E_b = \frac{1}{2}\left(M_b v^2\right) = \frac{1}{2}\left(\frac{10}{386.4}\right)(1200)$$

$$= 1051 \text{ in.-lb.}$$

On the assumption that the driving spring system absorbs this energy over its total deflection of 10 in., the average force is

$$F_a = \frac{\epsilon_b E_b}{L} = \frac{0.5 \times 1051}{10} = 52.6 \text{ lb.}$$

Earlier, a spring constant of K=3 appeared practical, but the resulting stress was too large. Also an earlier attempt at having a buffer stroke of half an inch proved impractical from the dynamic stress point of view. Increasing the stroke to one inch and applying recommended dynamic spring behavior, meanwhile retaining an acceptable firing rate, led to a feasible spring constant for all three springs – driving, buffer,

and barrel. The allowable static shear stress of the spring is

$$\tau = \frac{8F_m D}{\pi d^3} \qquad \text{(see Eq. 2–43)}$$

Since $T = 3.55 \times 10^{-5}\left(\frac{D^2}{d}\right)N$ (Ref. 1) and

$$N = \frac{Gd^4}{8KD^3} \qquad \text{(see Eqs. 2–40 and 2–41)}$$

substitute for T and N and solve for $\frac{d^3}{D}$ in the equation for τ and T.

Thus

$$\frac{d^3}{D} = \frac{8F_m}{\pi\tau} = \frac{8KT}{3.55 \times 10^{-5}G} \qquad (2\text{–}67a)$$

where $G = 11.5 \times 10^6$ lb/in.^{2}, torsional modulus

$\tau = 135{,}000$ lb/in.^{2}, allowable static shear stress

$$KT = \frac{F_m}{1037} \qquad (2\text{–}67b)$$

Based on constant acceleration, an approximate time of spring compression will, in most applications, determine a spring constant compatible with both spring dynamics and allowable stresses. The approximate time of bolt recoil is

$$t_r = \frac{2x_b}{v} = \frac{2(10)}{285} = 0.070 \text{ sec.}$$

TABLE 2–2. RECOIL TRAVEL OF 20 mm GUN

t, msec	Δt, msec	A_f, lb-sec/in.^{2}	$F_g \Delta t$, lb-sec	Δv, in./sec	v, in./sec	v_a, in./sec	Δx, in.	x, in.
0.25	0.25	3.44	1.77	11.4	11.4	5.7	0.0014	0.0014
0.50	0.25	10.15	5.24	33.7	45.1	28.2	0.0071	0.0085
0.75	0.25	11.89	6.13	39.5	84.6	64.8	0.0162	0.0247
1.00	0.25	11.12	5.74	37.0	121.6	103.1	0.0258	0.0505
1.25	0.25	9.25	4.76	30.6	152.2	136.9	0.0342	0.0847
1.50	0.25	7.30	3.76	24.2	176.4	164.3	0.0411	0.1258
1.75	0.25	5.23	2.69	17.3	193.7	185.0	0.0462	0.1720
2.00	0.25	3.71	1.91	12.6	206.3	200.0	0.0500	0.2220
2.25	0.25	2.58	1.34	8.6	214.9	210.6	0.0526	0.2746
2.50	0.25	1.82	0.94	6.1	221.0	218.0	0.0545	0.3291
2.75	0.25	1.39	0.72	4.6	225.6	223.3	0.0588	0.3849
3.00	0.25	1.06	0.55	3.5	229.1	227.4	0.0569	0.4418
3.252	0.252	0.97	0.50	3.2	232.3	230.7	0.0582	0.5000
4.00	0.748	1.37	0.70	27.0	258.3	245.3	0.1838	0.6838
5.00	1.00	0.97	0.50	19.3	278.6	269.0	0.2690	0.9528
6.00	1.00	0.32	0.165	6.4	285.0	281.8	0.2818	1.2346

Since $v < 25$ ft/sec. (see par. 2-2.3.5), $\frac{T_C}{T} = 3.8$, $T_c = t_r$ and $F_m = F_a + \frac{1}{2}(KL)$ (Eqs. 2-17 and 2-18), Eq. 2-67b, after $T_c/3.8$ is substituted for T, becomes

$$KT_c = \frac{F_a + 0.5KL}{273}$$

$$0.070K = \frac{52.6 + 5K}{273}.$$

Solve for K, thus

$$K = \frac{52.6}{14.11} = 3.72 \text{ lb/in.}$$

$$F_m = F_a + \frac{1}{2}(KL) = 52.6 + 5 \times 3.72 = 71.2 \text{ lb}$$

$$F_o = F_m - KL = 71.2 - 37.2 = 34.0 \text{ lb.}$$

Compute t from Eq. 2-23

$$t = \sqrt{\frac{eM_b}{K}} \text{ Cos}^{-1} \frac{F_o}{F_m}$$

$$= \sqrt{\frac{0.5 \times 10}{3.72 \times 386.4}} \text{ Cos}^{-1}\left(\frac{34.0}{71.2}\right)$$

$$= 0.059\left(\frac{61.5}{57.3}\right) = 0.063 \text{ sec.}$$

Recomputing by inserting the newly calculated time t for T_c, the data converge to $K = 4.4$ lb/in. and $t = 0.062$ sec.

The first set of detailed calculations (not shown) yielded a bolt recoil time of $t = T_c = 51.5$ msec. For this time, the computed spring constant of $K = 5.8$ lb/in. becomes the final value for computing the dynamics of Table 2-3.

The spring constant of the buffer system is found by assuming that the energy E_{to}=3491 in.-lb will be absorbed over the 1-inch buffer stroke. Later, adjustments will be made to compensate for the small discrepancies involving the spring forces. The time t_b of buffer action during recoil is

$$t_b = \frac{2L_b}{v_b} = \frac{2 \times 1.0}{232.3} = 0.0086 \text{ sec}$$

where L_b = buffer stroke

v_b = recoil velocity of barrel when buffer is contacted

The average buffer force F_{ab} is

$$F_{ab} = \frac{e_b E_{to}}{L_b} = \frac{0.3 \times 3491}{1.0} = 1047 \text{ lb.}$$

Follow the same procedure for the buffer as for the driving spring

$$K_b T_c = \frac{F_{ab} + 0.5K_b L_b}{273}$$

$$273 \times 0.0086K_b = 1047 + 0.5K_b.$$

Solve for K_b, thus

$K_b = \frac{1047}{1.85} = 566$ lb/in., buffer spring constant

$F_{mb} = 1047 + 283 = 1330$ lb, max buffer force

$F_{ob} = 1047 - 283 = 764$ lb, min buffer force

Compute t_b from Eq. 2-23

$$t_b = \sqrt{\frac{e_b M_t}{K_b}} \text{ Cos}^{-1} \frac{F_{ob}}{F_{mb}}$$

$$= \sqrt{\frac{0.3 \times 50}{566 \times 386.4}} \text{ Cos}^{-1}\left(\frac{764}{1330}\right) = 0.0079 \text{ sec.}$$

Recompute K_b by inserting the time 0.0079 sec for T_c. The new value of the spring constant K_b is 630 lb/in., but the new time remains $t_b = 0.0079$ sec.

The spring constant for the barrel spring is computed similarly but in this instance the spring force at the assembled height is set at F_o = 70 lb, a minimal value so that recoil distance and velocity are appropriate for bolt action. The time of barrel spring compression is the same as that for the buffer plus the propellant gas period.

$$t_t = t_b + t = 0.0079 + 0.006 = 0.0139 \text{ sec}$$

The barrel spring has an operating deflection of L_t = 2.0 in.

$F_{mt} = F_{ot} + K_t L_t = 70 + 2K_t$, max barrel spring force

With $T = \frac{T_c}{3.8} = \frac{0.0139}{3.8}$ sec,

Eq. 2-67b may be written as

$$0.0139K_t = \frac{70 + 2K_t}{273}.$$

Thus

$$K_t = \frac{70}{1.8} = 39 \text{ lb/in., barrel spring constant}$$

$$F_{mt} = 70 + 78 = 148 \text{ lb, max barrel spring force}$$

Before recomputing time t_t, according to Eq. 2-23, some allowance must be made for the effective barrel mass. Since both barrel and buffer springs are active over the buffer stroke, a logical distribution can be arranged according to the average spring forces. The effective mass for the barrel spring is

$$M_e = \frac{W_t}{g}\left(\frac{F_{ot} + F_{mt}}{F_{ob} + F_{mb}}\right) = \frac{50}{g}\left(\frac{218}{2096}\right) = \frac{5.2}{g}$$

$$t_t = \sqrt{\frac{e_t M_e}{K_t}} \operatorname{Cos}^{-1} \frac{F_{ot}}{F_{mt}}$$

$$= \sqrt{\frac{0.5 \times 5.2}{39 \times 386.4}} \operatorname{Cos}^{-1}\left(\frac{70}{148}\right)$$

$$= 0.0132\left(\frac{61.8}{57.3}\right) = 0.0142 \text{ sec.}$$

Substitute the new value of $T_c = t_t$ and compute. The time and spring constant coverge to t_t = 0.0143 sec and K_t = 37 lb/in., and F_m = 144 lb. The buffer spring constant is

$$K_{bs} = K_b - K_t = 630 - 37 = 593 \text{ lb/in.}$$

Now that the constants of all three springs are firmly established, more exact values of the minimum and maximum spring forces of the buffer spring system are computed. Since the driving spring does deflect while the propellant gas pressure is still effective, less than the full spring deflection is available to absorb the bolt energy. For this reason, increasing the initial load to F_o = 25 lb for early estimates seems advisable. This spring force became effective and therefore is included in Table 2-? after the 4 msec interval. In the meantime, the driving spring transfers some of the bolt energy to the moving barrel. The average driving spring force after bolt unlocking until, the barrel stops recoiling is approximately 27 lb.

$$E_t = E_{to} + \left(\frac{F_a}{e}\right)L_t'$$

$$= 3491 + \left(\frac{27}{0.5}\right)1.5 = 3572 \text{ in.-lb}$$

where L_t' is the barrel travel after the bolt is unlocked. From Table 2-2, when t = 3.252, x = 0.5, then $L_t' = L_t - x = 2.0 - 0.5 = 1.5$ in.

The energy absorbed by the barrel spring over the half-inch travel before the buffer is contacted is

$$\Delta E_t = \frac{1}{2}\left[\frac{(F_t' + F_t'')\Delta L}{e_t}\right] = \frac{(88.5 + 107)0.5}{2 \times 0.5}$$

$$= 98 \text{ in.-lb}$$

where F_t' and F_t'' are the barrel spring forces at half inch and one-inch travel positions, respectively.

The average force of the buffer spring system found according to Eq. 2-30 is

$$F_{ab} = \frac{e_5(E_t - \Delta E_t)}{L_b} = \frac{0.3 \times 3474}{1.0} = 1042 \text{ lb.}$$

The initial force of the buffer spring system is

$$F_{ob} = F_{ab} - \frac{1}{2}\left(K_b L_b \right) = 1042 - \frac{1}{2}\left(630 \right)1.0 = 727 \text{ lb}$$

$$F_{obs} = F_{ob} - \left(F_{ot} + 1.0 K_t \right) = 620 \text{ lb}$$

where K_b = 630 lb/in., the buffer spring system constant.

The maximum buffer spring system force is

$$F_{mb} = F_{ob} + K_b L_b = 727 + 630 \times 1.0 = 1357 \text{ lb}$$

$$F_{mbs} = F_{mb} - F_{mt} = 1213 \text{ lb}$$

The impact velocity of the barrel on the buffer spring is

$$v_t = \sqrt{\frac{2(E_t - \Delta E_t)}{M_t}} = \sqrt{\frac{2(3572 - 98)386.4}{50}} = 231.7 \text{ in./sec.}$$

The bolt is unlocked at 3.252 msec and continues to be accelerated until 6 msec. During most of the remaining time of 2.748 msec the barrel spring is the sole resistance to barrel recoil. After the barrel recoils a half-inch farther, the barrel spring is joined by the buffer spring. Based on Eq. 2–51, the time increment for this half-inch travel is

$$\Delta t_{rt} = \sqrt{\frac{e_t M_t}{K_t}} \left[\text{Sin}^{-1} \frac{F_t'' - \left(\frac{e_t}{e} \right) F}{Z} - \text{Sin}^{-1} \frac{F_t' - \left(\frac{e_t}{e} \right) F}{Z} \right]$$

$$= \sqrt{\frac{0.5 \times 50}{37 \times 386.4}} \left[\text{Sin}^{-1}\left(\frac{82}{369} \right) - \text{Sin}^{-1}\left(\frac{63.5}{369} \right) \right]$$

$$\Delta t_{rt} = 0.0418 \, (12.84 - 9.91) / 57.3 = 0.002137 \text{ sec}$$

where F = 25 lb, estimated driving spring force during period

F_t' = 88.5 lb, barrel spring force when bolt is unlocked

F_t'' = 107 lb, barrel spring force when buffer is contacted

e = 0.50, efficiency of driving spring

e_t = 0.50, efficiency of barrel spring

$$\left[F_t' - \left(\frac{e_t}{e}\right)F\right]^2 = 63.5^2 = 4032 \text{ lb}^2$$

$$e_t K_t M_t v_t^2 = 0.5 \times 37 \times 2E_t = 132{,}164 \text{ lb}^2$$

$$Z = \sqrt{\left[F_t' - \left(\frac{e_t}{e}\right)F\right]^2 + e_t K_t M_t v_t^2} = \sqrt{136307} = 369 \text{ lb.}$$

The time still remaining during propellant gas activity is

$$t_{rt} = 0.006 - 0.003252 - 0.002137 = 0.000611 \text{ sec.}$$

During this time the barrel contacts the buffer and continues rearward over a distance that is computed according to Eq. 2-51.

$$t_{rt} = \sqrt{\frac{e_b M_t}{K_b}}\left(\text{Sin}^{-1}\frac{F_{me}}{Z} - \text{Sin}^{-1}\frac{F_{oe}}{Z}\right)$$

$$0.000611 = \sqrt{\frac{0.3 \times 50}{630 \times 386.4}}\left[\text{Sin}^{-1}\left(\frac{630x_{to} + 711}{1348}\right) - \text{Sin}^{-1}\left(\frac{711}{1348}\right)\right]$$

where

e_b = 0.3, efficiency of buffer spring system

$$F_{oe} = F_{ob} - \left(\frac{e_b}{e}\right)F_a = 727 - \left(\frac{0.3}{0.5}\right)27 = 711 \text{ lb}$$

$$F_{me} = K_b x_{to} + F_{oe} = 630\,x_{to} + 711 \text{ lb}$$

$$e_b K_b M_t v_{ot}^2 = 2e_b K_b (E_t - \Delta E_t) = 0.3 \times 630 \times 6948 = 1{,}313{,}172 \text{ lb}^2$$

$$Z = \sqrt{F_{zz}^2 + \epsilon_b K_b M_t v_{zz}^2} = \sqrt{1,818,693} = 1348 \text{ lb}$$

Continuing

$$0.000611 = 0.00785 \left[\text{Sin}^{-1}\left(\frac{630 x_{to} + 711}{1348} \right) - \text{Sin}^{-1}\left(\frac{711}{1348} \right) \right]$$

$$0.0778 = \text{Sin}^{-1}\,(0.4674 x_{to} + 0.5274) - \text{Sin}^{-1}\,0.5274$$

$$\text{Sin}^{-1}\,(0.4674 x_{to} + 0.5274) = 31^\circ\ 50' + 4^\circ\ 28' = 36^\circ\ 18'$$

$$0.4674 x_{to} = 0.5920 - 0.5274 = 0.0646$$

$$x_{to} = 0.138 \text{ in.}$$

The barrel has 0.862 in. to go to complete its buffer stroke. The time needed to tranverse this distance is obtained from Eqs. 2–60c and 2–61c. Calculate the constants in Eq. 2–60c.

$$4\epsilon M_L = 4\left(0.5\right)\frac{10}{386.4} = 0.0518 \text{ lb-sec}^2/\text{in.}$$

$$\frac{1}{2\epsilon M_b} = \frac{386.4}{2 \times 0.5 \times 10} = 38.64 \text{ in./(lb-sec}^2)$$

$$\frac{K}{4\epsilon M_b} = \frac{5.8 \times 386.4}{4 \times 0.5 \times 10} = 112/\text{sec}^2$$

Substitute these values into Eq. 2–60c.

$$\Delta x = B\left[v_{(n-1)}\,\Delta t - 38.64\, F_{(n-1)}\,\Delta t^2 + 112\,\Delta t^2 \Delta x_t \right] \qquad (2\text{–}68a)$$

where

$$B = \frac{0.0518}{0.0518 + 5.8\,\Delta t^2}$$

Calculate the constants in Eq. 2–61c.

$$4\epsilon\epsilon_b M_t = \frac{4 \times 0.5 \times 0.3 \times 50}{386.4} = 0.0776 \text{ lb-sec}^2/\text{in.}$$

$$\epsilon K_b + \epsilon_b K = 0.5 \times 630 + 0.3 \times 5.8 = 316.7 \text{ lb/in.}$$

$$\frac{1}{2\epsilon_b M_t} = \frac{386.4}{2 \times 0.3 \times 50} = 12.88 \text{ in./(lb-sec}^2)$$

$$\frac{1}{2\epsilon M_t} = \frac{386.4}{2 \times 0.5 \times 50} = 7.73 \text{ in./(lb-sec}^2)$$

$$\frac{K}{4\epsilon M_t} = \frac{5.8 \times 386.4}{4 \times 0.5 \times 50} = 22.41/\text{sec}^2$$

Substitute in Eq. 2–61c.

$$\Delta x_t = A\left[v_{t(n-1)}\,\Delta t - 12.88 F_{b(n-1)}\,\Delta t^2 + 7.73 F_{(n-1)}\,\Delta t^2 + 22.41\,\Delta t^2 \Delta x \right] \qquad (2\text{–}68b)$$

where $A = \dfrac{0.0776}{0.0776 + 316.7\,\Delta t^2}$

Solve for the various parameters and then for Δt.

$$\Delta x_t = L_b - x_{to} = 1.00 - 0.138 = 0.862 \text{ in.}$$

The driving spring force is estimated as the average during this period

$F_{(n-1)}$ = 27 lb (assumed constant)

$F_{b(n-1)} = F_{ob} + K_b x_{to} = 727 + 630 \times 0.138 = 814$ lb

$$\Delta E_t' = \frac{1}{2e_b}\left[F_{ob} + F_{b(n-1)} \right] x_{to} = 354 \text{ in.-lb}$$

$E_{t(n-1)} = E_t - \Delta E_t - \Delta E_t' = 3572 - 98 - 354 = 3120$ in.-lb

$\Delta x = 1.928$ (assumed and then verified below)

$$v_{t(n-1)} = \sqrt{\frac{2E_{t(n-1)}}{M_t}} = \sqrt{\frac{6240 \times 386.4}{50}} = \sqrt{48223} = 219.6 \text{ in./sec}$$

$$0.862 = \left(\frac{0.0776}{0.0776 + 316.7\ \Delta t^2} \right) (219.6\ \Delta t - 10484\ \Delta t^2 + 209 \Delta t^2 + 43 \Delta t^2)$$

$$0.862 + 3518 \Delta t^2 = 219.6 \Delta t - 10232 \Delta t^2$$

$$\Delta t^2 - 15.97 \times 10^{-3} \Delta t + 62.70 \times 10^{-6} = 0$$

$$\Delta t = 6.96 \times 10^{-3}$$

Since $\Delta t^2 = 48.4 \times 10^{-6}$, the fraction $\dfrac{0.0518}{0.0518 + 5.8 \Delta t^2} = 0.9946$

$$\Delta x = 0.9946 \left[v_{(n-1)} \Delta t - 38.64 F_{(n-1)} \Delta t^2 + 112 \Delta t^2 \Delta x_t \right]$$

$$= 0.9946 \left[285 \times 6.96 \times 10^{-3} - (38.64 \times 27 - 112 \times 0.862)\ 48.4 \times 10^{-6} \right]$$

$$\Delta x = 0.9946 (1.984 - 0.046) = 1.928 \text{ in.}$$

The absolute distance traveled by the barrel at this time is 2.0 in., and x_b the distance that the bolt traveled with respect to the barrel is

$$x_b = \Sigma \Delta x - L_t + \Delta x = 1.235 - 2.0 + 1.928 = 1.163 \text{ in.}$$

The total time of buffer spring action during recoil is

$$t_{br} = t_{rt} + \Delta t = 0.00061 + 0.00696 = 0.00757 \text{ sec.}$$

The prevailing conditions at the end of the propellant gas period are now computed. The barrel travel is

$$x_t = \Sigma\Delta x_t + x_{tc} = 1.0 + 0.138 = 1.138 \text{ in.}$$

where $\Sigma\Delta x_t = 1.0$ in., barrel travel when it contacts buffer at 5.389 msec. The bolt travel or driving spring deflection is

$$x_{bo} = \Sigma\Delta x - x_t = 1.235 - 1.138 = 0.097 \text{ in.}$$

where $\Sigma\Delta x = 1.235$ in., absolute bolt travel at end of propellant gas period (Table 2–2). The average driving spring force for the remaining deflection is

$$F_a = \frac{eE_b}{L - x_{bo}} = \frac{0.5 \times 1051}{10.0 - 0.097} = 53.1 \text{ lb.}$$

For $K = 5.8$, the force at 0.10 in. deflection is

$$F'_o = F_a - \frac{1}{2} K(L - x_{bo}) = 53.1 - 28.7 = 24.4 \text{ lb.}$$

The driving spring force when the bolt is fully retracted is

$$F'_m = F'_o + K(L - x_{bo}) = 24.4 + 57.4 = 81.8 \text{ lb.}$$

The driving spring force at zero bolt travel is

$$F_o = F_m - KL = 81.8 - 58 = 23.8 \text{ lb.}$$

The bolt travel from the time that the propellant gas becomes ineffective until the barrel is fully recoiled is

$$x'_b = x_b - x_{bo} = 1.163 - 0.097 = 1.066 \text{ in.}$$

The driving spring force F is

$$F = F'_o + K\,x'_b = 24.4 + 5.8 \times 1.066 = 30.6 \text{ lb.}$$

The absorbed energy expressed as the differential energy ΔE is

$$\Delta E = \left[\frac{(F'_o + F)}{2e}\right] x'_b = \left(\frac{55}{2 \times 0.5}\right) 1.066 = 58.6 \text{ in.-lb.}$$

The energy remaining becomes

$$E = E_b - \Delta E = 1051 - 58.6 = 992.4 \text{ in.-lb.}$$

The bolt velocity at this time becomes

$$v = \sqrt{\frac{2E}{M_b}} = \sqrt{\frac{2 \times 992.4 \times 386.4}{10}}$$

$$= \sqrt{76693} = 276.9 \text{ in./sec.}$$

The time t at full recoil of the barrel or when barrel begins to counterrecoil is

$$t = t_g + \Delta t = 12.96 \text{ msec}$$

where $t_g = 0.006$ sec, duration of propellant gas period

$\Delta t = 0.00696$ sec, time for barrel to complete recoil after t_g.

2–4.4 COMPUTER ROUTINE FOR COUNTERRECOILING BARREL DYNAMICS

A digital computer routine is programmed in FORTRAN IV language for computing the dynamics of the barrel during counterrecoil. Since time and distance are the most pertinent parameters, the program is generated about these data. During a given differential time, Eqs. 2–60c and 2–64d give the differential travel distance of the bolt while Eqs. 2–63c and 2–65c give the differential travel distance of the barrel. Eq. 2–53a provides the relative travel which is equivalent to the driving spring compression. The differential relative travel between barrel and bolt is computed from Eq. 2–53b.

After substituting the various known constants, Eqs. 2–60c and 2–64d are rewritten as Eqs. 2–68a and 2–70a to define the action of the bolt during recoil and counterrecoil, respectively. The substitution of constants into Eq. 2–63c yields equations for the barrel travel while the bolt is recoiling; Eq. 2–69a when the buffer is active; and Eq. 2–69b when the barrel spring acts alone. Eq. 2–65c, after the substitution of numerical constants, becomes Eq. 2–70b which defines the differential barrel travel if the buffer is still active. When the buffer is inactive, Eq. 2–70c defines the differential barrel travel.

Since the equation for solving Δx includes an expression that contains Δx_t, and the equation for solving Δx_t includes an expression that contains Δx, the computer program contains an interative routine that approximates these two differential distances. The approximations for Δx and Δx_t eventually approach the true values close enough to render any error negligible.

The computed values of the constants in Eq. 2–63c for the barrel counterrecoiling under the influence of the buffer while the bolt is still recoiling are

$$4eM_t = \frac{4 \times 0.5 \times 50}{386.4} = 0.2588 \text{ lb-sec}^2/\text{in.}$$

$$ee_bK_b - K = 0.5 \times 0.3 \times 630 - 5.8 = 88.7 \text{ lb/in.}$$

$$\frac{e_b}{2M_t} = \frac{0.3 \times 386.4}{2 \times 50} = 1.159 \text{ in./(lb-sec}^2\text{)}$$

$$\frac{1}{2eM_t} = \frac{386.4}{2 \times 0.5 \times 50} = 7.73 \text{ in./(lb-sec}^2\text{)}$$

$$\frac{K}{4eM_t} = \frac{5.8 \times 386.4}{4 \times 0.5 \times 50} = 22.41 / \text{sec}^2$$

Substitute these constants in Eq. 2–63c

$$\Delta x_t = A\left[v_{t(n-1)}\Delta t + \left(1.159F_{b(n-1)} - 7.73F_{(n-1)}\right)\Delta t^2 - 22.41\,\Delta t^2\,\Delta x\right] \quad (2\text{–}69a)$$

where

$$A = \frac{0.2558}{0.2558 + 88.7\Delta t^2}$$

At the end of buffer return, only barrel and driving springs remain effective. These design data for the barrel spring are

$K_t = 37$ lb/in., $F_{ot} = 107$ lb, $e_t = 0.5$

The constants in Eq. 2–63c now become

$$ee_tK_t - K = 0.5 \times 0.5 \times 37 - 5.8 = 3.45 \text{ lb/in.}$$

$$\frac{e_t}{2M_t} = \frac{0.5 \times 386.4}{2 \times 50} = 1.932 \text{ in./(lb-sec}^2\text{)}.$$

Substitute the revised constants into Eq. 2–63c.

$$\Delta x_t = A\left\{ v_{t(n-1)}\Delta t + \left[1.932F_{b(n-1)} - 7.73F_{(n-1)}\right]\Delta t^2 - 22.41\,\Delta t^2\,\Delta x\right\} \quad (2\text{–}69b)$$

where

$$A = \frac{0.2558}{0.2558 + 3.45\Delta t^2}$$

The constants of Eq. 2–64d, when both bolt and barrel counterrecoil, are computed to be

$4M_b = 0.1035$ lb-sec^2/in.; $eK = 2.9$ lb/in.

$e/2M_b = 9.66$ in./(lb-sec^2); $eK/4M_b = 28/\text{sec}^2$

$$B = \frac{0.1035}{0.1035 - 2.9\Delta t^2}.$$

Eq. 2–64d now becomes

$$\Delta x = B\left[V_{(n-1)}\Delta t - 9.66F_{(n-1)}\Delta t^2 - 28\Delta t^2\Delta x_t\right]. \quad (2\text{–}70a)$$

The constants of Eq. 2–65c also change.

$4M_t = 0.518$ lb-sec^2/in. $eK/4M_t = 5.6/\text{sec}^2$

$e/2M_t = 1.932$ in./(lb-sec^2)

If the buffer is still active, the computed constants are

$$eK + e_b K_b = 0.5 \times 5.8 + 0.3 \times 630 = 191.9 \text{ lb/in.}$$

$$e_b/2M_t = 1.159 \text{ in./(lb-sec}^2\text{)}; \quad A = \frac{0.518}{0.518 + 191.9\Delta t^2}.$$

After substituting these constants into Eq. 2–65c, the differential barrel travel becomes

$$\Delta x_t = A\left\{ v_{t(n-1)}\,\Delta t + \left[1.159F_{b(n-1)} - 1.932F_{(n-1)} + 5.6\Delta x \right]\Delta t^2 \right\}. \qquad (2\text{–}70b)$$

With the buffer no longer active, the constants become

$$eK + e_t K_t = 0.5 \times 5.8 + 0.5 \times 37 = 21.4 \text{ lb/in.}$$

$$e_t/2M_t = 1.932 \text{ in./(lb-sec}^2\text{)}; \quad A = \frac{0.518}{0.518 + 21.4\Delta t^2}$$

After being assigned these constants, Eq. 2–65c becomes

$$\Delta x_t = A\left\{ v_{t(n-1)}\,\Delta t + \left[1.932F_{b(n-1)} - 1.932F_{(n-1)} + 5.6\Delta x \right]\Delta t^2 \right\}. \qquad (2\text{–}70c)$$

Although functions of the spring forces appear in the equations for computing the distance traveled by bolt and barrel, the spring forces must be computed for each increment of time since those values are projected into the next increment. At the end of each increment, the spring forces on bolt and barrel are computed, respectively, from Eqs. 2–55 and 2–56. The driving spring force is

$$F = F_{(n-1)} + 5.8\Delta x_b. \qquad (2\text{–}71a)$$

While the buffer is operating, the counterrecoil force on the barrel becomes

$$F_b = F_{b(n-1)} - 630\Delta x_t. \qquad (2\text{–}71b)$$

When the barrel spring operates alone, this force is

$$F_b = F_{b(n-1)} - 37\Delta x_t. \qquad (2\text{–}71c)$$

After the spring forces are computed, the respective energies and velocities of the bolt and barrel are computed from formulas based on Eqs. 2–66a, 2–66b, and 2–66d.

For convenience, the computer program is divided into four periods: (1) during buffer action, (2) during bolt recoil, (3) after buffer action, and (4) during bolt counterrecoil. Bolt action occurs simultaneously with barrel action (buffer action being a part of barrel action), but usually continues after the barrel is fully counterrecoiled. When the bolt is fully recoiled at t = 50.63 msec (Table 2–5), it immediately starts counterrecoiling with the barrel and these two now counterrecoil as one mass. The velocity at this instant is computed from the law of the conservation of momentum.

$$M_t v_t = (M_t + M_b) v_{t(n-1)} \qquad (2\text{–}71d)$$

Table 2–3 lists the variables and corresponding FORTRAN code in alphabetical order. Table 2–4 lists the input and Table 2–5 lists the output or results of the computer. The program is found in Appendix A–1 and its flow chart in Appendix A–2.

After the barrel has fully counterrecoiled, all remaining activity is confined to the bolt. It still has to negotiate its complete counterrecoil stroke. The time elasped for the bolt to complete the remaining counterrecoil stroke is computed from Eq. 2–26.

$$t_{crb} = \sqrt{\frac{M_b}{eK}}\left(\text{Sin}^{-1}\frac{-F_o}{\sqrt{F^2 + \left(\frac{K}{e}\right)M_b v^2}} - \text{Sin}^{-1}\frac{-F}{\sqrt{F^2 + \left(\frac{K}{e}\right)M_b v^2}} \right) \qquad (2\text{–}72)$$

$$t_{crb} = 0.0945\left[\text{Sin}^{-1}\left(\frac{-23.8}{88.38}\right) - \text{Sin}^{-1}\left(\frac{-81.77}{88.38}\right)\right]$$

$$= 0.0945\ [\text{Sin}^{-1}(-)\,0.2693 - \text{Sin}^{-1}(-)\,0.9252]$$

$$= 0.0945\ (344.37 - 292.3)/57.3 = 0.0859 \text{ sec}$$

TABLE 2-3. SYMBOL-CODE CORRELATION FOR DELAYED BLOWBACK PROGRAM

Symbol	Code	Symbol	Code
E	E	n	I
ΔE	DE	t	T
E_t	ET	Δt	DT
ΔE_t	DET	v	V
F	F	v_t	VT
F_b	FB	w_b	WB
F_o	FO	w_{bbl}	WBBL
g	G	Δx	DX
K	SK	x_b	XB
K_b	SKB	Δx_b	DXB
K_t	SKT	x_t	XT
M_b	EMB	Δx_t	DXT
M_t	EMT	ϵ	EPS
$M_b v$	BMV	ϵ_b	EPSB
$M_t v_t$	TMV	ϵ_t	EPST

where $M_b = \frac{10}{386.4}$ lb-sec^2/in., mass of bolt

K = 5.8 lb/in., driving spring rate

F_o = 23.8 lb, spring force when bolt is closed

F = 81.77 lb, last driving spring force in Table 2–5

$M_b v^2$ = $2E$ = 97 in.-lb, (E is last value of bolt energy in Table 2–5)

ϵ = 0.5, efficiency of driving spring

Time elapsed from the complete cycle of barrel action including free recoil, buffing, and counterrecoil is

t_{tc} = 54.73 msec, elapsed time of barrel cycle (Table 2–5)

$$t_c = t_{tc} + t_{crb} = 0.0547 + 0.0859 = 0.1406 \text{ sec.}$$

The firing rate is

$$f_r = \frac{60}{t_c} = \frac{60}{0.1406} = 426 \text{ rounds/min.}$$

The velocity of the bolt just as counterrecoil is completed is

$$v_{crb} = \sqrt{v_o^2 + \frac{2E}{M_b}} = \sqrt{v_o^2 + \frac{\epsilon(F_o + F)x_b}{M_b}}$$

$$= \sqrt{3745 + \frac{0.5 \times 105.57 \times 386.4 \times 9.995}{10}}$$

$$= 155.3 \text{ in./sec.}$$

TABLE 2–4. INPUT FOR DELAYED BLOWBACK PROGRAM

Code	Input	Code	Input
A1	0.2558	WB	10.0
A2	88.7	WBBL	50.0
A3	3.45	FO	23.8
A4	0.518	FST	107.0
A5	191.9	FKCR	9.66
A6	21.4	DKXTCR	28.0
B1	0.0518	DKXCR	5.603
B2	5.8	F(1)	30.6
B3	0.1035	FB(1)	1357.0
B4	2.9	V(1)	276.9
EPS	0.5	VT(1)	0.0
EPSB	0.5	XB(1)	1.163
EP3T	0.5	XT(1)	0.0
FK	38.64	T(1)	12.96
DXKT	112.0	DX(1)	0.0
BUFK	1.159	DXB(1)	1.066
BBLK	1.932	DXT(1)	0.0
DKX	22.41	DE(1)	0.0
FBK	7.73	DET(1)	0.0
SK	5.8	E(1)	992.4
SKB	630.0	ET(1)	0.0
SKT	37.0	G	386.4

2–4.5 SPRINGS

The driving, barrel, and buffer springs have been assigned characteristics in the dynamic analysis to meet the firing cycle requirements. The analyses which follow of the three springs determine their remaining characteristics that are congruous with the operational and strength requirements.

2–4.5.1 Driving Spring

Known Data:

K = 5.8 lb/in., spring constant

F_o = 23.8 lb, spring force with bolt closed

F_m = 81.8 lb, spring force at full recoil

L = 10.0 in., bolt travel

$T_c = t_{rb}$ = 0.0474 sec, compression time of spring

$v_i = v_f$ = 285 in./sec, bolt velocity of free recoil, impact velocity

The compression time of the spring is measured from the time (3.252 msec, Table 2–2) that the bolt is unlocked until it has fully recoiled (t = 50.6 msec, when x_b = 10.0 in., Table 2–5).

Since $v_i < 25$ fps, select $\frac{T_c}{T} = 3.8$, or

$$T = \frac{0.0474}{3.8} = 0.0125 \text{ sec.}$$

TABLE 2–5. COUNTERRECOIL DYNAMICS OF DELAYED BLOWBACK GUN

INCREMENT I	RELATIVE DELTA BOLT TRAVEL INCH	DELTA BOLT TRAVEL INCH	DELTA BARREL TRAVEL INCH	TOTAL BOLT TRAVEL INCH	TOTAL BARREL TRAVEL INCH	DRIVING SPRING FORCE POUND	BARREL SPRING FORCE POUND
1	.060	1.060	.000	1.060	.000	30.60	1357.6
2	.549	.554	.005	1.717	.005	33.76	1353.7
3	.538	.555	.017	2.272	.022	36.98	1343.2
4	.527	.555	.028	2.827	.050	40.20	1325.2
5	.514	.554	.040	3.381	.091	43.41	1299.9
6	.499	.551	.052	3.932	.142	46.61	1267.2
7	.483	.546	.063	4.478	.206	49.77	1227.4
8	.466	.540	.074	5.018	.280	52.91	1180.7
9	.447	.532	.085	5.550	.365	55.99	1127.2
10	.426	.521	.095	6.072	.460	59.02	1067.4
11	.404	.509	.105	6.580	.564	61.97	1001.5
12	.380	.494	.114	7.074	.678	64.83	929.9
13	.354	.476	.122	7.550	.800	67.59	853.0
14	.326	.455	.130	8.005	.930	70.23	771.3
15	.295	.425	.070	8.430	1.000	71.53	107.0
16	.278	.416	.138	8.846	1.138	73.95	101.9
17	.244	.383	.139	9.228	1.277	76.16	96.8
18	.206	.346	.140	9.575	1.417	78.17	91.6
19	.163	.305	.142	9.880	1.559	79.94	86.3
20	.114	.257	.143	9.937	1.702	81.43	81.0
21	.057	.064	.057	10.000	1.749	81.80	79.3
22	.000	.000	.000	10.000	1.749	81.80	79.3
23	-.125	-.003	.122	9.997	1.871	81.78	74.8
24	-.125	-.002	.123	9.995	1.994	81.77	70.2
25	-.006	.006	.006	9.995	2.000	81.77	70.0

INCREMENT I	TIME MSEC	DELTA BOLT ENERGY IN-LB	DELTA BARREL ENERGY IN-LB	BOLT ENERGY IN-LB	BARREL ENERGY IN-LB	BOLT VELOCITY IN/SEC	BARREL VELOCITY IN/SEC
1	12.96	.0	.0	992.4	.0	276.9	.0
2	14.96	35.7	2.2	956.7	2.2	271.9	5.8
3	16.96	39.3	6.8	917.5	8.9	266.3	11.7
4	18.96	42.8	11.4	874.6	20.3	260.0	17.7
5	20.96	46.3	15.8	828.3	36.1	253.0	23.6
6	22.96	49.6	20.0	778.7	56.1	245.3	29.4
7	24.96	52.7	23.6	726.1	79.7	236.9	35.1
8	26.96	55.5	26.8	670.6	106.5	227.7	40.6
9	28.96	57.9	29.4	612.7	135.9	217.6	45.8
10	30.96	60.0	31.3	552.7	167.2	206.7	50.8
11	32.96	61.5	32.5	491.2	199.6	194.8	55.5
12	34.96	62.6	32.9	428.6	232.6	182.0	60.0
13	36.96	63.0	32.6	365.6	265.2	168.1	64.0
14	38.96	62.6	31.6	302.8	296.8	153.0	67.7
15	39.99	31.9	15.7	271.0	312.5	144.7	69.5
16	41.99	60.5	7.2	210.5	319.7	127.5	70.3
17	43.99	57.4	6.9	153.0	326.6	108.8	71.1
18	45.99	53.4	6.6	99.6	333.2	87.7	71.8
19	47.99	48.3	5.3	51.4	339.6	63.0	72.4
20	49.99	41.4	6.0	9.9	345.5	27.7	73.1
21	50.63	10.4	1.9	.0	347.4	.0	73.5
22	50.63	48.3	106.2	48.3	241.3	-61.1	61.1
23	52.63	.1	4.7	48.4	246.0	-61.1	61.7
24	54.63	.1	4.5	48.5	250.4	-61.2	62.2
25	54.73	.0	.2	48.5	250.6	-61.2	62.2

Select a mean coil diameter of 1.0 in. Then according to Eq. 2–42, the wire diameter is

$$d = 0.27\sqrt[3]{DKT} = 0.27\sqrt[3]{0.0725} = 0.113 \text{ in.}$$

From Eq. 2–41

$$N = \frac{Gd^4}{8KD^3} = \frac{11.5 \times 10^6 \times 1.63 \times 10^{-4}}{8 \times 5.8 \times 1.0} = 40.5 \text{ coils.}$$

Static shear stress is

$$\tau = \frac{8F_mD}{\pi d^3} = \frac{8 \times 81.8 \times 1.0 \times 10^3}{3.14 \times 1.442} = 144{,}500 \text{ lb/in.}^2$$

Dynamic shear stress is

$$\tau_d = \tau\left(\frac{T}{T_c}\right)\left[f\left(\frac{T_c}{T}\right)\right] = \left(144{,}500\right)\frac{4.0}{3.8}$$

$$= 152{,}100 \text{ lb/in.}^2$$

2–4.5.2 Barrel Spring

Known Data:

K_t = 37 lb/in., spring constant

F_{ot} = 70 lb, spring force with barrel in battery

F_{mt} = 144 lb, spring force with barrel fully recoiled

L_t = 2.0 in., barrel travel

$T_c = t_r$ = 0.013 sec, compression time of spring

$v_i = v_f$ = 232.3 in./sec, barrel velocity of free recoil, impact velocity

The compression time of the spring includes the time of free recoil and that for the rest of the recoil distance.

Select $\frac{T_c}{T} = 3.8$, or

$$T = \frac{T_c}{3.8} = \frac{0.013}{3.8} = 0.0034 \text{ sec.}$$

Select a mean coil diameter of 1.0 in. According to Eq. 2–42, the wire diameter is

$$d = 0.27\sqrt[3]{DK_tT} = 0.27\sqrt[3]{0.1258} = 0.136 \text{ in.}$$

From Eq. 2–41

$$N = \frac{Gd^4}{8K_tD^3} = \frac{11.5 \times 10^6 \times 3.42 \times 10^{-4}}{8 \times 37 \times 1.0} = 13 \text{ coils.}$$

The static shear stress is

$$\tau = \frac{8F_{mt}D}{\pi d^3} = \frac{8 \times 144 \times 1.0}{3.14 \times 2.52 \times 10^{-3}} = 145{,}500 \text{ lb/in.}^2$$

The dynamic shear stress is

$$\tau_d = \tau\left(\frac{T}{T_c}\right)\left[f\left(\frac{T_c}{T}\right)\right] = \left(144{,}500\right)\frac{4.0}{3.8}$$

$$= 153{,}000 \text{ lb/in.}^2$$

2–4.5.3 Buffer Spring

Known Data:

F_{obs} = 620 lb, spring force when first contacted

F_{mbs} = 1213 lb, spring force at end of buffer stroke

K_{bs} = 593 lb/in., spring constant

L = 1.0 in., length of buffer stroke

$T_c = t_{br}$ = 0.00757 sec, compression time of spring (see p. 2–32)

v_i = 231.7 in./sec, impact velocity of buffer (see p. 2–29)

Select $\frac{T_c}{T} = 3.8$, or

$$T = \frac{T_c}{3.8} = \frac{0.00757}{3.8} = 0.00199 \text{ sec.}$$

Select a mean coil diameter of 1.75 in. The wire diameter, from Eq. 2–42, is

$$d = 0.27\sqrt[3]{DK_{bs}T} = 0.27\sqrt[3]{2.07} = 0.344 \text{ in.}$$

From Eq. 2–41

$$N = \frac{Gd^4}{8K_{bs}D^3} = \frac{11.5 \times 10^6 \times 0.014}{8 \times 593 \times 5.36} = 6.3 \text{ coils.}$$

The static shear stress is

$$\tau = \frac{8F_{mt}D}{\pi d^3} = \frac{8 \times 1213 \times 1.75}{3.14 \times 0.0407} = 133{,}000 \text{ lb/in.}^2$$

The dynamic stress is

$$\tau_d = \tau\left(\frac{T}{T_c}\right)\left[f\left(\frac{T_c}{T}\right)\right] = 133{,}000\left(\frac{4.0}{3.8}\right)$$

$$= 140{,}000 \text{ lb/in.}^2$$

2–5 RETARDED BLOWBACK

The retarded blowback is similar to the simple blowback except that a linkage supplements the massiveness of the bolt as the primary resistance to the early rearward movement of the cartridge case.

2–5.1 SPECIFIC REQUIREMENTS

To develop the same resistance as the inertia of a large mass, a linkage must have a large mechanical disadvantage during the period of high propellant gas pressure and then gradually relax this resistance as the pressure subsides. A linkage showing these features is illustrated in Fig. 2–8. When the force is greatest, the largest component resisting that force is in line with the bolt; thus only a small component is available to accelerate the bolt and linkage. Later, as the link closes, a larger share of the propellant gas force becomes useful for bolt retraction. Although the gas force has degenerated substantially, the accelerating component has grown to the proportions needed for a short firing cycle and, hence, a high rate of fire.

2–5.2 DYNAMICS OF RETARDED BLOWBACK

Fig. 2–9 illustrates graphically the kinematics of a retarded blowback linkage. Point A represents the position of the bolt as it moves linearly on line AC. Point B represents the position of the common joint between links AB and BC as BC rotates about the fixed point C. The equations of dynamic equilibrium are developed from the graphic illustration of Fig. 2–10. The kinematics are found by writing the two equations that define the geometric constraints of the linkage and then differentiating twice; then writing all variables in terms of x and its derivatives.

2–5.2.1 Kinematics of the Linkage

The two equations defining the geometric constraint are obtained from the geometry of the linkage, (see Fig. 2–9)

$$AB\cos\phi + BC\cos\theta = AC - x \qquad (2\text{–}73a)$$

$$AB\sin\phi - BC\sin\theta = 0 \qquad (2\text{–}73b)$$

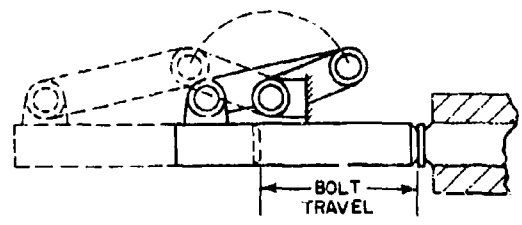
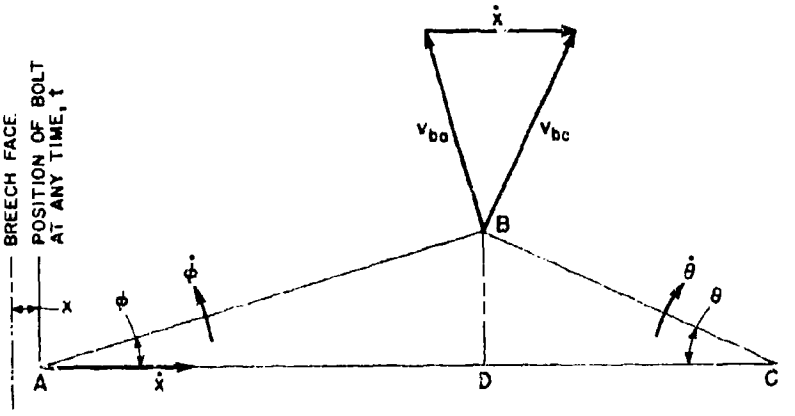
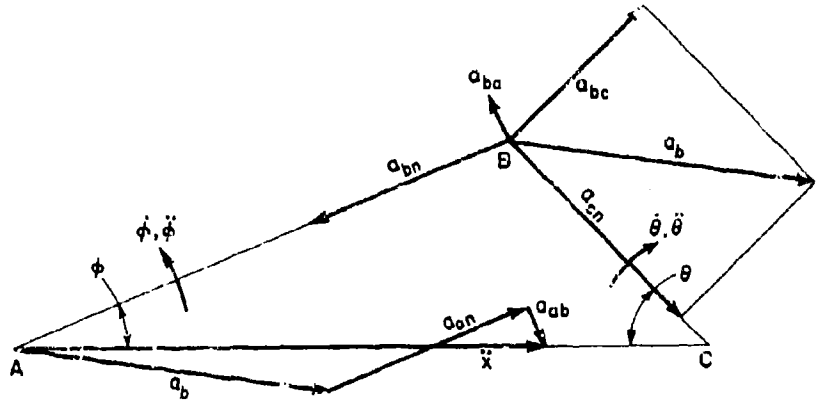


Figure 2–8. Schematic of Retarded Blowback Linkage



(A) VELOCITY DIAGRAM



(B) ACCELERATION DIAGRAM

Figure 2–9. Kinematics of Retarded Blowback Linkage

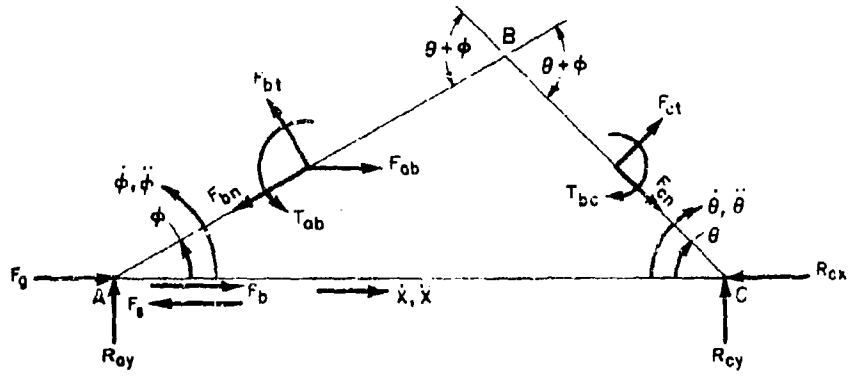


Figure 2–10. Dynamics of Bolt and Linkage

where x is the distance between the breech face and the bolt at any given time t. Differentiate the above equations twice with respect to t.

$$AB\ (\sin\phi)\,\dot{\phi} + BC\ (\sin\theta)\,\dot{\theta} = \dot{x} \qquad (2\text{–}74a)$$

$$AB\ [(\sin\phi)\,\ddot{\phi} + (\cos\phi)\,\dot{\phi}^2] + BC\ [(\sin\theta)\,\ddot{\theta} + (\cos\theta)\,\dot{\theta}^2] = \ddot{x} \qquad (2\text{–}74b)$$

$$AB\ (\cos\phi)\,\dot{\phi} - BC\ (\cos\theta)\,\dot{\theta} = 0 \qquad (2\text{–}75a)$$

$$AB\ [(\cos\phi)\,\ddot{\phi} - (\sin\phi)\,\dot{\phi}^2] - BC\ [(\cos\theta)\,\ddot{\theta} - (\sin\theta)\,\dot{\theta}^2] = 0 \qquad (2\text{–}75b)$$

Multiply Eq. 2–74b by $\cos\phi$ and Eq. 2–75b by $\sin\phi$ and subtract.

$$AB\ \dot{\phi}^2 + BC\ [(\cos\phi\sin\theta + \cos\theta\sin\phi)\,\ddot{\theta} + (\cos\phi\cos\theta - \sin\phi\sin\theta)\,\dot{\theta}^2] = \ddot{x}\cos\phi \qquad (2\text{–}76a)$$

or

$$AB\ \dot{\phi}^2 + BC\ [\ddot{\theta}\sin(\theta+\phi) + \dot{\theta}^2\cos(\theta+\phi)] = \ddot{x}\cos\phi \qquad (2\text{–}76b)$$

Now multiply Eqs. 2–74b and 2–75b by $\cos\theta$ and $\sin\theta$, respectively, and add.

$$AB\ [(\cos\theta\sin\phi + \cos\phi\sin\theta)\,\ddot{\phi} + (\cos\theta\cos\phi - \sin\phi\sin\theta)\,\dot{\phi}^2] + BC\,\dot{\theta}^2 = \ddot{x}\cos\theta \qquad (2\text{–}77a)$$

or

$$AB\ [\ddot{\phi}\sin(\theta+\phi) + \dot{\phi}^2\cos(\theta+\phi)] + BC\,\dot{\theta}^2 = \ddot{x}\cos\theta \qquad (2\text{–}77b)$$

Multiply Eq. 2–74a by $\cos\theta$ and Eq. 2–75a by $\sin\theta$ and add.

$$AB\ \dot{\phi}(\sin\phi\cos\theta + \cos\phi\sin\theta) = \dot{x}\cos\theta \qquad (2\text{–}78a)$$

or

$$AB\ \dot{\phi}\sin(\theta+\phi) = \dot{x}\cos\theta \qquad (2\text{–}78b)$$

Multiply the same equations by $\cos\phi$ and $\sin\phi$, respectively, and subtract.

$$BC\ \dot{\theta}(\sin\theta\cos\phi + \cos\theta\sin\phi) = \dot{x}\cos\phi \qquad (2\text{–}79a)$$

$$BC\ \dot{\theta}\sin(\theta+\phi) = \dot{x}\cos\phi \qquad (2\text{–}79b)$$

Solve for $\dot{\phi}$ and $\dot{\theta}$

$$\dot{\phi} = \frac{\dot{x} \cos \theta}{AB \sin (\theta + \phi)} \tag{2-80}$$

$$\dot{\theta} = \frac{\dot{x} \cos \phi}{BC \sin (\theta + \phi)} . \tag{2-81}$$

Solve Eqs. 2-76b and 2-77b for $\ddot{\theta}$ and $\ddot{\phi}$, respectively

$$\ddot{\theta} = \frac{\ddot{x} \cos \phi - AB \dot{\phi}^2}{BC \sin (\theta + \phi)} - \frac{\dot{\theta}^2 \cos (\theta + \phi)}{\sin (\theta + \phi)} \tag{2-82}$$

$$\ddot{\phi} = \frac{\ddot{x} \cos \theta - BC \dot{\theta}^2}{AB \sin (\theta + \phi)} - \frac{\dot{\phi}^2 \cos (\theta + \phi)}{\sin (\theta + \phi)} . \tag{2-83}$$

2-5.2.2 Equations of Dynamic Equilibrium

Fig. 2-10 shows the applied and inertial forces of the bolt and linkage. The inertial forces are functions of the kinematics of Fig. 2-9.

Nomenclature of symbols in Figs. 2-9 and 2-10, and in the dynamic analysis follow*:

a_{ab} = acceleration of A with respect to B

a_{an} = normal acceleration of A with respect to B

a_b = acceleration of B

a_{bn} = normal acceleration of B with respect to A

a_{ba} = tangential acceleration of B with respect to A

a_{bc} = tangential acceleration of B with respect to C

a_{cn} = normal acceleration of B with respect to C

AB = length of link AB

BC = length of link BC

F_a = applied force on recoiling parts

F_{ao} = linear inertial force of link AB

F_b = bolt inertial force

F_{bn} = normal force of link AB

F_{bt} = tangential inertial force of link AB

F_{cn} = normal force of link BC

F_{ct} = tangential inertial force of link BC

F_g = propellant gas force

F_s = driving spring force

F_{so} = initial spring force

I_{ab} = mass moment of inertia of link AB

I_{bc} = mass moment of inertia of link BC

K_s = spring constant

M_{ab} = mass of link AB

M_b = mass of bolt

M_r = mass of recoiling parts

R_{ay} = vertical reaction at A

R_{cx} = horizontal reaction at C

R_{cy} = vertical reaction at C

T_{ab} = inertial torque of link AB

T_{bc} = inertial torque of link BC

v_{ba} = velocity of B with respect to A

v_{bc} = velocity of B with respect to C

$\dot{x}$ = velocity of bolt at A

$\ddot{x}$ = acceleration of bolt at A

ϵ = efficiency of the spring system

E = $1/\epsilon$ during recoil; $E = \epsilon$ during counterrecoil

*Since these symbols are unique for this par., they are not repeated in the general List of Symbols.

θ = angle of BC with horizontal

$\dot{\theta}$ = angular velocity of BC, shown positive

$\ddot{\theta}$ = angular acceleration of BC, shown positive

ϕ = angle of AB with horizontal

$\dot{\phi}$ = angular velocity of AB, shown positive

$\ddot{\phi}$ = angular acceleration of AB, shown positive

To achieve equilibrium in the dynamic system, the applied forces and reactions of Fig. 2–10 are equated to the inertial forces. The reactions of the linkage ABC are computed by balancing the moments and forces of the complete system or of any individual link. The inertia forces and moments of each component are expressed in terms of the respective accelerations.

$$F_{ab} = M_{ab}\ddot{x} \tag{2–84a}$$

$$F_b = M_b\ddot{x} \tag{2–84b}$$

$$F_{bn} = M_{ab}\left(\frac{AB}{2}\right)\dot{\phi}^2 \tag{2–84c}$$

$$F_{bt} = M_{ab}\left(\frac{AB}{2}\right)\ddot{\phi} \tag{2–84d}$$

$$F_{cn} = M_{bc}\left(\frac{BC}{2}\right)\dot{\theta}^2 \tag{2–84e}$$

$$F_{ct} = M_{bc}\left(\frac{BC}{2}\right)\ddot{\theta} \tag{2–84f}$$

$$T_{ab} = I_{ab}\ddot{\phi} \tag{2–84g}$$

$$T_{bc} = I_{bc}\ddot{\phi} \tag{2–84h}$$

R_{cy}, the vertical reaction at C (Fig. 2–10) is found by computing the moments about A and dividing by length AC.

$$R_{cy} = \left\{ T_{ab} - T_{bc} - F_{ab}\left(\frac{AB}{2}\right)\sin\phi + \left(\frac{AB}{2}\right)F_b - F_{cn}\,AB\sin(\theta+\phi) + F_{ct}\left[AB\cos(\theta+\phi) + \frac{BC}{2}\right]\right\} / AC \tag{2–85}$$

R_{cx}, the horizontal reaction at C, is found by isolating link BC and equating the applied moment to the inertial moment.

$$R_{cx}\,BC\sin\theta - R_{cy}\,BC\cos\theta = T_{bc} - F_{ct}\left(\frac{BC}{2}\right) \tag{2–86}$$

$$R_{cx} = R_{cy}\frac{\cos\theta}{\sin\theta} + \frac{T_{bc}}{BC\sin\theta} - \frac{F_{ct}}{2\sin\theta} \tag{2–87}$$

The general equation for determining the dynamics of the system consists of the applied horizontal forces and reactions, and the horizontal components of the inertial forces. The inertial moments and vertical force components are not directly involved although they are needed to establish the general equation.

$$F_g - EF_s - R_{cx} = M_r\ddot{x} - F_{bn}\cos\phi - F_{bt}\sin\phi + F_{cn}\cos\theta + F_{cn}\sin\theta \tag{2–88}$$

where

$$F_s = E(F_{so} + K_s x)$$

$$M_r = M_{ab} + M_b$$

Eq. 2–88 may be solved by numerical integration after the variables $\dot{\phi}, \ddot{\theta}, \ddot{\phi}, \ddot{\theta}$ are written in terms of $\dot{x}$ and $\ddot{x}$.

2–5.2.3 Digital Computer Program for the Dynamic Analysis

A digital computer program is compiled in FORTRAN IV language for the UNIVAC 1107 computer. The various parameters are solved for each one of many small increments of time into which the recoil and counterrecoil periods are divided. The

solution follows the procedure of the Runge-Kutta-Gill Method of numerical integration. The program listing is in Appendix A–3; the corresponding Flow Chart in Appendix A–4.

Because Eq. 2–88 becomes extremely unwieldly when the appropriate expressions are substituted for $\dot{\phi}$, $\ddot{\phi}$, $\dot{\theta}$, $\ddot{\theta}$, simple coefficients are introduced in sequence to represent the cumbersome expressions. The continued substitution eventually leads to an equation of simple terms. The list of coefficients that follow are determined from Eqs. 2–80 to 2–83.

$$C1 = \cos\phi/BC \sin(\theta + \phi)$$

$$C2 = -AB/BC \sin(\theta + \phi)$$

$$C3 = -\cos(\theta + \phi)/\sin(\theta + \phi)$$

$$C4 = \cos\theta/AB \sin(\theta + \phi)$$

$$C5 = -BC/AB \sin(\theta + \phi)$$

$$C6 = C2 \cdot C4^2 + C3 \cdot C1^2$$

$$C7 = C5 \cdot C1^2 + C3 \cdot C4$$

Rewrite Eqs. 2–80 to 2–83 by inserting the proper coefficient.

$$\dot{\phi} = C4\dot{x} \qquad (2\text{–}89a)$$

$$\dot{\theta} = C1\dot{x} \qquad (2\text{–}89b)$$

$$\ddot{\theta} = C1\ddot{x} + C6\dot{x}^2 \qquad (2\text{–}89c)$$

$$\ddot{\phi} = C4\ddot{x} + C7\dot{x}^2 \qquad (2\text{–}89d)$$

Rewrite Eq. 2–85

$$R_{cy} = E3(C4\ddot{x} + C7\dot{x}^2) - E4\ddot{x} - E5 \cdot C1^2\dot{x}^2 + E6(C1\ddot{x} + C6\dot{x}^2) \qquad (2\text{–}90a)$$

where

$$E1 = M_{ab} \cdot AB/2$$

$$E2 = M_{bc} \cdot BC/2$$

$$E3 = (I_{ab} + E1 \cdot AB/2)/AC$$

$$E4 = E1 \sin\phi/AC$$

$$E5 = E2 \cdot AB \sin(\theta + \phi)/AC$$

$$E6 = \left\{E2[AB\cos(\theta + \phi) + BC/2] - I_{bc}\right\}/AC$$

Collect terms and assign new coefficients

$$R_{cy} = C8\ddot{x} + C9\dot{x}^2 \qquad (2\text{–}90b)$$

where

$$C8 = E3 \cdot C4 - E4 + E6 \cdot C1$$

$$C9 = E3 \cdot C7 - E5 \cdot C1^2 + E6 \cdot C6$$

Rewrite Eq. 2–87

$$R_{cx} = C8\left(\frac{\cos\theta}{\sin\theta}\right)\ddot{x} + C9\left(\frac{\cos\theta}{\sin\theta}\right) + E7(C1\ddot{x} + C6\dot{x}^2)/\sin\theta \qquad (2\text{–}91a)$$

$$R_{cx} = C10\ddot{x} + C12\dot{x}^2 \qquad (2\text{–}91b)$$

where

$$E7 = \frac{I_{bc}}{BC} - \frac{E2}{2}$$

$$C10 = (C8\cos\theta + E7 \cdot C1)/\sin\theta$$

$$C12 = (C9\cos\theta + E7 \cdot C6)/\sin\theta$$

Recall Eq. 2–89, solve for F and insert appropriate coefficients.

$$F_g = M_r x - E1(C4x + C7\dot{x}^2)\sin\phi - E1 \cdot C4^2\dot{x}^2\cos\phi + E2(C1\ddot{x} + C6\dot{x}^2)\sin\theta + E2 \cdot C1\dot{x}^2\cos\theta + C10\ddot{x} + C12\dot{x}^2 - E(F_o - K_s x) \qquad (2\text{–}92)$$

Collect terms and solve for $\ddot{x}$

$$C11\ddot{x} = F_g + C13\dot{x}^2 + C14 + C15x \qquad (2-93)$$

$$\ddot{x} = (F_g + C13\dot{x}^2 + C15x + C14)/C11 \qquad (2-94)$$

where

$$C11 = M_r - E1 \cdot C4 \sin\phi + E2 \cdot C1 \sin\theta + C10$$

$$C13 = E1 \cdot C7 \sin\phi + C1 \cdot C4^2 \cos\phi - E2 \cdot C6 \sin\theta - E2 \cdot C1^2 \cos\theta - C12$$

$$C14 = -EF_{so}$$

$$C15 = -EK_s$$

The computer solves for $\ddot{x}$ and then all the other variables for each increment of time. The program is also arranged for the interpolation of the gas force F_g when the time, and therefore force, for any particular computations fall between two data points selected from the force-time curve of Fig. 2–7.

Initial spring characteristics are usually based on those of a similar gun. After trial computations, the values are altered to be more compatible with specifications. For instance, in the sample problem, the initial values of initial buffer force and spring constant were F_{so} = 200 lb and K_s = 388 lb/in. This resulted in a buffer travel of almost twice the specified distance. After changing the spring constant to K_s = 760 lb/in. and F_{so} = 800 lb, the computed buffer stroke equalled that specified.

Table 2–6 lists the code for each symbol, Table 2–7 lists the input data for the computer program, and Table 2–8 lists the computed dynamics. Four series of computations are made for each increment I and, since there are almost 2000 increments, only the results of the fourth series of every 15th increment is printed. This procedure is followed except at the ends of the recoil and counterrecoil strokes where the results of each terminal increment are printed. By eliminating most of the output from the record, Table 2–8 is held to reasonable size but still contains enough data to show clearly, the trend in the dynamic behavior of the bolt mechanism during the firing cycle.

The final time (at increment I = 1889) of t = 0.067 sec shows a firing rate of

$$f_r = \frac{60}{t} = 895 \text{ rounds/min.}$$

TABLE 2–6. SYMBOL-CODE RELATIONSHIP FOR RETARDED BLOWBACK

Symbol	Code	Symbol	Code
F_a	FA	W_{ab}	WAB
F_g	FG	W_b	WB
F_{so}	FSO	W_{bc}	WBC
g	G	x	X
I_{ab}	EYEB	ϵ	EPS
I_{bc}	EYEC	θ	THETA
KS	SK	ϕ	PHI
M_{ab}	EMAB	$\sin\theta$	STHETA
M_b	EMB	$\cos\theta$	CTHETA
M_r	EMR	$\sin\phi$	SPHI
t	T	$\cos\phi$	CPHI
Δt	DT	$\sin(\theta+\phi)$	SUMSIN
v	VEL	$\cos(\theta+\phi)$	SUMCOS

The preferred method of increasing this rate is to increase the moment arm of the linkage, i. e., by decreasing the initial value of AC. A lower firing rate may be attained by decreasing the moment arm, i. e., by increasing the initial length of AC.

2.6 RATING OF BLOWBACK WEAPONS

The simple blowback machine gun, because of its simplicity, outranks all other types with respect to maintenance and relative cost. Moving parts are few, and normal care exercised in manufacture produces a gun whose reliability is considered good, i. e., ordinary malfunctions can be corrected in the field within 30 sec. Take-down, cleaning, lubricating, and reassembly requires little time and practically no tools. Although these attributes are encouraging, the simple blowback has its limitations. It is restricted to small caliber guns, low rates of fire, low muzzle velocities, and, therefore, short range. However, the gun is light enough to be carried by the foot soldier and is accurate enough at short ranges to make it a good antipersonnel weapon.

The delayed blowback machine gun is almost as easily maintained as the simple blowback but its relative cost is higher. It has a low to medium rate of fire and a medium to high muzzle velocity. The delayed blowback is not confined to small calibers. It outranges and has better accuracy than the simple blowback and, because of its greater fire power, is more versatile, being capable of destroying both materiel and personnel. The delayed blowback gun is durable and reliable, seldom becoming inoperative because of breakdown except after long usage, and can quickly be restored to operation after ordinary malfunction.

When compared with simple and delayed blowback guns, the advanced primer ignition and retarded blowback types are relegated to second position. The retarded blowback type, because it depends on a linkage system to control bolt recoil that is extremely sensitive to geometric proportions, does not have the reliability of the delayed type either in theory during design, or in practice during development and usage. The large loads applied to the linkage while in motion adversely affects the gun's durability. From these aspects alone the delayed blowback is preferred over the retarded type.

The advanced primer ignition gun is superior to the simple blowback because of its higher firing rate and lower recoil momentum. However, favorable performance depends on timing that must be precise. A slight delay in primer function, and the gun reverts to a simple blowback without the benefit of a massive bolt and stiffer driving spring to soften the recoil impact. Delayed primer ignition creates the hazard of extracting the cartridge case while subjected to pressures high enough to blow up the case. Although advanced primer ignition guns have been made, one by Becker, the exacting requirements in design and construction of gun and ammunition reduce this type almost to the point of academic interest only.

TABLE 2–7. INPUT DATA FOR RETARDED BLOWBACK

Code	Data	Code	Data
AB	7.0	NHEAD	630
AZ	12.9985	NPO	15
BC	6.0	N9	96
DT	0.000025	SK1	3.8
DTFG	0.0000625	SK2	760.0
DTNEW	0.00026	TCHANG	0.045
EPS	0.50	WAB	0.85
FS1	63.0	WB	8.0
FS2	800.0	WBC	1.5
G	386.4	XLIM	9.0
N	3000	XREC	9.95859
		XBATY	0.010

TABLE 2-8. RETARDED BLOWBACK DYNAMICS

I	TIME SECOND	APPLIED FORCE POUND	DISTANCE FROM BREECH INCH	VELOCITY IN/SEC	ACCELERATION IN/SEC/SEC
1	.0000250	398.0	.000000	.0	180.5
15	.0003750	18774.0	.000165	1.6	10185.6
30	.0007500	23834.0	.001883	9.2	36242.9
45	.0011250	18663.9	.009210	34.6	109085.5
60	.0015000	12783.8	.032415	96.7	220112.1
75	.0018750	7733.4	.085583	190.0	260383.3
90	.0022500	4922.7	.174304	281.2	224086.7
105	.0026250	3001.8	.294690	358.9	187483.0
120	.0030000	2670.7	.441364	420.8	140860.9
135	.0033750	1794.4	.608063	466.0	100246.5
150	.0037500	1103.0	.786991	497.0	66704.3
165	.0041250	651.6	.979433	517.3	43452.7
180	.0045000	425.1	1.176159	531.1	30563.6
195	.0048750	218.5	1.377183	540.3	19058.6
210	.0052500	107.0	1.580966	546.2	12324.8
225	.0056250	-9.6	1.786483	549.6	5869.6
240	.0060000	-141.1	1.992836	550.6	-900.6
255	.0063750	-142.7	2.199224	550.1	-1938.7
270	.0067500	-144.3	2.405343	549.2	-2753.7
285	.0071250	-145.8	2.611077	548.0	-3410.0
300	.0075000	-147.4	2.816333	546.6	-3950.3
315	.0078750	-149.0	3.021035	545.1	-4404.2
330	.0082500	-150.5	3.225119	543.3	-4792.3
345	.0086250	-152.1	3.428530	541.5	-5129.6
360	.0090000	-153.6	3.631220	539.5	-5427.2
375	.0093750	-155.1	3.833148	537.4	-5693.4
390	.0097500	-156.7	4.034276	535.2	-5934.5
405	.0101250	-158.2	4.234569	533.0	-6155.4
420	.0105000	-159.7	4.433997	530.6	-6360.1
435	.0108750	-161.2	4.632531	528.2	-6551.7
450	.0112500	-162.7	4.830144	525.7	-6732.7
465	.0116250	-164.2	5.026810	523.2	-6905.4
480	.0120000	-165.7	5.222506	520.5	-7071.6
495	.0123750	-167.2	5.417207	517.9	-7232.8
510	.0127500	-168.6	5.610891	515.1	-7390.5
525	.0131250	-170.1	5.803537	512.3	-7546.0
540	.0135000	-171.6	5.995121	509.5	-7700.6
555	.0138750	-173.0	6.185623	506.5	-7855.5
570	.0142500	-174.5	6.375019	503.6	-8012.0
585	.0146250	-175.9	6.563290	500.5	-8171.3
600	.0150000	-177.3	6.750411	497.4	-8334.9
615	.0153750	-178.7	6.936361	494.3	-8504.2
630	.0157500	-180.1	7.121114	491.1	-8681.2

TABLE 2–8. RETARDED BLOWBACK DYNAMICS (Con't.)

I	TIME SECOND	APPLIED FORCE POUND	DISTANCE FROM BREECH INCH	VELOCITY IN/SEC	ACCELERATION IN/SEC/SEC
645	.0161250	-181.5	7.304647	487.8	-8867.6
660	.0165000	-182.9	7.486933	484.4	-9066.0
675	.0168750	-184.3	7.667944	481.0	-9279.0
690	.0172499	-185.6	7.847650	477.4	-9509.9
705	.0176249	-187.0	8.026019	473.8	-9762.8
720	.0179999	-188.3	8.203013	470.1	-10042.5
735	.0183749	-189.7	8.378596	466.3	-10355.1
750	.0187499	-191.0	8.552722	462.3	-10708.1
765	.0191249	-192.3	8.725342	458.3	-11110.8
780	.0194999	-193.6	8.896399	454.0	-11575.0
795	.0198749	-1893.8	9.065089	439.4	-83221.1
810	.0202499	-2136.3	9.223800	406.5	-92816.8
825	.0206249	-2358.8	9.369479	369.9	-101264.3
840	.0209999	-2559.6	9.500939	330.5	-108497.8
855	.0213749	-2737.2	9.617160	288.7	-114496.0
870	.0217499	-2890.1	9.717299	244.8	-119288.4
885	.0221249	-3017.5	9.800679	199.4	-122954.1
900	.0224999	-3118.5	9.866794	152.8	-125611.6
915	.0228749	-3192.5	9.915237	105.3	-127399.2
930	.0232499	-3239.2	9.945783	57.3	-128449.3
945	.0236249	-3258.3	9.958274	9.0	-128860.8
948	.0236999	-614.7	9.958599	-.2	-32217.9
960	.0239999	-614.1	9.957093	-9.9	-32205.7
975	.0243749	-611.8	9.951135	-22.0	-32157.0
990	.0247499	-807.8	9.940655	-34.0	-32069.7
1005	.0251249	-802.1	9.925667	-46.0	-31941.7
1020	.0254999	-794.7	9.906187	-58.0	-31769.7
1035	.0258749	-785.5	9.882240	-69.8	-31550.1
1050	.0262498	-774.7	9.853856	-81.6	-31278.5
1065	.0266248	-762.2	9.821074	-93.3	-30950.7
1080	.0269998	-748.0	9.783940	-104.8	-30562.1
1095	.0273748	-732.2	9.742508	-116.2	-30108.6
1110	.0277498	-714.7	9.696843	-127.4	-29586.5
1125	.0281248	-695.7	9.647018	-138.4	-28992.3
1140	.0284998	-675.1	9.593116	-149.1	-28323.7
1155	.0288748	-653.0	9.535232	-159.6	-27578.8
1170	.0292498	-629.4	9.473469	-169.8	-26756.7
1185	.0296248	-604.4	9.407945	-179.7	-25857.1
1200	.0299998	-578.0	9.338783	-189.2	-24880.7
1215	.0303748	-550.2	9.266123	-198.3	-23828.9
1230	.0307498	-521.2	9.190113	-207.1	-22703.7
1245	.0311248	-491.0	9.110909	-215.3	-21507.8
1260	.0314998	-459.6	9.028681	-223.2	-20244.4

TABLE 2-8. RETARDED BLOWBACK DYNAMICS (Con't.)

I	TIME SECOND	APPLIED FORCE POUND	DISTANCE FROM BREECH INCH	VELOCITY IN/SEC	ACCELERATION IN/SEC/SEC
1275	.0316748	-48.5	8.944110	-226.5	-2930.1
1290	.0322998	-48.3	8.858986	-227.5	-2867.3
1305	.0326248	-48.2	8.773450	-228.6	-2809.0
1320	.0329998	-48.0	8.687536	-229.7	-2754.8
1335	.0333748	-47.8	8.601226	-230.7	-2704.3
1350	.0337497	-47.7	8.514535	-231.7	-2657.0
1365	.0341247	-47.5	8.427471	-232.7	-2612.7
1380	.0344997	-47.3	8.340039	-233.6	-2571.1
1395	.0348747	-47.2	8.252246	-234.6	-2531.9
1410	.0352497	-47.0	8.164096	-235.5	-2494.8
1425	.0356247	-46.8	8.075596	-236.5	-2459.8
1440	.0359997	-46.7	7.986750	-237.4	-2426.5
1455	.0363747	-46.5	7.897561	-238.3	-2394.7
1470	.0367497	-46.3	7.808036	-239.2	-2364.5
1485	.0371247	-46.2	7.718179	-240.1	-2335.3
1500	.0374997	-46.0	7.627992	-240.9	-2307.8
1515	.0378747	-45.8	7.537482	-241.8	-2281.1
1530	.0382497	-45.6	7.446650	-242.6	-2255.4
1545	.0386246	-45.5	7.355502	-243.5	-2230.5
1560	.0389996	-45.3	7.264040	-244.3	-2206.5
1575	.0393746	-45.1	7.172267	-245.1	-2183.1
1590	.0397496	-45.0	7.080187	-246.0	-2160.4
1605	.0401246	-44.8	6.987804	-246.8	-2138.2
1620	.0404996	-44.6	6.895120	-247.6	-2116.6
1635	.0408746	-44.4	6.802138	-248.4	-2095.4
1650	.0412496	-44.2	6.708861	-249.1	-2074.6
1665	.0416246	-44.1	6.615293	-249.9	-2054.1
1680	.0419996	-43.9	6.521436	-250.7	-2033.9
1695	.0423746	-43.7	6.427293	-251.4	-2014.0
1710	.0427496	-43.5	6.332866	-252.2	-1994.3
1725	.0431246	-43.4	6.238159	-252.9	-1974.7
1740	.0434995	-43.2	6.143175	-253.7	-1955.2
1755	.0438745	-43.0	6.047915	-254.4	-1935.9
1770	.0442495	-42.8	5.952383	-255.1	-1916.5
1785	.0446245	-42.6	5.856582	-255.8	-1897.2
1800	.0449995	-42.4	5.760514	-256.5	-1877.8
1815	.0485245	-40.7	4.844994	-262.8	-1686.5
1830	.0522745	-38.8	3.848134	-268.7	-1427.9
1845	.0560245	-36.9	2.831358	-273.3	-996.2
1860	.0597745	-34.9	1.801193	-275.4	88.0
1875	.0635245	-33.0	.776233	-267.8	6102.3
1889	.0670245	-31.5	.002236	-53.0	367185.9

CHAPTER 3

RECOIL-OPERATED WEAPONS

3–1 GENERAL

Recoil-operated weapons are those weapons that rely on recoil activity to operate the bolt and related parts. The bolt, locked to the barrel during firing, is released during recoil after the chamber pressure has become safe. Action is confined to two general types; long recoil and short recoil.

Long recoil has the barrel and bolt recoiling as a unit for the entire distance (Fig. 3–1). This recoil distance must be greater than the length of the complete round to provide space for loading. At the end of the recoil stroke, the bolt is held while the barrel counterrecoils alone. When sufficient space develops between bolt and breech, the spent case is ejected. Later, as the barrel reaches the in-battery position, the bolt is released to reload the gun.

Short recoil has the barrel and bolt recoiling as a unit for a distance shorter than the length of the complete round (Fig. 3–2). The bolt is unlocked shortly before the barrel negotiates its full stroke. As the barrel stops, the momentum of the bolt carries it farther rearward opening a space – between it and barrel – large enough for extracting the spent case and reloading. The returning bolt, while reloading, may push the barrel into battery or the barrel may counterrecoil independently of the bolt.

3–2 LONG RECOIL DYNAMICS

The dynamics of the long recoil-operated gun are similar to those of the blowback types except that the barrel and bolt units recoil together. Time of recoil may be decreased by delaying energy of recoil absorption until near the end of the recoil stroke, which can be done with a heavy buffer spring operating over a short stroke. The barrel spring should be stiff enough to hold the recoiling parts in battery while the bolt is returning whereas the bolt driving spring should be capable of closing the bolt in minimal time. The stiffer the spring, the less time needed for the return. However, since the converse is not true, some compromise must be arranged to achieve an acceptable firing rate. For initial estimates, the driving spring should have properties that are approximate to those needed to absorb the recoil energy of the bolt. Later adjustments can be made in the properties of all the springs in the system to achieve appropriate time and velocity criteria.

The buffer characteristics should be so arranged that its useful potential energy, when fully compressed, approximately equals that of the barrel spring, yet still is compatible with other design requirements. This arrangement gives the barrel sufficient momentum at the beginning of the counterrecoil stroke for a quick return without inducing excessive impact when stopping the returning barrel.

3–3 SAMPLE PROBLEM – LONG RECOIL MACHINE GUN

3–3.1 SPECIFICATIONS

Gun: 20 mm machine gun

Firing Rate: corresponding to minimum bolt travel

Interior ballistics: Pressure vs Time, Fig. 2–7

A_b = 0.515 in.^{2} bore area

3–3.2 DESIGN DATA

L = 10 in, recoil distance

W_b = 10 lb, weight of bolt unit

W_t = 50 lb, weight of barrel unit

ϵ = 0.5, efficiency of spring system

Table 3–1 has the numerical integration for a recoiling weight of 60 lb. The column A_i represents the area under the pressure-time curve, Fig. 3–1, for each interval of time.

$$F_g \Delta_t = 0.515\ A_i,\ \text{lb-sec.}$$

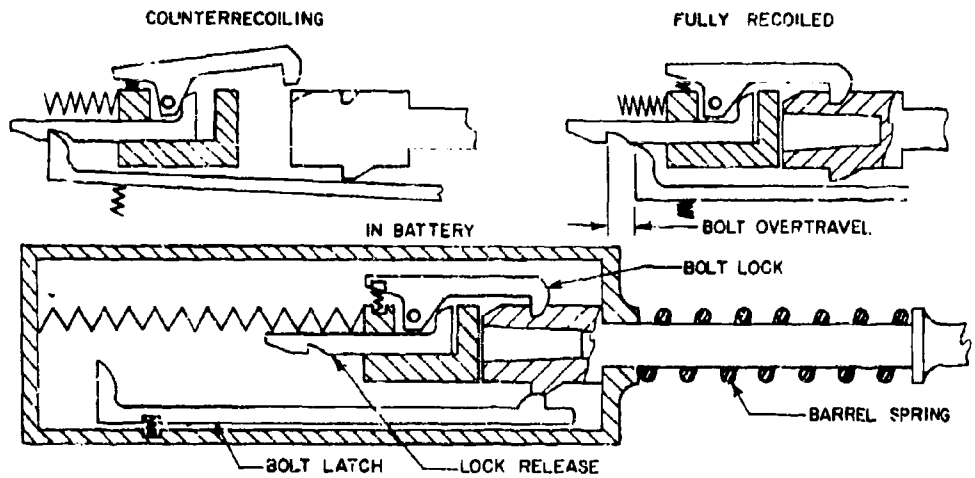


Figure 3–1. Schematic of Long Recoil System

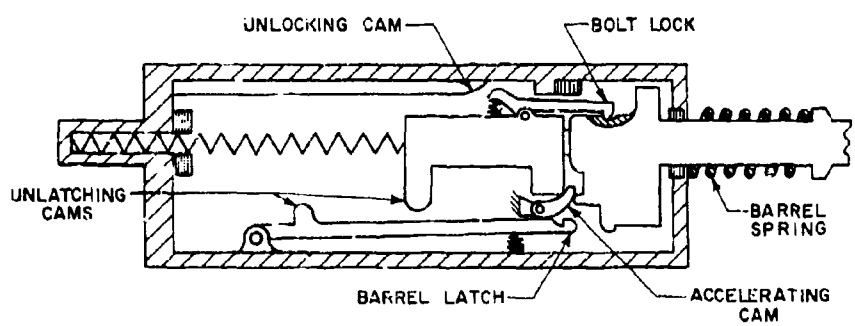


Figure 3–2. Schematic of Short Recoil System

TABLE 3-1. RECOIL TRAVEL OF 20 mm GUN

t, msec	Δt, msec	M_r, lb-sec/in.^{2}	$F_g\Delta t$, lb-sec	Δv, in./sec	v, in./sec	v_a, in./sec	Δx, in.
0.25	0.25	3.44	1.77	11.4	11.4	5.7	0.0014
0.50	0.25	10.15	5.24	33.7	45.1	28.2	0.0071
0.75	0.25	11.89	6.13	39.5	84.6	64.8	0.0162
1.00	0.25	11.12	5.74	37.0	121.6	103.1	0.0258
1.25	0.25	9.25	4.76	30.6	152.0	131.9	0.0330
1.50	0.25	7.10	3.76	24.2	176.4	159.3	0.0398
1.75	0.25	5.23	2.69	17.3	193.7	185.0	0.0462
2.00	0.25	3.71	1.91	12.6	206.3	200.0	0.0500
2.25	0.25	2.58	1.34	8.6	214.9	210.6	0.0526
2.50	0.25	1.82	0.94	6.1	221.0	218.0	0.0545
2.75	0.25	1.39	0.72	4.6	225.6	223.3	0.0558
3.00	0.25	1.06	0.55	3.5	229.1	227.4	0.0569
4.00	1.00	2.34	0.97	6.2	235.3	232.2	0.2322
5.00	1.00	1.04	0.40	2.6	237.9	236.6	0.2365
6.00	1.00	0.40	0.09	0.6	238.5	238.2	0.2382

$$\Delta v = F_g\left(\frac{\Delta t}{M_r}\right) = \frac{g}{W_r}\left(F_g\Delta t\right) = \left(\frac{386.4}{60}\right)F_g\Delta t$$
$$= 6.44\,F_g\Delta t \text{ in./sec}$$

where W_r = weight of recoiling parts

$$\Delta x = v_a\Delta t = \left(\frac{v_{(n-1)} + v}{2}\right)\Delta t, \text{ in.}$$

The distance recoiled during the effective propellant gas pressure period

$$x_r = \Sigma\Delta x = 1.15 \text{ in.}$$

The recoil velocity at this time is $v = 238.5$ in/sec (Table 3-1).

Three springs are in the system (Fig. 3-1). The bolt driving spring and barrel driving work in unison during recoil until the buffer spring is contacted; then all three work as a unit until the barrel and bolt come to a stop whereupon the bolt is latched, permitting the barrel spring and buffer spring to force the barrel to counterrecoil. These two springs function as one until the buffer spring completes its short travel, thereafter the barrel spring alone continues to counterrecoil the barrel. Just as the barrel stops counterrecoiling, the bolt becomes unlatched and the driving spring closes it.

The energy of recoil is

$$E_r = \frac{1}{2}\left(\frac{W_r}{g}\right)v^2 = \frac{1}{2}\left(\frac{60}{386.4}\right)56882$$
$$= 4416 \text{ in.-lb}$$

where

g = 386.4 in./sec^2

W_r = 60 lb, recoiling weight

v = 238.5 in./sec, velocity of recoil

Preliminary estimates of recoil time must be available to determine the spring characteristics. After an approximate recoil time has been established, some of

the data used in early calculations may be altered for greater accuracy. A reasonable approach is achieved by absorbing 75% of the recoil energy before the buffer is reached thereby reducing the recoil velocity by 50% during the same period. Assigning more energy within limits to the buffer will increase the firing rate and conversely, less energy absorbed by the buffer will decrease the firing rate. The energy to be absorbed by the buffer is

$$E_b = 0.25 E_r = 0.25 \times 4416 = 1104 \text{ in.-lb}$$

The recoil velocity as the buffer is contacted becomes

$$v_b = \sqrt{\frac{2E_b}{M_r}} = \sqrt{\frac{2208 \times 386.4}{60}} = \sqrt{14220}$$

$$= 119.25 \text{ in./sec}$$

The average force of the system which includes the driving, barrel, and buffer springs is

$$F_{as} = \frac{\epsilon E_b}{L_b} = \frac{0.5 \times 1104}{0.5} = 1104 \text{ lb}$$

where L_b = length of buffer stroke.

For constant acceleration, the buffing time and therefore the compression time of the springs is

$$T_c = t_b = \frac{2L_b}{v_b} = \frac{2 \times 0.5}{119.25} = 0.0084 \text{ sec.}$$

The corresponding surge time is computed to be

$$T = \frac{T_c}{3.8} = \frac{0.0084}{3.8} = 0.0022 \text{ sec.}$$

From Eq. 2-67

$$K_b T = \frac{F_{as} + \frac{1}{2}\left(K_b L_b\right)}{1037}$$

$$1037 \times 0.0022 K_b = 1104 + 0.25 K_b$$

$$K_b = \frac{1104}{2.031} = 543.6 \text{ lb/in., combined spring constant}$$

$$F_{mb} = F_{as} + 0.25 K_b = 1104 + 136 = 1240 \text{ lb}$$

$$F_{ob} = F_{as} - 0.25 K_b = 1104 - 136 = 968 \text{ lb.}$$

The new compression time of the springs, Eq. 2-23, becomes

$$T_c = \sqrt{\frac{\epsilon M_r}{K_b}} \cos^{-1} \frac{F_{ob}}{F_{mb}} = 0.0119 \times 0.675$$

$$= 0.0080 \text{ sec.}$$

By repeating the above process, T_c remains at 0.0080 sec and K_b changes to 572 lb/in.

$$F_{mb} = F_{as} + \frac{1}{2}\left(K_b L_b\right) = 1104 + 143 = 1247 \text{ lb}$$

$$F_{ob} = F_{as} - \frac{1}{2}\left(K_b L_b\right) = 1104 - 143 = 961 \text{ lb}$$

Assume constant deceleration, then the recoil time from the end of the accelerating period to buffer contact will be

$$t_r = \frac{2L_d}{v + v_b} = \frac{16.7}{238.5 + 119.25} = 0.0467 \text{ sec}$$

where $L_d = L - L_b - x = 10.0 - 0.5 - 1.15 = 8.35$ in.

$v = 238.5$ in./sec, recoil velocity at end of acceleration

$v_b = 119.25$ in./sec recoil velocity at start of buffing

The compression time of the springs includes the accelerating time and the buffing time.

$$T_c = t_a + t_r + t_b = 0.006 + 0.0467 + 0.008$$

$$= 0.0607 \text{ sec.}$$

The corresponding surge time is

$$T = \frac{T_c}{3.8} = \frac{0.0607}{3.8} = 0.0160 \text{ sec.}$$

The average combined force of the driving and barrel springs, based on 75% recoil energy absorption, becomes

$$F_a = \frac{0.75\epsilon E_r}{L_d} = \frac{0.75 \times 0.5 \times 4416}{8.35} = 198.3 \text{ lb.}$$

According to Eq. 2–67b,

$$K_s T = \frac{F_m}{1037} = \frac{F_a + \frac{1}{2}\left(K_s L_d\right)}{1037}$$

$$1037 \times 0.016\ K_s = 198.3 + 4.175\ K_s$$

$$K_s = \frac{198.3}{12.417} = 16.0 \text{ lb/in.}$$

$$F_{ms} = F_a + 4.175\,K_s = 198.3 + 66.8 = 265.1 \text{ lb}$$

$$F_{os} = F_a - 4.175\,K_s = 198.3 - 66.8 = 131.5 \text{ lb}$$

From Eq. 2–22 the time span between accelerating and buffing is

$$t_r = \sqrt{\frac{\epsilon M_r}{K_s}}\left(\text{Sin}^{-1}\frac{F_{ms}}{Z} - \text{Sin}^{-1}\frac{F_{os}}{Z}\right)$$

$$= 0.0697\,(\text{Sin}^{-1}\ 0.8938 - \text{Sin}^{-1}\ 0.4434)$$

$$= 0.0697 \times 0.647 = 0.0451 \text{ sec}$$

where $Z = \sqrt{F_{os}^2 + \epsilon K_r M_r v_o^2} = \sqrt{87948} = 296.6.$

The new compression time becomes

$$T_c = t_a + t_r + t_b = 0.006 + 0.0451 + 0.008$$
$$= 0.0591 \text{ sec.}$$

Repeating the above series of calculations has the time converging to $t_r = 0.044$ sec, or $T_c = 0.058$ sec and $K_s = 16.7$ lb/in. Before buffing, the driving and barrel springs function as one spring. The combined minimum and maximum forces are

$$F_{os} = F_a - K_s\left(\frac{1}{2}\,L_d + x_r\right)$$

$$= 198.3 - 16.7\,(4.175 + 1.15) = 198.3 - 88.9$$
$$= 109.4 \text{ lb}$$

$$F_{ms} = F_{os} + K_s L = 109.4 + 16.7 \times 10 = 276.4 \text{ lb}$$

The combined spring forces at end of acceleration period and at the beginning of buffing are

$$F'_{os} = F_{os} + K_s x_r = 109.4 + 16.7 \times 1.15 = 128.6 \text{ lb}$$

$$F'_{ms} = F_{ms} - K_s L_b = 276.4 - 16.7 \times 0.5 = 268 \text{ lb}$$

By setting the minimum driving spring force at $F_o = 25$ lb, the minimum barrel spring force becomes

$$F_{ot} = F_{os} - F_o = 109.4 - 25.0 = 84.4 \text{ lb.}$$

Maintain the same ratio between spring constants as for the initial forces. The driving and barrel spring constants become, respectively,

$$K = \left(\frac{F_o}{F_{os}}\right)K_s = \left(\frac{25}{109.4}\right)16.7 = 3.8 \text{ lb/in.}$$

$$K_t = \left(\frac{F_{ot}}{F_{os}}\right)K_s = \left(\frac{84.4}{109.4}\right)16.7 = 12.9 \text{ lb/in.}$$

The corresponding maximum forces are, respectively,

$$F_m = F_o + KL = 25 + 3.8 \times 10 = 63 \text{ lb}$$

$$F_{mt} = F_{ot} + K_t L = 84.4 + 12.9 \times 10 = 213.4 \text{ lb.}$$

The spring constant of the buffer spring is

$$K_{bs} = K_b - K_s = 572 - 16.7 = 555.3 \text{ lb/in.}$$

The buffer spring force at initial contact with recoiling parts is

$$F_{obs} = F_{ob} - F'_{ms} = 961 - 268 = 693 \text{ lb.}$$

At end of buffing, the maximum spring force is

$$F_{mbs} = F_{mb} - F_{ms} = 1247 - 276.4 = 970.6 \text{ lb.}$$

Table 3–2 lists design data and computed stresses for these three springs as well as for the springs of the three types of action employed in the short recoil gun. The calculations are based on the following formulas.

$$d = 0.27\sqrt[3]{DKT_c} \text{ (Based on Eq. 2–67a)}$$

$$N = \frac{Gd^4}{8KD^3}, \text{ number of coils}$$

$$\tau = 2.55\left(\frac{F_m D}{d^3}\right), \text{ static shear stress}$$

$$\tau_d = \frac{T}{T_c}\left[f\left(\frac{T_c}{T}\right)\right], \text{ dynamic shear stress}$$

$$H_s = dN, \text{ solid height}$$

The available potential energy in the buffer spring for counterrecoil is

$$E_{bc} = \frac{e}{2}(F_{mbs} + F_{obs})L_b = \frac{0.5}{2}(970.6 + 693)0.5$$

$$= 208 \text{ in.-lb.}$$

The available potential energy in the barrel spring for counterrecoil is

$$E_t = \frac{e}{2}(F_{mt} + F_{ot})L = \frac{0.5}{2}(213.4 + 84.4)10$$

$$= 744.5 \text{ in.-lb.}$$

The potential energy of the barrel spring that augments the buffer spring is

$$\Delta E_t = \frac{e}{2}(F_{mt} + F'_{mt})L_b = \frac{0.5}{2}(213.4 + 207)0.5$$

$$= 52.6 \text{ in.-lb.}$$

where

$$F'_{mt} = F_{mt} - K_t L_b = 213.4 - 12.9 \times 0.5 = 207 \text{ lb.}$$

The total energy of the counterrecoiling barrel at the end of buffer action becomes

$$E_{crb} = E_{bc} + \Delta E_t = 260.6 \text{ in.-lb.}$$

The corresponding velocity is

$$v_{crb} = \sqrt{\frac{2E_{crb}}{M_t}} = \sqrt{\frac{521.2 \times 386.4}{50}} = \sqrt{4028}$$

$$= 63.5 \text{ in./sec.}$$

The maximum energy of the counterrecoiling barrel is

$$E_{crt} = E_b + E_t = 208 + 744.5 = 952.5 \text{ in.-lb.}$$

The maximum velocity attained by the bolt in counterrecoil is

$$v_{crt} = \sqrt{\frac{2E_{crt}}{M_t}} = \sqrt{\frac{1905 \times 386.4}{50}} = \sqrt{14722}$$

$$= 121.3 \text{ in./sec.}$$

The maximum energy of the counterrecoiling bolt is

$$E_{crd} = \frac{e}{2}(F_m + F_o)L = \frac{0.5}{2}(63 + 25)10$$

$$= 220 \text{ in.-lb.}$$

The maximum velocity attained by the bolt in counterrecoil is

$$v_{cr} = \sqrt{\frac{2E_{crd}}{M_b}} = \sqrt{\frac{440 \times 386.4}{10}} = \sqrt{17002}$$

$$= 130.4 \text{ in./sec}$$

The time elapsed from the propellant gas period until the buffer is reached, obtained from Eq. 2–51, will be

$$t_r = \sqrt{\frac{\epsilon M_r}{K_s}}\left(\text{Sin}^{-1}\frac{F'_{ms}}{Z} - \text{Sin}^{-1}\frac{F'_{os}}{Z}\right)$$

$$t_r = 0.0682(\text{Sin}^{-1}\ 0.3904 - \text{Sin}^{-1}\ 0.4280)$$

$$= 0.0682(63.10 - 25.33)/57.3 = 0.045$$

where

$F'_{os} = 128.6$ lb ; $F'_{mt} = 268$ lb

$$\sqrt{\frac{eM_r}{K_s}} = \sqrt{\frac{0.5 \times 60}{16.7 \times 386.4}} = 0.068 \text{ sec}$$

$$Z = \sqrt{(F'_{os})^2 + eK_s M_r v_o^2} = \sqrt{16538 + 73747}$$
$$= 301 \text{ lb}$$

$K_s = 16.7$ lb/in.

$e = 0.5$

$M_r v_o^2 = 2E_r = 8832$ in.-lb

The time elapsed during buffing, Eq. 2–23, becomes

$$t_b = \sqrt{\frac{eM_r}{K_b}} \text{ Cos}^{-1} \frac{F_{ob}}{F_{mb}}$$

$$= \sqrt{\frac{0.5 \times 60}{572 \times 386.4}} \text{ Cos}^{-1} \frac{961}{1247}$$

$$= \sqrt{0.0001357} \text{ Cos}^{-1} 0.7706 = 0.0116 \left(\frac{39.6}{57.3}\right)$$

$= 0.008$ sec.

The time elapsed for counterrecoil at the end of buffer activity is obtained from Eq. 2–27.

$$t_{crb} = \sqrt{\frac{M_t}{e(K_{bs} + K_t)}} \text{ Cos}^{-1} \frac{F_{obs} + F'_{mt}}{F_{mbs} + F_{mt}}$$

$$= \sqrt{\frac{50}{0.5 \times 568.2 \times 386.4}} \text{ Cos}^{-1} \frac{900}{1184}$$

$$= 0.0214 \text{ Cos}^{-1} 0.7601 = 0.0214 \left(\frac{40.53}{57.3}\right)$$

$= 0.0151$ sec.

Compute the time elapsed for the barrel to negotiate the remaining distance in counterrecoil according to Eq. 2–26.

$$t_{crt} = \sqrt{\frac{M_t}{eK_t}} \left(\text{Sin}^{-1} \frac{-F_{ot}}{Z} - \text{Sin}^{-1} \frac{-F'_{mt}}{Z} \right)$$

$$= 0.1418 \left[\text{Sin}^{-1} (-0.3557) - \text{Sin}^{-1} (-0.8723) \right]$$

$$= 0.1418 (339.17 - 299.27)/57.3 = 0.0987 \text{ sec}$$

where $\sqrt{\frac{M_t}{eK_t}} = \sqrt{\frac{50}{0.5 \times 12.9 \times 386.4}}$

$$= \sqrt{0.0201} = 0.1418 \text{ sec}$$

$$Z = \sqrt{\left(F'_{mt}\right)^2 + \left(\frac{K_t}{e}\right) M v_{crb}^2}$$

$$= \sqrt{207^2 + \left(\frac{12.9}{0.5}\right) 521.6} = \sqrt{56306} = 237.3 \text{ lb}$$

The time elapsed for counterrecoil of the bolt, Eq. 2–27, is

$$t_{cr} = \sqrt{\frac{M_b}{eK}} \text{ Cos}^{-1} \frac{F_o}{F_m}$$

$$= \sqrt{\frac{10}{0.5 \times 3.8 \times 386.4}} \text{ Cos}^{-1} \frac{25}{63}$$

$$= \sqrt{0.01362} \text{ Cos}^{-1} 0.3968$$

$$= 0.1167 \left(\frac{66.12}{57.3}\right) = 0.1347 \text{ sec.}$$

Time of cycle will be

$$t_c = t_a + t_r + t_b + t_{crb} + t_{crt} + t_{cr}$$

$$= 0.006 + 0.045 + 0.008 + 0.0151 + 0.0987 + 0.1347$$

$= 0.3075$ sec

The rate of fire becomes

$$f_r = \frac{60}{t_c} = \frac{60}{0.3075} = 195 \text{ rounds/min.}$$

TABLE 3–2. SPRING DESIGN DATA OF RECOIL-OPERATED GUNS

Type Spring	Long Recoil			Short Recoil			Short Recoil			
							Bolt Buffer		Bolt Accelerator	
Data	Driving	Barrel	Buffer	Driving	Barrel	Buffer	Driving	Buffer	Driving	Barrel
K, lb/in.	3.8	12.9	555.3	2.6	35.4	579.6	2.4	229.6	29	200
F_m, lb	63	213.4	970.6	53.1	159.4	1645.6	36	344	320	284
T_c, msec	0.058	0.058	0.0080	0.0743	0.0165	0.0105	0.0529	0.0060	0.0347	0.0076
(T_c/T)	3.8	3.8	3.8	3.8	3.8	3.8	3.8	3.8	1.8	3.8
T, msec	0.0153	0.0153	0.0021	0.0196	0.0043	0.0028	0.0139	0.0016	0.0193	0.0020
D, in.	0.5	2.0	1.5	0.5	2.0	1.875	0.5	0.875	1.0	0.5
D^3, in.^{3}	0.125	8.0	3.375	0.125	8.0	6.592	0.125	0.766	1.0	0.125
DKT	0.0291	0.395	1.749	0.0255	0.304	3.043	0.0167	0.321	0.385	0.200
$\sqrt[3]{DKT}$	0.307	0.734	1.205	0.294	0.672	1.449	0.256	0.685	0.723	0.585
d, in.	0.083	0.199	0.325	0.079	0.181	0.391	0.069	0.185	0.195	0.158
$d^3 \times 10^3$, in.^{3}	0.572	7.880	34.33	0.493	5.930	59.78	0.329	6.331	7.530	3.944
$d^4 \times 10^4$, in.^{4}	0.475	15.68	111.6	0.390	10.73	233.7	0.227	11.71	14.76	6.232
G, kpsi	11.5	11.5	11.5	11.5	11.5	11.5	11.5	11.5	11.5	11.5
N	144	21.8	8.6	173	5.5	8.8	109	9.4	106	34
τ, kpsi	140	138	108	137	137	132	139	118	109	92
$f(T_c/T)$	4	4	4	4	4	4	4	4	2	4
τ_d, kpsi	148	145	114	144	144	139	146	125	115	97
H_s, in.	12.0	4.4	2.8	13.7	1.0	3.5	7.6	1.7	20.8	5.4

3–4 SHORT RECOIL DYNAMICS

The dynamics of the short recoil-operated gun approach those of the retarded blowback types more nearly than the long recoil. To eliminate all blowback tendencies, the bolt latch is not released until the propellant gas becomes ineffective. After unlatching, bolt and barrel continue recoiling, but as separate units. The barrel is arrested by the combined effort of the barrel spring and buffer. Having the same velocity of free recoil, but because it travels a much shorter distance than the bolt, the barrel will stop recoiling before the bolt. Both the bolt driving spring and buffer spring characteristics are determined from the recoil energy of the respective masses. The characteristics of the barrel spring are selected more arbitrarily but still must conform to the same initial load requirement as that for the long recoil barrel spring, i.e., sufficient to hold the barrel in battery.

3–5 SAMPLE PROBLEM – SHORT RECOIL MACHINE GUN

3–5.1 SPECIFICATIONS: Identical to long recoil problem (see par. 3–3.1)

3–5.2 DESIGN DATA

L = 10 in., minimum bolt travel distance

W_b = 10 lb, weight of bolt unit

W_t = 50 lb, weight of barrel unit

e = 0.5, efficiency of spring system

The numerical integration of Table 3–1 also applies to this problem, therefore, the distance recoiled during the effective pressure period of this propellant gas, x_r = 1.15 in. and the corresponding recoil velocity v = 238.5 in./sec. The recoil energy of the bolt is

$$E_{rb} = \frac{1}{2}\left(M_b v^2\right) = \frac{1}{2}\left(\frac{10}{386.4}\right)56882 = 736 \text{ in.-lb.}$$

The average force of the driving spring becomes

$$F_a = \frac{eE_{rb}}{L - x_r} = \frac{0.5 \times 736}{10.0 - 1.15} = 41.6 \text{ lb.}$$

To be compatible with allowable stresses the spring characteristics must conform to computed data obtained from Eqs. 2–23 and 2–67b. When based on constant deceleration, the time required to stop the bolt in recoil is

$$t = \frac{2(L - x_r)}{v_r} = \frac{2 \times 8.85}{238.5} = 0.0743 \text{ sec.}$$

Including the time of the effective gas period, the compression time of the driving spring is

$$T_c = t + t_a = 0.0743 + 0.006 = 0.0803 \text{ sec.}$$

The corresponding surge time will be

$$T = \frac{T_c}{3.8} = \frac{0.0803}{3.8} = 0.0211 \text{ sec.}$$

Apply Eq. 2–67b to compute the spring constant K.

$$KT = \frac{F_m}{1037} = \frac{F_a + \frac{1}{2}K(L - x_r)}{1037}$$

$$21.881\,K = 41.6 + 4.425\,K$$

$$K = \frac{41.6}{17.456} = 2.4 \text{ lb/in.}$$

$$F_m = F_a + 4.425\,K = 41.6 + 10.6 = 52.2 \text{ lb}$$

$$F_c' = F_a - 4.425\,K = 41.6 - 10.6 = 31.0 \text{ lb}$$

The decelerating time, Eq. 2–23, is

$$t = \sqrt{\frac{eM_b}{K}}\ \text{Cos}^{-1}\frac{F_c'}{F_m} = \sqrt{\frac{0.5 \times 10}{2.4 \times 386.4}}\ \text{Cos}^{-1}\frac{31.0}{52.2}$$

$$= 0.0735 \times 0.935 = 0.0687 \text{ sec.}$$

The total compression time of the spring is

$$T_c = t + t_a = 0.0687 + 0.006 = 0.0747 \text{ sec.}$$

Adjust the time and recompute Eqs. 2–67b and 2–23, the time and spring constant coverge to $t = 0.075$ sec and $K = 2.6$ lb/in., respectively.

The maximum driving spring force F_m is

$$F_m = F_a + \frac{1}{2}K(L - x_r) = 41.6 + 11.5 = 53.1 \text{ lb.}$$

The driving spring force at $x = 1.15$ in. is

$$F_o' = F_m - K(L - x_r) = 53.1 - 23.0 = 30.1 \text{ lb.}$$

The initial driving spring force is

$$F_o = F_m - KL = 53.1 - 26.0 = 27.1 \text{ lb.}$$

According to Eq. 2–22 the time of bolt recoil is

$$t_r = \sqrt{\frac{\epsilon M_b}{K}} \text{ Cos}^{-1} \frac{F_o'}{F_m}$$

$$= \sqrt{\frac{0.5 \times 10}{2.6 \times 386.4}} \text{ Cos}^{-1} \frac{30.1}{53.1}$$

$$= \sqrt{0.004976} \text{ Cos}^{-1} 0.5669 = 0.0706\left(\frac{55.47}{57.3}\right)$$

$$= 0.0683 \text{ sec.}$$

According to Eq. 2–27, the time of bolt counterrecoil is

$$t_{cr} = \sqrt{\frac{M_b}{\epsilon K}} \text{ Cos}^{-1} \frac{F_o}{F_m}$$

$$= \sqrt{\frac{10}{0.5 \times 2.6 \times 386.4}} \text{ Cos}^{-1} \frac{27.1}{53.1}$$

$$= \sqrt{0.0199} \text{ Cos}^{-1} 0.5104 = 0.1411\left(\frac{59.3}{57.3}\right)$$

$$= 0.1459 \text{ sec.}$$

The time elapsed during bolt action may determine the firing rate, provided that the barrel returns to battery before the bolt recoils fully. The recoil energy of the barrel is

$$E_{rt} = \frac{1}{2}\left(M_1 v^2\right) = \frac{1}{2}\left(\frac{50}{386.4}\right)56882$$

$$= 3680 \text{ in.-lb.}$$

The average buffing force, to be approximately the same as for the long recoil, should have a buffer travel of $L_b = 1.375$ in.

According to Eq. 2–16 the average spring force during buffing is

$$F_{ab} = \frac{\epsilon E_{rt}}{L_b} = \frac{0.5 \times 3680}{1.375} = 1338 \text{ lb.}$$

Assume constant deceleration so that the time needed to stop the barrel during recoil becomes

$$t_{rt} = \frac{2L_b}{v} = \frac{2.75}{238.5} = 0.0115 \text{ sec.}$$

This time is also the compression time T_c for the combined buffer and barrel springs. The surge time is

$$T = \frac{T_c}{3.8} = \frac{0.0115}{3.8} = 0.00302 \text{ sec.}$$

Apply Eq. 2–67b to solve for the spring constant and corresponding forces.

$$K_b T = \frac{F_{mb}}{1037} = \frac{F_{ab} + \frac{1}{2}\left(K_b L_b\right)}{1037}$$

$$3.132 K_b = 1338 + 0.688 K_b$$

$$K_b = \frac{1338}{2.444} = 547 \text{ lb/in.}$$

$$F_{mb} = 1338 + 0.688 K_b = 1338 + 376 = 1714 \text{ lb}$$

$$F_{ob} = 1338 - 0.688 K_b = 1338 - 376 = 962 \text{ lb}$$

The decelerating time, Eq. 2–23, will be

$$t = \sqrt{\frac{eM_t}{K_b}}\ \mathrm{Cos}^{-1}\ \frac{F_{ob}}{F_{mb}}$$

$$= \sqrt{\frac{0.5 \times 50}{547 \times 386.4}}\ \mathrm{Cos}^{-1}\ \frac{962}{1714}$$

$$= 0.0109 \times 0.975 = 0.0106 \text{ sec.}$$

By repeated computation, the time and spring constant quickly converge.

$t_{rt} = 0.0105$ sec

$K_b = 615$ lb/in.

$$F_{ob} = F_{ab} - \frac{1}{2}\left(K_b L_b\right) = 1338 - 423 = 915 \text{ lb}$$

$$F_{mb} = F_{ob} + K_b L_b = 915 + 846 = 1761 \text{ lb}$$

To realize an acceptable firing rate, the barrel spring force at firing is set as $F_{ot} = 70$ lb, the initial barrel spring force.

The compression time includes the propellant gas period and becomes

$$T_c = t_{rt} + t_a = 0.0105 + 0.006 = 0.0165 \text{ sec.}$$

The surge time $T = \frac{T_c}{3.8} = 0.00434$ sec.

The appropriate spring constant is computed from Eq. 2–67b.

$$1037 K_t T = F_m = F_{ot} + K_t L_t = 70 + 2.525 K_t$$

where $L_t = L_b + x_r = 1.375 + 1.15 = 2.525$ in.

$$K_t = \frac{70}{4.5 - 2.525} = \frac{70}{1.975} = 35.4 \text{ lb/in.}$$

The barrel spring force at end of recoil is

$$F_{mt} = F_{ot} + K_t L_t = 70 + 89.4 = 159.4 \text{ lb.}$$

The buffer spring constant is

$$K_{bs} = K_b - K_t = 615 - 35.4 = 579.6 \text{ lb/in.}$$

The barrel spring force at the end of the propellant gas period is

$$F_{tb} = F_{ot} + K_t x_r = 70 + 35.4 \times 1.15 = 110.7 \text{ lb.}$$

The buffer spring force at the beginning of buffing is

$$F_{obs} = F_{ob} - F_{tb} = 915 - 110.7 = 804.3 \text{ lb.}$$

The maximum buffer spring force is

$$F_{mbs} = F_{mb} - F_{mt} = 1761 - 159.4 = 1601.6 \text{ lb.}$$

The time of barrel recoil from Eq. 2–22 becomes

$$t_{rt} = \sqrt{\frac{eM_t}{K_b}}\ \mathrm{Cos}^{-1}\ \frac{F_{ob}}{F_{mb}}$$

$$= \sqrt{\frac{0.5 \times 50}{615 \times 386.4}}\ \mathrm{Cos}^{-1}\ \frac{915}{1761}$$

$$= \sqrt{0.000105}\ \mathrm{Cos}^{-1}\ 0.5196 = 0.01025\left(\frac{58.7}{57.3}\right)$$

$$= 0.0105 \text{ sec.}$$

The available energy released by the spring system at the end of buffer travel is

$$E_{crb} = \frac{\epsilon}{2}\left(F_{mb} + F_{ob}\right) L_b = \frac{0.5}{2}\left(1761 + 915\right) 1.375$$

$$= 920 \text{ in.-lb.}$$

The counterrecoil velocity at the end of buffer action becomes

$$v_{crb} = \sqrt{\frac{2E_{crb}}{M_t}} = \sqrt{\frac{1840 \times 386.4}{50}} = \sqrt{14220}$$

$$= 119.2 \text{ in./sec.}$$

The time consumed for counterrecoil by buffer action, Eq. 2–27, is

$$t_{crb} = \sqrt{\frac{M_t}{\epsilon K_b}} \text{ Cos}^{-1} \frac{F_{ob}}{F_{mb}} = \sqrt{\frac{50}{0.5 \times 615 \times 386.4}} \text{ Cos}^{-1} \frac{915}{1761}$$

$$= \sqrt{0.00042} \text{ Cos}^{-1} 0.5196 = 0.0205\left(\frac{58.7}{57.3}\right) = 0.0210 \text{ sec.}$$

The time of counterrecoil for the remaining barrel travel of $x_r = 1.15$ in. via Eq. 2–26 is

$$t_{crt} = \sqrt{\frac{M_t}{\epsilon K_t}} \left(\text{Sin}^{-1} \frac{-F_{ot}}{Z} - \text{Sin}^{-1} \frac{-F_{tb}}{Z} \right)$$

$$= 0.0855 \left[\text{Sin}^{-1} (-0.1854) - \text{Sin}^{-1} (-0.2934)\right]$$

$$= 0.0855 (349.32 - 342.93)/57.3 = 0.0095 \text{ sec}$$

where $\sqrt{\frac{M_t}{\epsilon K_t}} = \sqrt{\frac{50}{0.5 \times 35.4 \times 386.4}} = \sqrt{0.00731}$

$$= 0.0855 \text{ sec}$$

$$Z = \sqrt{F_{tb}^2 + \frac{K_t}{\epsilon} M v_{crb}^2}$$

$$= \sqrt{110.7^2 + \frac{35.4}{0.5} 1840}$$

$$= 377.5 \text{ lb}$$

The time elapsed for the complete barrel cycle is

$$t_{cr} = t_a + t_{rt} + t_{crb} + t_{crt}$$

$$= 0.0060 + 0.0105 + 0.0210 + 0.0095$$

$$= 0.0470 \text{ sec.}$$

The time of the barrel cycle is considerably less than the recoil time of the bolt, $t_r = 0.0683$ sec, and therefore has no influence on the firing cycle if its present operation remains undisturbed. The cyle time of the bolt is

$$t_c = t_a + t_r + t_{cr}$$

$$= 0.0060 + 0.0683 + 0.1459 = 0.2202 \text{ sec.}$$

The firing rate is

$$f_r = \frac{60}{t_c} = \frac{60}{0.2202} = 272 \text{ rounds/min.}$$

This rate is faster than for long recoil ($f_r = 195$) but slower than the recoil-operated delayed blowback gun ($f_r = 420$). The rate of the short recoil gun can be improved by resorting to a softer driving spring and the addition of a bolt buffer. The time of bolt travel will then be less in both directions thereby increasing the rate of fire. For example, to initiate the computations, select a driving spring having these preliminary characteristics:

F_o = 12 lb (2 lb greater than the 10 lb bolt weight)

K = 1.0 lb/in., preliminary spring constant

L_b = 0.5 in., buffer travel

The driving spring force when the buffer is reached becomes

$$F_{db} = F_o + K(L - L_b) = 12 + 1 \times 9.5 = 21.5 \text{ lb.}$$

The initial driving spring force at $x = 1.15$ in. is

$$F = F_o + Kx_r = 12 + 1.15 = 13.15 \text{ lb}$$

The energy absorbed during this period will be

$$E_d = \frac{1}{2\epsilon}(F + F_{db})L_d = \frac{1}{2 \times 0.5}\left(34.65\right)8.35$$

$$= 289 \text{ in.-lb}$$

where

$$L_d = L - L_b - x_r = 10.0 - 0.5 - 1.15 = 8.35 \text{ in.}$$

The energy to be absorbed by the combined effort of buffer and driving springs is

$$E_b = E_{rb} - E_d = 736 - 289 = 447 \text{ in.-lb}$$

The velocity of the bolt as it contacts the buffer is also the buffer velocity v_b during recoil.

$$v_b = \sqrt{\frac{2E_b}{M_b}} = \sqrt{\frac{894 \times 386.4}{10}} = \sqrt{34544}$$

$$= 185.9 \text{ in./sec}$$

The time during this decelerating period, based on constant deceleration, is

$$t_d = \frac{2L_d}{v + v_b} = \frac{2 \times 8.35}{238.5 + 185.9} = 0.0393 \text{ sec.}$$

Buffing time, based on constant deceleration, is

$$t_b = \frac{2L_b}{v_b} = \frac{2 \times 0.5}{185.9} = 0.0054 \text{ sec}$$

The total time of driving spring compression will be

$$T_c = t_a + t_d + t_b = 0.0507 \text{ sec.}$$

The spring surge time $T = \frac{T_c}{3.8} = 0.0133$ sec.

The required spring constant that supersedes the preliminary $K = 1.0$ is computed from Eq. 2–67b.

$$KT = \frac{F_m}{1037} = \frac{F + KL_d}{1037} = \frac{13.2 + 8.35K}{1037}$$

$$K = \frac{13.2}{13.79 - 8.35} = 2.4 \text{ lb/in.}$$

The spring forces at the limits of L_d are

$$F_d = F_o + Kx_r = 12.0 + 2.4 \times 1.15 = 14.8 \text{ lb}$$

$$F_{db} = F_o + K(L - L_b) = 12.0 + 2.4 \times 9.5 = 34.8 \text{ lb.}$$

The time for this driving spring to compress from the propellant gas period to the buffer is obtained from Eq. 2–22.

$$t_d = \sqrt{\frac{\epsilon M_b}{K}}\left(\text{Sin}^{-1}\frac{F_{db}}{Z} - \text{Sin}^{-1}\frac{F_d}{Z}\right)$$

$$= 0.0735\left(\text{Sin}^{-1}\,0.7807 - \text{Sin}^{-1}\,0.3318\right)$$

$$= 0.0735\,(51.18 - 19.28)/57.3 = 0.0409 \text{ sec}$$

where

$$\sqrt{\frac{\epsilon M_b}{K}} = \sqrt{\frac{0.5 \times 10}{2.4 \times 386.4}} = \sqrt{0.00539} = 0.0735 \text{ sec}$$

$$Z = \sqrt{F_d^2 + \epsilon K M_b v^2}$$

$$= \sqrt{219 + 0.5 \times 2.4 \times 1472} = 44.6 \text{ lb}$$

$$M_b v^2 = 2E_{rb} = 1472 \text{ in.-lb.}$$

t_d is somewhat higher than the initial $T_c = 0.0507$ sec. Repeating the computation establishes these values. To continue the analysis of the spring system, compute the energy to be absorbed by the buffer system.

$$E_b = E_{rb} - \left(\frac{F_d + F_{db}}{2\epsilon}\right) L_d = 736 - 414 = 322 \text{ lb}$$

where

$L_d = 8.35$ in.

$\epsilon = 0.5$

The average buffer spring system is

$$F_{as} = \frac{eE_b}{L_b} = \frac{0.5 \times 322}{0.5} = 322 \text{ lb.}$$

The velocity at buffer contact is

$$v_b = \sqrt{\frac{2E_b}{M_b}} = \sqrt{\frac{644 \times 386.4}{10}} = \sqrt{24894}$$

$$= 157.7 \text{ in./sec.}$$

For constant deceleration, the time of buffer action in recoil and also the compression time of the spring is

$$T_c = t_b = \frac{2L_b}{v_b} = \frac{2 \times 0.5}{157.7} = 0.0063 \text{ sec.}$$

The surge time $T = \frac{T_c}{3.8} = 0.0016$ sec.

Iterative computation has the spring characteristics converging rapidly. The computed buffer time, according to the procedure which follows, was 0.006 sec. Thus $T_c = t_b = 0.006$ sec and $T = 0.00158$ sec.

The spring constant is computed from Eq. 2-67b.

$$K_b T = \frac{F_m}{1037} = \frac{F_{as} + \frac{1}{2}\left(L_b K_b\right)}{1037} = \frac{F_{as} + 0.25 K_b}{1037}$$

$$1037 \times 0.00158 K_b = 322 + 0.25 K_b$$

$$K_b = \frac{322}{1.388} = 232 \text{ lb/in.}$$

$$F_{ob} = 322 - 0.25 K_b = 264 \text{ lb}$$

$$F_{mb} = 322 + 0.25 K_b = 380 \text{ lb.}$$

According to Eq. 2-23, the buffing time will be

$$t_b = \sqrt{\frac{eM_b}{K_b}} \text{Cos}^{-1} \frac{F_{ob}}{F_{mb}}$$

$$= \sqrt{\frac{0.5 \times 10}{232 \times 386.4}} \text{Cos}^{-1} \frac{264}{380}$$

$$= 10^{-3} \sqrt{55.78} \text{ Cos}^{-1} 0.6947 = 0.00747 \times 0.803$$

$$= 0.0060 \text{ sec}$$

which verifies that $t_b = 0.0060$ sec and fixes the spring constant at $K_b = 232$ lb/in. The spring constant of the buffer spring alone becomes

$$K_{bs} = K_b - K = 232 - 2.4 = 229.6 \text{ lb/in.}$$

$$F_{obs} = F_{as} - 0.25 K_b - F_{db} = 322 - 58 - 34.8$$

$$= 229.2 \text{ lb}$$

$$F_{mbs} = F_{obs} + K_{bs} L_b = 229.2 + 114.8 = 344 \text{ lb.}$$

The recoil time of the bolt and, therefore, the compression time of the driving spring is

$$t_{rb} = t_a + t_d + t_b = 0.0060 + 0.0409 + 0.0060$$

$$= 0.0529 \text{ sec.}$$

The time of bolt return from buffing action, Eq. 2–27, is

$$t_{crb} = \sqrt{\frac{M_b}{\epsilon K_b}} \cos^{-1} \frac{F_{ob}}{F_{mb}} = 0.0149 \times 0.803$$

$$= 0.012 \text{ sec.}$$

The energy of the moving bolt at the end of buffer return is

$$E_{crb} = \frac{\epsilon}{2}(F_{ob} + F_{mb})\, l_b = \frac{0.5}{2}(380 + 264)\, 0.5$$

$$= 80.5 \text{ in.-lb.}$$

The time elapsed for completing the bolt return, Eq. 2–26, becomes

$$t_{cr} = \sqrt{\frac{M_b}{\epsilon K}} \left(\text{Sin}^{-1} \frac{-F_o}{Z} - \text{Sin}^{-1} \frac{-F_{db}}{Z} \right)$$

$$= \sqrt{\frac{10}{0.5 \times 2.4 \times 386.4}} \left(\text{Sin}^{-1} \frac{-12}{44.54} - \text{Sin}^{-1} \frac{-34.8}{44.54} \right)$$

$$= 0.1468\,(344.37 - 308.62)/57.3 = 0.0916 \text{ sec}$$

where

$$Z = \sqrt{F_{db}^2 + \left(\frac{K}{\epsilon}\right) M v_{crb}^2} = \sqrt{34.8^2 + \left(\frac{2.4}{0.5}\right) 161}$$

$$= \sqrt{1984} = 44.54 \text{ lb.}$$

$$M v_{crb}^2 = 2E_{crb} = 161 \text{ in.-lb.}$$

Time of the complete cycle is

$$t_c = t_a + t_d + t_b + t_{crb} + t_{cr}$$

$$= 0.0060 + 0.0409 + 0.0060 + 0.0120 + 0.0916$$

$$= 0.1565 \text{ sec.}$$

The rate of fire is

$$f_r = \frac{60}{t_c} = \frac{60}{0.1565} = 383 \text{ rounds/min.}$$

This rate is an increase of 28% over the rate of the gun which does not have a buffer for the bolt.

3–6 ACCELERATORS

Recoil-operated machine guns are relatively slow firing because of their slow response to the propellant gas forces. This slow response is due primarily to the large inertial resistance that must be overcome while accelerating the recoiling parts. The entire dynamics structure depends on the velocity of free recoil; the higher the velocity, the higher the rate of fire, but the velocity of free recoil can be influenced only by the mass of the recoiling parts which, for any given gun, is usually limited by structural requirements. High speeds, therefore, must be gained by other means. One of these, as demonstrated in the preceding problem, involves the arrangement of springs whereby somewhat faster action develops by delaying large energy absorption until the buffer is reached. This constitutes the extent of control over firing rates of long recoil guns. However, for short recoil guns, higher rates can be achieved by installing accelerators.

An accelerator, Fig. 3–3, is merely a rotating cam arranged to transfer, over a short distance, some momentum from the rest of the recoiling parts to the bolt, thus augmenting its velocity. At any given instant, the cam and the two masses represent a rotating system. From the law of conservation of angular momentum, the total remains unchanged after an exchange of momentums.

$$r_t M_t v + r_b M_b v = r_t M_t v_t + r_b M_b v_b \qquad (3\text{–}1)$$

where g = acceleration of gravity

$M_b = \frac{W_b}{g}$, mass of bolt

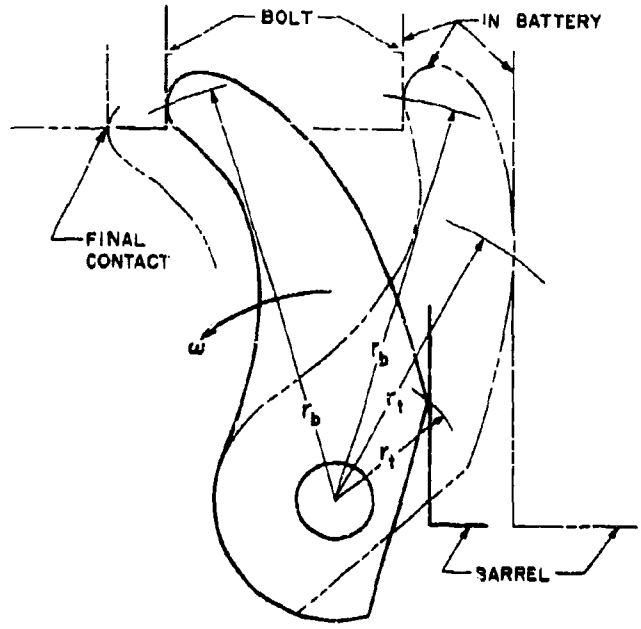


Figure 3–3. Accelerator Geometry

$M_t = \frac{W_t}{g}$, mass of barrel and components

r_b = cam radius to contact point on bolt

r_t = cam radius to contact point on barrel

v = velocity of recoiling parts just prior to accelerator action

v_b = velocity of bolt after accelerator action

v_t = velocity of barrel and components

W_b = weight of bolt

W_t = weight of barrel and components

At the instant of parting from the accelerator, the bolt has acquired a velocity higher than the recoiling barrel. Solving for v_b of Eq. 3–1

$$v_b = \frac{M_t(v - v_t)}{R_c M_b} + v \qquad (3–2)$$

where $R_c = \frac{r_b}{r_t}$.

The law of conservation of energy also applies.

$$\frac{1}{2}(M_t + M_b)v^2 = \frac{1}{2}\left(M_t v_t^2\right) + \frac{1}{2}\left(M_b v_b^2\right) \qquad (3–3)$$

By substituting the expression for v_b, Eq. 3–2, into Eq. 3–3 and collecting terms, we will have a quadratic equation having v_t as the only unknown. The solution for v_t in general terms is too unwieldy and hence not shown. A specific solution is demonstrated in the sample problem.

Other unknown factors are the energy absorbed by the driving and buffer springs and the subsequent change in recoil velocity while the accelerator functions. The procedure for computing these factors is interative. A specific analysis demonstrates this procedure far more readily than a general solution. If follows in the sample problem.

3–7 SAMPLE PROBLEM – ACCELERATOR

3–7.1 SPECIFICATIONS: Identical to long recoil problem (see par. 3–3.1)

3–7.2 DESIGN DATA:

L = 10 in., minimum bolt travel distance

W_b = 10 lb, weight of bolt unit

W_t = 50 lb, weight of barrel unit

ϵ = 0.5, efficiency of spring system

Table 3–3 has the numerical integration for a recoiling weight of 60 lb. The buffer or barrel spring and driving springs resist recoil from the start but are measureably effective only after 1/2 inch of recoil. The buffer spring is not compressed on installation. The accelerator (Fig. 3–3) is so designed that at final contact with the bolt, the bolt has moved 0.56 in., and the barrel, 0.28 in. The radii to the two contact points at this time, are

r_b = 0.90 in. when Δx_b = 0.56 in.

r_t = 0.25 in. when Δx_t = 0.28 in.

$$R_c = \frac{r_b}{r_t} = 3.6$$

At the end of the propellant gas period, when t = 6 msec, the barrel has recoiled x_r = 1.14 in. and has a velocity of free recoil $v_f = v$ = 234.1 in./sec. A preliminary analysis, conducted by the same procedure that follows showed that the transfer of momentum to the bolt caused the barrel to reverse its direction of motion. Also, appropriate spring constants were selected.

K = 20 lb/in., driving spring constant

K_t = 200 lb/in., barrel spring constant

TABLE 3–3. RECOIL TRAVEL OF 20 mm GUN EQUIPPED WITH ACCELERATOR

t, msec	Δt, msec	A_t, lb-sec/in.^{2}	$F\Delta t$, lb-sec	Δv, in./sec	v, in./sec	v_a, in./sec	Δx, in.
0.25	0.25	3.44	1.77	11.4	11.4	5.7	0.0014
0.50	0.25	10.15	5.24	33.7	45.1	28.2	0.0071
0.75	0.25	11.89	6.13	39.5	84.6	64.8	0.0162
1.00	0.25	11.12	5.74	37.0	121.6	103.1	0.0258
1.25	0.25	9.25	4.76	30.6	152.0	131.9	0.0330
1.50	0.25	7.10	3.76	24.2	176.4	159.3	0.0398
1.75	0.25	5.23	2.69	17.3	193.7	185.0	0.0462
2.00	0.25	3.71	1.91	12.6	206.3	200.0	0.0500
2.25	0.25	2.58	1.34	8.6	214.9	210.6	0.0526
2.50	0.25	1.82	0.94	6.1	221.0	218.0	0.0545
2.75	0.25	1.39	0.72	4.6	225.6	223.3	0.0558
3.00	0.25	1.06	0.55	3.5	229.1	227.4	0.0569
3.263	0.263	1.00	0.52*	3.3	232.4	230.8	0.0607
4.00	0.737	1.34	0.40*	2.6	235.0	233.7	0.1711
5.00	1.00	1.04	0.12*	0.8	235.8	235.4	0.2354
6.00	1.00	0.40	-0.27*	-1.7	234.1	235.0	0.2350

*Reduced by resistance of springs

$$x_r = \Sigma \Delta x = 1.14 \text{ in.}$$

The energy absorbed by the springs during the bolt acceleration period reduced the recoil velocity to 225.4 in./sec. This velocity was obtained by iterative computation. The energy absorbed by the barrel spring is

$$\Delta E_t = \left(\frac{F_t + F_{mt}}{2e}\right)\Delta x_t = \left(\frac{228 + 284}{2 \times 0.5}\right)0.28$$

$$= 143 \text{ in.-lb}$$

$F_t = K_t x_r = 200 \times 1.14 = 228$ lb, barrel spring force at beginning of accelerator action

$F_{mt} = K_t(x_r + \Delta x_t) = 200(1.14 + 0.28) = 284$ lb barrel spring force at end of barrel travel

$e = 0.5$, efficiency of spring system.

The two preceding sets of calculations had the energy absorbed by the driving spring equalling 3948 and 3923 in.-lb, respectively. With the average $E = 3936$ in.-lb, the average driving spring force over the remaining recoil distance becomes

$$F_a = \frac{eE}{L_{dr}} = \frac{0.5 \times 3936}{8.3} = 237 \text{ lb}$$

where

$$L_{dr} = L_d - x_r - \Delta x_b = 10.0 - 1.14 - 0.56 = 8.3 \text{ in.}$$

The driving spring force at the end of acceleration is

$$F_e = F_a - \frac{1}{2}\left(KL_{dr}\right) = 237 - 83 = 154 \text{ lb.}$$

The driving spring force at the end of recoil is

$$F_m = F_a + \frac{1}{2}\left(KL_{dr}\right) = 237 + 83 = 320 \text{ lb.}$$

The driving spring force at assembly is

$$F_o = F_m - KL_d = 320 - 200 = 120 \text{ lb.}$$

The energy absorbed by the driving spring force during acceleration is

$$\Delta E_b = \left(\frac{F_e + F}{2e}\right)\Delta x_b = \left(\frac{154 + 143}{2 \times 0.5}\right)0.56$$

$$= 166 \text{ in.-lb}$$

where $F = F_o + Kx_r = 120 + 20 \times 1.14 = 143$ lb.

The total recoil energy is

$$E_r = \frac{1}{2}\left(\frac{W_t + W_b}{386.4}\right)v_f^2 = \frac{60 \times 54803}{772.8} = 4255 \text{ in.-lb.}$$

The energy remaining in the moving parts is

$$E = E_r - \Delta E_t - \Delta E_b = 4255 - 143 - 166$$

$$= 3946 \text{ in.-lb.}$$

The corresponding velocity becomes

$$v = \sqrt{\frac{2E}{M_r}} = \sqrt{\frac{7892 \times 386.4}{60}} = \sqrt{50824}$$

$$= 225.4 \text{ in./sec}$$

$$v_b = \frac{M_t(v - v_t)}{R_c M_b} + v = \frac{50(225.4 - v_t)}{3.5 \times 10} + 225.4$$

$$= 538.5 - 1.39\,v_t$$

$$v_b^2 = 289982 - 1497.0\,v_t + 1.932\,v_t^2$$

To solve for v_t, multiply all terms by g and equate the equivalent energies

$$gE = \frac{1}{2}\left(W_t v_t^2\right) + \frac{1}{2}\left(W_b v_b^2\right)$$

$$386.4 \times 3946 = 25\,v_t^2 + 5\,(289982 - 1497\,v_t + 1.932\,v_t^2)$$

$$v_t^2 - 215.95\, v_t - 2158.8 = 0$$

$$v_t = -9.57 \text{ in./sec.}$$

The low negative velocity indicates a direction change near the end of the accelerating process.

$$v_b = 538.5 - 1.39\, v_t = 538.5 + 13.3 = 551.8 \text{ in./sec.}$$

Compute the energy of bolt and barrel

$$E_b = \frac{1}{2}\left(M_b v_b^2\right) = \left(\frac{10}{772.8}\right)304483 = 3940 \text{ in.-lb}$$

$$E_t = \frac{1}{2}\left(M_t v_t^2\right) = \left(\frac{50}{772.8}\right)92 = 6 \text{ in.-lb}$$

$$E = E_b + E_t = 3946 \text{ in.-lb}$$

This energy compares favorably with the earlier computed energy of 3946 in.-lb thereby rendering the last computed data substantially correct.

The time of bolt acceleration period is

$$t_{ab} = \frac{2\Delta x_b}{v + v_b} = \frac{2 \times 0.56}{225.4 + 551.8} = \frac{1.12}{777.2}$$

$$= 0.0014 \text{ sec.}$$

The time of bolt decelerating period during recoil, Eq. 2–23, is

$$t_{rb} = \sqrt{\frac{eM_b}{K}}\ \text{Cos}^{-1}\ \frac{F_c}{F_m}$$

$$= \sqrt{\frac{0.5 \times 10}{20 \times 386.4}}\ \text{Cos}^{-1}\ \frac{154}{320}$$

$$= \sqrt{0.000647}\ \text{Cos}^{-1}\ 0.4812 = 0.0254\left(\frac{61.23}{57.3}\right)$$

$$= 0.0271 \text{ sec.}$$

The time elapsed during recoil, which is the compression time of the barrel spring, is

$$t_{br} = t_{ab} + t_a = 0.0014 + 0.0060 = 0.0074 \text{ sec}$$

where $t_a = 0.0060$ sec, the propellant gas period.

The time elapsed during bolt recoil, which is the compression time of the driving spring, is

$$t_r = t_{br} + t_{rb} = 0.0074 + 0.0271 = 0.0345 \text{ sec.}$$

The time for the bolt to return as far as the latched barrel, Eq. 2–27, is

$$t_{crb} = \sqrt{\frac{M_b}{eK}}\ \text{Cos}^{-1}\ \frac{F}{F_m}$$

$$= \sqrt{\frac{10}{0.5 \times 20 \times 386.4}}\ \text{Cos}^{-1}\ \frac{148.4}{320}$$

$$= \sqrt{0.002588}\ \text{Cos}^{-1}\ 0.4638$$

$$= 0.0508\left(\frac{62.367}{57.296}\right) = 0.0553 \text{ sec}$$

where $F = F_o + K(\Sigma\Delta x + \Delta x_t) = 120 + 20 \times 1.42 = 148.4$ lb, the driving spring force as the barrel latch is released.

The energy of the bolt at this time is

$$E_b = e\left(\frac{F_m + F}{2}\right)(L - \Sigma\Delta x - \Delta x_t)$$

$$= 0.5\left(\frac{320 + 148.4}{2}\right)8.58 = 1004.7 \text{ in.-lb.}$$

The bolt velocity at barrel pick-up is

$$v_{crb} = \sqrt{\frac{2E_b}{M_b}} = \sqrt{\frac{2009.4 \times 386.4}{10}} = \sqrt{77643}$$

$$= 278.6 \text{ in./sec.}$$

The velocity of all counterrecoiling parts after the barrel is engaged by the bolt, according to the conservation of momentum, is

$$v_{cr} = \frac{M_b v_{crb}}{M_r} = 10\left(\frac{278.6}{60}\right) = 46.4 \text{ in./sec.}$$

With both springs acting as a unit, the combined spring constant is

$$K_s = K + K_t = 20 + 200 = 220 \text{ lb/in.}$$

The spring force at the time of impact is

$$F_s = F + F_{mt} = 148.4 + 284 = 432.4 \text{ lb.}$$

The spring force at the end of counterrecoil, since the barrel spring force reduces to zero, is

$$F_o = 120 \text{ lb.}$$

According to Eq. 2–26, the time elapsed for completing the recoiling parts return is

$$t_{cr} = \sqrt{\frac{M_r}{\epsilon K}}\left(\text{Sin}^{-1}\frac{-F_o}{Z} - \text{Sin}^{-1}\frac{-F_s}{Z}\right)$$

$$= \sqrt{\frac{60}{0.5 \times 220 \times 386.4}}\left(\text{Sin}^{-1}\frac{-120}{578} - \text{Sin}^{-1}\frac{-432.4}{578}\right)$$

$$= 0.0376\left(\frac{348.02 - 311.55}{57.3}\right) = 0.0239 \text{ sec.}$$

where

$$Z = \sqrt{F_i^2 + \frac{K}{e}\left(M_r v_{cr}^2\right)}$$

$$= \sqrt{432.4^2 + \frac{220}{0.5}\left(\frac{60}{386.4}\right)2153}$$

$$= \sqrt{334070} = 578 \text{ lb.}$$

The time consumed for the firing cycle is

$$t_c = t_{dr} + t_{crb} + t_{cr}$$

$$= 0.0345 + 0.0553 + 0.0239 = 0.1137 \text{ sec.}$$

The rate of fire

$$f_r = \frac{60}{0.1137} = 528 \text{ rounds/min.}$$

Recapitulating, the firing rates of the various types of recoil-operated guns are shown in the table which follows. All guns are identical except for the type of automatic action.

Type	Rate of Fire, rounds/min
Blowback	420
Long Recoil	195
Short Recoil (without bolt buffer)	272
Short Recoil (without bolt buffer)	383
Short Recoil (with accelerator)	528

3-8 RATING OF RECOIL-OPERATED GUNS

The recoil-operated machine guns are idealy suited for large caliber weapons. Their inherent low rate of fire keeps them out of the small caliber field but, for large calibers, the firing rate is relatively high and therefore acceptable. Of the two types involved, the long recoil is superior to some extent although the short recoil has a higher firing rate. Both have the same range but the long recoil is more accurate because the high loading accelerations of the short recoil gun disturb the sighting. Also the higher accelerations require heavier feeders and correspondingly heavier associated parts. The large loads imposed to accelerate these components have a tendency to cause them to wear out faster, thus decreasing the reliability and durability of the weapon.

CHAPTER 4

GAS-OPERATED WEAPONS

4–1 GENERAL REQUIREMENTS

Gas-operated automatic weapons are those weapons that have a gas driven mechanism to operate the bolt and its associated moving components. Except for the externally driven systems, all operating energy for automatic weapons is derived from the propellant gases. Nevertheless, gas-operated weapons are only those that draw a portion of the propellant gas through the barrel wall after the projectile has passed and then use this gas to activate a mechanism to retract the bolt. Timing and pressure are regulated by the location of the port along the barrel and by orifices restricting the gas flow. As soon as the projectile passes the port, propellant gases pour into the gas chamber and put pressure on the piston. The piston does not necessarily move at this time. Motion is delayed by bolt locks which are not released until chamber pressure has dropped to safe levels for cartridge case extraction.

4–2 TYPES OF GAS SYSTEMS

There are four basic types of gas systems: impingement, tappet, expansion, and cutoff expansion.

a. Impingement System: has a negligible gas volume at the cylinder; expansion depending on piston motion. As the piston moves, gas continues pouring through the port until the bullet exits at the muzzle. With the subsequent drop in pressure in the bore, the gas in the cylinder may either reverse its flow and return to the bore or it may exhaust through ports in the cylinder wall as shown in Fig. 4–1. The duration of the applied pressure is short, being dependent solely on the position of the gas port.

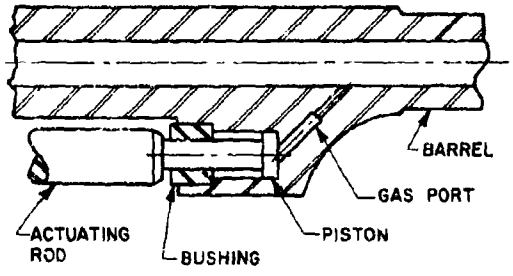


Figure 4–1. Impingement System

b. Tappet System: an impingement system having a short piston travel. (See Fig. 4–7.) The pressure force imparts a relatively high velocity to the piston which moves the operating rod and bolt. The tappet travel is short and its motion ceases as it strikes the end of its cylinder.

c. Expansion System: in contrast, has an appreciable initial volume in its expansion chamber which requires more time to pressurize the chamber, and also more time to exhaust the gas. By judicious selection of port size and location, the required pressurized gas can be drained from the bore.

d. Cutoff Expansion: similar to the direct expansion type, except for a valve which closes the port after the piston moves. As the pressure builds up to a specific value, the piston moves, closing the port and leaving the gas to expand polytropically* to provide the effort needed to operate the moving components of the bolt assembly. Fig. 4–2 shows a cutoff expansion system.

4–3 CUTOFF EXPANSION SYSTEM

4–3.1 MECHANICS OF THE SYSTEM

The final size and location of the gas port are determined by experimental firing. However, for initial design studies, tentative size and location may be computed. The acceleration of the moving parts of the gas-operated system may be expressed generally as

$$\frac{d^2s}{dt^2} = \frac{F}{M_o} = \left(\frac{A_c}{M_o}\right) p_c \qquad (4\text{–}1)$$

*Polytropic is the name given to the change of state in a gas which is represented by the general equation pV^k = constant. $k = c_p/c_v$, where c_p is the specific heat at constant pressure and c_v is the specific heat at constant volume. The specific heats vary with the temperature[27].

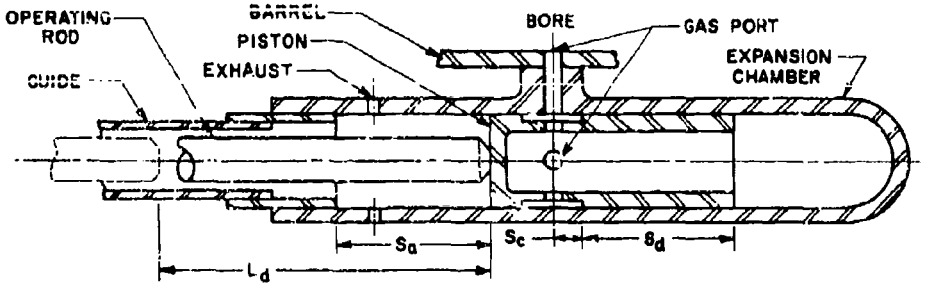


Figure 4–?. Cutoff Expansion System

where

A_c = piston area

M_o = mass of accelerating parts of operating rod

p_c = pressure in the gas cylinder at any time

The gas expands polytropically so that

$$p_c = p_1\left(\frac{V_1}{V_1 + A_c s}\right)^k = p_1\left(\frac{A_c s_o}{A_c s_o + A_c s}\right)^k$$

$$= p_1\left(\frac{s_o}{s_o + s}\right)^k \qquad (4-2)$$

where

k = ratio of specific heats

p_1 = initial pressure

s = travel distance of piston

s_o = initial distance equivalent to V_1

V_1 = initial gas volume

Substitute for p in Eq. 4–1

$$\frac{d^2s}{dt^2} = \frac{A_c p_1 s_o^k}{M_o}\left[\frac{1}{(s_o + s)^k}\right] \qquad (4-3)$$

but

$$\frac{d^2s}{dt^2} = \frac{dv}{dt} = \left(\frac{ds}{dt}\right)\left(\frac{dv}{ds}\right) = v\left(\frac{dv}{ds}\right)$$

Substitute $v\left(\frac{dv}{ds}\right)$ for $\frac{d^2s}{dt^2}$ and rearrange the terms in Eq. 4-3. The expression for vdv appears in Eq. 4–4.

$$vdv = \frac{A_c p_1 s_o^k}{M_o}\left[\frac{1}{(s_o + s)^k}\right] ds \qquad (4-4)$$

Now integrate Eq. 4–4.

$$v^2 = \frac{2A_c p_1 s_o^k}{(1-k)M_o}\left[\frac{1}{(s_o + s)^{k-1}}\right] + C_1 \qquad (4-5)$$

Solve for C_1

$$C_1 = v_o^2 + \frac{2A_c p_1 s_o}{(k-1)M_o} \tag{4-6}$$

When $s = 0$, $v = v_o$ generally, although $v_o = 0$ before the piston begins to move.

$$v = \frac{ds}{dt} = \sqrt{\frac{2A_c p_1}{(k-1)M_o}\left[s_o - \frac{s_o^k}{(s_o+s)^{k-1}}\right] + v_o^2} \tag{4-7}$$

$$\frac{ds}{dt} = \sqrt{K_a\left[\frac{1}{s_o^{k-1}} - \frac{1}{(s_o+s)^{k-1}}\right] + v_o^2} \tag{4-8}$$

where

$$K_a = \frac{2A_c p_1 s_o^k}{(k-1)M_o}$$

$$dt = \sqrt{\frac{s_o^{k-1}(s_o+s)^{k-1}}{K_a\left[(s_o+s)^{k-1} - s_o^{k-1}\right] + v_o^2 s_o^{k-1}(s_o+s)^{k-1}}}\, ds$$

$$= s_o^{(k-1)/2}\sqrt{\frac{\left(1+\frac{s}{s_o}\right)^{k-1}}{K_a\left[\left(1+\frac{s}{s_o}\right)^{k-1} - 1\right] + v_o^2 s_o^{k-1}\left(1+\frac{s}{s_o}\right)^{k-1}}}\, ds \tag{4-9}$$

Let $a = 1 + \frac{s}{s_o}$; $ds = s_o da$

$$dt = s_o^{(k+1)/2}\sqrt{\frac{a^{k-1}}{K_a(a^{k-1}-1) + v_o^2 s_o^{k-1} a^{k-1}}}\, da$$

$$dt = \frac{s_o^{(k+1)/2}}{\sqrt{K_a}}\,\frac{da}{\sqrt{1 - a^{1-k} + v_o^2 s_c^{k-1}/K_a}} \tag{4-10}$$

Let $B = 1 + \left(\frac{v_o^2}{K_a}\right) s_o^{k-1}$

$$dt = \frac{s_o^{(k+1)/2}}{\sqrt{K_a}} \left[B\left(1 - \frac{a^{1-k}}{B}\right)\right]^{-1/2} da \tag{4-11}$$

Expand according to the series $(1-x)^{-1/2}$

$$(1-x)^{-1/2} = 1 + \frac{1}{2}x + \frac{1}{2}\cdot\frac{3}{4}x^2 + \frac{1}{2}\cdot\frac{3}{4}\cdot\frac{5}{6}x^3$$

$$+ \frac{1}{2}\cdot\frac{3}{4}\cdot\frac{5}{6}\cdot\frac{7}{8}x^4 + \ldots. = A + A_1x + A_2x^2 + A_3x^3 + A_4x^4 + \ldots. \tag{4-12}$$

where A_1, A_2, A_3, etc., are coefficients of x of the expanded series.

Now let $a^{1-k} = x$

$$dt = \frac{s_o^{(k+1)/2}}{\sqrt{K_a}} \left[1 + A_1\frac{a^{(1-k)}}{B} + A_2\frac{a^{2(1-k)}}{B^2} + A_3\frac{a^{3(1-k)}}{B^3} + A_4\frac{a^{4(1-k)}}{B^4} + \ldots\right] da \tag{4-13}$$

Now integrate

$$t = \frac{s_o^{(k+1)/2}}{\sqrt{K_a}} \left[a + A_1\frac{a^{1-k}}{B(2-k)} + A_2\frac{a^{3-2k}}{B^2(3-2k)} + A_3\frac{a^{4-3k}}{B^3(4-3k)} + A_4\frac{a^{5-4k}}{B^4(5-4k)} + \ldots.\right] + C_2 \tag{4-14}$$

when $t = 0$, $s = 0$ and $a = 1.0$, thus

$$C_2 = -\frac{s_o^{(k+1)/2}}{\sqrt{K_a}} \left[1 + \frac{A_1}{(2-k)B} + \frac{A_2}{(3-2k)B^2} + \frac{A_3}{(4-3k)B^3} + \frac{A_4}{(5-4k)B^4} + \ldots.\right] \tag{4-15}$$

Before continuing with the analysis of the mechanics of the gas-operated system, several initial parameters must be established such as the characteristics of driving springs and buffers, time of recoil and counterrecoil, and port sizes and location. Since springs or their equivalent store energy for counterrecoil, they must be given the working capacity for reloading the gun and returning the recoiled parts in the prescribed time. Since the efficiency of the spring system involving recoil activity is relatively low in automatic guns, counterrecoil must necessarily take longer than recoil. Practice sets the preliminary estimate of counterrecoil time as

$$t_{cr} = 1.5t_r = 0.60t_c = \frac{36}{f_r} \text{ sec} \qquad (4-16)$$

where

f_r = firing rate, rounds/min

t_c = time of firing cycle, sec

t_r = time of recoil, sec

Driving and buffer springs, whether single springs or nests of two or more, are generally installed in series. The driving spring is the softer of the two and, during recoil, seats before the buffer springs begin to move. Its fully compressed load is less than the initial spring load of the buffers. Deflections are consistent with type, the driving spring has a large deflection whereas the much stiffer buffer springs deflect approximately 15% of the total recoil travel. In counterrecoil, the buffer springs complete their action first, then the driving spring continues the accelerating effort the rest of the way. Another proportion which must be considered during the preliminary design characteristics involves the ratio of counterrecoil energy contributed by the buffer springs to the total counterrecoil energy. A practical value is

$$\frac{E_{bc}}{E_{cr}} = 0.40. \qquad (4-17)$$

The counterrecoil velocity at the end of buffer spring action is computed from the kinetic energy equation.

$$v_{bc} = \sqrt{\frac{2 \times 0.4 E_{cr}}{M_r}} \qquad (4-18)$$

The velocity at the end of counterrecoil is computed similarly.

$$v_{cr} = \sqrt{\frac{2E_{cr}}{M_r}} \qquad (4-19)$$

Now

$$\frac{v_{bc}}{v_{cr}} = \sqrt{0.4} \text{ or } v_{bc} = 0.632 v_{cr}. \qquad (4-20)$$

Based on average velocities, the time required to negotiate the buffer spring travel becomes

$$t_{bc} = \frac{2L_b}{v_{bc}} = \frac{3.16L_b}{v_{cr}} \qquad (4-21)$$

where

L_b = travel of buffer spring.

The time required for the remaining counterrecoil travel is

$$t_{rs} = \frac{2L_d}{v_{bc} + v_{cr}} = \frac{1.225L_d}{v_{cr}} \qquad (4-22)$$

where

L_d = driving spring travel

The total time of counterrecoil is approximately t_{cr}.

$$t_{cr} = t_{bc} + t_{rs} = \frac{3.16 L_b + 1.225 L_d}{v_{cr}} \qquad (4-23)$$

Since t_{cr} is know, Eq. 4-16, the approximate maximum counterrecoil velocity is

$$v_{cr} = \frac{3.16 L_b + 1.225 L_d}{t_{cr}}. \qquad (4-24)$$

Sufficient data are now known so that, via Eq. 2–26, practical values of characteristics for the various springs can be estimated. Spring constants may vary greatly among those in the whole system but the loads should be reasonably proportioned. The minimum load on the driving spring should be 3 to 4 times the weight of the recoiling parts. The minimum load of the buffer springs in series should be equal and in turn should be about twice the fully compressed load of the driving spring.

4–3.1.1 Gas Filling Period

The time must also be computed during the period while the initial volume of the operating cylinder is being filled with propellant gas. The operating piston and rod begin to move as soon as the gas force is sufficient to overcome friction. According to the equation of gas flow through an orifice, the rate w of gas flow is [7]

$$w = CA_o p \sqrt{\left(\frac{g}{RT}\right) k \left(\frac{2}{k+1}\right)^{\frac{k+1}{k-1}}}, \text{ lb/sec} \qquad (4\text{–}25)$$

where

A_o = orifice area, in.^{2}

C = orifice coefficient

g = 386.4 in./sec^2, acceleration of gravity

k = ratio of specific heats

p = pressure in reservoir, lb/in.^{2}

RT = specific impetus, ft-lb/lb

Eq. 4–25 is valid as long as the discharge pressure does not exceed the critical flow pressure. For gases, the critical flow pressure p_{cr} is

$$p_{cr} = 0.53p. \qquad (4\text{–}26)$$

All the values of Eq. 4–25 are usually known except for orifice area and pressure so the equation may be simplified by substituting K_w for the product of C times the term under the radical of Eq. 4–25, i.e.,

$$w = K_w A_o p_a \qquad (4\text{–}27)$$

where the pressure now becomes p_a, the average pressure over a time interval. The time intervals should be short in duration so that the spread of values is small between average pressure and the maximum and minimum values, thereby minimizing the errors introduced by pressure variations over the interval. The weight ΔW_c of gas flowing into the operating cylinders during the time interval Δt is

$$\Delta W_c = w\Delta t \qquad (4\text{–}28)$$

Pressures are read from the pressure-time curve, the initial pressure being that corresponding to the position of the orifice in the barrel. A tentative location of the orifice may correspond approximately with bullet location when approximately 50 to 70 percent of its time in the barrel has elapsed. Pressures in the operating cylinder may be adjusted by increasing the orifice area for higher pressures or decreasing it for lower pressures. If higher pressures are needed but a larger orifice is not deemed wise, these higher pressures are available by locating the orifice nearer to the breech. Conversely, lower pressures are available by shifting the orifice toward the muzzle. In both alternatives, these latter effects follow the prescription only if the orifice size remains unchanged.

There are so many variables in this exercise that some values must be assigned arbitrarily in order to approach a practical solution. An initial close approximation of these assigned values saves considerable time, which emphasizes the value of experience. By the time that the gas operating mechanism is being considered, good estimates should have been made on the weights of the bolt and its related moving parts and on the travel distance of these components. With the help of these estimates and with Eqs. 4–16 through 4–24, the early characteristics of counterrecoil are determined to serve as data for determining the recoil characteristics. As the first step, let the accelerating distance of the gas piston be indicated by s_a.

$$s_a = 0.3(L_d + L_b) \qquad (4\text{–}29)$$

The velocity of recoil at the end of the gas piston stroke is a function of the counterrecoil velocity at the same bolt position. The two velocities are related by the efficiency of the spring system The counterrecoil velocity at this position is determined from Eq. 2–24, thus

$$v_{cr} = \sqrt{v_{bc}^2 + \frac{F_m (L_d - s_a) - \frac{1}{2} K (L_d - s_a)^2}{M_r}} . \qquad (4\text{–}30)$$

At any given position, the energy remaining to be absorbed by the spring may be expressed generally as ϵE_r

$$\epsilon E_r = \frac{\epsilon}{2} \left(M_r v_r^2 \right) = \left(\frac{F_m + F_o}{2} \right) L . \qquad (4\text{–}31)$$

At the same position during counterrecoil, the energy released by the spring is indicated by Eq. 4–32.

$$E_{cr} = \frac{1}{2} \left(M_r v_{cr}^2 \right) = \epsilon \left(\frac{F_m + F_o}{2} \right) L \qquad (4\text{–}32)$$

Solve for $\frac{F_m + F_o}{2} L$ in Eq. 4–32 and substitute the appropriate terms in Eq. 4–31 to obtain Eqs. 4–33 and 4–34.

$$\frac{\epsilon}{2} \left(M_r v_r^2 \right) = \frac{1}{2\epsilon} \left(M_r v_{cr}^2 \right) \qquad (4\text{–}33)$$

$$v_r = \frac{v_{cr}}{\epsilon} \qquad (4\text{–}34)$$

The work done during a polytropic expansion of a gas is defined in Eq. 4–35.

$$W = \frac{p_1 V_1 - p_2 V_2}{k - 1} \qquad (4\text{–}35)$$

where

k = ratio of specific heats

p_1 = initial pressure

p_2 = final pressure

V_1 = initial volume of gas cylinder

V_2 = final volume of gas cylinder

Since

$$p_2 = p_1 \left(\frac{V_1}{V_2} \right)^k$$

Eq. 4–35 may be written as

$$W = p_1 \left[\frac{V_1 - \left(\frac{V_1}{V_2} \right)^k V_2}{k - 1} \right] . \qquad (4\text{–}36)$$

By assigning a value to the ratio $\frac{V_2}{V_1}$ so that $V_2 = \left(\frac{V_2}{V_1} \right) V_1$, Eq. 4–36 may be written

$$W = \frac{p_1 V_1}{k - 1} \left[1 - \left(\frac{V_1}{V_2} \right)^{k-1} \right] . \qquad (4\text{–}37)$$

Experience has indicated that $k = 1.3$ and that the ratio $\frac{V_1}{V_2} = \frac{3}{5}$ offers a practical beginning in the design study. Substitute these values in Eq. 4–37 to express the work done by the expanding gas so that

$$W = 0.473 p_1 V_1 . \qquad (4\text{–}38)$$

This work is equal to the kinetic energy of the recoiling mass. By substitution, the expression for the energy in Eq. 4--38 becomes

$$\frac{1}{2}\left(M_r v_r^2\right) = 0.473 p_1 V_1 \qquad (4-39)$$

$$p_1 V_1 = 1.06 M_r v_r^2 . \qquad (4-40)$$

Neither p_1 or V_1 are known but gas volume and corresponding dimensions must be compatible with the dimensions of the gun. The initial pressure must be low enough to assure its attainability and still perform according to time limits. An initial pressure in the neighborhood of 1000 to 1500 psi is appropriate.

On the assumption that the preliminary design is completed to the extent that tentative sizes have been established and the gas port in the barrel located, the pressure in the operating cylinder becomes the primary concern. Note that before the bullet passes the port, the gas operating cylinder is empty. As soon as the bullet passes the port, gases pour into the cylinder and, when the pressure becomes high enough, the piston begins to move. However, a finite time is required, however small, for the gas to fill the cylinder. Also, the pressure in the bore is rapidly diminishing. For this reason, the pressure in the operating cylinder does not have sufficient time to reach bore pressure before cut off when the port is closed. The gas pressure in the operating cylinder is found by establishing a relationship between the gas weight in the cylinder and the total propellant gas weight, and between the cylinder volume and the effective volume of the bore. The effective volume assumes the barrel to be extended beyond the muzzle to correspond with pressure decay. V_b is the effective bore volume after the bullet leaves the barrel.

$$V_b = V_m \left(\frac{p_m}{p_a}\right)^{\frac{1}{k_b}} \qquad (4-41)$$

where

k_b = ratio of specific heats of propellant gas in bore, usually considered to be 1.2 as compared to 1.3 in operating cylinder since the two locations have different temperatures. See footnote, par. 4–3.1.

p_a = average propellant gas pressure

p_m = propellant gas pressure as bullet leaves muzzle

V_m = chamber volume plus total bore volume

The equivalent gas volume in the cylinder at p_a is shown as

$$V_e = \left(\frac{W_c}{W_g}\right) V_b \qquad (4-42)$$

where

W_c = $\Sigma \Delta W_c$, weight of gas in the cylinder

W_g = total weight of propellant gas

The gas pressure in the cylinder becomes

$$p_c = \left(\frac{V_e}{V_c}\right)^k p_a \qquad (4-43)$$

where

k = ratio of specific heats in operating cylinder

p_a = average bore pressure over a time increment

V_c = cylinder volume

The gas force applied to the piston in the operating cylinder

$$F_c = A_c p_c \tag{4-44}$$

The corresponding impulse $F_c \Delta t$ is obtained by multiplying the gas force by the differential time, Δt. Since momentum and impulse are the same dimensionally, the change in velocity of the recoiling unit during any given increment becomes Δv.

$$\Delta v = \frac{F_c \Delta t}{M_r} \tag{4-45}$$

where

M_r = mass of the recoiling unit

The velocity v at the end of any given increment is the summation of the Δv's.

$$v = \Sigma \Delta v = v_{n-1} + \Delta v \tag{4-46}$$

The distance s traveled by the operating unit at any given time of the s_1

$$s = s_1 + s_2 + s_{n-1} = \frac{1}{2}(\Delta v \Delta t) + v_{n-1} \Delta t + s_{n-1} \tag{4-47}$$

and the corresponding gas volume in the cylinder is

$$V_c = V_{co} + A_c s. \tag{4-48}$$

The entire computing procedure to arrange the dynamics of the recoiling system so that these data are compatible with counterrecoiling data is iterative and depends on the logical selection of initial values to hold the quantity of exploration to a minimum. Experience is the best guide in this respect but if lacking, definite trends in earlier computations should soon lead to the proper choice.

The initial orifice area is found by first solving for the weight of gas in the operating cylinder at cutoff and then, on the basis of average values, computing the area by Eq. 4-27. When the known or available values are substituted for the unkown in Eqs. 4-41, 4-42, 4-43, the solution for the weight of the gas becomes

$$W_c = W_g \left(\frac{V_c}{V_m}\right)\left(\frac{p_c^{1/k}}{p_m^{1/k_b}}\right) p_a^{(1/k_b - 1/k)} \tag{4-49}$$

Select an initial value of the cylinder pressure p_c. Assume that it is the critical flow pressure, thereby fixing the average bore pressure p_a (p in Eq. 4-26). Locate the pressure and the corresponding time on the pressure-time curve. Now measure the area under the pressure-time curve between the limits of the above time and when the bullet passes the gas port. The area divided by p_a gives the time needed to operate at the average pressure.

$$t = \frac{A_{pt}}{p_a} \tag{4-50}$$

where A_{pt} = area under pressure-time curve.

The rate of flow is now stated as

$$w = \frac{W_c}{t} \tag{4-51}$$

The orifice area A_o may now be computed from Eq. 4-27.

$$A_o = \frac{w}{K_w p_a} = \frac{W_c}{K_w A_{pt}} \tag{4-52}$$

4-3.1.2 Bolt Locking Cam

The cam that controls the locking and unlocking of the bolt is arranged for the bolt to be released completely only after the propellant gas pressure in the chamber is no longer dangerous and, conversely, completely locks the bolt before the chambered round

is fired. In a gas-operated machine gun such as the 7.62 mm. M60, the operating rod moves a short distance before bolt pickup. During this traverse, about half its axial length, the cam has a shallow constant slope to insure a small angular bolt travel and thereby exposes only the high strength end of the case at its rim. The cam then follows a parabolic curve to complete the unlocking process. A bolt having two locking lugs generally turns about sixty degrees (Fig. 4–3).

To simplify the dynamics of cam operation, all components are assumed to be rigid so that transfer of momentum or energy from translation to rotation is made without considering the elasticity of the system. Therefore, as soon as the cam follower moves under the influence of the operating rod, the bolt immediately assumes the angular kinetics of the moving system. Linear velocity converted to angular velocity becomes

$$\omega = \left(\frac{v_o}{R_c}\right) \tan\beta, \text{ rad/unit time} \qquad (4\text{–}53)$$

where

R_c = cam radius

v_o = operating rod velocity immediately preceding cam action

β = cam rise angle

Apply the law of the conservation of momentum, thus

$$M_o v_o = M_o v + I_b \frac{\omega}{R_c}$$

$$= \left[M_o + M_b \left(\frac{k^2}{R_c^2}\right) \tan\beta\right] v \qquad (4\text{–}54)$$

where

I_b = mass moment of inertia of bolt

k = bolt polar radius of gyration

M_b = mass of bolt

M_o = mass of operating rod assembly

v = axial linear velocity

Fig. 4–4 shows the accelerating force system involved in the cam dynamics. All forces and reactions are derived from the cam normal force and from the geometry of the bolt components.

F_L = transverse force on locking lug; reaction on bolt

N = cam normal force

N_a = axial force on cam and locking lug

N_c = tangential force on cam; reaction on bolt

N = reaction normal force

R = bolt radius

R_c = cam radius

R_L = radius of locking lug pressure center

λ = locking lug helix angle

μ_r = coefficient of rolling friction of cam roller

μ_s = coefficient of sliding friction

ω = angular velocity

From the geometry, the axial component of the normal cam force and the cam friction is

$$N_a = N(\sin\beta + \mu_r \cos\beta) \qquad (4\text{–}55)$$

Since the lug cam is analogous to a screw, the other forces and reactions are obtained by resolving the static forces accordingly. Let N_s be the reaction normal to the helix of the lug and $\mu_s N_s$, the frictional resistance. The axial component of these two forces is

$$N_a = N_s(\cos\lambda + \mu_s \sin\beta). \qquad (4\text{–}56)$$

The inertia force of the operating rod and the axial cam force must balance the accelerating force, thus

$$F_c = M_o a + N(\sin\beta + \mu_r \cos\beta) \qquad (4\text{–}57)$$

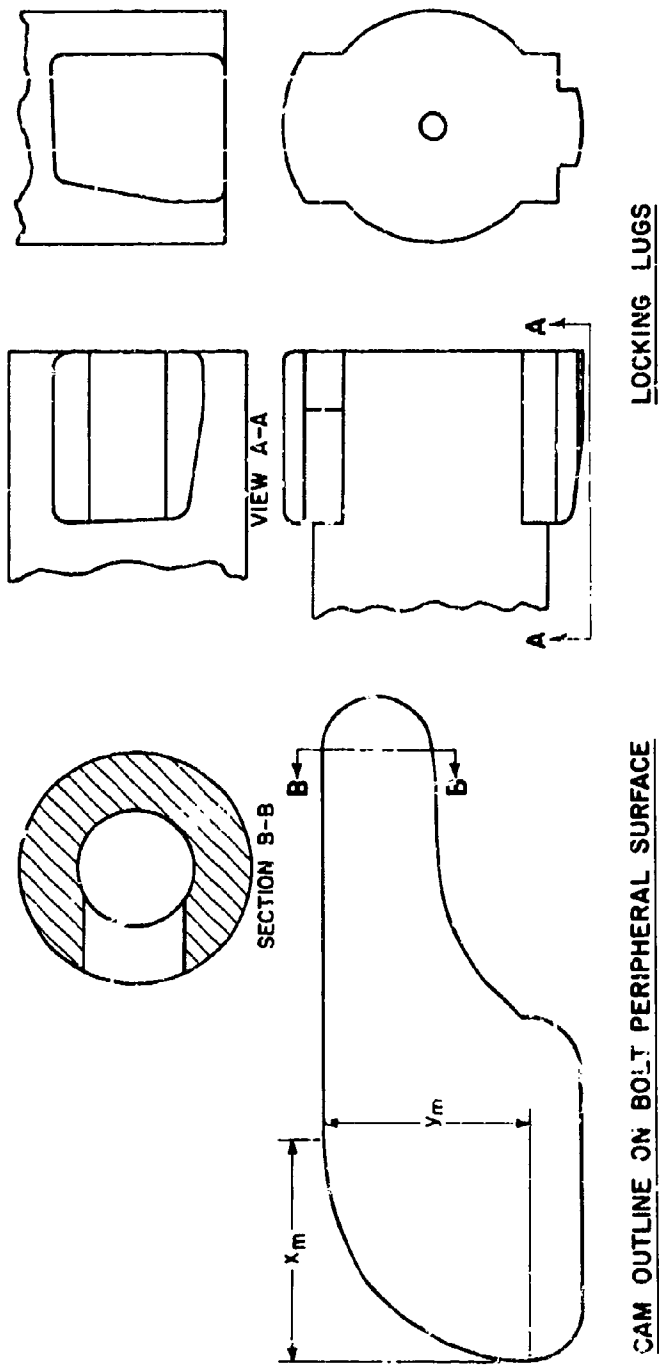


Figure 4–3 Rotating Bolt Lock and Activating Cam

where a = linear acceleration of locking lug.

The applied torque $N_c R_c$ of the transverse cam force must balance the rotational inertia of the bolt, plus the induced torque of the lug, plus the two components of frictional resistance of the bolt.

$$N_c R_c = I_b \alpha + F_L \ell_L + \mu_s N_c R + \mu_s F_L R \qquad (4\text{–}58)$$

where

I_b = mass moment of inertia of bolt

$N_c = N(\cos\beta - \mu_r \sin\beta)$

$F_L = N_s(\sin\lambda - \mu_s \cos\lambda)$

$I_b\alpha = M_b k^2 \left(\frac{a}{R_c}\right) \tan\beta$

α = angular acceleration of bolt

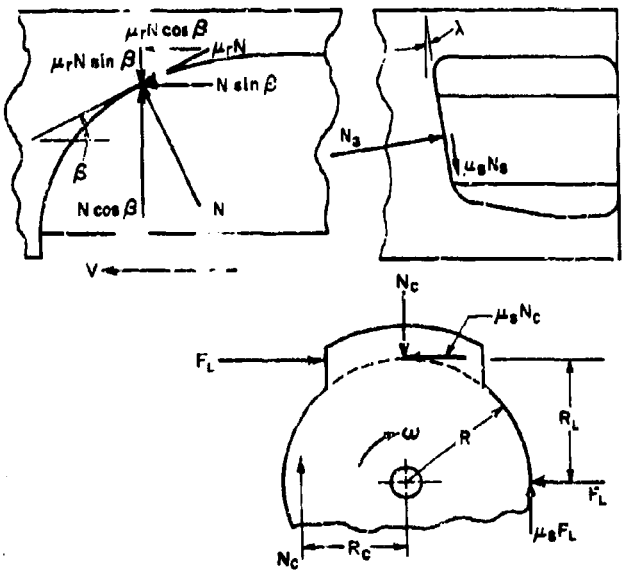


Figure 4–4. Force System of Bolt Cam

After these expressions are substituted into Eq. 4–58 and the terms collected, Eq. 4–59 may be compiled.

$$N(\cos\beta - \mu_r \sin\beta)(R_c - \mu_s R) = M_b \frac{k^2}{R_c} a \tan\beta - N_s(\sin\lambda - \mu_s \cos\lambda)(R_L - \mu_s R) \qquad (4\text{–}59)$$

Solve for N_s in terms of N via Eqs. 4–55 and 4–56.

$$N_s = N\left(\frac{\sin\beta + \mu_r \cos\beta}{\cos\lambda + \mu_s \sin\lambda}\right) \qquad (4\text{–}60)$$

Substitute for N_s in Eq. 4–59, collect terms and solve for N.

$$N = M_b a \frac{k^2 \tan\beta}{R_c \left[(R_c - \mu_s R)(\cos\beta - \mu_r \sin\beta) + C_\lambda (R_L - \mu_s R)(\sin\beta + \mu_r \cos\beta)\right]} \quad (4\text{–}61)$$

where

$$C_\lambda = \frac{\sin\lambda - \mu_s \cos\lambda}{\cos\lambda + \mu_s \sin\lambda}$$

Now substitute for N in Eq. 4–57 so that

$$F = a \left\{ M_o + M_b \frac{k^2 \tan\beta}{R_c \left[\frac{(R_c - \mu_s R)(\cos\beta - \mu_r \sin\beta)}{\sin\beta + \mu_r \cos\beta} + C_\lambda (R_L - \mu_s R)\right]} \right\} \quad (4\text{–}62)$$

For unlocking, F is the gas pressure force on the operating rod. It is the driving spring force during locking. The expression in the braces of Eq. 4–62 is equivalent to an effective mass M_e. Eq. 4–62 may now be written as

$$F_c = M_e a \quad (4\text{–}63)$$

$$a = \frac{F}{M_e} \quad (4\text{–}64)$$

During the unlocking period, the operating rod derives its accelerating force from the propellant gases which, after cutoff, expand polytropically. The pressure in the operating cylinder at a given position of the rod is computed according to Eq. 4–2 and the force according to Eq. 4–44.

$$p_c = p_1 \left(\frac{s_o}{s_o + s}\right)^k \quad \text{(from Eq. 4–2)}$$

$$F_c = A_c p_c \quad \text{(from Eq. 4–44)}$$

Both p_c and F_c may be found by assigning small increments to the operating rod travel s.

$$s = s_{n-1} + \Delta s \quad (4\text{–}65)$$

The average acceleration over the increment is

$$a_a = \frac{1}{2}(a_{n-1} + a_n) \quad (4\text{–}66)$$

The velocity at the end of each increment is obtained by first computing the energy E_o of the operating rod

$$E_o = E_{ol} + \Delta E_o = E_{o(n-1)} + \Delta E_o$$

$$= E_{o(n-1)} + \left[\frac{F_{c(n-1)} + F_{c(n)}}{2}\right] \Delta s \quad (4\text{–}67)$$

where E_{ol} = energy of operating rod at gas cutoff

then $$v = \sqrt{\frac{2E_o}{M_o}}. \quad (4\text{–}68)$$

The incremental time may be computed from the expression

$$\Delta s = v_{n-1}\Delta t_e + \frac{1}{2}\left(a_a \Delta t_e^2\right) \tag{4-69}$$

Solving for Δt_e, the incremental time of the gas expansion stroke becomes

$$\Delta t_e = -\frac{v_{n-1}}{a_a} \pm \sqrt{\left(\frac{v_{n-1}}{a_a}\right)^2 + \frac{2\Delta s}{a_a}} \tag{4-70}$$

The time for the total gas expansion stroke is t_e.

$$t_e = \Sigma \Delta t_e \tag{4-71}$$

During the locking period, the applied force is derived from the driving spring. The spring accelerating forces at any position of the operating rod when efficiency is considered is

$$F = \epsilon(F_i + Ks) = F_{n-1} + \epsilon K \Delta s \tag{4-72}$$

where

F_i = initial driving spring force as bolt seats

F_{n-1} = spring accelerating force of previous increment

K = spring constant

s = operating rod travel after bolt seats

Δs = incremental operating rod travel

ϵ = efficiency of the spring system

The breech end of the locking lugs carries the axial reaction on the bolt, thereby relieving the helix end of all loads during cam action. Therefore, in Eq. 4–62, $\lambda = 0$, and the effective mass becomes

$$M_e = M_o + M_b \left\{ \frac{k^2 \tan\beta}{R_c\left[\dfrac{(R_c - \mu_s R)(\cos\beta - u_r \sin\beta)}{\sin\beta + \mu_r \cos\beta} - \mu_s(R_L - \mu_s R)\right]} \right\} \tag{4-73}$$

Note that if the cam roller is not installed for either locking or unlocking, the coefficient of rolling friction μ_r changes to μ_s the coefficient of sliding friction in Eqs. 4–62 and 4–73.

4-3.1.3 Cam Curve

The cam curves on the breech end of the bolt are helices, usually having identical slopes. The straight slope merges smoothly with the parabolic curve which may be expressed as

$$y = Ax^2 + Bx + C. \qquad (4-74)$$

Locate the coordinate axes so that $y = 0$ when $x = 0$, thus $C = 0$ which reduces the equation to

$$y = Ax^2 + Bx \qquad (4-75)$$

The slope of the curve is defined as

$$\frac{dy}{dx} = 2Ax + B = \tan\beta \qquad (4-76)$$

when $x = 0; \beta_o = \beta, \frac{dy}{dx} = \tan\beta_o$, and $B = \tan\beta_o$, the slope of the helix and therefore the slope of the parabola where it joins the helix. When x and y reach their respective limits, dimensions that have been assigned and then substituted in Eq. 4–75 will yield the value of the coefficient A.

$$A = \frac{y_m - Bx_m}{x_m^2} \qquad (4-77)$$

where

x_m = axial length of the parabola (see Fig. 4–3)

y_m = peripheral width of the parabola (see Fig. 4–3)

From Eq. 4–62, the equivalent mass for the unlocking system is a constant when the cam action involves the helix. The values assigned to the parameters in the equation are:

k = 0.275 in., radius of gyration

R = 0.39 in., bolt radius

R_c = 0.32 in., cam radius

μ_r = 0.034 coefficient of rolling friction

μ_s = 0.30 coefficient of sliding friction

$\tan\beta_o$ = 0.007465, slope of cam helix

R_L = 0.5 in., radius of locking lug

W_b = 0.75 lb, bolt weight

W_o = 2.5 lb, operating rod weight

$\cos\beta_o$ = 0.999972

$\sin\beta_o$ = 0.0074648

λ = 3°, slope of lug helix

$$M_e = \frac{1}{386.4}\left\{ W_o + W_b \frac{k^2 \tan\beta_o}{R_c\left[\frac{(R_c - \mu_s R)(\cos\beta_o - \mu_r \sin\beta_o)}{\sin\beta_o + \mu_r \cos\beta_o} + C_\lambda (R_L - \mu_s R)\right]} \right\}$$

$$= \frac{1}{386.4}\left\{ 2.5 + 0.75 \left[\frac{0.0756 \times 0.007465}{0.32\,(0.203 \times 24.12 - 0.244 \times 0.383)}\right]\right\}$$

where

$$\frac{\cos\beta_o - \mu_r \sin\beta_o}{\sin\beta_o + \mu_r \cos\beta_o} = \frac{0.99997 - 0.00025}{0.00746 + 0.0340} = 24.12$$

$$C_\lambda = \frac{\sin\lambda - \mu_s \cos\lambda}{\cos\lambda + \mu_s \sin\lambda} = \frac{0.05234 - 0.29959}{0.99863 + 0.01570} = -0.244$$

$$M_e = \frac{2.5 + 0.75 \times 1.18 \times 10^{-4}}{386.4} = \frac{2.50001}{386.4} = 0.00647 \text{ lb-sec}^2/\text{in.}$$

The effective mass adds less than one percent to the operating rod mass as the cam follower progresses along the constant cam slope hence it need not be considered in the calculations until the parabolic curvature is reached. Because the entire bolt mass without modification was entered in the analysis of the period before gas cutoff, this analysis may be considered conservative. The effective mass while the cam follower negotiates the parabolic curvature of the cam for the unlocking process becomes (Eqs. 4–63 and 4–62)

$$M_e = 6.47 \times 10^{-3} + \frac{4.58 \times 10^{-4} \tan\beta}{0.203\left(\frac{\cos\beta - 0.034 \sin\beta}{\sin\beta + 0.034 \cos\beta}\right) - 0.093}$$

The effective mass for the locking process is obtained from Eq. 4–73.

$$M_e = 6.47 \times 10^{-3} + \frac{4.58 \times 10^{-4} \tan\beta}{0.203\left(\frac{\cos\beta - 0.034 \sin\beta}{\sin\beta + 0.034 \cos\beta}\right) - 0.115}$$

The straight slope of the cam is half the axial cam travel distance

$$x_c = \frac{1}{2} s_r = 0.5 \text{ in.}$$

$$x_m = s_r - s_c = 0.5 \text{ in., axial length of parabola}$$

According to Eq. 4–76, $B = \tan \beta_o = 0.007465$. The bolt must turn through an angle of 60° to unlock. The peripheral width of the parabola (see Fig 4–3) is

$$y_m = \left(\frac{60}{57.3} - B\right) R_c = 1.0397 \times 0.32 = 0.3327 \text{ in.}$$

From Eq. 4–77, the constant A is

$$A = \frac{y_m - Bx_m}{x_m^2} = \frac{0.3327 - 0.007465 \times 0.5}{0.25}$$
$$= 1.316/\text{in.}$$

The slope of the curve, Eq. 4–76, is

$$\tan\beta = \frac{dy}{dx} = 2.632x + 0.007465.$$

4–3.2 SAMPLE PROBLEM FOR CUTOFF EXPANSION SYSTEM

4–3.2.1 Specifications

Gun: 7.62 mm machine gun

Firing Rate: 1000 rounds/min

Interior Ballistics: Pressure vs Time, Fig. 4–5
Velocity vs Time, Fig. 4–5

4–3.2.2 Design Data, Computed

The time for the firing cycle, from Eq. 2–29, is

$$t_c = \frac{60}{f_r} = \frac{60}{1000} = 0.060 \text{ sec.}$$

The counterrecoil time t_{cr}, Eq. 4–16 , is

$$t_{cr} = 0.60 t_c = 0.036 \text{ sec}$$

The recoil time

$$t_r = t_c - t_{cr} = 0.060 - 0.036 = 0.024 \text{ sec.}$$

Fig. 4–6 shows a sketch of the various distances involved in the operation of the moving mechanisms during the firing cycle. These initial distances are based on those of an earlier gun.

d_c = 0.874 in., gas cylinder diameter

d_p = 0.135 in., gas port diameter

L_b = 1.00 in., buffer stroke

L_{b1} = 0.75 in., operating distance of primary buffer spring

L_{b2} = 0.25 in., operating distance of secondary buffer spring

L_d = 5.5 in., operating distance of operating rod spring

s_a = 2.0 in., accelerating distance of gas piston

s_b = 4.5 in., distance of bolt retraction during recoil.

s_c = 0.20 in., cutoff distance

s_d = 1.8 in., dwell distance

s_r = 1.00 in., operating rod travel before bolt pickup

V_o = 1.8 in.^{3}, initial gas volume of operating cylinder

W_b = 0.75 lb, weight of bolt

W_o = 2.5 lb, weight of moving operating mechanism

W_r = $W_b + W_o$ = 3.25 lb, weight of recoiling parts

e = 0.50, efficiency of spring system

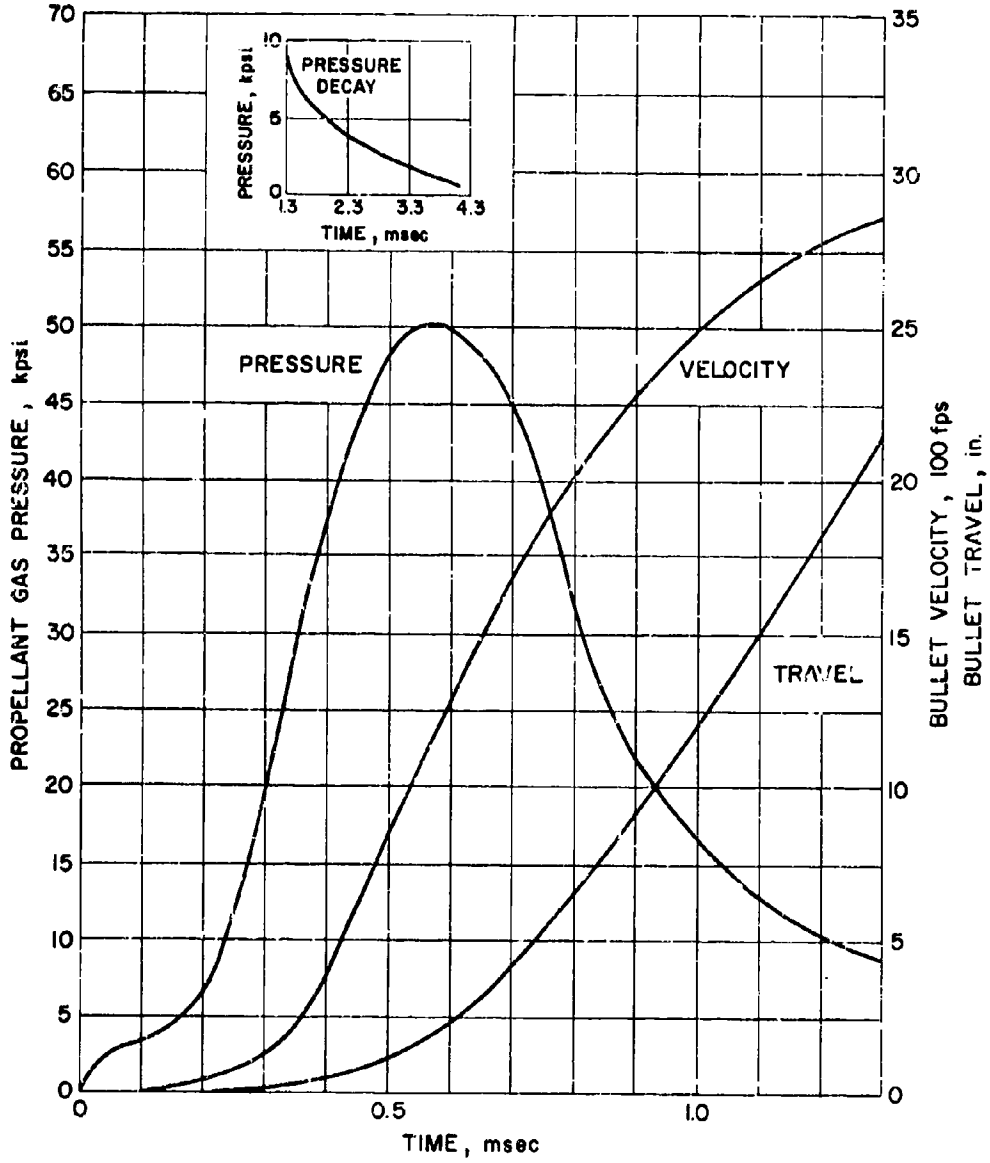


Figure 4–5. Pressure-time Curve of 7.62 mm Round

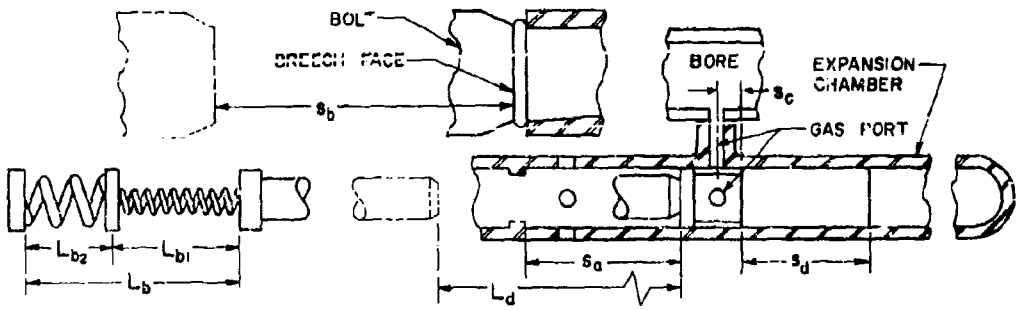


Figure 4–6. Operating Distances of Moving Parts

4–3.2.3 Counterrecoil Computed Data

From Eq. 4–24 the approximate maximum counterrecoil velocity is computed to be

$$v_{cr} = \frac{3.16\,L_b + 1.228\,L_d}{t_{cr}} = \frac{3.16 + 6.75}{0.036}$$

$$= 275 \text{ in./sec.}$$

From Eq. 4–20 the approximate counterrecoil velocity at the end of buffer spring action becomes

$$v_{bc} = 0.632\,v_{cr} = 174 \text{ in./sec.}$$

According to Eq. 2–24, by substituting F_a for $\left(F_m - \frac{1}{2}Kx\right)$ and L_d for x, the expression L_dF_a is

$$L_dF_a = \frac{1}{\epsilon}\left[\frac{1}{2}\left(M_r v_{cr}^2\right) - \frac{1}{2}\left(M_r v_{bc}^2\right)\right]$$

where v_{bc} is equivalent to v_o of Eq. 2–24.

F_a can now be determined.

$$M_r = \frac{W_r}{g}$$

g = 386.4 in./sec^2, acceleration of gravity

L_d = 5.5 in., operating distance of spring

$$5.5\,F_a = \frac{1}{0.5}\left(\frac{1}{2}\right)\left(\frac{3.25}{386.4}\right)(75625 - 30276)$$

$$F_a = 69.3 \text{ lb}$$

For the first trial a spring constant of 4 lb/in. was selected but proved to be too highly stressed. However, the first trial indicated a compression time of 16.6 msec. With an impact velocity above 25 ft/sec, the spring surge time is

$$T = \frac{T_c}{1.8} = \frac{0.0166}{1.8} = 0.0092 \text{ msec.}$$

According to Eq. 2–67b,

$$KT = \frac{F_m}{1037} = \frac{F_a + \frac{1}{2}\left(L_dK\right)}{1037}$$

$$0.0092K = \frac{69.3 + 2.75K}{1037}$$

$$K = 10.2 \text{ lb/in.}$$

$$F_m = F_a + \frac{1}{2}\left(KL_d\right) = 69.3 + 28.1 = 97.4 \text{ lb}$$

$$F_o = F_m - KL_d = 97.4 - 56.1 = 41.3 \text{ lb.}$$

For the buffer springs in series, the spring constant K_b is

$$K_b = 60 \text{ lb/in.}$$

$$L_b = 1.0 \text{ in.}$$

$$\frac{1}{2}\left(M_r v_{bc}^2\right) = \frac{1}{2}\left(F_{mb}L_b\right) - \frac{1}{4}\left(K_b L_b^2\right)$$

where $v_o = 0$, at the start of counterrecoil

$$\frac{1}{2} F_{mb} = \frac{1}{2}\left(\frac{3.25}{386.4}\right) 30{,}276 + \frac{1}{4}\left(60\right) 1.0$$

$$F_{mb} = 2(127.3 + 15) = 284.6 \text{ lb, say, } 285 \text{ lb}$$

$$F_{ob} = F_m - K_b L_b = 285 - 60 = 225 \text{ lb.}$$

Since the buffer springs in series should have the same terminal loads, spring constants will vary inversely as their deflections. Thus,

$$\frac{K_1}{K_2} = \frac{L_{b2}}{L_{b1}} = \frac{0.25}{0.75} \quad \text{or } K_2 = 3K_1$$

The spring constants of the primary and secondary springs of the buffer are

$$K_1 = \frac{F_{mb} - F_{ob}}{L_{b1}} = \frac{60}{0.75} = 80 \text{ lb/in.}$$

$$K_2 = 3K_1 = 240 \text{ lb/in.}$$

4-3.2.4 Counterrecoil Time

The counterrecoil time is divided into two periods, i.e., during buffer spring action and during driving spring action. Both are computed according to Eq. 2-26. For the buffer springs, $v_o = 0$ therefore

$$t_{bc} = \sqrt{\frac{M_r}{\epsilon K_b}}\left[\text{Sin}^{-1}\left(\frac{K_b L_b - F_{mb}}{F_{mb}}\right) - \frac{3\pi}{2}\right]$$

$$t_{bc} = \sqrt{\frac{2 \times 3.25}{386.4 \times 60}}\left[\text{Sin}^{-1}\left(\frac{1.0 \times 60 - 285}{285}\right) - \frac{3\pi}{2}\right]$$

$$= 0.01675\left[\text{Sin}^{-1}\left(-0.78947\right) - 4.7124\right]$$

$$= 0.01675\,(5.3733 - 4.7124) = 0.0111 \text{ sec.}$$

From Eq. 2-24, the buffer counterrecoil velocity is expressed in terms of spring energy.

$$v_{bc}^2 = \frac{F_{mb}L_b - \frac{1}{2}\left(K_b L_b^2\right)}{M_r}$$

$$= \frac{(285 \times 1.0 - 30 \times 1.0)386.4}{3.25}$$

$$v_{bc}^2 = \frac{255 \times 386.4}{3.25} = 30318 \text{ in.}^2/\text{sec}^2$$

$$v_{bc} = 174.1 \text{ in./sec, buffer counterrecoil velocity}$$

which checks favorably with the first computed velocity of 174 in./sec

The time consumed for counterrecoil during driving spring action also is divided into two periods, when the total recoiling mass is considered, and after the bolt stops when the moving mass consists only of the moving parts of the operating rod unit. According to Eq. 2-26, the first time component is

$$t'_{cr} = \sqrt{\frac{M_r}{\epsilon K}}\left[\text{Sin}^{-1}\left(\frac{Ks_b - F_m}{\sqrt{F_m^2 + 2KM_r v_{bc}^2}}\right) - \text{Sin}^{-1}\left(\frac{-F_m}{\sqrt{F_m^2 + 2KM_r v_{bc}^2}}\right)\right]$$

$$t'_{cr} = \sqrt{\frac{3.25}{386.4 \times 0.5 \times 10.2}}\left[\text{Sin}^{-1}\ \frac{10.2 \times 4.5 - 97.4}{\sqrt{9487 + 5202}} - \text{Sin}^{-1}\ \frac{-97.4}{\sqrt{9487 + 5202}}\right]$$

$$= 0.04061\left[\text{Sin}^{-1}(-0.4249) - \text{Sin}^{-1}(-0.8036)\right]$$

$$= 0.04061\ (334.85 - 306.52)/57.3 = 0.04061 \times 0.4944 = 0.0201 \text{ sec}$$

where

F_m = 97.4 lb $\qquad$ s_b = 4.5 in.

K = 10.2 lb/in. $\qquad$ v_{bc}^2 = 30,318 in.^{2}/sec^2

$M_r = \frac{3.25}{386.4}$ lb-sec^2/in. $\qquad$ ϵ = 0.50

According to Eq. 2-24, the expression for the counterrecoil velocity is

$$v_{cr}^2 = v_{bc}^2 + \frac{2\epsilon\left[(F_m s_b - \frac{1}{2}\left(Ks_b^2\right)\right]}{M_r}$$

$$= 30318 + \frac{97.4 \times 4.5 - 10.2 \times 20.25/2}{3.25}\ 386.4$$

$$= 30318 + 39832 = 70150 \text{ in.}^2/\text{sec}^2$$

v_{cr} = 264.9 in./sec = 22.08 ft/sec, maximum bolt velocity on return.

The terminal part of the counterrecoil stroke occurs after the bolt is in battery and the operating rod components are the remaining moving parts. From Eq. 2-26, the second time component is

$$t''_{cr} = \sqrt{\frac{M_o}{\epsilon K}}\left[\text{Sin}^{-1}\ \frac{K(L_d - s_b) - F_m}{\sqrt{F_m^2 + 2KM_o v_o^2}} - \text{Sin}^{-1}\ \frac{-F_m}{\sqrt{F_m^2 + 2KM_o v_o^2}}\right]$$

$$t''_{cr} = \sqrt{\frac{2.5}{386.4 \times 0.5 \times 10.2}} \left[\text{Sin}^{-1} \frac{-41.3}{\sqrt{2652 + 9258}} - \text{Sin}^{-1} \frac{-51.5}{\sqrt{2652 + 9258}} \right]$$

$$= 0.03562 \left[\text{Sin}^{-1} (-0.3784) - \text{Sin}^{-1} (-0.4719) \right]$$

$$= 0.03562 (337.77 - 331.85)/57.3 = 0.0037 \text{ sec}$$

where

$F_{ri} = 51.5$ lb

$F_D = 41.3$ lb

$K = 10.2$ lb/in.

$L_d = 5.5$ in.

$M_o = \frac{2.5}{386.4}$ lb-sec^2/in.

$s_b = 4.5$ in.

$v'^2_o = 70147$ in.^{2}/sec^2

$\epsilon = 0.50$

The total counterrecoil time is

$$t_{cr} = t_{bc} + t'_{cr} + t''_{cr} = 0.0349 \text{ sec.}$$

This computed time compares favorably with the assigned time (0.036 sec) for counterrecoil thus supporting the characteristics of the selected spring.

At the end of counterrecoil the velocity of the operating rod moving parts, according to Eq. 2–24 is

$$v_{cr} = \sqrt{v_o^2 + 2\epsilon \left[F_m (L_d - s_b) - \frac{1}{2} K (L_d - s_b)^2 \right] / M_o}$$

$$= \sqrt{70147 + (51.5 \times 1.0 - 10.2 \times 1.0/2) 386.4/2.5}$$

$$= \sqrt{77318} = 278 \text{ in./sec} = 23.08 \text{ ft/sec} = 277 \text{ in./sec}$$

which checks with the first computed velocity of 275 in./sec.

4–3.2.5 Recoil Time

The dynamics of the operating rod and bolt while propellant gases are active in the gas cylinder do not include the resistance of the driving spring since the spring forces are negligible as compared to gas forces. With respect to the dynamics, two periods are involved, i. e., accelerating and decelerating. Initially, the time of each is proportioned according to their respective distance of operation. The decelerating time is computed to be

$$t_d = \left(\frac{L_d + L_b - s_a}{L_d + L_b}\right) t_r = \left(\frac{5.5 + 1.0 - 2.0}{5.5 + 1.0}\right) 0.024$$

$$= 0.0166 \text{ sec}$$

where t_r = 0.024 sec (see par. 4–3.2.2) and

where s_a = 2.0 in., the distance that the piston moves while being accelerated by the propellant gas.

The counterrecoil velocity at this position is computed according to Eq. 2–24

$$v_{cr} = \sqrt{v_{bc}^2 + 2\epsilon \left[F_m(L_d - s_a) - \frac{1}{2} K(L_d - s_a)^2\right] / M_r}$$

$$= \sqrt{30318 + (97.4 \times 3.5 - 10.2 \times 12.25/2)386.4/3.25}$$

$$= 251.8 \text{ in./sec.}$$

From Eq. 4–34, the velocity of recoil at this position becomes

$$v_r = \frac{1}{\epsilon} v_{cr} = \frac{251.8}{0.5} = 503.6 \text{ in./sec.}$$

4–3.2.5.1 *Recoil Time, Decelerating*

As computed above, the recoil velocity at the end of the operating cylinder stroke is 503.6 in./sec which becomes the initial velocity of the spring system as deceleration begins. At this time the driving spring has been compressed to the extent of the two inches that the operating gas piston has traveled. The design data include

F_{sa} = 41.3 + Ks_a = 41.3 + 20.4 = 61.7 lb

K = 10.2 lb/in., spring constant

M_r = 3.25/g, lb-sec^2/in.

s_a = 2.0 in.

v_o = 503.6 in./sec, initial velocity

ϵ = 0.5, efficiency of spring system

The working distance of the drive spring during the decelerating period of recoil is L_r.

$$L_r = L_d - s_a = 5.5 - 2.0 = 3.5 \text{ in.}$$

Expand Eq. 2–22 to include the limits of $x = 0$ to $x = L_r$, thus the time to compress the drive spring is

$$t_{dr} = \sqrt{\frac{\epsilon M_r}{K}} \left(\text{Sin}^{-1} \frac{F_{sa} + KL_r}{\sqrt{F_{sa}^2 + \epsilon K M_r v_o^2}} - \text{Sin}^{-1} \frac{F_{sa}}{\sqrt{F_{sa}^2 + \epsilon K M_r v_o^2}} \right)$$

$$= \sqrt{0.0004123} \left(\text{Sin}^{-1} \frac{97.4}{121.2} - \text{Sin}^{-1} \frac{61.7}{121.2} \right)$$

$$= 0.0081 \text{ sec.}$$

The velocity of the recoiling parts as the buffer is contacted is

$$v_b^2 = v_o^2 - \frac{(2F_{sa} + KL_r)L_r}{\epsilon M_r}$$

$$= 253613 - \frac{159.1 \times 3.5 \times 386.4}{0.50 \times 3.25}$$

$$v_b = \sqrt{253613 - 132410} = \sqrt{121203} = 348.1 \text{ in./sec.}$$

Since the buffer absorbs the remaining energy,

$$\sqrt{F_{ob}^2 + \epsilon K_b M_r v_b^2} = F_{mb},$$

therefore, Eq. 2–23 becomes the expression for recoil time during buffing,

$$t_b = \sqrt{\frac{\epsilon M_r}{K}} \cos^{-1} \frac{F_{ob}}{F_{mb}} = \sqrt{\frac{0.5 \times 3.25}{60 \times 386.4}} \cos^{-1} \frac{225}{295}$$

$$= 0.00837 \cos^{-1} 0.78947 = 0.00837 \left(\frac{37.89}{57.3}\right)$$

$$= 0.0055 \text{ sec.}$$

The total recoil time during deceleration

$$t_r' = t_{dr} + t_b = 0.0081 + 0.0055 = 0.0136 \text{ sec.}$$

4–3.2.5.2 Recoil Time, Accelerating

The time needed to accelerate the recoiling mass consists of two parts, i. e., time before cutoff and time after cutoff. First, the tentative size of the operating cylinder must be determined. According to Eq. 4–40, the work done by the expanding gas is

$$p_1 V_1 = 1.06 M_r v_r^2 = 1.06 \left(\frac{3.25}{386.4}\right) 253613$$

$$= 2261 \text{ in.-lb}$$

Select $p_1 = 1250$ lb/in.^{2}

$$V_1 = \frac{p_1 V_1}{p_1} = \frac{2261}{1250} = 1.8 \text{ in.}^3$$

With the ratio $\frac{V_1}{V_2} = \frac{3}{5}$, the volume at the end of the gas expansion stroke is V_2.

$$V_2 = \frac{5}{3} V_1 = \left(\frac{5}{3}\right) 1.8 = 3.0 \text{ in.}^3$$

The selected cylinder pressure is $p_c = p_1 = 1250$ psi. Assume this pressure to be the critical flow pressure. Therefore, the average pressure in the barrel needed to provide it is, according to Eq. 4–26,

$$p_a = \frac{p_c}{0.53} = 2360 \text{ lb/in.}^2$$

Other values are

k = 1.3, ratio of specific heats in operating cylinder

k_b = 1.2, ratio of specific heats in bore

p_m = 9000 lb/in.^{2}, muzzle pressure from Fig. 4–5

V_{co} = V_1 = 1.8 in.^{3}, initial volume of operating cylinder

V_m = 1.74 in.^{3}, chamber volume plus bore volume

W_g = 0.00629 lb, weight of propellant

The weight of the gas in the operating cylinder at its maximum pressure, according to Eq. 4–49, is

$$W_c = W_g \left(\frac{V_{co}}{V_m}\right) p_c^{1/k} p_a^{(1/k_b - 1/k)} / p_m^{1/k_b}$$

$$= 0.00629 \left(\frac{1.8}{.74}\right) \left(\frac{241 \times 1.56}{1970}\right) = 0.00132 \text{ lb.}$$

To insure total access, the diameter of the orifice should not exceed the cutoff distance; thus the two orifices of 0.162 in. diameter.

The measured area under the pressure-time curve between 0.0002 sec and 0.0032 sec is equivalent to $A_{pt} = 16.43$ lb-sec/in.^{2} The first time (0.0002 sec) represents approximately 70% of the bullet travel and the second corresponds with the pressure, $p_a = 2360$ psi. From Eq. 4–52, the first estimate of the orifice area is

$$A_o = \frac{W_c}{K_w A_{pt}} \qquad \frac{0.00132}{0.00192 \times 16.43} = 0.042 \text{ in.}^2$$

where, in Eq. 4–25, the expression for the term K_w is

$$K_w = C\sqrt{\frac{g}{RT}\,k\left(\frac{2}{k+1}\right)^{(k+1)/(k-1)}}$$

$$= 0.00192/\text{sec}$$

C = 0.30, orifice coefficient

g = 32.2 ft/sec^2

k = 1.3

RT = 350,000 ft-lb/lb, specific impetus

With $A_O = 0.042$ in.^{2} detailed iterative computations are performed in Table 4–1. These calculations indicate a cutoff at $s = 0.20$ in. of piston travel. Also, an orifice area of 0.042 in.^{2} seems sufficient. A piston area of 0.60 in.^{2} is suitable. Note that in the listed values of the cylinder pressure p_c never exceeds the critical flow pressure of $p_{cr} = 0.53\ p_a$ except for the last increment. Here the computed pressure of 1134 psi via Eq. 4–43 is considered reasonable inasmuch as the pressure of polytropic expansion during the interval drops only to 1105 psi and the continued flow from the barrel should be enough so that the cylinder pressure will approach the 1134 psi.

TABLE 4–1. COMPUTED DYNAMICS OF GAS CUTOFF SYSTEM

$t \times 10^4$, sec	p_a, psi	A_O, in.^{2}	w, lb/sec	$\Delta W_a \times 10^4$, lb	$W_c \times 10^4$, lb	V_b, in.^{3}	V_e, in.^{3}	$V_{c'}$, in.^{3}
9	26000	0.042	2.096	2.096	2.096	0.837	0.0278	1.8000
10	19000	0.042	1.531	1.531	3.627	0.942	0.0543	1.8002
11	14800	0.042	1.193	1.193	4.820	1.147	0.0879	1.8003
12	11400	0.042	0.919	0.919	5.739	1.366	0.1246	1.8006
13	9600	0.042	0.774	0.774	6.513	1.600	0.1657	1.8011
18	6600	0.042	0.532	2.660	9.173	2.255	0.329	1.8080
23	4500	0.042	0.363	1.815	10.988	3.120	0.545	1.8236
28	3200	0.037	0.227	1.135	12.123	4.130	0.796	1.850
33	2400	0.025	0.115	0.575	12.698	5.240	1.058	1.888
36.31	1800	0.007	0.024	0.088	12.786	6.650	1.350	1.920

$t \times 10^4$, sec	$p_{c'}$, psi	$F_{c'}$, lb	$F_c \Delta t$, lb-sec	Δv, in./sec	v, in./sec	$s_1 \times 10^4$, in.	$s_2 \times 10^4$, in.	$s \times 10^4$, in.
9	114	69	0.0069	0.82	0.82	0	0	0
10	202	121	0.0121	1.44	2.26	1	1	2
11	294	176	0.0176	2.09	4.35	1	2	5
12	354	212	0.0212	2.52	6.87	1	4	10
13	425	255	0.0255	3.03	9.90	2	7	19
18	717	430	0.2150	25.56	35.46	64	50	133
23	934	560	0.280	33.29	68.75	83	177	393
28	1069	641	0.321	38.17	106.9	95	344	832
33	1128	677	0.339	40.31	147.2	101	535	1468
36.31	1134	680	0.225	26.75	174.0	44	487	1999

At cutoff, the velocity of the moving parts has reached 174 in./sec. This represents a kinetic energy of

$$E_c = \frac{1}{2}\left(Mv^2\right) = \frac{1}{2}\left(\frac{3.25}{386.4}\right) 30276 = 127.3 \text{ in.-lb.}$$

The work done by polytropic expansion, Eq. 4–35, is

$$W = \frac{p_1 V_1 - p_2 V_2}{k - 1} = \frac{1134 \times 1.92 - 635 \times 3.0}{1.3 - 1.0}$$

$$= 907.6 \text{ in.-lb}$$

where

$$p_2 = p_1 \left(\frac{V_1}{V_2}\right)^k = 1134 \left(\frac{1.92}{3}\right)^{1.3}$$

$$= 1134 \times 0.56 = 635 \text{ lb/in.}$$

$$V_1 = V_{co} + A_c s = 1.8 + 0.6 \times 0.2 = 1.92 \text{ in.}^3$$

The total work done by the operating cylinder is

$$E_r = E_c + W = 127.3 + 907.6 = 1034.9 \text{ in.-lb}$$

The velocity of the system at the end of the accelerating period becomes

$$v_r = \sqrt{\frac{2E_r}{M_r}} = \sqrt{\frac{2069.8 \times 386.4}{3.25}} = 496.07 \text{ in./sec.}$$

This velocity compares favorably with the required velocity of 503.6 in./sec (par. 4–3.2.5) and represents an error of only 1.5%. A slight increase in orifice area or location will match the two velocities, but the small error involved does not warrant further computation.

Although the weight of recoiling parts does not become 3.25 lb until the bolt is picked up after ⅛ inch of travel, the bolt weight is included to compenstate for whatever losses are experienced during the accelerating stroke.

The analysis which follows for the time, $t = 2.8 \times 10^{-3}$ sec, illustrates the mechanics for computing the results listed in Table 4–1. The increment of time $\Delta t = 0.0005$ sec and the corresponding average pressure are read from the pressure decay-time curve (see insert) of Fig. 4–5, $p_a = 3200$ psi. Resorting to Eq. 4–57 to estimate the travel during the interval, observe that Δv is unknown. However, in the preceding interval, the difference in Δv

$$[\Delta v \text{ for } (t = 2.3 \times 10^{-3})] - [\Delta v \text{ for } (t = 1.8 \times 10^{-3})]$$

< 8 in./sec. Add this increment to Δv $(t = 2.3 \times 10^{-3})$. Thus, $\Delta v = 33 + 7 = 40$ in./sec.

The rate of flow by Eq. 4–27 is computed to be

$$w = K_w A_o p_a = 0.00192 \times 0.037 \times 3200$$

$$= 0.227 \text{ lb/sec.}$$

The weight of the gas flowing through the orifice during the 0.0005 sec increment according to Eq. 4–28 is

$$\Delta W_c = w\Delta t = 0.227 \times 5 \times 10^{-4} = 1.135 \times 10^{-4} \text{ lb.}$$

The total weight of the gas in the cylinder

$$W_c = \Sigma \Delta W_c = W_{c(n-1)} + \Delta W_c$$

$$= (10.988 + 1.135)10^{-4} = 0.0012123 \text{ lb.}$$

By first trial, the distance traveled by the operating unit (Eq. 4–47) is

$$s = \frac{1}{2}\Delta v \Delta t + v_{n-1}\Delta t + s_{n-1}$$

$$= \frac{40}{2}\left(0.0005\right) + 68.75 \times 0.0005 + 0.0393$$

$$= 0.0837 \text{ in.}$$

From Eq. 4–48, the cylinder volume

$$V_c = V_{co} + A_c s = 1.8 + 0.6 \times 0.0837 = 1.850 \text{ in.}^3$$

According to Eq. 4–41,

$$V_b = V_{in}\left(\frac{p_m}{p_a}\right)^{1/k_b} = 1.74\left(\frac{3000}{3200}\right)^{1/1.3}$$

$$= 1.74 \times 2.37 = 4.13 \text{ in.}^3$$

From Eq. 4–42, the equivalent gas volume in the operating cylinder at the average bore pressure p_a becomes

$$V_e = \left(\frac{W_c}{W_g}\right)V_b = \left(\frac{0.0012123}{0.00629}\right)4.13 = 0.796 \text{ in.}^3$$

From Eq. 4–43, the gas pressure in the operating cylinder is

$$p_c = \left(\frac{V_e}{V_c}\right)^k p_a = \left(\frac{0.796}{1.850}\right)^{1.3} 3200$$

$$= 0.334 \times 3200 = 1069 \text{ lb/in.}^2$$

The gas force applied to the operating rod, Eq. 4–44, is

$$F_c = A_c p_c = 0.6 \times 1069 = 641 \text{ lb.}$$

The impulse during the interval is

$$F_c \Delta t = 641 \times 0.0005 = 0.321 \text{ lb-sec.}$$

The velocity at the end of the time interval. Eq. 4–46, is

$$v = v_{n-1} + \frac{F_c \Delta t}{M_r} = 68.75 + \frac{0.321 \times 386.4}{3.25}$$

$$= 68.75 + 38.17 = 106.9 \text{ in./sec.}$$

The distance traveled by the operating unit, Eq. 4–47, is

$$s = \frac{1}{2}\left(\Delta v \Delta t\right) + v_{n-1}\Delta t + s_{n-1}$$

$$= \left(\frac{38.17}{2} + 68.75\right) 0.0005 + 0.0393$$

$$= 0.0095 + 0.0344 + 0.0393 = 0.0832 \text{ in.}$$

From Eq. 4–48, the chamber volume is

$$V_c = V_{co} + A_c s = 1.8 + 0.6 \times 0.0832 = 1.850 \text{ in.}^3$$

This volume matches the earlier estimate thereby completing this series of calculations. Had the volumes not checked, a new change in volume would be investigated and the series of calculations repeated.

The time elapsed between firing and complete cutoff is the final figure (36.31) in the time column of Table 4–1.

$$t_{co} = 0.0036 \text{ sec.}$$

The time of the remaining accelerating period is determined by Eqs. 4–14 and 4–15. The known data follow:

A_c = 0.60 in.^{2}, area of operating piston

k = 1.3, ratio of specific heats

$M_r = \frac{3.25}{386.4}\ \frac{\text{lb-sec}^2}{\text{in.}}$, mass of recoiling unit

p_1 = 1134 lb/in.^{2}, initial pressure

s = 1.8 in., total travel of piston

s_o = 3.2 in., equivalent travel distance at p_1

v_o = 174 in./sec, initial velocity

Substitute the expression for C_2, Eq. 4–15, in Eq. 4–14, and rewrite, for convenience, the time for the gas expansion stroke

$$t_c = \frac{s_o^{(k+1)/2}}{\sqrt{K_a}} \left[\left(a + \Sigma A_y \frac{a^z}{zB^y} \right) - \left(1 + \Sigma \frac{A_y}{zB^y} \right) \right]$$

$$t_e = \frac{3.81}{1563} (4.658 - 2.763) = 0.0046 \text{ sec}$$

where

$$a = 1 + \frac{s}{s_o} = 1 + \frac{1.8}{3.2} = 1.562$$

$$K_a = \frac{2A_c p_1 s_o^k}{(k-1)M_r} = \frac{2 \times 0.6 \times 1134 \times 4.53 \times 386.4}{(1.3 - 1)\,3.25}$$

$$= 2{,}443{,}000 \text{ in.}^2/\text{sec}^2$$

$$\sqrt{K_a} = 1{,}563 \text{ in./sec}$$

$$B = 1 + \frac{v_o^2}{K_a} s_o^{k-1} = 1 + \frac{30276 \times 1.418}{2443000} = 1.018$$

$$s_o^{(k+1)/2} = 3.2^{1.15} = 3.81$$

$$y = 1, 2, 3 \ldots\ldots$$

$$z = (y + 1) - yk = 1.0 - 0.3y$$

$\Sigma A_y \frac{a^z}{zB^y}$ = 3.0959 (summation of last column in Table 4–2)

$\Sigma \frac{A_y}{zB^y}$ = 1.763 (summation of next to last column in Table 4–2)

The detailed calculations are tabulated for convenience in Table 4–2.

The total recoil time is

$$t_r = t_{co} + t_e + t_r'$$

$$= 0.0036 + 0.0046 + 0.0136 = 0.0218 \text{ sec.}$$

This is only 2.2 msec less that the specified 24 msec (par. 4–3.2.1) and, therefore, is acceptable. The time for the firing cycle is

$$t_c = t_{cr} + t_r = 0.0349 + 0.0218 = 0.0567 \text{ sec.}$$

The rate of fire is

$$f_r = \frac{60}{t_c} = 1058 \text{ rounds/min.}$$

This rate is only 5.8% over the specified rate of 1000 (par. 4–3.2.1) and is acceptable. Firing tests will determine the accuracy of the theoretical rate and any undesirable discrepancies are to be corrected in compliance with the test data.

4–3.3 DIGITAL COMPUTER ROUTINE FOR CUTOFF EXPANSION

This digital computer program is compiled in FORTRAN IV language for the UNIVAC 1107 Computer. The program considers the dynamics of the gas, the bolt operating cam, the bolt, and the operating rod. The specified and computed data are the same as those for the sample problem of par. 4–3.2. The program also follows the same sequence of computations except for the inclusions of the bolt unlocking and locking processes. Each set of computations is discussed in sequential order.

4–3.3.1 Gas Dynamics Before Cutoff

This analysis follows the same procedure as that for the preceding example of Table 4–1 except that the bolt is being turned by the helix portion of the cam. Bolt frictional and rotational inertia forces are considered by substituting the effective mass of Eq. 4–62 for the actual mass of the operating rod. At gas cutoff, the operating rod velocity is set for approximately 350 in./sec and to reach this velocity, the gas port is assigned an initial area of 0.40 in.^{2} If the computed velocity at gas cutoff exceeds ±10 in./sec, the port area is adjusted accordingly and the

TABLE 4–2. GAS EXPANSION TIME CALCULATIONS

y	A_y	B^y	z	a^z	zB^y	A_y/zB^y	$A_y a^z/zB^y$
1	0.5000	1.018	0.7	1.366	0.713	0.7013	0.9580
2	0.3750	1.036	0.4	1.195	0.414	0.9058	1.0824
3	0.3125	1.055	0.1	1.045	0.106	2.9481	3.0808
4	0.2734	1.074	-0.2	1/1.093	-0.215	-1.2716	-1.1634
5	0.2461	1.093	-0.5	1/1.25	-0.547	-0.4490	-0.3599
6	0.2256	1.113	-0.8	1/1.428	-0.890	-0.2535	-0.1775
7	0.2095	1.134	-1.1	1/1.634	-1.247	-0.1680	-0.1028
8	0.1964	1.154	-1.4	1/1.868	-1.615	-0.1216	-0.0651
9	0.1855	1.175	-1.7	1/2.14	-1.998	-0.0928	-0.0434
10	0.1762	1.196	-2.0	1/2.44	-2.392	-0.0736	-0.0302
11	0.1682	1.217	-2.3	1/2.79	-2.799	-0.0601	-0.0215
12	0.1612	1.238	-2.6	1/3.19	-3.219	-0.0501	-0.0157
13	0.1550	1.261	-2.9	1/3.65	-3.657	-0.0424	-0.0116
14	0.1495	1.284	-3.2	1/4.17	-4.109	-0.0364	-0.0087
15	0.1445	1.307	-3.5	1/4.76	-4.574	-0.0316	-0.0066
16	0.1400	1.331	-3.8	1/5.45	-5.058	-0.0277	-0.0051
17	0.1359	1.355	-4.1	1/6.22	-5.556	-0.0245	-0.0039
18	0.1321	1.380	-4.4	1/7.11	-6.072	-0.0218	-0.0030
19	0.1286	1.404	-4.7	1/8.12	-6.599	-0.0195	-0.0024
20	0.1254	1.429	-5.0	1/9.30	-7.145	-0.0176	-0.0019
21	0.1224	1.455	-5.3	1/10.65	-7.712	-0.0159	-0.0015
22	0.1196	1.481	-5.6	1/12.2	-8.294	-0.0144	-0.0011
						$\Sigma = 1.7631$	$\Sigma = 3.0959$

computation is repeated. Operating rod travel is also computed and should not exceed the axial length of the cam helix. Table 4–5 lists the computed data.

4–3.3.2 Gas Dynamics After Cutoff

4–3.3.2.1 Bolt Unlocking During Helix Traverse

If a portion of the helix remains to be traversed by the cam follower, the time is computed according to Eqs. 4–6 through 4–15. This procedure was also used to compute the values of Table 4–2. The velocity at the end of the helix is obtained from Eq. 4–7. Although the bolt moves axially over the small distance permitted by the locking lug, the effects of this distance and corresponding velocity have a negligible effect on the dynamics of the system and, therefore, are not included in the analysis. Computed data are listed in Table 4–6.

4–3.3.2.2 Bolt Unlocking During Parabola Traverse

The major part of the unlocking process is done by the parabolic portion of the cam (see Figs. 4–3 and 4–4). For the same reason as for the helix analysis, only bolt rotational effects are considered. The axial length of the parabola is divided into short equal increments. Cam curve characteristics are then determined and these are integrated with the rest of the analysis. The equivalent mass of the system is found from Eq. 4–73. The cam constants and variables are determined elsewhere (see par. 4–3.1).

TABLE 4–3. SYMBOL-CODE CORRELATION FOR CUTOFF EXPANSION

Symbol	Code	Symbol	Code	Symbol	Code
A_o	AO	p_a	PA	V_c	VC
A_c	AC	p_c	PC	V_{co}	VCYL
A_y	AY	p_1	P1	V_e	VE
a	A	R	R	v	V
a^2	AZ	R_c	RC	v_{bc}	VBCR
B^y	BY	R_L	RL	v_m	VMAX
C_λ	CLAMDA	s	S	v_o	VO
dx	DX	s_a	SA	v_{sc}	VSCR
E_b	EB	s_c	SCYL	Δv	DELV
E_{bc}	EBCR	s_m	SMAX	W_b	WB
E_{cr}	E	s_o	SO	W_c	WC
E_r	ER	$s_r - x_m$	HELIX1	ΔW_c	DELW
E_{sc}	ESCR	$s_{(1)}$	S(1)	W_o	WO
F	F	s_1	S1	w	W
F_{mb}	FBM	s_2	S_2	x	X
F_{ob}	FBO	t	TEP	x_m	HELIX2
ΔF	DELF	t_{bc}	TBRC	y	Y
g	G	t_{br}	TBR	z	Z
K	DRK	t_{cr}	TDCR	β	B
K_a	SKA	t_{dr}	TDR	ϵ	EPS
K_b	BK	$t_{(1)}$	T1	λ	DLAMDA
k	RADGYR	Δt	DELT	μ_r	EMUR
L_b	BL	$\tan\beta_o$	TANBO	μ_s	EMUS
M_e	EM	V	VB		

x_m = 0.5 in., axial length of parabola (Eq. 4–77)

y_m = 0.3327 in., peripheral width of parabola (Eq. 4–77)

A = 1.3161 in. (Eq. 4–77)

B = 0.007465 in. (Eq. 4–77)

$y = Ax^2 + Bx = 1.316x^2 + 0.007465x$ (Eq. 4–75)

$\frac{dy}{dx} = 2Ax + B = 2.632x + 0.007465$ (Eq. 4–76);

$\tan\beta = \frac{dy}{dx}$

At any given position of x,

$$x = \Sigma\Delta x = x_{n-1} + \Delta x$$

the corresponding length of the gas cylinder is

$$s = s_o + x = 3.5 + x \text{ , in.}$$

The operating cylinder pressure, according to Eq. 4–2, becomes

$$p_c = p_1\left(\frac{s_o}{s}\right)^k = p_1\left(\frac{3.5}{s}\right)^{1.3} \text{ ,psi}$$

According to Eq. 4–7, the velocity at the end of each increment of travel is

$$v = \sqrt{4\left(\frac{p_1}{M_e}\right)\left(3.5 - \frac{5.09675}{3.5 + s^{0.3}}\right) + v_o^2}\ , \text{in./sec.}$$

The corresponding time interval and total time are

$$\Delta t = \frac{\Delta x}{v_a}\ , \text{sec}; \quad t = \Sigma \Delta t, \text{sec}$$

where

v_a = average velocity over the increment.

Computed data are listed in Table 4–7.

4–3.3.2.3 Bolt Unlocked, Bolt Traveling With Operating Rod

At the time that the bolt is completely unlocked, bolt and operating rod begin to travel as a unit. However, one inch of operating rod travel still remains under the influence of cylinder pressure. Except for the initial conditions involving velocity, pressure, distance, and mass; the analytic procedure is the same as mentioned in par. 4–3.3.2.1. Only linear motion prevails since cam action is complete; therefore the mass of the bolt is no longer influenced by rotational effects. Now the bolt and operating rod are moving as a unit at the same velocity; the bolt acquired its initial velocity just as unlocking became complete. As all of the momentum just prior to this event was concentrated in the operating rod, some of it was transferred to the bolt with a subsequent reduction in velocity. Based on the law of conservation of momentum, this velocity is the velocity of the recoiling parts and has the value

$$v_r = \frac{M_o v_o}{M_r} = \frac{2.5\, v_o}{3.25}\ , \text{in./sec.}$$

where

$M_o = W_o/g$, mass of operating rod

$M_r = W_r/g$, mass of recoiling parts

v_o = velocity of operating rod at transition

Table 4–8 has the computed data.

TABLE 4–4. INPUT FOR CUTOFF EXPANSION PROGRAM

Code	Data	Code	Data
AC	0.60	RL	0.5
BK	60.0	SA	2.0
DELV(1)	0.5	SCYL	3.0
DLAMDA	3	SMAX	5.0
DRK	10.2	SO	3.5
DX	0.05	S(1)	0
EMUR	0.034	TANBO	0.007465
EMUS	0.3	T(1)	0.8
EPS	0.5	VCYL	1.8
G	386.4	VMAX	350
HELIX1	0.5	V(1)	0
HELIX2	0.5	WB	0.75
R	0.39	WC1	0
RADGYR	0.275	WO	2.5
RC	0.32		

TABLE 4-5. COMPUTED DYNAMICS BEFORE GAS CUTOFF

I	TIME MSEC	PRESS PSI	PORT AREA SQ-IN	GAS FLOW RATE LB/SEC	GAS IN CYL LB	EQUIV BORE VOL CU-IN	EQUIV CYL VOL CU-IN
2	.900	26000.	.0580	2.895	.00029	.837	.0385
3	1.000	19000.	.0580	2.116	.00050	.932	.0743
4	1.100	14000.	.0580	1.648	.00067	1.147	.1214
5	1.200	11400.	.0580	1.270	.00079	1.366	.1722
6	1.300	9600.	.0580	1.069	.00090	1.600	.2289
7	1.800	6600.	.0580	.735	.00127	2.255	.4543
8	2.300	4500.	.0580	.501	.00152	3.120	.7529
9	2.800	3200.	.0530	.326	.00168	4.130	1.1035
10	3.300	2400.	.0410	.189	.00178	5.240	1.4788
11	3.665	1800.	.0230	.079	.00180	6.650	1.9074

I	CYL VOL CU-IN	CYL PRESS PSI	PISTON FORCE LB	IMPULSE LB-SEC	DELTA VEL IN/SEC	ROD VEL IN/SEC	ROD TRAVEL IN
2	1.8000	175.5	105.4	.011	1.63	1.6	.0001
3	1.8002	301.1	180.7	.018	2.79	4.4	.0004
4	1.8006	444.5	266.7	.027	4.12	8.5	.0010
5	1.8013	538.8	323.3	.032	5.00	13.5	.0021
6	1.8023	656.4	393.9	.039	6.09	19.6	.0038
7	1.8157	1089.8	653.9	.327	50.53	70.2	.0262
8	1.8456	1401.8	841.1	.421	65.00	135.2	.0776
9	1.8981	1581.0	948.6	.474	73.31	208.5	.1635
10	1.9721	1650.7	990.4	.495	76.54	285.0	.2869
11	2.0406	1648.7	989.2	.361	55.81	340.8	.4011

4-3.3.3 Dynamics After Gas Cylinder Operation

After the gas cylinder reaches its total displacement, the recoiling parts, consisting of operating rod and bolt, have only the driving and buffer springs to provide the external forces. These springs stop the recoiling parts and then force them to counterrecoil: the driving spring and momentum of the moving mass finally lock the bolt in the firing position.

Computed spring operating data appear in Table 4-6 and the computed locking data are listed in Table 4-9.

4-3.3.3.1 Recoil Dynamics

The remaining distance for bolt and rod to compress the driving spring fully is

$$L_r = L_d - s_a = 5.5 - 2.0 = 3.5 \text{ in.}$$

The energy to be absorbed by the driving and buffer springs is

$$E_r = 1/2\, M'_r v^2_{sa} \text{ in.-lb}$$

TABLE 4–6. COMPUTED DYNAMICS AFTER GAS CUTOFF
BOLT UNLOCKING DURING HELIX TRAVERSE

Y	AY	BY	Z	AZ	ZBY	QUOT1	QUOT2
1.0	.5000	1.0335	.7	1.0203	.7235	.6911	.7051
2.0	.3750	1.0681	.4	1.0115	.4273	.8777	.8878
3.0	.3125	1.1039	.1	1.0029	.1104	2.8308	2.8389
4.0	.2734	1.1409	-.2	.9943	-.2282	-1.1982	-1.1913
5.0	.2461	1.1792	-.5	.9858	-.5896	-.4174	-.4115
6.0	.2256	1.2187	-.8	.9773	-.9749	-.2314	-.2262
7.0	.2095	1.2595	-1.1	.9690	-1.3855	-.1512	-.1465
8.0	.1964	1.3017	-1.4	.9607	-1.8224	-.1078	-.1035
9.0	.1855	1.3453	-1.7	.9524	-2.2871	-.0811	-.0773
10.0	.1762	1.3904	-2.0	.9443	-2.7808	-.0634	-.0598
11.0	.1682	1.4370	-2.3	.9362	-3.3051	-.0509	-.0476
12.0	.1612	1.4851	-2.6	.9282	-3.8614	-.0417	-.0387
13.0	.1550	1.5349	-2.9	.9202	-4.4512	-.0348	-.0320
14.0	.1495	1.5863	-3.2	.9123	-5.0763	-.0295	-.0269
15.0	.1445	1.6395	-3.5	.9045	-5.7383	-.0252	-.0228
16.0	.1400	1.6944	-3.8	.8968	-6.4389	-.0217	-.0195
17.0	.1359	1.7512	-4.1	.8891	-7.1800	-.0189	-.0168
18.0	.1321	1.8099	-4.4	.8815	-7.9636	-.0166	-.0146
19.0	.1286	1.8705	-4.7	.8739	-8.7916	-.0146	-.0128
20.0	.1254	1.9332	-5.0	.8665	-9.6661	-.0130	-.0112
21.0	.1224	1.9980	-5.3	.8590	-10.5894	-.0116	-.0099
22.0	.1196	2.0650	-5.6	.8517	-11.5638	-.0103	-.0088
					TOTALS	1.8603	1.9540

EXPANSION TIME DURING HELIX TRAVERSE (TEH) = .00022 SECONDS

V = 381.89 IN/SEC PC = 1588.4 PSI S = 3.5000 IN.

TABLE 4–7. COMPUTED DYNAMICS AFTER GAS CUTOFF
BOLT UNLOCKING DURING PARABOLA TRAVERSE

I	PARAB DIST IN	EQUIV CYL LENGTH IN	CAM SLOPE DEG	CYL PRESS PSI	EQUIV RECOIL MASS W/G	ROD VEL IN/SEC	TIME MSEC
13	.050	3.550	7.917	1559.4	.006529	400.05	.1279
14	.100	3.600	15.145	1531.3	.006689	416.71	.2503
15	.150	3.650	21.913	1504.1	.006974	431.83	.3682
16	.200	3.700	28.096	1477.7	.007419	445.33	.4822
17	.250	3.750	33.643	1452.1	.008072	457.19	.5930
18	.300	3.800	38.557	1427.3	.008999	467.39	.7011
19	.350	3.850	42.882	1403.3	.010303	475.98	.8071
20	.400	3.900	46.676	1379.9	.012142	483.03	.9114
21	.450	3.950	50.003	1357.3	.014778	488.66	1.0143
22	.500	4.000	52.926	1335.3	.018676	492.99	1.1162

TABLE 4–8. COMPUTED DYNAMICS AFTER GAS CUTOFF
BOLT AND ROD UNIT RECOILING AFTER CAM ACTION

Y	AY	BY	Z	AZ	ZBY	QUOT1	QUOT2
1.0	.5000	1.0566	.7	1.0859	.7396	.6760	.7341
2.0	.3750	1.1164	.4	1.0482	.4466	.8397	.8802
3.0	.3125	1.1796	.1	1.0118	.1180	2.6491	2.6805
4.0	.2734	1.2464	-.2	.9767	-.2493	-1.0967	-1.0712
5.0	.2461	1.3170	-.5	.9428	-.6585	-.3737	-.3524
6.0	.2256	1.3916	-.8	.9101	-1.1133	-.2026	-.1844
7.0	.2095	1.4704	-1.1	.8785	-1.6174	-.1295	-.1138
8.0	.1964	1.5536	-1.4	.8480	-2.1751	-.0903	-.0766
9.0	.1855	1.6416	-1.7	.8185	-2.7907	-.0665	-.0544
10.0	.1762	1.7345	-2.0	.7901	-3.4690	-.0508	-.0401
11.0	.1682	1.8327	-2.3	.7627	-4.2152	-.0399	-.0304
12.0	.1612	1.9365	-2.6	.7362	-5.0348	-.0320	-.0236
13.0	.1550	2.0461	-2.9	.7107	-5.9337	-.0261	-.0186
14.0	.1495	2.1620	-3.2	.6860	-6.9183	-.0216	-.0148
15.0	.1445	2.2844	-3.5	.6622	-7.9953	-.0181	-.0120
16.0	.1400	2.4137	-3.8	.6392	-9.1720	-.0153	-.0098
17.0	.1359	2.5504	-4.1	.6170	-10.4564	-.0130	-.0080
18.0	.1321	2.6947	-4.4	.5956	-11.8569	-.0111	-.0066
19.0	.1285	2.8473	-4.7	.5749	-13.3824	-.0096	-.0055
20.0	.1254	3.0085	-5.0	.5549	-15.0426	-.0083	-.0046
21.0	.1224	3.1789	-5.3	.5357	-16.8479	-.0073	-.0039
22.0	.1196	3.3588	-5.6	.5171	-18.8095	-.0064	-.0033
					TOTALS	1.9459	2.2606

EXPANSION TIME DURING HELIX TRAVERSE (TEH) = .00110 SECONDS

V = 481.66 IN/SEC PC = 1145.7 PSI S = 4.5000 IN.

MINIMUM BUFFER FORCE = 176.8 LB
MAXIMUM BUFFER FORCE = 236.8 LB
DRIVING SPRING RECOIL TIME = .000553 SEC
BUFFER RECOIL TIME = .006092 SEC
BUFFER COUNTERRECOIL TIME = .012190 SEC
DR SPRING COUNTERRECOIL TIME = .021407 SEC
BUFFER COUNTERRECOIL VELOCITY = 136.81 IN/SEC
DR SPR COUNTERRECOIL VELOCITY = 253.81 IN/SEC

where

v_{sa} = velocity of recoiling parts at s_a

The driving spring force at s_a is F_{sa} = 61.7 lb (par. 4–3.2.5.1). Since the spring force when fully compressed is F_m = 97.4 lb (par. 4–3.2.4), the energy absorbed by the driving spring is

$$E_d = \frac{1}{2}(F_{sa} + F_m) L_r/\epsilon = 557 \text{ in.-lb}$$

where $\epsilon = 0.5$, the efficiency of the system. The energy consumed by the buffer is

$$E_b = E_r - E_d = E_r - 557 \text{ in.-lb.}$$

The effective spring constant and the buffer stroke are K_b = 60 lb/in. and L_b = 1.0 in., respectively. The initial and final spring forces are found by equating the spring work to the energy to be absorbed

$$\frac{1}{2}(F_{ob} + F_{mb})L_b/\epsilon = E_b$$

where

$F_{mb} = F_o + K_b L_b$, the initial buffer force is

$$F_{ob} = \frac{\epsilon E_b}{L_b} - 1/2\,K_b L_b = 0.5E_r - 309, \text{lb}$$

The recoil time while the driving spring is functioning is computed by expanding Eq. 2–22 to include the limits of $x = 0$ to $x = L_r$ and by proper substitution for the other variables.

$$t_{dr} = \sqrt{\frac{\epsilon M_r}{K}}\left(\text{Sin}^{-1}\frac{F_m}{Z} - \text{Sin}^{-1}\frac{F_{so}}{Z}\right)$$

$$= 0.0203\left(\text{Sin}^{-1}\frac{97.4}{Z} - \text{Sin}^{-1}\frac{61.7}{Z}\right), \text{sec}$$

where

$$Z = \sqrt{F_{sa}^2 + \epsilon K M_r v_{sa}^2} = \sqrt{3807 + 10.2E_r}$$

The buffer recoil time is found similarly. However, since the buffer absorbs the remaining energy, the buffer recoil time is computed according to Eq. 2–23.

$$t_{br} = \sqrt{\frac{\epsilon M_r}{K_b}}\,\text{Cos}^{-1}\frac{F_{ob}}{F_{mb}}$$

$$= 0.00837\,\text{Cos}^{-1}\frac{F_{ob}}{F_{mb}}, \text{sec}$$

4–3.3.3.2 Counterrecoil Dynamics

The time required for counterrecoil during buffer action is found from Eq. 2–27.

$$t_{bc} = \sqrt{\frac{M_r}{\epsilon K_b}}\,\text{Cos}^{-1}\frac{F_{ob}}{F_{mb}} = 0.01675\,\text{Cos}^{-1}\frac{F_{ob}}{F_{mb}}, \text{sec}$$

The velocity at the end of the buffer stroke is found by equating the work done by the springs to the expression for kinetic energy and then solving for the velocity

$$E_{bc} = \left(\frac{F_{mb} + F_{ob}}{2}\right)L_b$$

$$= (F_{mb} + F_{ob})/4 = 1/2\,M_r v_{bc}^2$$

$$v_{bc} = \sqrt{2E_b/M_r}.$$

TABLE 4–9. COMPUTED DYNAMICS, COUNTERRECOIL BOLT LOCKING DURING PARABOLA TRAVERSE

TRAVEL INCH	FORCE POUND	BETA DEGREE	MASS 1000#	DELTAT MILSEC	VELOCITY IN/SEC	TIME MILSEC
.05	50.99	50.003	.01582	.1963	254.41	.1963
.10	50.48	46.676	.01219	.1958	255.00	.3921
.15	49.97	42.882	.01006	.1954	255.59	.5875
.20	49.46	38.557	.00871	.1950	256.16	.7825
.25	48.95	33.643	.00783	.1945	256.73	.9770
.30	48.44	28.096	.00725	.1941	257.30	1.1712
.35	47.93	21.913	.00687	.1937	257.85	1.3649
.40	47.42	15.145	.00664	.1933	258.40	1.5581
.45	46.91	7.917	.00652	.1929	258.94	1.7510
.50	46.40	.428	.00647	.1925	259.48	1.9435
1.00	41.30	.428	.00647	1.8730	264.75	3.8166

The time required for counterrecoil during driving spring action and while bolt and operating rod are moving as a unit is computed from Eq. 2–26

$$t_{cr} = \sqrt{\frac{M_r}{\epsilon K}} \left(\text{Sin}^{-1} \frac{-F_{sb}}{Z} - \text{Sin}^{-1} \frac{-F_m}{Z} \right)$$

$$= 0.04061 \left(\text{Sin}^{-1} \frac{-51.5}{Z} - \text{Sin}^{-1} \frac{-97.4}{Z} \right)$$

where

$$F_{sb} = F_m - K(L_d - L_b)$$

$$= 97.4 - 10.2 \times 4.5 = 51.5 \text{ lb}$$

$$Z = \sqrt{F_m^2 + KM_r v_{bc}^2/\epsilon} + \sqrt{9487 + 40.8 E_{bc}}$$

The total work done by all springs until locking starts is

$$E_{sc} = E_{bc} + \left(\frac{F_m + F_{sb}}{2} \right) (L_d - L_b)\epsilon$$

$$= E_{bc} + 167.5 \text{ , in.-lb.}$$

The velocity at this time is

$$v_{sc} = \sqrt{2E_{sc}/M_r} \text{ , in./sec.}$$

4–3.3.5.3 Bolt Locking Dynamics

When the bolt reaches the breech face, the operating rod continues on its linear path for the remaining one inch of travel. In the meantime, the cam follower on the operating rod locks the bolt, riding over the parabolic cam curve for a half inch of travel and over the helix for the other half inch. Meanwhile, the driving spring continues to force the moving parts into battery.

The cam action during locking is the reverse of that during unlocking but follows a similar pattern. The axial length of the parabola is divided into equal length increments. The spring force is determined at the end of each increment to compute the time and velocity for each increment. Eq. 2–26 yields the differential time with M_e being the effective mass obtained from Eq. 4–73. For counterrecoil, the cam follower is a sliding surface, therefore, $\mu_r = \mu_1$.

$$M_e = 0.00647 + \frac{0.000458 \tan\beta}{0.203 \left(\frac{\cos\beta - 0.3 \sin\beta}{\sin\beta + 0.3 \cos\beta} - 0.1149 \right)}$$

While the cam follower is traversing the helix during the last stage of locking the bolt, the operating rod continues toward its in-battery position.

The differential time for any increment of travel is

$$t_{ci} = \sqrt{\frac{M_e}{\epsilon K}} \left(\text{Sin}^{-1} \frac{-F_{c2}}{Z} - \text{Sin}^{-1} \frac{-F_{c1}}{Z} \right)$$

$$= 0.4428 \sqrt{M_e} \left(\text{Sin}^{-1} \frac{-F_{c2}}{Z} - \text{Sin}^{-1} \frac{F_{c1}}{Z} \right)$$

where

F_{c1} = spring force at beginning of increment

$F_{c2} = F_{c1} - K\Delta s$, spring force at end of increment

Δs = increment of counterrecoil travel

$Z = \sqrt{F_{c1}^2 + KM_e v^2/\epsilon} = \sqrt{F_{c1}^2 + 40.8 E_{cri}}$

E_{cri} = counterrecoil energy at beginning of increment

The energy at the end of each increment is

$$E_{cr} = E_{cri} + \frac{\epsilon}{2} (F_{c1} + F_{c2})\Delta s$$

$$= E_{cri} + 0.25 (F_{c1} + F_{c2})\Delta s \text{ , in.-lb.}$$

The counterrecoil velocity at the end of each increment is

$$v_{cr} = \sqrt{2E_{cr}/M_c} \text{ , in./sec.}$$

4–3.3.4 Firing Rate

The time of each firing cycle is the total accumulated by all operations.

Time, sec	Operation	Table
0.003665	Before Gas Cutoff	4-5
0.000220	Bolt Unlocking, Helix	4-6
0.001116	Bolt Unlocking, Parabola	4-7
0.001100	Gas Expansion After Cam Action	4-8
0.000553	Driving Spring Recoil	4-8
0.006092	Buffer Recoil	4-8
0.012190	Buffer Counterrecoil	4-8
0.021407	Driving Spring Counterrecoil	4-8
0.003817	Bolt Locking	4-9
0.050160	Total Firing Cycle	

Firing rate $f_r = \dfrac{60.0}{0.05016} = 1196$ rounds/min.

4–3.4 SPRINGS

4–3.4.1 Driving Spring

The driving spring, in order to comply with the dynamic requirements of the gun, is assigned the following data

K = 10.2 lb/in., spring constant

F_o = 41.3 lb, load at assembled height

F_m = 97.4 lb, load at fully compressed height

L_d = 5.5 in., operating distance of spring

t_b = 0.0055 sec (see par. 4-3.2.5.1)

t_r = 0.0218 sec (see par. 4-3.2.5.2)

v_i = v_r = 503.6 in./sec, impact velocity (see par. 4-3.2.5)

Since $v_i > 25$ ft/sec, select $\dfrac{T_c}{T} = 1.8$; therefore

$$T = \frac{T_c}{1.8} = \frac{0.0163}{1.8} = 0.0906 \text{ sec, surge time}$$

where $T_c = t_r - t_b$, the compression time.

Set the coil diameter at $D = 0.375$ in. According to Eq. 2-42, the wire diameter is

$$d = 0.27\sqrt[2]{DKT} = 0.27\sqrt[3]{0.0333}$$

$$= 0.27 \times 0.322 \quad 0.087 \text{ in.}$$

The number of coils from Eq. 2-41 is

$$N = \frac{Gd^4}{8D^3K} = \frac{11.5 \times 10^6 \times 57.3 \times 10^{-6}}{8 \times 0.0527 \times 10.2} = 152 \text{ coils}$$

where G = shear modulus.

The static torsional stress, Eq. 2-43, is

$$\tau = \frac{8F_m D}{\pi d^3} = \left(\frac{8 \times 97.4 \times 0.375}{3.14 \times 0.659}\right) 10^3$$

$$= 141{,}000 \text{ lb/in.}^2$$

The dynamic torsional stress, Eq. 2-44, is

$$\tau_d = \tau\left(\frac{T}{T_c}\right)\left[f\left(\frac{T_c}{T}\right)\right] = 141{,}000\left(\frac{2.0}{1.8}\right)$$

$$= 157{,}000 \text{ lb/in.}^2$$

The solid height is

$$H_s = Nd = 152 \times 0.087 = 13.22 \text{ in.}$$

4–3.4.2 Buffer Spring

During recoil, the buffer springs are contacted at an impact velocity of $v_i = v_b = 348.1$ in./sec (see par. 4-3.2.5.1). Since $v_i > 25$ ft/sec, the surge time

$$T = \frac{T_c}{1.8} = \frac{0.0055}{1.8} = 0.00306 \text{ sec}$$

where

$T_c = t_{br} = 0.0055$ sec, compression time of buffer spring.

A nest of two springs is used in both primary and secondary systems. The inner spring has 40% of the load and spring constant of the system. The assigned and computed data are listed in Table 4–10. Design data are also listed for single primary and secondary springs and for a single buffer spring to offer comparative values.

The single buffer spring is obviously, too highly stressed to be acceptable. Of the two other types, the stresses are satisfactory; this leaves the choice to available space, depending on which is the more critical length or diameter. The nested spring requires less longitudinal space whereas the single units require less diametral space.

4–4 THE TAPPET SYSTEM

The tappet system (Fig. 4–7), by virtue of its extremely short stroke, is usually confined to low muzzle velocity guns and to unlocking mechanisms. Since no initial cylinder volume exists, the delivered gases work at peak pressures immediately, no loss in pressure being suffered because a container must first be pressurized. However, the gas flow calculations will follow the same procedure that is outlined for the cutoff expansion system except that pressure on the tappet is considered to be the initial pressure unless the travel of the tappet creates a gas volume that is not compatible with the critical pressure.

4–4.1 SAMPLE PROBLEM

4–4.1.1 Specifications

Gun. Cal .30 Carbine (7.62 mm)

A_b = 0.0732 in.^{2}, bore area

f_r = 600 rounds/min, firing rate

L_{bl} = 16.2 in., length of bullet travel in barrel

V_{ch} = 0.057 in.^{3}, chamber volume

W_g = 13 grains = 0.00186 lb weight of propellant

Interior Ballistics: Pressure vs Time, Fig. 4–8
Velocity vs Time, Fig. 4–8

4–4.1.2 Preliminary Design Data

d_t = 0.40 in., diameter of tappet

L = 2.5 in., bolt travel

L_t = 0.15 in., tappet travel

W_r = 0.67 lb, weight of recoiling unit

ϵ = 0.40, efficiency of automatic mechanism

4–4.1.3 Design Data, Computed

The time for the firing cycle, Eq. 2–29, is

$$t_c = \frac{60}{f_r} = \frac{60}{600} = 0.100 \text{ sec.}$$

By employing Eq. 4–21 and assuming constant acceleration, the time for counterrecoil and recoil are, respectively,

$$t_{cr} = \frac{2L}{v_{cr}}, \qquad t_r = \frac{2L}{v_r} = \frac{2\epsilon L}{v_{cr}}$$

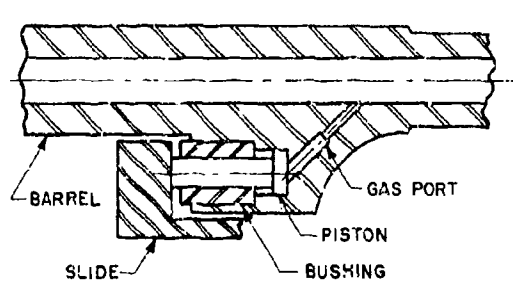


Figure 4–7. Tappet System

TABLE 4–10. BUFFER SPRING DESIGN DATA

Type	Primary, Double		Secondary, Double		Primary	Secondary	Single
Data	Inner	Outer	Inner	Outer	Single	Single	Only
K, lb/in.	32	48	96	144	80	240	60
F_m, lb	114	171	114	171	285	285	285
T, msec	3.06	3.06	3.06	3.06	3.06	3.06	3.06
D_1, in.	0.5	0.875	0.6	1.125	0.5	1.00	0.75
D^3, in.^{3}	0.125	0.67	0.2	1.424	0.125	1.00	0.422
DKT	0.049	0.1285	0.1763	0.4957	0.1224	0.735	0.1377
$\sqrt[3]{DKT}$	0.366	0.505	0.561	0.79	0.497	0.902	0.516
d, in.	0.100	0.136	0.151	0.213	0.134	0.243	0.139
$d^3 \times 10^3$, in.^{3}	1.0	2.52	3.44	9.67	2.4	14.3	2.69
$d^4 \times 10^4$, in.^{4}	1.0	3.42	5.2	20.58	3.22	34.9	3.73
$G \times 10^{-6}$, psi	11.5	11.5	11.5	11.5	11.5	11.5	11.5
N	36	15.3	36	14.4	46.3	20.9	21.2
$\tau \times 10^{-3}$, psi	145	151	51	46	151	51	202
$\tau_d \times 10^{-3}$, psi	162	168	56	51	168	56	225
H_s, in.	3.6	2.08	5.44	3.07	6.2	5.08	2.95

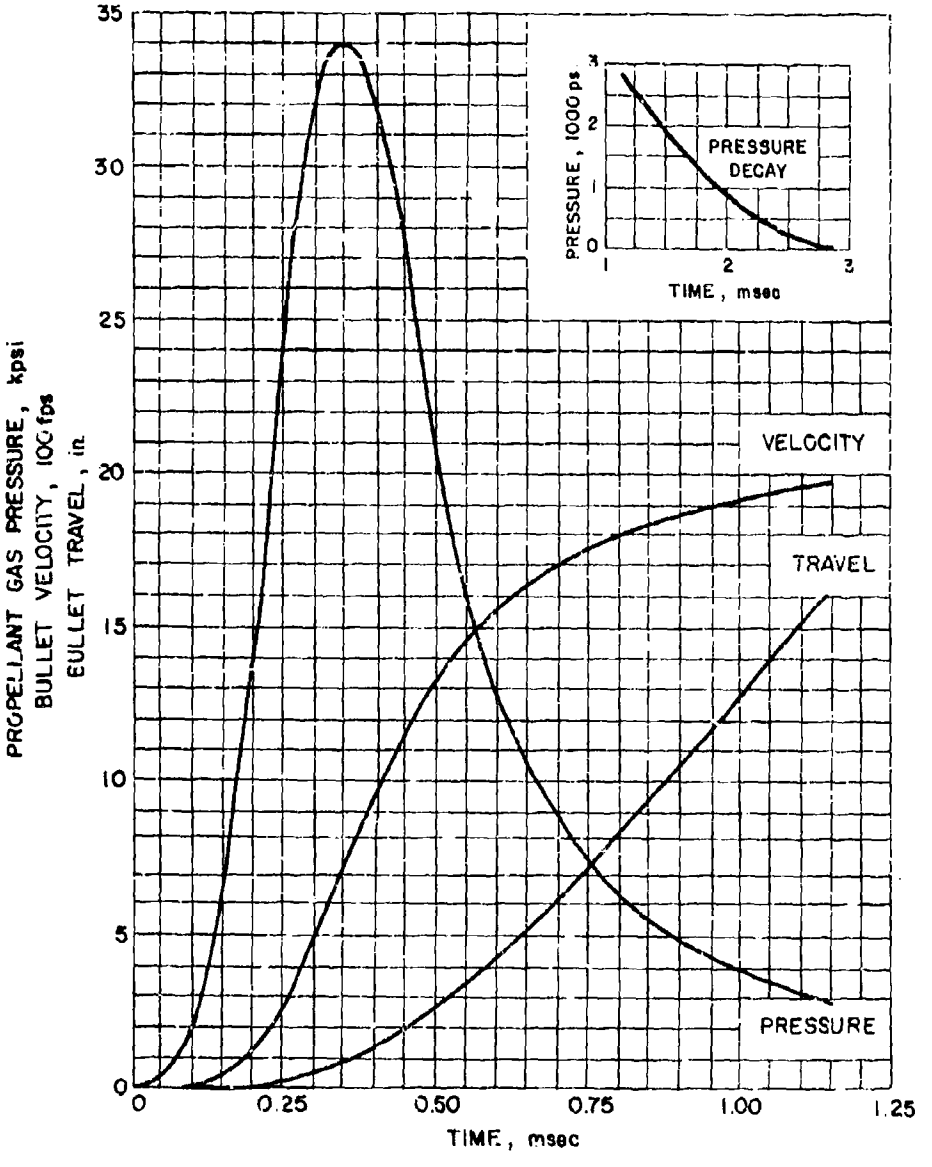


Figure 4–8. Pressure-time Curve of 7.62 mm Carbine Round

Solve both equation for v_{cr}, equate and reduce to the simplest terms

$$t_r = 4t_{cr} = 0.40t_{cr}$$

$$t_r + t_{cr} = 1.40t_{cr} = 0.100 \text{ sec}$$

$$t_{cr} = 0.071 \text{ sec}$$

$$t_r = 0.029 \text{ sec}$$

The counterrecoil velocity is

$$v_{cr} = \frac{2L}{t_{cr}} = \frac{2 \times 2.5}{0.071} = 70.4 \text{ in./sec.}$$

The recoil velocity is

$$v_r = \frac{2L}{t_r} = \frac{2 \times 2.5}{0.029} = 172 \text{ in./sec.}$$

The energy of the recoiling part, Eq. 2-15, is

$$E_r = \frac{1}{2}\left(\frac{W_r}{g}\right) v_r^2 = \frac{1}{2}\left(\frac{0.67}{386.4}\right) 29600$$

$$= 25.65 \text{ in.-lb.}$$

The average force on the tappet, Eq. 2-16, is

$$F_a = \frac{E_r}{L_t} = \frac{25.65}{0.15} = 171 \text{ lb.}$$

The momentum of the recoiling parts Mv_r is

$$Mv_r = \left(\frac{0.67}{386.4}\right) 172 = 0.298 \text{ lb-sec.}$$

Equate momentum and impulse, and solve for time t.

$$t = \frac{Mv_r}{F_a} = \frac{0.298}{171} \text{ lb} = 0.00175 \text{ sec}$$

This is the time needed for the tappet to reach the velocity of 172 in./sec. The average pressure in the tappet cylinder is

$$p_c = \frac{F_a}{A_t} = \frac{171}{0.1257} = 1360 \text{ lb/in.}^2$$

where

$$A_t = \frac{\pi}{4} d_t^2 = 0.1257 \text{ in.}^2, \text{ tappet area}$$

$$d_t = 0.40 \text{ in., tappet diameter}$$

Assume that the pressure in the tappet cylinder is the critical pressure, then the corresponding pressure in the bore becomes, Eq. 4-26,

$$p_b = \frac{p_c}{0.53} = 2566 \text{ lb/in.}^2$$

The area of the pressure-time corresponding to the impulse of the tappet, Eq. 4-50, is

$$A_{pt} = p_b t = 2566 \times 0.00175 = 4.5 \text{ lb-sec/in.}^2$$

According to Eq. 4-49, when the bullet is still in the barrel, $p_m = p_b$ and $V_m = V_b$, therefore, if $k_b = k = 1.3$

$$W_c = W_g \left(\frac{V_c}{V_b}\right)\left(\frac{p_c}{p_b}\right)^{1/1.3} = 0.614\, W_g \left(\frac{V_c}{V_b}\right)$$

$$= 0.614 \left(0.00186\right) \frac{0.0189}{1.245} = 1.728 \times 10^{-5} \text{ lb}$$

where

$p_c = 0.53p_b$, the pressure in the tappet cylinder, considered to be the critical pressure

$V_c = A_t L_t = 0.0189 \text{ in.}^3$, volume of tappet displacement

$V_b = V_{ch} + A_b L_{bt} = 1.245 \text{ in.}^3$, chamber plus bore volumes

The estimated orifice area, Eq. 4–52 is

$$A_o = \frac{W_c}{K_w A_{pt}} = \frac{1.728 \times 10^{-5}}{1.92 \times 10^{-3} \times 4.5} = 0.002 \text{ in.}^2$$

where

$$K_w = 0.00192/\text{sec (see par. 4–3.2.5.2)}$$

The orifice diameter $d_o = 0.0505$ in.

If we proceed with the above computed parameters and with the assumed critical pressures, data similar to those in Table 4–11 were computed for the period of time starting at 0.53 msec and extending to the muzzle at 1.15 msec. The area under the pressure-time curve within these time limits equals the 4.5 area computed earlier. Although the required tappet velocity of 172 in./sec was obtained, the tappet travel of 0.072 in. was far short of the required 0.15 in. The required travel could be obtained by merely shifting the gas port toward the muzzle. However, the computed equivalent volumes V_e, Eq. 4–42, were always larger than the computed chamber volume V_c, Eq. 4–48. This created the illusion that the tappet cylinder pressure p_c, Eq. 4–43, was much higher that the available bore pressure, a physical impossibility substantiated by the rate of pressure decline in the bore, so that pressure in the cylinder cannot be maintained higher than that in the bore.

Based on the first computed data, the gas port was moved farther toward the muzzle. Minimum limits on size precluding the use of a port small enough to regulate the pressure to be compatible with velocity and distance had the original port location been kept. Tappet cylinder pressures were assumed to be bore pressure. The assumption is virtually correct since a much higher mass of gas can pass through the port than volume created to accommodate it on the other side by the accelerating tappet.

The pressure in the tappet cylinder now being the same as the bore pressure, the area under the pressure-time curve becomes

$$A_{pt} = p_c t = 1360 \times 0.00175 = 2.38 \text{ lb-sec/in.}^2$$

Now that the gas port has been moved closer to the muzzle, some of the area of the pressure time curve beyond the muzzle must be considered to compensate for that lost by the relocation of the port. The first set of calculations is a good guide for locating the new port position. After the second set of calculations are completed, the exact velocity and tappet travel are determined by manipulating the areas under the pressure-time curve of the first and last increment. That amount subtracted from one must be added to the other to maintain the same area and hence velocity. If the travel distance is too short, the acceleration at the beginning is too high. Lowering the acceleration at the beginning grants the additional time needed at the end to cover the total required distance. A reduction of the area of the pressure-time curve at the start of the activity and its equal added to the end resolves this problem. If travel distance goes beyond that required, an increase in acceleration at the beginning is needed so that the terminal tappet velocity is realized at a shorter distance. A transfer of pressure-time area from the end to the beginning will serve the purpose. When both tappet travel distance and velocity comply with the required values, the gas port becomes located along the length of the barrel corresponding with the time when this activity started.

The data presented in Table 4–11 are the results of a series of computations arriving at a terminal tappet velocity of 172 in./sec on moving a distance of 0.15 in. the required value. The pressure is read from the pressure-time curve in Fig. 4–8 between the time limits 0.867 msec to 2.13 msec, which extends into the decay period after the bullet leaves the muzzle. While the bullet is still in the barrel, the pressures are read at the time interval and are assumed to be constant over the interval. To illustrate the procedure, the sequence of calculations for $t = 1.1$ msec follows.

$$\text{At } t = 11.0 \times 10^{-4}, p_a = 3100 \text{ lb/in.}^2 \text{ (Fig. 4–8)}$$

(The average pressure for 1.65 and 2.13 msec is obtained by dividing the differential area of the pressure-time curve by the corresponding time increment.)

The increment of time, $\Delta t = 0.00005$ sec.

The impulse on the tappet is

$$F\Delta t = A_t F_a \Delta t = 0.0195 \text{ lb-sec}$$

where

$$A_t = 0.1257 \text{ in.}^2, \text{ area of tappet}$$

TABLE 4–11. DYNAMICS OF TAPPET

t, msec	$\Delta t \times 10^5$, sec	p_a, psi	s_b, in.	$F\Delta t \times 10^4$, lb-sec	Δv, in/sec	v, in/sec	$\Delta s \times 10^5$, in.
0.876	1.7	5200	9.6	111	6.4	6.4	5
0.90	5	4800	10.4	302	17.4	23.8	44
0.95	5	4300	11.5	270	15.6	39.4	39
1.00	5	3900	12.7	246	14.2	53.6	36
1.05	5	3500	13.9	220	12.7	66.3	32
1.10	5	3100	15.1	195	11.3	77.6	28
1.15	5	2800	16.2	176	10.1	87.7	25
1.65	50	1630	—	1022	58.9	146.6	1472
2.13	48	730	—	440	25.4	172.0	610

t, msec	$\Delta s_2 \times 10^5$, in.	$s \times 10^5$, in.	$V_c \times 10^3$, in.^{3}	$\Delta W \times 10^6$, lb	V_b, in.^{3}	$W_c \times 10^6$, lb	$V_c \times 10^3$, in.^{3}
0.876	0	5	0.0063	0.340	0.759	0.34	0.139
0.90	32	81	0.102	0.924	0.819	1.264	0.556
0.95	119	239	0.300	0.826	0.899	2.09	1.010
1.00	197	472	0.590	0.750	0.987	2.84	1.505
1.05	268	772	0.970	0.622	1.075	3.462	2.00
1.10	332	1132	1.42	0.595	1.165	4.06	2.54
1.15	388	1545	1.95	0.538	1.245	4.60	3.08
1.65	4385	7402	9.34	3.130	3.67	7.72	15.26
2.13	7047	15059	18.9	1.344	6.24	9.07	30.4

The velocity at the end of the time interval, Eqs. 4–45 and 4–46, is

$$v = v_{n-1} + \frac{F\Delta t}{M_r} = 66.3 + \frac{0.0195 \times 386.4}{0.67}$$

$$= 66.3 + 11.3 = 77.6 \text{ in./sec.}$$

The distance traveled by the tappet, Eq. 4–47, becomes

$$s = \frac{1}{2}\,\Delta v \Delta t + v_{n-1}\Delta t + s_{n-1}$$

$$= \left(\frac{11.3}{2} + 66.3\right) 0.00005 + 0.00772$$

$$= 0.00028 + 0.00332 + 0.00772 = 0.01132 \text{ in.}$$

The gas volume in the cylinder according to Eq. 4–48 is

$$V_c = V_{co} + A_t s = 0.1257 \times 0.01132 = 0.00142 \text{ in.}^3$$

where the initial volume $V_{c0} = 0$.

The rate of flow, Eq. 4–27, is

$$w = K_w A_o p_a = 0.00129 \times 0.002 \times 3100$$

$$= 0.01190 \text{ lb/sec.}$$

The weight of the gas flowing through the port during the interval, Eq. 4–28, is

$$\Delta W_c = \Delta t w = 0.00005 \times 0.01190 = 5.95 \times 10^{-7} \text{ lb.}$$

The total weight of the gas in the tappet cylinder is W_c.

$$W_c = W_{c(n-1)} + \Delta W_c = (3.462 + 0.595)10^{-6}$$

$$= 4.057 \times 10^{-6} \text{ lb.}$$

The equivalent volume of this gas at 3100 psi pressure, according to Eq. 4–42 becomes

$$V_e = \left(\frac{W_c}{W_g}\right) V_b = \frac{4.057 \times 10^{-6}}{1.86 \times 10^{-3}} \; 1.165$$

$$= 0.00254 \text{ in.}^3$$

where V_b is the gas volume of the barrel.

$$V_b = V_o + A_b s_b = 0.057 + 0.0732 \times 15.1 = 1.165 \text{ in.}^3$$

where

V_o = 0.057 in.^{3}, initial volume (chamber)

A_b = 0.0732 in.^{2}, bore area

s_b = 15.1 in., bullet travel at $t = 1.1$ msec (Fig. 4–8)

According to Eq. 4–43

$$p_c = \left(\frac{V_e}{V_c}\right)^k p_a = \left(\frac{2.54}{1.42}\right)^{1.3} 3100$$

$$= 2.13 \times 3100 = 6600 \text{ lb/in.}^2$$

This pressure is absurd but it does indicate that more gas is capable of flowing through the port than the cylinder, as the receiver, can admit; therefore, the assumption that cylinder pressure is nearly equal to bore pressure is highly probable particularly since $V_e > V_c$ throughout the operation. Further assurance is available by computing the time needed during each interval to bring the pressure in the cylinder to the critical. In each increment, the gas flow is rapid enough to reach the critical before the moving tappet creates the corresponding volume. This approach is conservative since the differential pressures in the computations were based solely on critical pressures as limits although considerable time is available for additional gas flow into the cylinder, thus tending to approach the bore pressure. For example, continue with the same sequence of calculations for $t = 1.1$ msec. The critical pressure is

$$p_{cr} = 0.53 p_a = 0.53 \times 3100 = 1640 \text{ lb/in.}^2$$

The pressure due to expansion of the gas in the cylinder during the interval provided that gas flow ceases is p_e.

$$p_e = p_{cr-1} \left(\frac{V_{c-1}}{V_c}\right)^k = 1860 \left(\frac{0.97}{1.42}\right)^{1.3}$$

$$= 1135 \text{ lb/in.}^2$$

where

p_{cr-1} = 1860 lb/in.^{2}, the critical pressure of the previous interval

V_c = 0.00142 in.^{3}, the gas volume in the tappet cylinder

V_{c-1} = 0.00097 in.^{3}, the gas volume of the previous interval

The differential pressure between the expanded gas in the cylinder and the critical pressure provided by gas flow

$$\Delta p_c = p_{cr} - p_e = 1640 - 1135 = 505 \text{ lb/in.}^2$$

The equivalent bore volume of the gas expanded to the critical pressure is

$$V_{ec} = V_b\left(\frac{p_a}{p_c}\right)^{\frac{1}{k}} = 1.162\left(\frac{3100}{1640}\right)^{\frac{1}{1.3}} = 1.90 \text{ in.}^3$$

The weight of the gas at the critical pressure in the tappet cylinder is

$$W_c = \left(\frac{V_c}{V_e}\right) W_g = \left(\frac{0.00142}{1.90}\right) 0.00186$$

$$= 1.39 \times 10^{-6} \text{ lb.}$$

The weight of the gas flowing into the cylinder is that needed to increase the pressure from p_e to p_{cr}.

$$\Delta W_{ce} = \left(\frac{\Delta p_c}{p_{cr}}\right) W_c = \frac{505}{1640}\left(1.39\right) 10^{-6}$$

$$= 4.28 \times 10^{-7} \text{ lb.}$$

The time needed for the flow is

$$\Delta t_w = \frac{\Delta W_{ce}}{w} = \frac{4.28 \times 10^{-7}}{0.0119} = 3.60 \times 10^{-5} \text{ sec.}$$

The time is about 70% that of the specified interval of 5×10^{-5} sec. The results of the rest of the calculations appear in Table 4–12. On further examination of the tabulated results – since time is available for gas flow beyond the critical – note that the pressure due to expansion p_e would be greater than shown, thereby reducing the time needed to reach the critical pressure, and meanwhile, providing more time for the tappet cylinder pressure to reach the bore pressure.

4–4.1.4 Spring Design Data

Spring characteristics are determined more readily during recoil since more data are immediately available. According to Eq. 2–15, after the bolt has traveled its full distance in recoil, the energy to be absorbed by the spring is E_r .

$$E_r = \frac{1}{2}\left(M_b v_r^2\right) = 25.65 \text{ in.-lb}$$

where

$$M_b = \frac{0.67}{386.4} \frac{\text{lb-sec}^2}{\text{in.}}, \text{ mass of bolt unit}$$

v_r = 172 in./sec, recoil velocity

From Eq. 2–67b

$$KT = \frac{F_m}{1037} = \frac{F_a + \frac{1}{2}\left(L_d K\right)}{1037}$$

where

$$K = \frac{4.36}{0.0071 \times 1037 - 1.175} = \frac{4.36}{6.188}$$

$$= 0.70 \text{ lb, spring constant}$$

$$T = \frac{T_c}{3.8} = 0.0071 \text{ sec, surge time of spring}$$

$T_c = t_r - t = 0.029 - 0.0021 = 0.0269$ sec, preliminary estimate of compression time of spring

The average spring force, Eq. 2–30, is

$$F_a = \frac{\epsilon E_r}{L_d} = \frac{0.040 \times 25.65}{2.35} = 4.36$$

where

$L_d = L - L_t = 2.35$ in., spring deflection after tappet stops.

TABLE 4-12. CRITICAL PRESSURE TIME REQUIREMENTS

t, msec	p_{cr}, psi	$w \times 10^3$, lb/sec	$V_c \times 10^3$, in.^{3}	P_e, psi	Δp_c, psi	V_{ec}, in.	$W_c \times 10^6$, lb	$\Delta W_{cc} \times 10^6$, lb	$\Delta t_w \times 10^5$, sec
0.867	2760	20.00	0.0063	0	2760	1.24	0.001	0.001	0.05
0.90	2540	18.46	0.102	73	2467	1.34	0.142	0.138	0.77
0.95	2280	16.52	0.300	625	1655	1.47	0.380	0.276	1.67
1.00	1990	15.00	0.590	945	1045	1.61	0.683	0.376	2.50
1.05	1860	12.44	0.970	1040	820	1.75	1.03	0.453	3.64
1.10	1640	11.90	1.42	1135	505	1.90	1.39	0.428	3.60
1.15	1480	10.76	1.95	1088	392	2.03	1.79	0.474	4.40
1.65	870	6.26	9.34	182	688	5.98	2.90	2.250	36.60
2.13	387	2.80	18.90	348	39	16.18	3.46	0.348	12.40

The driving spring force when the bolt is fully retracted is

$$F_m = F_o + \frac{1}{2}\left(KL_d\right) = 4.36 + \frac{1}{2}\left(2.35\right)\ 0.70$$

$$= 5.18 \text{ lb.}$$

The driving spring force when tappet contacts bolt is

$$F_o = F_m - KL_d = 5.18 - 2.35 \times 0.70 = 3.54 \text{ lb.}$$

The time for the bolt to recoil, excluding the time of the initial 0.15 in. of tappet travel, is computed via Eq. 2–23.

$$t_r = \sqrt{\frac{\epsilon M_b}{K}}\ \text{Cos}^{-1}\ \frac{F_o}{F_m}$$

$$= \sqrt{\frac{0.4 \times 0.67}{0.70 \times 386.4}}\ \text{Cos}^{-1}\ \frac{3.54}{5.18}$$

$$= 0.0315 \times 0.818 = 0.0258 \text{ sec}$$

Spring data and time are now computed for counterrecoil

$$F_o = F_m - KL = 5.18 - 0.70 \times 2.5 = 3.43 \text{ lb}$$

where

L = 2.5 in., total length of bolt travel including tappet travel.

The time of counterrecoil, Eq. 2–27,

$$t_{cr} = \sqrt{\frac{M_b}{\epsilon K}}\ \text{Cos}^{-1}\ \frac{F_o}{F_m}$$

$$= \sqrt{\frac{0.67}{0.4 \times 386.4 \times 0.70}}\ \text{Cos}^{-1}\ \frac{3.43}{5.18}$$

$$= 0.079 \times 0.847 = 0.0669 \text{ sec.}$$

The time needed to accelerate the bolt during recoil is obtained from Table 4–11 where $t_a = t = 0.0021$ sec, the last value (rounded to 4 places) in the time column.

The elapsed time for the firing cycle becomes

$$t_c = t_a + t_r + t_{cr} = 0.0021 + 0.0258 + 0.0669$$

$$= 0.0948 \text{ sec.}$$

The new firing rate of

$f_r = \frac{60}{t_c} = 633$ rounds/min is acceptable since it is only 5.5% higher than the specified rate.

The revised surge time of the spring becomes

$$T = \frac{T_c}{3.8} = \frac{t_a + t_r}{3.8} = \frac{0.0021 + 0.0258}{3.8} = 0.00734 \text{ sec.}$$

Having set the coil diameter at $D = 0.25$ in., we establish the spring constant at $K = 0.70$ lb/in., thus the wire diameter according to Eq. 2–42 becomes

$$d = 0.27\ \sqrt[3]{DKT} = 0.27\ \sqrt[3]{0.001286}$$

$$= 0.27 \times 0.1088 = 0.0294 \text{ in.}$$

The number of coils, Eq. 2–41, is N.

$$N = \frac{Gd^4}{8D^3K} = \frac{11.5 \times 10^6 \times 74.7 \times 10^{-8}}{8 \times 0.0156 \times 0.66} = 104 \text{ coils}$$

The static torsional shear stress becomes

$$\tau = \frac{8F_mD}{\pi d^3} = \frac{8 \times 5.18 \times 0.25}{3.14 \times 25.4 \times 10^{-6}} = 130{,}000 \text{ lb/in.}^2$$

The dynamic stress is

$$\tau_d = \tau\left(\frac{T}{T_c}\right)\left[f\left(\frac{T_c}{T}\right)\right] = 130{,}000\left(\frac{4.0}{3.8}\right)$$

$$= 137{,}000 \text{ lb/in.}^2$$

The solid height is

$$H_s = Nd = 104 \times 0.0294 = 3.06 \text{ in.}$$

CHAPTER 5

REVOLVER-TYPE MACHINE GUNS

5-1 SINGLE BARREL TYPE*

Revolver-type machine guns are distinguished from other types by the revolving drum, a feature borrowed from the revolver. The operational characteristics of the two weapons, machine gun and pistol, are basically similar except for refinements in the former that convert it from an ordinary repeater to a machine gun. These refinements involve automatic loading, firing, and ejecting operations. Fig. 5-1 is a schematic of a revolver type machine gun. Its essential components are receiver, drum cradle, drum, barrel, gas operating mechanism, slide, feeder, rammer, driving spring, and adapter.

Fig. 5-1 illustrates a gas-operated gun, however, external power may also be used for this type. When a round is fired, the recoiling parts comprising barrel, drum, and cradle recoil a short distance before being stopped by the adapter. In the meantime, the slide assembly recoils with these parts until a portion of the propellant gas passing from barrel to operating cylinder induces a relative velocity between recoiling parts and slide. As the recoiling parts stop, the slide continues to be accelerated rearward until the piston in the operating cylinder stops. The slide now has sufficient momentum to operate all moving parts until the next round is fired.

Continuing rearward, the slide, through the medium of a cam, imparts motion to the drum and then comes to rest after transferring all its energy less substantial frictional losses to the drum and driving spring. The drum now has the momentum to continue all operations. As it rotates, it actuates the feeder which pulls the ammunition belt far enough to align the next round with an empty chamber and the rammer. Cam action now imparts forward motion to the slide and rammer, the two components being integral. Cam forces – augmented by the driving spring force – drive the slide forward, eject the spent cartridge case, ram a full round into a chamber, and stop the drum as the loaded chamber reaches alignment with the bore just before the round is fired and the whole sequence repeats.

*General information was obtained from Refs. 8, 9, 10, and 11.

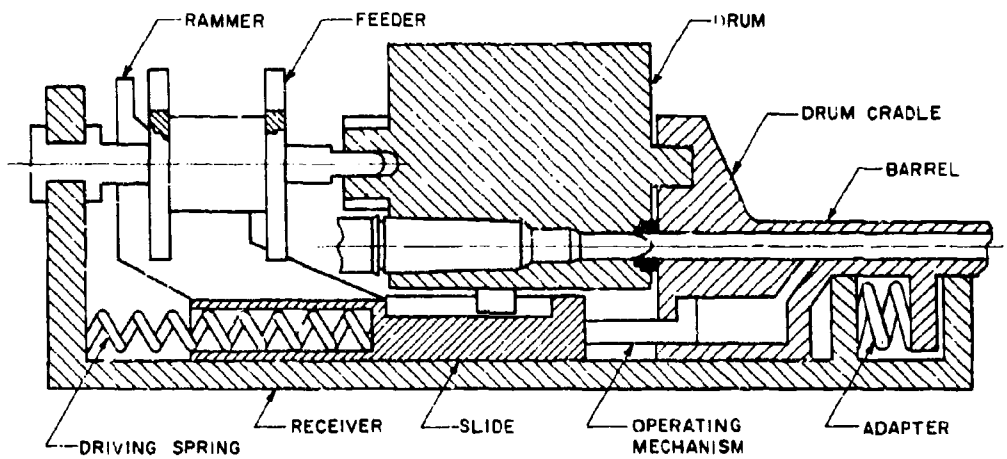


Figure 5-1. Schematic of Single Barrel Revolver-type Machine Gun

Ramming is a two-stage activity. The first stage involves stripping the round from the belt and pushing it about halfway along its path to the chamber. The second stage completes the chambering. Fig. 5–2 shows this two-step action. Actually, the entire process occurs during one cycle but on two adjacent rounds. While first-stage activity is confined to a new round, second-stage activity simultaneously completes the ramming of the round introduced during the preceding firing sequence. This two-stage ramming process represents a major advantage over a single-chambered gun by its ability to reduce the ramming distance to half its usual length thereby decreasing cycle time and increasing the rate of fire. Another contributing factor is the reduction of shocks resulting in higher allowable slide velocities (up to 50 ft/sec) than those usually associated with conventional mechanisms.

5–1.1 PRELIMINARY DYNAMICS OF FIRING CYCLE

The normal approach to the study of the dynamics during the firing cycle is to consider the various operations in their operational sequence. By considering firing as the initial condition, the first response of the gun is recoil. In many applications, since propellant gas forces are appreciable, the effects of recoil mechanism resistance are assumed negligible without introducing serious errors. However, for revolver-type machine guns, the recoil stroke is so short that considerable resistance must be provided immediately to preclude high recoil velocities and to keep recoil travel to the desired minimum. Left unimpeded, the distance of free recoil of a 20 mm barrel (Table 2–2) is almost 5 times that of an existing (M39) gun.

Performing an analysis similar to that defined in Eqs. 2–45 through 2–49, with due attention to the adapter resistance, the following iterative procedure is suggested. Compute the free recoil characteristics similar to those of Table 3–2. After obtaining the velocity and distance of free recoil, efforts must be directed toward reducing the velocity to zero over the prescribed recoil distance. One way of computing a zero velocity is to employ the weighted arithmetic mean of the impulse which yields an average force

$$F_a = \frac{\Sigma F_g \Delta t}{\Sigma \Delta t} \qquad (5\text{–}1)$$

Let this average force become the adapter resistance and compute what may be considered to be a resisting

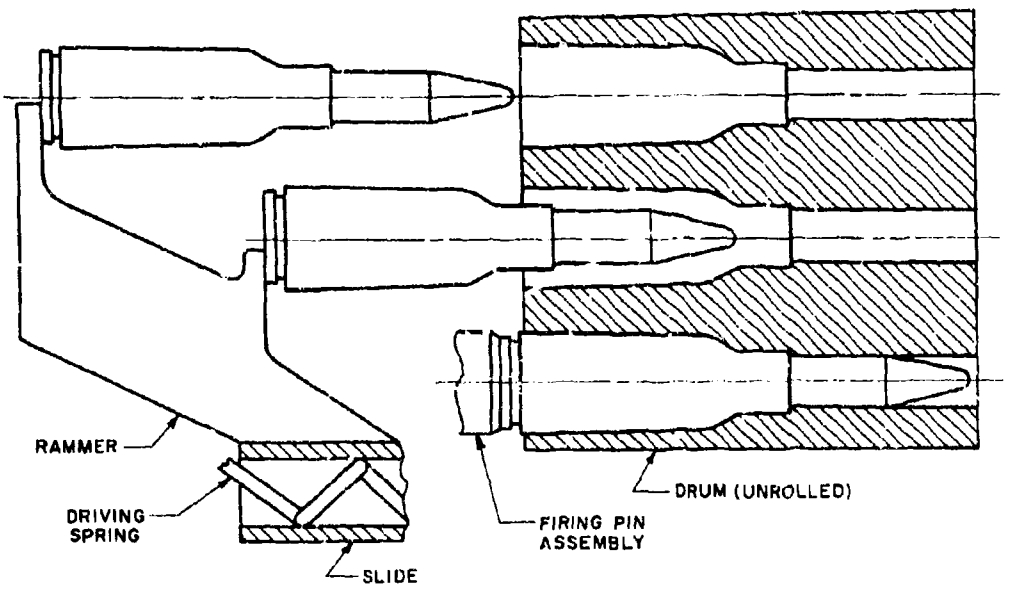


Figure 5–2. Two Stage Ramming

impulse for each increment of time, which, when subtracted from the original impulse, will yield an effective impulse.

$$(F\Delta t)_e = F_g\Delta t - F_a\Delta t \qquad (5-2)$$

The change in velocity during each time interval will be

$$\Delta v = \frac{(F\Delta t)_e}{M_r} .$$

This procedure will always have $\Sigma\Delta v = 0$, thus meeting one of the design criteria. The recoil distance is obtained from Eqs. 2–47, 2–48, and 2–49.

The data of Table 2–2 can illustrate the above procedure

$$F_a = \frac{\Sigma F_g \Delta t}{\Sigma \Delta t} = \frac{37.42}{0.006} = 6237 \text{ lb}$$

$$(F\Delta t)_e = (F_g\Delta t - F_a\Delta t) = 0$$

$$\Sigma\Delta v = \Sigma\left(\frac{F\Delta t_e}{M_r}\right) = 0$$

$$x = \Sigma\Delta x = 0.4313 \text{ in.}$$

If x is too large, F_a is increased; if too small, it is decreased. Based on the 0.25 in. recoil distance of the M39 Machine Gun, F_a must be increased. Although the adapter resistance increases as recoil progresses, the error in assuming F_a constant is minimal since the distance over which it functions is extremely short.

The recoiling parts continue to accelerate until $(F\Delta t)_e$ becomes zero. When this happens, the recoiling parts begin to decelerate but the slide continues to move under its own inertia unless the projectile has already passed the operating cylinder's gas port. In this event, a strong probability, the slide continues to accelerate under the influence of the newly supplied force source. Fig. 5–3 is a force diagram showing the accumulated effect of the various applied and induced forces

where

F_t = adapter force

F_c = operating cylinder force

F_g = propellant gas force

M_s = mass of slide

When slide and recoiling parts act as a unit $M = M_r + M_s$ (otherwise $M = M_r$ the mass of the recoiling parts), the recoil acceleration becomes

$$a_r = \frac{F_g - F_t - F_c}{M_r + M_s} . \qquad (5-4)$$

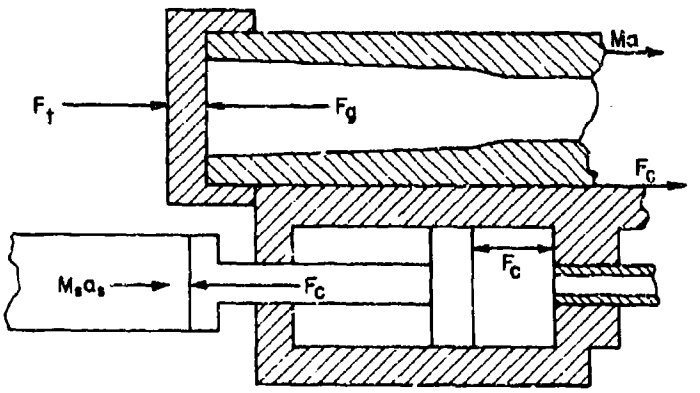


Figure 5–3. Force Diagram of Recoiling Parts and Slide

The slide acceleration becomes

$$a_s = a_r + \frac{F_c}{M_s} \quad (5\text{-}5)$$

The dynamics of the gas operating cylinder follow a procedure similar to that for the cutoff expansion system (see par. 4–3.1.1).

Before continuing with the gas system analysis, the required operating energy must be estimated which leads to the selection and analysis of the slide and drum dynamics. Transfer of energy of slide to drum and driving spring and then back to slide must be achieved with operative efficiency and tolerable forces. A system such as this is notorious for its high energy losses and large forces. These two characteristics are kept within bounds by an elliptical cam, although other curves may be used if they display similar properties with respect to cam action.

The physical dimensions of the drum are best suited to generate other design parameters. Drum length is dictated by round length. Its outer radius is based on the number of chambers and the strength of the outer wall. A minimum of 4 chambers is sufficient to meet the basic operating requirements of present revolver-type machine gun concepts but may prove awkward in actual practice because of large angular displacement for each firing cycle, thus reducing the firing rate and putting an added burden on the designer to provide more power and acceptable mechanisms such as rammers. A design study at Springfield Armory indicates an optimum number of 5 chambers when based on kinematics alone. When other factors were considered, 5 or 6 chambers showed little difference with 5 having a slightly lower firing rate but definitely lower forces and less weight, thus leaning toward 5 as the recommended number. With the number of chambers established, the linear dimensions are now available from which the mass of the drum can be estimated.

Present practice has the weight of the slide approximately 1/3 the weight of the drum. Another established criterion that provides acceptable design parameters of the cam is the relationship shown in Eq. 5–6a.

$$\frac{M_d}{M_s}\left(\frac{b^2}{a^2}\right) = 1.0 \quad (5\text{–}6a)$$

where

a = major axis of elliptical cam

b = minor axis of elliptical cam

M_d = mass of drum

M_s = mass of slide

When $M_d = 3M_s$,

$$a = 1.732\,b. \quad (5\text{–}6b)$$

Another design parameter, the index of friction,

$$\mu_f = \pi\left(\frac{a}{b} + \frac{b}{a}\right) \quad \text{(Ref. 14)} \quad (5\text{–}7a)$$

Substitute the value for a in Eq. 5–6b into Eq. 5–7a

$$\mu_f = \pi(1.732 + 0.577) = 7.23. \quad (5\text{–}7a)$$

This index may vary if other ratios of a and b become more attractive.

The slide travel relative to the receiver need be only slightly more than half the round length since ramming takes place in two stages. The addition to the half-length depends on the desired clearances between projectile nose and drum, and between rammer and cartridge case base. Straight portions of the cam provide a dwell period for the drum before and after firing; one over the first part of slide travel during recoil, the other over the last part of counterrecoil. These straight portions may be of different lengths as may be the width of the cam curves for recoil and counterrecoil. Because cam forces are inherently less severe during counterrecoil, a larger sweep of the curve for recoil has the tendency to equalize the forces of the two actions, thereby increasing the efficiency of the system. A separate study of the individual cases is recommended but the relative dimension of an existing system serves as a guide. Fig. 5–4 is a schematic of such an arrangement.

$$L_c = a_{rec} + s_{ocr} \quad (5\text{–}8)$$

$$L_c = a_{crc} + s_{ocr}$$

$$\frac{a_{crc}}{a_{rec}} = 0.6 \qquad (5-9)$$

$$\frac{b_{cr}}{b_r} = 0.75 \qquad (5-10)$$

$$\frac{s_{or}}{a_{rec}} = 0.5 \qquad (5-11)$$

$$\frac{s_{ocr}}{a_{crc}} = 1.5 \qquad (5-12)$$

$$L_c = \frac{1}{2} L_r + C_r, \text{ cam length} \qquad (5-13)$$

where

L_r = length of round

C_r = total clearance of the round at both ends

The cam width is

$$w_c = b_r + b_{cr} = \frac{2\pi R_{ch}}{N_c} \qquad (5-14)$$

where

N_c = number of chambers in drum

R_{ch} = radius of chamber about drum axis

After the preliminary cam dimensions have been estimated, attention is now directed toward the effort needed to operate all moving parts at speeds commensurate with the firing rate of the gun. Operations that require energy include feeding, ramming, and ejecting. Components that must be activated are slide and rammer, drum, feeder, and loaded ammunition belt. The size of the drum, based on present 20 mm data, has the length L_d and diameter D_d indicated in Eqs. 5-15a and 5-15b.

$$L_d = L_r, \text{ drum length} \qquad (5-15a)$$

$$D_d = 6D_b, \text{ drum diameter} \qquad (5-15b)$$

where

D_b = bore diameter.

The mass of the drum and rotating feeder components may be estimated as the solid cylinder having the above dimensions. For moving ammunition by the feeder, an additional 10 percent is added to the effort. For ramming, the mass of two rounds is added to that of slide and rammer, whose mass M_s is approximately equal to 1/3 of the drum components M_d, thus

$$M_s = 1/3\, M_d. \qquad (5\ 16)$$

The spent cartridge case should be ejected at a velocity of approximately 70 ft/sec. The velocity of other moving parts depend on the rate of fire f_r. However, since the maximum velocity of the slide should not exceed 50 ft/sec, this limit may be used as the initial estimate of the maximum slide velocity. The energy of the slide at this velocity represents the input energy of the system.

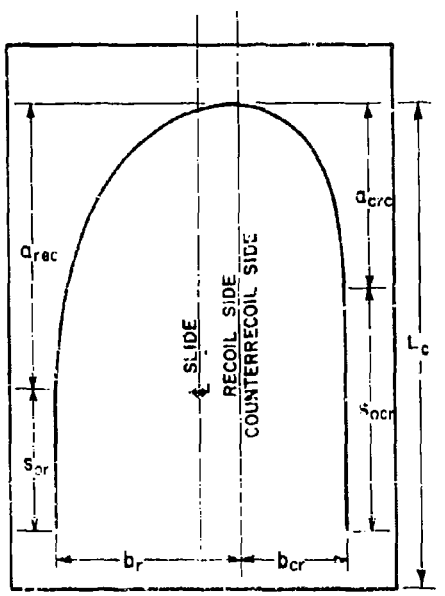


Figure 5-4. Schematic of Cam Geometry

By the time that all moving parts have returned to the firing position, where all motion ceases, considerable energy has been expended to friction, loading, and ejection. According to Ref. 14 when $x = L$, the loss of energy from slide to drum due to friction is

$$E_{\mu d} = (1.0 - e^{-\mu_f \mu}) E_d \qquad (5-17)$$

where E_d is the total energy transferred from slide to drum if the system were frictionless and μ is the coefficient of friction. The energy of the drum alone (belt energy is of no help because it cannot push) just as the slide starts to counterrecoil is computed from Eq. 59, Ref. 9, and shown in Eq. 5–18

$$E_{dcr} = \left(\frac{M_d}{M_{de}}\right) e^{-\mu_f \mu} E_d \qquad (5-18)$$

where

M_d = mass of drum

M_{de} = effective mass of drum and ammunition belt

According to Eq. 69, Ref. 9, when $x = 0$, the frictional energy loss in the slide when fully counterrecoiled is

$$E_{\mu s} = (1.0 - e^{-\mu_f \mu}) E_{dcr} . \qquad (5-19)$$

The loss attributed to the driving spring is

$$E_\epsilon = E_s(1 - \epsilon^2) \qquad (5-20)$$

where

E_s = energy transferred from slide to driving spring

ϵ = efficiency of spring system

The energy expended to eject the spent cartridge case at velocity v_e is

$$E_e = \frac{1}{2}\left(M_c v_e^2\right) \qquad (5-21)$$

where M_c = mass of cartridge case

The total expenditure of energy of the drum and its associated components during a firing cycle is expressed in Eq. 5–22.

$$E_\mu = E_{\mu d} + E_{\mu s} + E_\epsilon + E_e \qquad (5-22)$$

The energy of the slide derived from normal recoil and the gas operating cylinder is

$$E_{sr} = \frac{1}{2}\left(M_s v_{sm}^2\right) \qquad (5-23)$$

where

$v_{sm} \leq 50$ ft/sec, maximum slide velocity

M_s = mass of slide

A relatively stiff driving spring is recommended to hold the maximum velocity of drum and belt to a minimum (Ref. 9). If ρ is the ratio of spring energy E_s to drum energy E_d,

$$\rho = \frac{E_s}{E_d} . \qquad (5-24)$$

Since the slide energy is converted to spring and drum energy, $E_{sr} = E_s + E_d$, the total energy transferred to the drum is shown to be

$$E_d = E_{sr}/(1 + \rho) . \qquad (5-25)$$

The preliminary firing rate is estimated from the times of recoil and counterrecoil when based on the relative velocity of the cam follower on the drum and the cam in the slide. The recoil time (Eq. 38, of Ref. 9) is

$$t_r = \gamma\left(\frac{2s_r}{v_{sm} + v_{dm}}\right) \qquad (5-26)$$

where

s_r = cam length for recoil

v_{dm} = maximum peripheral velocity of drum

γ = correction factor

The counterrecoil time will be

$$t_{cr} = \gamma \left(\frac{2 s_{cr}}{v_{dm} + v_{scr}} \right) \qquad (5-27)$$

where

s_{cr} = cam length for counterrecoil

v_{scr} = counterrecoil velocity of slide

Based on operating guns, the empirical $\gamma = 0.935$ (Ref. 9).

The firing rate is

$$f_r = \frac{60}{t_r + t_{cr}} \text{, rounds/min.} \qquad (5-28)$$

5-1.1.1 Sample Problem of Preliminary Firing Rate Estimate

Given data W_d = 30 lb, weight of drum

W_s = 10 lb, weight of slide

W_a = 0.6 lb, weight of round

W_{cc} = 0.2 lb, weight of case

R_d = 3 in., radius of cam contact point to drum axis

L_c = 5 in., distance of slide travel (same as cam length)

N_c = 5 chambers

$a_{rec} = \frac{L_c}{1.5} = 3.33$ in. (from Eqs. 5-8 and 5-11)

$a_{crc} = 0.6\, a_{rec} = 2.0$ in. (from Eq. 5-9)

$b_r + b_{cr} = \frac{2\pi R_d}{5} = 3.77$ in., peripheral cam travel

$b_r = \frac{b_r + b_{cr}}{1.75} = 2.15$ (from Eq. 5-10)

$b_{cr} = 3.77 - 2.15 = 1.62$ in.

$s_{or} = L_c - a_{rec} = 1.67$ in.

$s_{ocr} = L_c - a_{crc} = 3.0$ in.

$s_r = s_{or} + \frac{\pi}{2} \sqrt{\frac{a_{rec}^2 + b_r^2}{2}} = 1.67 + 4.40 = 6.07$ in.,

cam follower travel during recoil

$s_{cr} = s_{ocr} + \frac{\pi}{2} \sqrt{\frac{a_{crc}^2 + b_{cr}^2}{2}} = 3.0 + 2.86 = 5.86$ in.,

cam follower travel during counterrecoil

v_e = 840 in./sec, maximum recommended ejection velocity of cartridge

v_{sm} = 600 in./sec, maximum allowable slide velocity

$E_{sr} = \frac{1}{2} \left(M_s v_{sm}^2 \right) = \frac{10 \times 360000}{2 \times 386.4}$

= 4658.4 in.-lb, maximum slide energy of recoil

Select $\rho = 0.25$

$E_d = \frac{E_{sr}}{1 + \rho} = \frac{4658.4}{1.25}$

= 3726.7 in.-lb, energy to be transferred to drum

$E_s = E_{sr} - E_d = 931.7$ in.-lb,

energy to be transferred to driving spring

At the end of slide recoil, the energy in the drum, Eq. 5-18, becomes

$$E_{dcr} = \left(\frac{M_d}{M_{de}}\right) e^{-\mu_f \mu} E_d = \frac{30}{33}\left(\frac{3726.7}{e^{0.723}}\right)$$

$$= \frac{111801}{68} = 1644.1 \text{ in.-lb}$$

where

$$M_{de} = 1.1\, M_d = 33/g$$

$$\mu_f \mu = 7.23 \times 0.1 = 0.723$$

$$E_{dcr} = \frac{1}{2}\left(I_d \omega_d^2\right) = \frac{1}{2}\left(M_d k^2 \omega_d^2\right)$$

$$= \frac{1}{2} M_d \left(\frac{R_d^2}{2}\right)\left(\frac{v_{dm}^2}{R_d^2}\right) = \frac{1}{4} M_d v_{dm}^2$$

where I_d = mass moment of inertia of drum

k = radius of gyration

ω_d = angular velocity of drum

$$v_{dm} = \sqrt{\frac{4E_{dcr}}{M_d}} = \sqrt{\frac{4 \times 386.4 \times 1644.1}{30}}$$

$$= \sqrt{84704} = 291 \text{ in./sec, maximum}$$

peripheral velocity of drum

The energy transferred from drum to slide, from Eq. 5-19, is

$$E_{sd} = e^{-\mu_f \mu} E_{dcr} = \frac{1644.1}{2.06} = 798.1 \text{ in.-lb.}$$

The energy transferred from driving spring to slide, assuming 80% efficiency, Eq. 5-20, is

$$E_{ss} = e^2 E_s = 0.64 \times 931.7 = 596.3 \text{ in.-lb.}$$

The energy expended for ejection, Eq. 5-21, is

$$E_e = \frac{1}{2}\left(M_{ce} v_e^2\right) = \frac{0.2 \times 705600}{2 \times 386.4} = 182.6 \text{ in.-lb.}$$

The energy in the slide at end of counterrecoil is

$$E_{scr} = E_{sd} + E_{ss} - E_e = 1211.8 \text{ in.-lb.}$$

The velocity of the slide at end of counterrecoil when it bears the additional weight of two rounds is

$$v_{scr} = \sqrt{\frac{2E_{scr}}{M_s + 2M_a}} = \sqrt{\frac{2 \times 1211.8 \times 386.4}{10 + 2 \times 0.6}}$$

$$= \sqrt{83614} = 289 \text{ in./sec.}$$

According to Eqs. 5-26 and 5-27, the firing cycle time becomes

$$t_c = 2\gamma\left(\frac{s_r}{v_{sm} + v_{dm}} + \frac{s_{cr}}{v_{dm} + v_{scr}}\right)$$

$$= 1.87\left(\frac{6.07}{891} + \frac{5.86}{580}\right)$$

$$= 1.87\,(0.0068 + 0.0101) = 0.0316 \text{ sec}$$

where $\gamma = 0.935$.

The firing rate, Eq. 5-28, is estimated to be

$$f_r = \frac{60}{t_c} = \frac{60}{0.0316} = 1898 \text{ rounds/min.}$$

If the firing rate is too high, the initial velocity of the slide may be reduced proportionately. If too low, other avenues of design improvement must be explored since the upper limit of slide velocity has been incorporated. A stiffer driving spring, variations in moving masses, and efficiency improved by lowering frictional resistance represent three means of achieving a higher firing rate. All involve refinements in design.

5-1.1.2 Analysis of Cam Action

The forces induced by cam action on the slide and drum roller are shown diagrammatically in Fig. 5-5

for both the recoiling and counterrecoiling slide. Because the slide and drum are constrained in the y- and x-directions, respectively, their motions are restricted to axial and peripheral travel, respectively. Other forces are also present; on the slide, the driving spring force and track reactions; on the drum, the thrust and radial bearing reactions. The accelerating forces on either slide or drum are affected only to the extent of the frictional resistances provided by these reactions.

Before resolving the cam forces, the influence of the drum roller must be considered. If the cam follower were a sliding rather than a rolling element, the tangential frictional force on the cam would be merely μN. The roller reduces μN to a lesser value depending on the ratio of pin radius to roller radius. In the drum roller force diagram of Fig. 5–5, the friction resistance is generated between the roller and the pin since no sliding takes place on the rolling surface. Equate the moments about the pin center.

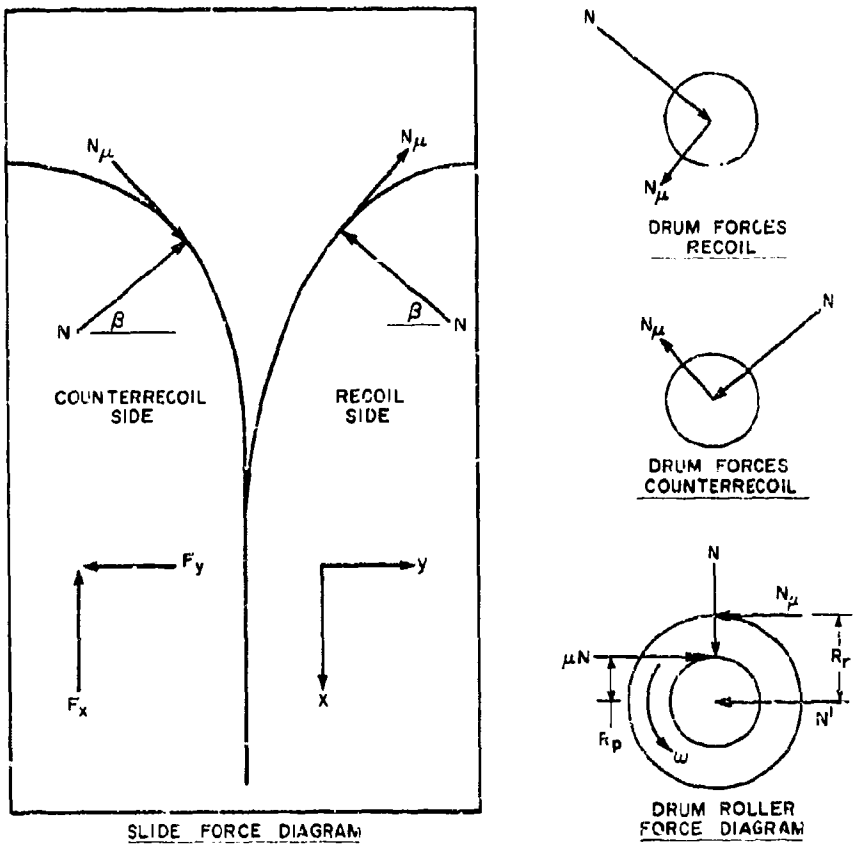


Figure 5–5. Cam-slide Force Diagrams

$$N_\mu R_r = \mu N R_p \qquad (5-29)$$

$$N_\mu = \mu N \left(\frac{R_p}{R_r}\right) \qquad (5-30)$$

$$N' = \mu N - N_\mu = \mu N \left(1 - \frac{R_p}{R_r}\right). \qquad (5-31)$$

The resultant load on the roller pin becomes

$$F_p = \mu N - N' = \mu N \left(\frac{R_p}{R_r}\right) = N_\mu . \qquad (5-32)$$

Resolve the cam forces during slide recoil so that

$$F_x = N \sin\beta + N_\mu \cos\beta$$

$$= N\left[\sin\beta + \mu\left(\frac{R_p}{R_r}\right)\cos\beta\right] = NK_x \qquad (5-33)$$

$$F_y = N\cos\beta - N_\mu \sin\beta$$

$$= N\left[\cos\beta - \mu\left(\frac{R_p}{R_r}\right)\sin\beta\right] = NK_y . \qquad (5-34)$$

Resolve the cam forces during counterrecoil

$$F_x = N\left[\sin\beta - \mu\left(\frac{R_p}{R_r}\right)\cos\beta\right] = NK_x \qquad (5-35)$$

$$F_y = -N\left[\cos\beta + \mu\left(\frac{R_p}{R_r}\right)\sin\beta\right] = NK_y . \qquad (5-36)$$

Fig. 5–6 shows the applied and induced forces on the drum. Except for the cam force F_y, only the frictional components affect the dynamics. The horizontal reaction on the drum shaft is

$$R_y = F_y - \mu F_g \qquad (5-37a)$$

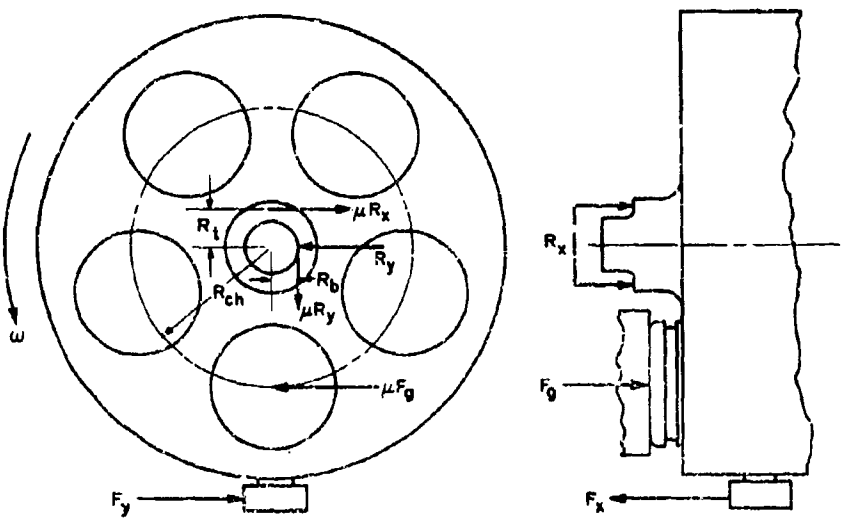


Figure 5–6. Single Barrel Drum Loading Diagram

where

F_g = residual propellant gas force of the round just fired

$$R_x = F_x \tag{5-37b}$$

The frictional force on the thrust bearing μR_x is distributed over the entire annular area and its resultant in any direction is zero. All frictional forces on the drum affect its angular motion. The accelerating torque is expressed as

$$T_\alpha = T_\theta - T_\mu = I_d \alpha_d \tag{5-38}$$

where

I_d = mass polar moment of inertia of drum about its shaft

α_d = angular acceleration of drum

$T_\theta = R_d F_y = N R_d K_y$, applied torque (5-39)

$$T_\mu = R_b \mu R_y + \mu F_x \left[R_t + R_d \left(\frac{R_p}{R_r} \right) \right] + R_{ch} \mu F_g, \text{ resisting torque} \tag{5-40}$$

Note that $\mu F_x R_t$ has been substituted for $\mu R_x R_t$. (See Eq. 5-37b)

Observe in Eq. 5-40 that $\mu F_x R_d \left(\frac{R_p}{R_r} \right)$ is the torque resistance contributed by the cam. This expression is derived from the axial component of the cam force, acts in the y-direction, and may be computed by substituting F_x for N in Eq. 5-30.

Substitute for R_y and collect terms, thus

$$T_\mu = \mu \left\{ R_b F_y + \left[R_t + R_d \left(\frac{R_p}{R_r} \right) \right] F_x + (R_{ch} - \mu R_b) F_g \right\} \tag{5-41}$$

Substitute for F_x and F_y and let $\mu(R_{ch} - \mu R_b)F_g = T_g$.

$$T_\mu = \mu N \left\{ \left[R_t + R_d \left(\frac{R_p}{R_r} \right) \right] K_x + R_b K_y \right\} + T_g \tag{5-42}$$

An expression for α can be found from the kinematics of Fig. 5-7. As the cam moves, the relative velocity of the drum roller at any position is v_c. The cam path being curved, the normal acceleration, again at any given position, is

$$a_n = \frac{v_c^2}{R_c} \tag{5-43}$$

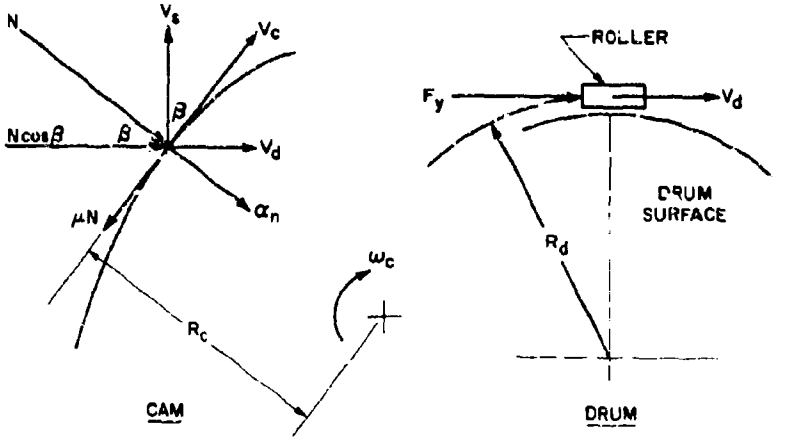


Figure 5-7. Single Barrel Drum Dynamics

However, the roller on the drum can physically travel only in the direction indicated by its tangential velocity v_d, hence the tangential roller acceleration becomes

$$a_d = a_n \cos\beta = \frac{v_c^2}{R_c} \cos\beta \tag{5-44}$$

With $v_s = v_c \cos\beta$, the angular acceleration of the drum may be expressed in terms of the slide velocity.

$$\alpha_d = \frac{a_d}{R_d} = \frac{v_s^2}{R_c R_d \cos\beta} \tag{5-45}$$

Rewrite Eq. 5-38 with appropriate substitutions and solve for N. Thus,

$$NR_d K_y - \mu N \left\{ \left[R_t + R_d \left(\frac{R_p}{R_r} \right) \right] K_x + R_b K_y \right\} - T_g = I_d \left(\frac{v_s^2}{R_c R_d \cos\beta} \right) \tag{5-46}$$

$$N = \frac{\dfrac{I_d v_c^2 \cos\beta}{R_c R_d} + T_g}{(R_d - \mu R_b) K_y - \mu \left[R_t + R_d \left(\dfrac{R_p}{R_r} \right) \right] K_x} \tag{5-47}$$

In the meantime, the slide is subjected to cam forces as well as the driving spring force F and also the frictional resistance μF_y of the slide tracks.

The cam is the medium for transferring energy. The equation of an elliptical cam is

$$\frac{x^2}{a^2} + \frac{y^2}{b^2} = 1 \tag{5-48}$$

or

$$y = \pm \frac{b}{a} \sqrt{a^2 - x^2} \tag{5-49}$$

where

a = half of the major axis in x-direction

b = half of the minor axis in y-direction

The slope at any point is $\tan \beta$.

$$\tan \beta = \frac{dy}{dx} = \frac{b}{a}\left(\frac{x}{\sqrt{a^2 - x^2}}\right) \tag{5-50}$$

$$\frac{d^2y}{dx^2} = \frac{ab}{(a^2 - x^2)^{3/2}} \tag{5-51}$$

The radius of the curvature of the cam at any position is R_c

$$R_c = \frac{\left[1.0 + \left(\frac{dy}{dx}\right)^2\right]^{3/2}}{\frac{d^2y}{dx^2}} = \frac{\left[a^2 - \frac{x^2}{a^2}(a^2 - b^2)\right]^{3/2}}{ab} \tag{5-52}$$

The cam dynamics involve an iterative integration procedure for which the law of conservation of energy becomes a convenient basis for computing the values of each increment. For any increment

$$E_i = E_{sr} + E_d + \Delta E + E_\mu = \frac{1}{2}\left(M_s v_s^2\right) + I_d\left(\frac{\tan^2 \beta}{2R_d^2}\right) v_s^2 + \frac{1}{\epsilon} F_a \Delta x + E_\mu \tag{5-53}$$

where

ΔE = differential driving spring energy

E_d = drum energy at end of increment

E_i = input energy of each increment

E_{sr} = slide energy at end of increment

F_a = average driving spring force

Δx = incremental travel of slide

E_μ = frictional losses during increment

ϵ = spring efficiency.

Note that for the next increment,

$$E_i = \text{preceding } E_i = E_\mu \tag{5-54}$$

The object now is to put E_μ into terms of v_s so that Eq. 5–53 may be solved. The resultant frictional force in the x-direction is composed of the frictional resistance of slide tracks and that of the cam in the x-direction

$$F_{\mu s} = \mu F_y + \mu F_y \left(\frac{R_\rho}{R_r}\right) = \mu F_y \left(1.0 + \frac{R_\rho}{R_r}\right) \tag{5–55}$$

Write F_y in terms of N.

$$F_{\mu s} = \mu N K_y \left(1.0 + \frac{R_\rho}{R_r}\right) \tag{5–56}$$

The energy loss in the slide is

$$E_{\mu s} = \frac{1}{2}\,(F_{\mu s1} + F_{\mu s2})\,\Delta x\,. \tag{5–57}$$

where subscripts 1 and 2 indicate values for adjacent increments.

The energy loss in the drum becomes

$$E_{\mu d} = \frac{1}{2}\,(T_{\mu 1} + T_{\mu 2})\,\Delta\theta\,. \tag{5–58}$$

The total frictional losses in drum and slide is the sum of the two components

$$E_\mu = E_{\mu d} + E_{\mu s}\,. \tag{5–59}$$

5–1.1.2.1 Sample Calculation of Cam Action

The sample problem is the continuation of the one outlined in par. 5–1.1.1, at a time when the slide has traveled 2.0 inches on the cam. Thus, $x_1 = 2.0$. From Eq. 5–49.

$$y_1 = \frac{b}{a}\sqrt{a^2 - x^2} = \frac{2.15}{3.33}\sqrt{11.09 - 4}$$

$$= 0.6456 \times 2.6627 = 1.719 \text{ in.}$$

$$\tan\beta_1 = \frac{b}{a}\left(\frac{x}{\sqrt{a^2 - x^2}}\right) = \frac{2.15}{3.33}\left(\frac{2.0}{2.6627}\right)$$

$$= 0.4850 \text{ (from Eq. 5-50)}$$

$$\beta_1 = 25^\circ\,52.2' = 0.4470 \text{ rad}$$

$$\sin\beta_1 = 0.4364$$

$$\cos\beta_1 = 0.8998$$

$$\frac{d^2y}{dx^2} = \frac{ab}{(a^2 - x^2)^{3/2}} = \frac{3.33 \times 2.15}{18.88}$$

$$= 0.379 \text{ (from Eq. 5–51).}$$

According to Eq. 5–52

$$R_{c1} = \frac{\left[a^2 - \frac{x^2}{a^2}\,(a^2 - b^2)\right]^{3/2}}{ab}$$

$$= \frac{\left[11.09 - \frac{4.0}{11.09}\,(11.09 - 4.62)\right]^{3/2}}{7.16}$$

$$= 3.62 \text{ in.}$$

At this time the driving spring has been compressed by

$$L_x = s_{or} + x = 1.67 + 2.0 = 3.67 \text{ in.}$$

The energy absorbed by the spring at this position is E_s.

$$E_s = \frac{3.67}{5.0}\;931.7 = 684 \text{ in.-lb}$$

The energy confined to the drum-slide system is

$$E_{ds} = E_{tr} - E_s = 3974.4 \text{ in.-lb.}$$

After losses have been deleted, the energy remaining in the system is

$$E'_{ds} = E_{ds} e^{-\mu_f \mu \frac{x}{a}} \quad \text{(Ref. 14)} \tag{5–60}$$

$$E'_{ds} = 3974.4\, e^{-0.434} = \frac{3974.4}{1.543} = 2576 \text{ in.-lb}$$

where $-\mu_i \mu \frac{x}{a} = -7.23 \times 0.1 \times 2.0/3.33 = -0.434$

$$E'_{ds} = \frac{1}{2}\left(I_{de}\omega_d^2\right) + \frac{1}{2}\left(M_s v_s^2\right)$$

$$= \left(\frac{1}{4} M_{de} \tan^2 \beta_1 + \frac{1}{2} M_s\right) v_s^2$$

$$v_s^2 = \frac{2576 \times 386.4}{1.94 + 5.0} = 143{,}425 \text{ in.}^2/\text{sec}^2$$

$$v_s = 378.7 \text{ in./sec}$$

where

$$\frac{1}{4} M_{de} \tan^2 \beta_1 = 1.94/g$$

$$\frac{1}{2} M_s = 5.0/g$$

The above given and computed values are assumed to be the values of the parameters at $x = 2.0$ in. To illustrate the integration process, assume an incremental travel of $\Delta x = 0.05$ in.

$$x_2 = x_1 + \Delta x = 2.00 + 0.05 = 2.05 \text{ in.}$$

$$y_2 = \frac{b}{a}\left(\sqrt{a^2 - x^2}\right) = \frac{2.15}{3.33}\sqrt{11.09 - 4.203}$$

$$= 0.6456 \times 2.6243 = 1.694 \text{ in.}$$

$$\tan \beta_2 = \frac{b}{a}\left(\frac{x}{\sqrt{a^2 - x^2}}\right) = \frac{2.15 \times 2.05}{3.33 \times 2.6243}$$

$$= \frac{4.4075}{8.7389} = 0.5044$$

$$\beta_2 = 26^\circ\ 46.1' = 0.4672 \text{ rad}$$

$$\sin \beta_2 = 0.4504$$

$$\cos \beta_2 = 0.8929$$

$$\Delta y = y_1 - y_2 = 0.025$$

$$\Delta\theta = \frac{\Delta y}{R_d} = \frac{0.025}{3.0} = 0.00833 \text{ rad}$$

$$\frac{d^2y}{dx^2} = \frac{ab}{(a^2 - x^2)^{3/2}} = \frac{3.33 \times 2.15}{18.07} = 0.396$$

$$R_{c2} = \frac{\left[a^2 - \frac{x^2}{a^2}(a^2 - b^2)\right]^{3/2}}{ab}$$

$$= \frac{\left[11.09 - \left(\frac{4.203}{11.09}\right) 6.47\right]^{3/2}}{7.16} = 3.55 \text{ in.}$$

Additional given data are now listed.

F_g = 1000 lb, propellant gas force (residual)

R_b = 1.0 in., radius of radial bearing

R_{ch} = 1.5 in., chamber center to drum axis

R_p = 0.25 in., radius of roller pin

R_r = 0.5 in., roller radius

R_t = 1.25 in., thrust bearing pressure radius

μ = 0.10, coefficient of friction

In Eq. 5-42,

$$T_g = \mu(R_{ch} - \mu R_b)F_g = 0.10(1.5 - 0.10 \times 1.0)1000$$

= 140 in.-lb

$$I_d = M_d k^2 = M_d\left(\frac{R_d^2}{2}\right) = \frac{30}{386.4}\left(\frac{9}{2}\right)$$

= 0.35 lb-in.-sec^2, mass moment of inertia of drum

During slide recoil when the ammunition must also be accelerated, the effective mass moment of inertia I_{de} changes from I_d to

$$I_{de} = (1.1)I_d = 0.385 \text{ lb-in.-sec}^2.$$

From Eq. 5-33

$$K_{x1} = \sin\beta_1 + \mu\left(\frac{R_p}{R_r}\right)\cos\beta_1 = 0.4364 + 0.10 \times 0.5 \times 0.8998 = 0.4814$$

$$K_{x2} = \sin\beta_2 + \mu\left(\frac{R_p}{R_r}\right)\cos\beta_2 = 0.4505 + 0.10 \times 0.5 \times 0.8929 = 0.4950.$$

From Eq. 5-34

$$K_{y1} = \cos\beta_1 - \left(\frac{R_p}{R_r}\right)\sin\beta_1 = 0.8998 - 0.10 \times 0.5 \times 0.4364 = 0.8780$$

$$K_{y2} = \cos\beta_2 - \left(\frac{R_p}{R_r}\right)\sin\beta_2 = 0.8929 - 0.10 \times 0.5 \times 0.4504 = 0.8704.$$

Since the slide is recoiling, substitute $v_s/\cos\beta$ for v_c in Eq. 5-47, thus

$$N_1 = \frac{\dfrac{I_{dc}v_{s1}^2}{R_{c1}R_d\cos\beta_1} + T_g}{(R_d - \mu R_b)K_{y1} - \mu\left[R_t + R_d\left(\dfrac{R_p}{R_r}\right)\right]K_{x1}}$$

$$= \frac{\dfrac{0.385 \times 143425}{3.62 \times 3.0 \times 0.8998} + 140}{(3.0 - 0.10 \times 1.0)\,0.8780 - 0.10\,(1.25 + 3.0 \times 0.5)\,0.4814} = \frac{5651 + 140}{2.546 - 0.132} = \frac{5791}{2.414} = 2399 \text{ lb}$$

$$N_2 = \frac{\dfrac{I_{dc}v_{s2}^2}{R_{c2}R_d\cos\beta_2} + T_g}{(R_d - \mu R_b)K_{y2} - \mu\left[R_t + R_d\left(\dfrac{R_p}{R_r}\right)\right]K_{x2}}$$

$$= \frac{\dfrac{0.385\,v_{s2}^2}{3.55 \times 3.0 \times 0.8929} + 140}{2.9 \times 0.8704 - 0.275 \times 0.4950} = \frac{0.0405\,v_{s2}^2 + 140}{2.524 - 0.136} = 0.01696\,v_{s2}^2 + 59.$$

The preliminary characteristics of the driving spring are based on an assumed efficiency of 80% and for $F_m \approx 2F_o$. The average spring force F_a over the full recoil distance is now computed.

$$F_a = \frac{eE_s}{L_s} = \frac{0.8 \times 931.7}{5} = 149 \text{ lb}$$

$$F_a = \frac{F_o + F_m}{2} = \frac{F_o + 2F_o}{2} = 149$$

$$F_o = \frac{298}{3} = 99.3; \quad F_m = 198.7 \text{ lb}.$$

The spring constant

$$K = \frac{F_m - F_o}{L} = \frac{99.4}{5} = 19.88 \text{ lb/in.}$$

$$F_{x1} = F_o + 3.67K = 99.3 + 73.0 = 172.3 \text{ lb}$$

$$F_{x2} = F_o + 3.72K = 99.3 + 74.0 = 173.3 \text{ lb}.$$

Isolate the components of Eq. 5-53 to compute the combined energy of drum and slide

$$E_i = E'_{ds} = 2576 \text{ in.-lb}$$

$$E_{sr} = \frac{1}{2}\left(M_s v_{s2}^2\right) = \frac{10 v_{s2}^2}{2 \times 386.4} = 0.01294\, v_{s2}^2$$

$$E_d = \frac{1}{2} I_{de}\left(\frac{\tan^2 \beta_2}{R_d^2}\right) v_{s2}^2$$

$$= \left(\frac{0.385 \times 0.2544}{2 \times 9}\right) v_{s2}^2 = 0.00544\, v_{s2}^2$$

$$\Delta E = \frac{1}{\epsilon} F_{sa}\, \Delta x = \left(\frac{172.3 + 173.3}{0.8 \times 2}\right) 0.05$$

$$= 10.8 \text{ in.-lb}.$$

Insert the appropriate values in Eqs. 5-42 and 5-56 and compute the torsional and slide frictional resistance

$$T_{\mu s1} = N_1 (0.275 K_{x1} + 0.1 K_{y1}) + T_g$$

$$= 2399 (0.1324 + 0.0878) + 140 = 668.3 \text{ lb-in.}$$

$$T_{\mu s2} = N_2 (0.275 K_{x2} + 0.1 K_{y2}) + T_g$$

$$= (0.01696 v_{s2}^2 + 59)(0.1361 + 0.0870) + 140$$

$$= 0.00378 v_{s2}^2 + 153.2 \text{ lb-in.}$$

$$F_{\mu s1} = 0.15 K_{y1} N_1 = 0.15 \times 0.8780 \times 2599$$

$$= 315.9 \text{ lb}$$

$$F_{\mu s2} = 0.15 K_{y2} N_2 = 0.15 \times 0.8704 (0.01696 v_s^2 + 59)$$

$$= 0.00221 v_{s2}^2 + 7.7 \text{ lb}$$

According to Eqs. 5-57 and 5-58, the energy losses are

$$E_{\mu s} = \frac{1}{2}(315.9 + 7.7 + 0.00221\, v_{s2}^2)\, 0.05$$

$$= 8.1 + 5.525 \times 10^{-5} v_s^2$$

$$E_{\mu d} = \frac{1}{2}(668.3 + 153.2 + 0.00378\, v_{s2}^2)\, 0.00833$$

$$= 3.4 + 1.574 \times 10^{-5} v_{s2}^2$$

Insert computed values in Eq. 5-53 and solve for slide velocity v_s and the energy E_i.

$$2576 = (1294 + 544 + 5.525 + 1.574) v_{s2}^2 \times 10^{-5}$$

$$+ 10.8 + 8.1 + 3.4$$

$$1845.1 \times 10^{-5} v_{s2}^2 = 2553.7$$

$$v_{s2} = \sqrt{138{,}412} = 372 \text{ in./sec}$$

$$E_\mu = 11.5 + 7.099 \times 10^{-5} v_{s2}^2 = 11.5 + 9.9 = 21.4 \text{ in.-lb}$$

$$E_l = E_{l(-1)} - \Delta E - E_\mu = 2543.8 \text{ in.-lb}$$

5–1.1.2.2 Driving Spring

The average force on each of two driving springs over the decelerating period of the slide is computed from the known slide energy.

$$F_a = \frac{eE_s}{2a_{rec}} = \frac{0.8 \times 931.7}{2 \times 3.33} = 111.9 \text{ lb.}$$

where

a_{rec} = 3.33 in., slide travel during slide deceleration

E_s = 931.7 in.-lb, slide energy

e = 0.80, system efficiency (assumed)

Investigation shows that $K = 20$ lb/in. is a practical spring constant. The compression time of the spring

$$T_c = t_r = 1.87 \times 0.0068 = 0.0127 \text{ sec}$$

(see par. 5–1.1.1).

The surge time $T = \frac{T_c}{1.8} = 0.00706$ sec (see par. 2–2.3.5).

Select a spring diameter of $D = 1.0$ in., then compute the wire diameter according to Eq. 2–42.

$$d = 0.27 \sqrt[3]{DKT} = 0.27 \sqrt[3]{0.1412} = 0.1406 \text{ in.}$$

Compute the number of coils from Eq. 2–41.

$$N = \frac{Gd^4}{8D^3K} = \frac{11.5 \times 10^6 \times 3.90 \times 10^{-4}}{8 \times 1.0 \times 20} = 28.1 \text{ coils}$$

The spring solid height is

$$H_s = Nd = 28.1 \times 0.1406 = 4 \text{ in.}$$

Since $F_a = \frac{F_o + F_m}{2}$ and $F_o = F_m - Ka_r$

$$F_m = F_a + \frac{1}{2} Ka_{rec} = 111.9 + 33.3 = 145.2 \text{ lb}$$

The static torsional stress, Eq. 2–43, is

$$\tau = \frac{8F_m D}{\pi d^3} = \frac{8 \times 145.2 \times 1.0}{\pi \times 2.78 \times 10^{-3}} = 133{,}200 \text{ lb/in.}^2$$

The dynamic torsional stress, Eq. 2–44, is

$$\tau_d = \tau\left(\frac{1}{T_c}\right)\left[f\left(\frac{T_c}{T}\right)\right] = 133{,}200 \left(\frac{1}{1.8}\right) 2 = 148{,}000 \text{ lb/in.}^2$$

5–1.2 FINAL ESTIMATE OF THE COMPLETE FIRING CYCLE

This sample problem involves the procedures for computing all the data involved for making an accurate estimate of the firing rate for a drum-type machine gun by analyzing the firing cycle in detail. The interior ballistics of Fig. 5–8 are for a 20 mm gun firing a 2000-gram projectile with a 500-grain propellant charge. The pressure has been modified so that the impulse generated by the gas force is congruous with the momentum of projectile and gas from the expression obtained from Eq. 2–14

$$F_g dt = (M_p + \frac{1}{2} M_g) dv$$

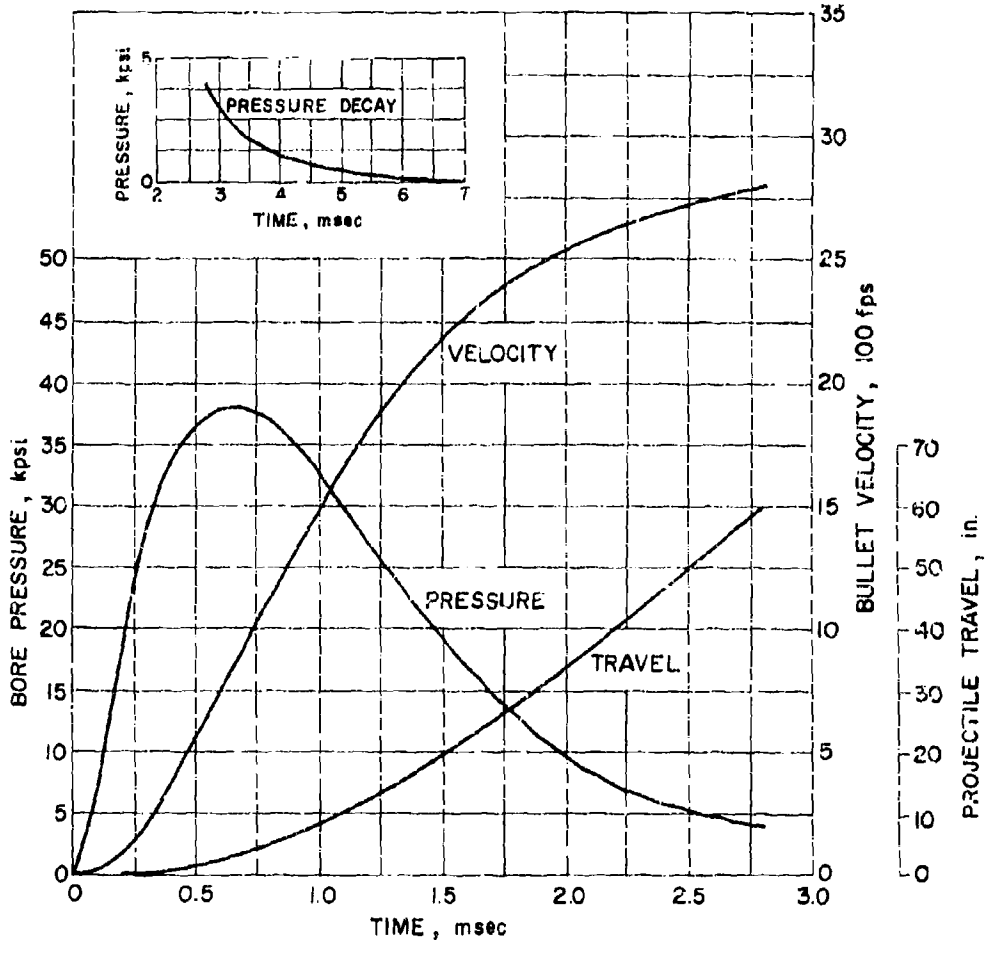


Figure 5–8. Interior Ballistics of 20 mm Revolver-type Gun

Only half the mass of the propellant gas is assumed in motion. This assumption is based on the theory that the velocity of the gas varies linearly as the distance that the projectile has traveled in the bore. It varies from zero in the chamber to the projectile velocity. Thus, if the projectile velocity is v, the momentum of the propellant gas at any time is $M_g v/2$, which indicates that the equivalent mass moving at projectile velocity is $1/2\ M_g$.

5-1.2.1 Control of Recoil Travel During Propellant Gas Period

The given design data include all the given and computed data available from the preliminary firing rate and cam analyses. The additional design data include

L_t = 0.25 in., recoil distance of barrel

L_p = 16 in., location of gas port along barrel

W_r = 96 lb, weight of recoiling parts including 10-lb slide

Table 5-1 shows a free recoil distance of x = 0.572 in. that exceeds the specified travel L_t = 0.25 in. To curb free recoiling tendencies, the adapter resists the propellant gas force at all times. To realize a shorter recoil stroke, the resistance of the adapter and the influence of the gas pressure force in the operating cylinder must be used. This effort is shown in Table 5-2. Since the gas activity in the slide operating cylinder has not been analyzed, its effect on the recoiling parts at this stage is assumed to be included in the adapter performance.

Before computing the data in Table 5-2, some of the data in Table 5-1 are modified to fit more closely the design requirements. The impulse of the propellant gas force forms the basis for the modified values, $F_g \Delta t$ = 29.65 lb-sec. If left uninhibited, a free recoil velocity of 119.4 in./sec is induced, a condition that should not prevail. Lower velocities are achieved by establishing lower effective impulses. The total impulse at t = 1.375 msec when the projectile reaches the gas port $(\Sigma F_g \Delta t)_p$ = 20.31 lb-sec. At this time, the force on the slide operating piston is arbitrarily assumed to exceed the component of the propellant gas force (see Fig. 5-1).

$$F_c > F_g \left(\frac{W_s}{W_r + W_s} \right)$$

Thus separating the slide from the recoiling parts and reducing the latter's weight from 96 to 86 lb tends to increase recoil accelerations, provided that the parts are subjected to the same impulses. The average impulsive force corrected for the change of weight is

$$F_a = \frac{1}{t} \left\{ (\Sigma F_g \Delta t)_p + \left[\Sigma F_g \Delta t - (\Sigma F_g \Delta t)_p \right] \frac{86}{96} \right\}$$

$$= \frac{20.31 + 8.37}{0.006} = 4780 \text{ lb}$$

(t = 0.006 sec from last entry in the first column Table 5-2).

The impulse of the propellant gas is present over the entire recoil stroke, therefore, to have the recoil velocity reach zero just at full recoil, a resisting impulse equal to the applied impulse must be made available. This impulse should be distributed so that the full stroke and zero velocity are reached simultaneously which can be achieved by iterative computation with time rather than distance determining the distribution of forces. The initial and final resisting forces are determined from the average with the former low enough not to limit recoil travel too severely, and the latter not to reach loads that cannot be tolerated with respect to handling and structural sizes. During the first 0.25 msec, the average gas force is F_g = 5600 lb. Since motion should not be totally impeded, a resisting force of about half this value, or F_{ot} = 3000 lb may serve as a first trial. The corresponding resistance offered by the adapter is the maximum adapter force.

$$F_{mt} = 2F_a - F_{ot} = 9560 - 3000 = 6560 \text{ lb}$$

The resisting force at any time is based on the initial force of F_{ot}

$$F_t = F_{ot} + \left(\frac{F_{mt} - F_{ot}}{\Delta t} \right) t = 3000 + \left(\frac{3560}{0.006} \right) t$$

$$= 3000 + 593333t$$

TABLE 5–1. FREE RECOIL DATA OF 20 mm REVOLVER-TYPE MACHINE GUN

t, msec	Δt, msec	A_i, lb-sec/in.^{2}	$F_g \Delta t$, lb-sec	Δw_f, in./sec	v_f, in./sec	v_e, in./sec	Δx, in.	x, in.
0.25	0.25	2.72	1.40	5.6	5.6	2.8	0.0007	0.0007
0.50	0.25	8.06	4.15	16.7	22.3	14.0	0.0035	0.0042
0.75	0.25	9.44	4.86	19.6	41.9	32.1	0.0080	0.0122
1.00	0.25	8.84	4.55	18.3	60.2	52.0	0.0130	0.0252
1.25	0.25	7.32	3.77	15.2	75.4	67.8	0.0170	0.0422
1.375	0.125	3.06	1.58	6.4	81.8	78.6	0.0098	0.0520
1.50	0.125	2.72	1.40	5.6	87.4	84.6	0.0106	0.0626
1.75	0.25	4.14	2.13	8.6	96.0	91.7	0.0229	0.0855
2.00	0.25	2.95	1.52	6.1	102.1	99.0	0.0248	0.1103
2.25	0.25	2.06	1.06	4.3	106.4	104.2	0.0260	0.1363
2.50	0.25	1.46	0.75	3.0	109.4	107.9	0.0270	0.1633
2.80	0.30	1.51	0.78	3.1	112.5	111.0	0.0333	0.1966
3.00	0.20	0.73	0.38	1.5	114.0	113.2	0.0226	0.2192
4.00	1.00	1.57	0.81	3.3	117.3	115.6	0.1156	0.3348
5.00	1.00	0.75	0.39	1.6	118.9	118.1	0.1181	0.4529
6.00	1.00	0.24	0.12	0.5	119.4	119.2	0.1192	0.5721

TABLE 5–2. PRELIMINARY RECOIL ADAPTER DATA

t, msec	F_t, lb	$F_t\Delta t$, lb-sec	$F_e\Delta t$, lb-sec	Δv_r, in./sec	v_r, in./sec	v_g, in./sec	Δx, in.	x, in.
0.25	3150	0.79	0.61	2.5	2.5	1.2	0.0003	0.0003
0.50	3300	0.82	3.33	13.4	15.9	9.2	0.0023	0.0026
0.75	3440	0.86	4.00	16.1	32.0	24.0	0.0060	0.0086
1.00	3590	0.90	3.65	14.7	46.7	39.4	0.0098	0.0184
1.25	3740	0.94	2.83	11.4	58.1	52.4	0.0131	0.0315
1.375	3820	0.48	1.10	4.4	62.5	60.3	0.0075	0.0390
1.50	3890	0.49	0.91	4.1	66.6	64.6	0.0081	0.0471
1.75	4040	1.01	1.12	5.0	71.6	69.1	0.0173	0.0644
2.00	4190	1.05	0.47	2.1	73.7	72.6	0.0182	0.0826
2.25	4330	1.08	-0.02	- 0.1	73.6	73.6	0.0184	0.1010
2.50	4480	1.12	-0.37	- 1.7	71.9	72.8	0.0182	0.1192
2.80	4660	1.40	-0.62	- 2.8	69.1	70.5	0.0225	0.1417
3.00	4780	0.96	-0.58	- 2.6	66.5	67.8	0.0136	0.1553
4.00	5370	5.37	-4.56	-20.5	46.0	56.2	0.0562	0.2115
5.00	5970	5.97	-5.58	-25.1	20.9	33.4	0.0334	0.2449
5.74	6410	4.74	- 4.65	-20.9	0	10.4	0.0077	0.2526

The resisting impulse at any increment of time is $F_a\Delta t$ and the effective impulse on the recoiling parts is

$$F_e\Delta t = (F_g\Delta t - F_t\Delta t)$$

where $F_g\Delta t$ is read from Table 5–1. The other data of Table 5–2 are computed similarly to those of Table 5–1. When completed, Table 5–2 (for the first trial) shows that the recoiling parts stop before the propellant gas pressure period ends but very close to the 0.25 in. allotted recoil stroke. This close proximity between computed and specified distance is attributed to the choice of F_o = 3000 lb, a shear coincidence. If recoil action over the whole gas period is desired, the adapter force is reduced proportionately and the values of Table 5–2 recomputed.

The recoil data are revised by proportioning the recoiling masses and the corresponding impulses according to time. Since the slide and recoiling parts move as a unit for 1.375 msec and the slide is a separate mass afterwards, the effective mass for the period is

$$M_e = \frac{1.375}{6}\ (M_s + M_r) + \left(\frac{4.625}{6}\right) M_r$$

$$= \frac{1}{6}\left(\frac{1.375 \times 96 + 4.625 \times 86}{386.4}\right) = \frac{529.75}{2316.4}$$

$$= 0.2285\ \text{lb}\cdot\text{sec}^2/\text{in.}$$

A negative velocity of 7.5 in./sec at the end of 6 msec is eliminated by reducing the adapter force of Table 5–2 thereby permitting a larger portion of the gas impulse to act on the recoiling parts. Compute the momentum for the negative velocity and solve for the force of the equivalent impulse.

$$\Delta F = \frac{\Delta F t}{t} = \frac{M_e \Delta v_r}{t} = \frac{0.2285\,(-7.5)}{0.006}$$

$$= -286, \text{ say, } -300\ \text{lb}$$

By adding -300 lb to each F_t in Table 5–2, a new set of data is computed and arranged in Table 5–3. The final results show practically zero velocity in the allotted time but a larger recoil stroke than the prescribed, which may be corrected by changing the slope of the adapter load while retaining the same area under the force-time curve. However, the data of Tables 5–2 and 5–3 need not be more accurate for preliminary estimates inasmuch as the adapter resistance varies with distance rather than with time. Later when the dynamics of the slide operating cylinder are developed, the recoil analysis will be more precise since the effects of all variables, such as time and distance, will be included.

5–1.2.2 Operating Cylinder Design

Aside from the requirements dictated by the slide, the design data of the operating cylinder are based on four parameters: orifice size, orifice location, cylinder diameter, and stroke. If the cam dwell corresponds with the power stroke, only three parameters need to be resolved. These three parameters may be resolved by searching for compatible relationships among bore pressure, cylinder pressure, and operating cylinder size. An early estimate may be had by calculating the average performance data. The known data at this stage are

s_{or} = 1.67 in., length of power stroke

v_{so} = 62.5 in./sec, slide velocity v_r at t = 1.375 msec (Table 5–2)

v_{sm} = 600 in./sec, maximum slide velocity

W_o = 1.0 lb, weight of moving operating cylinder components

W_{os} = $W_o + W_s$ = 11.0 lb, combined weight of components and slide

W_s = 10 lb, weight of slide

The slide velocity of 62.5 in./sec will be computed more accurately later but is sufficiently accurate for its intended purpose now.

The energy still needed to bring the slide to speed is

$$E_{cs} = \frac{W_{os}}{g}\ (v_{sm}^2 - v_{so}^2) = \frac{11 \times 356100}{386.4}$$

$$= 10{,}140\ \text{in.-lb.}$$

TABLE 5–3. REVISED PRELIMINARY RECOIL ADAPTER DATA

t, msec	F_t, lb	$F_t\Delta t$, lb-sec	$F_c\Delta t$, lb-sec	Δv_r, in./sec	v_r, in./sec	v_a, in./sec	Δx, in.	x, in.
0.25	2850	0.71	0.69	2.8	2.8	1.4	0.0004	0.0004
0.50	3000	0.75	3.40	13.7	16.5	9.6	0.0024	0.0028
0.75	3140	0.78	4.08	16.4	32.9	24.7	0.0062	0.0090
1.00	3290	0.32	3.73	15.0	47.9	40.4	0.0101	0.0191
1.25	3440	0.86	2.91	11.7	59.6	53.8	0.0134	0.0325
1.375	3520	0.44	1.14	4.6	64.2	61.9	0.0077	0.0402
1.50	3590	0.45	0.95	4.3	68.5	66.4	0.0083	0.0485
1.75	3740	0.94	1.19	5.3	73.8	71.2	0.0178	0.0663
2.00	3890	0.97	0.55	2.5	76.3	75.0	0.0188	0.0851
2.25	4030	1.01	0.05	0.2	76.5	76.4	0.0191	0.1042
2.50	4180	1.04	-0.29	- 1.3	75.2	75.8	0.0190	0.1232
2.80	4360	1.31	-0.53	- 2.4	72.8	74.0	0.0222	0.1454
3.00	4480	0.90	-0.52	- 2.3	70.5	71.6	0.0143	0.1597
4.00	5070	5.07	-4.26	-19.1	51.4	61.0	0.0610	0.2207
5.00	5670	5.67	-5.28	-23.7	27.7	39.6	0.0396	0.2603
6.00	6260	6.26	-6.14	-27.6	0.1	13.9	0.0139	0.2742
		27.98						

The average operating cylinder force is

$$F_{ca} = \frac{E_{cs}}{s_{or}} = \frac{10140}{1.67} = 6072 \text{ lb.}$$

Assume that the gas pressure in the cylinder does not drop below 1000 psi, therefore, flow from bore to operating cylinder ceases at 3.85 msec. The area under the pressure time curve from 1.375 to 3.85 msec is

$$A_l = 17 \text{ lb-sec/in.}^2$$

The average bore pressure for this interval is

$$p_a = \frac{A_l}{\Delta t} = \frac{17}{0.00385 - 0.001375} = \frac{17}{0.002475}$$

$$= 6870 \text{ lb/in.}^2$$

Based on critical flow pressure, the average pressure in the operating cylinder during the same interval is

$$p_c = 0.53 p_a = 3640 \text{ lb/in.}^2$$

The required piston area is

$$A_{cr} = \frac{F_{ca}}{p_c} = \frac{6072}{3540} = 1.67 \text{ in.}^2$$

The corresponding piston diameter $d_p = 1.46$ in. A nominal diameter of 1.5 in., has an area of

$$A_c = 1.767 \text{ in.}^2$$

The operating cylinder displacement is

$$V_{co} = s_{or} A_c = 1.67 \times 1.767 = 2.95 \text{ in.}^3$$

The initial orifice area is estimated by finding the quantity W_c of gas flowing into the operating cylinder. Eq. 4–49 serves the purpose by substituting p_a for p_m since the muzzle pressure does not apply, hence

$$W_c = W_g \left(\frac{V_{co}}{V_m} \right) \left(\frac{p_c}{p_a} \right)^{1/k} = 0.0039 \text{ lb}$$

where

k = 1.3, ratio of specific heats

V_m = 33.1 in.^{3}, bore volume plus chamber volume

W_g = 500 gr = 0.0714 lb, propellant gas weight

The rate of flow, Eq. 4–51, is

$$w = \frac{W_c}{\Delta t} = \frac{0.0039}{0.002475} = 1.58 \text{ lb/sec.}$$

The first estimate of orifice area, Eq. 4–52, is

$$A_o = \frac{w}{K_w p_a} = \frac{1.58}{0.00192 \times 6870} = 0.120 \text{ in.}^2$$

The orifice diameter = 0.391 in.

Computed data of the operating cylinder are listed in Tables 5–4 to 5–7. The analyses do not consider the influence of recoil adapter or driving spring since they are an attempt to learn how the gas behaves when entering the operating cylinder. After the nature of gas activity becomes known, all contributing factors to the operating cylinder dynamics will be included in the digital computer program where the effects of their simultaneous activity can be computed in a reasonable time.

Computations in the four tables follow essentially the same procedure. Three values are read directly from Fig 5–8: t, the time; s_b, the bore travel; and p_a, the average bore pressure selected as the pressure falling half way between time intervals. The time of $t = 10^3 = 4.00$ in Table 5–7 illustrates the procedure. From Eq. 4–27

$$w = K_w A_o p_a = 0.00192 \times 0.06 \times 1700 = 0.196 \text{ lb/sec}$$

where

K_w = 0.00192/sec (see par. 4–3.2.5.2)

The amount of gas capable of passing through the orifice at 1700 psi during the interval of 0.001 sec is

$$\Delta W_c = w \Delta t = 0.196 \times 0.001 = 1.96 \times 10^{-4} \text{ lb.}$$

TABLE E-4. OPERATING CYLINDER DATA FOR 0.12 in.^{2} ORIFICE (CRITICAL PRESSURE)

$t \times 10^3$, sec	s_b, in.	p_a, psi	w, lb/sec	$\Delta W_c \times 10^3$, lb	$W_c \times 10^3$, lb	V_b, in.^{3}	V_c, in.^{3}	P_c, psi
1.50	19.2	19200	4.424	1.106	1.106	12.1	0.187	4800
1.75	26.2	13700	3.156	0.789	1.895	15.7	0.416	7260
2.00	33.7	9500	2.189	0.547	2.442	19.6	0.669	5040
2.25	41.5	6800	1.567	0.392	2.834	23.6	0.935	3600
2.50	49.7	5200	1.198	0.300	3.134	27.8	1.219	2760
2.80	57.0	4400	1.014	0.304	3.438	31.6	1.519	2330
3.00	60.0	3400	0.783	0.157	3.595	37.9	1.907	1800
4.00		1700	0.392	0.393	3.987	67.5	3.769	900
5.00		740	0.170	0.170	4.157	135.0	7.860	390
6.00		250	0.058	0.058	4.215	334.3	19.73	130

$t \times 10^3$, sec	F_c, lb	$F_c \Delta t$, lb/sec	Δv_s, in./sec	v_s, in./sec	s_1, in.	s_2, in.	s, in.	V_c, in.^{3}
1.50	8480	2.120	74.5	137.0	0.016	0.009	0.025	0.544
1.75	12800	3.200	112.4	249.4	0.034	0.014	0.073	0.629
2.00	8900	2.225	78.2	327.6	0.062	0.010	0.145	0.756
2.25	6400	1.600	56.2	383.8	0.096	0.007	0.248	0.938
2.50	4900	1.225	43.0	426.8	0.082	0.005	0.335	1.092
2.80	4100	1.230	43.2	470.0	0.128	0.005	0.468	1.327
3.00	3200	0.640	22.5	492.5	0.094	0.002	0.564	1.496
4.00	1600	1.600	56.2	548.7	0.492	0.028	1.084	2.415
5.00	690	0.690	24.2	572.9	0.549	0.012	1.645	3.407
6.00	230	0.230	8.1	581.0	0.573	0.004	2.222	4.926

TABLE 5–5. OPERATING CYLINDER DATA FOR 0.12 in.^{2} ORIFICE

$t \times 10^2$, sec	s_b, in.	p_e, psi	w, lb/sec	$\Delta W_c \times 10^3$, lb	$W_c \times 10^3$, lb	V_b, in.^{3}	V_e, in.^{3}	p_c, psi
1.50	19.2	19200	4.424	1.106	1.106	12.1	0.187	4800
1.75	26.2	13700	3.156	0.789	1.895	15.7	0.416	7690
2.00	33.7	9500	2.189	0.547	2.442	19.6	0.669	7880
2.25	41.5	6800	1.567	0.392	2.834	23.6	0.935	6530
2.50	49.7	5200	1.198	0.300	3.134	27.8	1.219	5200
2.80	57.0	4400	1.014	0.304	3.438	31.6	1.519	
3.00	60.0	3400	0.783	0.157	3.595	37.9	1.907	
4.00		1700	0.392	0.392	3.987	67.5	3.769	
5.00		740	0.170	0.170	4.157	135.0	7.860	
6.00		250	0.058	0.058	4.215	334.3	19.73	

$t \times 10^3$, sec	F_c, lb	$F_c \Delta t$, lb/sec	Δv_s, in./sec	v_s, in./sec	s_1, in.	s_2, in.	s, in.	V_c, in.^{3}
1.50	8480	2.120	74.5	137.0	0.016	0.009	0.025	0.544
1.75	14060	3.515	123.5	260.5	0.034	0.015	0.074	0.631
2.00	13920	3.480	122.2	382.7	0.065	0.015	0.154	0.772
2.25	11540	2.885	101.2	484.0	0.096	0.013	0.263	0.965
2.50	9190	2.298	80.7	564.7	0.121	0.010	0.394	1.196

TABLE 5-6. OPERATING CYLINDER DATA FOR 0.09 in.^{2} ORIFICE

$t \times 10^3$, sec	s_b, in.	p_a, psi	w, lb/sec	$\Delta W_c \times 10^3$, lb	$W_c \times 10^3$, lb	V_b, in.^{3}	V_c, in.^{3}	p_c, psi
1.50	19.2	19200	3.318	0.830	0.830	12.1	0.141	3360
1.75	26.2	13700	2.367	0.592	1.422	15.7	0.312	5710
2.00	33.7	9500	1.642	0.410	1.832	19.5	0.503	5940
2.25	41.5	6800	1.175	0.294	2.126	23.6	0.702	5140
2.50	49.7	5200	0.898	0.224	2.350	27.8	0.915	4340
2.80	57.0	4400	0.760	0.228	2.578	31.6	1.140	3700
3.00	60.0	3400	0.588	0.118	2.696	37.9	1.430	3220
4.00		1700	0.294	0.294	2.990	67.5	2.826	1700
5.00		740	0.128	0.128	3.118	135.0	5.893	
6.00		250	0.043	0.043	3.161	334.3	14.794	

$t \times 10^3$, sec	F_c, lb	$F_c \Delta t$, lb-sec	Δv_s, in./sec	v_s, in./sec	s_1, in.	s_2, in.	s, in.	V_c, in.^{3}
1.50	5940	1.485	52.2	114.7	0.016	0.007	0.023	0.541
1.75	10090	2.522	88.6	203.3	0.029	0.011	0.063	0.611
2.00	10500	2.625	92.2	295.5	0.051	0.012	0.126	0.723
2.25	9080	2.270	79.7	375.2	0.074	0.010	0.210	0.871
2.50	7670	1.917	67.3	442.5	0.094	0.008	0.312	1.051
2.80	6450	1.962	68.9	511.4	0.133	0.010	0.455	1.304
3.00	5650	1.138	40.0	551.4	0.102	0.004	0.561	1.491
4.00	3000	3.000	135.0	686.4	0.551	0.068	1.180	2.585

TABLE 5–7. OPERATING CYLINDER DATA FOR 0.06 $in.^2$ ORIFICE

$t \times 10^3$, sec	s_b, in.	p_a, psi	w, lb/sec	$\Delta W_c \times 10^3$, lb	$W_c \times 10^3$, lb	V_b, $in.^3$	V_c, $in.^3$	p_c, psi
1.50	19.2	19200	2.212	0.553	0.553	12.1	0.094	2000
1.75	26.2	13700	1.578	0.395	0.948	15.7	0.208	3560
2.00	33.7	9500	1.094	0.274	1.222	19.6	0.335	3870
2.25	41.5	6800	0.783	0.196	1.418	23.6	0.468	3550
2.50	49.7	5200	0.599	0.150	1.568	27.8	0.598	3030
2.80	57.0	4400	0.507	0.152	1.720	31.6	0.761	2800
3.00	60.0	3400	0.392	0.078	1.798	37.9	0.954	2490
4.00		1700	0.196	0.196	1.994	67.5	1.884	1580
5.00		740	0.085	0.085	2.079	135.0	3.929	740
6.00		250	0.029	0.029	2.108	334.3	9.866	250

$t \times 10^3$, sec	F_c, lb	$F_c \Delta t$, lb-sec	Δv_s, in./sec	v_s, in./sec	s_1, in.	s_2, in.	s, in.	V_c, $in.^3$
1.50	3530	0.882	31.0	93.5	0.016	0.004	0.020	0.535
1.75	6290	1.572	55.2	148.7	0.023	0.007	0.030	0.588
2.00	6840	1.710	60.1	208.8	0.037	0.008	0.095	0.668
2.25	6270	1.568	55.1	263.9	0.052	0.007	0.154	0.772
2.50	5350	1.338	47.0	310.9	0.066	0.006	0.225	0.899
2.80	4950	1.485	52.2	363.1	0.093	0.008	0.327	1.078
3.00	4400	0.880	30.9	394.0	0.073	0.003	0.403	1.212
4.00	2790	2.790	98.0	492.0	0.394	0.049	0.846	1.991
5.00	1310	1.310	46.0	538.0	0.492	0.023	1.361	2.995
6.00	440	0.440	15.5	553.5	0.538	0.008	1.907	3.869
		13.975						

The total weight of gas in the operating cylinder is

$$W_c = W_{c(n-1)} + \Delta W_c = (1.798 + 0.196) \times 10^{-3} = 1.994 \times 10^{-3} \text{ lb.}$$

The equivalent volume of the bore, since the projectile has left the muzzle, according to Eq. 4--51 is

$$V_b = V_m \left(\frac{p_m}{p_a} \right)^{1/k_b} = 67.5 \text{ in.}^3$$

where

p_m = 4000 lb/in.^{2}, muzzle pressure

V_m = 33.1 in.^{3}, bore volume plus chamber volume

k_b = 1.2, ratio of specific heats of bore gas

The equivalent gas volume V_e in the cylinder at p_a = 1700 psi is

$$V_e = \left(\frac{W_c}{W_g} \right) V_b = \frac{1.994 \times 10^{-3}}{0.0714} \; 67.5 = 1.884 \text{ in.}^3$$

Since the cylinder volume $V_c = 0.50 + A_c s = 0.5C + 1.767 s$ is not known at this time, a trial and error procedure is adopted. First anticipate a change in slide velocity; that for the preceding interval is adequate. Then calculate, in turn, the differential travel, the total travel, the new cylinder gas volume, its pressure, piston force, corresponding impulse and change in slide velocity, and continue until the values converge to prescribed limits. Convergence for these calculations is rapid.

	1st Trial	2nd Trial	3rd Trial
$t = 4 \times 10^{-3}$ sec $\Delta t = 0.001$ } from Table 5--7			
n	1	2	3
$\Delta v_s = \Delta v_{s(n-1)}$*	30.9	101.8	98.0
$s_1 = v_{n-1} \Delta t$	0.394	0.394	0.394
$s_2 = \frac{1}{2} (\Delta v \Delta t)$	0.015	0.051	0.049

*Note that for the first trial $\Delta v_{s(n-1)} = 30.9$ is obtained from Table 5--7 for $t = 0.003$ sec.

	1st Trial	2nd Trial	3rd Trial
$s = s_{n-1} + s_1 + s_2$	0.812	0.848	0.846
$V_c = 0.50 + 1.767s$	1.935	1.998	1.995
$(V_e/V_c)^{1.3}$	0.967	0.927	0.928
$p_c = p_a (V_e/V_c)^{1.3}$	1640	1580	1580
$F_c = A_c p_c = 1.767\, p_c$	2900	2790	--
$F_c \Delta t = 0.001F$	2.90	2.79	--
$\Delta v_{s(n)} = \frac{F_c \Delta t}{M_{cs}} = 35.127\, F_c \Delta t$	101.8	98.0	--

In the third trial, the cylinder pressure equals that of the second trial within three significant figures so that all values after $p_c = 1580$ psi in the second trial are final and the slide velocity at the end of this interval is

$$v = v_{n-1} + \Delta v = 394.0 + 98.0 = 492.0 \text{ in./sec.}$$

The data in Table 5-4 were computed to ascertain whether the critical flow pressures could be used as the operating cylinder pressure. Under this condition, the travel and corresponding gas volume indicated that the gas flow during the first two increments was sufficient to drive the piston over the rest of its stroke by normal polytropic expansion without the benefit of continued gas flow through the orifice. Since continued gas flow is provided, higher than critical flow pressures are certain. For this reason, the data of Tables 5-5, 5-6, and 5-7 were computed. These tables although similar, show how variations in orifice area lead to specified slide velocity and travel, and help establish acceptable limits in computer programming.

The last values of Table 5-5 indicate that the slide velocity of 50 fps will be reached within less than 30 percent of the stroke. If permitted to function with an orifice of this size, slide velocities would far exceed their limit. A smaller orifice area and hence less pressure would make velocity and travel more compatible. The data of Table 5-6 indicate this trend and those in Table 5-7 almost meet the requirements. A velocity of slightly less than 50 fps is acceptable but to be an accurate estimate, it must be achieved during the complete piston travel. A computed overtravel, a physical impossibility, is not acceptable. Under the conditions enumerated in Table 5-7, the slide velocity lacks approximately 4.5 fps at a travel of 1.67 in. and is definitely acceptable at this stage even though the full 6 msec of effort are not used. The design analysis may now be organized to consider all variables simultaneously.

5-1.2.3 Dynamics of Simultaneous Adapter-Operating Cylinder Action

The resultant force on the recoiling parts (Fig. 5-3) is

$$F_r = F_b - F_c - F_t - F = p_a A_b - p_c A_c - F_t - F \qquad (5\text{-}61)$$

where

A_b = bore area

A_c = piston area of slide operating cylinder

F_t = adapter force

F = driving spring force

F_c = operating cylinder force

F_g = propellant gas force

p_a = average chamber pressure during each increment

p_c = operating cylinder pressure

During each time increment Δt, the recoiling parts are subjected to the impulse $F_g \Delta t$ that induces a change in velocity defined by Eq 4-55.

$$\Delta v_r = \frac{F_g \Delta t}{M_r} \qquad (5-62)$$

where M_r represents the mass of all the recoiling parts until the projectile passes the gas port where it loses the burden of the slide and moving operating cylinder components but picks up the operating cylinder force. During counterrecoil it regains the mass of the operating cylinder components. The velocity at the end of each increment is

$$v_r = \Sigma \Delta v_r = v_{r(n-1)} + \Delta v_r. \qquad (5-63)$$

The recoil travel is

$$x = x_{n-1} + x_1 + x_2$$

$$= x_{n-1} + \Delta t \Delta v_{r(n-1)} + \frac{1}{2}\left(\Delta t \, \Delta v_r\right). \qquad (5-64)$$

After the projectile passes the gas port and propellant gases begin to act on the slide operating mechanism, the kinematics of the recoiling parts are superimposed on the slide. If the slide unit is isolated, the dynamics of the system follow those expressed in Eqs. 4-51 to 4-58 but modified to fit the prevailing conditions. The resultant force on the piston of the operating cylinder is

$$F_c = A_c p_c - F_d \qquad (5-65)$$

The absolute differential velocity of the slide (absolute refers to the nonrecoiling parts as the fixed reference) is

$$\Delta v = \Delta v_r + \Delta v_s = \Delta v_r + \frac{F_c \Delta t}{M_{cs}} \qquad (5-66)$$

The absolute slide velocity and travel are the same as for the recoiling parts until the projectile passes the gas port. The absolute velocity is

$$v = \Sigma \Delta v = v_{n-1} + \Delta v. \qquad (5-67)$$

The absolute slide travel is

$$s = s_{n-1} + \Delta t v_{n-1} + \frac{1}{2}\left(\Delta t \Delta v\right). \qquad (5-68)$$

The slide travel with respect to recoil travel is the piston travel, thus

$$x_s = s - x. \qquad (5-69)$$

The corresponding gas volume in the operating cylinder becomes

$$V_c = V_{co} + A_c x_s \qquad (5-70)$$

5-1.2.4 Sample Calculation for Complete Firing Cycle

The preliminary calculations summarized in Tables 5-3 and 5-7 provide the initial values for the complete firing cycle analysis. The functioning times of each are identical to the propellant gas period and, although the final results do not conform exactly to specifications, they are close enough to be acceptable; all fall within design specification acceptance limits. To present simultaneous activity, the effects of the adapter and slide forces during the gas period must be synchronized. In Table 5-3, $\Sigma F_t \Delta t = 27.98$ lb-sec; in Table 5-7, $\Sigma F_c \Delta t = 13.98$ lb-sec. Based on time, the average adapter force

$$F_c = \frac{\Sigma F_t \Delta t - \Sigma F_c \Delta t}{t} = \frac{14}{0.006} = 2330 \text{ lb}$$

Maintain the proportions of Table 5-3 where $F_a = 27.98/0.006 = 4660$ lb, thus the minimum F_{ot} and maximum F_{mt} adapter forces are

$$F_{ot} = \left(\frac{2330}{4660}\right) 2850 = 1425 \text{ lb}$$

where 2850 is first value in F_t column of Table 5-3, and

$$F_{mt} = \left(\frac{2330}{4660}\right) 6260 = 3130 \text{ lb}$$

where 6260 is the last value in F_t column of Table 5-3.

Convert these limits to forces of a ring spring having a conical angle $\alpha = 15°$, a coefficient of friction $\mu = 0.10$, and an efficiency of $e = 0.45$ (Ref. 15),

$$F_o = F_{ot} = 0.45 \times 1425 = 640 \text{ lb}$$

$$F_m = F_{mt} = 0.45 \times 3130 = 1410 \text{ lb}$$

Distance now, as well as time, becomes a critical parameter in the analysis. For a recoil travel of 0.25 in., the equivalent spring constant of the ring spring is K_t.

$$K_t = \frac{F_m - F_o}{x} = \frac{1410 - 640}{0.25} = 3080 \text{ lb/in.}$$

The average adapter force for any differential recoil travel Δx is

$$F_a = \frac{1}{e}\left[F_{n-1} + \frac{1}{2}\left(K_t \Delta x\right)\right] = \frac{1}{0.45}\left[F_{n-1} + 1540\Delta x\right]$$

The two driving springs offer a similar but milder effort. Their combined characteristics follow:

K = 40 lb/in., spring constant

F_o = 85 lb, minimum operating load

F_m = 285 lb, maximum operating load

e = 0.80, efficiency

The average driving spring load for any differential travel Δs of the operating slide is

$$F = \frac{1}{e}\left[F_{(n-1)} + \frac{1}{2}\left(K\Delta s\right)\right] = \frac{1}{0.80}\left[F_{(n-1)} + 20\Delta s\right]$$

where $\Delta s = \Delta x$ until the projectile passes the gas port. Observe that after propellant gases become active in the operating cylinder, F loses its identity by becoming a component of F_c which heretofore had been zero.

5–1.2.4.1 Counterrecoil Time of Recoiling Parts

By restricting the barrel-drum unit to linear travel only during counterrecoil, the time required for the activity according to Eq. 2–27 is

$$t_{cr} = \sqrt{\frac{M_r}{e_t K_t}} \text{Cos}^{-1} \frac{F_o}{F_m} = \sqrt{\frac{86}{0.45 \times 3080 \times 386.4}} \text{Cos}^{-1} \frac{640}{1410}$$

$$= 0.01303 \times \text{Cos}^{-1} 0.4539 = 0.01303 \times 1.1 = 0.01433 \text{ sec.}$$

Earlier, the total time of recoil was estimated to be t_r = 0.0127 sec.* Since 0.006 sec has been consumed for the 1.67 in. of recoil, the remaining time of 0.0067 sec indicates that the counterrecoil of barrel and slide will overlap and a component of the adapter force will be transmitted to the slide-rotating drum combination. Because of the simultaneous activity, the applied force on the slide will be modified according to the involved masses and the cam slope. The components of the adapter force allotted to recoiling parts, drum, and slide are found by a procedure based on the laws of conservation of momentum and energy. Equate the adapter impulse to the linear momentum of recoiling parts and slide so that

$$\bar{F}_t dt = M_r v_{cr} + M_s v_s = M_r v_{cr} + M_s v_c \cos\beta \quad (5-71)$$

where $\bar{F}_t$ is the average adapter force for the time interval dt and v_c is the velocity of the cam follower along the cam. This form of showing the slide velocity is adopted to avoid the use of tan β which eventually becomes infinite and cannot be used in the digital computer. The energy of the adapter distributed to the various moving element is

$$\frac{1}{e_t}\ \bar{F}_t\,\Delta x = \frac{1}{2}\left(M_r v_{cr}^2\right) + \frac{1}{2}\left(M_s v_c^2 \cos^2\beta\right) + \frac{1}{2}\left(M_{de} v_c^2 \sin^2\beta\right) \quad (5-72)$$

where

M_{de} = effective mass of the rotating drum.

The two simultaneous equations may be solved by obtaining the expression for v_{cr} in Eq. 5-71 and substituting it into Eq. 5-72. This process merely involves algebraic gymnastics and, since the solution is unwieldly, the expressions for the two velocities are left in their present state. However, with the various constants known, the solutions reduce to a simple quadratic equation of the order

$$Av_c^2 + Bv_c - C = 0 \quad (5-73)$$

*Par. 5-1.1.2.2

One great advantage inherent in the revolver-type machine gun is the independence of loading and ejecting. Both occur simultaneously with neither interfering with the other. Cam action is illustrated in Figs. 5-9 and 5-10 which show the mechanics of operation. The striker and extractor are fixed to and move with the operating slide whereas the extractor mechanism is fixed to the drum housing and moves with it. As the drum completes its angular travel, the spent cartridge case has moved into contact with the extractor and, in the meantime, lifting the antidouble feed safety switch to break the electric firing circuit so that inadvertent firing of the newly positioned round is precluded. During counterrecoil, the return cam has enough clearance to avoid contact with the extractor cam but, at a prescribed position, the striker hits the extractor cam with the impact needed to rotate the extractor, thereby extracting and ejecting the empty case. After the cam leaves, the antidouble feed safety switch drops into place to reclose the firing circuit. Extraction failure maintains an open circuit until the malfunction is corrected.

During slide recoil, the extractor return cam forces the extractor cam into its normal position. The torsion spring does not activate the extractor, being used primarily as a safety to hold the extractor firmly in position. The cams transmit all effort from slide to extractor. Relative dimensions must comply with required ejection velocity. Once the counterrecoil velocity of the slide is estimated, the ratio of extractor radius to striker radius, r_e/r_s, can be arranged to fit the ejection velocity requirement. The required ratio

$$\frac{r_e}{r_s} = \frac{v_e}{v_{scr}} \quad (5-74)$$

where

v_{scr} = counterrecoil velocity of the slide

The ejection velocity is assumed immediately at impact of the striker on the ejecter cam, resulting in a change of momentum of all involved moving parts. According to the conservation of momentum,

$$M_s v'_{scr} = M_s v_{scr} + M_{ee} v_e \quad (5-75)$$

where

M_{ee} = effective mass of extractor unit

v'_{scr} = slide velocity before impact.

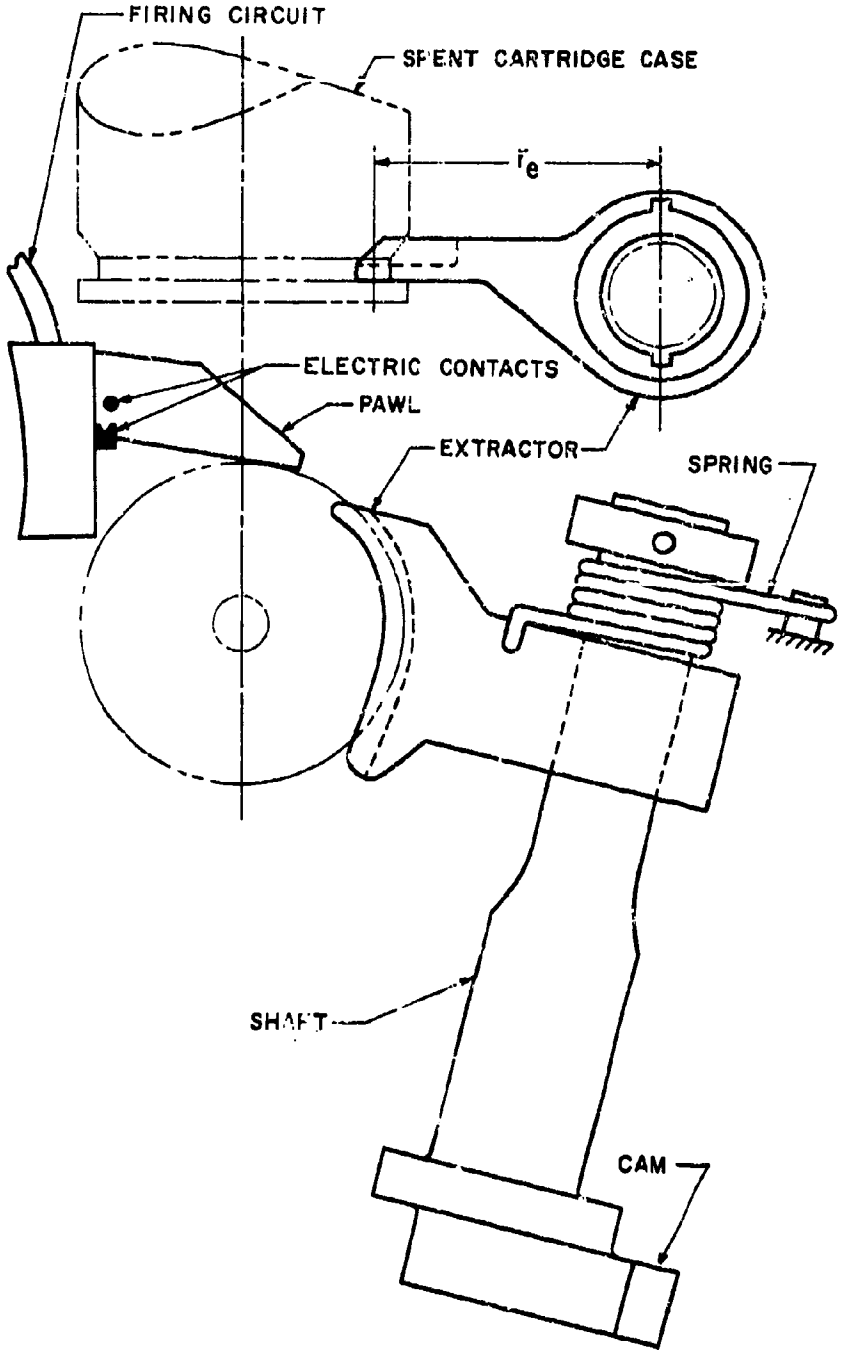


Figure 5–9. Extractor Assembly With Antidouble Feed Mechanism

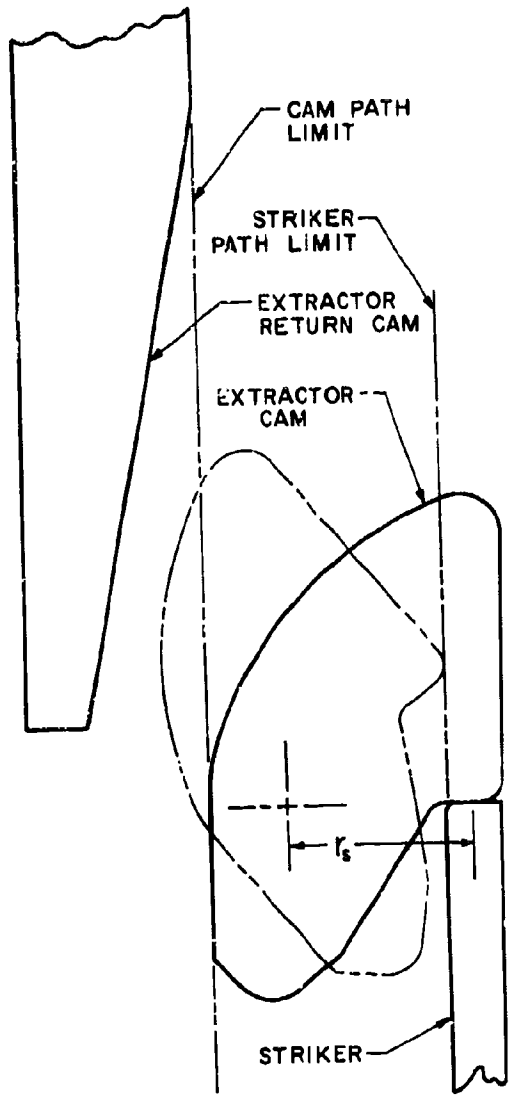


Figure 5–10. Extractor Cam Assembly

5–1.2.4.2 Digital Computer Analyses of Barrel-drum Dynamics

Three digital computer programs are compiled in FORTRAN IV language for the UNIVAC 1107 computer. The first computes the data and performance characteristics during the activity of the gas operating cylinder. This program follows the same general procedure that was used for computing the data of Table 5–7 where data cover the effective propellant gas period of 6 msec and the slide travel of 1-2/3 in. The symbol-code relationships are shown in Table 5–8, the input data as well as the computed results are printed in Table 5–12. In the Appendix, A–1 is the flow chart and A–8 is the program listing.

The second program begins where the first terminates; just as the follower enters the curved portion of the cam to start the drum rotating, then continuing until the follower has traversed the accelerating portion of the cam and the slide has completed its rearward travel. The third program begins here and computes the data for the decelerating portion of the cam and the first part of the slide travel during counterrecoil. Both programs follow the procedure outlined in par. 5–1.2.2. Since the second and third programs are similar, differing only because of direction, the symbol-code relationships (Table 5–9) serve both programs. Inputs are listed in Tables 5–10 and 5–11 for the recoil and the counterrecoil dynamics, respectively.

Computed results are printed in Table 5–13 for the cam and drum dynamics during recoil and in Table 5–14 for the dynamics during counterrecoil. The flow chart and program listing are found in Appendixes A–9 and A–10 for recoil and, in A–11 and A–12, respectively, for counterrecoil.

TABLE 5–8. SYMBOL-CODE CORRELATION FOR OPERATING CYLINDER

Symbol	Code	Symbol	Code
A_o	AO	V_b	VB
F	FD	V_c	VC
$F\Delta t$	FDT	V_{co}	VCO
F_c	FC	V_e	VE
$F_c\Delta t$	FCDDT	v	V
F_r	F	v_s	VS
F_t	FA	Δv	DV
M_e	EME	Δv_s	DVS
p_a	PA	W_c	WC
p_c	PC	ΔW_c	DWC
s	S	w	W
s_1	S1	x	X
s_2	S2	x_1	X1
Δs	DS	x_2	X2
t	T	x_s	XS
Δt	DT	Δx	DX

TABLE 5–9. SYMBOL-CODE CORRELATION FOR CAM DYNAMICS

Symbol	Code	Symbol	Code
C_x	CX	R_d	RD
C_y	CY	s	S
E	E	Δs	DSI
E_{bbl}	EBBL	s_x	SX
ΔE_{bbl}	DEBBL	Δs_x	DSX
E_d	ED	T_g	TG
E_l	EI	T_μ	TMU
E_μ	EMU	t	TM
$E_{\mu d}$	EMD	Δt	DELT
$E_{\mu s}$	EMS	Δt_{cr}	DTCR
F	FD	v	V
F_t	FA	v_c	VC
F_x	FX	v_d	VD
F_y	FY	v_s	VS
F_{us}	FUS	x	X
I_d	DIE	Δx	DXI
K_y	YK	Δx_o	DXIO
K_x	XK	Δx_1	DXI1
M_r	EMR	y	Y
M	EMSL	β	BETAD
N	EN	θ	THETA
R_c	RC	$\Delta\theta$	DTHETA

TABLE 5–10. INPUT DATA FOR DRUM DYNAMICS DURING RECOIL

Symbol	Data	Code	Data
CX	0.275	FA(17)	1278.72
CY	2.9	FD(17)	151.8
DF	0.15	S(17)	1.67
DIE	0.385	TM(17)	6.0
EMR	0.22	VC(17)	478.8
EMSL	0.02568	VS(17)	478.8
RD	3.0	X(16)	0.224
TG	140.0	X(17)	0.224

TABLE 5-11. INPUT DATA FOR DRUM DYNAMICS DURING COUNTERRECOIL

Code	Data	Code	Data
CY	2.9	FX (2)	333.0
CX	0.275	FY (2)	14.25
DF	0.15	S (2)	5.0
DFE	0.35	SX (2)	0.0
EMR	0.22	TM (1)	18.6
EMSLR	0.029	TM (2)	19.5968
RD	3.0	TMU (2)	50.014
TG	140.0	V (2)	0.0
BETAD (2)	90.0	VC (2)	199.1
E (2)	848.01	VD (2)	199.1
EN (2)	333.0	VS (2)	0.0
FA (2)	1256.0	X (1)	0.2112
FD (2)	285.0	X (2)	0.2113
FUS (2)	2.1	Y (2)	0.0

5-1.2.4.3 Firing Rate Computation

Just as the cam completes its cycle, the drum reaches its next firing position and rotation has ceased. According to the print out of the values, neither recoiling parts nor slide has completed its return. The prevailing conditions are

t_e = 0.0329 sec,* elapsed time since firing

s_{or} = 1.67 in., position where slide contacts gas operating unit

F_t = 1210 lb,* recoil adapter force

F = 204 lb,* driving spring force

K_t = 1780 lb/in., recoil adapter spring constant

K = 40 lb/in., driving spring constant of 2 springs

v_{cr} = 8.91 in./sec,* barrel counterrecoil velocity

v_{scr} = 231.6 in./sec,* slide counterrecoil velocity

*Obtained from Table 5-14.

s = 2.974 in.,* remaining counterrecoil travel of slide

x = 0.1854 in.,* remaining counterrecoil travel of barrel

W_r = 85 lb, weight of barrel and other recoiling parts

W_{sr} = 11.2 lb, weight of slide with 2 rounds

W_{srp} = 12.2 lb, W_{sr} + weight of gas operating unit

ϵ_t = 0.45, efficiency of recoil adapter

ϵ = 0.80, efficiency of driving spring

According to Eq. 2-26, the time of counterrecoil under spring action

$$t_{cr} = \sqrt{\frac{M_r}{\epsilon_t K_t}} \left(\mathrm{Sin}^{-1} \frac{K_t x - F_t}{f(F)} - \mathrm{Sin}^{-1} \frac{-F_t}{f(F)} \right)$$

where

$$f(F) = \sqrt{F_t^2 + \frac{K_t}{\epsilon_t} \left(M_r v_{cr}^2 \right)}$$

TABLE 5–12. COMPUTED RECOIL AND OPERATING CYLINDER DATA FOR ORIFICE AREA OF 0.042 in.^{2}

TIME MILSEC	BORE VOLUME CU IN	AVERAGE BORE PRESSURE PSI	PROP GAS FORCE LB	ADAPTER FORCE LB	DRIVING SPRING FORCE LB	RESULT RECOIL FORCE LB	RECOIL IMPULSE LB-SEC	DIFFER RECOIL VEL IN/SEC	RECOIL VEL IN/SEC	DIFFER RECOIL TRAVEL IN	RECOIL TRAVEL IN
.250	2.2	10800.	5562.	880.	85.	3499.	.87	3.5	3.5	.0004	.0004
.500	3.0	32200.	16585.	885.	85.	14510.	3.63	14.6	18.1	.0027	.0031
.750	4.3	37700.	19415.	897.	85.	17315.	4.33	17.4	35.5	.0067	.0099
1.000	6.3	35300.	18179.	917.	86.	16035.	4.01	16.1	51.7	.0109	.0208
1.250	9.0	29300.	15089.	942.	86.	12887.	3.22	13.0	64.6	.0145	.0353
1.375	10.5	24500.	12617.	957.	87.	10382.	1.30	5.2	69.9	.0084	.0437
1.500	12.1	21800.	11227.	973.	87.	7745.	.97	4.4	74.3	.0090	.0527
1.750	15.7	16500.	8497.	1007.	88.	1725.	.43	2.0	76.2	.0188	.0715
2.000	19.6	11800.	6077.	1040.	89.	-2653.	-.66	-3.0	73.2	.0187	.0902
2.250	23.6	8200.	4223.	1072.	91.	-4565.	-1.14	-5.2	68.0	.0177	.1079
2.500	27.8	5800.	2987.	1101.	94.	-4939.	-1.25	-5.7	62.4	.0163	.1242
2.800	33.1	4500.	2317.	1132.	97.	-5093.	-1.53	-6.9	55.4	.0177	.1418
3.000	37.9	3700.	1905.	1151.	100.	-5342.	-1.01	-4.6	50.8	.0106	.1525
4.000	67.5	1600.	823.	1224.	115.	-4243.	-4.24	-19.3	31.5	.0412	.1937
5.000	135.0	760.	391.	1265.	133.	-3765.	-3.76	-17.1	14.4	.0230	.2167
6.000	334.5	230.	118.	1278.	152.	-3129.	-3.13	-14.2	.2	.0073	.2240

TIME MILSEC	GAS FLOW RATE LB/SECXM	OPER CYL GAS LBXM	EQUIV CYL VOLUME CU IN	OPER CYL VOLUME CU IN	OPER CYL PRES PSI	OPER PISTON FORCE LB	OPER CYL IMPULSE LB-SEC	DIFFER SLIDE VEL IN/SEC	SLIDE VEL IN/SEC	DIFFER SLIDE TRAVEL IN	SLIDE TRAVEL IN
.250	.0	.000	.000	.000	0.	0.	.000	3.5	3.5	.000	.000
.500	.0	.000	.000	.000	0.	0.	.000	14.6	18.1	.002	.003
.750	.0	.000	.000	.000	0.	0.	.000	17.4	35.5	.007	.010
1.000	.0	.000	.000	.000	0.	0.	.000	16.1	51.7	.011	.021
1.250	.0	.000	.000	.000	0.	0.	.000	13.0	64.6	.015	.035
1.375	.0	.000	.000	.000	0.	0.	.000	5.2	69.9	.008	.044
1.500	1763.0	.220	.037	.301	746.	1318.	.151	5.3	75.2	.009	.053
1.750	1334.4	.554	.122	.510	2566.	4535.	1.106	35.9	111.0	.024	.077
2.000	954.3	.793	.217	.938	3631.	6415.	1.576	55.4	169.4	.035	.112
2.250	663.2	.958	.317	.593	3626.	6406.	1.575	55.3	224.6	.049	.161
2.500	469.1	1.076	.419	.673	3130.	5530.	1.353	47.5	272.2	.061	.222
2.800	363.9	1.185	.549	.797	2770.	4894.	1.432	50.3	322.5	.088	.310
3.000	299.2	1.245	.660	.897	2485.	4390.	.853	30.0	352.4	.067	.377
4.000	129.4	1.374	1.298	1.498	1328.	2347.	2.203	77.4	429.8	.382	.759
5.000	51.5	1.435	2.713	2.239	760.	1343.	1.177	41.3	471.1	.442	1.201
6.000	18.6	1.454	6.805	3.052	230.	406.	.217	7.6	478.8	.468	1.668

TABLE 5–13. CAM AND DRUM DYNAMICS DURING RECOIL

TIME MILSEC	RECOIL ADAPTER FORCE LB	DRIVING SPRING FORCE LB	NORMAL CAM FORCE LB	AXIAL CAM TRAVEL IN	PERIPH CAM TRAVEL IN	CAM SLOPE DEGREE	DRUM VEL IN/SEC	COUNTER RECOIL VEL IN/SEC	COUNTER RECOIL POSITION IN	SLIDE VEL IN/SEC	SLIDE TRAVEL IN
6.18857	1279.	155.4	2010.	.0900	.0009	1.0	8.3	.4308	.2240	476.2	1.760
6.37862	1278.	159.0	1988.	.1800	.0033	2.0	16.5	.7931	.2238	472.2	1.850
6.57050	1278.	162.6	1967.	.2700	.0072	3.0	24.6	1.1304	.2237	467.9	1.940
6.76435	1278.	166.2	1947.	.3600	.0128	4.0	32.5	1.4427	.2234	463.3	2.031
6.96032	1277.	169.6	1928.	.4500	.0195	5.0	40.4	1.7303	.2231	458.4	2.121
7.15858	1276.	173.5	1911.	.5400	.0286	6.1	48.1	1.9927	.2227	453.2	2.211
7.35930	1276.	177.1	1895.	.6300	.0390	7.1	55.7	2.2296	.2223	447.8	2.302
7.56266	1275.	180.7	1880.	.7200	.0510	8.1	63.2	2.4405	.2218	442.0	2.392
7.76886	1274.	184.3	1865.	.8100	.0647	9.2	70.6	2.6252	.2213	436.0	2.483
7.97811	1273.	187.9	1852.	.9000	.0802	10.3	77.9	2.7826	.2208	429.6	2.573
8.19065	1272.	191.6	1840.	.9900	.0974	11.4	85.0	2.9121	.2202	423.0	2.664
8.40671	1271.	195.2	1829.	1.0800	.1164	12.5	92.1	3.0123	.2195	416.0	2.754
8.62658	1270.	198.8	1819.	1.1700	.1372	13.6	99.0	3.0823	.2189	408.7	2.845
8.84718	1268.	202.4	1809.	1.2600	.1600	14.8	105.9	3.1123	.2182	401.3	2.934
9.07557	1267.	206.0	1802.	1.3500	.1847	15.0	112.6	3.1089	.2175	393.7	3.025
9.30510	1266.	209.6	1548.	1.4400	.2116	17.2	119.3	3.0673	.2168	384.9	3.114
9.53975	1265.	213.1	1845.	1.5300	.2405	18.5	125.6	2.9786	.2161	376.2	3.204
9.78003	1263.	216.7	1842.	1.6200	.2717	19.8	132.0	2.8450	.2154	367.1	3.293
10.02648	1262.	220.3	1841.	1.7100	.3053	21.1	138.2	2.6625	.2147	357.7	3.382
10.28347	1261.	223.9	1777.	1.8000	.3413	22.5	144.3	2.4429	.2140	347.8	3.473
10.54794	1260.	227.5	1775.	1.8900	.3800	24.0	150.2	2.1809	.2134	337.5	3.564
10.82061	1259.	231.2	1775.	1.9800	.4215	25.5	155.0	1.8591	.2129	326.7	3.654
11.10237	1258.	234.8	1775.	2.0700	.4660	27.1	161.6	1.4711	.2124	315.5	3.745
11.39427	1257.	238.4	1777.	2.1600	.5138	28.8	167.1	1.0082	.2120	303.7	3.835
11.69755	1257.	242.0	1781.	2.2500	.5651	30.6	172.4	.4612	.2118	291.3	3.925
11.93028	1257.	244.7	1785.	2.3166	.6057	32.0	176.2	.0000	.2118	281.7	3.992
12.25745	1257.	248.3	1885.	2.4066	.6641	34.0	181.0	.0000	.2117	268.2	4.082
12.60215	1257.	251.9	1900.	2.4966	.7274	36.2	185.6	.0000	.2117	253.8	4.172
12.96759	1257.	255.5	1918.	2.5866	.7960	38.5	189.9	.0000	.2116	238.5	4.262
13.35799	1257.	259.1	1940.	2.6766	.8710	41.1	193.9	.0000	.2116	222.3	4.352
13.77909	1257.	262.7	1968.	2.7666	.9535	43.9	197.5	.0000	.2116	204.9	4.442
14.23911	1256.	266.3	2005.	2.8566	1.0452	47.1	200.6	.0000	.2115	186.2	4.532
14.75046	1255.	269.9	2056.	2.9466	1.1485	50.8	203.2	.0000	.2115	165.7	4.622
15.33356	1256.	273.5	2133.	3.0366	1.2677	55.1	205.0	.0000	.2114	142.9	4.712
16.02666	1256.	277.1	2268.	3.1265	1.4102	60.4	205.6	.0000	.2114	118.7	4.802
16.92005	1256.	280.7	2605.	3.2166	1.5938	67.5	204.1	.0000	.2114	84.7	4.892
19.59680	1256.	285.2	-333.	3.3300	2.1500	90.0	199.1	.0000	.2113	-.0	5.005

TABLE 5-14. CAM AND DRUM DYNAMICS DURING COUNTERRECOIL

TIME	RECOIL ADAPTER FORCE	DRIVING SPRING FORCE	NORMAL CAM FORCE	AXIAL CAM TRAVEL	PERIPH CAM TRAVEL	CAM SLOPE	DRUM VEL	COUNTER RECOIL VEL	COUNTER RECOIL POSITIONN	SLIDE VEL	SLIDE TRAVEL
MILSEC	LB	LB	LB	IN	IN	DEGREE	IN/SEC	IN/SEC	IN	IN/SEC	IN
22.17219	1254.	281.0	1405.	.100	.5058	67.9	193.3	.0000	.2103	78.4	4.893
23.26010	1253.	276.9	1346.	.200	.7061	59.1	179.4	.0000	.2093	107.2	4.798
24.11989	1251.	272.9	1238.	.300	.8534	52.6	166.9	.0000	.2083	127.7	4.697
24.86381	1249.	268.8	1167.	.400	.9720	47.2	155.3	.0000	.2073	143.8	4.596
25.53465	1247.	264.8	1114.	.500	1.0715	42.6	144.4	.0000	.2063	157.2	4.495
26.15502	1245.	260.8	1074.	.600	1.1569	38.4	133.8	.0000	.2053	168.5	4.394
26.73740	1244.	256.7	1041.	.700	1.2311	34.7	123.5	.0000	.2043	178.3	4.293
27.28523	1244.	252.7	1029.	.800	1.2960	31.5	113.5	.0000	.2043	186.9	4.193
27.81027	1245.	248.7	1006.	.900	1.3530	28.1	103.7	.2408	.2042	194.3	4.093
28.31741	1243.	244.7	986.	1.000	1.4030	25.1	93.5	.6028	.2040	200.9	3.993
28.81013	1242.	240.7	970.	1.100	1.4467	22.2	84.4	1.0728	.2036	206.7	3.892
29.29120	1241.	236.7	957.	1.200	1.4848	19.5	74.9	1.6378	.2029	211.8	3.792
29.76285	1240.	232.6	945.	1.300	1.5175	16.8	65.4	2.2897	.2020	216.2	3.691
30.22697	1237.	228.6	936.	1.400	1.5454	14.3	56.0	3.0212	.2008	220.0	3.590
30.68518	1235.	224.5	929.	1.500	1.5686	11.8	46.7	3.8271	.1992	223.3	3.488
31,13890	1231.	220.4	924.	1.600	1.5873	9.4	37.4	4.7035	.1973	226.0	3.386
31.58948	1227.	216.3	920.	1.700	1.6017	7.0	28.0	5.6505	.1950	228.2	3.284
32.03813	1222.	212.2	918.	1.800	1.6119	4.7	18.7	6.6670	.1925	229.8	3.181
32.48601	1217.	208.1	918.	1.900	1.6180	2.3	9.4	7.7509	.1891	231.0	3.078
32.93430	1210.	204.0	918.	2.000	1.6200	.0	.0	8.9058	.1854	231.6	2.974

For counterrecoil of the barrel

$$f(F) = \sqrt{1210^2 + \frac{1780}{0.45}\left(0.22\right)8.91^2} = 1238.2.$$

The time required to complete the counterrecoil of the barrel

$$t'_{cr} = \sqrt{\frac{0.22}{0.45 \times 1780}}\left(\text{Sin}^{-1}\ \frac{1780 \times 0.1854 - 1210}{1238.2} - \text{Sin}^{-1}\ \frac{-1210}{1238.2}\right)$$

$$= 0.01657\ [\text{Sin}^{-1}\ (-0.71070) - \text{Sin}^{-1}\ (-0.97722)]$$

$$t'_{cr} = 0.01657\left(\frac{314.71 - 282.25}{57.296}\right) = 0.0094 \text{ sec.}$$

The energy of the moving unit at the end of counterrecoil

$$E_{cr} = \frac{1}{2}\left(M_r v_o^2\right) + \epsilon_t\left(F_t - \frac{1}{2}K_t x\right)x$$

$$= \frac{1}{2}\left(\frac{85}{386.4}\right)8.91^2 + 0.45\left[1210 - \frac{1780}{2}\left(0.1854\right)\right]0.1854$$

$$= 95.9 \text{ in.-lb.}$$

The maximum counterrecoil velocity

$$v_{cr} = \sqrt{\frac{2E_{cr}}{M_r}} = \sqrt{871.9} = 29.53 \text{ in./sec.}$$

Compute the counterrecoil time of the slide in three steps, before the slide contacts the gas operating unit, the effect of cartridge case ejection, and after the slide picks up the operating unit. The distance traveled before contact is

$$s_c = s - s_{or} = 2.974 - 1.67 = 1.304 \text{ in.}$$

The time to traverse this distance, Eq. 2-26,

$$t'_{scr} = \sqrt{\frac{M_{sr}}{\epsilon K}}\left(\text{Sin}^{-1}\ \frac{Ks_c - F}{f(F)} - \text{Sin}^{-1}\ \frac{-F}{f(F)}\right)$$

where

$$\sqrt{\frac{M_{sr}}{\epsilon K}} = \sqrt{\frac{11.2}{0.8 \times 40 \times 386.4}} = \sqrt{0.000906} = 0.0301$$

$$f(F) = \sqrt{F^2 + \frac{K}{\epsilon} M_{sr} v_{scr}^2} = \sqrt{204^2 + \frac{40}{0.8} \times 0.029 \times 231.6^2} = 345.5.$$

Therefore

$$t'_{scr} = 0.0301 \left(\text{Sin}^{-1} \frac{40 \times 1.304 - 204}{345.5} - \text{Sin}^{-1} \frac{-204}{345.5} \right) = 0.0301 \left[\text{Sin}^{-1} (-0.43946) - \text{Sin}^{-1} (-0.59045) \right]$$

$$= 0.0301 \left(\frac{333.93 - 323.81}{57.3} \right) = 0.0053 \text{ sec.}$$

The slide energy at this position

$$E_s = \frac{1}{2} \left(M_{sr} v_{scr}^2 \right) + \epsilon \left(F - \frac{1}{2} K s_c \right) s_c = \left(\frac{0.029}{2} \right) 231.6^2 + 0.8 \left[204 - \frac{40}{2} \left(1.304 \right) \right] 1.304$$

$$= 963.4 \text{ in.-lb.}$$

The corresponding velocity

$$v'_{scr} = \sqrt{\frac{2E_s}{M_{sr}}} = \sqrt{\frac{1926.8}{0.029}} = \sqrt{66441} = 257.8 \text{ in./sec.}$$

To avoid duplication of the above exercise, assume that cartridge case ejection and gas operating piston pick-up occur at the same time. When pick-up occurs, the slide gains one pound. From the conservation of momentum when the ejection velocity, v_e = 840 in./sec,

$$\left(\frac{W_{sr}}{g} \right) v'_{scr} = \left(\frac{W_{srp}}{g} \right) v_{scr} + \frac{W_{cc}}{g} v_e$$

$$\left(\frac{11.2}{386.4} \right) 257.8 = \left(\frac{12.2}{386.4} \right) v_{scr} + \left(\frac{0.2}{386.4} \right) 840$$

$$v_{scr} = \frac{2887 - 168}{12.2} = 222.9 \text{ in./sec}$$

where

W_{sr} = weight of slide with 2 rounds

W_{srp} = weight of slide, 2 rounds, and gas operating unit

The time to complete slide counterrecoil is

$$t''_{scr} = \sqrt{\frac{M_{srp}}{\epsilon K}} \left(\text{Sin}^{-1} \frac{Ks_r - F}{f(F)} - \text{Sin}^{-1} \frac{-F}{f(F)} \right)$$

where

$$\sqrt{\frac{M_{srp}}{\epsilon K}} = \sqrt{\frac{12.2}{0.8 \times 40 \times 386.4}} = \sqrt{0.00987} = 0.0314$$

$$F = 204 - Ks_c = 204 - 52.16 = 151.84 \text{ lb.}$$

$$f(F) = \sqrt{F^2 + \frac{K}{\epsilon} \left(M_{srp} v^2_{scr} \right)} = \sqrt{151.84^2 + \frac{40}{0.8} \left(0.0316 \right) 222.9^2} = 318.7.$$

Thus

$$t''_{scr} = 0.0314 \left(\text{Sin}^{-1} \frac{40 \times 1.67 - 151.84}{318.7} - \text{Sin}^{-1} \frac{-151.84}{318.7} \right) = 0.0314 \left[\text{Sin}^{-1} (-0.26683) - \text{Sin}^{-1} (-0.47643) \right]$$

$$= 0.0314 \left(\frac{344.52 - 331.55}{57.3} \right) = 0.0071 \text{ sec.}$$

The total slide counterrecoil time after cam action is

$$t_{scr} = t'_{scr} + t''_{scr} = 0.0053 + 0.0071 = 0.0124 \text{ sec.}$$

The slide energy and velocity at the end of counterrecoil are

$$E_s = \frac{1}{2} \left(M_{srp} v^2_{scr} \right) + \epsilon \left(F - \frac{1}{2} Ks_{or} \right) s_{or}$$

$$= \left(\frac{0.0316}{2} \right) 222.9^2 + 0.8 \left[151.84 - \frac{40}{2} \left(1.67 \right) \right] 1.67 = 943.8 \text{ in.-lb.}$$

$$v_{scr} = \sqrt{\frac{2E}{M_{srp}}} = \sqrt{\frac{1887.6}{0.0316}} = \sqrt{59734} = 244.4 \text{ in./sec.}$$

The time of slide counterrecoil exceeds that for the barrel, therefore, the firing rate is based on the former. The total time to complete the firing cycle

$$t_c = t_e + t_{scr} = 0.0329 + 0.0124 = 0.0453 \text{ sec.}$$

The rate of fire

$$f_r = \frac{60}{t_c} = 1324 \text{ rounds/min.}$$

Originally, the maximum recoil velocity of the slide was assumed to be 600 in./sec but, to satisfy some of the other design criteria, this velocity reduces to 478.8 in./sec. Rather than manipulate other variables to reach the 600 in./sec velocity, 478.8 in./sec was accepted to continue the analysis. When this reduced velocity was introduced in the earlier time estimates of par. 5–1.1.1, a revised rate of fire of 1590 rounds/min was computed. These two firing rates – one obtained by means of a digital computer, the other by a short cut estimate – are within 80% agreement of each other.

5–2 DOUBLE BARREL TYPE

The Navy MK 11 Gun is an excellent example of a double barrel revolver-type machine gun. This gun is recoil-operated and fires 4000 rounds/min at a muzzle velocity of 3300 ft/sec (Ref. 16). The high rate of fire is attributed to (1) the simultaneous loading, firing, and ejection of two belts of ammunition for each operation, (2) the use of advance primer ignition technique, and (3) the absence of conventional recoil and counterrecoil shock absorbing elements.

5–2.1 FIRING CYCLE

The firing cycle involves three basic operations: ramming, firing, and case ejection. All perform simultaneously at six chambers of the eight-chambered drum. Fig. 5–11 locates the relative positions of these operations. One belt of ammunition enters the rear drum area from each side of the gun and assumes the respective positions. The rounds in the top and bottom chambers, properly aligned with the barrels, are fired simultaneously. Propellant gases, bled from one barrel only, actuate the rammers and eject the empty cases, all other mechanical functions depend on recoil activity. Since firing must precede ramming and ejecting, an imperceptible lag occurs between firing and the two other functions.

At the start of each burst, only one shot is fired, always from the same *first-fire* barrel. Thus, the momentum of the recoiling parts is equivalent to the impulse generated by the propellant of this single shot. During the latter part of the recoil travel, the energy of translation of the recoiling parts is converted to rotational energy of the drum by cam action. The drum now acts as a flywheel, delivering energy needed to operate the feed system, meanwhile storing the remainder that eventually would be reconverted, by continued action, into the translational energy of counterrecoil. Just before reaching the in-battery position, both barrels are fired. Part of the total impulse of the two shots compensate for the momentum of counterrecoil to stop the moving parts in their forward motion. The remaining impulse induces the recoil that follows. This action continues until the end of the burst when a single shot is fired in the *last-fire* barrel, as opposed to the *first-fire* barrel that starts the burst. The impulse of this shot stops the counterrecoiling parts. Any residual impulse is absorbed by a buffer which also absorbs the full counterrecoil shock in the event of a misfire.

5–2.1.1 Cam Function

The drum has eight elliptical cams cut into its outer surface in the arrangement shown in Fig. 5–12. Forward and rear cam followers, mounted on a pivoting arm, engage alternately forward and rear cams during successive rounds. Fig. 5–12(A) shows the gun in battery with the forward cam follower engaged in a forward cam. As the gun recoils, the follower moves along the straight portion of the cam. The relative motion between cam and follower is augmented by the rocker arm which pivots about its fixed center. As its lower end swings forward during recoil, it draws the cam followers forward thus increasing the relative motion between cam and follower. Fig. 5–12(B) shows the positions at full recoil. By this time the follower has traversed half the curved distance and rotated the drum 22-1/2 deg. All energy is now rotational energy with only the drum and associated parts in motion. As the drum continues to turn, it actuates the follower which induces counterrecoil thereby reversing all translational motion that occurred during recoil. Fig. 5–12(C) shows the positions of the various components after all rotation has reverted to translation. Fig. 5–12(D) shows the respective positions after the return to battery. The front follower has been lowered to disengage it from the cam while the rear follower has been raised to engage the next cam which reaches this position after the drum has completed the 45 deg of travel during the firing cycle.

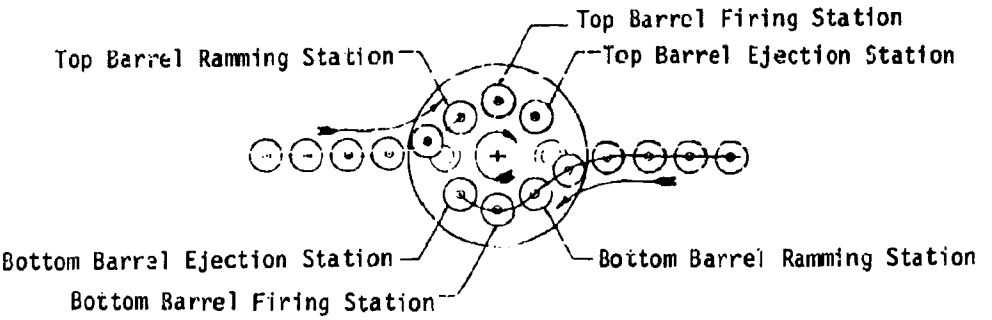


Figure 5–11. Location of Basic Operations

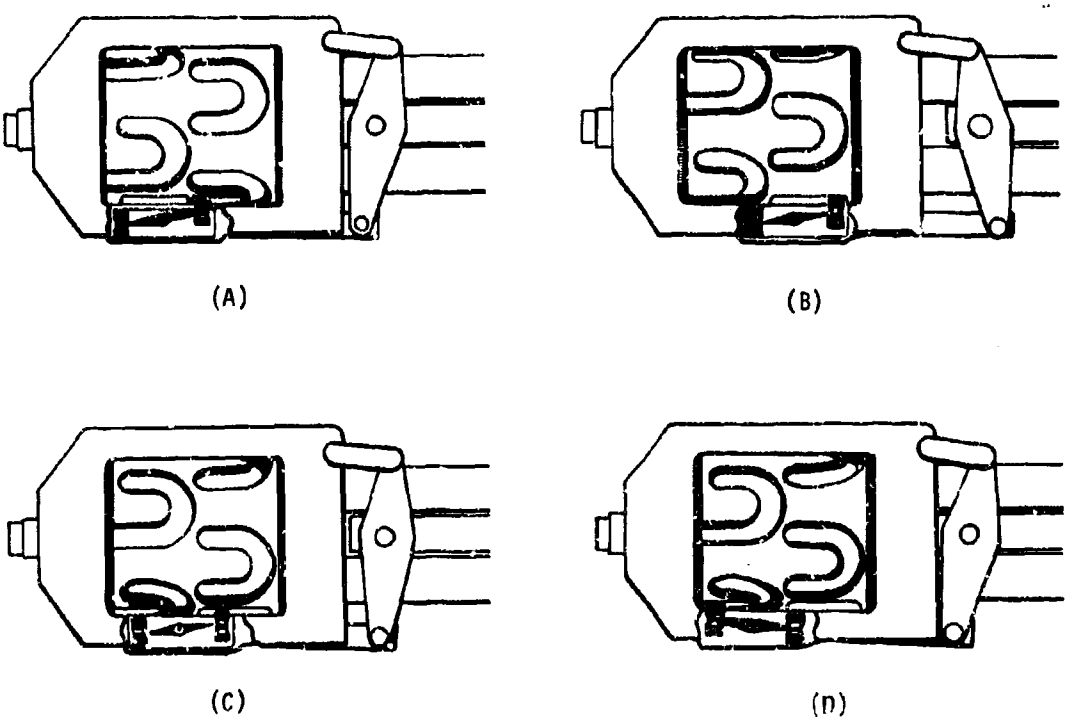


Figure 5–12. Schematic of Double Barrel Drum-cam Arrangements

5–2.1.2 Loading and Ejecting

Ammunition is conveyed to the gun in cylindrical links which are connected to form a belt. Each link has a pin and hook diametrically opposite to each other. The hook of one link engages the pin of the following link to form a joint of limited flexibility that permits the belt to be twisted or folded. Two belts feed the gun, one from each side. The intermittent rotation of the feed sprocket, which is splined to the drum shaft, pulls the ammunition belts into the loader. Two gas-operated rammers, diametrically opposite with reference to the drum, simultaneously strip a round from a link of each belt and ram the ammunition at a speed of 50 ft/sec into the empty chambers adjacent to the barrels. On the next cycle these two rounds are fired. The following cycle, after the drum rotates 45 deg, finds the chambers containing the spent cases and their corresponding links in line with the gas ejector ports and ejection ducts. Propellant gases, tapped from the *first-fire* barrel, issue from the ports at high velocity and blow the empty cases into the empty links. The case momentum is high enough to seat the cases in the links, slip the belt attachment, and carry the case-link unit into the mouth of the ejection ducts at a velocity of 75 ft/sec which is enough to insure emergence from the ducts at 50 ft/sec. During the next cycle, the emptied chambers remain empty and advance to the 3 and 9 o'clock positions, where the two ammunition belts enter the loader (see Fig. 5–11). By remaining empty, the two idle chambers provide the space requirements for efficient operation.

5–2.1.3 Ammunition Feed System

The ammunition feed system consists of a pneumatic motor, a drive system, and an ammunition magazine. The system functions as a unit – the motor provides the power, the drive transmits the power to the ammunition belts and magazine, while the magazine releases the ammunition and rotates to maintain proper alignment between stored belt and feed throat. Fig. 5–13 is a schematic of the feed system that illustrates the functions in sequence. Although the gun is self-feeding, the pneumatic power boosters at the magazine insure high rate of fire and high functional link belt reliability. The power is transmitted by drive shafts and gear boxes to the sprockets which (1) engage the ammunition belts, (2) pull the belts from the magazine, and (3) drive the ammunition toward the loader. Another power drive, reduced to low speeds, turns the magazine.

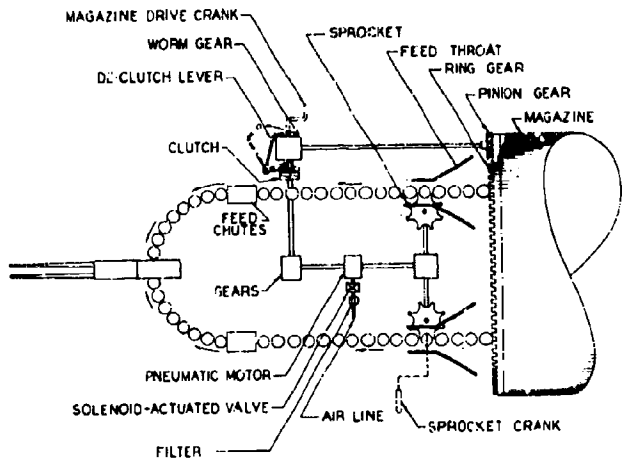


Figure 5–13. Schematic of Ammunition Feed System

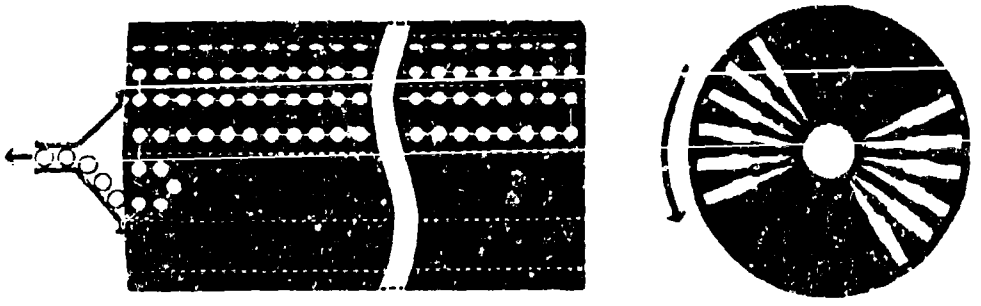


Figure 5–14. Schematic of Ammunition Magazine

The feed system is equipped with two manually operated driving units that are turned by hand cranks. When the magazine is being loaded, a jaw clutch is disengaged, separating magazine drive from ammunition drive so that magazine and feed sprockets can be rotated independently. One unit turns the magazine worm drive which rotates the magazine to the desired loading position; the other manual drive turns the feed sprocket to move the ammunition belt into the magazine.

The magazine is a cylindrical drum that has an even number of radial partitions. Each partition houses 60 rounds of ammunition. The two ammunition belts are loaded symmetrically about the axis so that the belts can be withdrawn simultaneously from two diametrically opposite sectors. Fig. 5–14 shows the arrangement of the stored ammunition and the method of withdrawal. The end view shows the balanced nature of the stored ammunition while the arrow indicates the direction of rotation. The side view shows how a belt is folded in the partitions. The belts leave the magazine through the feed throat on the left. Ammunition in the sectors is so arranged that only a small segment of each belt is accelerated at any time during a burst. As the ammunition empties from one sector, the next loaded sector – by virtue of the slowly rotating magazine – comes into line with the feed throat. Alignment is assured by synchronizing belt speed with the rotational speed of the magazine.

5–2.2 DYNAMICS OF FIRING CYCLE

To introduce the dynamics of the firing cycle, assume that the machine gun is operating normally, i. e., both barrels are firing simultaneously. Since the gun fires out of battery, the momentum of the counterrecoiling mass must be dissipated before recoil can begin. This momentum is counteracted by the initial impulse of the propellant gas force. The remaining impulse is converted to linear momentum of the recoiling parts and later, by cam action, the linear momentum is converted into angular momentum of the drum and its associated moving parts.

The cam arrangement is such that only linear motion of the recoiling parts occurs shortly before, during, and immediately following firing. The dynamics are readily computed if the firing time is divided into small increments of time. If the acceleration during this short time interval is assumed to be constant, the various parameters can be computed for each time increment. Thus, after the increment of time Δt, the momentum of the counterrecoiling parts at increment n is

$$M_n = M_{n-1} + F_g \Delta t \qquad (5-76)$$

where F_g = propellant gas force during Δt

M_{n-1} = momentum just preceding Δt

During counterrecoil, momentum and velocity are considered to be negative as opposed to positive during recoil. Propellant gas force is always positive. Momentum is defined as Mv, therefore the velocity after Δt is

$$v_n = \frac{M_n}{M_r} \qquad (5-77)$$

where M_r = mass of recoiling parts.

The distance traveled during Δt is

$$\Delta x_r = (v_n + v_{n-1})\,\Delta t/2. \qquad (5-78)$$

Designate x_r the distance that the recoiling parts are out of battery.

$$x_r = x_{r(n-1)} + \Delta x \qquad (5-79)$$

During recoil, x_r is the recoil travel distance of barrel and drum assembly.

5-2.2.1 Cam Analysis

The forces induced by cam action are shown diagrammatically in Fig. 5-15. Because the cam follower is constrained in the y-direction, motion in this direction is restricted to the peripheral travel of the drum. Because of the linkage arrangement shown in Fig. 5-12, the cam-to-cam follower position is determined by the relative displacement of the cam during recoil, or counterrecoil, and the movement of the cam follower that is determined by the link rotation.

The resolution of cam forces and the mutual influence of the various moving parts on one another are illustrated in Figs. 5-15, 5-16, and 5-17; and are defined, except for those referring to the springs and slide, by the expressions of Eqs. 5-29 through 5-47. Because this cam analysis follows the same procedure as that developed for the slide-cam analysis, only the pertinent equations will be given, thus avoiding repetition. According to Eqs. 5-33 through 5-36, the directional coefficients during recoil are

$$K_x = \sin\beta + \mu\left(\frac{R_p}{R_r}\right)\cos\beta \qquad (5-80)$$

$$K_y = \cos\beta - \mu\left(\frac{R_p}{R_r}\right)\sin\beta \qquad (5-81)$$

and during counterrecoil, they are

$$K_x = \sin\beta - \mu\left(\frac{R_p}{R_r}\right)\cos\beta \qquad (5-82)$$

$$K_y = \cos\beta + \mu\left(\frac{R_p}{R_r}\right)\sin\beta \qquad (5-83)$$

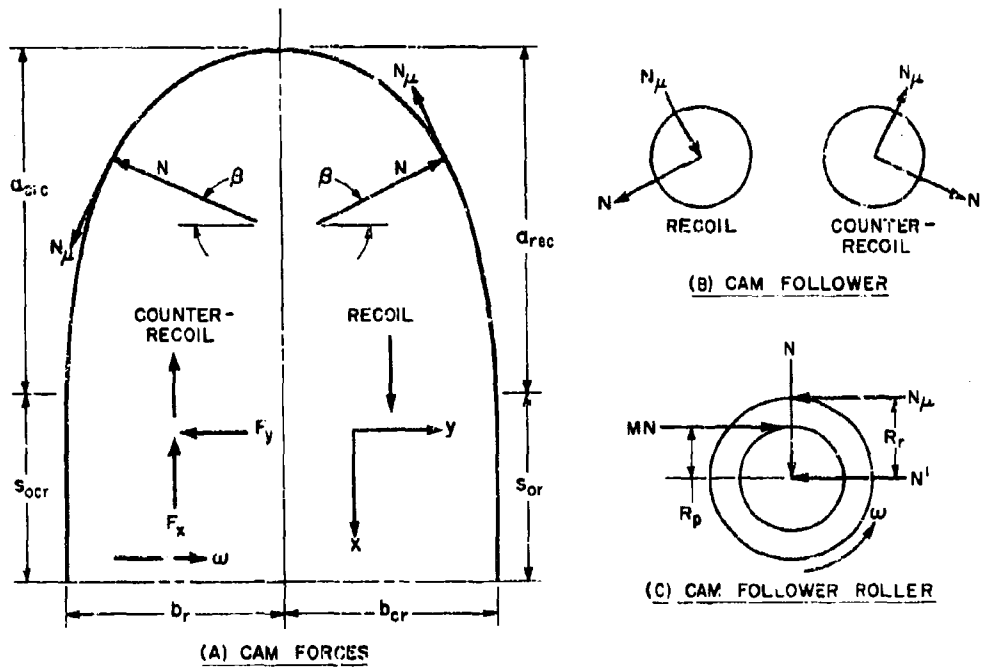


Figure 5-15. Double Barrel Cam Force Diagrams

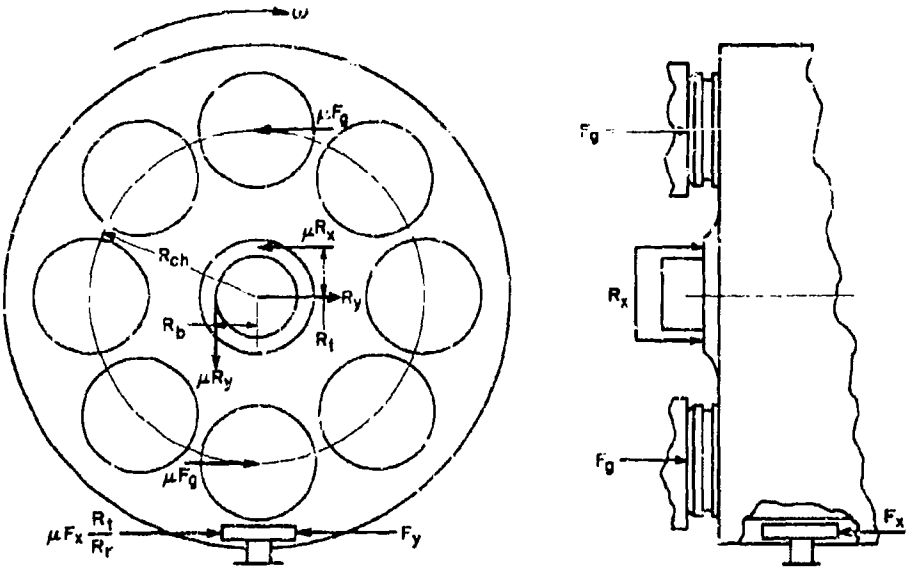


Figure 5–16. Double Barrel Drum Loading Diagram

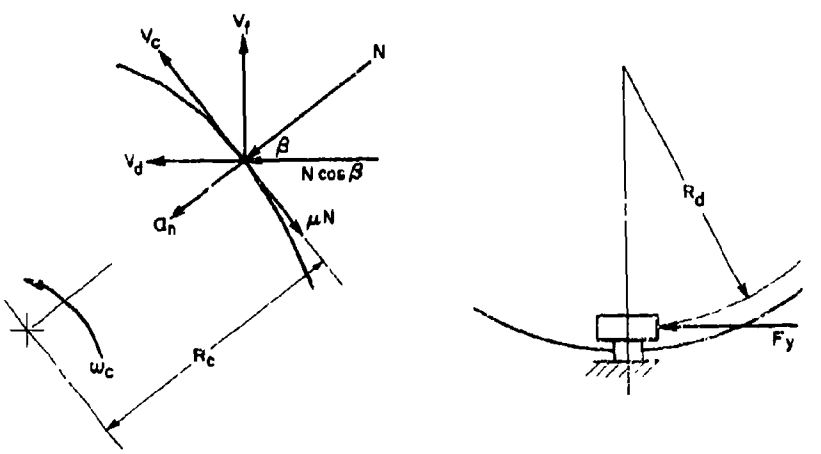


Figure 5–17 Double Barrel Drum Dynamics

The axial and tangential cam forces are, respectively,

$$F_x = NK_x \tag{5-84}$$

$$F_y = NK_y \tag{5-85}$$

From Eq. 5-81, the resisting torque induced by the residual propellant gas force is

$$T_g = \mu(R_{ch} - \mu R_b) F_g \tag{5-86}$$

The cam normal force, Eq. 5-47, is

$$N = \frac{\dfrac{I_d v_s^2}{R_c R_d \cos\beta} + T_g}{(R_d - \mu R_b) K_y - \mu \left[R_t + R_d \left(\dfrac{R_p}{R_r} \right) \right] K_x} \tag{5-87}$$

where v_s is the axial relative velocity between cam follower and cam which is also the slide velocity. The various parameters of the cam geometry are expressed in Eqs. 5-48 through 5-52.

5-2.2.2 Energy Concept

During the early part of the recoil stroke and the latter part of the counterrecoil stroke, the cam follower moves axially in the straight portion of the cam; therefore, no energy is exchanged between rotating and translating parts. When the cam follower is riding in the curved portion of the cam, an exchange of energy takes place. At any given time, by the law of conservation of energy, the total energy remains unchanged. By dividing the cam travel into short increments, the amount of energy E_l in each group of moving parts may be expressed with negligible error in terms of total energy and the changing geometry of cam.

$$E_l = E_r + E_d + E_a + E_\mu \tag{5-88}$$

where E_a = energy of ammuntion belt

E_d = energy of rotating parts

E_l = total energy at any given increment

E_r = energy of recoiling parts

E_μ = energy losses due to friction

Note that for the next increment,

$$E_i = E_{l-1} - E_\mu . \tag{5-89}$$

The individual energy forms are expressed in terms of the linear velocity of the recoiling parts as shown in the next three equations.

$$E_d = I_d \left(\frac{\tan^2\beta}{R_d^2} \right) v_r^2 \tag{5-90}$$

$$E_r = \frac{1}{2} \left(M_r v_r^2 \right) \tag{5-91}$$

$$E_a = \frac{1}{2} \left(N_a M_a r_a v_r^2 \right) \tag{5-92}$$

where I_d = mass moment of inertia of drum

M_a = mass of one link of ammunition

M_r = mass of recoiling parts

N_a = number of links of ammunition affected

R_d = distance of cam to center of drum

r_a = effective ratio between v_r and belt velocity

v_r = velocity of recoiling parts

5-2.2.3 Digital Computer Program for Firing Cycle

A digital computer program is arranged to compute the significant data occurring during the firing cycle. It is an iterative procedure that first computes the total impulse. The force-time curve of the interior ballistics is divided into small time increments from which the respective propellant gas force is read. The median force is assumed to be the average. The differential time

between any two adjacent forces is small enough so that the corresponding portion of the curve approximates a straight line; therefore, the assumption is considered accurate. The computed area under the curve is the total impulse. The force-time curve is shown in Fig. 5–18.

The velocity of free recoil is found by equating the impulse to the momentum of the recoiling parts. The energy of free recoil may now be computed. However, this energy is a fictitious value since the gun is fired out of battery. Also, frictional losses in the system account for additional energy loss. To compensate for this loss during the first set of computations, only 70 percent of the energy of free recoil is entered toward computing the counterrecoil velocity plus the initial momentum of counterrecoil just as the first two chambered rounds are fired simultaneously. Each differential impulse is subtracted from the momentum until zero velocity is achieved. Subsequently, the remaining impulse determines the new recoil velocity. The dynamics of the cam system are now computed and if the resulting counterrecoil velocity – after the cam is negotiated by the cam follower – does not match its original value, the initial counterrecoil is adjusted accordingly, and the process continued.

The area under the force-time curve for a given time represents the cumulated impulse of the propellant gas force to that term. The area is computed by employing the trapezoid rule.

$$A_n = A_{n-1} + F\Delta t \tag{5-93}$$

$$F\Delta t = \frac{1}{2}\left[F_{g(n-1)} + F_{g(n)}\right]\Delta t. \tag{5-94}$$

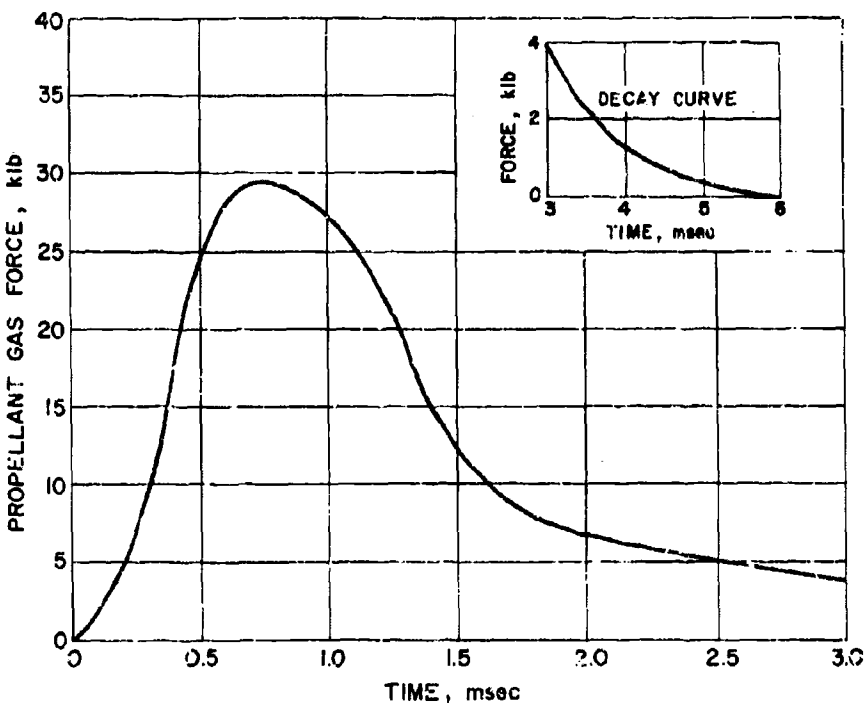


Figure 5–18. Force-time Curve of 20 mm Revolver-type Gun

The momentum during counterrecoil at any given time is

$$M_n = M_{n-1} - F\Delta t. \tag{5-95}$$

The momentum during recoil is

$$M_n = M_{n-1} + F\Delta t. \tag{5-96}$$

The velocity, energy, and distance can now be computed at the end of each time interval. Note that no cam activity must take place while the projectiles are still in the bores. To insure this requirement, the cam follower rides the linear portion of the cam (the dwell period) until the propellant gas pressure has theoretically dropped to zero. Actually some residual gas pressure may still persist and is considered as one of the forces in the cam analysis.

The conservation of energy concept introduced earlier is generally followed with some variations to make the analysis more manageable. These variations are the various components of the energy lost to friction. Two primary components are the linear and angular sliding frictional losses. The linear component consists of the frictional resistance indicated by the transverse cam force F_y and its reaction R_y on the drum bearing (see Fig. 5-16). The frictional resistance created by μR_y is relatively small and may be ignored. The work done by the average forces over small increments of travel is

$$E_{\mu s(n)} = \frac{\mu}{2}\left\{\left[F_{y(n-1)} + F_{y(n)}\right]\left(\frac{R_p}{R_r}\right)\Delta x + \left[R_{y(n-1)} + R_{y(n)}\right]\Delta x_r\right\}. \tag{5-97}$$

Note that Δx is influenced by the friction of the cam follower roller to the extent of the indicated ratio of two radii (see Eq. 5-32). According to Fig. 5-19, $\rho = r_c/r_d$. Since $R_y = F_y$ and $\Delta x_r = \Delta x/\rho$, and according to Eq. 5-85, $F_y = NK_y$, therefore

$$E_{\mu s(n)} = \frac{1}{2}\,\mu\left[\left(NK_y\right)_{(n-1)} + \left(NK_y\right)_{(n)}\right]\left(\frac{1}{\rho} + \frac{R_p}{R_r}\right)\Delta x. \tag{5-98}$$

The respective velocities, v_s and v_r of the slide and recoiling parts during cam activity, are

$$v_s = v_c\cos\beta; \quad v_r = v_c/\rho. \tag{5-99}$$

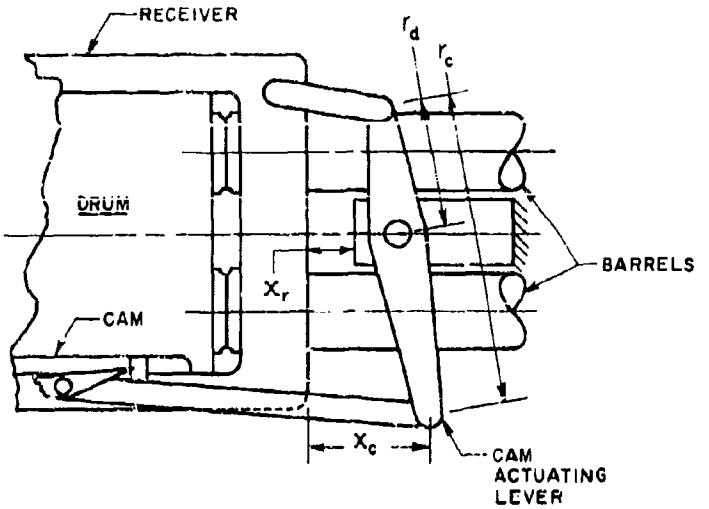


Figure 5–19. Geometry of Cam Actuating Lever

At the same time, the distances traveled are computed from the position of cam follower and cam as indicated in Eq. 5–49. Since the distance x on the curve indicates the relative travel along the x-axis between cam follower and cam, the total axial distance at any given interval is

$$x_s = s_{or} + x \qquad (5\text{–}100)$$

where s_{or} is the straight length of the cam. The corresponding travel x_r of the recoiling parts (drum and barrel assemblies) is

$$x_r = x_s/\rho. \qquad (5\text{–}101)$$

During the cam dwell period, the travel of the recoiling parts is

$$x_{rd} = x_{rd(n-1)} + \frac{1}{2}\left[v_{r(n-1)} + v_{r(n)}\right] \Delta t \qquad (5\text{–}102)$$

where x_{rd} is used instead of x_r to differentiate between the dwell period and the active cam period. The interval Δt_1 spans the time when the follower enters the dwell and until the propellant gas forces of the next round become effective. Here, Δt_1 is the first time interval of the firing cycle.

$$\Delta t_1 = \left[\left(s_{or}/\rho\right) - x_{ru}\right]/v_{cr} \qquad (5\text{–}103)$$

where v_{cr} = counterrecoil velocity

x_{ru} = counterrecoil travel during impulse period

The time interval after the impulse period and until cam action begins during recoil is

$$\Delta t_n = \left[\left(s_{or}/\rho\right) - x_{rn}\right]/v_m \qquad (5\text{–}104)$$

where v_m = max recoil velocity

x_{rn} = recoil travel during impulse period

TABLE 5–15. SYMBOL-CODE CORRELATION FOR DOUBLE BARREL MACHINE GUN

Symbol	Code	Symbol	Code
a	A	s_o	SC
A_n	FTAREA	s_{or}/ρ	SR
b	B	t	T
C_x	CX	Δt	DT
C_y	CY	t_m	TM
E	E	T_g	TG
F_g	FG	v	V
F_{gr}	FGRES	v_c	VC
$F\Delta t$	FDT	v_d	VD
g	G	v_s	VS
I_d	DI	W_a	WA
K_x	XK	W_r	WR
K_y	YK	x	X
L_c	CL	Δx	DX
L_r	RL	x_s	XC
M_a	EMA	x_{rd}	XR
M_r	EMR	Δx_r	DXR
M_n	EMV	x_i	XREC
N	EN	y	Y
R_b	RR	Δy	DY
R_{ch}	RCH	β	BETA
R_d	RD	θ	THETA
R_p	RP	$\Delta\theta$	DTHETA
R_r	RR	μ	EMU
R_t	RT	ρ	RHO

TABLE 5–16. INPUT DATA FOR DOUBLE BARREL MACHINE GUN

Code	Value	Code	Value
A	1.5	RD	3.25
B	1.276275	RHO	2.5
CL	3.125	RL	1.25
DI	0.81	RP	0.25
EMU	0.1	RR	0.5
FGRES*	200.0	RT	1.25
G	386.4	SR	0.65
RB	1.0	WA	12.256
RCH	2.25	WR	120.0

*The values of FG are listed in the output, Table 7-11.

Throughout the computer program, several combinations of values are repeated. Also, similar terms appearing in more than one equation are lifted from those equations and combined into another unique expression. To avoid recomputation and for programming convenience, each combination is treated as a coefficient which is identified by a new symbol. These coefficients, when isolated, have little physical significance, and therefore, can be defined best by association throughout the development of the computer program.

For any given increment n, both $N_{(n-1)}$ and $K_{y\,(n-1)}$ are known so that

$$E_{\mu s(n-1)} = \frac{1}{2}\left[\mu(NK_y)_{(n-1)}\right]\left(\frac{1}{\rho} + \frac{R_p}{R_r}\right)\Delta x$$

$$= C_{m(n-1)}N_{(n-1)}\Delta x/2. \qquad (5-105)$$

Note that in general, $C_m = \mu K_y\left(\frac{1}{\rho} + \frac{R_p}{R_r}\right)$

The other part involving NK_y has unkown values and these are expressed in terms of computable parameters. Thus

$$E_{\mu s(n)} = \frac{1}{2}\,\mu\,(NK_y)_n\left[\frac{1}{\rho} + \frac{R_p}{R_r}\right]\Delta x$$

$$= C_{m(n)}N_{(n)}\Delta x/2 \qquad (5-106)$$

By combining the various expressions of Eq. 5–47 into simple terms

$$N = \frac{\left[C_{id}\left(\frac{\cos\beta}{R_c}\right)v_c^2 + T_g\right]}{\left(C_yK_y - C_xK_x\right)}. \qquad (5-107)$$

$$N = C_{vc}v_c^2 + T_{gn} \qquad (5-108)$$

Now substitute for N in Eq. 5–106

$$E_{\mu s(n)} = E_{\mu sm} + C_{dx}T_{gn} \qquad (5-109)$$

where

$$E_{\mu sm} = C_{fx}v_c^2 \qquad (5-110)$$

The resolution of the angular component of sliding friction follows a similar procedure. The total energy lost to friction in the rotating drum is

$$E_{\mu d} = \frac{1}{2}\left[T_{\mu(n-1)} + T_{\mu(n)}\right]\Delta\theta. \qquad (5-111)$$

where T_μ is the frictional torque. The equation for the frictional torque may be composed by referring to Fig. 5–16.

$$T_\mu = \mu F_y R_b + \mu F_x\left[R_t + R_d\left(\frac{R_p}{R_r}\right)\right] + 2\mu F_{gr}R_{ch} \qquad (5-112)$$

$$T_\mu = N\left(\mu R_b K_y + C_x K_x\right) + T_g = C_{t\mu}N + T_g. \qquad (5-113)$$

At the beginning of each increment, all data are known.

$$T_{\mu(n-1)} = C_{t\mu(n-1)}N_{(n-1)} + T_g \qquad (5-114)$$

At the end of each increment, N is not known but may be expressed in terms of computable parameters

$$T_{\mu(n)} = C_{t\mu}N + T_g \qquad (5-115)$$

$$T_{\mu(n)} = C_{t\mu}C_{vc}v_c^2 + C_{t\mu}T_{gn} + T_g. \qquad (5-116)$$

The various terms for energy may now be expressed by multiplying the frictional torques by $\Delta\theta/2$ and combining the terms when appropriate

Compute the energy of the $N_{(n-1)}$ term of Eq. 5–114.

$$E_{\mu d1} = \frac{1}{2}\left[\Delta\theta\, C_{t\mu(n-1)}N_{(n-1)}\right] \qquad (5-117)$$

Compute the energy of the v_c term of Eq. 5–116

$$E_{\mu dn} = \frac{\Delta\theta}{2}\left(C_{t\mu}C_{vc}v_c^2\right) = C_{tq}v_c^2 \qquad (5-118)$$

Compute the energy of the T_{gn} terms of Eqs. 5–109 and 5–116

$$E_{\mu rtg} = \left[C_{dx} + C_{t\mu}\left(\frac{\Delta\theta}{2}\right)\right]T_{gn} = \left(C_{dx} + C_{dt}\right)T_{gn} \qquad (5-119)$$

Compute the energy of the T_g terms of Eqs. 5–114 and 5–116.

$$E_{\mu dtg} = \frac{\Delta\theta}{2}\left(T_g + T_g\right) = \Delta\theta\, T_g. \qquad (5-120)$$

The total readily computable energy loss is

$$E_{\mu 1} = E_{\mu r1} + E_{\mu rtg} + E_{\mu dtg} + E_{\mu dl}. \qquad (5-121)$$

The effective masses of the recoiling parts (M_{re}), ammunition (M_{ae}), and drum (I_{de}) with respect to the cam velocity when energy is involved are

$$M_{re} = \frac{M_r}{2\rho^2}; \quad M_{ae} = \frac{M_a}{2\rho^2}; \quad I_{de} = \frac{I_d}{R_d^2 + \rho^2}. \qquad (5-122)$$

The energy that remains in the system after the readily computable energy loss is subtracted

$$E_{le} = E_{l-1} - E_{\mu 1} = E_r + E_a + E_d + E_{\mu sn} + E_{\mu dn}$$

$$= \left| M_{re}\sin^2\beta + \left(M_{ae} + I_{de}\right)\cos^2\beta + C_{fx} + C_{tg}\right| v_c^2$$

$$E_{le} = \left(C_{mr} + C_{ma} + C_{id} + C_{fx} + C_{tg}\right)v_c^2 = C_e v_c^2 \qquad (5-122)$$

where C_e is the coefficient of v_c^2

$$v_c = \sqrt{E_{le}/C_e} \qquad (5-124)$$

$$E_\mu = E_{\mu 1} + C_{fx} + \left(C_{fx} + C_{tg}\right)v_c^2 \qquad (5-125)$$

$$E_l = E_{l-1} - E_\mu \qquad (5-126)$$

The computed results show the time for one cycle to be 26.2 msec (see Table 5–17) which indicates a firing rate of 4580 rounds/min since both barrels are firing simultaneously.

TABLE 5–17. DOUBLE BARREL MACHINE GUN DYNAMICS

I	TIME MSEC	PROPELLANT GAS FORCE LB	IMPULSE LB-SEC	RECOIL VEL IN/SEC	AXIAL CAM VEL IN/SEC	RECOIL TRAVEL IN	AXIAL CAM TRAVEL IN
1	6.071	.0	.00	97.6	243.9	.0577	.1442
2	6.196	2500.0	.16	96.9	241.4	.0456	.1139
3	6.321	7000.0	.75	92.7	231.8	.0337	.0843
4	6.446	15200.0	2.14	83.8	209.5	.0227	.0567
5	6.571	23600.0	4.56	68.2	170.4	.0132	.0330
6	6.696	28400.0	7.01	47.2	118.1	.0060	.0150
7	6.821	29500.0	11.43	23.9	59.9	.0015	.0038
8	6.946	28600.0	15.06	.6	1.4	.0000	.0000
9	6.950	28573.6	18.55	.0	.0	-.0000	-.0000
10	7.196	24800.0	21.80	42.9	107.1	.0053	.0132
11	7.321	22000.0	24.72	61.7	154.2	.0118	.0295
12	7.446	16200.0	27.11	77.0	192.6	.0205	.0512
13	7.571	12400.0	28.90	88.6	221.4	.0308	.0771
14	7.696	10000.0	30.30	97.6	243.9	.0425	.1062
15	7.821	8500.0	31.46	105.0	262.6	.0551	.1378
16	7.946	7500.0	32.46	111.5	278.7	.0687	.1717
17	8.071	6800.0	33.35	117.2	293.0	.0830	.2074
18	8.196	6400.0	34.17	122.5	306.3	.0979	.2449
19	8.321	6000.0	34.95	127.5	318.8	.1136	.2839
20	8.446	5500.0	35.67	132.1	330.4	.1298	.3245
21	8.571	5200.0	36.34	136.5	341.1	.1466	.3665
22	8.696	4800.0	36.96	140.5	351.2	.1639	.4097
23	8.821	4500.0	37.54	144.2	360.6	.1817	.4542
24	8.946	4200.0	38.09	147.7	369.3	.1999	.4998
25	9.071	3900.0	38.59	151.0	377.5	.2186	.5465
26	9.821	1700.0	40.69	164.5	411.3	.3369	.8423
27	10.571	700.0	41.59	170.3	425.8	.4625	1.1562
28	11.321	200.0	41.93	172.5	431.2	.5910	1.4775
29	12.071	.0	42.01	173.0	432.4	.7206	1.8014
30	12.071	.0	.00	173.0	432.4	.6500	1.6250

TABLE 5–17. DOUBLE BARREL MACHINE GUN DYNAMICS (Con't.)

I	TIME MSEC	NORMAL CAM FORCE LB	CAM SLOPE DEG	PERIPH DRUM VEL IN/SEC	AXIAL CAM VEL IN/SEC	RECOIL VEL IN/SEC	PERIPH DRUM TRAVEL IN	AXIAL CAM TRAVEL IN	RECOIL TRAVEL IN
31	12.2452	8450.0	2.44	18.3	430.6	172.3	.0016	1.7000	.6800
32	12.4202	8416.9	4.89	36.5	426.6	170.7	.0064	1.7750	.7100
33	12.5970	8396.9	7.36	54.4	421.7	168.7	.0144	1.8500	.7400
34	12.7761	8390.0	9.85	72.2	415.9	166.4	.0258	1.9250	.7700
35	12.9579	8396.3	12.39	89.9	409.1	163.7	.0405	2.0000	.8000
36	13.1429	8416.1	14.98	107.4	401.4	160.5	.0588	2.0750	.8300
37	13.3319	8449.6	17.64	124.8	392.5	157.0	.0807	2.1500	.8600
38	13.5254	8498.2	20.37	142.1	382.6	153.0	.1065	2.2250	.8900
39	13.7243	8562.2	23.21	159.2	371.4	148.6	.1365	2.3000	.9200
40	13.9297	8642.9	26.16	176.3	358.9	143.6	.1710	2.3750	.9500
41	14.4885	8937.7	34.37	218.9	320.1	128.0	.2615	2.5647	1.0259
42	14.9598	9274.3	41.53	250.0	282.3	112.9	.3920	2.7067	1.0827
43	15.3618	9660.9	48.14	273.6	245.1	98.0	.5026	2.8179	1.1272
44	15.7730	10132.5	54.44	291.2	208.2	83.3	.6131	2.9066	1.1626
45	16.1442	10774.9	60.55	303.9	171.6	68.6	.7236	2.9771	1.1908
46	16.5027	11619.7	66.54	312.1	135.4	54.2	.8342	3.0321	1.2128
47	16.8545	14079.2	72.45	315.5	99.8	39.9	.9447	3.0735	1.2294
48	17.2056	23522.3	78.32	312.0	64.5	25.8	1.0552	3.1023	1.2409
49	17.5623	17832.9	84.17	303.9	31.1	12.4	1.1657	3.1194	1.2477
50	17.9252	96.6	90.00	299.8	.0	.0	1.2763	3.1250	1.2500
51	18.2994	10835.6	84.17	294.9	30.1	12.1	1.3868	3.1194	1.2477
52	18.6825	7595.4	78.32	284.5	58.8	23.5	1.4973	3.1023	1.2409
53	19.0802	6612.2	72.45	272.6	86.2	34.5	1.6079	3.0735	1.2294
54	19.4973	5983.9	66.54	258.4	112.2	44.9	1.7184	3.0321	1.2128
55	19.9399	5470.2	60.55	241.9	136.6	54.6	1.8289	2.9771	1.1908
56	20.4164	5007.2	54.44	222.8	159.2	63.7	1.9394	2.9066	1.1626
57	20.9388	4572.5	48.14	201.1	180.1	72.1	2.0500	2.8179	1.1272
58	21.5256	4157.6	41.53	176.4	199.1	79.7	2.1605	2.7067	1.0827
59	22.2093	3757.6	34.37	147.8	216.1	86.4	2.2710	2.5647	1.0259
60	23.0589	3365.8	26.16	113.3	230.6	92.2	2.3816	2.3750	.9500
61	23.3814	3243.0	23.21	100.6	234.5	93.8	2.4160	2.3000	.9200
62	23.6991	3134.4	20.37	88.2	237.6	95.1	2.4460	2.2250	.8900
63	24.0131	3038.2	17.64	76.3	240.0	96.0	2.4718	2.1500	.8600
64	24.3245	2952.9	14.98	64.7	241.8	96.7	2.4938	2.0750	.8300
65	24.6339	2877.3	12.39	53.4	243.0	97.2	2.5120	2.0000	.8000
66	24.9422	2810.4	9.85	42.3	243.6	97.4	2.5268	1.9250	.7700
67	25.2500	2751.3	7.36	31.5	243.7	97.5	2.5381	1.8500	.7400
68	25.5580	2699.4	4.89	20.8	243.4	97.3	2.5462	1.7750	.7100
69	25.8667	2654.1	2.44	10.3	242.6	97.0	2.5510	1.7000	.6800
70	26.1767	2614.9	.00	.0	241.3	96.5	2.5525	1.6250	.6500

CHAPTER 6

MULTIBARREL MACHINE GUN

6-1 GENERAL

The Gatling Gun type of machine gun provides very high rates of fire by being capable of what may essentially be called simultaneous loading, firing, extracting, and ejecting and still not overexpose any one barrel to the effects of rapid, continuous fire. Each of the above four functions are performed in separate barrels during the same interval thus fixing four as the lower limit for the number of barrels, to the gun. Physical size establishes the upper limit but five or six is the usual number of barrels in each cluster with six being preferred. Several of these six-barreled guns have proved successful and are production items.

6-2 BOLT OPERATING CAM DEVELOPMENT

The closing and opening of the bolts of a multibarreled gun are regulated by a cam attached to or cut into the inner housing wall. Each bolt has a cam follower equipped with a roller that rides in the cam. As the gun rotates, carrying the bolts with it, the cam followers force these bolts into prescribed directions. Fig. 6-1 shows a cam contour. It has two dwell periods, the rear when the bolt is fully retracted and the front when the bolt is closed. The rear dwell provides time to complete the cartridge case ejection and to receive a new round. The front dwell provides firing time and holds the bolt closed until propellant gas pressures reduce to safe limits. The feeding and ejection periods have three intervals: accelerating, constant velocity, and decelerating. Because of the differences in cam force during the two periods, the accelerating distance is generally three times that of the decelerating. The constant velocity period is not absolutely essential but incorporating it has the advantage of distributing power requirements.

6-2.1 CAM ACTION

Parabolic curves are selected for the accelerating and decelerating portions of the cams because of the constant acceleration characteristic. In the same sense, straight lines form the constant velocity portions of the cam. Fig. 6-2 shows the loading diagram on the bolt and cam arrangements during acceleration. Fig. 6-3 isolates the feeding portion of the cam path shown in Fig. 6-1. It consists of two parabolic curves tangent to a straight line. The analysis for feeding or ejecting are identical. Acceleration ends at P_1 and deceleration starts at P_2, the slope β being the same at these two points. The expression for the accelerating curve is

$$y^2 = Kx. \tag{6-1}$$

The slope is

$$\frac{dx}{dy} = \frac{2y}{K} = \frac{2y}{y^2/x} = \frac{2x}{y} = \tan\beta. \tag{6-2}$$

The slope at P_1 is

$$\left(\frac{dx}{dy}\right)_1 = \frac{2x_1}{y_1}. \tag{6-3}$$

The expression for the decelerating curve is

$$(y_2 - y)^2 = K(x_2 - x). \tag{6-4}$$

Solve for x.

$$x = x_2 - \frac{1}{K}(y_2 - y)^2 \tag{6-5}$$

$$\frac{dx}{dy} = \frac{2}{K}(y_2 - y) \tag{6-6}$$

when $y = 0$, $x = 0$, and $\frac{dx}{dy} > 0$, therefore $K = \frac{y_2^2}{x_2}$

The slope at P_2, where $y = 0$, is

$$\left(\frac{dx}{dy}\right)_2 = \frac{2x_2}{y_2} \tag{6-7}$$

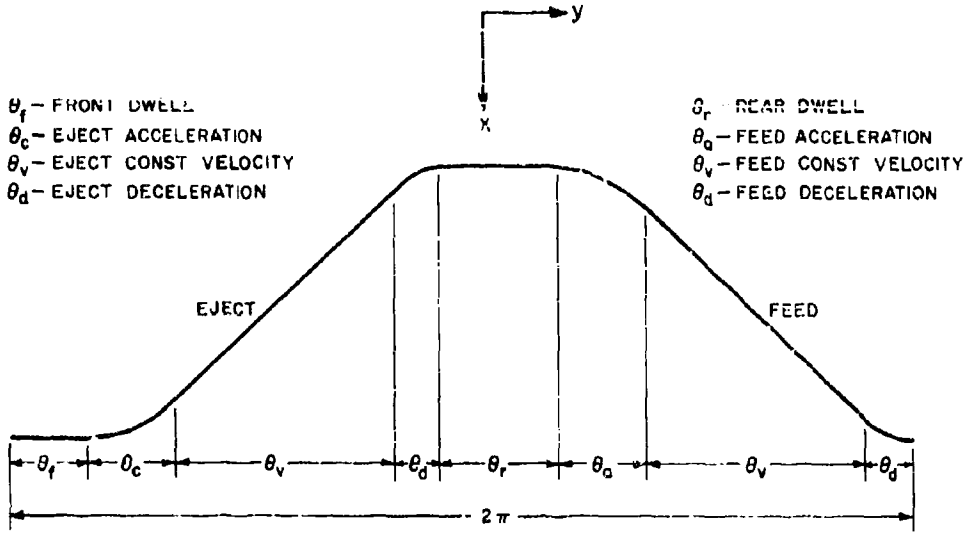


Figure 6–1. Cam Contour of Multibarrel Gun

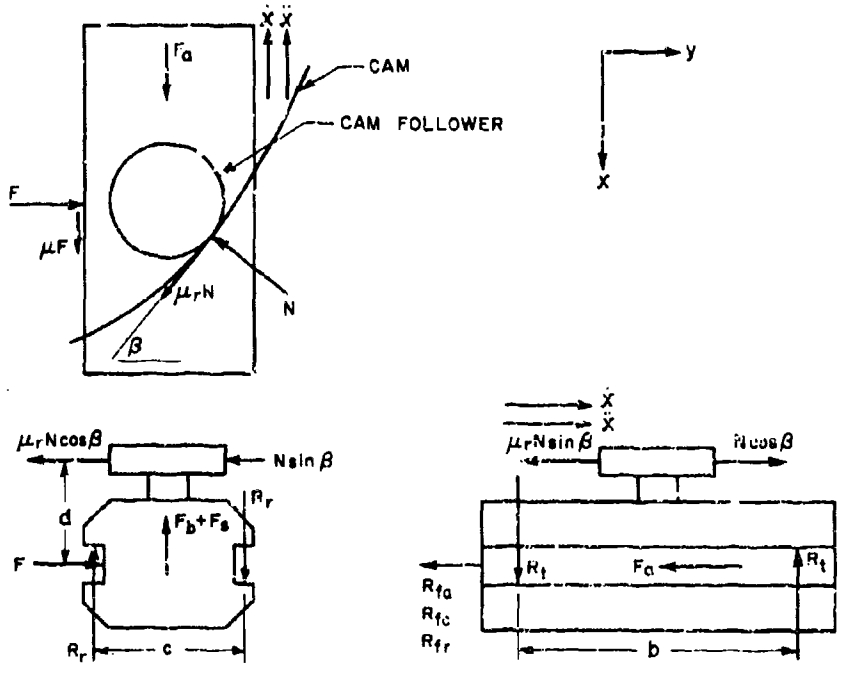


Figure 6–2. Loading Diagram of Bolt and Cam During Acceleration

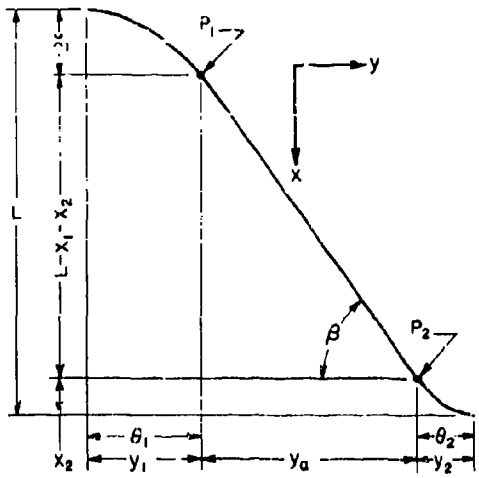


Figure 6–3. Feed Portion of Cam

Since the same straight line is tangent to the curves at P_1 and P_2, their slopes are equal at these points.

Therefore

$$\frac{x_1}{y_1} = \frac{x_2}{y_2} \tag{6–8}$$

$$x_2 = \left(\frac{y_2}{y_1}\right) x_1 . \tag{6–9}$$

The rotor, after its accelerating period turns at a constant velocity and the lengths of y_1 and y_2 are known, is chosen to comply with desired design conditions.

$$y_1 = R_c\theta_1 = R_c\omega t_1 \tag{6–10}$$

$$y_2 = R_c\theta_1 = R_c\omega t_1 \tag{6–11}$$

where R_c = cam radius

ω = angular velocity of the rotor

L_c = total peripheral length of the cam.

$$L_c = 2\pi R_c \tag{6–12}$$

y_a is the peripheral length of the constant slope of the cam

$$y_a = \theta_a R_c \tag{6–13}$$

where θ_a = rotor travel for constant cam slope

The slope at P_1 is the differential

$$\left(\frac{dx}{dy}\right)_1 = \frac{L - x_1 - x_2}{y_a} \approx \frac{L - x_1}{y_a}\left(1 + \frac{y_2}{y_1}\right). \tag{6–14}$$

Equate the slopes of Eqs. 6–2 and 6–14, and solve for x_1.

$$x_1 = \frac{Ly_1}{2y_a + y_1 + y_2} \tag{6–15}$$

6–2.1.1 Cam Kinematics

After x_1 and x_2 are computed, the slope at P_1 and P_2 and the value of the constant in Eq. 6–1 can be found. Sufficient information is now available to determine the mechanics of the system. Based on Eqs. 6–9, 6–1, and 6–3, the mechanics during feed acceleration follow.

$$x = \frac{1}{K}\left(y^2\right) = \frac{1}{K}\left(R_c^2\omega^2 t^2\right) \tag{6–16}$$

The axial velocity of the bolt becomes

$$\dot{x} = \frac{2}{K}\left(R_c^2\omega^2 t\right), \tag{6–17}$$

The corresponding acceleration is

$$\ddot{x} = \frac{2}{K}\left(R_c^2\omega^2\right) \tag{6–18}$$

which is constant, conforming to the characteristics of the parabola. For the straight lines connecting the two parabolas where β is constant

$$x = y\tan\beta = R_c\omega t\tan\beta \tag{6–19}$$

$$\dot{x} = R_c\omega\tan\beta \text{ (constant)} \tag{6–20}$$

$$\ddot{x} = 0 \tag{6–21}$$

The mechanics of the cam during feed deceleration are determined by developing Eq. 6–5. Substitute $R_c\omega t$ for y.

$$x = x_2 - \frac{1}{K}\left(y_2^2 - 2y_2R_c\omega t + R_c^2\omega^2t^2\right) \quad (6\text{–}22)$$

$$\dot{x} = \frac{2}{K}\left(y_2R_c\omega - R_c^2\omega^2t\right) \quad (6\text{–}23)$$

$$\ddot{x} = -\frac{2}{K}\left(R_c^2\omega^2\right). \quad (6\text{–}24)$$

The ejection part of the cam behaves similarly but in the opposite direction. The curve for ejection acceleration is

$$-y^2 = Kx \quad (6\text{–}25)$$

$$x = -\frac{1}{K}\left(y^2\right) \quad (6\text{–}26)$$

$$\frac{dx}{dy} = -\frac{2}{K}\left(y\right) \quad (6\text{–}27)$$

when $y = y_2$, $x = x_2$, and $\frac{dx}{dy} < 0$,

therefore $K > 0$ and $K = \frac{y_2^2}{x_2}$.

Continue with the mechanics and substitute $R_c\omega t$ for y.

$$x = -\frac{1}{K}\left(R_c^2\omega^2t^2\right) \quad (6\text{–}28)$$

$$\dot{x} = -\frac{2}{K}\left(R_c^2\omega^2t\right) \quad (6\text{–}29)$$

$$\ddot{x} = -\frac{2}{K}\left(R_c^2\omega^2\right) \quad (6\text{–}30)$$

While ejecting over the straight portion of the cam, the mechanics are

$$x = -R_c\omega t\tan\beta \quad (6\text{–}31)$$

$$\dot{x} = -R_c\omega\tan\beta \quad (6\text{–}32)$$

$$\ddot{x} = 0. \quad (6\text{–}33)$$

The curve for the ejection deceleration is defined as

$$-\left(y_2 - y\right)^2 = K\left(x_2 - x\right) \quad (6\text{–}34)$$

when $y = 0$, $x = 0$, $x_2 < 0$

$$x = -x_2 + \frac{1}{K}\left(y_2^2 - 2y_2y + y^2\right) \quad (6\text{–}35)$$

$$\frac{dx}{dy} = \frac{1}{K}\left(-2y_2 + 2y\right) = \frac{2}{K}\left(y - y_2\right) \quad (6\text{–}36)$$

when $y = 0$, $\frac{dx}{dy} < 0$, therefore $K > 0$ and $K = \frac{y_2^2}{x_2}$

Continue the mechanics and substitute $R_c\omega t$ for y

$$x = -x_2 + \frac{1}{K}\left(y_2^2 - 2y_2R_c\omega t + R_c^2\omega^2t^2\right) \quad (6\text{–}37)$$

$$\dot{x} = \frac{2}{K}\left(R_c^2\omega^2t - y_2R_c\omega\right) \quad (6\text{–}38)$$

$$\ddot{x} = \frac{2}{K}\left(R_c^2\omega^2\right) \quad (6\text{–}39)$$

6–2.1.2 Definition of Symbols

b = moment arm for tipping track reactions

c = moment arm for rotating track reactions

d = distance, CG of bolt to center of cam roller surface

F = driving force

F_a = axial inertial force of bolt and round or of bolt and case

F_b = centrifugal force of bolt

F_{ba} = tangential inertia force of bolt

F_s = centrifugal force of round or of case

F_{sa} = tangential inertia force of round or of case

F_α = tangential inertia force of bolt and round or of bolt and case

I_G = mass moment of inertia of all rotating parts

L = length of bolt travel

$M = M_b + M_a$ = mass of bolt unit

M_a = mass of round

M_b = mass of bolt

M_{cc} = mass of case

N = normal force on roller

N_a = axial component of the normal force of the roller

N_t = transverse component of the normal force of the roller

R = radius, gun axis to bolt

R_c = cam radius

R_{fa} = frictional resistance due to tangential inertia forces

R_{fc} = frictional resistance due to centrifugal forces

R_{fr} = frictional resistance due to track reactions

R_r = track reactions due to rotational forces

R_t = track reactions due to tipping forces

T = torque about gun axis

$\ddot{x}$ = axial acceleration of bolt

α = angular acceleration of rotor

β = angle of cam path (slope)

θ = angular displacement of rotor

μ_r = coefficient of rolling friction

μ_s = coefficient of friction of case

μ_t = coefficient of friction of track

ω = angular velocity of rotor

6–2.1.3 Cam Forces

The axial inertia force of the bolt and round is

$$F_a = (M_b + M_a)\ddot{x} . \qquad (6–40)$$

The centrifugal force of the bolt is

$$F_b = M_b R\omega^2 . \qquad (6–41)$$

The centrifugal force of the round is

$$F_a = M_a R\omega^2 . \qquad (6–42)$$

The frictional resistance due to centrifugal force is

$$R_{fc} = \pm (\mu_t F_b + \mu_s F_a) . \qquad (6–43)$$

The tangential inertia force of bolt and round induced by angular acceleration is

$$F_\alpha = F_{ba} + F_{sa} = M_b R\alpha + M_a R\alpha . \qquad (6–44)$$

The frictional resistance due to the tangential inertia forces is

$$R_{fa} = \pm (\mu_t F_{ba} + \mu_s F_{sa}) . \qquad (6–45)$$

The axial component of the normal force of the roller is

$$N_a = N\cos\beta - \mu_r N\sin\beta \qquad (6–46)$$

where $\mu_r N$ is the resistance induced by rolling friction.

The transverse component of the normal force is

$$N_t = N\sin\beta + \mu_r N\cos\beta . \qquad (6–47)$$

The driving force of the cam is

$$F = N_t = N(\sin\beta + \mu_r \cos\beta) . \qquad (6–48)$$

The track reactions due to rotational forces are found by balancing moments in the plane perpendicular to the bolt axis.

$$cR_r = dF$$

$$R_r = \left(\frac{d}{c}\right)F \qquad (6\text{–}49)$$

The track reactions due to tipping forces are found by balancing moments in the vertical plane parallel to the bolt axis.

$$bR_t = dN_a$$

$$R_t = \left(\frac{d}{b}\right)N_a \qquad (6\text{–}50)$$

The frictional resistance due to track reactions is

$$R_{fr} = \pm 2\mu_t(R_r + R_t).$$

R_{fa}, R_{fc} and R_{fr} have the same algebraic sign as $\dot{x}$.

The normal force on the cam roller is found by balancing the axial forces thus $\Sigma F_x = 0$

$$F_a + \mu_t N_t + R_{fc} - N_a + R_{fr} + R_{fc} = 0 \qquad (6\text{–}51)$$

Substitute all values containing N for the terms in Eq. 6–51 and then solve for N. Note that N is always positive.

$$N = \left|(F_a + R_{fc} + R_{fa})/\left[(\mu_r + \mu_t + 2\frac{d}{c}\mu_t - 2\frac{d}{b}\mu_r\mu_t)\sin\beta + (\mu_r\mu_t + 2\frac{d}{c}\mu_r\mu_t + 2\frac{d}{b}\mu_t - 1.0)\cos\beta\right]\right| \qquad (6\text{–}52)$$

This force system also applies to the constant velocity portions of the cam, F_a being zero but all other force components acting in the same direction.

Fig. 6–4 shows the loading diagram on the bolt and cam arrangement during deceleration. All the developing equations are the same as for acceleration except

$$N_a = N\cos\beta + \mu_r N\sin\beta \qquad (6\text{–}53)$$

$$N_t = N\sin\beta - \mu_r N\cos\beta \qquad (6\text{–}54)$$

$$F = N_t = N(\sin\beta - \mu_r\cos\beta). \qquad (6\text{–}55)$$

Equate the sum of the forces along the x-axis to zero, $\Sigma F_x = 0$.

$$F_a + \mu_t N_t + R_{fc} + N_a + R_{fr} + R_{fa} = 0 \qquad (6\text{–}56)$$

Substitute all values containing N for the terms in Eq. 6–56 and solve for N.

$$N = \left|(F_a + R_{fc} + R_{fa})/\left[(\mu_r\mu_t + 2\frac{d}{c}\mu_r\mu_t - 2\frac{d}{b}\mu_t - 1.0)\cos\beta - (\mu_r + \mu_t + 2\frac{d}{b}\mu_r\mu_t + 2\frac{d}{c}\mu_t)\sin\beta\right]\right| \qquad (6\text{–}57)$$

The driving torque about the gun axis is

$$T = \Sigma FR_c + I\alpha \qquad (6\text{–}58)$$

where ΣF is the total driving force on all bolts.

6–2.1.4 Locking Angle

The cam becomes self-locking when the required driving force becomes infinite. Substitution of the expression for N of Eq. 6–52 into Eq. 6–48 indicates that $F = \infty$ when the denominator becomes zero. Equate the denominator to zero; divide by $\cos\beta$; and then solve for β_L, the locking angle, defined by Eq. 6–59.

$$\beta_L = \mathrm{Tan}^{-1}\frac{\mu_r\mu_t\left(1 + 2\frac{d}{c}\right) + 2\mu_t\left(\frac{d}{b}\right) - 1.0}{\mu_t\left[2\mu_r\left(\frac{d}{b}\right) - 2\left(\frac{d}{c}\right) - 1\right] - \mu_r} \qquad (6\text{–}59)$$

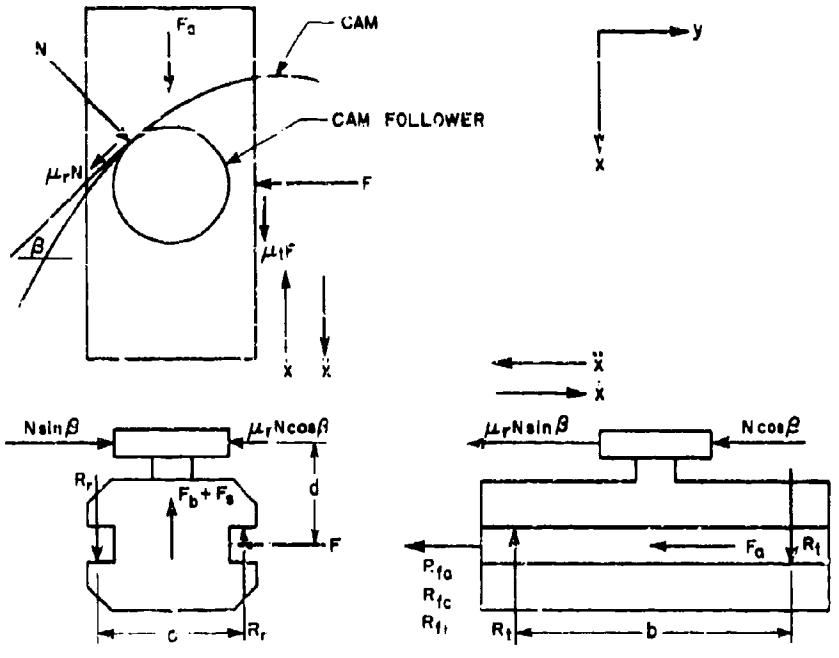


Figure 6–4. Loading Diagram of Bolt and Cam During Deceleration

6–2.2 ROTOR KINEMATICS

The rotor is brought to speed under constant, varying, or a combination of both types angular acceleration during a prescribed period of time t. During the acceleration of the rotor, the acceleration of the round induced by the cam is modified by the components derived from the angular acceleration. If the acceleration is constant at α, the angular velocity is

$$\omega = \alpha t \tag{6–60}$$

and the angular travel becomes

$$\theta = \frac{1}{2}\left(\alpha t^2\right). \tag{6–61}$$

While the rotor has constant acceleration when traversing the constant slope of the cam, the axial travel of the cam follower according to Eqs. 6–19 and 6–31 is

$$x = \pm\left(R_c\theta\right)\tan\beta = \pm\frac{1}{2}\left(R_c\alpha t^2\right)\tan\beta. \tag{6–62}$$

Positive indicates feed; negative, ejection. The linear velocity is

$$\dot{x} = \pm R_c\alpha t\tan\beta. \tag{6–63}$$

The linear acceleration becomes

$$\ddot{x} = \pm R_c\alpha\tan\beta. \tag{6–64}$$

When traversing the feed and ejection acceleration portions of the cam, in this case a parabola, the axial travel, Eq. 6–16, while the rotor has constant acceleration is defined by

$$x = \pm\frac{1}{K}\left(R_c^2\theta^2\right) = \frac{R_c^2}{4K}\left(\alpha^2 t^4\right) \tag{6–65}$$

$$\dot{x} = \pm\frac{R_c^2}{K}\left(\alpha^2 t^3\right) \tag{6–66}$$

$$\ddot{x} = \pm 3\left(\frac{R_c^2}{K}\right)\left(\alpha^2 t^2\right) \tag{6–67}$$

Positive indicates feed acceleration whereas negative indicates ejection acceleration. During feed and ejection deceleration, Eq. 6–22, while the rotor has constant acceleration, Eq. 6–61, the mechanics alternate correspondingly.

$$x = \pm x_2 \mp \frac{1}{K}\left[y_2^2 - y_2 R_c \alpha t^2 + \frac{1}{4}\left(R_c^2 \alpha^2 t^4\right)\right] \tag{6–68}$$

$$\dot{x} = \mp \frac{1}{K}\left(R_c^2 \alpha^2 t^3 - 2y_2 R_c \alpha t\right) \tag{6–69}$$

$$\ddot{x} = \mp \frac{1}{K}\left(3R_c^2 \alpha^2 t^2 - 2y_2 R_c \alpha\right) \tag{6–70}$$

During dwell periods at constant rotor acceleration, the travel, velocity, and acceleration are all zero, i.e., $x = 0, \dot{x} = 0, \ddot{x} = 0$.

When the rotor has a variable acceleration, a constantly decreasing one is generally preferred, thus

$$\frac{d\alpha}{dt} = \frac{d^3\theta}{dt^3} = K_\alpha \tag{6–71}$$

$$\alpha = \frac{d^2\theta}{dt^2} = K_\alpha t + C_1 \tag{6–72}$$

$$\omega = \frac{d\theta}{dt} = \frac{1}{2}\left(K_\alpha t^2\right) + C_1 t + C_2 \tag{6–73}$$

$$\theta = \frac{1}{6}\left(K_\alpha t^3\right) + \frac{1}{2}\left(C_1 t^2\right) + C_2 t + C_3 \tag{6–74}$$

While traversing the constant slope of the cam for feed and ejection, Eqs. 6–19 and 6–31, when $x = \pm R_c\theta$, tan β, the mechanics are alternately

$$x = \pm R_c\left[\frac{1}{6}\left(K_\alpha t^3\right) + \frac{1}{2}\left(C_1 t^2\right) + C_2 t + C_3\right] \tan\beta \tag{6–75}$$

$$\dot{x} = \pm R_c\left[\frac{1}{2}\left(K_\alpha t^2\right) + C_1 t + C_2\right] \tan\beta \tag{6–76}$$

$$\ddot{x} = \pm R_c\left(K_\alpha t + C_1\right) \tan\beta. \tag{6–77}$$

While traversing the increasing slope of the cam, Eqs. 6–16 and 6–28, when $x = \pm \frac{1}{K}\left(R_c^3\theta^2\right)$, the mechanics for feed and ejection appear, respectively,

$$x = \pm \frac{R_c^2}{K}\left[\left(\frac{K_\alpha^2}{36}\right)t^6 + \left(\frac{K_\alpha C_1}{6}\right)t^5 + \left(\frac{4K_\alpha C_2 + 3C_1^2}{12}\right)t^4 + \left(\frac{K_\alpha C_3 + 3C_1 C_2}{3}\right)t^3 + \left(C_1 C_3 + C_2^2\right)t^2 + 2C_2 C_3 t + C_3^2\right] \tag{6–78}$$

$$\dot{x} = \pm \frac{R_c^2}{K}\left[\frac{K_\alpha^2 t^5}{6} + \left(\frac{5K_\alpha C_1}{6}\right)t^4 + \left(\frac{4K_\alpha C_2 + 3C_1^2}{3}\right)t^3 + \left(K_\alpha C_3 + 3C_1 C_2\right)t^2 + 2\left(C_1 C_3 + C_2^2\right)t + 2C_2 C_3\right] \tag{6–79}$$

$$\ddot{x} = \pm \frac{R_c^2}{K}\left[\left(\frac{5K_\alpha^2}{6}\right)t^4 + \left(\frac{10}{3}K_\alpha C_1\right)t^3 + \left(4K_\alpha C_2 + 3C_1^2\right)t^2 + 2\left(K_\alpha C_3 + 3C_1 C_2\right)t + 2\left(C_1 C_3 + C_2^2\right)\right] \tag{6–80}$$

If $F\left(K_\alpha t\right)$ represents the function in the brackets of Eq. 6–78, then the last three equations reduce to

$$x = \pm \frac{R_c^2}{K}\left[F(K_\alpha t)\right] \tag{6–81}$$

$$\dot{x} = \pm \frac{R_c^2}{K}\left[F'(K_\alpha t)\right] \tag{6–82}$$

$$\ddot{x} = \pm \frac{R_c^2}{K}\left[F''(K_\alpha t)\right]. \tag{6–83}$$

The mechanics for deceleration during feed, Eq. 6–22, and ejection, Eq. 6–37, are alternately

$$x = \pm x_2 \mp \frac{1}{K}\left\{ y_2^2 - 2y_2R_c\left[\left(\frac{1}{6}K_\alpha\right)t^3 + \left(\frac{1}{2}C_1\right)t^2 + C_2t + C_3\right] + R_c^2\left[F(K_\alpha t)\right]\right\} \quad (6\text{–}84)$$

$$\dot{x} = \pm\frac{1}{K}\left\{2y_2R_c\left[\left(\frac{1}{2}K_\alpha\right)t^2 + C_1t + C_3\right] - R_c^2\left[F'(K_\alpha t)\right]\right\} \quad (6\text{–}85)$$

$$\ddot{x} = \pm\frac{1}{K}\left\{2y_2R_c(K_\alpha t + C_1) - R_c^2\left[F''(K_\alpha t)\right]\right\}. \quad (6\text{–}86)$$

6–2.3 ILLUSTRATIVE PROBLEM

Compute the cam accelerating forces, the torque needed to develop these forces, and all associated data to operate a 20 mm, 6-barreled gun. The assigned data

b = 3.0 in., moment arm of tipping track reactions

c = 1.5 in., moment arm of rotational track reactions

d = 0.732 in., CG of bolt to center of cam roller surface

f_r = 3000 rounds/min, firing rate (equivalent to angular velocity of 52.36 rad/sec)

I_d = 11.2 lb-in.-sec^2, moment of inertia of all rotating parts

L = 6.6 in., length of bolt travel

R = 2.643 in., radius, gun axis to bolt CG

R_c = 3.375 in., cam radius

t_α = 0.35 sec, accelerating time of rotor

W_b = 1.15 lb, bolt weight

W_a = 0.57 lb, weight of total round

W_{cc} = 0.25 lb, weight of empty case

α_m = 200 rad/sec^2, maximum acceleration of rotor

μ_r = 0.063, coefficient of rolling friction of cam roller

μ_s = 0.22, coefficient of friction of case

μ_t = 0.125, coefficient of friction of track

Fig. 6–1 illustrates the developed cam. For an effective firing cycle, the bolt travel in terms of peripheral travel of the rotor

θ_r = 36°, dwell while bolt is fully retracted

θ_a = 42°, acceleration distance with total round

θ_v = 90°, distances at constant velocity in each direction

θ_d = 12°, decelerating distance in each direction

θ_f = 40°, dwell while firing

θ_c = 38°, acceleration distance with empty case

The total peripheral length of the cam, Eq. 6–12

$$L_c = 2\pi R_c = 6.75\pi = 21.2058 \text{ in.}$$

6–2.3.1 Cam Analysis During Feed, Rotor at Constant Velocity

The peripheral travel of the bolt while carrying the total round via Eq. 6–10

$$y_1 = R_c\theta_a = 3.375\left(\frac{42\pi}{180}\right) = 2.4740 \text{ in.}$$

$$y_2 = R_c\theta_d = 3.375\left(\frac{12\pi}{180}\right) = 0.7069 \text{ in.}$$

The peripheral travel during constant velocity, Eq. 6-13

$$y_a = \frac{\pi}{2} R_c = 3.3014 \text{ in.}$$

From Eq. 6-15

$$x_1 = \frac{Ly_1}{2y_a + y_1 + y_2} = \frac{6.6 \times 2.474}{13.7937} = 1.1846 \text{ in.}$$

From Eq. 6-9

$$x_2 = \left(\frac{y_2}{y_1}\right) x_1 = \left(\frac{0.7069}{2.474}\right) 1.1846$$

$$= 0.3385 \text{ in.}$$

From Eq. 6-2

$$\beta = \text{Tan}^{-1} \frac{2x_2}{y_2} = \text{Tan}^{-1} \frac{0.677}{0.7069}$$

$$= \text{Tan}^{-1} 0.9577 = 43°46'$$

$$\sin \beta = 0.69172$$

$$\cos \beta = 0.72216.$$

According to Eq. 6-2, for the accelerating curve

$$K_1 = \frac{2y_1}{\tan \beta} = \frac{4.948}{0.9577} = 5.1665 \text{ in.}$$

For the decelerating curve, K_2 is found when $y = 0$ in Eq. 6-6

$$K_2 = \frac{2y_2}{\tan \beta} = \frac{1.4138}{0.9577} = 1.4762 \text{ in.}$$

The firing rate of 3000 rounds/min is equivalent to 500 rpm since there are six barrels. The angular velocity is

$$\omega = \frac{2 \times 500\pi}{60} = 52.36 \text{ rad/sec.}$$

The bolt acceleration with total round, Eq. 6-18, is

$$\ddot{x} = \frac{2}{K_1} \left(R_c^2 \omega^2\right) = \frac{22.78 \times 2742}{5.1665}$$

$$= 12089 \text{ in./sec}^2 = 31.29 \text{ g.}$$

The inertia force of bolt and round, Eq. 6-40, is

$$F_a = (M_b + M_a) \ddot{x} = 1.72 \times 31.29 = 53.9 \text{ lb.}$$

The centrifugal forces of bolt and round according to Eqs. 6-41 and 6-42 are

$$F_b = \left(\frac{W_b}{g}\right) R\omega^2 = 1.15 \times 18.8 = 21.6 \text{ lb}$$

where

$$\frac{R\omega^2}{g} = \frac{2.643 \times 2742}{386.4} = 18.8 \text{ g}$$

$$F_s = M_s R\omega^2 = 0.57 \times 18.8 = 10.7 \text{ lb.}$$

The frictional resistance due to centrifugal force (Eq. 6-43, $\dot{x} > 0$)

$$R_{fc} = \mu_1 F_b + \mu_2 F_s = 0.125 \times 21.6 + 0.22 \times 10.7$$

$$= 5 \text{ lb.}$$

$$R_{fa} = 0 \quad (\text{since } \alpha = 0)$$

If we substitute the numerical equivalents for the general terms, Eq. 6-52 may be written

$$N = \frac{58.8}{0.9234 \cos \beta - 0.3062 \sin \beta}.$$

The locking angle, Eq. 6-59, is

$$\beta_L = \text{Tan}^{-1} \frac{0.9234}{0.3062} = \text{Tan}^{-1} 3.0157 = 71°39'.$$

The bolt deceleration with total round, Eq. 6-24, is

$$\ddot{x} = -\left(\frac{2}{K_2}\right) R_c^2 \omega^2 = \frac{-22.78 \times 2742}{1.4762}$$

$$= -42{,}313 \text{ in./sec}^2 = -109.5 \text{ g}.$$

The inertia force of bolt and round, Eq. 6-40, is

$$F_a = (M_b + M_a) \ddot{x} = 1.72 (-109.5) = -188.3 \text{ lb.}$$

By proper substitution of numerical equivalents, Eq. 6-57 reads ($\dot{x} > 0$)

$$N = \frac{183.3}{1.0454 \cos \beta + 0.3138 \sin \beta} .$$

While the bolt moves along the constant slope of the cam, $\ddot{x} = 0$, and the normal force on the roller becomes

$$N = \frac{R_{fc}}{0.9234 \cos \beta - 0.3062 \sin \beta} = \frac{5}{0.6668 - 0.2118} = 11 \text{ lb.}$$

6-2.3.2 Cam Analysis During Ejection, Rotor at Constant Velocity

The peripheral travel of the bolt carrying the empty case during acceleration is computed from Eq. 6-10

$$y_1 = R_c \theta_c = 3.375 \left(\frac{38\pi}{180} \right) = 2.2384 \text{ in.}$$

$y_2 = 0.7069$ in., $y_a = 5.3014$ in., same as for total round.

From Eq. 6-15

$$x_1 = \frac{Ly_1}{2y_a + y_1 + y_2} = \frac{6.6 \times 2.2384}{13.5481} = 1.0904 \text{ in.}$$

From Eq. 6-9

$$x_2 = \left(\frac{y_2}{y_1} \right) x_1 = \left(\frac{0.7069}{2.2384} \right) 1.0904 = 0.3441 \text{ in.}$$

From Eq. 6-2

$$\beta = \text{Tan}^{-1} \frac{2x_1}{y_1} = \text{Tan}^{-1} \frac{2.1808}{2.2384} = \text{Tan}^{-1} 0.97426 = 44°15'$$

$$\sin \beta = 0.69779 \qquad \cos \beta = 0.71630.$$

For the accelerating curve, Eq. 6-2,

$$K_1 = \frac{2y_1}{\tan \beta} = \frac{4.4768}{0.9743} = 4.5944 \text{ in.}$$

For the decelerating curve, K_2 is found when $\dot{y} = 0$ in Eq. 6-6

$$K_2 = \frac{2y_2}{\tan \beta} = \frac{1.4138}{0.9743} = 1.4509 \text{ in.}$$

The bolt acceleration with empty case, Eq. 6–30, is

$$\ddot{x} = -\left(\frac{2}{K_1}\right) R_c^2\omega^2 = -\frac{22.78 \times 2742}{4.5944}$$

$$= -13595 \text{ in./sec}^2 = -35.2 \text{ g.}$$

The inertia force of bolt and empty case, Eq. 6–40, is

$$F_a = (M_b + M_{cc})\ddot{x} = 1.40(-35.2) = -49.3 \text{ lb.}$$

The forces during ejection have the same identification as those during feed since the same dynamic equations apply to both periods.

The centrifugal force F_s of the empty case, Eq. 6–42, is

$$F_s = M_{cc}R\omega^2 = 0.25 \times 18.8 = 4.7 \text{ lb.}$$

The frictional resistance due to centrifugal force (Eq. 6–43, $\dot{x} < 0$)

$$R_{fc} = -(\mu_t F_b + \mu_s F_s)$$

$$= -(0.125 \times 21.6 + 0.22 \times 4.7) = -3.7 \text{ lb.}$$

$$R_{fa} = 0$$

After numerical equivalents are substituted, Eq. 6–52 reads

$$N = \frac{53.0}{0.9234 \cos\beta - 0.3062 \sin\beta}.$$

The bolt deceleration with empty case, Eq. 6–39, becomes

$$\ddot{x} = \left(\frac{2}{K_2}\right) R_c^2\omega^2 = \frac{22.78 \times 2742}{1.4509}$$

$$= 43{,}051 \text{ in./sec}^2 = 111.4 \text{ g.}$$

From Eq. 6–40

$$F_a = (M_b + M_{cc})\ddot{x} = 1.40 \times 111.4 = 156 \text{ lb.}$$

The substitution of numerical equivalents makes Eq. 6–57 read ($\dot{x} < 0$)

$$N = \frac{152.3}{1.0454 \cos\beta + 0.3138 \sin\beta}.$$

For the constant slope portion of the cam while $\ddot{x} = 0$,

$$N = \frac{R_{fc}}{0.9234 \cos\beta - 0.3062 \sin\beta} = \frac{3.7}{0.4452} = 8 \text{ lb.}$$

6–2.3.3 Cam Analysis During Rotor Acceleration

The rotor is brought to speed under a constant acceleration of 200 rad/sec^2 for 0.1736 sec and then at a constantly reducing acceleration that is defined in Eqs. 6–71 and 6–72. When $t = 0$ and $\alpha = 200$, in Eq. 6–72, $C_1 = 200$; when $\alpha = 0$, $K_\alpha t = -200$ Under constant acceleration, the rotor has achieved an angular velocity of 34.72 rad/sec; therefore, for the initial conditions of Eq. 6–73, when $t = 0$, $\omega = 34.72$ and $C_2 = 34.72$,

$$\omega = \frac{d\theta}{dt} = \frac{1}{2}\left(K_\alpha t^2\right) + 200t + 34.72 \qquad (6\text{–}87)$$

substitute -200 for $K_\alpha t$ and 52.36 rad/sec for ω (see par. 6–2.3.1), the upper limit of the angular velocity

$$52.36 = -100t + 200t + 34.72$$

$$t = \frac{17.64}{100} = 0.1764 \text{ sec}$$

$$K_\alpha = -\frac{200}{0.1764} = -1133.79.$$

Rewrite Eqs. 6–72 and 6–73 and include the time elapsed during constant acceleration

$$\alpha = \frac{d^2\theta}{dt^2} = -1133.79(t - 0.1736) + 200 \qquad (6\text{–}88)$$

$$\omega = \frac{d\theta}{dt} = -566.895(t - 0.1736)^2 + 200(t - 0.1736) + 34.72 \qquad (6\text{–}89)$$

Substitute the proper values into Eq. 6–74 and integrate

$$\theta = -188.965\,t^3 + 100\,t^2 + 34.72\,t + C_3 \qquad (6\text{–}90)$$

when $t = 0$, $\theta = 3.014$, and $C_3 = 3.014$. Modify the time by compensating for the constant acceleration period

$$\theta = -188.965(t - 0.1736)^3 + 100(t - 0.1736)^2 + 34.72(t - 0.1736) + 3.014 \qquad (6\text{–}91)$$

when $t = 0.35$ sec

$$\theta = -1.037 + 3.112 + 6.125 + 3.014 = 11.215 \text{ rad.}$$

During constant acceleration of $\alpha = 200$,

$$\omega = \alpha t = 200t \text{ when } t \leq 0.1736 \qquad (6-92)$$

$$\theta = \frac{1}{2}\left(\alpha t^2\right) = 100t^2 \text{ when } t \leq 0.1736 \qquad (6-93)$$

6-2.3.4 Digital Computer Routine for Gun Operating Power

A digital computer program has been compiled in FORTRAN IV language for the UNIVAC 1107 Computer. The program follows, in proper sequence, the computing procedures discussed throughout Chapter 6 i.e., begin with constant acceleration; continue at a reducing acceleration at a constant rate; and then complete the computations while the rotor is turning at constant velocity.

Fig. 6-5 is a visual concept of the analysis. The drum and, therefore, the projected cam periphery are divided into six equal zones, each zone being occupied by one cam follower and corresponding bolt which are numbered in sequence according to zone number. Although all bolts travel the full periphery during each rotor revolution, we assume that each travels, from θ_0 to θ_s six times in one zone. Thus, in Fig. 6-5, Bolt No. 1 moves from 0° to 60°. On reaching 60° (θ_s) it becomes Bolt No. 2. In the meantime, Bolt No. 2 moves from 60° (θ_0) to 120° (θ_s) where it becomes Bolt No. 3. The sequence continues until Bolt No. 6 becomes Bolt No. 1 and then the cycle repeats. This procedure is a convenient method for defining the dynamics of all bolts at any position on the cam. For the analysis, all bolts are assumed to start from θ_0 and in line, and traverse the distance to θ_s. Fig. 6-1 shows the relative positions on the cam.

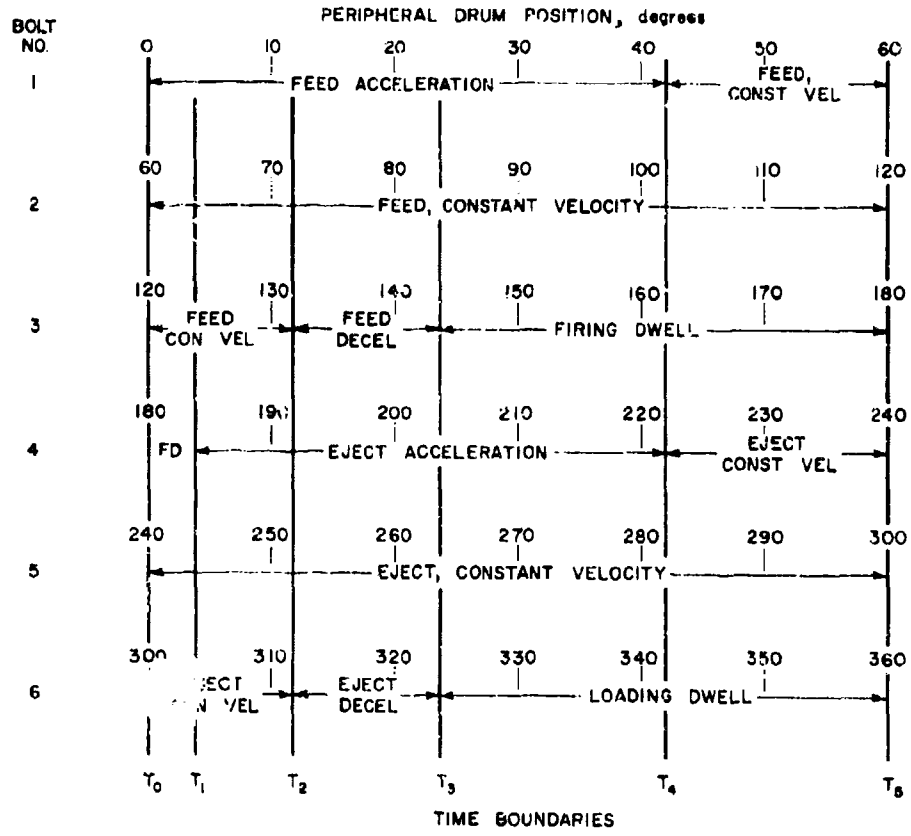


Figure 6-5. Bolt Position Diagram for Computer Analysis

Each accelerating period, constant and varying, is divided into 40 equal differential time increments. A time increment of one millisecond is then assigned to the period of constant velocity. The analysis continues the constant velocity period until one cycle of bolt travel, θ_0 to θ_8 is completed. After the torque, Eq. 6–58, has been computed for a given increment, the required horsepower to produce this torque is computed

$$HP = T\omega/6600$$

where 1 horsepower = 6600 in.-lb/sec.

Table 6–1 lists the symbol-code correlation for the computed variables of the computer program. Table 6–2 lists the symbol-code correlation and the numerical values of the constants. Computed cam dynamics for three increments of time are listed in Table 6–3 as a sample output, while Table 6–4 lists the computed torques and horsepower required for each increment. The flow chart, A–13, and the program listing, A–14, are in the Appendix.

6–3 RATING OF GAS-OPERATED AND EXTERNALLY POWERED GUNS

The choice of a gas-operated gun, or whether an externally powered weapon should be selected over a gas-operated one, is not the superiority of one type over another but rather the tactical purpose of each type. The impingement and tappet types are usually assigned to carbines and subcaliber automatic guns with neither being markedly superior to the other. For small caliber machine guns, cal .30 and .50, firing at the rate of about 1000 rpm, the cut-off expansion or expansion types are appropriate. Rate of fire within limits is controlled by design detail. Everything being equal, the expansion type should be faster; its gas port is never sealed off from the bore gases.

High rates of fire for large caliber machine guns, cal .60 and above, are generally not feasible for the single chambered type. Long bolt travel for loading and extracting consumes too much time for high cyclic rates. The revolver-and Gatling-types restore the large calibers to the high firing rate category. The revolver-types may be gas-operated or may be driven by external power. Firing rates are in the order of 1000 to 1200 rpm. Gatling-types, because of ducting problems, are consigned to external drives and normally have the highest sustained rate of fire of all machine guns. The multiple barrels of the Gatling-type provide superiority over the single-barreled revolver-type in the areas of fire power, reliability and durability, and generally require less maintenance. On the other hand, the revolver-type has better handling characteristics and is more versatile with respect to efficiency, the Gatling-type being restricted to those periods of highly intensive fire for short periods of time such as in air-to-air combat.

TABLE 6–1. SYMBOL-CODE CORRELATION OF VARIABLES FOR MULTIBARREL GUN

Symbol	Code	Symbol	Code
F	F	t (msec)	TIMEM
F_a	FA	x	X
FR_c	TORKB	$\dot{x}$	V
ΣFR_c	BTSUM	$\ddot{x}$	A
HP	POWER	y	Y
$I_d\alpha$	TORKI	α	ALPHA
N	EN	β	B
R_{fa}	RFA	β°	BDEG
R_{fc}	RFC	θ	THETA
T	TORK	θ°	THETAD
t	T	ω	OMEGA

TABLE 6–2. SYMBOL-CODE CORRELATION AND INPUT FOR GUN OPERATING POWER

No.	Symbol	Code	Data	No.	Symbol	Code	Data
1	K_{af}	AFK	5.1774	24	α_o	ALPHAO	200
2	K_{df}	DFK	1.4762	25	ω_{max}	OMEGAM	52.36
3	K_{ae}	AEK	4.5944	26	y_{1f}	Y1F	2.4740
4	K_{de}	DEK	1.4509	27	y_{2f}	Y2F	0.7069
5	K_{α}	AK	-1133 79	28	x_{1f}	X1F	1.1846
6	C_1	C1	200.0	29	x_{2f}	X2F	0.3383
7	C_2	C2	34.72	30	$tan\beta_f$	TANBF	0.9577
8	C_3	C3	3.014	31	$tan\beta_e$	TANBE	0.9743
9	θ_1	ANGLE1	0.0698	32	y_{1e}	Y1E	2.2384
10	θ_2	ANGLE2	0.2094	33	y_{2e}	Y2E	0.7069
11	θ_3	ANGLE3	0.4189	34	x_{1e}	X1E	1.0904
12	θ_4	ANGLE4	0.7330	35	x_{2e}	X2E	0.3444
13	θ_5	ANGLE5	1.0472	36	g	G	386.4
14	l	EL	6.6	37	Δt_1	DELT1	0.00434
15	R	R	2.643	38	Δt_2	DELT2	0.00441
16	R_c	RC	3.375	39	Δt_3	DELT3	0.001
17	W_b	WB	1.15	40	μ_r	EMUR	0.063
18	W_s	WST	0.57	41	μ_s	EMUS	0.22
19	W_{cc}	WSE	0.25	42	μ_t	EMUT	0.125
20	K_{c1}	COEFC1	0.9234	43	I	EYE	11.2
21	K_{c2}	COEFC2	1.0454	44	β_{f1}	BF1	0.76387
22	K_{s1}	COEFS1	0.3062	45	β_{e1}	BE1	0.75230
23	K_{s2}	COEFS2	0.3138				

TABLE 6-3. CAM DYNAMICS

CAM DYNAMICS AT 116.59 MILLISECONDS

BOLT NO	BOLT ACCELERATION IN/SEC/SEC	BOLT VELOCITY IN/SEC	BOLT AXIAL TRAVEL INCH	AXIAL INERTIA FORCE POUND	NORMAL FRICTION FORCE POUND	ANGULAR INERTIA FORCE POUND	CAM CURVE ANGLE DEGREE	CAM NORMAL FORCE POUND	CAM DRIVING FORCE POUND	BOLT DRIVING TORQUE LB-IN
1	54.	5.91	.214	0.	1.	0.	22.143	1.	1.	2.
2	646.	75.37	3.209	3.	1.	0.	43.767	8.	6.	20.
3	536.	38.40	6.512	2.	1.	0.	26.012	5.	2.	8.
4	-34.	-27.30	6.458	-0.	1.	0.	19.133	1.	0.	1.
5	-641.	-74.72	3.530	-2.	1.	0.	43.517	7.	5.	17.
6	-622.	-38.07	.888	-2.	1.	0.	25.817	4.	2.	7.

CAM DYNAMICS AT 118.84 MILLISECONDS

BOLT NO	BOLT ACCELERATION IN/SEC/SEC	BOLT VELOCITY IN/SEC	BOLT AXIAL TRAVEL INCH	AXIAL INERTIA FORCE POUND	NORMAL FRICTION FORCE POUND	ANGULAR INERTIA FORCE POUND	CAM CURVE ANGLE DEGREE	CAM NORMAL FORCE POUND	CAM DRIVING FORCE POUND	BOLT DRIVING TORQUE LB-IN
1	72.	8.06	.293	0.	1.	0.	25.449	2.	1.	3.
2	646.	75.82	3.380	3.	1.	0.	43.767	8.	6.	20.
3	486.	19.75	6.578	2.	1.	0.	13.831	4.	1.	4.
4	-50.	-33.90	6.389	-0.	1.	0.	22.911	1.	1.	2.
5	-641.	-76.16	3.361	-2.	1.	0.	43.517	7.	5.	17.
6	-599.	-19.58	.823	-2.	1.	0.	13.716	4.	1.	4.

CAM DYNAMICS AT 121.08 MILLISECONDS

BOLT NO	BOLT ACCELERATION IN/SEC/SEC	BOLT VELOCITY IN/SEC	BOLT AXIAL TRAVEL INCH	AXIAL INERTIA FORCE POUND	NORMAL FRICTION FORCE POUND	ANGULAR INERTIA FORCE POUND	CAM CURVE ANGLE DEGREE	CAM NORMAL FORCE POUND	CAM DRIVING FORCE POUND	BOLT DRIVING TORQUE LB-IN
1	93.	11.08	.386	0.	1.	0.	28.641	2.	1.	3.
2	646.	78.27	3.554	3.	1.	0.	43.767	8.	6.	20.
3	427.	-.02	6.680	2.	1.	0.	-.013	3.	0.	1.
4	-69.	-40.85	6.306	-0.	1.	0.	26.555	2.	1.	3.
5	-641.	-77.60	3.188	-2.	1.	0.	43.517	7.	5.	17.
6	-567.	.02	.801	-2.	1.	0.	-.013	3.	0.	1.

TABLE 6–4. GUN OPERATING POWER

INCREMENT	TIME MILSEC	ROTOR ANGULAR ACCELERATION RAD/SEC/SEC	ROTOR ANGULAR VELOCITY RAD/SEC	ROTOR ANGULAR TRAVEL DEGREE	BOLT PERIPHERAL TRAVEL INCH	TOTAL CAM TORQUE LB-IN	ROTOR TORQUE LB-IN	REQUIRED TORQUE LB-IN	REQUIRED HORSE-POWER
1	26.420	200.00	5.28	5.0	.236	62.	2240.	2302.	1.8
2	31.255	200.00	6.25	5.6	.330	63.	2240.	2303.	2.2
3	36.090	200.00	7.22	7.5	.440	64.	2240.	2304.	2.5
4	40.925	200.00	8.19	9.6	.565	66.	2240.	2306.	2.9
5	45.760	200.00	9.15	12.0	.707	67.	2240.	2307.	3.2
6	50.501	200.00	10.10	14.6	.861	51.	2240.	2291.	3.5
7	55.241	200.00	11.05	17.5	1.030	47.	2240.	2287.	3.8
8	59.982	200.00	12.00	20.6	1.214	48.	2240.	2288.	4.2
9	64.722	200.00	12.94	24.0	1.414	53.	2240.	2293.	4.5
10	69.946	200.00	13.99	28.0	1.651	60.	2240.	2300.	4.9
11	75.169	200.00	15.03	32.4	1.907	72.	2240.	2312.	5.3
12	80.392	200.00	16.08	37.0	2.181	87.	2240.	2327.	5.7
13	85.615	200.00	17.12	42.0	2.474	107.	2240.	2347.	6.1
14	93.974	200.00	18.79	50.6	2.981	69.	2240.	2309.	6.6
15	102.333	200.00	20.47	60.0	3.534	71.	2240.	2311.	7.2
16	105.688	200.00	21.14	64.0	.236	72.	2240.	2312.	7.4
17	107.291	200.00	21.46	66.0	.351	72.	2240.	2312.	7.5
18	108.893	200.00	21.78	67.9	.468	73.	2240.	2313.	7.6
19	110.496	200.00	22.10	70.0	.586	74.	2240.	2314.	7.7
20	112.098	200.00	22.42	72.0	.707	74.	2240.	2314.	7.9
21	114.348	200.00	22.87	74.9	.878	63.	2240.	2303.	8.0
22	116.590	200.00	23.32	77.9	1.053	55.	2240.	2295.	8.1
23	118.837	200.00	23.77	80.9	1.232	49.	2240.	2289.	8.2
24	121.083	200.00	24.22	84.0	1.414	44.	2240.	2284.	8.4
25	124.168	200.00	24.83	88.3	1.669	46.	2240.	2286.	8.6
26	127.253	200.00	25.45	92.8	1.931	50.	2240.	2290.	8.8
27	130.339	200.00	26.07	97.3	2.199	54.	2240.	2294.	9.1
28	133.424	200.00	26.68	102.0	2.474	60.	2240.	2300.	9.3
29	139.372	200.00	27.81	110.3	2.993	79.	2240.	2319.	9.8
30	144.720	200.00	28.94	120.0	3.534	81.	2240.	2321.	10.2
31	147.112	200.00	29.42	124.0	.236	82.	2240.	2322.	10.3
32	148.280	200.00	29.66	126.0	.352	82.	2240.	2322.	10.4
33	149.447	200.00	29.89	128.0	.469	83.	2240.	2323.	10.5
34	150.615	200.00	30.12	130.0	.588	84.	2240.	2324.	10.6
35	151.783	200.00	30.36	132.0	.707	85.	2240.	2325.	10.7
36	153.471	200.00	30.69	135.0	.881	73.	2240.	2313.	10.8
37	155.158	200.00	31.03	137.9	1.056	64.	2240.	2304.	10.8
38	156.846	200.00	31.37	141.0	1.234	57.	2240.	2297.	10.9
39	158.534	200.00	31.71	144.0	1.414	51.	2240.	2291.	11.0
40	160.938	200.00	32.19	148.4	1.673	53.	2240.	2293.	11.2
41	163.341	200.00	32.67	152.9	1.936	56.	2240.	2296.	11.4
42	165.745	200.00	33.15	157.4	2.203	60.	2240.	2300.	11.6
43	168.149	200.00	33.63	162.0	2.474	65.	2240.	2305.	11.7
44	173.600	200.00	34.72	172.7	3.103	89.	2240.	2329.	12.3
45	177.237	195.88	35.44	180.0	3.534	54.	2194.	2277.	12.2

TABLE 3-4. GUN OPERATING POWER (Con't.)

INCREMENT	TIME MILSEC	ROTOR ANGULAR ACCELERATION RAD/SEC/SEC	ROTOR ANGULAR VELOCITY RAD/SEC	ROTOR ANGULAR TRAVEL DEGREE	BOLT PERIPHERAL TRAVEL INCH	TOTAL CAM TORQUE LB-IN	ROTOR TORQUE LB-IN	REQUIRED TORQUE LB-IN	REQUIRED HORSEPOWER
46	179.195	193.66	35.82	184.0	.236	112.	2169.	2281.	12.4
47	180.159	192.56	36.01	186.0	.352	132.	2157.	2289.	12.5
48	181.122	191.47	36.19	188.0	.470	147.	2144.	2291.	12.6
49	182.086	190.38	36.38	190.0	.588	162.	2132.	2294.	12.6
50	183.049	189.29	36.56	192.0	.707	177.	2120.	2297.	12.7
51	184.458	187.69	36.82	195.0	.881	-437.	2102.	1665.	9.3
52	185.867	186.09	37.09	197.9	1.056	-206.	2084.	1878.	10.6
53	187.276	184.49	37.35	200.9	1.233	18.	2066.	2084.	11.8
54	188.685	182.90	37.61	204.0	1.414	247.	2048.	2295.	13.1
55	190.738	180.57	37.98	208.4	1.673	296.	2022.	2319.	13.3
56	193.791	178.24	38.35	212.9	1.938	354.	1996.	2350.	13.7
57	194.843	175.91	38.71	217.4	2.205	419.	1970.	2389.	14.0
58	196.896	173.59	39.07	222.0	2.474	492.	1944.	2437.	14.4
59	200.852	169.10	39.75	230.9	3.000	93.	1894.	1987.	12.9
60	204.808	164.62	40.41	240.0	3.534	93.	1844.	1936.	11.9
61	206.531	162.66	40.69	244.0	.236	120.	1822.	1942.	12.0
62	207.584	161.70	40.83	246.0	.355	141.	1811.	1952.	12.1
63	208.237	160.73	40.97	248.0	.472	155.	1800.	1955.	12.1
64	209.091	159.76	41.10	250.0	.590	170.	1789.	1959.	12.2
65	209.944	158.79	41.24	252.0	.707	186.	1778.	1964.	12.5
66	211.1[illegible]	157.37	41.44	255.0	.884	-425.	1763.	1337.	8.4
67	212.451	155.95	41.63	258.0	1.060	-196.	1747.	1551.	9.8
68	213.704	154.53	41.83	261.0	1.236	27.	1731.	1757.	11.1
69	214.957	153.11	42.02	264.0	1.414	250.	1715.	1965.	12.5
70	216.801	151.02	42.30	268.5	1.678	300.	1691.	1991.	12.6
71	218.645	148.93	42.58	272.9	1.940	357.	1668.	2025.	13.1
72	220.489	146.84	42.85	277.4	2.206	421.	1645.	2065.	13.4
73	222.332	144.75	43.12	282.0	2.474	493.	1621.	2114.	13.8
74	225.931	140.67	43.63	290.9	3.000	100.	1575.	1675.	11.1
75	229.530	136.59	44.13	300.0	3.534	100.	1530.	1630.	10.9
76	231.107	134.80	44.35	304.0	.236	126.	1510.	1636.	11.0
77	231.890	133.91	44.45	306.0	.352	147.	1500.	1647.	11.1
78	232.673	133.02	44.56	308.0	.469	161.	1490.	1651.	11.1
79	233.456	132.14	44.65	310.0	.587	176.	1480.	1656.	11.2
80	234.238	131.25	44.76	312.0	.707	192.	1470.	1662.	11.3
81	235.400	129.93	44.91	315.0	.881	-424.	1455.	1031.	7.0
82	236.561	128.62	45.06	318.0	1.057	-196.	1440.	1244.	8.5
83	237.722	127.30	45.21	321.0	1.234	29.	1426.	1455.	10.0
84	238.884	125.98	45.36	324.0	1.414	254.	1411.	1665.	11.4
85	240.597	124.04	45.57	328.4	1.675	303.	1389.	1692.	11.7
86	242.311	122.10	45.79	332.9	1.939	359.	1367.	1727.	12.0
87	244.025	120.15	45.99	337.4	2.204	423.	1346.	1768.	12.3
88	245.736	118.21	46.20	341.9	2.474	495.	1324.	1819.	12.7
89	249.122	114.37	46.59	350.9	3.001	106.	1281.	1387.	9.8
90	252.505	110.54	46.97	360.0	3.534	106.	1238.	1344.	9.6

TABLE 6-4. GUN OPERATING POWER (Con't.)

INCREMENT	TIME MILSEC	ROTOR ANGULAR ACCELERATION RAD/SEC/SEC	ROTOR ANGULAR VELOCITY RAD/SEC	ROTOR ANGULAR TRAVEL DEGREE	BOLT PERIPHERAL TRAVEL INCH	TOTAL CAM TORQUE LB-IN	ROTOR TORQUE LB-IN	REQUIRED TORQUE LB-IN	REQUIRED HORSE-POWER
91	253.989	108.86	47.13	364.0	.236	132.	1219.	1351.	9.6
92	254.727	108.02	47.21	366.0	.354	153.	1210.	1363.	9.7
93	255.465	107.18	47.29	368.0	.471	167.	1200.	1368.	9.8
94	256.203	106.35	47.37	370.0	.589	182.	1191.	1373.	9.9
95	256.941	105.51	47.45	372.0	.707	198.	1182.	1380.	9.9
96	258.040	104.26	47.57	375.0	.884	-416.	1168.	752.	5.4
97	259.139	103.02	47.68	378.0	1.060	-186.	1154.	968.	7.0
98	260.237	101.77	47.79	381.0	1.237	35.	1140.	1176.	8.5
99	261.336	100.53	47.90	384.0	1.414	256.	1126.	1382.	10.0
100	262.965	98.68	48.07	388.5	1.678	307.	1105.	1412.	10.3
101	264.594	96.83	48.22	393.0	1.943	363.	1085.	1447.	10.6
102	266.222	94.99	48.38	397.5	2.209	426.	1064.	1490.	10.9
103	267.851	93.14	48.53	402.0	2.474	497.	1043.	1540.	11.3
104	271.069	89.49	48.83	411.0	3.004	110.	1002.	1113.	8.2
105	274.288	85.84	49.11	420.0	3.534	110.	961.	1071.	8.0
106	275.707	84.23	49.23	424.0	.236	136.	943.	1079.	8.1
107	276.415	83.43	49.29	426.0	.355	157.	934.	1092.	8.2
108	277.122	82.63	49.35	428.0	.472	172.	925.	1097.	8.2
109	277.830	81.83	49.41	430.0	.590	187.	916.	1103.	8.3
110	278.537	81.02	49.46	432.0	.707	202.	907.	1110.	8.3
111	279.592	79.83	49.55	435.0	.885	-411.	894.	483.	3.6
112	280.648	78.63	49.63	438.0	1.061	-181.	881.	700.	5.3
113	281.703	77.43	49.72	441.0	1.238	40.	867.	907.	6.8
114	282.759	76.24	49.80	444.0	1.414	259.	854.	1112.	8.4
115	284.329	74.46	49.92	448.5	1.580	309.	834.	1143.	8.6
116	285.899	72.68	50.03	453.0	1.944	365.	814.	1179.	8.9
117	287.469	70.90	50.14	457.5	2.210	428.	794.	1222.	9.3
118	289.039	69.12	50.25	462.0	2.474	498.	774.	1273.	9.7
119	292.153	65.59	50.46	471.0	3.005	114.	735.	848.	6.5
120	295.266	62.06	50.66	480.0	3.534	113.	695.	808.	6.2
121	296.643	60.49	50.75	484.0	.236	139.	678.	817.	6.3
122	297.330	59.72	50.79	486.0	.355	160.	669.	829.	6.4
123	298.017	58.94	50.83	488.0	.473	175.	660.	835.	6.4
124	298.704	58.16	50.87	490.0	.591	190.	651.	841.	6.5
125	299.390	57.38	50.91	492.0	.707	205.	643.	848.	6.5
126	300.417	56.22	50.97	495.0	.885	-407.	630.	222.	1.7
127	301.444	55.05	51.02	498.0	1.062	-178.	617.	439.	3.4
128	302.470	53.89	51.08	501.0	1.239	43.	604.	647.	5.0
129	303.497	52.72	51.13	504.0	1.414	260.	591.	851.	6.6
130	305.028	50.99	51.21	508.5	1.680	311.	571.	882.	6.8
131	306.559	49.25	51.29	513.0	1.945	367.	552.	918.	7.1
132	308.090	47.52	51.36	517.5	2.211	430.	532.	962.	7.5
133	309.622	45.78	51.44	522.0	2.474	500.	513.	1012.	7.9
134	312.668	42.33	51.57	531.0	3.006	116.	474.	590.	4.6
135	315.715	38.87	51.69	540.0	3.534	115.	435.	551.	4.3

TABLE 6-4. GUN OPERATING POWER (Con't.)

INCREMENT	TIME MILSEC	ROTOR ANGULAR ACCELERATION RAD/SEC/SEC	ROTOR ANGULAR VELOCITY RAD/SEC	ROTOR ANGULAR TRAVEL DEGREE	BOLT PERIPHERAL TRAVEL INCH	TOTAL CAM TORQUE LB-IN	ROTOR TORQUE LB-IN	REQUIRED TORQUE LB-IN	REQUIRED HORSE-POWER
136	317.064	37.34	51.75	544.0	.236	141.	418.	559.	4.4
137	317.736	36.58	51.77	546.0	.356	162.	410.	572.	4.5
138	318.412	35.81	51.79	548.0	.473	177.	401.	578.	4.5
139	319.086	35.05	51.82	550.0	.591	192.	393.	584.	4.6
140	319.760	34.29	51.84	552.0	.707	287.	384.	671.	4.8
141	320.768	33.14	51.88	555.0	.886	-405.	371.	-34.	-.3
142	321.777	32.00	51.91	558.0	1.062	-176.	358.	182.	1.4
143	322.786	30.85	51.94	561.0	1.239	45.	346.	390.	3.1
144	323.795	29.71	51.97	564.0	1.414	261.	333.	594.	4.7
145	325.304	28.00	52.01	568.5	1.681	312.	314.	625.	4.9
146	326.812	26.29	52.06	573.0	1.946	368.	294.	662.	5.2
147	328.320	24.58	52.09	577.5	2.211	430.	275.	706.	5.6
148	329.829	22.87	52.13	582.0	2.476	500.	256.	756.	6.0
149	332.838	19.46	52.19	591.0	3.006	117.	218.	335.	2.6
150	335.848	16.05	52.25	600.0	3.534	116.	180.	296.	2.3
151	337.183	14.53	52.27	604.0	.236	142.	163.	304.	2.4
152	337.850	13.77	52.28	606.0	.355	165.	154.	317.	2.5
153	338.518	13.02	52.29	608.0	.473	177.	146.	323.	2.6
154	339.185	12.26	52.29	610.0	.591	192.	137.	330.	2.6
155	339.852	11.50	52.30	612.0	.707	208.	129.	336.	2.7
156	340.853	10.37	52.31	615.0	.885	-406.	116.	-289.	-2.3
157	341.854	9.24	52.32	618.0	1.062	-176.	103.	-73.	-.6
158	342.855	8.10	52.33	621.0	1.239	44.	91.	135.	1.1
159	343.855	6.97	52.34	624.0	1.414	261.	78.	339.	2.7
160	345.355	5.27	52.35	628.5	1.680	312.	59.	371.	2.9
161	346.854	3.57	52.35	633.0	1.945	367.	40.	407.	3.2
162	348.354	1.87	52.36	637.5	2.210	430.	21.	451.	3.6
163	350.000	-.00	52.36	642.5	2.474	500.	-0.	500.	4.0
164	353.000	.00	52.36	651.5	3.031	64.	0.	64.	.5
165	356.001	.00	52.36	660.5	3.534	64.	0.	64.	.5
166	357.334	.00	52.36	664.5	.236	96.	0.	96.	.8
167	358.000	.00	52.36	666.5	.381	132.	0.	132.	1.0
168	358.667	.00	52.36	668.5	.498	152.	0.	152.	1.2
169	359.333	.00	52.36	670.5	.616	174.	0.	174.	1.4
170	360.000	.00	52.36	672.5	.737	191.	0.	191.	1.5
171	361.000	.00	52.36	675.5	.911	-626.	0.	-626.	-5.0
172	362.001	.00	52.36	678.5	1.087	-285.	0.	-285.	-2.2
173	363.001	.00	52.36	681.5	1.264	43.	0.	43.	.3
174	364.001	.00	52.36	684.5	1.414	314.	0.	314.	2.5
175	365.501	.00	52.36	689.0	1.706	384.	0.	384.	3.0
176	367.001	.00	52.36	693.5	1.971	457.	0.	457.	3.6
177	368.500	.00	52.36	698.0	2.235	537.	0.	537.	4.3
178	370.000	.00	52.36	702.5	2.474	615.	0.	615.	4.9
179	373.000	.00	52.36	711.5	3.031	64.	0.	64.	.5
180	376.001	.00	52.36	720.5	3.534	64.	0.	64.	.5

CHAPTER 7

COMPONENT DESIGN

7–1 GENERAL

Automatic weapons are equipped with practically the same components that other weapons need to insure effective and safe (to the operator) performance. Differences lie only in application since the components in the automatic weapon must be geared to automatic performance. These components include feed mechanisms, breech locking systems, sears, firing mechanisms, extractors, ejectors, and cocking mechanisms. Characteristics of other components such as muzzle devices which include silencers are presented in detail in other design handbooks [25] or published reports [26]. Each component generally has features unique to automatic weapons.

7–2 FEED MECHANISM DESIGN

Automatic weapons are fed ammunition from magazines, clips, and belts; the type and capacity depending upon type of weapon. The bolt, moving in counterrecoil, strips the round from the feed mechanism and carries it into the chamber. The withdrawn round is instantly replaced by the next round of the supply.

The first step in designing a feed mechanism is defining the feed path. The feed path is the course of the round from mechanism to chamber. Two requisites take precedence: (1) to have the initial position of the projectile move as close to the chamber as the system permits, and (2) to have the base of the cartridge case as close in line to the center line of the bore as possible at the time of feed. The ideal would have the center lines of round and bore collinear. The ideal is not always possible; therefore, other arrangements must suffice but care must be exercised to avoid impact between bolt face and primer since bolt contacts cartridge during counterrecoil. The primer is the restricting element. The two views of Fig. 7–1 illustrate this characteristic. Unless surface contact is assured at impact, the outer edge of the bolt face must never extend into the primer surface, otherwise the edge may strike the primer with enough resulting penetration to set it off. To preclude premature discharge, a minimum space of 0.010 in. between the edges of the primer and bolt face is necessary. Because of override, impact cannot be eliminated; thereby, obviating this approach as a solution for premature firing. *Override* is the clearance between bolt face and cartridge case base needed to position the round before the bolt moves forward. Interference here cannot be tolerated, otherwise malfunction is inevitable.

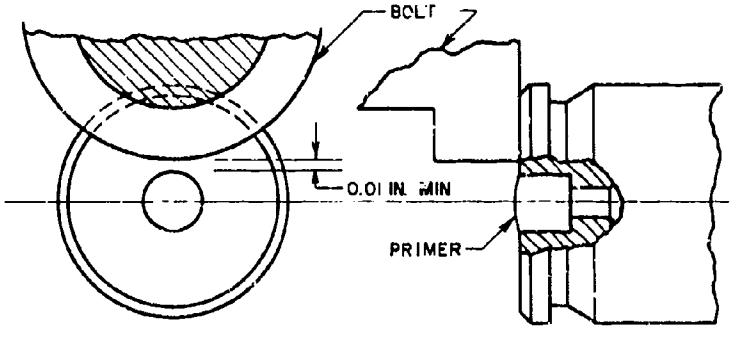


Figure 7–1. Initial Contact of Bolt and Cartridge Case Base

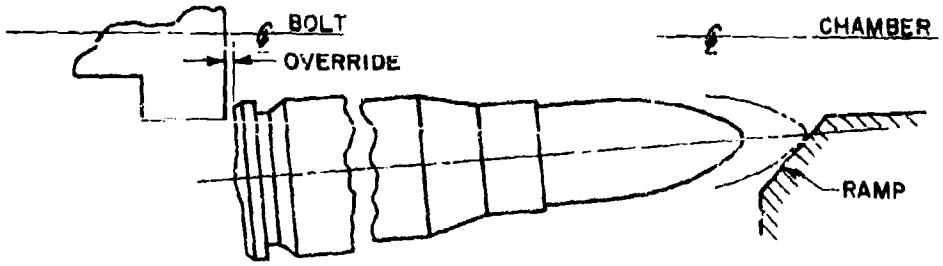


Figure 7–2. Chamber-projectile Contact

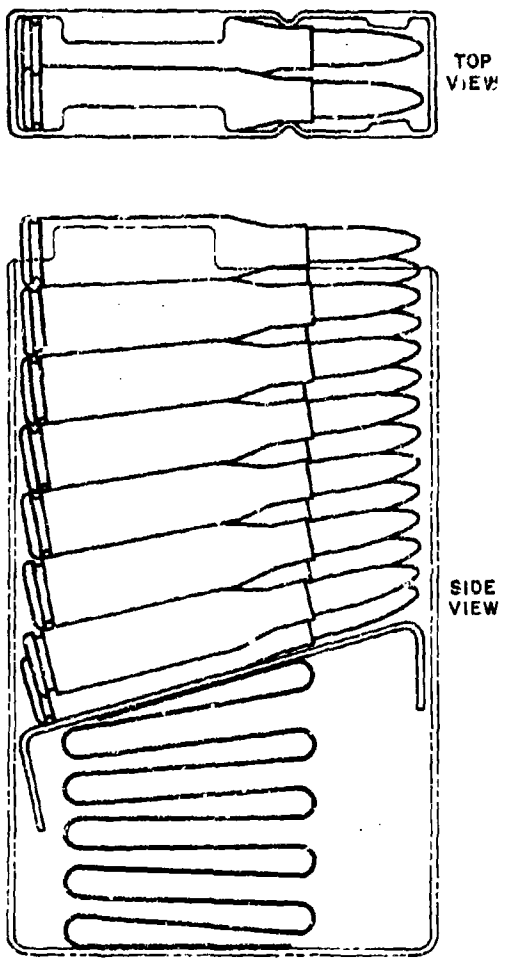


Figure 7–3. Box Magazine

The next design operation is to provide a path for the round between the immediate receptacle and chamber, and guidance along this path. The receptacle—whether magazine, clip, or belt—provides the initial guidance which will be discussed later. The chamber provides the terminal guidance. The entrance to the chamber and the path of the round should be so arranged that any contact between chamber and projectile will take place on the ogive. Fig. 7–2 shows this arrangement. The chamber entrance may be enlarged by a ramp to eliminate the probability of the nose striking the chamber walls first.

7–2.1 MAGAZINES

Magazines, box or drum, are of limited capacity. Box magazines generally hold from 7 to 20 rounds in single or double rows; drums, up to 150 rounds.

7–2.1.1 Box Magazines

A box magazine may be attached to the receiver or it may be an integral part of it. Both types have a spring to keep forcing the rounds toward the bolt as firing continues. The box not only stores the rounds but also restrains their outward motion at the mouth and guides each round as the bolt strips it from the box. The restraining and guiding elements, called lips, are integral with the sides. Fig. 7–3 shows a box magazine with several rounds of ammunition.

Correct lip length is vital to dependable loading. Combined with the direction of the spring force, the lips control the position of the round as it enters the chamber. As indicated in Fig. 7–3, continuous control is exercised by the lips while they restrain the round and so long as the resultant spring force passes within their confines. If the resultant spring force falls forward of the lips, the round will have a tendency to tip excessively

and increase the probability of jamming. Fig. 7–4 demonstrates how a short lip may fail to guide a round so that it enters the chamber without interference. Fig. 7–4 demonstrates how a longer lip will retain contact with the round long enough for the ogive to hit the ramp just prior to entering the chamber.

The shape of the lip has considerable influence on feeding. The round to be loaded should be restrained by line contact between the cartridge case and lip. Fig. 7-5 shows how this effect can be arranged by making the inner radius of the lip less than the radius of the cartridge case. Absolute assurance of line contact is assured by forming the lip by a right angle bend. The spring load holds the round firmly until the bolt dislodges it. On the other hand, if the lip radius is larger than the cartridge case radius, accurate positioning of the rounds cannot be achieved with any degree of assurance. The cartridge case position, from round to round, may virtually float; thereby, causing an inconsistency in contact area between the bolt face and the rounds. Fig. 7–5 shows how the positions may vary with respect to the fixed bolt position. The larger the radius, the less assurance of sufficient contact area between the bolt face and cartridge case base. In extreme cases the bolt may hit the primer first and initiate it.

The dimensions of the cartridge and the intended capacity determine the size of the magazine. For a single row of cartridges, the width equals the diameter of the base plus 0.005 in.

$$w = D_c + 0.005 \qquad (7\text{–}1)$$

where D_c = diameter of cartridge case base

w = inside width of magazine

Double rows of cartridges are stacked so that the centers form an equilateral triangle as shown in Fig. 7–6 where the inside width of the magazine is

$$w = 1.866\, D_c + 0.005. \qquad (7\text{–}2)$$

The nominal depth of the magazine storage space with double rows is

$$h = \frac{1}{2} D_c (N + 1) \qquad (7\text{–}3)$$

where h = depth

N = number of rounds

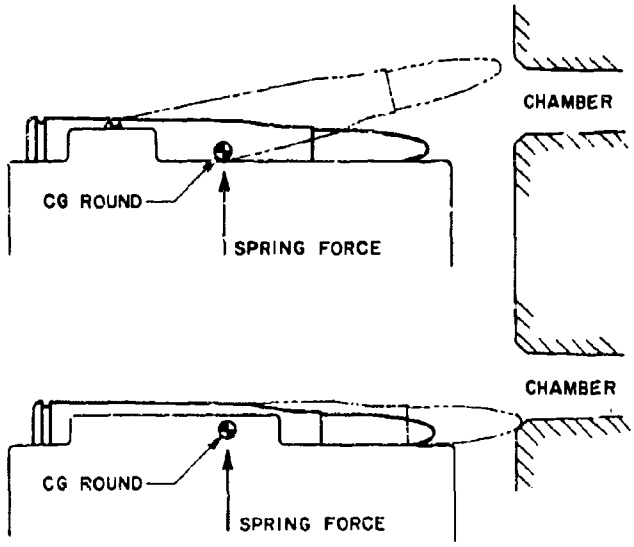
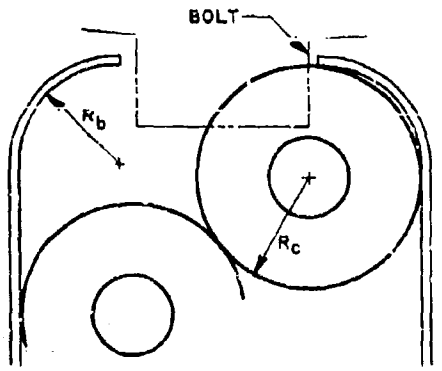
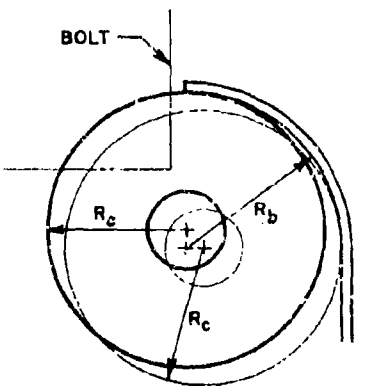


Figure 7–4. Lip Guides



(A) PROPER ARRANGEMENT, $R_b < R_c$



(B) POOR ARRANGEMENT, $R_b > R_c$

Figure 7–5. Lip-cartridge Case Orientation

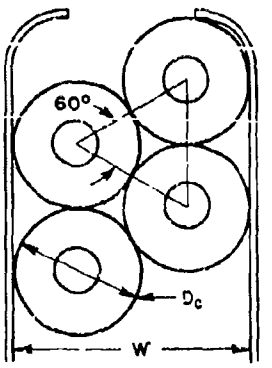


Figure 7–6. Geometry of Double Row Stacking

7–2.1.2 Box Feed System

The box feed system has three major components, the box which has been discussed, the follower, and the spring. The follower separates the column of cartridges from the spring, transmits the spring force to the cartridges, and provides the sliding surface for the last (single row) or last two (double row) cartridges. The follower also holds the stored rounds in alignment. It should never restrict spring activity. Fig. 7–7 shows three views of a follower. The spring may be a round wire spring shaped into rectangular coils or it may be a flat steel tape folded over at regular intervals to approximate the side view of a helix.

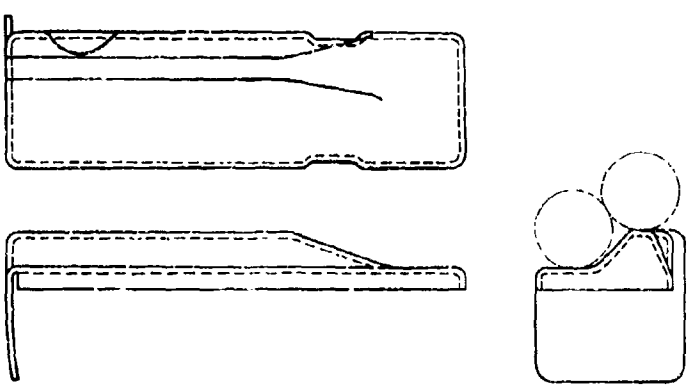


Figure 7–7. Box Magazine Follower

7-2.1.2.1 Flat Tape Spring

The flat steel spring functions in bending rather than in torsion. Each segment behaves as a cantilever beam that has the loaded end restrained from rotating. Fig. 7-8 shows this analogy and the loading diagram. Beginning at the follower, the bending moment M_o at the bend, when the applied load is assumed to be concentrated at the middle of the follower is

$$M_o = \frac{1}{2}\left(FL\right) \qquad (7\text{-}4)$$

where F = spring force

L = length of each spring segment

The bending moment at the end of the first free segment

$$M = M_o + FL = \frac{1}{2}\left(FL\right). \qquad (7\text{-}5)$$

This moment is identical and, therefore, constant for all segments of the spring. The deflection of one end of each segment with respect to the opposite one is

$$\Delta y = \frac{M_o L^2}{2EI} + \frac{FL^3}{3EI} = \frac{FL^3}{12EI} \qquad (7\text{-}6)$$

where E = modulus of elasticity

I = area moment of inertia of the spring cross section

The total deflection of a spring having N active segments is

$$y = \Sigma \Delta y = N \Delta y = \frac{NFL^3}{12EI} \qquad (7\text{-}7)$$

Solve for the spring constant.

$$K = \frac{F}{y} = \frac{12EI}{NL^3} \qquad (7\text{-}8)$$

Not only must the spring exert enough force to hold the ammunition in position but it must also provide the acceleration to advance the ammunition and the other moving parts over the distance of one cartridge space in time for the bolt to feed the next round. The equivalent mass of all moving parts in the ammunition box is

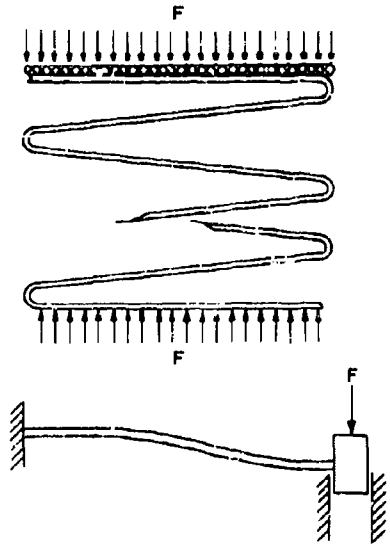


Figure 7-8. Flat Tape Spring and Loading Analogy

$$M_e = \left[(N-1) W_a + W_f + W_{se} \right] / g \qquad (7\text{-}9)$$

where g = acceleration of gravity

N = number of rounds in the box

W_f = weight of follower

W_a = weight of each round

W_s = weight of spring

$W_{se} = \frac{1}{3} W_s$, equivalent weight of spring in motion

The time required for any one particular displacement will be similar to that of Eq. 2-27

$$t = \sqrt{\frac{M_e}{cK}} \cos^{-1} \frac{F_o}{F_m} \qquad (7\text{-}10)$$

where F_m = maximum spring force (preceding one cartridge displacement)

F_o = minimum spring force (following one cartridge displacement)

K = (Eq. 7–5)

M_e = (Eq. 7–6)

ϵ = efficiency of system, generally assumed to be 0.5 for initial design analysis

For initial estimates, provide a spring load of F_i pounds for an empty box and one of F_f for a full box.

The folded flat spring is less desirable than the rectangular coil spring because the latter can be compressed to its solid height whereas total compression of the flat spring is limited by the radius of the folds, thereby, requiring a longer box to house the spring and store the ammunition. Par. 7–2.1.2.2 discusses the rectangular coil spring.

7–2.1.2.2 Rectangular Coil Spring

The rectangular coil spring is a torsion element. Fig. 7–8 illustrates the mechanics of operation. Torsion in each straight segment rotates the adjacent segment. Although bending occurs along the span of each segment, the corners move with respect to each other only by torsional deflection. Bending deflections at the corners are neutralized by equal and opposite bending moments.

Rectangular coil spring characteristics are computed according to procedures similar to helical springs. The applied load is assumed to be concentrated on the axis. The torque T_1 on the long segment is

$$T_1 = \frac{1}{2}\left(aF\right) \qquad (7–11)$$

and torque T_2 on the short segment is

$$T_2 = \frac{1}{2}\left(bF\right) \qquad (7–12)$$

where a = length of short segment

b = length of long segment

F = spring force (7–13)

The corresponding angular deflections are

$$\theta_1 = \frac{bT_1}{JG} = \frac{abF}{2JG} \qquad (7–14)$$

$$\theta_2 = \frac{aT_2}{JG} = \frac{abF}{2JG} \qquad (7–15)$$

where G = torsional modulus

J = area polar moment of inertia of wire

The axial deflection of each segment of a coil varies directly with the sum of the products of the two segment lengths times the sine of the angular deflection of the adjacent segment (see Fig. 7–9). Stated in algebraic expressions the two deflections are

$$\Delta y_1 = b \sin\theta_1 \qquad (7–16)$$

$$\Delta y_2 = a \sin\theta_2 \ . \qquad (7–17)$$

But, according to Eqs. 7–14 and 7–15, $\theta_1 = \theta_2$, and if we let this angle be equal to θ, the deflection of two adjacent segments of a coil is

$$\Delta y = (\Delta y_1 + \Delta y_2) = (a + b) \sin\theta \qquad (7–18)$$

Since there are 4 segments to each coil, the total deflection of a spring having N active coils is

$$y = 2N\Delta y. \qquad (7–19)$$

The spring constant, if y is based on a free spring, is

$$K = \frac{F}{y} \ . \qquad (7–20)$$

The time required for any given displacement can be computed from Eq. 7–10.

7–2.1.3 Example Problems

Compute the spring characteristics for a double row box feed system that holds 20 rounds. Each round weighs 420 grains and has a cartridge case base diameter of 0.48 in. To function properly in the box, the spring should fit in a projected area of 1.75 × 5 in. The initial spring load should be approximately 4 pounds.

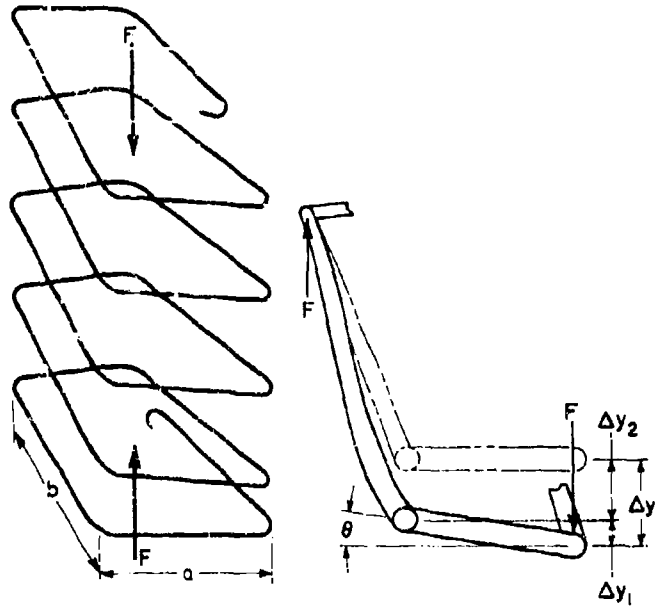


Figure 7--9. Rectangular Coil Spring and Loading Characteristics

7–2.1.3.1 Flat Tape Spring

Set the following initial parameters:

F_i = 4.0 lb, initial spring load

L = 1.75 in., length of each spring segment

N = 14, number of active segments, arbitrary choice but based on previous designs

w = 0.75 in., width of spring

σ_w = 200,000 lb/in.^{2}, working stress of spring

The spring deflection, Eq. 7–3, inside the box caused by the cartridge displacement is

$$y_c = \frac{1}{2} D_c(N+1) = \frac{0.48}{2} (20+1) = 5.04 \text{ in.}$$

where N = 20 rounds.

Assume, as a first estimate, that the deflection on assembly approximates the total cartridge displacement.

y_i = 5.0 in., the initial deflection

According to Eq. 7–8, $K = \frac{F_i}{y_i} = \frac{4.0}{5.0} = 0.8$ lb/in.

Now solving for I in the same equation

$$I = \frac{KNL^3}{12E} = \frac{0.8 \times 14 \times 1.75^3}{12 \times 30 \times 10^6} = \frac{1}{6} \times 10^{-6}$$

Since $I = \frac{1}{12} wt_s^3$, $t_s^3 = \frac{12I}{w} = \frac{8}{3} \times 10^{-6}$.

Therefore t_s = 0.014 in. the required spring thickness. The bending moment, Eq. 7–5, is

$$M = \frac{1}{2}\left(FL\right) = \frac{1}{2} \times 8 \times 1.75 = 7 \text{ lb-in.}$$

where $F = Ky = 0.8 \times 10 = 8$ lb.

The bending stress is

$$\sigma = \frac{Mc}{I} = \frac{7 \times 0.007}{0.1667 \times 10^{-9}} = 294{,}000 \text{ lb/in.}^2$$

where $c = \frac{t_s}{2}$ in.

This stress is too high. To lower it to acceptable levels, the initial and final loads were reduced to 1.0 and 2.0 pounds, respectively. Subsequent computation produced the following data:

$K = 0.2$ lb/in.

$t_s = 0.00874$ in.

$M = 1.75$ lb-in.

$\sigma = 183{,}000$ lb/in.^{2}

The bending stress is still uncomfortably high which almost rules out this type spring for the above application. However, a time analysis will give additional data. The time will be computed for spring action after the first and next to the last round are removed. If the spring weighs 0.063 lb and the follower 0.044 lb, the equivalent moving mass for 19 rounds, according to Eq. 7-9, is

$$M_e = \left(19 \times 0.06 + 0.044 + \frac{0.063}{3}\right)/386.4$$

$$= 0.00312 \text{ lb-sec}^2/\text{in.}$$

Substitute the appropriate values in Eq. 7-10 to compute the time for the first round

$$t = \sqrt{\frac{M_e}{\epsilon K}} \cos^{-1} \frac{F}{F_i} = \sqrt{\frac{0.00312}{0.5 \times 0.2}} \cos^{-1} \frac{1.952}{2.0}$$

$$= \sqrt{0.0312} \cos^{-1} 0.976 = 0.1765 \times 0.22$$

$$= 0.039 \text{ sec}$$

where $\epsilon = 0.5$, the efficiency of the system.

For the last round

$$M_e = \left(0.06 + 0.044 + \frac{0.063}{3}\right)/386.4$$

$$= 0.000323 \text{ lb-sec}^2/\text{in.}$$

$$t = \sqrt{\frac{0.000323}{0.5 \times 0.2}} \cos^{-1} \frac{F}{F_i} = \sqrt{0.00323} \cos^{-1} \frac{1.0}{1.048}$$

$$= 0.057 \times 0.301 = 0.0172 \text{ sec}$$

The slower of the two is equivalent to 1500 rounds/min which is more than adequate.

7-2.1.3.2 Rectangular Coil Spring

Set the following initial parameters:

$a = 0.75$ in., length of short segment

$b = 1.75$ in., length of long segment

$F_i = 4.0$ lb, initial spring load

$N = 7$, number of coils, arbitrary choice but based on previous designs

$y_c = 5.04$ in., cartridge displacement (see par. 7-2.1.3.1)

$y_i = 5.0$ in., assembled deflection (see par. 7-2.1.3.1)

$$K = \frac{F_i}{y_i} = \frac{4.0}{5.0} = 0.8 \text{ lb/in.}$$

The total deflection for a full box of cartridges is

$$y = y_c + y_i = 10.04 \text{ in.}$$

The deflection for two adjacent segments of a coil from Eq. 7-19 is

$$\Delta y = \frac{y}{2N} = \frac{10.04}{14} = 0.717 \text{ in.}$$

The angular displacement according to Eq. 7-18 is

$$\sin\theta = \frac{\Delta y}{a+b} = \frac{0.717}{2.5} = 0.2868$$

$$\theta = 16°40' = 0.291 \text{ rad.}$$

Solve for J in Eq. 7-15.

$$J = \frac{abF}{2G\theta} = \frac{0.75 \times 1.75 \times 8.032}{2 \times 12 \times 10^6 \times 0.291} = 1.509 \times 10^{-6} \text{ in.}^4$$

where $F = Ky = 0.8 \times 10.04 = 8.032$ lb, maximum spring load

$G = 12 \times 10^6$ lb/in.^{2}, torsional modulus of steel

Since $J = \left(\frac{\pi}{32}\right) d^4 = 1.509 \times 10^{-6}$

$d^4 = 15.37 \times 10^{-6}$

$d = 0.0626$ in., say, 0.0625 in.

Then $J = 1.5 \times 10^{-6}$ in.^{4} and the maximum spring force F_m is

$$F_m = \frac{2JG\theta}{ab} = \frac{35 \times 0.291}{1.3125} = 8.0 \text{ lb.}$$

The maximum torque, Eq. 7–12, is

$$T_2 = \frac{1}{2} bF_m = \frac{1}{2}\left(1.75\right) 8.0 = 7.0 \text{ lb-in.}$$

The torsional shear stress is

$$\tau = \frac{T_2 c}{J} = \frac{7.0 \times 0.03125}{1.5 \times 10^{-6}} = 146{,}000 \text{ lb/in.}^2$$

where $c = \frac{d}{2} = 0.03125$ in.

This stress is acceptable.

If the spring weighs 0.036 lb, and the follower 0.044 lb, the moving mass for 20 rounds, according to Eq. 7–9 is

$$M_e = \left(19 \times 0.06 + 0.044 + \frac{0.036}{3}\right) / 386.4$$

$$= 0.0031 \text{ lb-sec}^2/\text{in.}$$

For 19 cartridges,

$y_c = 4.8$ in. and $F_o = (5.0 + 4.8)\, 0.8 = 7.84$ lb.

The time to move this mass through the space left by the departed projectile is computed by Eq. 7–10.

$$t = \sqrt{\frac{M_e}{eK}} \text{ Cos}^{-1} \frac{F_o}{F_m} = \sqrt{\frac{0.0031}{0.5 \times 0.8}} \text{ Cos}^{-1} \frac{7.84}{8.0}$$

$$= 0.088 \times 0.201 = 0.018 \text{ sec}$$

where $e = 0.5$, the efficiency of the system.

The time of 18 msec is far less than needed to operate under any existing conditions.

7–2.2 BOLT-OPERATED FEED SYSTEM

The bolt-operated feed system illustrated in Figs. 7–10 and 7–11 represents one of many similar types. The operating features are described by partially isolating each function and then later showing the coordination that exists in the whole system. Fig. 7–10 shows the ammunition belt system including the components directly associated with it. Sketch (A) shows the position of all parts just as the chambered round has been fired. Sketch (B) shows all parts in the same position except that Round 1 and the empty case are partially extracted, and the feed slide has moved to the left with the feed pawl riding on Round 2. Note that if Round 1 had not been extracted from the belt, the pawl arm would ride over this round to lift the feed pawl above Round 2 to preclude engagement between pawl and Round 2. This operation prevents double feeding or jamming. With Round 1 extracted, the feed pawl carried by pawl arm and slide, continues across Round 2 and eventually engages it as shown in Sketch (C). In the meantime the holding pawl prevents the belt from moving backward.

After the slide completes its travel to the left, the extractor pushes Round 1 downward to align it with the chamber and eject the empty case. After this effort, the slide begins its return to the right and since the feed pawl has engaged Round 2, the slide forces the belt to move also. Two positions of the return are shown in Sketches (C) and (D). Round 3 forces the holding pawl downward to permit belt travel. As soon as Round 2 reaches the original position of Round 1 and all other rounds have simultaneously moved up one position, all feed belt activity will stop with all components taking the positions according to Sketch (A).

The feed slide is activated by the feed lever which in turn is activated by the bolt. The lever fulcrum is fitted to the cover of the receiver, one end activates the slide while the other end rides in a cam groove in the bolt's top surface. Each end of the cam is straight and parallel to the longitudinal axis of the bolt in order to permit a short dwell period for the slide at the end of each half cycle. Shifting the emphasis between the upper and lower illustrations of Fig. 7–11 provides the opportunity of outlining the whole loading and firing cycle. Assume that the bolt is in battery and firing is imminent. The upper picture shows, in phantom, Round 1 of Fig. 7–10 (A) ready to be stripped. The extractor lip is in the extractor groove of the cartridge case. At this same time, the

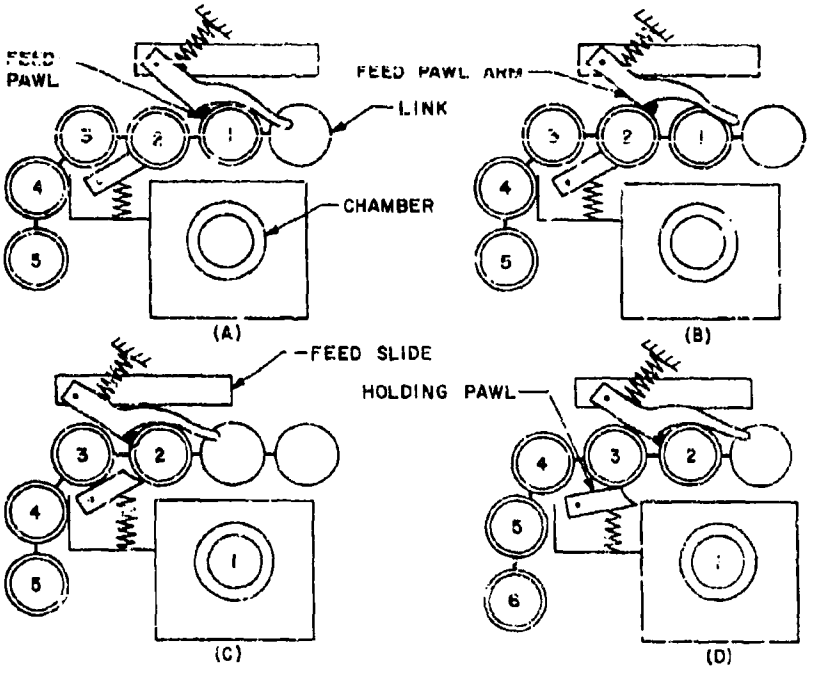


Figure 7–10. Schematic of Feed System, End View

lower picture, in phantom, shows the position of the feed slide and feed lever. None of the components is moving in this stage.

After firing the bolt has recoiled to the position shown in full view in the upper picture. As the bolt travels rearward, the extractor and the T-slot in the face of the bolt strip the round from the link at 1 and extract the empty case from the chambers at 2. During this time, the bolt feed cam pivots the feed lever counterclockwise to move the feed slide outward, and a cam depresses the extractor to fit the cartridge case base into the T-slot. Also, the unattached link falls free of the belt just as the round is stripped. All of this action has been completed by the time that the rearmost bolt position has been reached. The cutaway of the slide shows the feed pawl in contact with the round it is about to push into the vacated position above the chamber.

The full view of the lower picture shows the bolt shortly after it began to counterrecoil. The cam has continued the downward movement of the extractor to align the live round with the chamber and eject the spent case. The cam on the bolt is now causing the feed lever to pivot clockwise and push the first round into position where the extractor, as the bolt reaches the inbattery position, will be lowered into the extractor groove to complete this cycle.

7–2.3 ROTATING FEED MECHANISM

The rotating feed mechanism operates on the chain-sprocket principle where the chain is represented by the belt of ammunition; the rounds being the rollers. The power that turns the sprockets or their equivalent, may be derived from recoil or propellant gas operating mechanisms, or from electric motors.

7–2.3.1 Recoil-operated Feed Mechanism

In a recoil-operated mechanism such as shown schematically in Fig. 7–12, the recoil energy is transformed to rotational effort before it reaches the starwheel. Two starwheels are generally used, one engages the cartridge case back of the belt link while

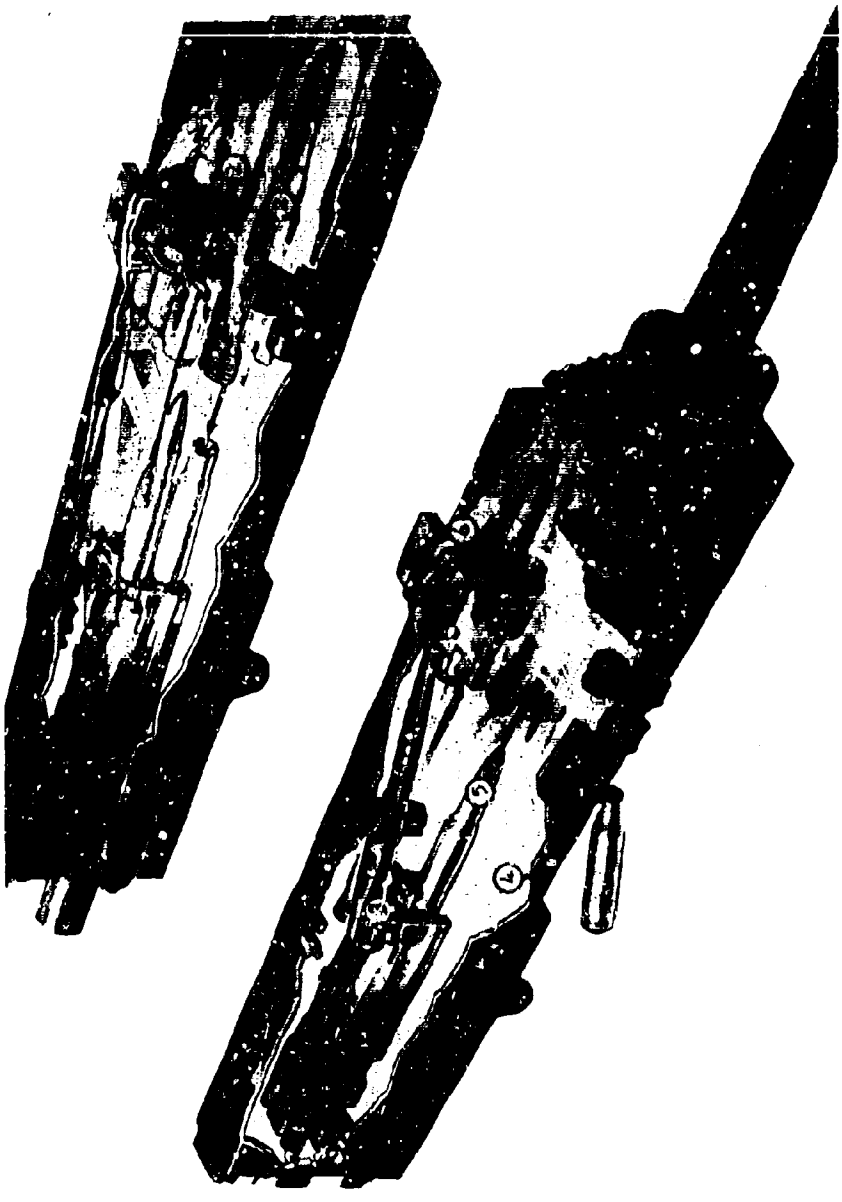


Figure 7–11. Feed System Illustrating Mechanics of Operation

the other engages the projectile just ahead of the rotating band. As the belt and ammunition move with the starwheels, stripper cams wedge between the cartridge case and the clamps of the belt links and pry the links off the case. The freed single end of the link, with its double end still attached to the next round, is guided by the link deflector into the link chute. Freeing the double end releases the link completely from the belt. The detached link falls through the link chute for retrieval or discard. Meanwhile, the link-free round, guided by outer cover and starwheels, continues on its circular path. As it approaches the feed mouth, the round begins to fall away from its cradled position in the starwheels and into the lower contour of the cartridge guides (Fig. 7–12 (B)). The guides complete the path to the feed mouth entrance. Before reaching the mouth, the round contacts the spring-loaded, cartridge holding cams. Forced by the lag tooth of each starwheel, the round pushes the holding cams aside and enters the mouth. As the lag teeth ride over the round, gaps between round and cam surfaces occur to permit the cams to swing back to establish contact between cam surface and round (Fig. 7-12 (B)). The spring loads on the cams force the round downward and simultaneously prevent it from reversing its direction.

The round continues downward until it alights on top of the bolt which is locked in the firing position. It remains in this position until the chambered round is fired and the bolt recoils. The round now moves to the bottom of the mouth where it is retained by a constriction in the mouth. This constriction, or way, is sloped forward at an angle of about three degrees. The round is held in this position by the vertical component of the starwheel force transmitted by the round following. While counterrecoiling, the bolt contacts the lower portion of the cartridge case base and drives the round toward the chamber; the three-degree slope prescribes the desired projectile feed path. As the round clears the ways it is forced downward to become correctly aligned with the bolt. Its former space is now occupied with the next round.

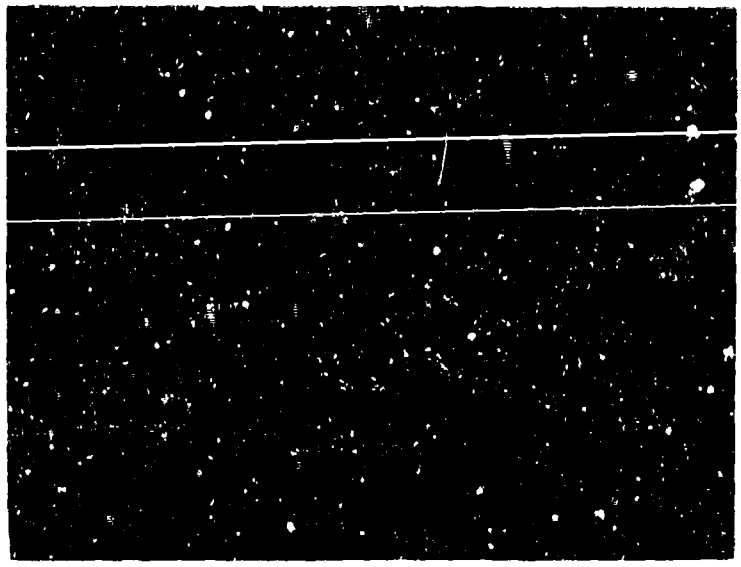
Just prior to entering the feed mouth, the round contacts the lower edge of the spring-loaded cartridge control pawl (Fig. 7–12 (C)). Continued round travel raises the pawl which in turn lifts the holding dog. This action removes the obstruction that the normal position of the dog provides and gives free access at the feed mouth entrance to the preceding round. This process is continuous for the entire length of the ammunition belt except for the last round. Because no round follows to lift the pawl, the dog remains undisturbed and holds the last round at the mouth entrance, but at a position low enough to clear the starwheel. If the last round should be able to drop to the top of the bolt as the next-to-last round is fired, all positive control over it is lost, thereby increasing the probability of jamming. But, since it is held, the counterrecoiling bolt merely closes on an empty chamber. Action resumes when the first round of a new belt reaches the control pawl.

7–2.3.2 Electrically Driven Feed Mechanism

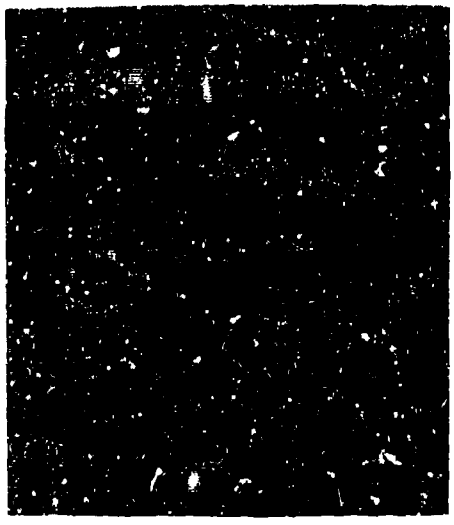
The round and link control of an electrically driven feed mechanism consists of two operating units, the feed wheel unit and the operating lever unit. The feed wheel unit contains two feed wheels, two loading levers, and a bank of three link strippers. The operating lever unit contains two operating levers, two loading guides, and one round retaining finger. The related components between these two units are shown schematically in Fig. 7–13 where the round is used as a common reference. Loading lever and retaining finger are spring loaded; the spring force to the loading lever is transmitted by the operating lever. The retaining finger has its own spring.

The electric motor turns the feed wheel shaft through a gear and clutch system. The two feed wheels draw the belt of ammunition into the feeder at the stripper location (Fig. 7–14 (A)). The link stripper rotates with the feed wheel shaft and its three segments contact the crimp between the leading double and lagging single end of the link. The prying action of the link stripper force on the link crimp and the stripper cover reaction snaps the double end of the link off the lead round (Fig. 7–14 (B)). But the single end of the link is still attached to the lag round. However, continued action of the stripper on the crimp guides the link into the link chute while the freed round continues on its circular path, guided by the feed wheel and link chute support (Fig. 7–14 (C)). As the ammunition belt continues to advance, the prying action of the chute on the double end, combined with the restriction imposed on the lag round by feed wheel and chute support, releases the single end from the round, permitting the now freed link to fall through the link chute.

The freed round continues along the curved chute support until it reaches the entrance to the feed mouth where it contacts the loading guides on the opposite side of the mouth. These guides form the path for the round as it moves into the mouth. Here the round contacts the loading levers and retaining finger. As the feed wheel



(A) Stripper Cam Action



(B) Holding Cam Action



(C) Holding Dog and Control Pawl Action

Figure 7–12. Recoil-operated Rotating Feed Mechanism

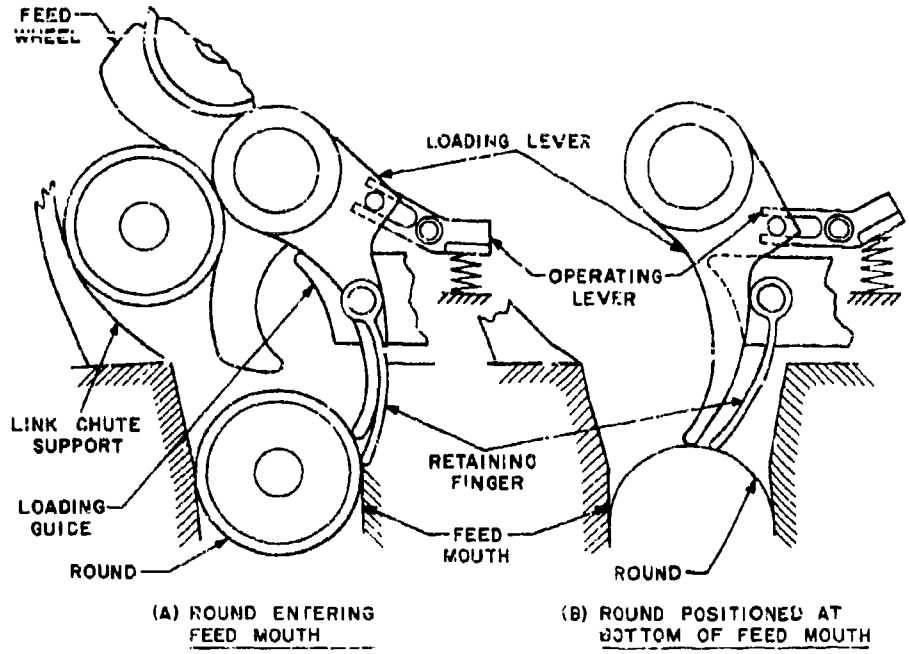


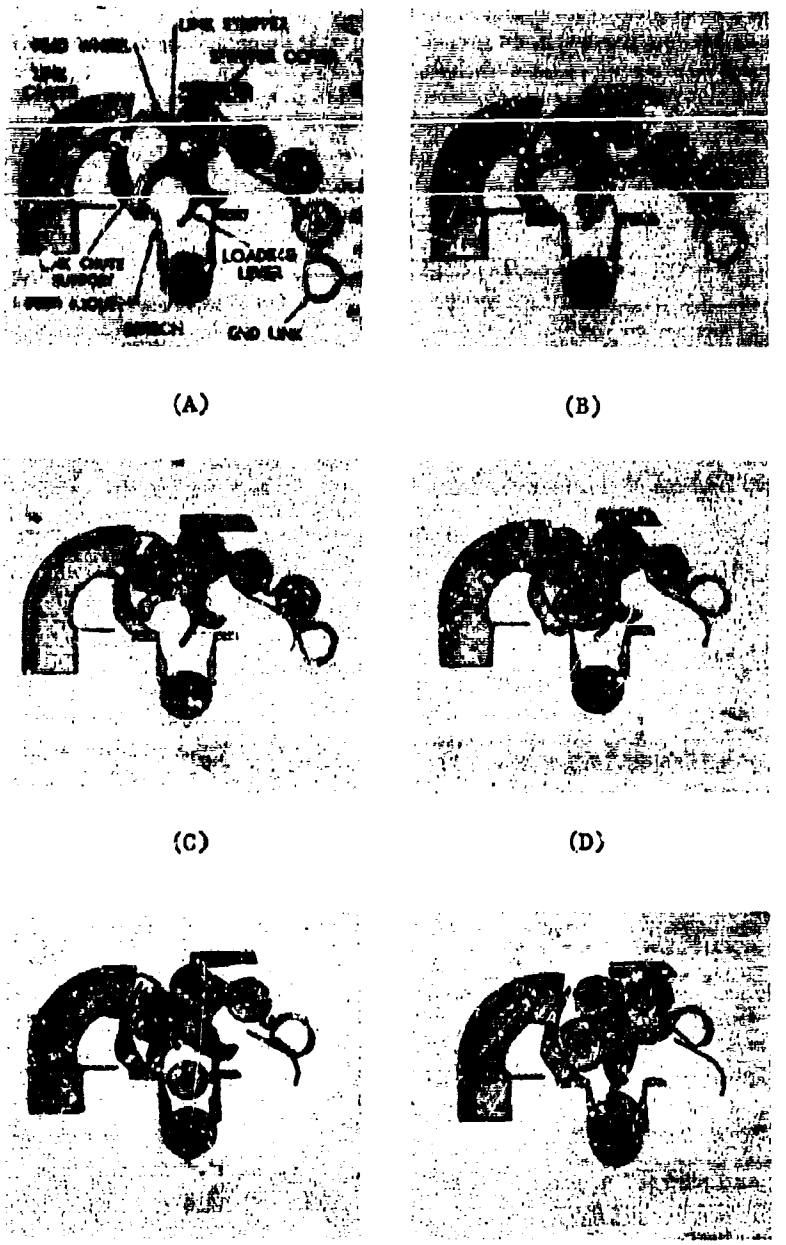
Figure 7–13. Feed Wheel and Operating Lever Units

continues to push the round downward, forces transmitted through the round rotate loading levers and retaining finger outward until the round moves free of the feed wheel. At this stage, being free of the influence of the feed wheel, the loading levers are ready to return to their original position, meanwhile holding the round against the top of the bolt. As soon as the bolt recoils, the loading levers snap the round downward to the ways where it is held in proper alignment by the levers and retaining finger until pushed forward and chambered by the bolt. (This series of events is illustrated in parts (D), (E), (F) of Fig. 7–14.) Unlike the recoil-operated feed mechanism, the last round in the belt may be fired without fear of jamming because of the position control on the round exercised by the loading levers and retaining finger.

While each round is resting on top of the bolt waiting for recoil, the loading mechanism stops. Although these intervals are short, a friction clutch slips a short distance during each interval to prevent the motor from overloading.

7–2.4 LINKLESS FEED SYSTEM

The linkless feed system was developed in order to provide a reliable high speed method of feeding ammunition to a gun without inducing the tremendously high inertia forces that are normally experienced with the conventional link systems. Not only are accelerating forces in the conveyor held to a minimum, but the linkless feed system also provides a large, convenient storage capacity for the ammunition. The major components are the fixed outer drum that stores the ammunition, the rotating inner drum that advances the stored ammunition for loading and feeding purposes, the exit unit that transfers ammunition from drum to conveyor belt, and the conveyor system that carries the loaded ammunition to the gun and carries the spent cases to the entrance unit where these cases are returned to the drum assembly. Two transfer units, at the rear of the gun, transfer live and spent ammunition from conveyor belt to gun and later from gun to conveyor belt. There are two general classes of linkless ammunition feed, the double and



(A) (B)

(C) (D)

(E) (F)

Figure 7--14. Electrically Operated Rotating Feed Mechanism

single end. The double end system has all the features defined above whereas the single end system has only those components that operate with live ammunition; all spent cases and unfired rounds that pass the transfer unit at the gun are dumped from the system by the gun.

The outer drum is a stationary storage compartment that may hold as many as 1200 20 mm rounds. It is a large cylinder that is lined with L-shaped double partitions that extend along the entire drum length and protrude radially toward the axis. Rounds of ammunition occupy the parallel spaces between the partitions. Near the drum wall, a longitudinal rib on each side of the partitions engages the extractor groove to hold the round in place with the nose pointed toward the axis. The partitions also guide the rounds as they are advanced along the drum. Fig. 7–15 is a typical outer drum showing the partition and ammunition arrangement. Two adjacent spaces near the exit and entrance units remain empty at all times to avoid jamming operation.

The inner drum is the rotating member of the two drums. It is a tube with thin sheet metal forming a double helix attached to the outer periphery (Fig. 7–16). The outer periphery of the helix is large enough to engage the ogive of each round. As the drum rotates, the helix advances the ammunition longitudinally along the outer drum. During each revolution, two radial layers of ammunition are carried to the conveyor by virtue of the double helix which assures continuous feed. Each exit and entrance of the double helix has a scoop disc arrangement, which is merely an extension of the helix, to remove or replace a component of ammunition as the scoop passes the respective storage space on the outer drum. A sprocket carries the round along the scoop and deposits it into a compartment in the retainer partition assembly.

The retainer partition assembly is mounted on the end cover of the outer drum and transfers the rounds from scoop disc to exit unit. The retainer has two less partitions ($n - 2$) than the number of spaces in the outer drum. The fewer partitions compensate for the two empty storage spaces in the outer drum and permit a continuous flow of ammunition to the gun. All gearing of the rotating components is timed to insure synchronization. The ammunition is removed from the retainer partition assembly by another scoop-sprocket mechanism and loaded in the ammunition conveyor.

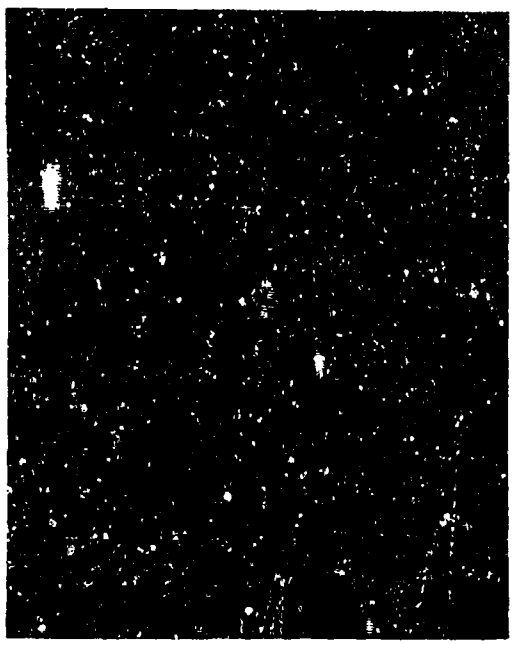


Figure 7–15. Outer Drum

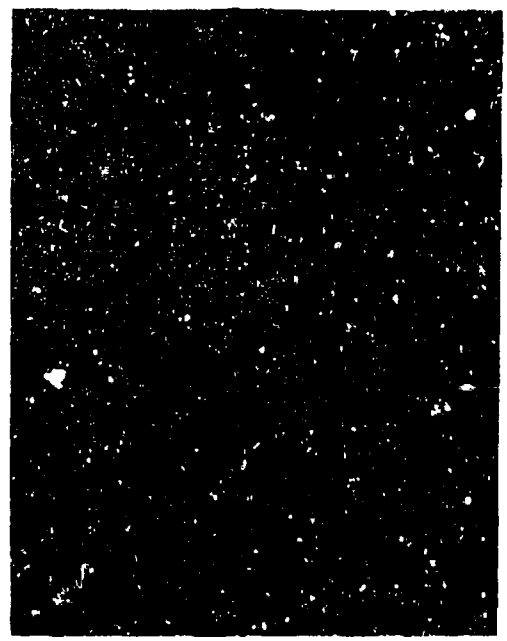


Figure 7–16. Inner Drum Helix

The conveyor is an endless belt made of elements similar to conventional ammunition links. The belt travels in two chutes; the feed chute and the return chute. The former supports and guides the loaded ammunition belt from drum assembly to the gun while the latter supports and guides the empty belt from gun to drum. The chute consist of many links or frames that are hooked together to form a smooth, continuous track which can twist and bend to assume the desired path contours. The chute end frames have snap fasteners for ready attachment to other system components thus providing a good maintenance characteristic.

Each conveyor element is made of two semicircular loops of different size that are held together by a rivet. The larger loop has lugs that engage the extractor groove of the cartridge case. When connected, the smaller loop of one element rests under a tab in the forward part of the larger loop of the adjacent element. Fig. 7–17 shows several elements joined in this manner. One holds a round of ammunition. On the left, a small loop is shown free with its larger counterpart shown on the right. The element does not grip the case tightly and can fully support the round only with aid of the chutes. Once outside the chutes, the rounds or cases are easily lifted from or placed into the elements by the sprockets of the various transfer units. Once the element is relieved of the case, the belt can be easily disconnected or folded over itself. Since the belt is so folded as it passes through the feeder, two elements could part if at least one of them were empty while in the feed chute. Therefore, all elements should be loaded while in the feed chute.

Fig. 7–18 is a schematic of the operating features of a double end linkless feed system. Both conveyor belt and ammunition loop are continuous circuits. The stationary outer drum shows only one row of ammunition. When the rotating elements turn (in the direction indicated by the heavy arrows) the helix on the inner drum advances the ammunition to the right where the scoop picks up the round as it leaves the helix at A. As the scoop continues toward the next stored row of ammunition, a sprocket in the scoop disc assembly carries the round to the retainer partition assembly where the transfer is made at B. To have an empty partition available for the next round, B must travel faster than A. The round leaves the retainer partition at C, the transfer point to the ammunition exit unit. In the meantime, the retainer partition assembly continues to rotate, but the partitions between C and D are empty and will not receiver any rounds until B passes C. The scoop disc at D, the end of the other helix, is diametrically opposite A. It too is collecting a round from each row of stored ammunition and depositing it into a retainer partition. Since the retainer is moving faster than the scoop, all partitions between D and B will be filled by the scoop at D, just as B passes C. However, because the exit unit at C occupies some space, the flow of ammunition from A to B must be interrupted to avoid jamming the rounds against the exit unit. For this reason, two rows of storage space, accurately indexed ahead of C, will interrupt the flow until the required clearance is achieved. Until pick-up is resumed, empty partitions continue to accumulate beyond C. Proper synchronization by gear trains insure continuous ammunition supply to the conveyor.

If there are n storage rows in the outer drum, then there are $n - 2$ rows of stored ammunition. Since two layers of rounds are removed for each revolution of the inner drum, the total number reaches $N = 2(n - 2)$. To retrieve this discharge, the retainer partition assembly must rotate at least twice the speed of the



Figure 7–17. Conveyor Elements

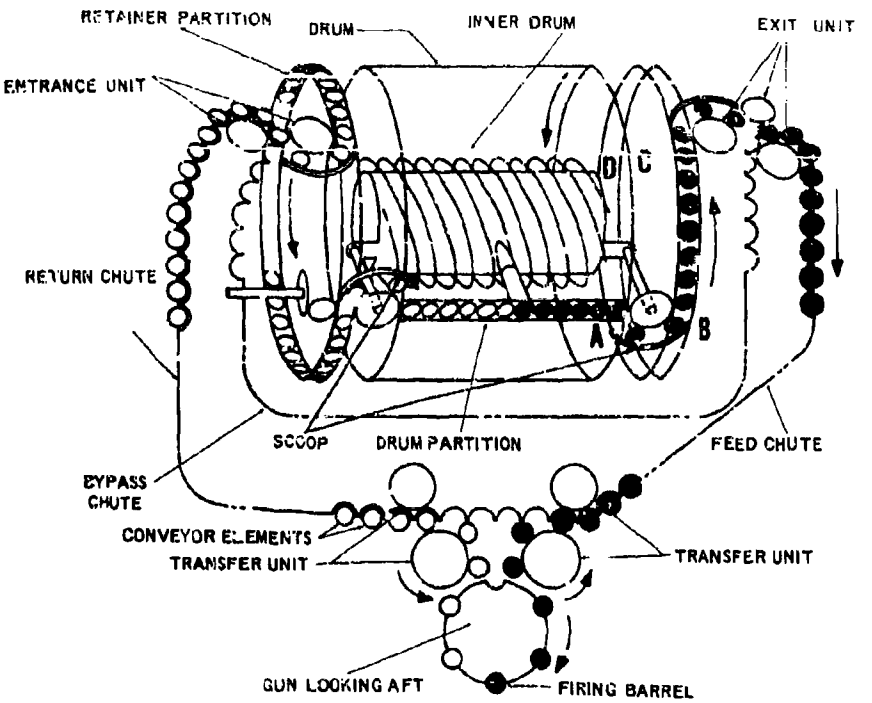


Figure 7–18. Schematic of Linkless Feed System

inner drums. However, while the scoop passes two rows, four empty partitions pass by C. Therefore, for proper indexing, the number of partitions in the retainer $N_r = n - 4$. But the retainer must pick up N rounds, hence its angular velocity ω_r must be

$$\omega_r = \left(\frac{N}{N_r} \right) \omega_d \qquad (7\text{–}21)$$

where ω_d is the angular velocity of the inner drum. If $n = 32$ rows, then $N = 60$ rounds per revolution, and $N_r = 28$ compartments. Therefore $\omega_r = (15/7)\,\omega_d$, i.e., the retainer partition assembly must rotate 2-1/7 times faster than the drum.

After the ammunition leaves the retainer partition at C, it passes through the exit unit where it is loaded into the elements of the conveyor. The conveyor carries the ammunition through the feed chute to the transfer unit where it is loaded into the gun. After firing, the spent case is returned to the transfer unit and reloaded in the conveyor which now moves through the return chute and back to the ammunition entrance unit. The entrance unit removes the cases, and the empty conveyor completes its loop to the exit unit. The empty cases now repeat the same functions as the live rounds but in reverse order, eventually to be stored again in the outer drum.

The single end linkless feed system operates similarly to the double end system except that empty cases and unfired rounds are not returned to the drum but are ejected completely from the system. Therefore, the various ammunition handling units are needed only at the exit end of the drum. Fig. 7–19 shows the operation schematically. Since empty cases and unfired rounds no longer need to be reloaded into the conveyor, the transfer unit is simplified to the point where it actually becomes little more than a feeder. The drum is loaded by disconnecting the system at the exit unit and reversing the direction of moving units and ammunition.

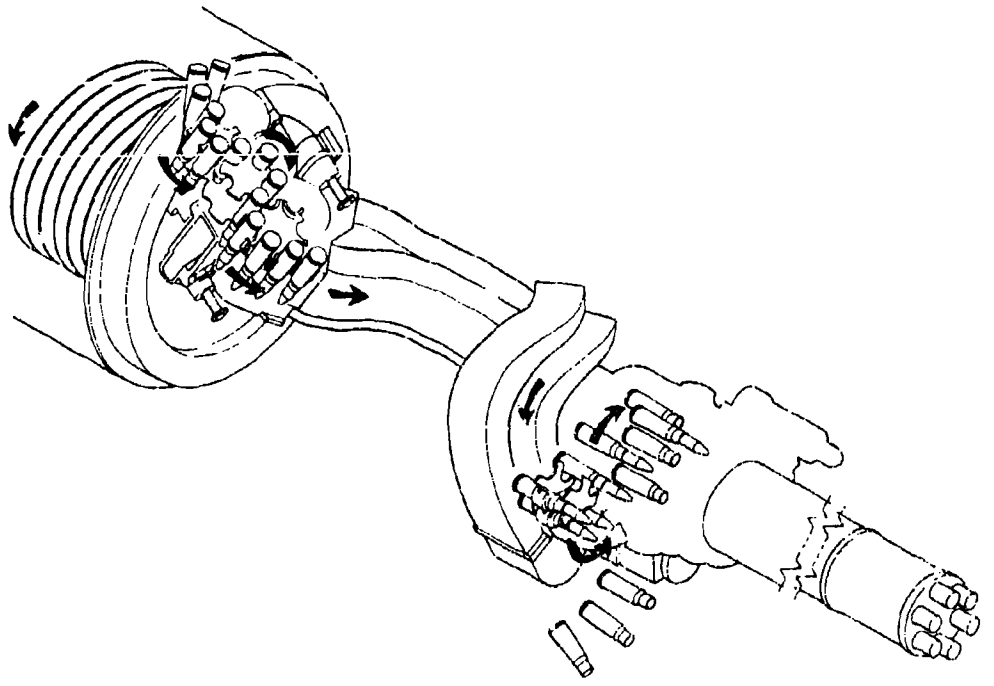


Figure 7–19. Path of Rounds in Single-end System

All linkless feed systems, whether single or double ended, require continuous external power. Also the feeder must be declutched or disengaged from the gun to provide gun clearing after each burst or single shot to prevent "cook-off".

7–2.4.1 Power Required

The power required to operate a linkless feed system includes the power to accelerate the ammunition and all moving components, and that needed to overcome the frictional resistance to all motion. Velocities and accelerations vary from component to component of the feed system; therefore, to maintain a reasonable perspective of the action in each component, the velocity and acceleration of each component is given in terms of its counterpart in the gun. The action throughout the system may be demonstated more clearly by realizing that each time a new round is accepted by the gun: (1) the rounds in each component advance through the respective spaces between rounds, and (2) that the acceleration and velocity for any given component will vary as the linear distance between the rounds. The schematic of Fig. 7–18 illustrates and identifies the components.

The following symbols will be used in the equation for computing the power required to drive a linkless feed system:

a = general term for linear acceleration

F = general term for force

I = general term for the mass moment of inertia

P = general term for power

p = general term for space between rounds (pitch)

N = number of rounds or elements, loaded or empty in each component

R = general term for radius; gun axis to chamber center

T = general term for torque

v = general term for linear velocity

α = general term for angular acceleration

ϕ = double helix drive angle

ω = general term for angular velocity

The following subscripts refer to the specific component of the terms just defined:

c = chute; feed, bipass, or return

d = drum, inner

e = exit or entrance unit

r = retainer partition

t = transfer unit

The peripheral acceleration and velocity at the chamber axis are

$$a = \alpha R \tag{7-22}$$

$$v = \omega R. \tag{7-23}$$

The corresponding accelerations and velocities of the rounds in the other components of the feed system will vary according to the ratio of the pitches. In the transfer unit

$$a_t = a\left(\frac{p_t}{p}\right) \tag{7-24}$$

$$v_t = v\left(\frac{p_t}{p}\right). \tag{7-25}$$

In any of the chutes

$$a_c = a_t\left(\frac{p_c}{p_t}\right) = a\left(\frac{p_c}{p}\right) \tag{7-26}$$

$$v_c = v_t\left(\frac{p_c}{p_t}\right) = v\left(\frac{p_c}{p}\right). \tag{7-27}$$

In the ammunition entrance and exit units

$$a_e = a_c\left(\frac{p_e}{p_c}\right) = a\left(\frac{p_e}{p}\right) \tag{7-28}$$

$$v_e = v_c\left(\frac{p_e}{p_c}\right) = v\left(\frac{p_e}{p}\right). \tag{7-29}$$

In the retainer partition assembly

$$a_r = a_e\left(\frac{p_r}{p_e}\right) = a\left(\frac{p_r}{p}\right) \tag{7-30}$$

$$v_r = v_e\left(\frac{p_r}{p_e}\right) = v\left(\frac{p_r}{p}\right). \tag{7-31}$$

If the storage drum has N storage spaces of which two are empty, and the retainer has $N-4$ partitions, the ratio of the kinematics of retainer partition to inner drum is

$$\rho_d = \frac{2(N-2)}{N-4}. \tag{7-32}$$

provided that the inner drum has a double helix drive. If ϕ is the angle of the double helix drive and p_d is the pitch, the slope of the helix is

$$\tan\phi = p_d/2\pi R_d. \tag{7-33}$$

To express the axial acceleration and velocity along the outer drum spaces in terms of their retainer counterparts, the ratio of the radii of inner drum and retainer must also be included. The axial acceleration and velocity of the stored rounds are

$$a_a = \frac{a_r}{p_d}\left(\frac{R_d}{R_r}\right)\tan\phi \tag{7-34}$$

$$v_a = \frac{v_r}{p_d}\left(\frac{R_d}{R_r}\right)\tan\phi \tag{7-35}$$

Eqs. 7-22 through 7-35 contain the information needed to compute the power required to overcome the

resistance of friction and inertia. The axial force F_a on the helix that will drive the rounds contained in the outer drum is

$$F_a = N_d W_a \left(\frac{a_a}{g} + \mu \right) \qquad (7\text{-}36)$$

where g = acceleration of gravity

N_d = total rounds in outer drum

W_a = weight of each round

μ = coefficient of friction

The corresponding power required is

$$P_a = F_a v_a. \qquad (7\text{-}37)$$

The torque required to turn the inner drum and overcome the sliding friction on the helix is

$$T_d = I_d \alpha_d + \mu F_a R_d \qquad (7\text{-}38)$$

where $\alpha_d = \frac{a_a}{R_d \tan \phi}$. The expression for power is

$$P_d = T_d \omega_d = T_d \left(\frac{v_a}{R_d \tan \phi} \right). \qquad (7\text{-}39)$$

The torque required to turn the retainer partition will also include that necessary to turn the ammunition in half the partitions since this number of rounds is never exceeded.

$$T_r = I_r \alpha_r + N_r \left(\frac{W_a}{g} \right) a_r R_a \qquad (7\text{-}40)$$

where R_a = radius to the *CG* of the round

$\alpha_r = a_r / R_r$

The corresponding power is

$$P_r = T_r \omega_r = T_r \left(\frac{v_r}{R_r} \right) \qquad (7\text{-}41)$$

Similar equations are used, where applicable, for the other components. In the ammunition entrance and exit units the force is

$$F_e = N_e \left(\frac{W_u}{g} \right) a_e \qquad (7\text{-}42)$$

where $W_u = W_e + W_a$ or $W_e + W_{cc}$ for exit and entrance units, respectively.

$$T_e = I_e \alpha_e = I_e \left(\frac{a_e}{R_e} \right) \qquad (7\text{-}43)$$

$$P_e = F_e v_e + T_e \left(\frac{v_e}{R_e} \right) \qquad (7\text{-}44)$$

In the chutes

$$F_c = N_c W_c \left(\frac{a_c}{g} + \mu \right) \qquad (7\text{-}45)$$

$$P_c = F_c v_c$$

Observe that N_c and W_c represent the number and weight of round and conveyor element for the feed chute, the number and weight of only the empty cartridge case and conveyor element for the return chute, and the number and weight of the element above for the bypass chute. In the transfer unit

$$F_t = N_t \left(\frac{W_t}{g} \right) a_t \qquad (7\text{-}46)$$

where W_t may be W_r or W_{cc}, depending on whether the round is entering or the case emerging from the gun.

$$T_t = I_t \left(\frac{a_t}{R_t} \right) \qquad (7\text{-}47)$$

$$P_t = F_t v_t + T_t \left(\frac{v_t}{R_t} \right) \qquad (7\text{-}48)$$

7-2.4.2 Example Problem for Power Required

Compute the power required for a double end linkless feed system having the following design data:

I_d = 9.32 lb-in.-sec^2

I_e = 0.032 lb-in.-sec^2

I_r = 2.54 lb-in.-sec^2

I_t = 0.095 lb-in.-sec^2

N = 32 partitions

N_c = 45 feed; 35 bypass; 25 return

N_d = 1200 rounds

N_e = 3 rounds; 3 cases

N_t = 2 rounds; 2 cases

p = 2.77 in.

p_c = 1.62 in.

p_d = 2.54 in.

p_e = 2.09 in.

p_r = 2.24 in.

p_t = 2.09 in.

R = 2.643 in.

R_c = 8.0 in.

R_d = 7.0 in.

R_t = 2.0 in.

R_r = 10.0 in.

R_t = 2.0 in.

W_a = 0.57 lb, weight of round

W_{cc} = 0.25 lb, weight of case

W_e = 0.12 lb, weight of element

μ = 0.22, coefficient of friction

All data computed from Eqs. 7–22 through 7–48 are put in terms of the gun kinematics.

$$a_t = \left(\frac{2.09}{2.77}\right) a = 0.755\,a \qquad v_t = 0.755\,v$$

$$a_c = \left(\frac{1.62}{2.77}\right) a = 0.585\,a \qquad v_c = 0.585\,v$$

$$a_e = \left(\frac{2.09}{2.77}\right) a = 0.755\,a \qquad v_e = 0.755\,v$$

$$a_r = \left(\frac{2.24}{2.77}\right) a = 0.809\,a \qquad v_r = 0.809\,v$$

$$\rho_d = \frac{2(32-2)}{32-4} = \frac{60}{28} = 2.143$$

$$\tan\phi = \frac{2.54}{14\pi} = 0.05775$$

$$a_a = \left(\frac{0.809a}{2.143}\right)\left(\frac{7}{10}\right) 0.05775$$

$$= 0.0153\,a, \text{ in./sec}^2;\ v_a = 0.0153\,v, \text{ in./sec}$$

$$F_a = N_d W_a \left(\frac{a_a}{g} + \mu\right)$$

$$= 1200 \times 0.57\,(0.0000396\,a + 0.22)$$

$$= 150.48 + 0.027\,a, \text{ lb}$$

$$P_a = F_a v_a = (2.302 + 0.00041\,a)\,v, \text{ in.-lb/sec}$$

$$T_d = I_d \alpha_d + \mu F_a R_d = 9.32\left(\frac{0.0153\,a}{0.404}\right)$$

$$+ 0.22\,(150.48 + 0.027a)7.0 = 0.3530\,a$$

$$+ 231.7 + 0.0416\,a = 231.7 + 0.3946\,a, \text{ lb-in.}$$

$$P_d = T_d \omega_d = (231.7 + 0.3946a)\left(\frac{0.0153\,v}{0.404}\right)$$

$$= (8.775 + 0.01494\,a)\,v, \text{ in.-lb/sec}$$

$$T_r = 2.54\left(\frac{0.809\,a}{10.0}\right) + 14\left(\frac{0.57}{386.4}\right)\left(0.809\,a\right) 6.0$$

$$= (0.2055 + 0.1002)\,a = 0.3057\,a, \text{ lb-in.}$$

where $N_r = \frac{1}{2}(N-4) = 14$

R_r = 10.0 in.

$$P_r = T_r\left(\frac{v_r}{R_r}\right) = \left(0.3057\,a\right)\left(\frac{0.809\,v}{10.0}\right)$$

$$= 0.02473\,av, \text{ in.-lb/sec}$$

The combined data in the entrance and exit units according to Eqs. 7–42, 7–43, and 7–44 are

$$F_e = N_e\left(\frac{\Sigma W_u}{g}\right)a_e = \frac{3(0.37+0.69)}{386.4}\,0.755a = 0.00621a, \text{ lb}$$

where $\Sigma W_u = (W_e + W_{cc}) + (W_e + W_a) = (0.37 + 0.69)$.

$$T_e = 2I_e\left(\frac{a_e}{R_e}\right) = 2 \times 0.032 \times 0.755a/2.0 = 0.024160a, \text{ lb-in.}$$

$$P_c = F_e v_e + T_e\left(\frac{v_e}{R_e}\right) = 0.00621a \times 0.755v + 0.02416a \times 0.755v/2.0 = 0.00469av$$

$$+ 0.00912av = 0.01381av, \text{ in.-lb/sec.}$$

The accumulated data in the chutes according to Eqs. 7–45 and 7–46 are

$$F_c = \left[N_f(W_a + W_c) + N_p W_c + N_r(W_{cc} + W_c)\right]\left(\frac{a_c}{g} + \mu\right)$$

$$= (45 \times 0.69 + 35 \times 0.12 + 25 \times 0.37)\left(\frac{0.585a}{386.4} + 0.22\right)$$

$$= 9.79 + 0.06737a, \text{ lb}$$

where $N_f = N_c = 45$; $N_p = N_c = 35$; $N_r = N_c = 25$.

$$P_c = F_c v_c = 0.585vF_c = (5.727 + 0.03941a)v, \text{ in.-lb/sec}$$

The accumulated data in the transfer unit are computed according to Eqs. 7–44, 7–45, and 7–46.

$$F_t = N_t(W_a + W_{cc})a_t/g = 2(0.57 + 0.25)0.755a/386.4 = 0.0032a, \text{ lb}$$

$$T_t = I_t\left(\frac{a_t}{R_t}\right) = 0.095 \times 0.755a/2.0 = 0.03586a, \text{ lb-in.}$$

$$P_t = F_t v_t + T_t\left(\frac{v_t}{R_t}\right) = 0.0032a \times 0.755v + 0.03586a\left(\frac{0.755v}{2.0}\right) = 0.00242av$$

$$+ 0.01353av = 0.01595av, \text{ in.-lb/sec.}$$

The total power required to drive the linkless feed system is

$$P_f = P_a + P_d + P_r + P_e + P_c + P_t = (2.302 + 0.00041a)v + (8.775 + 0.01494a)v$$

$$+ 0.02473av + 0.01381av + (5.727 + 0.03941a)v + 0.01595av$$

$$= 16.804v + 0.1093av = P_v + P_{av}, \text{ in.-lb/sec}$$

The power will be computed for several increments i taken from the tabulated values of Table 6–4, the Gun Operating Power computations. From Eqs. 7–22 and 7–23, the linear acceleration and velocity are

$$a = 2.643\alpha$$

$$v = 2.643\omega$$

The computed data are listed in Table 7–1. The two components of the total power are

$$P_v = 16.804v$$

$$P_{av} = 0.1053av$$

7–3 EXTRACTORS, EJECTORS, AND BOLT LOCKS

7–3.1 EXTRACTORS

Extractors are machined components that pull the cartridge case from the chamber as the bolt recoils. Assembled near the breech face of the bolt, they are generally spring loaded to tilt toward the longitudinal axis of the bolt and thus direct a continuous clamping effort on the cartridge case. This clamping effort is sometimes supplemented by the restraining wall of the receiver or by the induced moment of the axial forces needed for extraction. The source of whatever effort is applied is determined by the type extractor.

Four types of extractor are shown in Fig. 7–20. Of these, (A) and (C) are similar insofar as spring installation is concerned but differ with respect to method of transmitting the tipping action. (A) is the extractor used in the 7.62 mm, M60 Machine Gun. The helical compression spring provides the clamping effort. The plunger transmits the spring force to the outer portion of the extractor while the bolt offers the reaction on the inner portion. Contact between extractor and bolt is effected by a boss on the extractor which rests in a recess in the bolt. The front surface of the boss is conical and is matched by its female counterpart. Tipping action uses this location as the fulcrum.

Springs must be reasonably stiff so that an appreciable effort is demanded to release the case rim. For instance, the nominal spring load is F_s = 15 lb on the extractor, (M60 Machine Gun). The horizontal reaction H_s (Fig. 7–21 (A)) has the same value but since it is on a slope of 20° 40′, it has a vertical component.

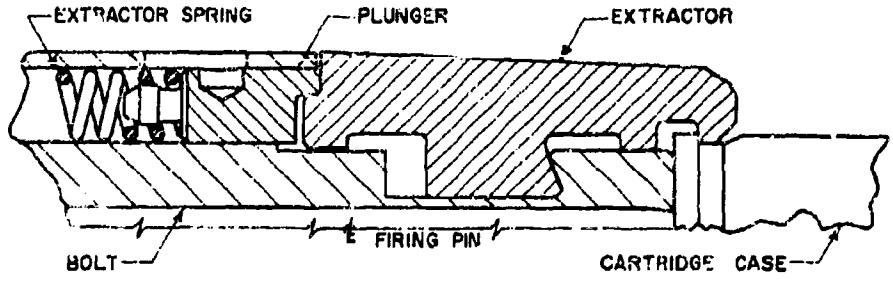
$$V_s = H_s \tan 20°40' = 15 \times 0.377 = 5.65 \text{ lb}$$

The vertical reactions on the pads at A and B (Fig. 7–21 (A)) do not contribute to the solution of F_e for the reaction at B gradually disappears as F_e increases to the value that displaces the extractor outward. The value

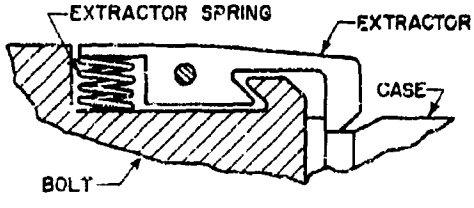
TABLE 7–1. POWER REQUIRED FOR LINKLESS BELT FEED SYSTEM

i	α, rad/sec^2	ω, rad/sec	a, in./sec^2	v, in./sec	P_v, in.-lb/sec	P_{av}, in.-lb/sec	P_f, in.-lb/sec	HP
44	200.0	34.72	528.6	91.8	1543	5304	6847	1.04
58	173.6	39.07	458.8	103.3	1737	5180	6917	1.05
60	164.6	40.41	435.0	106.8	1795	5078	6873	1.04
73	144.8	43.12	382.7	114.0	1916	4768	6684	1.01
88	118.2	46.20	312.4	122.1	2052	4169	6221	0.94
100	98.7	48.07	260.9	127.0	2134	3622	5756	0.87
120	62.1	50.66	164.1	133.9	2250	2402	4652	0.70
130	51.0	51.21	134.8	135.3	2274	1993	4267	0.65
140	34.3	51.84	90.6	137.0	2302	1357	3659	0.55
150	16.1	52.25	42.6	138.1	2321	643	2964	0.45
162	1.9	52.36	5.0	138.4	2326	76	2402	0.36

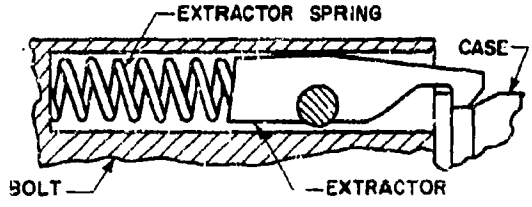
Since the maximum power required to operate the gun is 14.4 HP., at increment i = 58 (see Table 6–4) the total power for gun and feed system totals 15.45 HP.



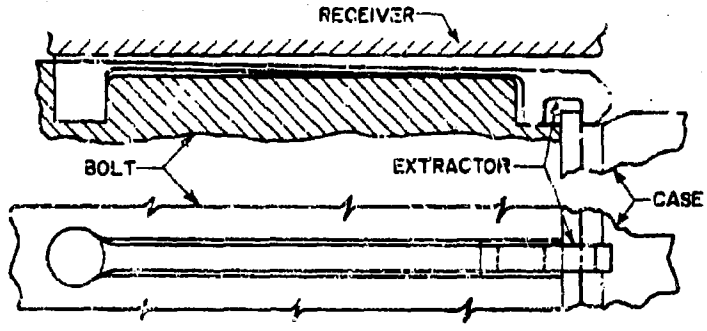
(A) EXTRACTOR WITH PLUNGER AND AXIAL SPRING



(B) EXTRACTOR WITH RADIAL SPRING



(C) EXTRACTOR WITH AXIAL SPRING



(D) EXTRACTOR WITH INTEGRAL FLAT SPRING

Figure 7–20. Extractors

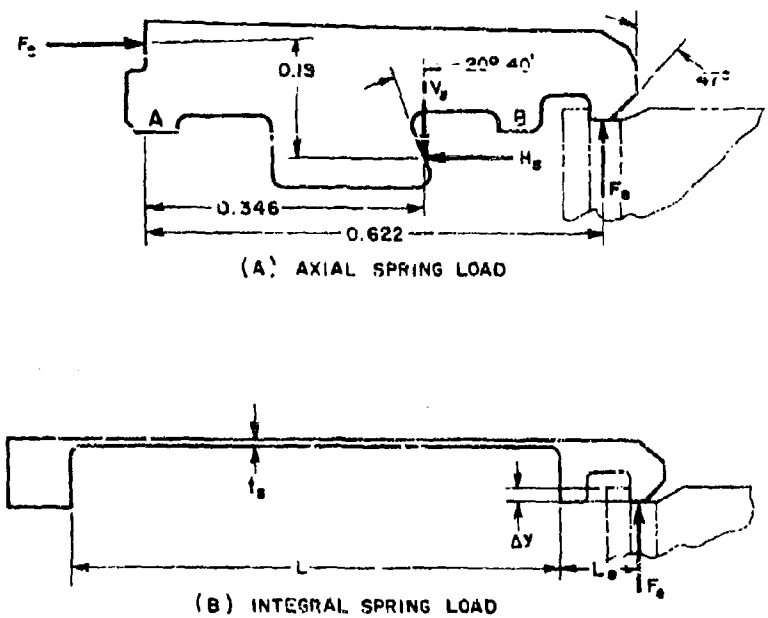


Figure 7–21. Extractor Loading Diagrams

of F_e, the maximum extractor load to clear the cartridge case, is found by balancing moments about A.

$$F_e = \frac{0.18F_s + 0.346V_s}{0.622} = \frac{2.70 + 1.96}{0.622} = 7.5 \text{ lb.}$$

If the outer slope of the lip is θ, the horizontal force on the extractor that will tilt it is

$$F_c = F_c \tan \theta$$

F_c represents the force that the new round must exert on the extractor for proper engagement during loading. In the present example $\theta = 47°$, therefore,

$$F_c = 7.5 \times 1.072 = 8.04 \text{ lb.}$$

The other extractors in Fig. 7–20 behave similarly except for (D), the integral flat spring type. Its initial force on the cartridge case base should be such that the spring is just free of contact with the bolt. The maximum outward force will be the force needed to snap the extractor far enough outward to clear the case rim.

The sample problem involves the extractor shown in Fig. 7–21 (B). Assume the maximum load to clear the case $F_e = 7.5$ lb, the same as in the earlier example, and the corresponding load when the case is seated, $F_{es} = 5$ lb. All design data are known except for spring thickness.

L = 1.8 in., spring length

L_e = 0.2 in., extractor length

E = 29×10^6 lb/in.^{2}, modulus of elasticity of steel

Δy = 0.032 in., outward displacement needed to clear rim

b = 0.4 in., spring width

The spring functions as a cantilever. Four components of deflection are involved, the linear and angular deflections, both due to shear and end moment. The total deflection is

$$y = y_e + y_m + L_e\theta_e + L_e\theta_m = \left(\frac{2.66F_e}{EI}\right)$$

where

$$y_s = \frac{F_e L^3}{3EI} = \frac{5.832F_e}{3EI}$$

$$= \frac{1.944F_e}{EI}, \text{ shear deflection}$$

$$y_m = \frac{L_e F_e L^2}{2EI} = \frac{0.2 \times 3.24F_e}{2EI}$$

$$= \frac{0.324F_e}{EI}, \text{ moment deflection}$$

$$\theta_e = \frac{F_e L^2}{2EI} = \frac{3.24F_e}{2EI}$$

$$= \frac{1.62F_e}{EI}, \text{ angular shear deflection}$$

$$\theta_m = \frac{M_e L}{EI} = \frac{0.2 \times 1.8F_e}{EI}$$

$$= \frac{0.36F_e}{EI}, \text{ angular moment deflection}$$

The differential deflection from F_{es} to F_e

$$\Delta y = y_1 - y_2 = \frac{2.66}{EI}(F_e - F_{es})$$

$$= \frac{2.66}{29 \times 10^6 I}(7.5 - 5.0) = 0.032 \text{ in}$$

$$I = 7.16 \times 10^{-6} \text{ in.}^4$$

But $I = \frac{1}{12}\left(bt_s^3\right)$, therefore

$t_s = 0.06$ in., required spring thickness

7–3.2 EJECTORS

Ejectors are simple mechanisms that force the cartridge case from the receiver. They usually are spring-operated but may derive their energy from other sources such as small quantities of the propellant gas. There are perhaps as many kinds of ejectors as there are of their immediate associates, the extractors. Ejectors may be assembled either in the bolt or they may be attached to the receiver. Fig. 7–22 shows four types of ejectors, three are housed in the bolt, one in the chamber; Fig. 7–22 (A) is like that in the 7.62 mm. M60 Machine Gun. The spring force, via the ejector, is always applied to the edge of the cartridge case base. As soon as all radial restraint is removed diametrically opposite, the ejector will flip out the case. The off-center spring force accelerates the case angularly as well as linearly. However, the recoiling velocity at the time will compensate to some degree the forward velocity derived from the spring.

7–3.2.1 Ejector Dynamics

Because of its mass relative to the masses of ejector and cartridge case, the spring must be considered in the dynamics of the ejection mechanism. One-third of the spring mass—when included in the expressions for energy, velocity, and time—will yield approximate but sufficiently accurate results. The equivalent mass of the whole unit is

$$M_e = \frac{1}{3}M_s + M_{ej} + \left(\frac{k^2 + \bar{r}^2}{\bar{r}^2}\right) M_{cc} \qquad (7\text{–}49)$$

where M_{cc} = mass of the case

M_{ej} = mass of the ejector

M_s = mass of the spring

k = radius of gyration of the case about its CG

$\bar{r}$ = distance from tipping point on rim to CG of case

The equivalent mass of the case involves its mass moment of inertia since it is rotating. Fig. 7–23 shows a diagram of the pertinent dimensions. The equivalent mass may now be used in the appropriate formulas to determine the dynamics, Eq. 2–27 for the time, and the conventional equations for energy and velocity.

7–3.2.2 Sample Problem of Ejector Dynamics

The sample problem illustrating the ejector dynamics involves a cal .30 cartridge case. The known data together with the diagram in Fig. 7–23 provide the needed information

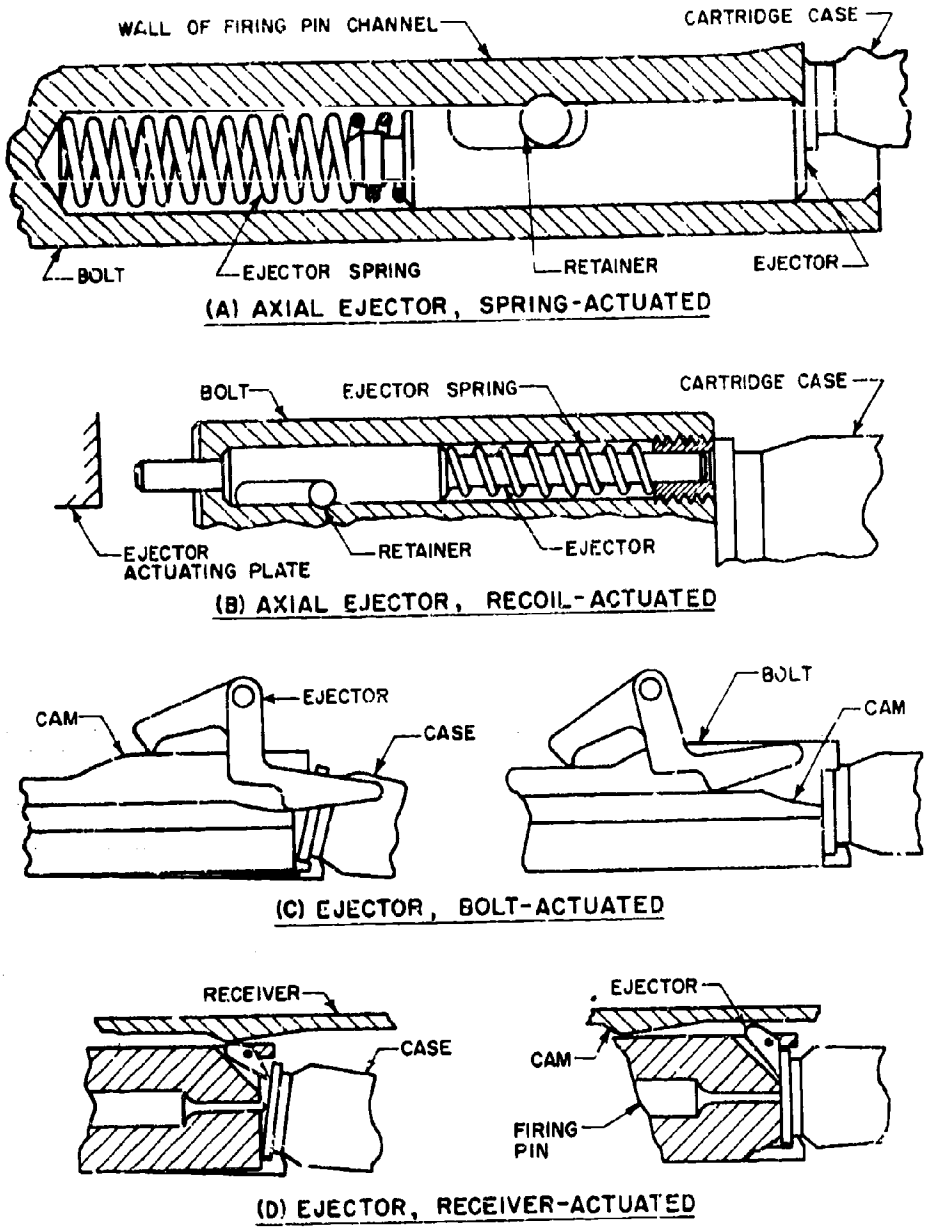


Figure 7-22. Ejectors

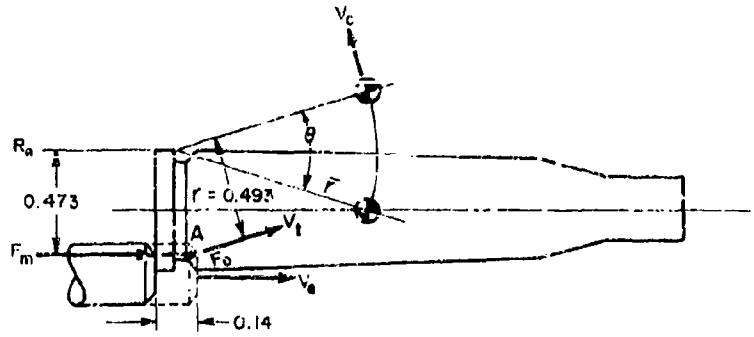


Figure 7–23. Ejector Loading Diagram

F_o = 14.5 lb, minimum spring force

F_m = 24.0, maximum spring force

k = 0.794 in, radius of gyration of case about its CG

K = 68 lb/in., spring constant

$\bar{r}$ = 1.1 in., distance from tipping point on rim to CG of case

W_{cc} = 0.0293 lb, weight of case

W_{ej} = 0.0492 lb, weight of ejector

W_s = 0.0039 lb, weight of spring

Δy = 0.14 in, spring deflection during ejector operation

From Eq. 7–49,

$$M_e = \frac{1}{g}\left(\frac{1}{3} W_s + W_{ej} + \frac{k^2 + \bar{r}^2}{\bar{r}^2} W_{cc}\right)$$

$$= \frac{1}{386.4}\left[0.0013 + 0.0492 + \left(\frac{0.63 + 1.21}{1.21}\right) 0.0293\right]$$

$$= 2.46 \times 10^{-4} \text{ lb-sec}^2/\text{in.}$$

To find the time of case ejection, apply Eq. 2–27 and then assume that the spring is 90% effective

$$t_e = \sqrt{\frac{M_e}{eK}} \text{ Cos}^{-1} \frac{F_o}{F_m} = \sqrt{\frac{2.46 \times 10^{-4}}{0.9 \times 68}} \text{ Cos}^{-1} \frac{14.5}{24}$$

$$= 2.005 \times 10^{-3} \text{ Cos}^{-1} 0.604 = 0.002005 \left(\frac{52.8}{57.3}\right)$$

$$= 0.00184 \text{ sec.}$$

The velocity of the ejector at this time is found from the expressions for kinetic energy and the work done by the spring by resorting to the appropriate portions of Eq. 2–24 and solving for the velocity.

$$v_e = \sqrt{\frac{e(F_o + F_m)\,\Delta y}{M_e}} = \sqrt{\frac{0.9 \times 38.5 \times 0.14}{2.46 \times 10^{-4}}}$$

$$= 140 \text{ in./sec}$$

During this time, with the extractor as the center of rotation, the case has traveled through the angle θ (Fig. 7–23). The last point of contact between base of case and ejector is shown at A. The tangential velocity at this point, since the case is still rotating, is the component of v_e that is perpendicular to the turning radius r.

$$v_t = v_e \cos\theta = 140 \times 0.959 = 134.3 \text{ in./sec}$$

where $\theta = \text{Tan}^{-1} \frac{0.14}{0.473} = \text{Tan}^{-1} 0.296 = 16°30'$.

The corresponding angular velocity is

$$\omega = \frac{v_t}{r} = \frac{134.3}{0.493} = 273 \text{ rad/sec.}$$

If the case comes free of the extractor at this instant, the tangential velocity v_c becomes the linear ejected velocity.

$$v_c = \omega r = 273 \times 1.1 = 300 \text{ in./sec}$$

This velocity is one of two components and is directed in a 16.5° angle forward. Chances are that the case will not become detached from the extractor simultaneously with the ejector, consequently the case path will be even less than 16.5°. Regardless of the extractor behavior, the other velocity component, recoil velocity at the time of release may have the influence to direct the ejected case rearward.

The other three ejectors depend on the velocity of recoil for their effectiveness. The ejector in Fig. 7–22 (B) becomes active near the end of the bolt recoil. Recoil velocity here is relatively slow, therefore, this type may not operate quickly enough for fast firing guns. The remaining two, Figs. 7–22 (C) and 7–22 (D), can be activated at any position along the recoil stroke. These two ejectors are cam-operated and the ejection speed is dependent on bolt recoil speed and cam angle. With the cam rise being as abrupt as can be tolerated, the maximum ejection speed becomes available immediately after the cartridge case clears the chamber where useful bolt recoil velocity is highest. But ejection may be delayed because those components assembled near the breech present structural difficulties that prohibit the size opening needed for the ejection port. Many other types of ejectors have been successful but almost all depend on recoil energy directly for ejection effort or indirectly by storing latent energy in springs to be released when appropriate for ejection. Some type machine guns are particularly adaptable to incorporate an ejection effort derived directly from the propellant gas. One such gun is the revolver-type whose case can remain in the chamber and then be blown out by the next round fired. The details of this type ejection appears elsewhere in the text with the discussion on the revolver-type machine gun.

7–3.3 BOLT LOCKS

The bolt is held tightly against the base of the cartridge case during firing. Lugs or some similar type of projection bear against a cammed surface on the receiver, thereby locking it in position to provide the resistance to the rearward thrust of the propellant gas pressure. Some locking devices need not be integral with the bolt. One such is the breech lock shown in Fig. 7–24. This type, used on the M2 Cal .50 Machine Gun, has a breech lock that rises and falls in response to the action of one of two cams. Four positions of bolt and lock are illustrated. In the locked position, just before the round is fired, driving and buffer springs hold the bolt and recoiling parts in battery, with the breech lock holding them together and maintaining this state during the first part of the recoil stroke. Thus, all recoiling parts move as a unit until the lock pin, serving as a cam follower, contacts the depressor. By this time the projectile has emerged from the muzzle and gas pressures have dropped to safe levels for case extraction. When the pin first contacts the cammed surface of the depressor, it has already cleared the locking cam to permit a free downward unlocking movement which is effected by the depressor as the recoiling parts continue rearward. As soon as the lock exits from the bolt recess (Fig. 7–24 (C)), the now unattached bolt is accelerated rearward while the rest of the recoiling parts are stopped by the buffer and held in the fully recoiled position until the returning bolt releases them to reverse the activity. Shortly before reaching battery, the lock pin rides upward on the locking cam and enters the bolt recess to repeat its locking function.

Fig. 4–3 represents a bolt having integral locking lugs near its breech face. Locking and unlocking actions involve bolt rotation which is controlled by a cam cut into the wall of the bolt. The M60 7.62 mm Machine Gun has this type locking device. Bolt activity obtains all needed energy from the gas operating cylinder; the cam actuator, or follower, serving as the rigid link between operating rod and bolt. The actuator, moving rearward, rotates the bolt to unlock it according to the dictates of the cam. When the bolt is unlocked, the actuator forces it open by continued rearward motion. Bolt opening, and therefore case extraction, is delayed until propellant gas pressure drops to a safe level. Delay is controlled by: the location of the gas port along the barrel; the time needed to fill the gas chamber of the operating cylinder; and the time consumed for unlocking the bolt.

Locking action occurs during counterrecoil of the bolt. The driving spring forces the operating rod forward carrying the cam actuator and bolt with it. The locking lugs, riding in guides, prevent rotation while the concave recess at the beginning of the cam surface offers a

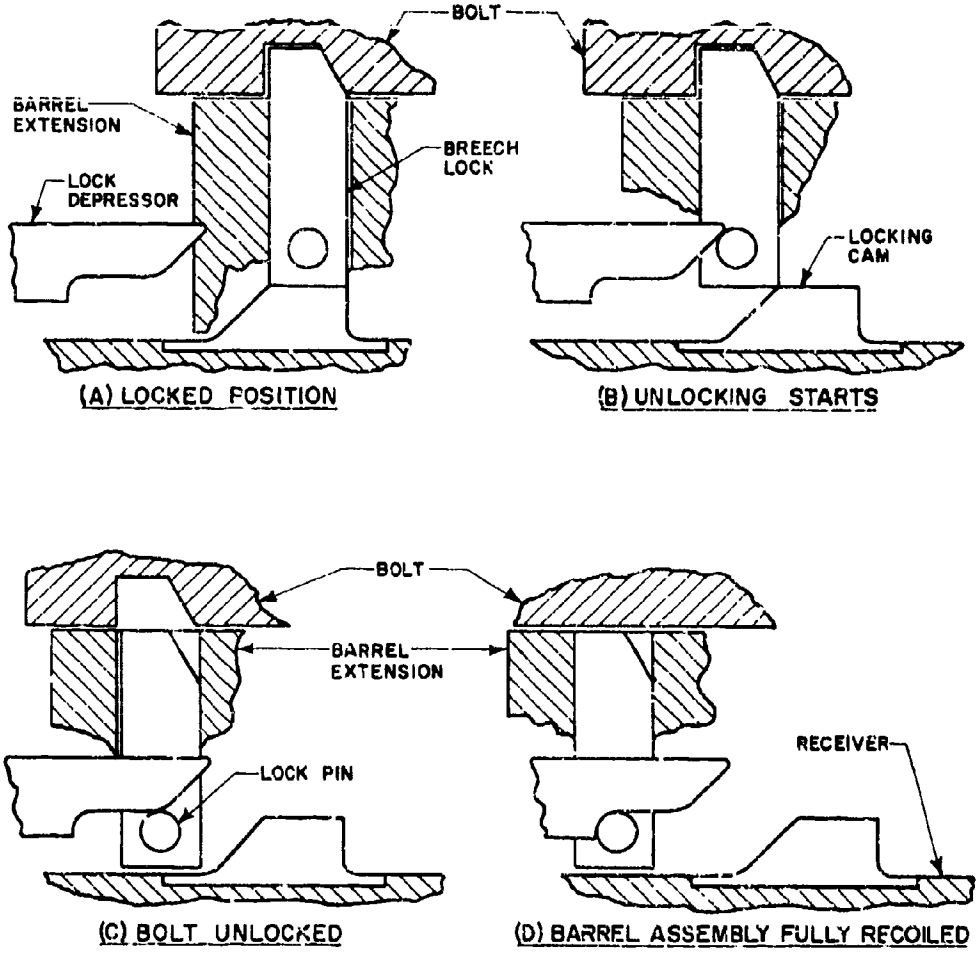


Figure 7–24. Sliding Breech Lock

convenient force transferring area. Somewhere along its return stroke, the bolt picks up a new round. Just as the cartridge case seats: the locking lugs leave the confines of the guides; angular restraint disappears; and the cam actuator, no longer restrained, leaves the recess to continue forward along the cam surface. Since the cam is forced to follow the path of the cam actuator, the bolt rotates into locked position to complete the cycle.

Several variations of the above lug type of bolt lock exist. Two such are the multiple lug lock and the interrupted thread lock. Both are adaptable to either gas- or recoil-operated machine guns. If recoil-operated, the receiver has a sleeve to perform the female function of the lock. As the gun recoils, a cam follower, integral with the sleeve, rotates it to free the lugs or interrupted threads on the bolt which then recoils by itself. The peripheral width of each lug or the length of each thread segment determines the angular distance through which the sleeve must turn to unlock the bolt. On gas-operated machine guns, the bolt is more apt to be the rotating element since the bolt, already actuated by the operating rod of the gas cylinder for linear motion, may just as readily be actuated by the rod for the angular motion of

unlocking. Actually, no set format applies to the unlocking method for any particular type gun. Design expediency usually controls the choice.

Another type of bolt lock that resorts to rotation, but in this case a tipping action, operates in the manner shown in Fig. 7–25. Rather than rotate in a vertical plane perpendicular to the bore axis, this one tips in a vertical plane along the bore axis. Locking and unlocking are readily accomplished by the action of the operating rod in a gas-operated gun. Locked in position when the round is fired, the bolt remains in this state until propellant gases in the operating cylinder force the rod and carrier rearward. This rearward action causes the unlocking link to rotate forward and pull the locking lug from its notch in the receiver.

7–4 FIRING MECHANISM

7–4.1 COMPONENTS, TYPES, AND ACTION

The firing mechanism is a linkage that releases the firing pin or its equivalent to initiate firing. It has several components including trigger, sear, hammer, firing pin, cocking device, locking device, and safety. Each may be a separate component or may be integral with another. For instance, the trigger may also provide the sear and cocking facility as in some revolvers or pistols. However, in machine guns, the sear is generally a separate link. It engages the sear notch on the hammer, firing pin, or bolt or some appendage attached rigidly to one of those components. Cocking devices are arrangements that arm the firing mechanism by retracting the pertinent components to the position where the sear engages the sear notch to be held until triggered. Loading devices are mostly spring installations that provide the impetus to the firing pin. Safeties are machine elements that lock trigger, sear, or hammer to preclude inadvertent firing. A safety which locks the sear or hammer is more positive than one which locks only the trigger and is to be preferred. Fig. 7–26, 7–27, and 7–28 shown three types of firing mechanism.

Fig. 7–26 shows a firing mechanism similar to that of the M2, Cal .50 Machine Gun. Three positions are represented: in battery, start of recoil, and fully recoiled positions. Except for a hammer, this example has all the components mentioned earlier. In battery, the spring-loaded sear holds the cocked firing pin by means of the sear notch at the end of the firing pin extension. Downward displacement of the sear releases the firing pin to be snapped toward the primer by the firing pin spring. Being somewhat remote from the sear, the trigger depresses it by lifting the tripper bar on one end thereby rotating the other end downward on the sear. The sear contacting surface of the trigger bar is cammed to minimize impact during counterrecoil when the sear end is held down for continuous firing.

Cocking the firing pin automatically is achieved by the cocking lever which rides in a stationary V-slot actuator. During recoil, the actuator flips the cocking lever forward thus rotating the lower end. The rotating lower end engages the firing pin extension and forces it rearward, meanwhile compressing the firing pin spring. In the fully recoiled position the cocking lever holds the sear beyond the sear notch to provide sufficient

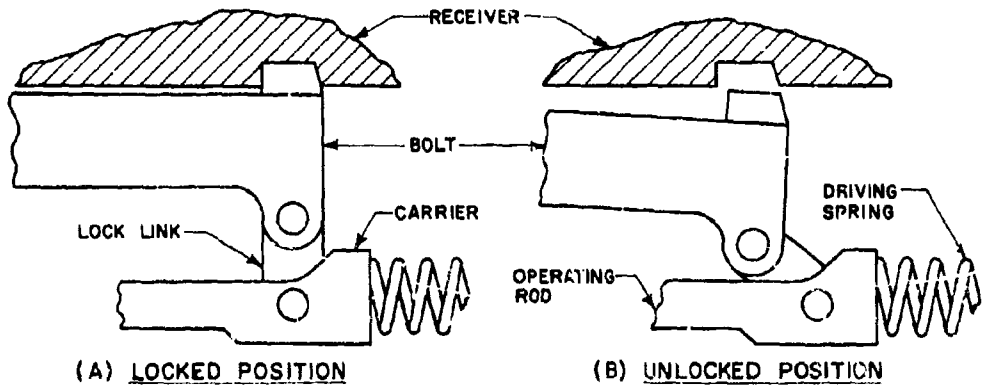


Figure 7–25. Tipping Bolt Lock

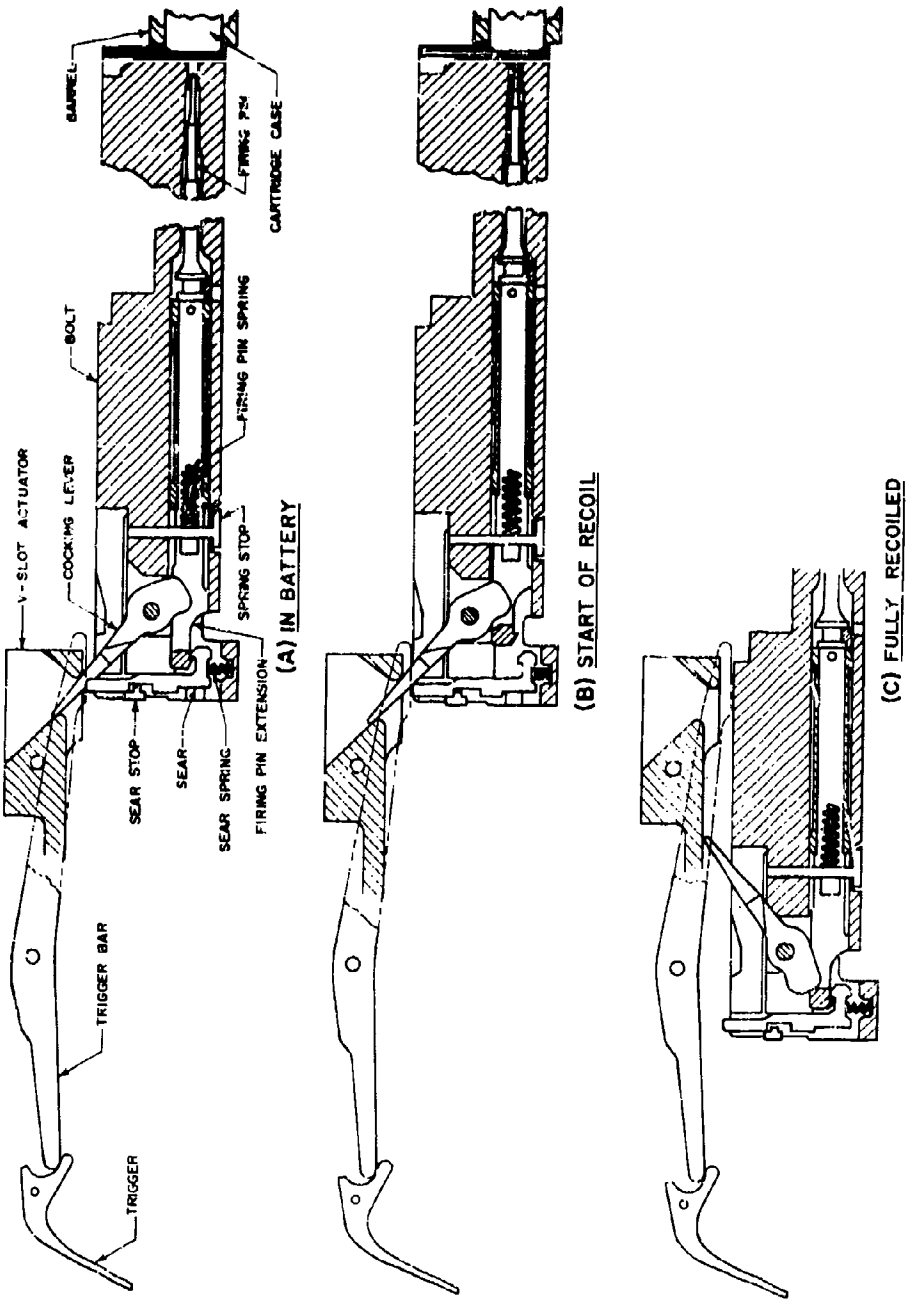


Figure 7–26. Firing Mechanism for Recoil Machine Gun

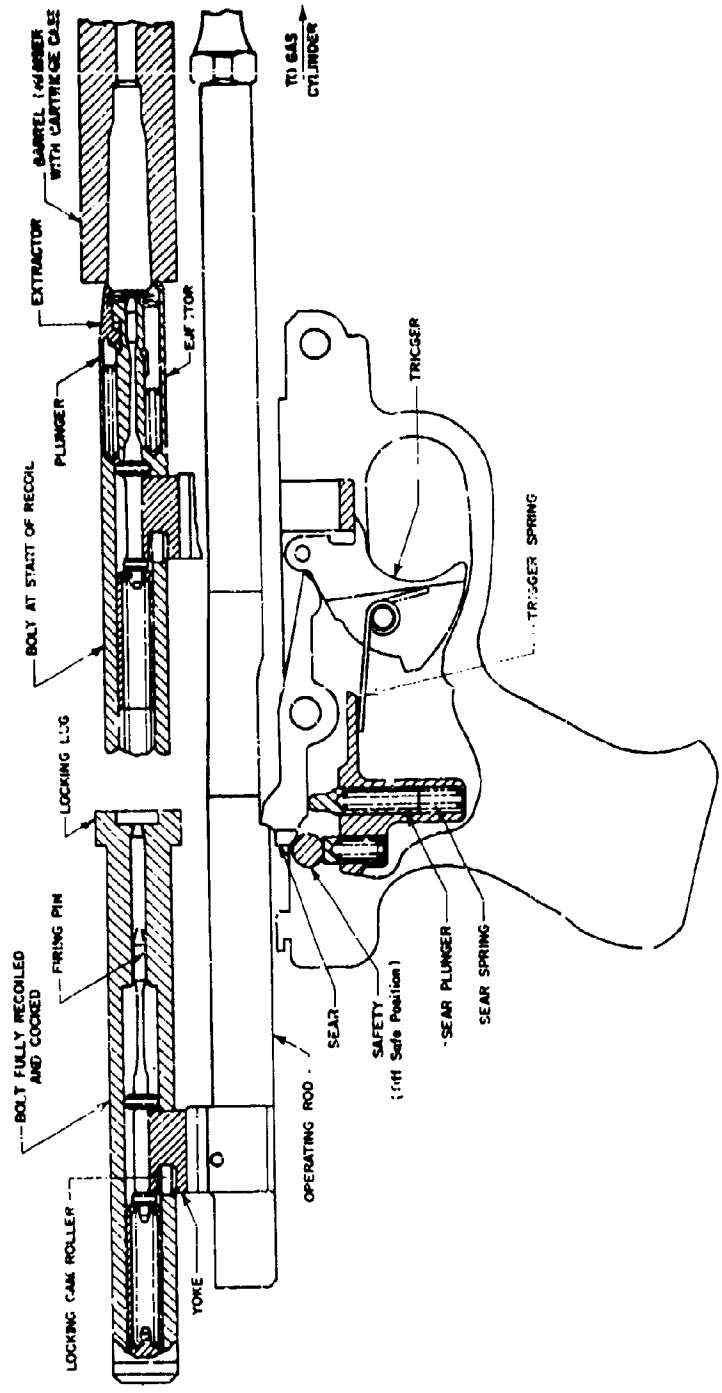


Figure 7–27. Firing Mechanism for Gas-operated Machine Gun

clearance and time for the sear to engage the notch properly thereby reducing the possibility of a prematurely released firing pin. A spring forces the sear upward into the latching position. As the bolt counterrecoils, the cocking lever continues to hold the firing pin in its most rearward position until the lever is rotated by the actuator to free the firing pin and permit it to slide forward a short distance to engage the sear notch. This action is completed when the recoiling parts are almost in battery and just short of the position where the sear passes beneath the trigger.

This firing mechanism is essentially one for automatic operation. Although adaptable to other types, this firing mechanism was designed for a recoil-operated gun, a type whose firing rate is largely determined by the inertial properties of the recoiling parts. Another limit on the firing rate is imposed by the sear spring. Since the spring force must be compatible with trigger pull, the spring may not have the capacity of lifting the sear into latching position before the cocking lever tends to release the firing pin if the bolt is moving too fast. In this event, the unrestrained firing pin will follow the cocking lever and lose the effectiveness of its spring, thus reducing the striking velocity on the primer. Should the firing pin velocity be lowered too much, the primer may not initiate, reducing the gun to inadvertent single shot operation. Planned single shot operation depends on the quick reflexes of the gunner to release the trigger before the sear hits the trigger bar during second round activity. However, positive single shot control is available by installing a bolt latch unit to the receiver. This unit latches to the recoiled bolt and retains it, thus interrupting the firing sequence until released manually. The interruption permits single shot firing.

Fig. 7–27 shows the type firing mechanism used in the M60, 7.62 mm Machine Gun. Two views of the bolt show the travel limits of it and the firing pin. Trigger and sear are shown only in the cocked position but their directions of motion and relative displacements when actuated are readily visualized in the sketch. The sear functions through the notch in the operating rod by holding rod, bolt, and all associated moving parts in the cocked position – the bolt being fully retracted except for the length of buffer travel. Here the sear engages the sear notch to stop all further counterrecoil progress. The sear pivots on a pin and is held in the cocked position by the trigger on one end and by sear plunger and safety on the other. All three are spring loaded. Trigger travel is limited on either end by a fixed limit stop. When the trigger is squeezed, it lifts its end of the sear and depresses the other end against (1) the resistance of sear and safety springs and (2) the frictional resistance induced by the driving spring between sear and sear notch. As the sear clears the sear notch, the driving spring forces the operating rod, bolt, and firing pin forward; closing the bolt and firing the round.

A yoke connects the operating rod to the bolt and firing pin. It is fastened rigidly to the operating rod but rides in a cammed slot in the wall of the bolt and cradles the firing pin. As the rod moves, the yoke carries the bolt in the same direction. This action is described in detail in par. 4–3.1.2. Relative linear motion between the yoke and bolt causes the firing pin to slide inside the bolt. Only linear travel of the firing pin is essential. Any angular motion between it and its adjacent components is inconsequential, contributing nothing to firing efforts. The firing pin rests in the saddle of the yoke, the two integral collars serving as force transmitters, guides, and retainers. As retainers, they prevent relative linear motion between yoke and pin. As a guide, the front collar helps center the firing pins. As force transmitters, the front collar serves during firing activity whereas the rear one serves during retraction as well as the transmitter of the firing pin spring force. The firing pin opening becomes useful after the locking lug engages the lock to provide the necessary external reaction. This arrangement augments the driving spring effort in maintaining a counterrecoil velocity and, subsequently, a firing pin velocity conducive to rapid bolt closing and primer initiation. Designed for automatic operation only, this mechanism continues to fire as long as the trigger is held depressed. When released, all elements return to the cocked position as the sear catches the operating rod during the early part of counterrecoil to stop further firing activity. Afterwards the firing mechanism may be put on safe by rotating the safety until its plunger is seated to establish a rigid link between sear and trigger housing. No matter what position the trigger now assumes, the rest of the firing mechanism is firmly locked to eliminate accidental firing.

Fig. 7–28 illustrates a method whereby firing control is achieved by a three-position lever: the first for automatic, the intermediate for semi-automatic, and the third for putting the gun on safety. The safety is a secondary lever integral with the selector lever. It bears against the sear, holding that component firmly in the slot. When in this position, any pull on the trigger will not disturb the bolt. In either firing position, the safety swings free of the sear and offers no further interference.

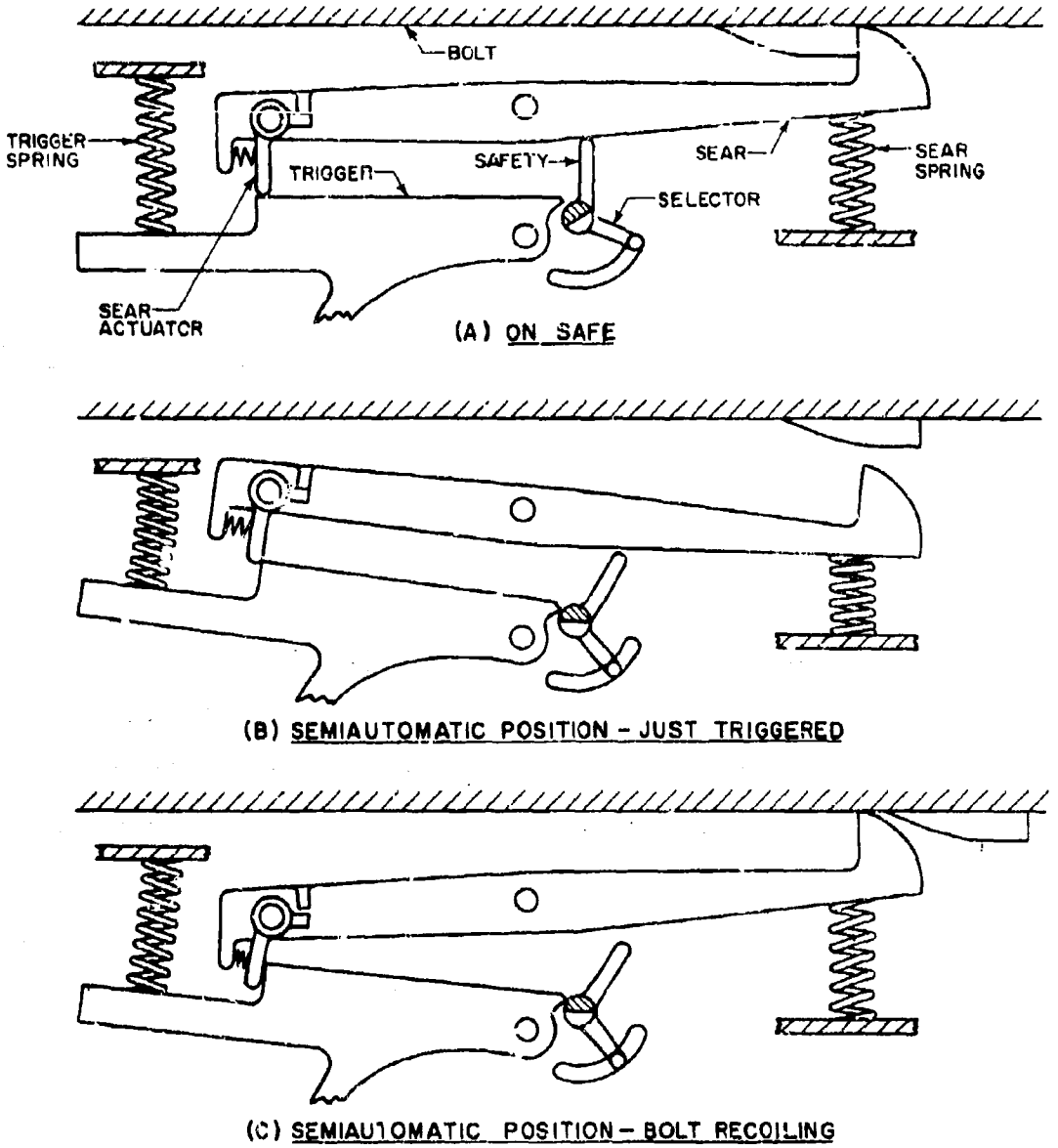
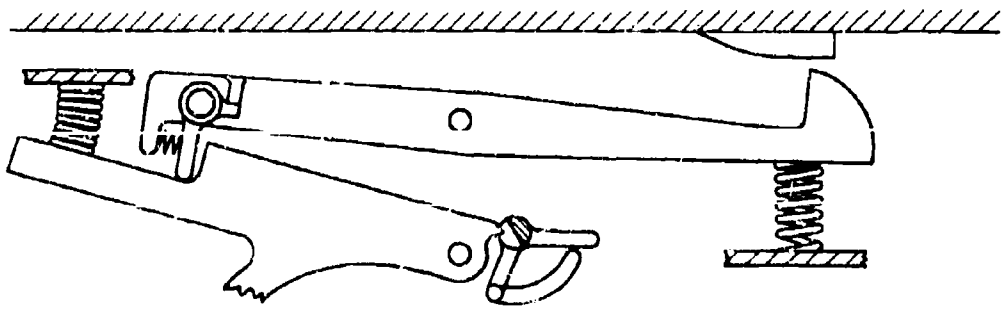


Figure 7–28. Three-position Firing Mechanism (1 of 2)



(D) AUTOMATIC POSITION - SEAR HELD DEPRESSED

Figure 7–28. Three-position Firing Mechanism (2 of 2)

With the selector in the semiautomatic position and as the trigger is being pressed, the selector pushes the actuator upward to rotate the sear and release the bolt. As trigger and sear rotate, the actuator moves rearward on the trigger and eventually slips off the stop to release the sear and permit it to resume its normal position and latch the bolt as it begins to close again—the depressed trigger meanwhile being limited in its movement by the selector. Before the next shot can be fired, the trigger must be released so that the sear actuator too can assume its original cocked position.

Automatic firing is achieved by turning the selector until the trigger can clear it entirely and sweep through the semiautomatic position. The advanced trigger position continues pressure on the sear actuator, thereby, holding the sear in its uncocked position leaving the bolt free to travel at will in either direction, continuing to fire until the trigger is released.

7–4.1.1 Trigger Pull

Computing the trigger pull is primarily an exercise in statics. Fig. 7–29 represents a typical triggering mechanism showing the applied loads on the various links. The trigger pull is found by balancing the moments about S, the pivot of the sear, and therefore, resolving the reaction between sear and trigger. This reaction – when applied to the trigger as a load – and the effects of the trigger spring, determine the trigger pull by balancing the moments about O, the pivot of the trigger. Balance moments about S.

$$1.28\,R_t = 0.84\,F_s + 1.30\,F_{sv} + 0.13\,F_{sh} + 0.46\,F + 1.02\,\mu F$$

$$= 13.4 + 26.0 + 2.6 + 12.0 + 2.7 = 56.7 \text{ lb-in}$$

where F = 26 lb, driving spring force

μF = 2.6 lb, frictional resistance at sear notch

F_s = 16 lb, sear spring force

F_{sv} = 20 lb, safety spring force

F_{sh} = 20 lb, horizontal component of safety spring force

P_t = trigger reaction on sear

μ = 0.10, coefficient of friction

The trigger reaction on the sear is

$$R_t = \frac{56.7}{1.28} = 44.3 \text{ lb}$$

Balance moments about O,

$$1.06\,P_t = 0.23\,R_t + T + 0.63\,F_t$$

$$= 10.0 + 1.0 + 0.6 = 11.6 \text{ lb-in.}$$

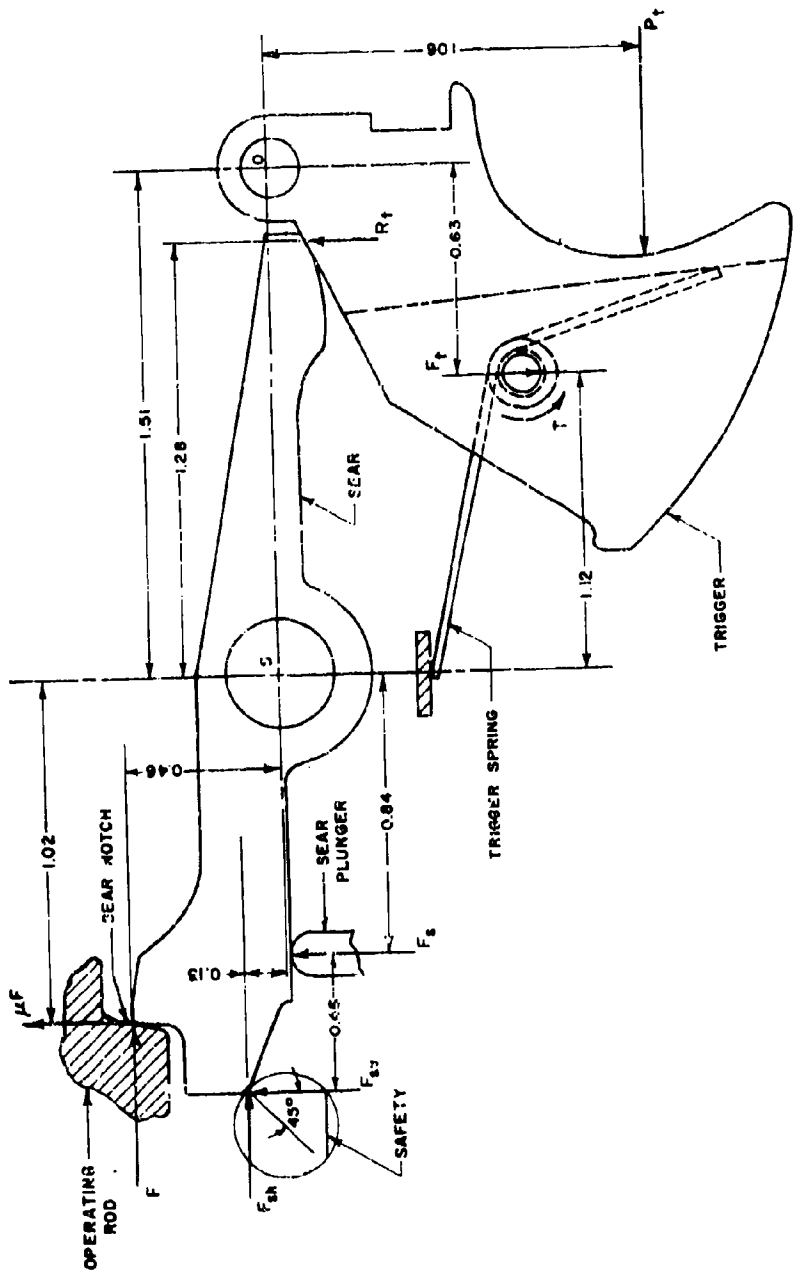


Figure 7–29. Triggering Mechanism Loading

where T = 1.0 lb-in, applied torque of trigger spring, and P_t is the trigger pull.

$$F_t = \frac{T}{1.12}$$

= 0.89 lb, vertical reaction of trigger spring pin

The trigger pull becomes

$$P_t = \frac{11.6}{1.0\epsilon} = 10.9 \text{ lb}$$

7–4.1.2 Firing Pin Design

Design criteria for firing pins are published elsewhere[22] but two basic requirements are essential for all percussion primers. A minimum amount of energy must be transmitted from firing pin to primer at a minimum striking velocity of 7 ft/sec. The energy is specified in inch-ounces. An upper limit of striking velocity also is specified to avoid puncturing the primer cap. Specifying both energy and velocity removes considerable control over the dynamics of a mechanism; control that normally should be available. For a given firing pin energy, the corresponding striking velocity is

$$v = \sqrt{\frac{2E}{M_e}} \qquad (7\text{–}50)$$

where

E = energy available

$M_e = \frac{W_e}{g}$ = equivalent mass of the moving parts

W_e = equivalent weight of the moving parts

A compressed coil spring provides the energy.

$$E = \frac{\epsilon (F_o + F_m)}{2} x \qquad (7\text{–}51)$$

where $F_m = F_o + Kx$, maximum spring force (in initial position)

F_o = minimum spring force (in final position)

K = spring constant

x = length of travel

ϵ = spring efficiency

The time elapsed during firing pin action according to Eq. 2–27

$$t = \sqrt{\frac{M_e}{\epsilon K}} \cos^{-1} \frac{F_o}{F_m} \qquad (7\text{–}52)$$

Because M_e is generally small and E relatively large, the striking velocity v will be large. If v exceeds safe limits, the energy should be reduced to its lower limit and the weight of the firing pin increased to proportions that are compatible with good design. Table 7–2 lists various combinations of design parameters and how they affect the velocity and time. The firing pin energy will be held constant at E = 60 in.-oz. The efficiency of the firing pin spring system is also a constant at ϵ = 0.80. By holding the equivalent weight constant and varying the spring characteristics to be compatible with the distance, the time interval increases with respect to distance but the terminal velocity remains constant. But when weight varies and distance is constant, the time increases while terminal velocity decreases. A review of the data in Table 7–2 indicates a wide latitude in spring selection exists for any given firing pin weight. The tabulated data also show that the striking velocity can be lowered only by increasing the firing pin weight. A word of caution should be introduced here. An increase in weight may not be helpful because the vibration of the firing pin mechanism may be out of phase with the mechanical action. Past experience has proved that correcting this type of disorder can be achieved only by reducing the weight of the firing pin; altering the spring characteristics was not effective.

7–5 LINKS

Early machine gun ammunition belts were made of cloth fabric but the susceptibility of cloth to adverse climatic conditions led to its replacement by the modern metallic link belts. The metal belts consist of many links joined in series by some type of mechanical fastener, such as a pin. Many belts use the rounds themselves as pins. In addition to being able to survive most climatic conditions, the metal links have other desirable characteristics, two of which are: (1) the strength needed to transmit the high accelerations imposed by the loading devices of rapid fire guns, and (2) the ability to extend belt lengths quickly by merely joining the last link of one to the first link of another belt.

TABLE 7–2. FIRING PIN DYNAMICS

W_e, oz	x, in.	K, lb/in.	F_o, lb	F_m, lb	t, sec	v, in./sec
0.5	0.50	13.5	6.00	12.75	0.00296	304
1.0	0.50	13.5	6.00	12.75	0.00418	215
1.5	0.50	13.5	6.00	12.75	0.00513	175
2.0	0.50	13.5	6.00	12.75	0.00592	152
0.5	0.75	8.0	3.25	9.25	0.00445	304
1.0	0.75	8.0	3.25	9.25	0.00629	215
1.5	0.75	8.0	3.25	9.25	0.00771	175
2.0	0.75	8.0	3.25	9.25	0.00890	152
0.5	1.00	3.5	2.94	6.44	0.00590	304
1.0	1.00	3.5	2.94	6.44	0.00834	215
1.5	1.00	3.5	2.94	6.44	0.01022	175
2.0	1.00	3.5	2.94	6.44	0.01180	152

7–5.1 TYPES OF LINK

There are three general types of link: the old or extracting type, and the new push through and side stripping types. The extracting type has its round gripped in the cannelure of the cartridge case base and then pulled rearward from the link. When completely withdrawn, the round is lowered into the bolt path and rammed, by the bolt, into the chamber. The push through type depends on a rammer or bolt to push the round directly through the link toward the chamber. The round in the side stripping type link is forced out by applying a force, usually by cam action, perpendicular to the axis of the round. After leaving the link, the round continues its sidewards path until in line with rammer or bolt.

7–5.2 DESIGN REQUIREMENTS

Fig. 7–30 shows a link that may fit any of the above three categories. It components consist of two retaining loops, a connecting loop, and a retaining arm. The retainer loops grip the cartridge case and hold it firmly with respect to any lateral motion between round and link. The retaining arm prevents longitudinal relative motion between round and link. The connecting loop fits loosely over the preceding round to preserve the continuation of the belt. For this link configuration, the rounds are analogous to pins in a chain. Clearances between connecting loop and cartridge case determine the amount of free flexibility in an ammunition belt. The attachment between the connecting loop and the retaining loops, if not rigid, also lend a degree of free flexibility to the belt. *Free flexibility* is the flexing of the belt so that it will assume a fan-like position or form a helix, made available by taking up the slack provided by the accumulated clearances in all the links. Its counterpart, *induced* or *forced flexibility*, may be either helical or fanning but the deflection is derived from the elastic deflection within the individual links. Allowable induced flexibility is determined experimentally; helical by measuring the torque necessary to twist the belt through a given angle, and fanning by fixing one end of the belt in a guided circle and hanging a weight on the other end. Either type of induced flexibility must always perform within the elastic range of the link material.

The ammunition belt may assume two positions for fanning flexibility, the nose fanning of Fig. 7–31 where touching is not permissible, and the base fanning of Fig. 7–32 where touching is permissible. Only free flexibility is represented since the ends of the belts are not constrained which is necessary to induce elastic deflection. Fig. 7–33 shows the geometry of two adjacent rounds in a base fanned belt. Free helical flexibility is shown in Fig. 7–34. Another type of belt configuration involves the fold radius. When the connector is a loop over the case (see Fig. 7–30), the linked round can rotate through a complete circle except for the interference of the adjacent round. Thus when a belt of ammunition in 7.62 mm M13 Links is housed in

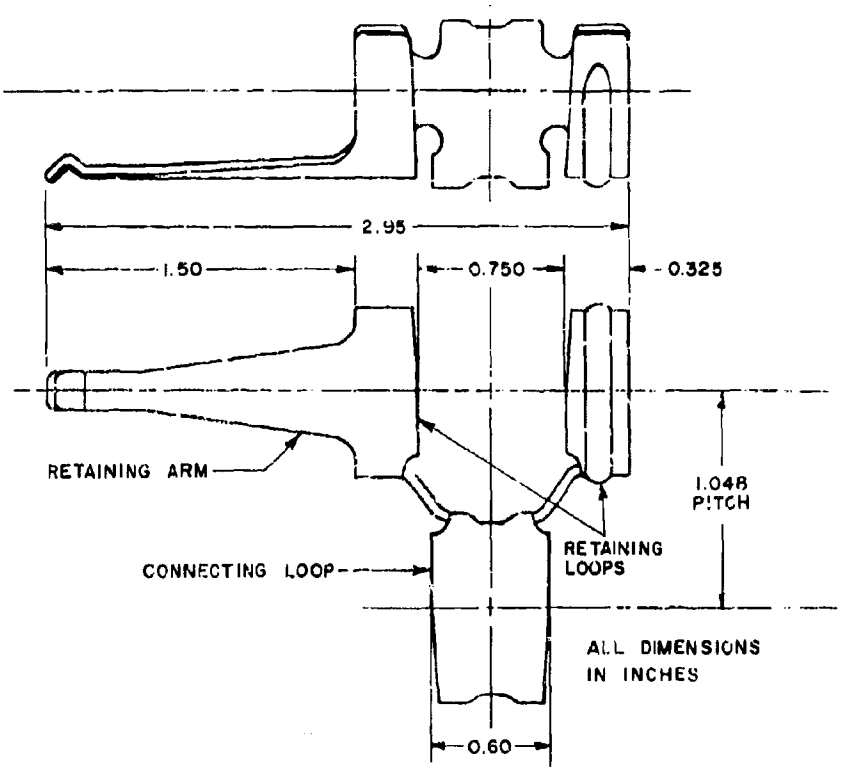


Figure 7–30 Ammunition Link, Cal .50 Round

a magazine or storage container (Fig. 7–35), little space is wasted since the belt can be stacked in horizontal rows. When the connector does not wrap around the case but instead merely joins the retaining loops of adjacent links, the rotation of one round about its neighbor is severely limited since the rotation center is near the case surface instead of being at the axis of the round. Ammunition belts made of links with this type connector will have some waste space when stored (see Fig 7–36 for 7.62 mm links). Another type connector, called a connecting member, operates similarly to a universal joint, i.e., it permits rotation between links about two perpendicular axes. All belts so equipped, have unlimited free flexibility.

Initial link design is based on past experience. Belt strength is the most important requirement, to be followed closely by retention capability. Forces imposed on the belt are determined by the type of feed system (drum, chute, magazine) and the feed accelerations. Deflections in the links and, therefore, in the belt are not necessarily objectionable provided that round retention is maintained. Any variation in pitch due to belt stretch is corrected by the holding pawl which insures constant pitch and, therefore, proper feeding. Later, the feeding pawl controls the round as it is extracted from the link.

Usage determines the configuration and type of link. If the belts are to be discarded after firing, *disintegrating* ones are used where the link drops from the belt immediately after the round is stripped from it, or is forced from the belt by the ejected cartridge case. If the belts are to be retained, then maintaining the empty belt as a unit may be desired. Open links may also be desired. They are good for carrying out the round but are relatively poor with respect to belt strength, and round retention can be a problem. For this reason, tolerances are small, to insure a reasonable consistency in retention loads. Should these loads prove to be too high, lightening holes (see Fig. 7–34) are made to provide more flexibility and less snap-in force when joining two belts. The *snap-in* technique is superior to and preferred over the older *push-through* technique. In contrast to

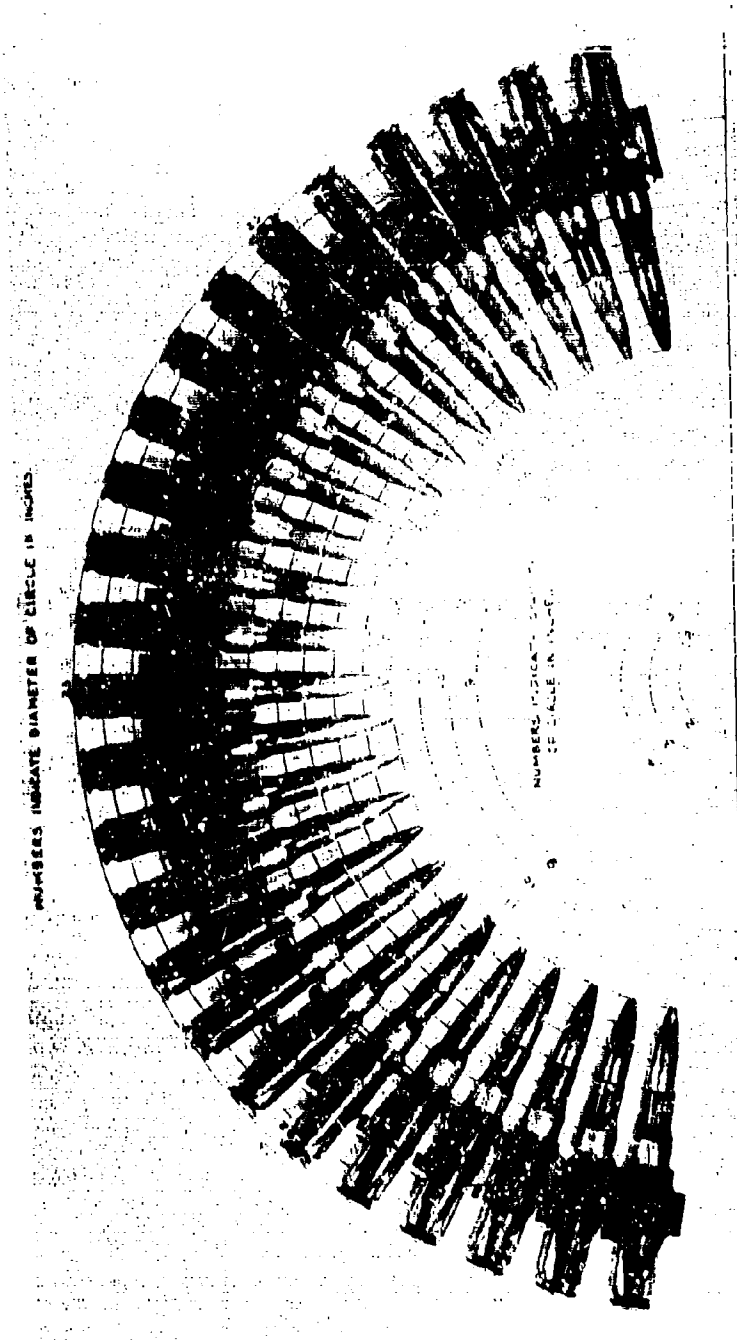


Figure 7–31. Nose Fanning Flexibility, 7.62 mm Link

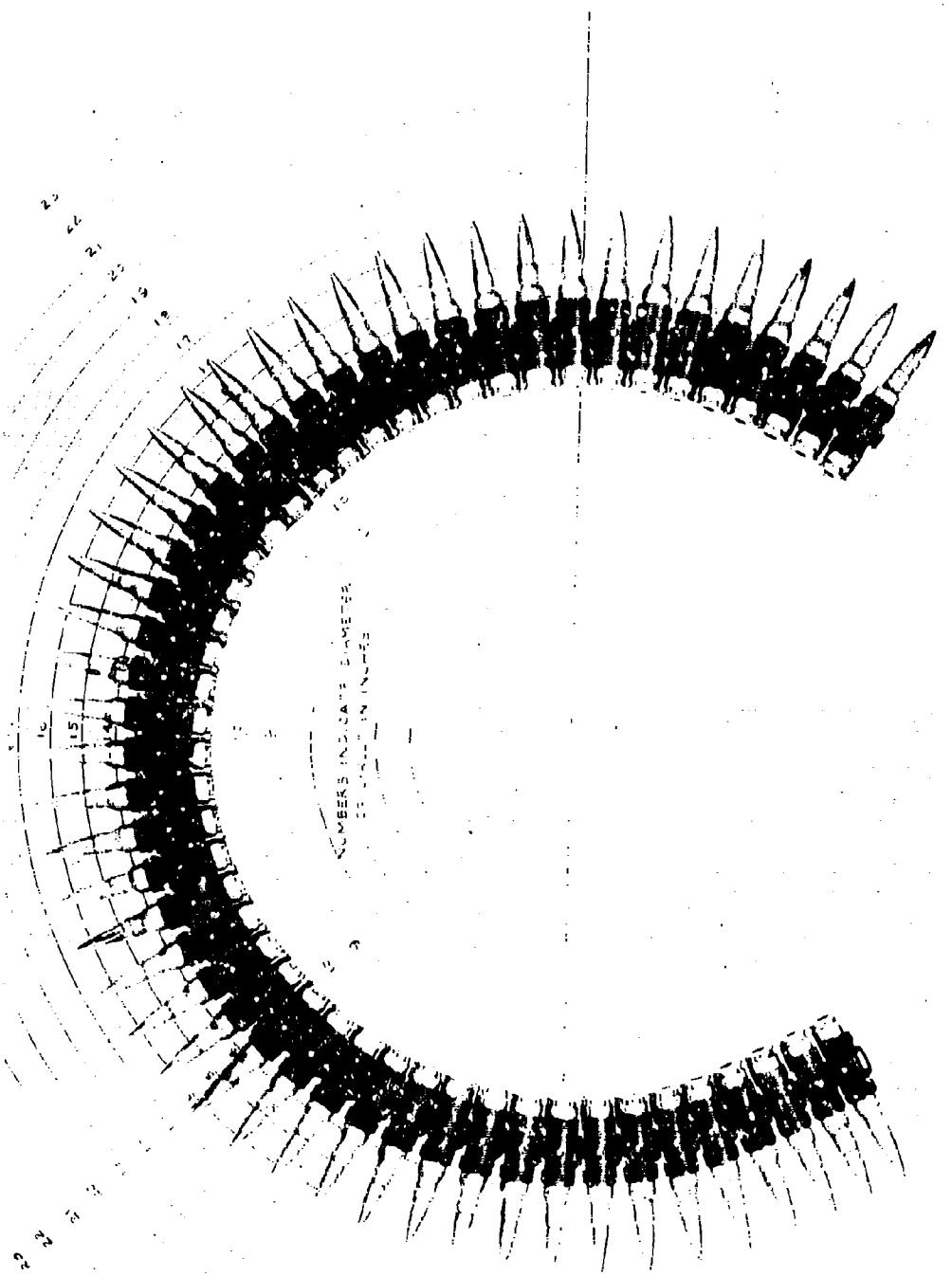


Figure 7–32. Base Fanning Flexibility, 7.62 mm Link

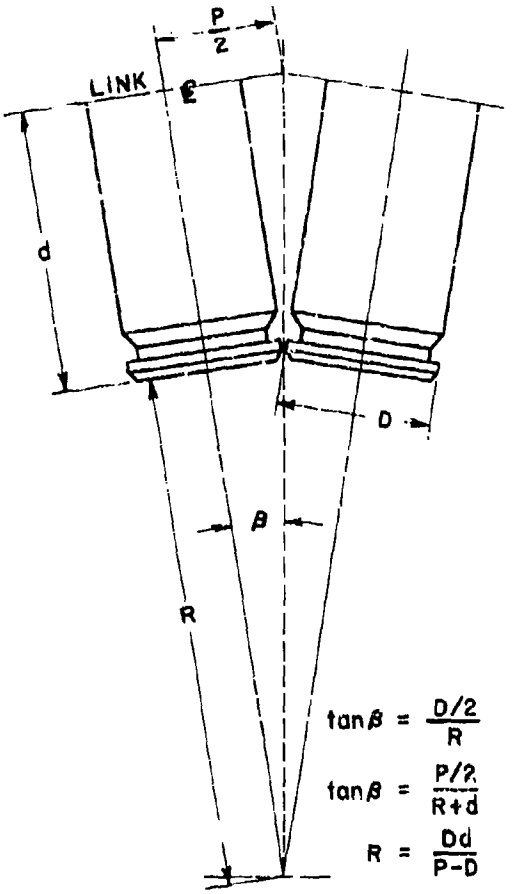


Figure 7–33. Geometry of Base Fanning

open links, closed loop links provide excellent belt strength and retentivity. Extracting the round may be a bit more troublesome than that experienced for the open loop but if a removable cover is used to complete the loop, an effective open loop link can be had by first stripping off the cover thus exposing the round to the extracting mechanism.

A unique means has been devised to protect electric primers from being initiated inadvertently. This hazard is usually associated with aircraft since radiation emanating from communication (radio), detection (radar), and fire direction (usually on shipboard) facilities are generally associated with air terminals. A compatible antenna, such as a screwdriver, with a different potential in the established radiation field, may induce a spark at the primer to initiate it. This hazard is primarily a ground handling one which is most prevalent during loading, connecting, or breaking ammunition belts. Effective protection is available through the use of a *RADHAZ* (radiation hazard) shown in Fig. 7–37. It is merely an extension of the link bent over the primer to form a cover. The primer is thus shielded from any metal rod that is brought near it.

After the initial design or subsequent modification, pilot lots are made to determine acceptability. The links are stamped out in the annealed state, then heat treated. Extreme care must be exercised to hold the small tolerances. The pilot lots are tested in accordance with operating requirements. One of these is the catenary test to check retention under shock loads. If a free span of belt exists in the installation, a similar length of belt is lifted at midspan to a prescribed height and released to approximate belt whip. If the link is found wanting from this or any of the other tests, the design is modified to strengthen the weak areas, and the manufacturing and testing procedures repeated until an acceptable link evolves. Because of its trial and error nature and because of demanding manufacturing technique long periods of time, in some cases more than a year, are devoted to designing and producing a successful link.

7–8 MOUNTS

Machine gun mounts are either fixed to vehicles or rest on the ground. Generally simple structures, mounts are adapted to the required limits of elevation and traverse and must be stable within these limits. Stability is readily achieved on vehicles by merely fastening the mount rigidly to the structure of the vehicle. But, if it rests on the ground, a mount such as the tripod type must depend on geometric proportions for stability. For this type, stability is a function of recoil force, command height, total weight, and length of the legs. If traverse is limited to the spread of the rear legs, the position of any given angle of elevation is that at zero traverse.

7–6.1 GEOMETRY AND RESOLUTION OF FORCES

Fig. 7–38 shows the forces involved in the side view projection. Take moments about A and solve for the reaction at B

$$R_b = \left[D_r (W + F_r \sin\theta) - HF_r \cos\theta \right] / L \qquad (7-53)$$

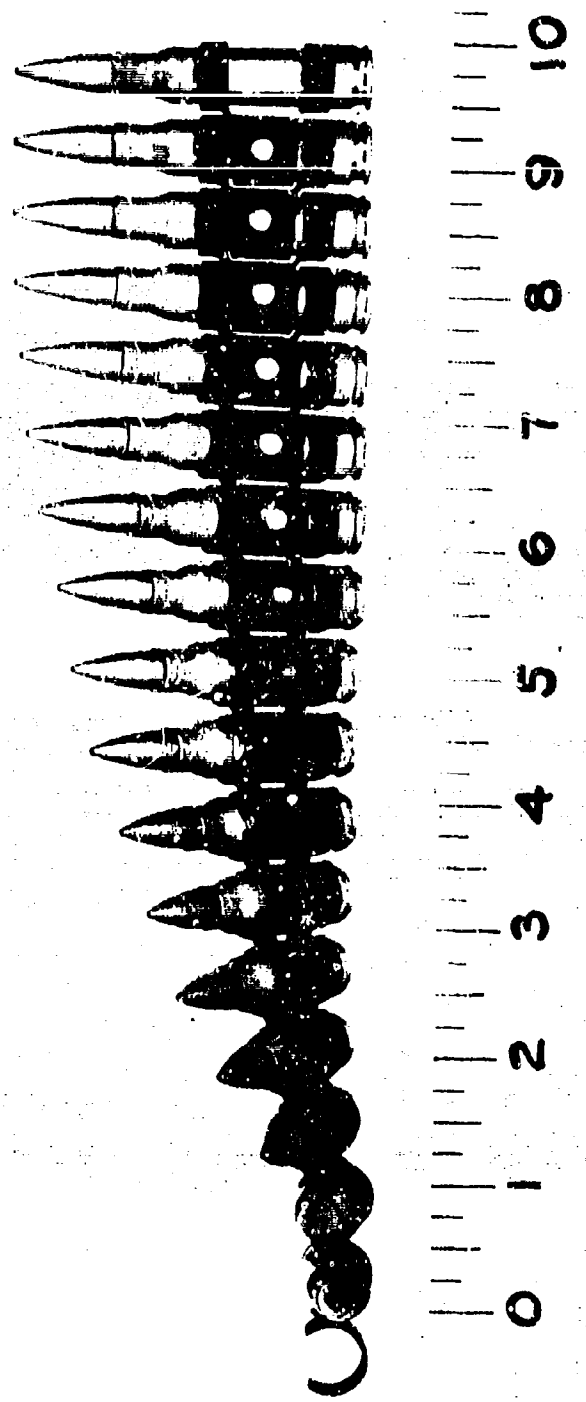


Figure 7–34. Helical Flexibility, 7.62 mm Link

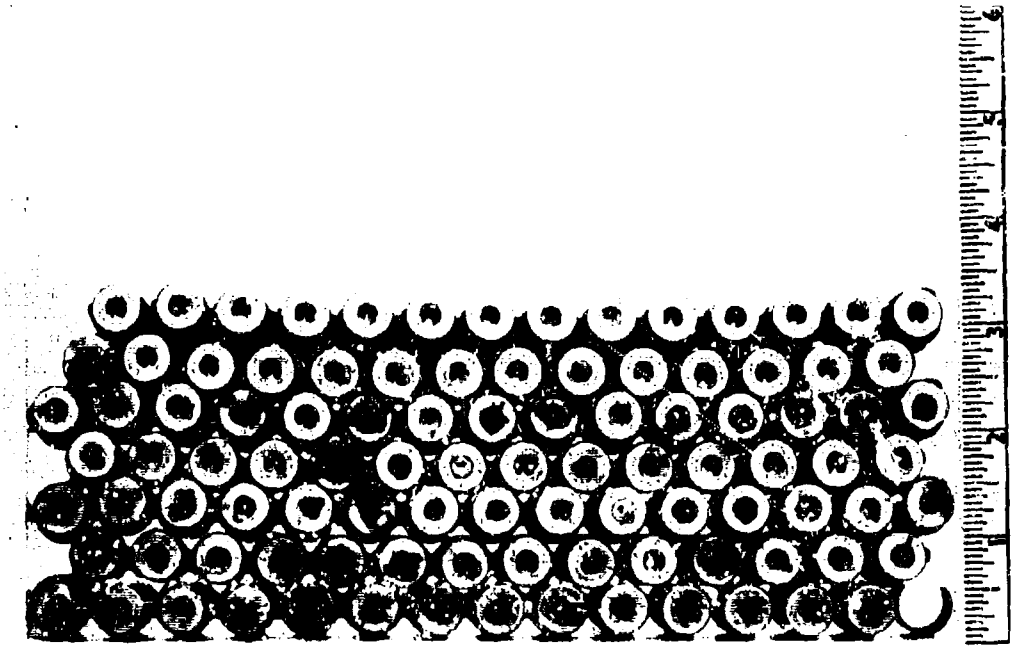


Figure 7–35. Total Folding 7.62 mm Ammunition Belt

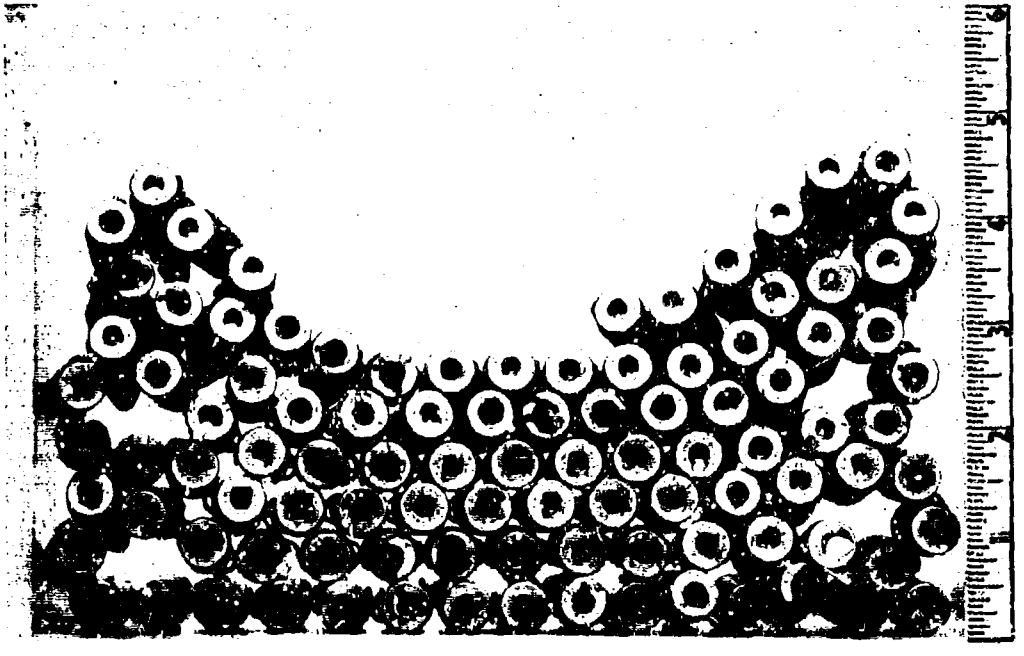


Figure 7–36. Partial Folding 7.62 mm Ammunition Belt

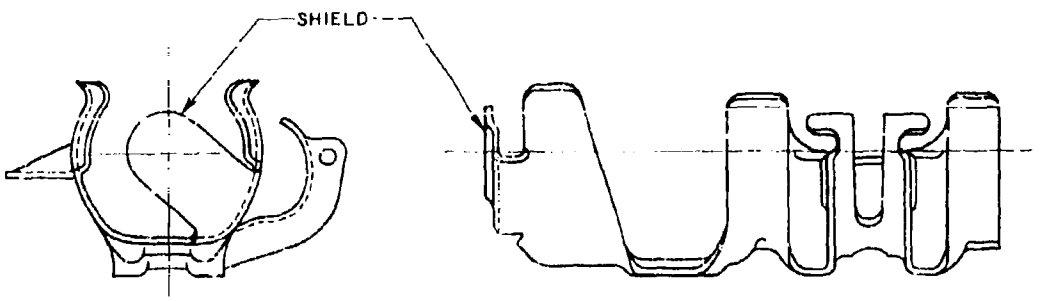


Figure 7–37. Loading Link With RADHAZ Shield

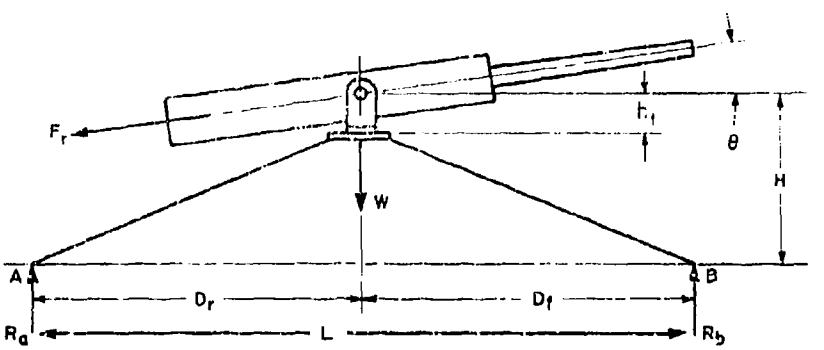


Figure 7–38. Loading Diagram of Mount

where D_r = horizontal distance between trunnion and rear support

F_r = recoil force

H = command height

L = distance between front and rear leg supports

R_a = reaction at rear support

R_b = reaction at front support

θ = angle of elevation

If R_a is positive or zero, the weapon is stable.

The recoil force F_r is assumed to be the average force during the recoil cycle. It may be computed by resolving the impulse-momentum characteristics of the recoiling parts. Add the expressions for the time recoil t_r and counterrecoil t_{cr} of Eqs. 2–23 and 2–27 for the total time of one cycle t_c period of oscillation.

$$t_c = \frac{\epsilon + 1}{\sqrt{\epsilon}} \sqrt{\frac{M_r}{K}} \cos^{-1} \frac{F_o}{F_m} \qquad (7\text{–}54)$$

where F_m = spring force at end of recoil

F = spring force at beginning of recoil

K = spring constant

M_r = mass of recoiling parts

ϵ = efficiency of spring

The impulse on the recoiling parts induced by the propellant charge may be obtained by measuring the area under the propellant gas force-time curve or by computing the velocity of free recoil and then the momentum of the recoiling parts which is equal numerically to the impulse. The momentum of recoil

$$M_n = \left(\frac{W_r}{g}\right) v_f = (W_p v_m + 4700\, W_g)/g \qquad \text{(Ref. 23)} \tag{7-55}$$

where g = acceleration due to gravity

v_f = velocity of free recoil

v_m = muzzle velocity of projectile

W_g = weight of propellant charge

W_p = weight of projectile

W_r = weight of recoiling parts

4700 = empirical value of the propellant gas velocity in ft/sec, therefore, the other kinematic parameters must be dimensioned in ft and sec.

Since impulse is numerically equal to momentum, Eq. 2-14, the average recoil force is

$$F_r = \frac{\int F dt}{t_c} = \frac{M_n}{t_c} \tag{7-56}$$

The length of the rear legs extending from the spade to the intersection of leg and pintle is computed by first equating the weight and force moments about A at zero elevation.

$$D_r W = H F_r \tag{7-57}$$

The projected horizontal distance between spade and trunnion is

$$D_r = \frac{H F_r}{W} \tag{7-58}$$

The rear leg length becomes

$$L_r = \sqrt{D_r^2 + (H - h_t)^2}/\cos\phi \tag{7-59}$$

where h_t = distance between trunnion and pintle leg intersection

ϕ = half of the angular spread between the rear legs.

Half of the average force during the recoil cycle is assumed to be the applied forward acting force just as the cycle is completed. The distance needed to balance this forward upsetting moment with the weight moment is

$$D_f = \frac{H F_r}{2W} = \frac{1}{2} D_r \ . \tag{7-60}$$

The length of the front leg is

$$L_f = \sqrt{D_f^2 + (H - h_t)^2} \ . \tag{7-61}$$

The structural requirements of the legs, size, strength, and rigidity are satisfied through the usual procedure for computing stresses and deflections of an eccentrically loaded column of uniform cross section[24]. If the leg varies in cross section, the area moment of inertia of the cross section is a function of the distance, and the bending moment is a function of the distance and of the deflection. Unless some simplifying assumptions are made, the alternative rigorous analysis is performed most conveniently with a digital computer.

7-6.2 SAMPLE PROBLEM

Compute the recoil spring characteristics and lengths of the legs of a tripod mount for a gun having the following data:

H = 14 in., command height

h_t = 5 in., height of trunnion above pintle

K = 2000 lb/in., spring constant (ring spring)

L = 0.5 in., length of recoil

v_m = 3000 ft/sec, muzzle velocity

W = 225 lb, estimated weight of weapon

W_g = 0.09 lb, weight of propellant charge

W_p = 0.2 lb, weight of projectile

W_r = 110 lb, weight of recoiling parts

ϵ = 0.50, efficiency of ring spring

θ = 0°, angle of elevation

2ϕ = 50°, spread of rear legs

From Eq. 7–55, the velocity of free recoil is

$$v_f = \frac{0.2 \times 3000 + 4700 \times 0.09}{110} = 9.3 \text{ ft/sec.}$$

The energy to absorbed during recoil is

$$E_r = \frac{1}{2}\left(M_r v_f^2\right) = \left(\frac{110}{64.4}\right) 86.49 = 147.73 \text{ ft-lb.}$$

The total average recoil force is

$$F_r = \frac{E_r}{L} = \frac{147.73 \times 12}{0.5} = 3546 \text{ lb.}$$

Since the efficiency of the spring, $\epsilon = 0.50$, assists in stopping the recoiling parts, the actual average spring force is

$$F_{as} = \epsilon F_r = 1773 \text{ lb.}$$

But

$$F_{as} = \frac{1}{2}(F_o + F_m) = \frac{1}{2}(F_o + F_o + KL)$$

$$= F_o + \frac{1}{2} KL$$

$$F_o = F_{as} - \frac{1}{2} KL = 1773 - \frac{1}{2}\left(2000\right) 0.5$$

$$= 1273 \text{ lb.}$$

$$F_m = F_o + KL = 1273 + 1000 = 2273 \text{ lb}$$

According to Eq. 7–54

$$t_c = \frac{e+1}{\sqrt{e}} \sqrt{\frac{M_r}{K}} \text{ Cos}^{-1} \frac{F_o}{F_m}$$

$$= \frac{1.5}{0.707} \sqrt{\frac{110}{2000 \times 386.4}} \text{ Cos}^{-1} 0.56005$$

$$= 2.122 \times 0.0119 \times 0.976 = 0.0246 \text{ sec.}$$

The average impulsive force during the recoil cycle, Eq. 7–56, is

$$F_r = \frac{M_n}{t_c} = \frac{110 \times 9.3}{32.2 \times 0.0246} = \frac{1023}{0.792} = 1292 \text{ lb.}$$

The projected horizontal distance of the rear leg, Eq. 7–58, is

$$D_r = \frac{HF_r}{W} = \frac{14 \times 1292}{225} = 80.4 \text{ in.}$$

The length of this rear leg, Eq. 7–59, is

$$L_r = \sqrt{D_r^2 + (H - h_f)^2}/\cos\phi = \sqrt{\frac{6545.16}{0.906}} = 89.3 \text{ in.}$$

The length of the front leg, Eqs. 7–60 and 7–61, is

$$L_f = \sqrt{D_f^2 + (H - h_f)^2} = \sqrt{1697.04} = 41.2 \text{ in.}$$

CHAPTER 8

LUBRICATION OF MACHINE GUNS

Conventional, good lubrication design practice is required in machine gun design. Excess, rather than insufficient, lubricant is to be avoided on most sliding parts. If the coat of oil or grease is too thick, dust will readily collect, cause excessive wear, and impede action sometimes to the extent of malfunction. Maintenance instructions stress this fact by emphasizing that all excess lubricant be wiped off all surfaces. Not all self-operating machine guns require reservoirs of lubrication. In some cases, the recoil adapter spring or the driving spring may be lubricated with a graphite grease. In electric or hydraulic-driven machine guns, the driving units are lubricated by applying grease or oil to the moving parts which are usually protected from exposure to dirt by their housings.

A well-designed machine gun is inherently a readily lubricated one, particularly if only a thin coating of lubricant is needed on the sliding part. The lubricant is usually applied after cleaning, which procedure follows after prolonged firing or during periodic inspection and maintenance. Because of this practice, emphasis is generally placed on the lubricant rather than on specific design practices that are controlled by lubrication requirements.

8–1 GENERAL CONCEPT

The machine gun designer must be cognizant of the lubrication requirements for the sliding surfaces of his design. His primary objective is smooth surfaces coupled with his acquaintance with available lubricants, and their general properties and uses. If lubricant properties and required lubricating properties are compatible, the designer's problem is solved. If a proper lubricant is not available, a search for one must be made or the weapon relegated to limited specific conditions, which normally is undesirable. Another alternative involves auxiliary equipment such as heaters to keep the viscosity level of the lubricant in an acceptable range.

The lubrication of machine guns is usually confined to applying a thin film of oil, grease, or other material to sliding surfaces with the expectation that it will last until the next general cleaning time. Military Specifications define in detail the properties of available lubricants. Substitutes are acceptable only after extensive tests prove that the new product has all the necessary properties. The Specifications enumerate all known data from preparation to delivery and storage. A general outline is prepared for illustration.

1. SCOPE. Type of lubricant, general usage, and operating temperature range.

2. APPLICABLE DOCUMENTS

   2.1 A list of Federal and Military Specifications supplementing the given specifications.

   2.2 Standards prepared by accepted private organizations.

3. REQUIREMENTS

   3.1 Qualification. The material must have passed qualifying tests.

   3.2 Material. The ingredients of the material must conform to specification.

   3.3 Physical and chemical requirements. Some of these are listed as flash point, pour point, viscosity at temperature limits, hydroelectric stability, oxidation stability, storage stability, rust prevention, gun performance, workmanship (homogeneous, clear, and with no visibly suspended matter).

4. QUALITY ASSURANCE PROVISIONS

   4.1 Specified inspection procedure.

   4.2 Specified tests.

8–2 EXAMPLES OF LUBRICANTS

Unless a smoother finish is required, an RMS (rough machine surface) of 16 to 32 μin. will provide proper sliding action when covered with a thin layer of lubricant. However, under extremely adverse conditions, the designer may be helpless to cope with the sliding surface preparation. A number of activities associated with machine gun fire at high altitudes demonstrates the difficulties experienced in attempts to eliminate malfunctions. These activities deal with lubricant rather than design.

During World War II, high-flying airplanes had gun malfunction at temperatures below −20°F. This led to gun heaters, but the added weight and not complete reliability led to attempts to develop new lubricants that would correct the malfunctioning components[17]. The investigation yielded success in three operations. Low temperature exposure at high altitude followed by condensation at warmer levels and again freezing after returning to high altitudes caused the triggering solenoid to become frozen in place. A free-moving solenoid was assured by spraying the unit with silicone oil to prevent the water condensate from collecting. The material is an open chain methyl silicone having a viscosity of 20 cSt at 77°F and 300 cSt at −65°F, and a pour point of −75°F. Dodecane phosphoric acid (0.1 percent by weight) was added for lubrication. This material was labeled NRL S-75-G interim. In the meantime, special attention to ammunition feeders led to "trouble-free lifetime lubrication" with the application of MIL-G-15793 (BuOrd) grease. Also, synthetic oil MIL-L-17353 (BuOrd) with 2 percent by weight of trecresyl phosphate for wear prevention was discovered to perform adequately for other moving parts of the gun.

In contrast, tests conducted with the Cal .50 M3 Machine Gun, to prove the reliability of removing gun heaters, when lubricated with PD 500 oil gave totally negative results[18]. Remember that this oil made feasible the removal of heaters from the 20 mm M24A1 Gun without the gun malfunctioning at low temperatures. Apparently some inherent feature in each type of gun rendered acceptance and rejection in the particular weapon. Unfortunately, the tests were not sufficiently broad in scope to determine what design features were responsible.

A semi-fluid grease and an oil blend were developed with satisfactory performance at extreme temperatures for the M61 Multibarreled Gun[19]. Test results indicate that either lubricant satisfied all requirements, but the semi-fluid grease had longer life and was therefore selected as the lubricant for the M61 Gun.

Dry lubricants are recommended for slowly moving parts with relatively few cycles of operation. Tests of 18 resin systems pigmented with molybdenum disulfide were tested[20]. A pigment-to-resin ratio of 9:1 was found most effective. Epoxy-phenolic and epoxy-polyamide resin systems were best for both lubrication and storage stability.

8-3 CASE LUBRICANT

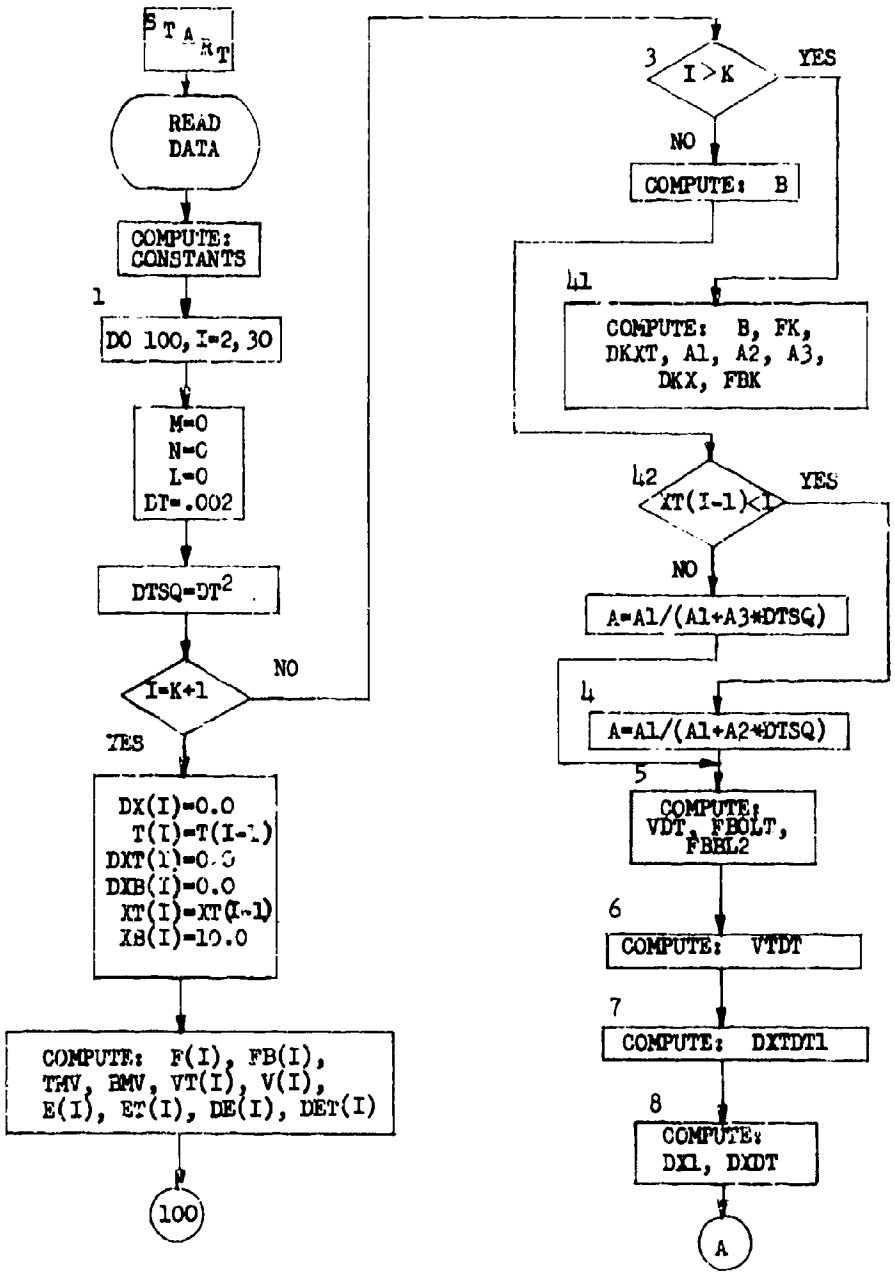
Although the gun designer is not directly involved with ammunition design, he is directly concerned with handling, loading, and extracting during firing. A smooth chamber is essential for extraction and a properly lubricated case is a decided asset. The lubricant should be a dry lubricant and should be applied at the factory. Considerable effort has been made to find suitable lubricants for this purpose. Some success has been achieved but continued search is still being advised, especially since two independent facilities are not in total agreement.

The Naval Research Laboratories conducted tests of brass and steel cartridge cases coated with films of polytetrafluoroethylene (Teflon)[28]. Results were outstanding in meeting required protection and lubrication properties. Laboratory results, later confirmed by firing tests, showed low friction and consequently less wear in gun barrels. Other desirable features include freedom from cartridge malfunction, no chamber deposits, decreased ice adhesion, and less chance of thermal "cook-off". Teflon can be applied to steel and brass ammunition by mass production methods. Its protective ability permits prebelting and packaging of ammunition since no further handling prior to use is necessary. Its supply is abundant and its cost reasonable. Thus the use of Teflon in this capacity seems ideal.

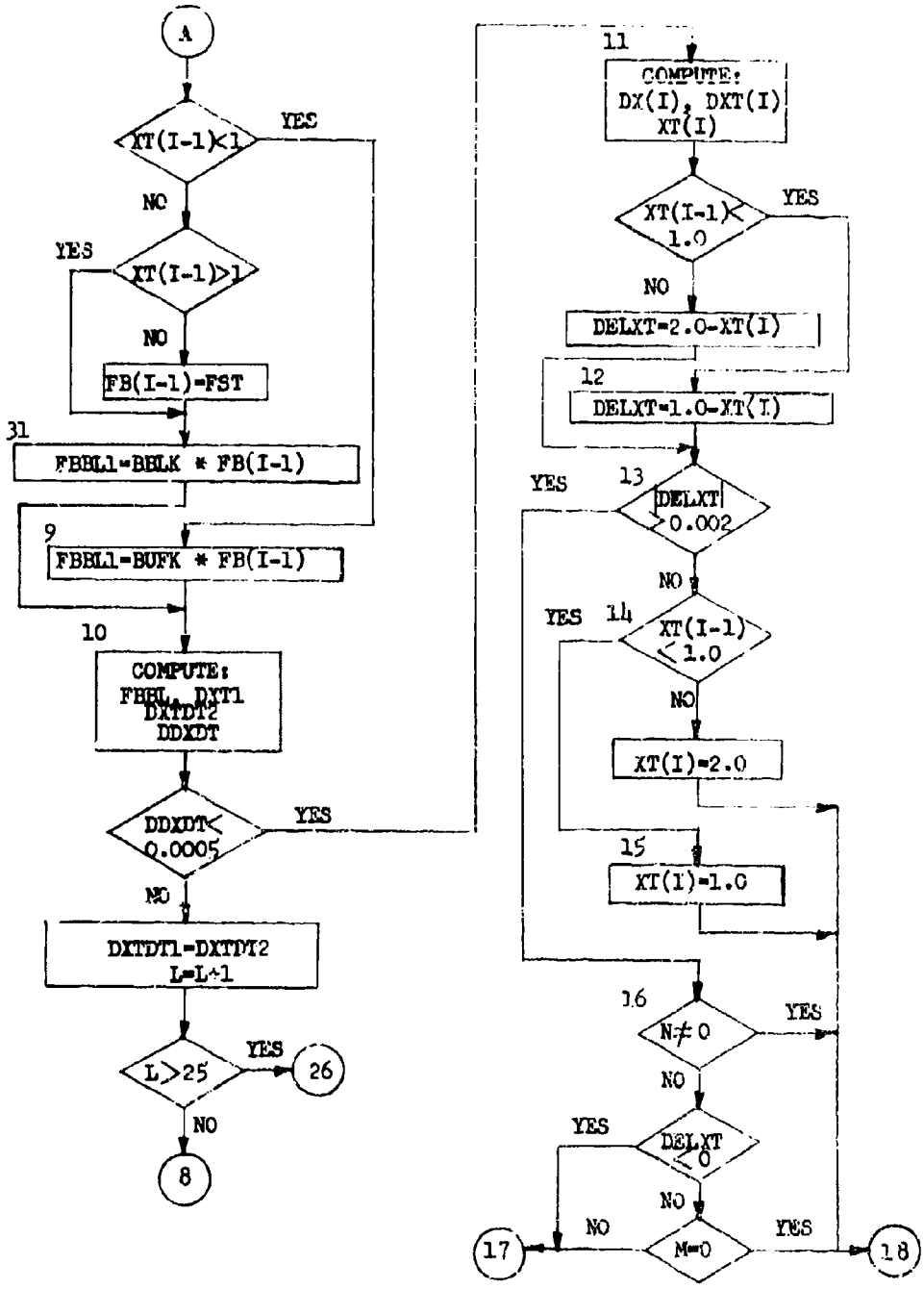
Aberdeen Proving Ground is more reserved in its appraisal of Teflon coating[21]. Whether or not the techniques of applying the coatings were similar, those used at APG were not free of coating defects; a high cull rate existed. When tested with cartridges coated with microcrystalline wax, ceresin wax, and uncoated ammunition; the Teflon-coated wax showed many advantages but was also found wanting in some respects. Teflon and micro-wax had better extraction properties and Teflon left a much cleaner chamber than the others; micro-wax was second best. About 50 percent of the Teflon-coated cases had slight bulges after extraction; other types also were similarly damaged but with no apparent significance attached to a definite choice. For dusted ammunition, the Teflon and micro-wax were far superior to the other two types with Teflon having a slight advantage, although when fired in a comparatively rough chamber, Teflon was outperformed by all. Reiterating, the gun designer, aside from providing smooth sliding surfaces, is almost totally dependent on the physical properties of the lubricant to make his gun perform satisfactorily under all assigned conditions.

APPENDIX A

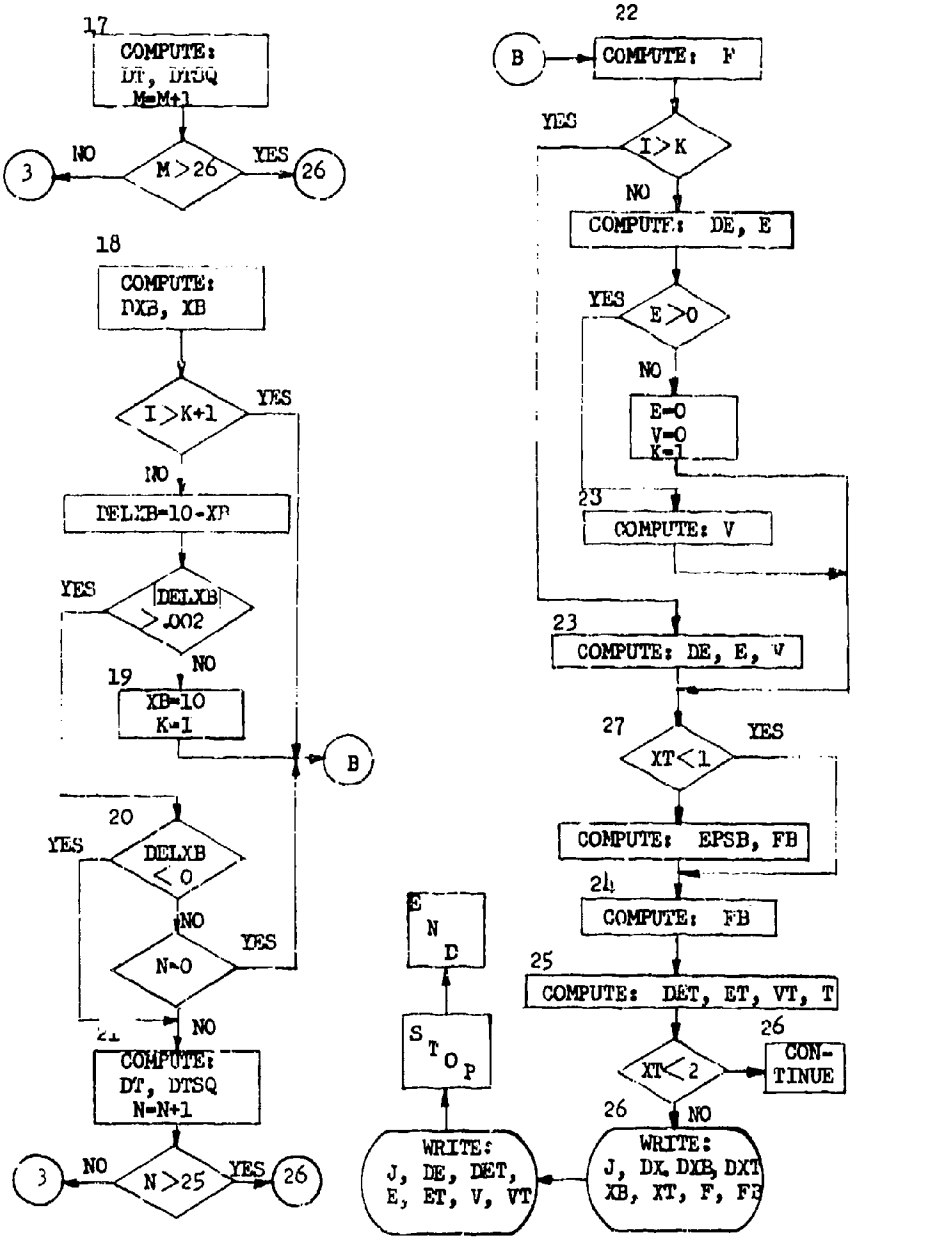
A-1. FLOW CHART FOR DELAYED BLOWBACK



A–1. (Con't.)


A
XT(I-1)<1
YES
NO
XT(I-1)>1
YES
NO
FB(I-1)=FST
31
FBBLl=BBLK * FB(I-1)
9
FBBLl=BUFK * FB(I-1)
10
COMPUTE:
FBBL, DXT1
DXTDT2
DDXDT
DDXDT<
0.0005
YES
NO
DXTDT1=DXTDT2
L=L+1
L>25
YES
26
NO
8
11
COMPUTE:
DX(I), DXT(I)
XT(I)
XT(I-1)<
1.0
YES
NO
DELXT=2.0-XT(I)
12
DELXT=1.0-XT(I)
YES
13
DELXT
>0.002
NO
YES
14
XT(I-1)
<1.0
NO
XT(I)=2.0
15
XT(I)=1.0
16
N≠0
YES
NO
YES
DELXT
<0
NO
NO
M=0
YES
17
18

A-1. (Cont'd)


17
COMPUTE: DT, DTSQ M=M+1
NO
M>26
YES
3
26
18
COMPUTE: DXB, XB
I>K+1
YES
NO
DELXB=10-XB
YES
|DELXB| >.002
NO
19
XB=10 K=1
B
20
YES
DELXB <0
NO
N=0
YES
NO
COMPUTE: DT, DTSQ N=N+1
3
NO
N>25
YES
26
22
B
COMPUTE: F
YES
I>K
NO
COMPUTE: DE, E
YES
E>0
NO
E=0 V=0 K=1
23
COMPUTE: V
23
COMPUTE: DE, E, V
27
XT<1
YES
COMPUTE: EPSB, FB
24
COMPUTE: FB
25
COMPUTE: DET, ET, VT, T
26
XT<2
CON-TINUE
26
NO
WRITE: J, DX, DXB, DXT XB, XT, F, FB
WRITE: J, DE, DET, E, ET, V, VT
STOP
END

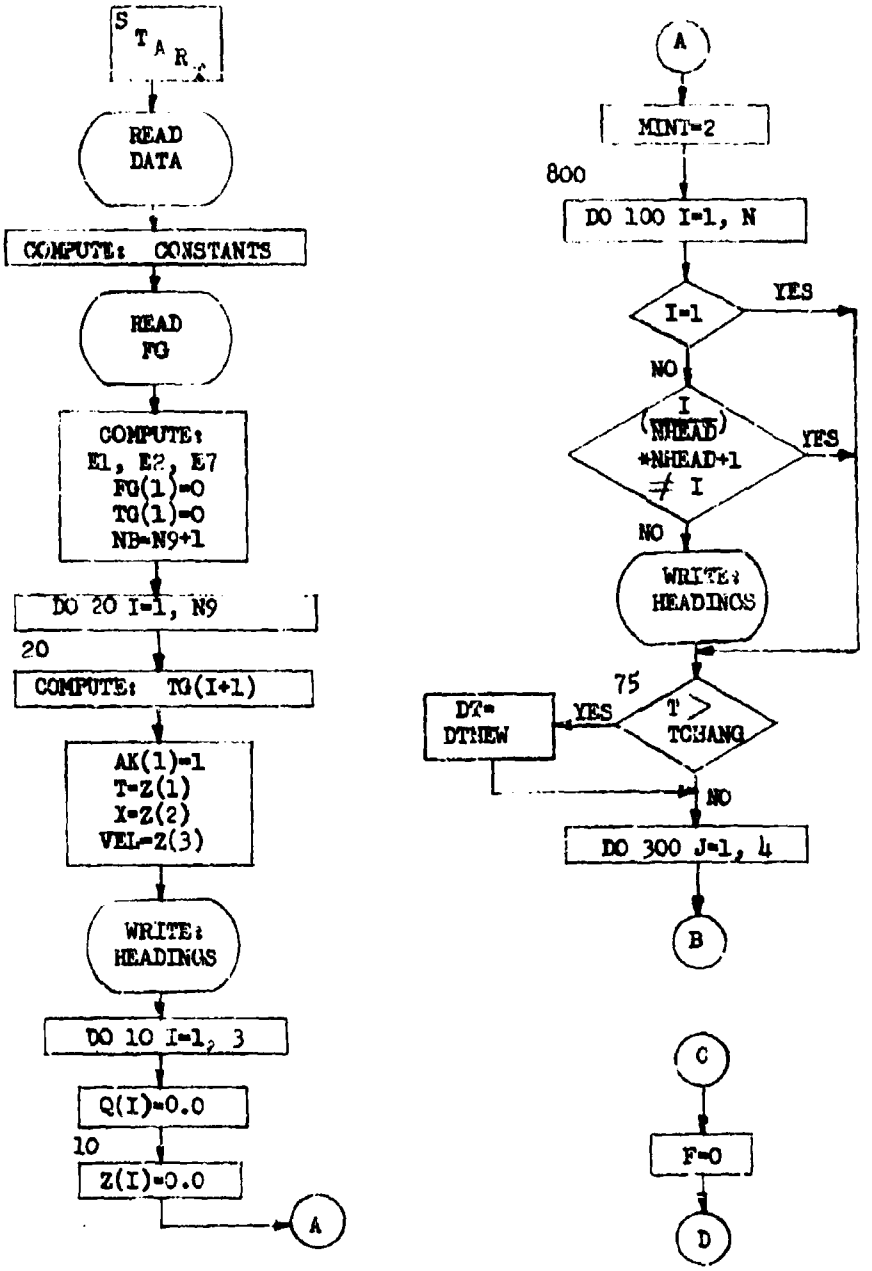
A–2. LISTING FOR DELAYED BLOWBACK PROGRAM

```
00100     1.      DIMENSION  T(30), DXT(30), DXB(30), DXT(30), XB(30), XT(30), V(30),
00101     2.     1 FB(30), DE(30), DET(30), E(30), ET(30), V(30), VT(30)
00102     3.      READ(5,101) EPS,EPSB,EPST,A1,A2,A3,B1,B2,FK,DKXT,BUFK,
00103     4.     1 BBLK, DKX, FUK, SK, SK3, SKT, WB, WBBL, F0, FST, F(1),FB(1),
00104     5.     2 V(1),VT(1),XB(1),XT(1),T(1),DX(1),DXB(1),DXT(1) DE(1),
00105     6.     3 DET(1),E(1),ET(1),A4,A5,A6,FKCR,DKXTCR,DKXCR,B3,B4
00106     7.   101 FORMAT(7F10.0)
00161     8.      G = 386.4
00162     9.      K = 100
00163    10.      EMB = WB/G
00164    11.      EMT=WBBL/G
00165    12.     1 DO 100 I=2,30
00170    13.      M=0
00171    14.      N=0
00172    15.      L = 0
00173    16.      DT=0.002
00174    17.     2 DTSQ=DT**2
00175    18.      IF(I.NE.K+1)GO TO 3
00177    19.      DX(I)=0.0
00200    20.      T(I)=T(I-1)
00201    21.      DXT(I)=0.0
00202    22.      DXB(I)=0.0
00203    23.      XT(I)=XT(I-1)
00204    24.      XB(I)=10.000
00205    25.      F(I)=F0+10.0*SK
00206    26.      FB(I)=FB(I-1)
00207    27.      TMV=EMT*VT(I-1)
00210    28.      BMV=EMB*V(I-1)
00211    29.      VT(I)=(TMV+BMV)/(EMT+EMB)
00212    30.      V(I)=-VT(I)
00213    31.      E(I)=0.5*EMB*V(I)**2
00214    32.      ET(I)=0.5*EMT*VT(I)**2
00215    33.      DE(I)=E(I)
00216    34.      DET(I)=ET(I-1)-ET(I)
00217    35.      GO TO 100
00220    36.     3 IF(I.GT.K)GO TO 41
00222    37.      B=B1/(B1+B2*DTSQ)
00223    38.      GO TO 42
00224    39.    41 B=B3/(B3-B4*DTSQ)
00225    40.      FK= FKCR
00226    41.      DKXT=-DKXTCR
00227    42.      A1=A4
00230    43.      A2=A5
00231    44.      A3=A6
00232    45.      DKX=-DKXCR
00233    46.      FBK=BULK
00234    47.    42 IF(XT(I-1).LT.1.0)GO TO 4
00236    48.      A=A1/(A1+A3*DTSQ)
00237    49.      GO TO 5
00240    50.     4 A=A3/(A1+A2*DTSQ)
00241    51.     5 VDT=V(I-1)*DT
00242    52.      FBBLT=FK*F(I-1)*DTSQ
00243    53.      FBBL2=FBK*F(I-1)
00244    54.     6 VTDT=VT(I-1)*DT
00245    55.     7 DXTDT1=DKXT*VTDT*DTSQ
00246    56.     8 DX1=B*(VDT-FBBLT+DXTDT1)
00247    57.      DXDT=DKX*DX1*DTSQ
00250    58.      IF(XT(I-1).LT.1.0)GO TO 9
00252    59.      IF(XT(I-1).GT.1.0)GO TO 31
00254    60.      FB(I-1)=FS1
00255    61.     9 FBBL1=BBLK*FB(I-1)
00256    62.      GO TO 10
00257    63.     9 FBBL1=BUFK*FB(I-1)
00260    64.    10 FBBL=(FBBL1-FBBL2)*DTSQ
00261    65.      DXT1=A*(VTDT+FBBL-DXDT)
00262    66.      DXTDT2=DKXT*DXT1*DTSQ
00263    67.      DDXDT=ABS(ABS(DXTDT2)-ABS(DXTDT1))
00264    68.      IF(DDXDT.L.T.0.0005)GO TO 11
00266    69.      DXTDT1=DXTDT2
00267    70.      L = L+1
00270    71.      IF(L.GT.25)GO TO 26
00272    72.      GO TO 8
00273    73.    11 DX(I)=DX1
00274    74.      DXT(I)=DXT1
00275    75.      XT(I)=XT(I-1)+DXT(I)
00276    76.      IF(XT(I-1).LT.1.0)GO TO 12
00300    77.      DELXT=2.0-XT(I)
00301    78.      GO TO 13
```

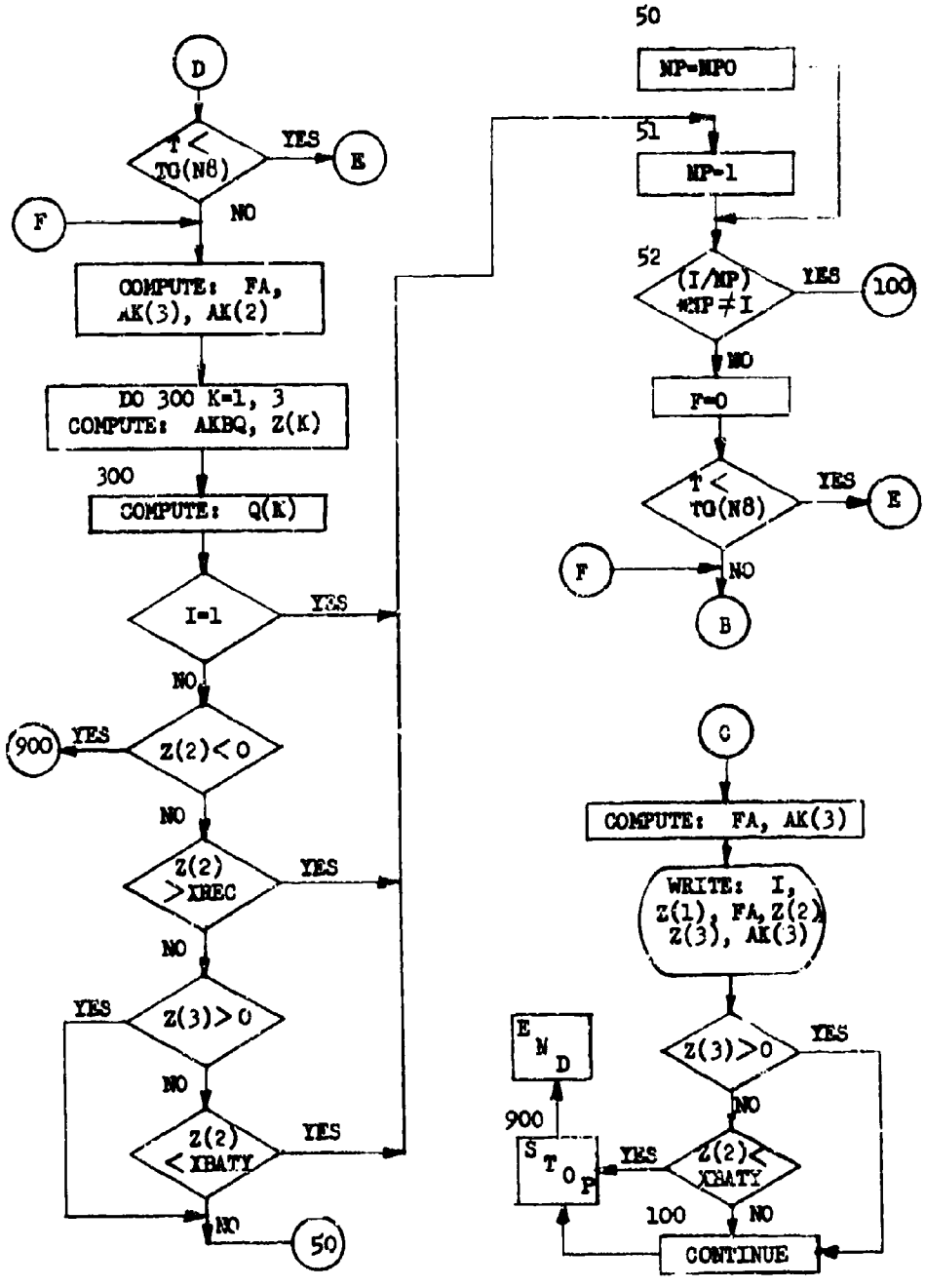
A–2. (Con't.)

```
00302    79.      12 DELXT=1.0-XT(I)                                                    70
00303    80.         IF(ABS(DELXT).GT.0.002)GO TO 16                                    71
00305    81.         IF(XT(I)-1.).LT.1.0)GO TO 15                                       72
00307    82.         XT(I)=2.0                                                          73
00310    83.         GO TO 18                                                           74
00311    84.      15 XT(I)=1.0                                                          75
00312    85.         GO TO 18                                                           76
00313    86.      16 IF(N.NE.0)GO TO 18                                                 77
00315    87.         IF(DELXT.LT.0.0)GO TO 17                                           78
00317    88.         IF(N.EQ.0)GO TO 18                                                 79
00321    89.      17 DT=ABS(DT*(DXT(I)+DELXT)/DXT(I))                                   80
00322    90.         DTSQ=DT**2                                                         81
00323    91.         N=N+1                                                              82
00324    92.         IF(N.GT.25)GO TO 26                                                83
00326    93.         GO TO 3                                                            84
00327    94.      18 DXB(I)=DX(I)+DXT(I)                                                85
00330    95.         XB(I)=XB(I-1)+DXB(I)                                               86
00331    96.         IF(I.GT.(K+1))GO TO 22                                             87
00333    97.         DELXB=10.0-XB(I)                                                   88
00334    98.         IF(ABS(DELXB).GT.0.002)GO TO 20                                    89
00336    99.      19 XB(I)=10.0                                                         90
00337   100.         K=I                                                                91
00340   101.         GO TO 22                                                           92
00341   102.      20 IF(DELXB.LT.0.0)GO TO 21                                           93
00343   103.         IF(N.EQ.0)GO TO 22                                                 94
00345   104.      21 DT=ABS(DT*(DXB(I)+DELXB)/DXB(I))                                   95
00346   105.         DTSQ=DT**2                                                         96
00347   106.         N=N+1                                                              97
00350   107.         IF(N.GT.25)GO TO 26                                                98
00352   108.         GO TO 3                                                            99
00353   109.      22 F(I)=F0+SK*XB(I)                                                   100
00354   110.         IF(I.GT.K)GO TO 23                                                 101
00356   111.         DE(I)=DXB(I)*(F(I)+F(I-1))/(2.0*EPS)                               102
00357   112.         E(I)=E(I-1)-DE(I)                                                  103
00360   113.         IF(E(I).GT.0.0)GO TO 28                                            104
00362   114.         E(I)=0.0                                                           105B
00363   115.         V(I)=0.0                                                           105C
00364   116.         K = I                                                              105D
00365   117.         GO TO 27                                                           105E
00366   118.      28 V(I)=SQRT(2.0*E(I)/EMB)                                            105F
00367   119.         GO TO 27                                                           106
00370   120.      23 DE(I)=ABS(DXB(I)*(F(I)+F(I-1))*EPS/2.0)                            107
00371   121.         E(I)=E(I-1)          +DE(I)                                        108
00372   122.         V(I)=-SQRT(2.0*E(I)/EMB)                                           109
00373   123.      27 IF(XT(I-1).LT.1.0)GO TO 24                                         110
00375   124.         EPSB=EPST                                                          111
00376   125.         FB(I)=FST-SKT*(XT(I)-1.0)                                          112
00377   126.         GO TO 25                                                           113
00400   127.      24 FB(I)=FB(1)-SKB*XT(I)                                              114
00401   128.      25 DET(I)=DXT(I)*(FB(I-1)+FB(I))*EPSB/2.0                             115
00402   129.         ET(I)=ET(I-1)+DET(I)                                               116
00403   130.         VT(I)=SQRT(2.0*ET(I)/EMT)                                          117
00404   131.         T(I)=T(I-1)+1000.0*DT                                              118
00405   132.         IF(XT(I).LT.2.0)GO TO 100                                          119A
00407   133.         GO TO 26                                                           119B
00410   134.     100 CONTINUE                                                           120
00412   135.      26 WRITE(6,102)                                                       121
00414   136.         WRITE(6,103)(J,DX(J),DXB(J),DXT(J),XB(J),XT(J), F(J),FB(J),       122
00414   137.        1 J = 1,I)                                                         123
00431   138.         WRITE(6,104)                                                       124
00433   139.     102 FORMAT(1H1/12X,57HTABLE 2-5 COUNTERRECOIL DYNAMICS OF DELAYED BLOW 125A
00433   140.        1 BACK GUN//                                                       125B
00433   141.        2          14X,63H RELATIVE   DELTA   DELTA    TOTAL    TOTAL   D 126
00433   142.        3RIVING   BARREL/77H      INCRE=    DELTA     BOLT    BARREL    BOL 127
00433   143.        4T    BARREL    SPRING   SPRING/6X,70H MENT    TRAVEL   TRAVEL   T 128
00433   144.        5RAVEL   TRAVEL    TRAVEL    FORCE    FORCE/8X,1HI,7X,60H ENCH    I 129
00433   145.        6NCH     INCH      INCH      INCH     POUND    POUND//)             130
00434   146.     103 FORMAT(I9,F12.3,2F9.3,F10.3,F9.3,F9.2,F10.1)                       131
00435   147.     104 FORMAT(1H1/9X,62HTABLE 2-5 CONTD-COUNTERRECOIL DYNAMICS OF DELAYED 132A
00435   148.        1 BLOWBACK GUN//                                                   132B
00435   149.        2          25X,14H DELTA   DELTA/6X,6HINCRE=,13X,53H BOLT    BARREL 133
00435   150.        3   BOLT    BARREL     BOLT     BARREL/6X,74H MENT      TIME    ENE 134
00435   151.        4RGY    ENERGY    ENERGY    ENERGY    VELOCITY   VELOCITY/8X,1HI,7X,63H 135
00435   152.        5 MSEC     IN-LB     IN-LB     IN-LB     IN-LB      IN/SEC     IN/SEC//) 136
00436   153.         WRITE(6,105) (J,T(J),DE(J),DET(J),E(J),ET(J),V(J),VT(J),          137
00436   154.        1 J = 1,I)                                                         138
00453   155.     105 FORMAT(I9,F12.2, 2F9.1, F10.1, F9.1,2F10.1)                        139
00454   156.     199 STOP                                                               140
00455   157.         END                                                                141
```

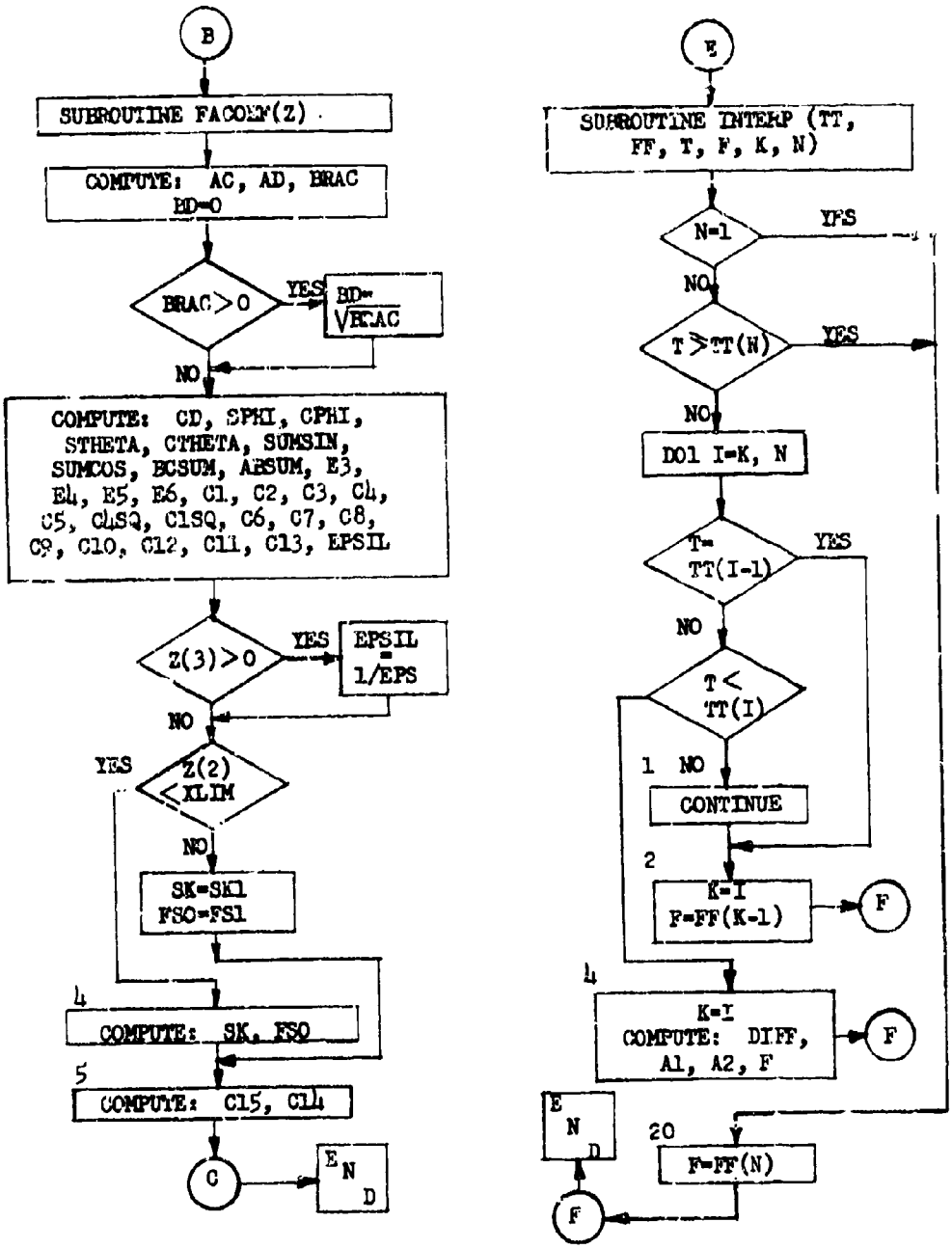
A–3. FLOW CHART FOR RETARDED BLOWBACK



A–3. (Con't.)


D
T < TO(N8)
YES
E
NO
F
COMPUTE: FA, AK(3), AK(2)
DO 300 K=1, 3
COMPUTE: AKBQ, Z(K)
300
COMPUTE: Q(K)
I=1
YES
NO
900
YES
Z(2)<0
NO
Z(2) >XREC
YES
NO
YES
Z(3)>0
NO
Z(2) <XRATY
YES
NO
50
50
MP=MPO
51
MP=1
52
(I/MP) *MP≠I
YES
100
NO
F=0
T < TO(N8)
YES
E
F
NO
B
C
COMPUTE: FA, AK(3)
WRITE: I, Z(1), FA, Z(2) Z(3), AK(3)
Z(3)>0
YES
NO
900
STOP
YES
Z(2)< XRATY
100
NO
CONTINUE
END

A-3. (Con't.)


B
SUBROUTINE FACOEF(Z)
COMPUTE: AC, AD, BRAC
BD=0
BRAC>0
YES
BD=√BRAC
NO
COMPUTE: CD, SPHI, CPHI, STHETA, CTHETA, SUMSIN, SUMCOS, BCSUM, ARSUM, E3, E4, E5, E6, C1, C2, C3, C4, C5, C4SQ, C1SQ, C6, C7, C8, C9, C10, C12, C11, C13, EPSIL
Z(3)>0
YES
EPSIL = 1/EPS
NO
YES
Z(2) <XLIM
NO
SK=SK1
FSO=FS1
4
COMPUTE: SK, FSO
5
COMPUTE: C15, C14
C
END
E
SUBROUTINE INTERP (TT, FF, T, F, K, N)
N=1
YES
NO
T≥TT(N)
YES
NO
DO1 I=K, N
T=TT(I-1)
YES
NO
T<TT(I)
1 NO
CONTINUE
2
K=I
F=FF(K-1)
F
4
K=I
COMPUTE: DIFF, A1, A2, F
F
END
20
F=FF(N)
F

A–4. LISTING FOR RETARDED BLOWBACK PROGRAM

```
00101     1.        DIMENSION FG(50),Z(3),G(3),A(3),TG(50),A(4),B(4),C(4)                    1
00103     2.        COMMON AZ,ABC,ABSQ,AB,BC,EYEB,E1,E2,EYEC,E7,EMR,EPS,XLIM,SK1,FS1,        8
00103     3.       1SK2,FS2,E3,E4,E5,E6,C1,C2,C3,C4,C5,C6,C7,C8,C9,C10,C11,C12,C13,C14       3
00103     4.       2,C15,AC,AD,GD,CD,FG0,SUMS1N,SUMCOS,SPHI,CPHI,STHETA,CTHETA               4
00104     5.        EQUIVALENCE (Z(1),T),(Z(2),X),(Z(3),VEL)                                 2
00105     6.        DATA A(1),C(1),C(4),B(1),B(4),B(2),B(3),A(3),C(3),A(2),C(2),A(4)/        3
00105     7.       1 34.5,2*2.,24.,2*1.70710678,2*.292893219,.166666667/                     4
00122     8.        READ(5,1)N,DT,N9,DTFG,NP0,TCHANG,DTNEW,NHEAD                             5
00134     9.      1 FORMAT(I6,E12.0,I6,E12.0,I6,2E12.0,I6)                                   6
00135    10.        READ(5,2)XREC,XLIM,AB,BC,WP,WAB,WBC,G,SK1,SK2,FS1,FS2,AZ,EPS,XBATY       7
00156    11.        ABSQ = AB*AB                                                             8A
00157    12.        BCSQ = BC*BC                                                             8B
00160    13.        ABC = ABSQ - BCSQ                                                        8C
00161    14.        EMB = WB/G                                                               8D
00162    15.        EMAB = WAB/G                                                             8E
00163    16.        EMR = EMB + EMAB                                                         8F
00164    17.        EYEB  = EMAB*ABSQ/12.0                                                   8G
00165    18.        EMBC = WBC/G                                                             8H
00166    19.        EYEC = EMBC*BCSQ/12.0                                                    8I
00167    20.      2 FORMAT(6F12.0)                                                           9
00170    21.        READ(5,10)(FG(I+1),I=1,N9)                                               10
00176    22.       15 FORMAT(9F8.0)                                                          11
00177    23.        E1 = EMAB*AB/2.0                                                        12A
00200    24.        E2=EMBC*BC/2.0                                                          12B
00201    25.        E7=EYEC/BC-E2/2.0                                                       12C
00202    26.        FG(1)=0.0                                                               13A
00203    27.        TG(1)=0.                                                                13B
00204    28.        N8=N9+1                                                                 13C
00205    29.        DO 20 I=1,N9                                                            14
00210    30.       20 TG(I+1)=TG(I)+DTFG                                                    15
00212    31.        AK(1)=1.0                                                               16
00212    32.  C     T=Z(1)                                                                  17
00212    33.  C     X=Z(2)                                                                  18
00212    34.  C     VEL=Z(3)                                                               19A
00213    35.        WRITE(6,3)                                                             19B
00215    36.      3 FORMAT(1H1/25X,37H TABLE 2-8 RETARDED BLOWBACK DYNAMICS/)              19C
00216    37.        WRITE (6,708)                                                          19D
00220    38.      708 FORMAT(30X,23HAPPLIED        DISTANCE/25X,4HTIME,12X,5THFORCE       19E
00220    39.         1   FROM BREECH       VELOCITY      ACCELERATION/20H    I          S 19F
00220    40.         2ECOND,11X5HPOUND,11X4HINCH,11X,25H IN/SEC         IN/SEC/SEC)       19G
00221    41.        DO 10 I=1,3                                                             20
00224    42.        G(I)=0.0                                                                21
00225    43.       10 Z(I)=0.0                                                              22
00227    44.        MINT=2                                                                  23
00230    45.      800 DO 100 I=1,N                                                         24A
00233    46.        IF(I.EQ.1)GO TO 75                                                     24B
00235    47.        IF((I/NHEAD)*NHEAD+1.NE.I)GO TO 75                                     25A
00237    48.        WRITE(6,707)                                                           25B
00241    49.        WRITE (6,708)                                                          25C
00243    50.      707 FORMAT(1H1/22X,44H TABLE 2-8 CONTD. RETARDED BLOWBACK DYNAMICS/)     25D
00244    51.       75 IF(T.GT.TCHANG)DT=DTNEW                                            25E
00246    52.        DO 300 J=1,4                                                            26
00251    53.        CALL FACOEF(Z)                                                          52
00252    54.        F = 0.0                                                                 64
00253    55.        IF(T.LT.TG(N8))CALLINTERP(TG,FG,T,F,MINT,N8)                            65
00255    56.        FA = F+(C14+C15*Z(2))                                                   55
00256    57.        AK(3)=(FA+C13*Z(3)**2)/C11                                              56
00257    58.        AK(2)=Z(3)                                                              67
00260    59.        DO 300 K=1,3                                                            68
00263    60.        AKBG=A(J)*(AK(K)-B(J)*G(K))                                             69
00264    61.        Z(K)=Z(K)+DT*AKBG                                                       70
00265    62.      300 G(K)=G(K)+3.0*AKBG-C(J)*AK(K)                                         71
```

A-4. (Con't.)

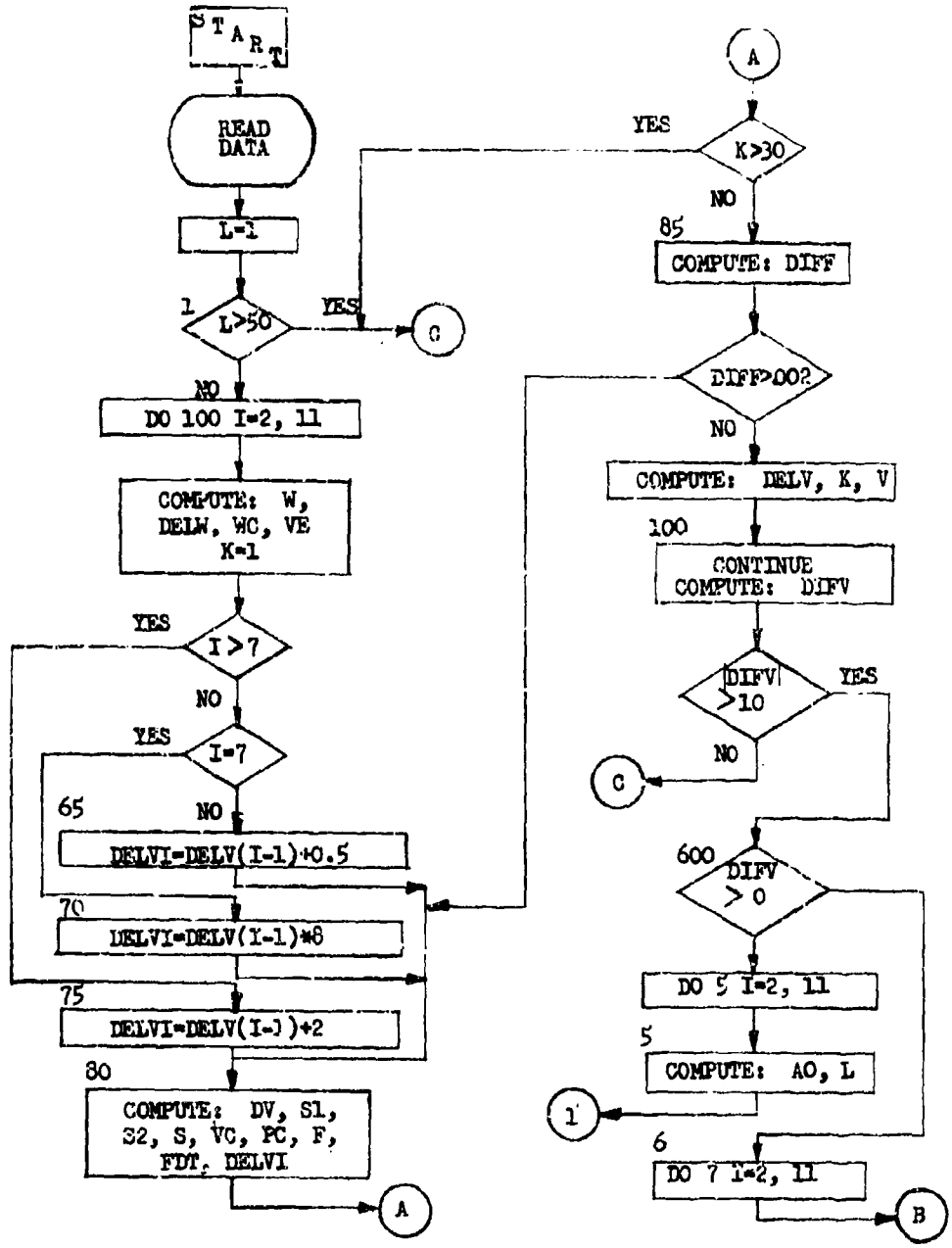
```
00270    63.        IF(I.EQ.1 )GO TO 51                                    71X
00272    64.        IF(Z(2).LT.0.0)GO TO 900                               72
00274    65.        IF(Z(2).GT.XREC)GO TO 51                               73A
00275    66.        IF(Z(3).GT.0.0)GO TO 50                                73B
00300    67.        IF(Z(2).LT.XBATY)GO TO 51                              73C
00302    68.     50 NP=NP0                                                 73D
00303    69.        GO TO 52                                               73E
00304    70.     51 NP=1                                                   74
00305    71.     52 IF((1/NP)*NP.NE.I)GO TO 100                            75
00307    72.        F = 0.0                                                76
00310    73.        IF(T.LT.TG(N8))CALL.INTERP(TG,FG,T,F,MINT,N8)          77
00312    74.        CALL FACOEF(Z)                                         78
00313    75.        FA = F*(C14+C15*Z(2))                                  79
00314    76.        AK(3)=(FA*C13*Z(3)**2)/C11                             80
00315    77.        WRITE(6,5)I,Z(1),FA,Z(2),Z(3),AK(3)                    81
00325    78.        IF(Z(3).GT.0.)GO TO 100
00327    79.        IF(Z(2).LT.XBATY)STOP                                  81A
00331    80.     100 CONTINUE                                              82
00333    81.       6 FORMAT(I6,F15.7,F15.1,F17.6,F16.1,F17.1)              83
00334    82.     900 STOP                                                  84
00335    83.        END                                                    85
```

A—4. (Con't.)

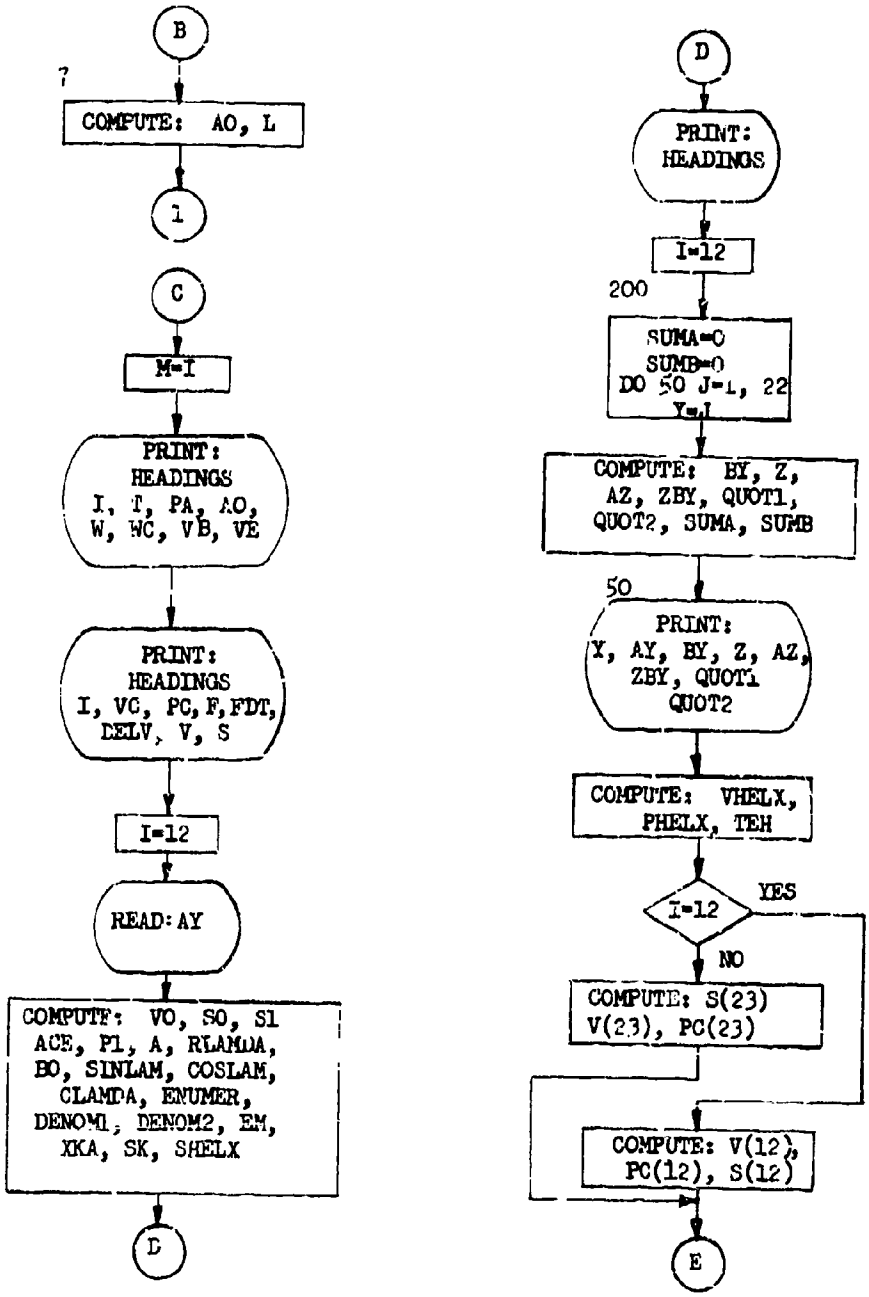
```
                                                                    INPUT CARD COUNT
      SUBROUTINE INTERP(T1,FF,T,F,K,N)                                      1
      DIMENSION TT(1),FF(1)                                                 2
      IF(N.EQ.1)GO TO 20                                                    3
      IF(T.GE.TT(N))GO TO 20                                                4
      DO 1 I=K,N                                                            5
      IF(T.EQ.TT(I-1))GO TO 2                                               6
      IF(T.LT.TT(I))GO TO 4                                                 7
    1 CONTINUE                                                              8
    2 K=I                                                                   9
      F=FF(K-1)                                                            10
      RETURN                                                               11
    4 K=I                                                                  12
      DIFF=TT(K)-TT(K-1)                                                   13
      A1=(T-TT(K-1))/DIFF                                                  14
      A2=(TT(K)-T)/DIFF                                                    15
      F=A1*FF(K)+A2*FF(K-1)                                                16
      RETURN                                                               17
   20 F=FF(N)                                                              18
      RETURN                                                               19
      END                                                                  20
```

```
00101     1.        SUBROUTINE FACOEF(Z)                                    S1
00102     2.        COMMON AZ,ABC,ABSQ,AB,BC,EYEB,E1,E2,EYEC,E7,EMR,EPS,XLIM,SK1,FS1,       S2
00103     3.       1SK2,FS2,E3,E4,E5,E6,C1,C2,C3,C4,C5,C6,C7,C8,C9,C10,C11,C12,C13,C14      3
00103     4.       2,C15,AC,AD,BD,CD,FS0,SUMSIN,SUMCOS,SPHI,CPHI,STHETA,CTHETA             4
00104     5.        DIMENSION Z(3)                                          S4
00105     6.        AC=AZ-Z(2)                                              27
00106     7.        AD=(ABC+AC**2)/(2.0*AC)                                 28
00107     8.        BRAC=ABSQ-AD**2                                        29A
00110     9.        BD=0.                                                  29B
00111    10.        IF(BRAC.GT.0.)BD=SQRT(BRAC)                            29C
00113    11.        CD = AC-AD                                              30
00114    12.        SPHI = BD/AB                                            31
00115    13.        CPHI = AD/AB                                            32
00116    14.        STHETA = BD/BC                                          33
00117    15.        CTHETA = CD/BC                                          34
00120    16.        SUMSIN = STHETA*CPHI + CTHETA*SPHI                      35
00121    17.        SUMCOS = CTHETA*CPHI - STHETA*SPHI                      36
00122    18.        BCSUM = BC*SUMSIN                                       37
00123    19.        ABSUM = AB*SUMSIN                                       38
00124    20.        E3 = (EYEB + E1*AB/2.0)/AC                             39A
00125    21.        E4=E1*SPHI/AC                                          39B
00126    22.        E5=E2*ABSUM/AC                                         39C
00127    23.        E6 = (E2*(AB*SUMCOS + BC/2.0) - EYEC)/AC               39D
00130    24.        C1 = CPHI/BCSUM                                         40
00131    25.        C2 = -AB/BCSUM                                         41A
00132    26.        C3 = -SUMCOS/SUMSIN                                    41B
00133    27.        C4 = CTHETA/ABSUM                                       42
00134    28.        C5 = -BC/ABSUM                                          43
00135    29.        C4SQ = C4**2                                            44
00136    30.        C1SQ = C1**2                                           45A
00137    31.        C6 = C2*C4SQ+C3*C1SQ                                   45B
00140    32.        C7 = C5*C1SQ+C3*C4SQ                                    46
00141    33.        C8=E3*C4+E6*C1-E4                                       47
00142    34.        C9=E3*C7+E6*C6-E5*C1SQ                                  48
00143    35.        C10=(C8*CTHETA+E7*C1)/STHETA                            49
00144    36.        C12=(C9*CTHETA+E7*C6)/STHETA                            50
00145    37.        C11=EMR+E2*C1*STHETA-E1*C4*SPHI*C10                     51
00146    38.        C13=E1*C4SQ*CPHI+F1*C7*SPHI-E2*C1SQ*CTHETA-E2*C6*STHETA-C12            52
00147    39.        EPSIL = EPS                                             53
00150    40.        IF(Z(3).GT.0.0)EPSIL=1.0/EPS                            54
00152    41.        IF(Z(2).GT.XLIM)GO TO 4                                 55
00154    42.        SK = SK1                                                57
00155    43.        FS0 = FS1                                               58
00156    44.        GO TO 5                                                 59
00157    45.      4 SK = SK1+SK2                                            60
00160    46.        FS0 = FS1+FS2-SK2*XLIM                                  61
00161    47.      5 C15 = -SK*EPSIL                                         62
00162    48.        C14 = -FS0*EPSIL                                        63
00163    49.        RETURN                                                 S48
00164    50.        END                                                    S49
```

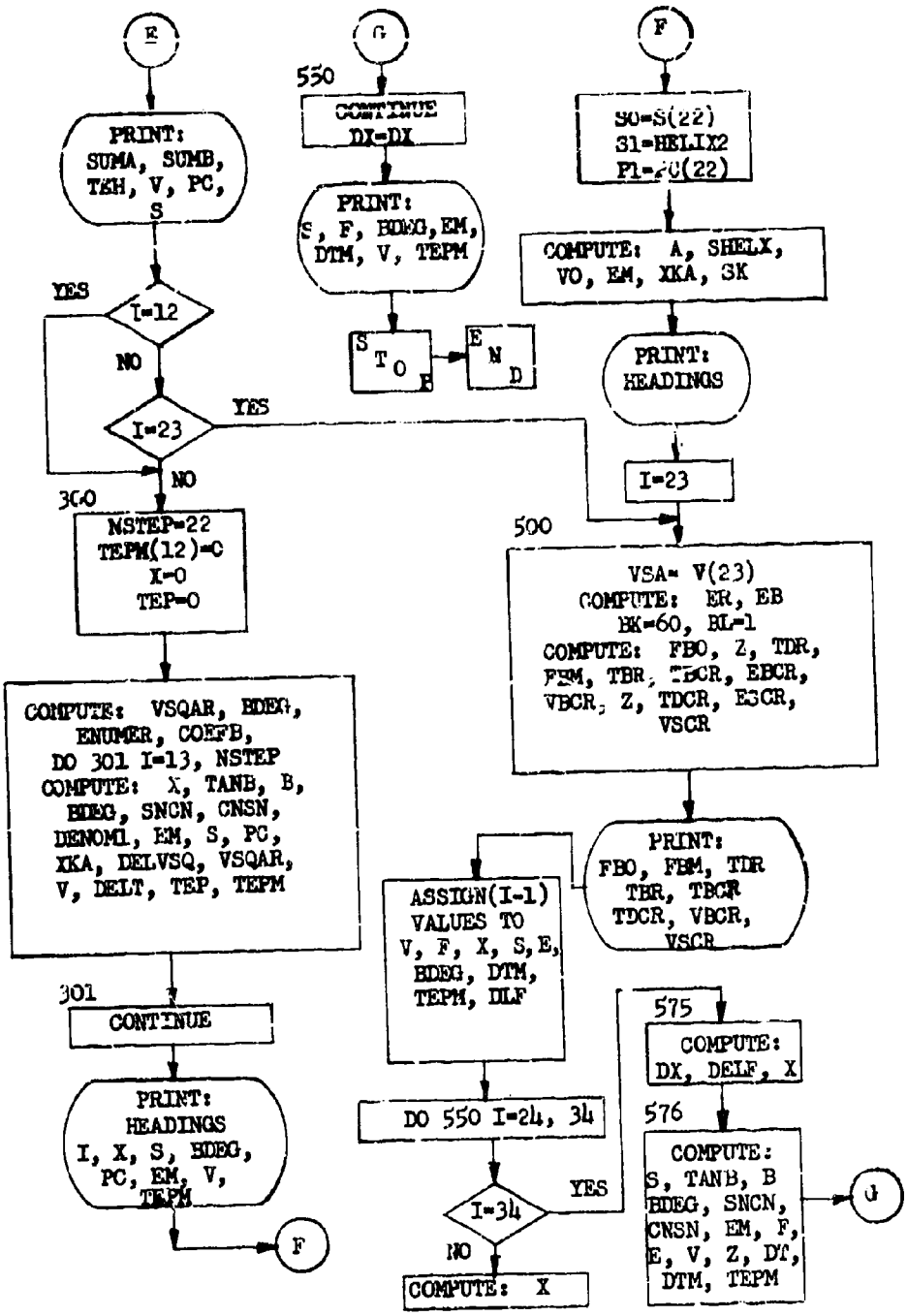
A–5. FLOW CHART FOR CUTOFF EXPANSION



A–5. (Con't.)


B
7
COMPUTE: AO, L
1
C
M=I
PRINT:
HEADINGS
I, T, PA, AO,
W, WC, VB, VE
PRINT:
HEADINGS
I, VC, PC, F, FDT,
DELV, V, S
I=12
READ: AY
COMPUTE: VO, SO, S1
ACE, P1, A, RLAMDA,
BO, SINLAM, COSLAM,
CLAMDA, ENUMER,
DENOM1, DENOM2, EM,
XKA, SK, SHELX
D
D
PRINT:
HEADINGS
I=12
200
SUMA=0
SUMB=0
DO 50 J=1, 22
Y=J
COMPUTE: BY, Z,
AZ, ZBY, QUOT1,
QUOT2, SUMA, SUMB
50
PRINT:
Y, AY, BY, Z, AZ,
ZBY, QUOT1
QUOT2
COMPUTE: VHELX,
PHELX, TEH
I=12
YES
NO
COMPUTE: S(23)
V(23), PC(23)
COMPUTE: V(12),
PC(12), S(12)
E

A-5. (Con't.)


E
PRINT:
SUMA, SUMB,
TEH, V, PC,
S
YES
I=12
NO
I=23
YES
NO
300
NSTEP=22
TEPM(12)=C
X=0
TEP=0
COMPUTE: VSQAR, BDEG,
ENUMER, COEFB,
DO 301 I=13, NSTEP
COMPUTE: X, TANB, B,
BDEG, SNCN, CNSN,
DENOM1, EM, S, PC,
XKA, DELVSQ, VSQAR,
V, DELT, TEP, TEPM
301
CONTINUE
PRINT:
HEADINGS
I, X, S, BDEG,
PC, EM, V,
TEPM
F
G
550
CONTINUE
DX=DX
PRINT:
S, F, BDEG, EM,
DTM, V, TEPM
STOP
END
F
S0=S(22)
31=HELIX2
F1=F0(22)
COMPUTE: A, SHELX,
VO, EM, XKA, SK
PRINT:
HEADINGS
I=23
500
VSA= V(23)
COMPUTE: ER, EB
BK=60, BL=1
COMPUTE: FBO, Z, TDR,
FBM, TBR, TBCR, EBCR,
VBCR, Z, TDCR, ESCR,
VSCR
PRINT:
FBO, FBM, TDR
TBR, TBCR
TDCR, VBCR,
VSCR
ASSIGN(I-1)
VALUES TO
V, F, X, S, E,
BDEG, DTM,
TEPM, DLF
DO 550 I=24, 34
I=34
YES
NO
COMPUTE: X
575
COMPUTE:
DX, DELF, X
576
COMPUTE:
S, TANB, B
BDEG, SNCN,
CNSN, EM, F,
E, V, Z, DT,
DTM, TEPM
J

A–6. LISTING FOR CUTOFF EXPANSION PROGRAM

```
00101     1.      DIMENSION T(50),DELT(50),AQ(50),PA(50),VB(50),DELV(50),VC(50),          1
00101     2.     1P(50),RC(50),AY(50),W(50),S(50),PC(50),BDEG(50),                        2
00101     3.     2EM(50),V(50),VE(50),FDT(50),X(50),DTA(50),TEPM(50)                      3
00103     4.      READ 400,(T(I),I=2,11),(DELT(I),I=2,11),(PA(I),I=2,11),                4A
00103     5.     1(VB(I),I=2,11),(AQ(I),I=2,11)                                          4B
00131     6.    400 FORMAT (11F7.3)                                                      5
00132     7.      M=100                                                                  6
00133     8.      READ 350,VMAX,DELV(1),T(1),AL,..O,WB,WC(1),VCYL,DLAMDA,RC,R,RL,G,      7
00153     9.     1SA,EMUR,EPS,IAND0,EPS,RADGYR,          SMAX,CX,      BK,BHK,V(1),     8
00133    10.      3S(1),HELIA1,HELIX2,SCYL                                               9
00171    11.    350 FORMAT (6F12.0)                                                      10
00172    12.      L=1                                                                    11
00173    13.      1 IF(L.GT.50)GO TO 7                                                   12
00175    14.        DO 100 I=2,11                                                        13
00200    15.        W(I)=0.00192*AQ(I)*PA(I)                                             14
00201    16.        DELW=W(I)*DELT(I)                                                    15
00202    17.        AC(I)=AC(I-1)+DELW                                                   16
00203    18.        VE(I)=AC(I)*VB(I)/0.00029                                            17
00204    19.        K=1                                                                  18
00205    20.        IF(I.EQ.7)GO TO 70                                                   19
00207    21.        IF(I.GT.7)GO TO 75                                                   20
00211    22.       65 DELVI= DELV(I-1)+0.5                                               21
00212    23.          GO TO 80                                                          22
00213    24.       70 DELVI= DELV(I-1)*0.0                                              23
00214    25.          GO TO 80                                                          24
00215    26.       75 DELVI= DELV(I-1)+2.0                                              25
00216    27.       80 DV=DELVI                                                          26
00217    28.          S1=0.5*DV*DELT(I)                                                 27
00220    29.          S2=V(I-1)*DELT(I)                                                 28
00221    30.          S(I)=S1+S2+S(I-1)                                                 29
00222    31.          VC(I)=VCYL+AC*S(I)                                                30
00223    32.          PC(I)=(VE(I)/VC(I))**1.3*PA(I)                                    31
00224    33.          F(I)=0.60*PC(I)                                                   32
00225    34.          FDT(I)=F(I)*DELT(I)                                               33
00226    35.          DELVI = 154.50*FDT(I)                                             34
00227    36.          IF(K.GT.30)GO TO 2                                                35
00231    37.       85 DIFF= ABS ((DELVI-DV)/DELVI)                                      36
00232    38.          IF(DIFF.GT..002)GO TO 80                                          37
00234    39.          DELV(I)=DELVI                                                     38
00235    40.          K=K+1                                                             39
00236    41.          V(I)=V(I-1)+DELV(I)                                               40
00237    42.      100 CONTINUE                                                          41
00241    43.          DIFV=V(11)-VMAX                                                   42
00242    44.          IF(ABS (DIFV).GT.10.0)GO TO 600                                   43
00244    45.          GO TO 2                                                           44
00246    46.      600 IF(DIFV.GT.0.0)GO TO 6                                            45
```

A-6. (Con't.)

```
00247    47.        DO 5 I=2,11                                                    46
00252    48.      5 AO(I)=AO(I)+0.0010                                             47
00255    49.        L = L + 1                                                      48
00255    50.        GO TO 1                                                        49
00256    51.      6 DO 7 I=2,11                                                    50
00261    52.      7 AO(I)=AO(I)-0.0010                                             51
00263    53.        L=L+1                                                          52
00264    54.        GO TO 1                                                        53
00265    55.      2 M=1                                                            54
00266    56.        PRINT 23,(I,T(I),PA(I),AO(I),W(I), WC(I),VB(I),VE(I),I=2,11)   55
00303    57.        PRINT 24,(I,VC(I),PC(I),F(I),FDT(I),DELV(I),V(I),S(I),I=2,11)  56
00320    58.      230FORMAT (1H1/          9X,46H TABLE 4-5 COMPUTED DYNAMICS BEFORE GAS   57
00320    59.        1 CUTOFF//33X,31H GAS      GAS     EQUIV     EQUIV/24X,39H PORT     F  58A
00320    60.        2LOW     IN      BORE     CYL/                          7X 96H TIME   PRES  58B
00320    61.        3S    AREA      RATE     CYL     VOL      VOL/64H    I     MSEC     PS   59
00320    62.        4I      SQ-IN   LB/SEC     LB     CU-IN    CU-IN//(14,F8.3,F9.0,F9.4      60
00320    63.        5,F8.3,F9.5,F8.3,F9.4))                                        61
00321    64.      240FORMAT(//6A,23H CYL      CYL     PISTON,12X,20HDELTA     ROD      ROD   62
00321    65.        1/8X,57H VOL      PRESS     FORCE  IMPULSE     VEL      VEL     TRAVEL/6  63
00321    66.        23H    1    CU-IN      PSI       LB      LB-SEC    IN/SEC  IN/SEC    IN/  64
00321    67.        9/(I4,F9.4,2F9.1,F8.3,F9.2,F8.1,F9.4))                         65
00322    68.        I=12                                                           66
00323    69.        READ 250,(AY(J),J=1,22)                                        67
00331    70.        V0=V(11)                                                       68
00332    71.        CORS(11)+SCYL                                                  69
00333    72.        S1=HELIX1 -S(11)                                               70
00334    73.        ACE=2.0*AC/0.3                                                 71
00335    74.        P1=PC(11)                                                      72
00336    75.        A=1.0+S1/50                                                    73
00337    76.        RLAMDA=DLAMDA/57.296                                           74
00340    77.        B0=ATAN(TANB0)                                                 75
00341    78.        SINLAM=SIN(RLAMDA)                                             76
00342    79.        COSLAM=COS(RLAMDA)                                             77
00343    80.        CLAMDA=SIN.LAM=EMUS*COSLAM)/(COSLAM+EMUS*SINLAM)               78
00344    81.        ENUMER=2*B*HAUGYH**2*TANB0/RC                                  79
00345    82.        DENOM1=(RC-EMUS*R)*(COS(B0)-EMUR*SIN(B0))/(SIN(B0)+EMUR*COS(B0))  80
00346    83.        DENOM2=CL*ADA*(RL-EMUS*R)                                      81
00347    84.        EM(12)=(W0*WB* ENUMER/(DENOM1+DENOM2))/6                       82
00350    85.        XKA=ACE*P1*S0**1.3/EM(12)                                      83
00351    86.        SK = 50**1.15/SQRT(XKA)                                        84
00352    87.        SHLLX=SCYL*HELIX1                                              85
00353    88.        PRINT 41                                                       86
00355    89.      41 FORMAT(1H1 /                                                  87
00355    90.        1  17X,45H TABLE 4-6 COMPUTED DYNAMICS AFTER GAS CUTOFF/21X,37H BOL  88
00355    91.        2I UNLOCKING DURING HELIX TRAVERSE// 3X,2H Y,6X,3H AY,7X,3H BY,    89
00355    92.        37X,2H Z, 6X,3H AZ,7X,4H ZBY,6X,6H QUOT1, 5X,6H QUOT2/ )           90
00356    93.        I=12                                                           91A
00357    94.      200 SUMA=0                                                       91B
00360    95.        SUMB = 0                                                       92
00361    96.        DO 50 J = 1,22                                                 93
00364    97.        Y=J                                                            94
00365    98.        BY = (1.0 + (V0**2/XKA)*50**0.3)**Y                            95
00366    99.        Z = 1.0 - 0.3*Y                                                96
00367   100.        AZ = A**Z                                                      97
00370   101.        ZBY = Z*BY                                                     98
00371   102.        QUOT1 = AY(J)/ZBY                                              99
00372   103.        QUOT2 = AZ*QUOT1                                              100
00373   104.        SUMA = SUMA + QUOT1                                           101
```

A–6. (Con't.)

```
00374   105.        SUMB = SUMB + GUOT2                                          102
00375   106.     50 PRINT 21,Y,AA(I),BY, X, AZ, JUY, GUOTA, GUOTB               103
00410   107.     21 FORMAT (F6.1, 2F10.4, F8.1, F10.4, 3F11.4)                   104
00411   108.        VHELX=SQRT(XKA*((1.0/S0**0.3)-1.0/SHELX**0.3)+V0**2)         105
00412   109.        PHELX=P1*(S0/SHELX)**1.3                                     106
00413   110.        TEH= SK*(A+SUMB - 1.0*SUMA)                                  107
00414   111.        IF(I.LE.12)GO TO 201                                         108
00416   112.        S(23)=S(22)+HELIX2                                           109A
00417   113.        V(23)=VHELX                                                  109B
00420   114.        PC(23)=PHELX                                                 110
00421   115.        GO TO 202                                                    111
00422   116.     201 V(12)=VHELX                                                 112
00423   117.        PC(12)=PHELX                                                 113A
004.    118.        S(12)=SHELX                                                  113B
00425   119.     202 PRINT 51, SUMA,SUMB,TEH,V(I),PC(I),S(I)                     114
00435   120.      51 FORMAT(//49X,6HTOTALS,2F11.4//9X,44HEXPANSION TIME DURING HELIX TR  115
00435   121.        1AVERSE (TEH) = F8.5,8H SECONDS //9X,3HV =F7.2,7H IN/SEC,5X,5H PC =  116
00436   122.        2F7.1,4H PSI,5X,3HS =F7.4,4H IN.)                            117
00436   123.          IF(I.EQ.12)GO TO 300                                       118
00440   124.          IF(I.EQ.23)GO TO 500                                       119
00442   125.     300 NSTEP=22                                                    120
00443   126.         TEPM(12)=0.0                                                121
00444   127.         X(I)=0.0                                                    122
00445   128.         TEP = 0.0                                                   123A
00446   129.         VSQAR=V(12)**2                                              123B
00447   130.         BDEG(12)=6.4426                                             123C
00450   131.         ENUMER=WB*RADGYR**2/RC                                      125
00451   132.         COEFB=RC-EMUS*R                                             126
00452   133.         DO 301 I=13,NSTEP                                           127
00455   134.         X(I)=X(I-1)+DX                                              128
00456   135.         TANB=2.632*X(I)+TANB0                                       129
00457   136.         B=ATAN(TANB)                                                130
00460   137.         BDEG(I)=57.2958*B                                           131
00461   138.         SNCN =SIN(B)+EMUR*COS(B)                                    132
00462   139.         CNSN =COS(B)-EMUR*SIN(B)                                    133
00463   140.         DENOM1=COEFB*CNSN/SNCN                                      134
00464   141.         EM(I)=(WO*ENUMER*TANB/(DENOM1+DENOM2))/G                    135
00465   142.         S(I)=S(I-1)+DX                                              136
00466   143.         PC(I)=PC(I-1)*(S(I-1)/S(I))**1.3                            137
00467   144.         XKA=AGE*PC(I)/EM(I)                                         138
00470   145.         DELVSQ=XKA*(S(I-1)-S(I-1)**1.3/S(I)**0.3)                   139
00471   146.         VSQAR=DELVSQ+VSQAR                                          140
00472   147.         V(I)=SQRT(VSQAR)                                            141
00473   148.         DELT=2.0*DX/(V(I)+V(I-1))                                   142
00474   149.         TEP = TEP+DELT                                              143
00475   150.         TEPM(I)=1000.0*TEP                                          144
00476   151.      301 CONTINUE                                                   145
00500   152.         PRINT 302,(I,X(I),S(I),BDEG(I),PC(I),EM(I),V(I),TEPM(I),I=13,22)  146
00515   153.      302FORMAT(1H1/                                                 147A
00515   154.        1  12X,45H TABLE 4-7 COMPUTED DYNAMICS AFTER GAS CUTOFF/14X,40H BOL  147B
00515   155.        2T UNLOCKING DURING PARABOLA TRAVERSE//14X,6H EQUIV,21X,6H EQUIV/55  148
00515   156.        3H      PARAB     CYL       CAM       CYL       RECOIL     ROD/65H  149
00515   157.        4  DIST   LENGTH   SLOPE     PRESS     MASS      VEL        TIME/65H  150
00515   158.        5I      IN        IN        DEG       PSI       W/G        IN/SEC     MSEC// (  151A
00515   159.        6I4,2F8.3,F9.3,F9.1,F10.6,F9.2,F9.4))                        151B
00516   160.      405 S0=S(22)                                                   152
00517   161.          S1=HELIX2                                                  153
00520   162.          P1=PC(22)                                                  154A
```

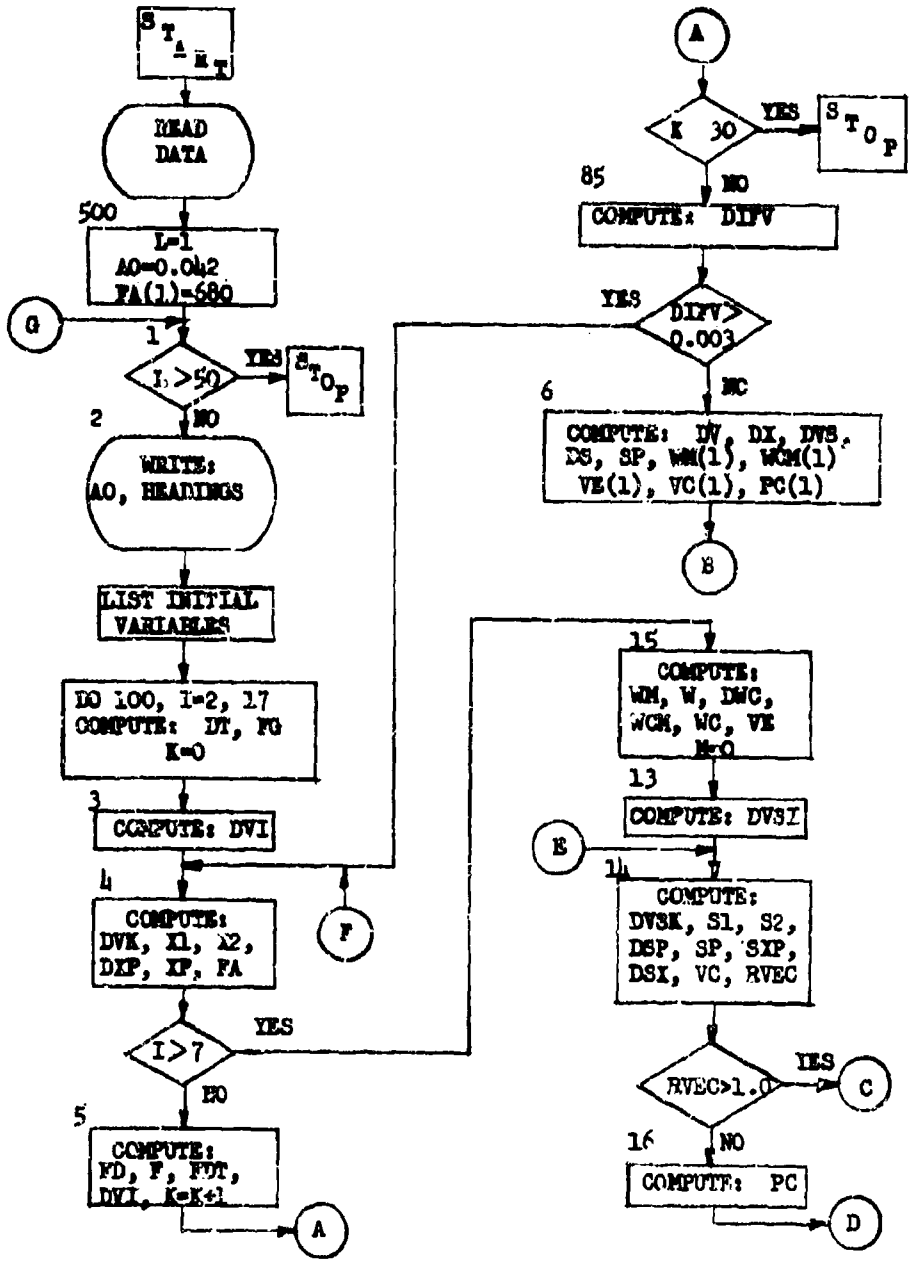
A–6. (Con't.)

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00521  165.          A=1.0*G1/SA                                                  154B
00522  166.          SHELA=SQRT(A)                                                154C
00523  167.          V0=V(22)+W0/(W0+W3)                                          155
00524  168.          EM=(W0+W3)/G                                                 156
00525  169.          XKA=ACE*P1*S0**1.5/EM                                        157
00526  170.          SX=S0**1.5/SQRT(XKA)                                         158
00527  171.          PRINT 410                                                    159A
00531  172.          I=23                                                         159B
00532  173.          GO TO 200                                                    159C
00533  174.    410FORMAT(1H1/          17X,45H TABLE 4-8 COMPUTED DYNAMICS AFTER GAS C  160
00533  175.       1UTOFF/17X,46H BOLT AND ROD UNIT RECOILLING AFTER CAM ACTION//3X,2H  161
00533  176.       2 Y,6X,3H AY,7X,3H DY,7X,3HZ,8X,3H AZ,7X,4H ZDY,6X,6H QUOT1,5X,6H Q  162
00533  177.       3UOT2/ )                                                         163
00534  178.    500 VSA=V(23)                                                      164
00535  179.          ER=EM*VSA**2/2.0                                             165
00536  180.          EB=EM-50.0                                                   166
00537  181.          BK=60.0                                                      167
00540  182.          BL=1.0                                                       168
00541  183.          FB0=EPS*EB-BK*BL/2.0                                         169
00542  184.          Z=SQRT(3807.0+20.4*ER)                                       170
00543  185.          TDR=3.00203*(ASIN(97.4/Z)-ASIN(61.7/Z))                      171
00544  186.          FBM=FB0+BK*BL                                                172
00545  187.          TBR=0.00937*ACOS(FB0/FBM)                                    173
00546  188.          TBCR=0.01675*ACOS(FB0/FBM)                                   174
00547  189.          EBCR=(FBM+FB0)/4.9                                           175
00550  190.          VBCR=SQRT(2.0*EBCR/EM)                                       176
00551  191.          Z=SQRT(9467.0+40.0*EBCR)                                     177
00552  192.          TDCR=0.04001*(ASIN(97.4/Z)-ASIN(51.5/Z))                     178
00553  193.          ESCR=EBCR+167.5                                              179
00554  194.          VSCR=SQRT(2.0*ESCR/EM)                                       180
00555  195.          PRINT 501,FB0,FBM,TDR,TBR,TBCR,TDCR,VBCR,VSCR                181
00567  196.    501FORMAT(///20X,23H MINIMUM BUFFER FORCE =F7.1,3H LB/20X,23H MAXIMUM  182
00567  197.       1 BUFFER FORCE =F7.1,3H LB/20X,29H DRIVING SPRING RECOIL TIME =F9.6  183
00567  198.       2,4H SEC/20X,28H BUFFER RECOIL TIME =F9.6,4H SEC/20X,28H BUFFER COU  184
00567  199.       3NTERRECOIL TIME =F9.6,4H SEC/20X,31H DR SPRING COUNTERRECOIL TIME   185
00567  200.       4= F9.6,4H SEC/20X,32H BUFFER COUNTERRECOIL VELOCITY =F7.2,7H IN/SE  186
00567  201.       5C/20X,32H DR SPR COUNTERRECOIL VELOCITY =F7.2,7H IN/SEC)            187
00570  202.    510 V(23)=VSCR                                                     188
00571  203.          F(23)=51.5                                                   189
00572  204.          X(23)=0.5                                                    190
00573  205.          S(23)=0.0                                                    191A
00574  206.          E=ESCR                                                       191B
00575  207.          BDEG(23)=52.92                                               192
00576  208.          F(23)=51.5                                                   193
00577  209.          DTM(23)=0.0                                                  194
00600  210.          TEPM(23)=0.0                                                 195
00601  211.          DELF=DRK*DX                                                  196
00602  212.          NSTEP=34                                                     197
00603  213.          DO 550 I=24,NSTEP                                            198
00606  214.          IF(I.EQ.NSTEP)GO TO 575                                      199
00610  215.          X(I)=X(I-1)+DX                                               200
00611  216.          GO TO 576                                                    201
00612  217.    575 DX=HELIX1                                                      202
00613  218.          DELF = DRK*DX                                                203A
00614  219.          X(I)=0.0                                                     203B
00615  220.    576 S(I)=S(I-1)+DX                                                 204
00616  221.          TANB = 2.632*X(I) + TANB0                                    205
00617  222.          B = ATAN(TANB)                                               206
```

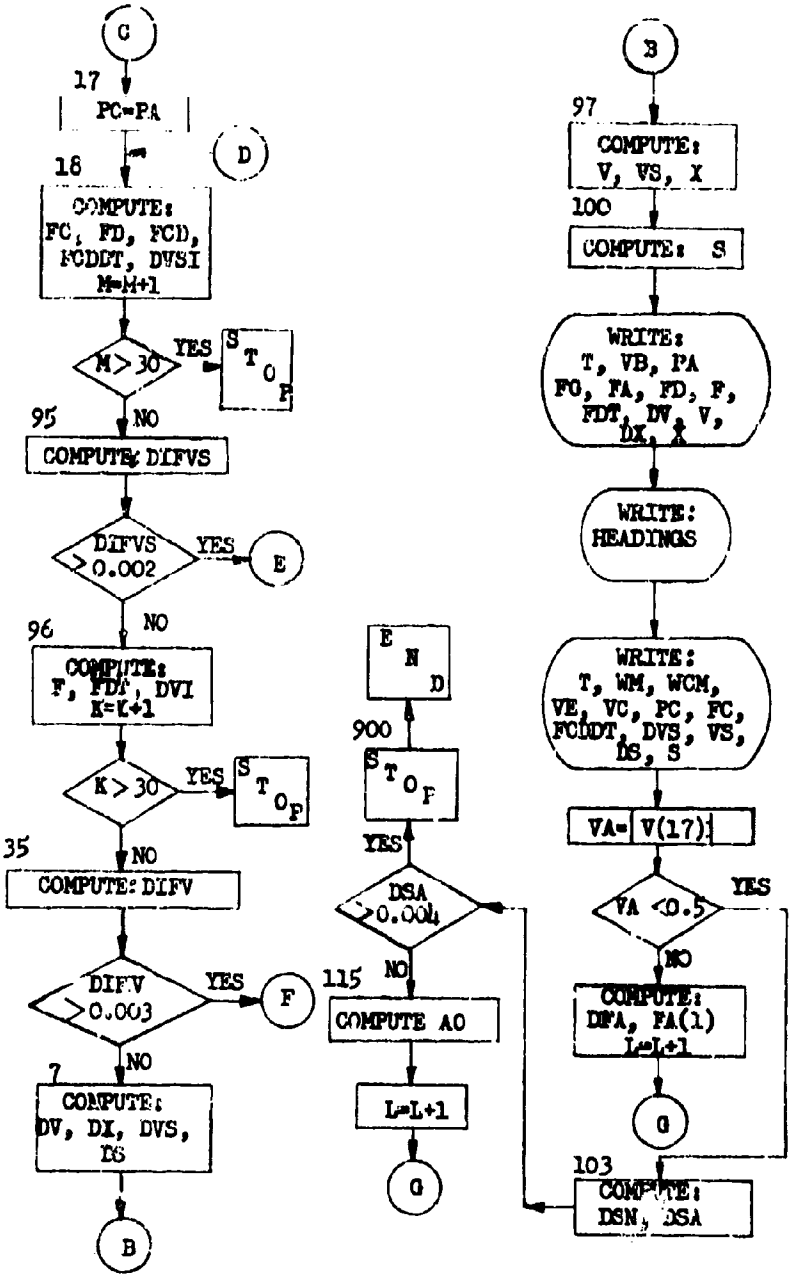
A–6. (Con't.)

```
00620   221.        BDEG(I)=57.296*B                                          207
00621   222.        SNCN = SIN(B)+EMUR*COS(B)                                 208
00622   223.        CNSN = COS(B)-EMUR*SIN(B)                                 209
00623   224.        EM(I)=.00647 +(0.000345*TANB/(0.203*CNSN/SNCN-0.1149))    210
00624   225.        F(I)=F(I-1)-DELF                                          211
00625   226.        E=E+0.25*(F(I-1)+F(I))*DX                                 212
00626   227.        V(I)=SQRT(2.0*E/EM)                                       213
00627   228.        Z=SQRT(F(I-1)**2+40.8*E)                                  214
00630   229.        DT=0.4428*SQRT(EM)*(ASIN(F(I-1)/Z)-ASIN(F(I)/Z))          215
00631   230.        DTM(I)=1000.0*DT                                          216
00632   231.        TEPM(I)=TEPM(I-1)+DTM(I)                                  217
00633   232.    550 CONTINUE                                                  218A
00634   233.        DX=DX                                                     218B
00636   234.        PRINT 551,(S(I),F(I),BDEG(I),EM(I),DTM(I),V(I),TEPM(I),I=24,NSTEP)  219
00652   235.    551 FORMAT                                          (1H1/     220
00652   236.       1 15X,42H TABLE 4-9 COMPUTED DYNAMICS,COUNTERRECOIL/17X,37HBOLT LOC  221
00652   237.       2KING DURING PARABOLA TRAVERSE// 2X,6HTRAVEL,4X,5HFORCE,6X,4HDETA,   222
00652   238.       36X,5HMASS ,6X,6HDELTAT,4X,8HVELOCITY,5X,4HTIME,/3X,4HINCH,5X,5HPOU  223
00652   239.       4ND,6X,6HDEGREE,5X,5H1000X,6X,6HMILSEC,5X,6HIN/SEC,5X,6HMILSEC//     224
00652   240.       5        (F7.2,F10.2, F11.3, F11.5, F11.4, F11.2, F11.4))     225
00653   241.        STOP                                                      226
00654   242.        END                                                       227
```

A–7. FLOW CHART FOR OPERATING CYLINDER



A-7. (Con't.)


C
17
PC=PA
D
18
COMPUTE:
FC, FD, FCD,
FCDDT, DVSI
M=M+1
M > 30
YES
STOP
95
NO
COMPUTE: DIFVS
DIFVS > 0.002
YES
E
96
NO
COMPUTE:
F, FDT, DVI
K=K+1
K > 30
YES
STOP
35
NO
COMPUTE: DIFV
DIFV > 0.003
YES
F
7
NO
COMPUTE:
DV, DI, DVS,
DS
B
END
900
STOP
YES
DSA > 0.004
NO
115
COMPUTE AO
L=L+1
G
B
97
COMPUTE:
V, VS, X
100
COMPUTE: S
WRITE:
T, VB, PA
FC, FA, FD, F,
FDT, DV, V,
DX, X
WRITE:
HEADINGS
WRITE:
T, WM, WCM,
VE, VC, PC, FC,
FCDDT, DVS, VS,
DS, S
VA=V(17)
VA < 0.5
YES
NO
COMPUTE:
DFA, FA(1)
L=L+1
G
103
COMPUTE:
DSN, DSA

A–8. LISTING FOR OPERATING CYLINDER PROGRAM

```
BIT   FOR REVMOD
COMPILATION BY UNIVAC 1107 FORTRAN IV DATED-    MAY 10,1966  F4010
THIS COMPILATION WAS DONE ON 16 JUN 68 AT 08:46:48


   MAIN PROGRAM          ENTRY POINT 000000

   STORAGE USED (BLOCK, NAME, LENGTH)

        0001   *CODE   000610
        0000   *DATA   001211
        0002   *BLANK  000000


   EXTERNAL REFERENCES (BLOCK, NAME)

        0003   NRDC$
        0004   NIOI$
        0005   NIO2$
        0006   NSTOP$
        0007   NPRT$
        0010   NEXP63
        0011   NWDU$


   STORAGE ASSIGNMENT FOR VARIABLES (BLOCK, TYPE, RELATIVE LOCATION, NAME)

  0001   000036 1L        0000   000652 10F       0000   001133 101F      0001   000557 103L      0001   000004 1056
  0001   000014 1136      0001   000024 1216      0001   000235 14L       0001   000212 15L       0001   000072 1516
  0001   000303 17L       0001   000305 18L       0001   000436 3016      0001   000501 3246      0000   000650 353F
  0001   000105 4L        0001   000415 97L       0000   001006 98F       0000   001027 99F       0000 R 000611 AO
  0000 R 000645 DFA       0000 R 000629 DIFV      0000 R 000643 DIFVS     0000 R 000566 DS        0000 R 000647 DSA
  0000 R 000646 DSN       0000 R 000636 DSP       0000 R 000640 DSX       0000 R 000614 DT        0000 R 000210 DV
  0000 R 000616 DVI       0000 R 000617 DVK       0000 R 000231 DVS       0000 R 000632 DVSI      0000 R 000533 DVSK
  0000 R 000627 DWC       0000 R 000356 DX        0000 R 000622 DXP       0000 R 000612 EME       0000 R 000314 F
  0000 R 000063 FA        0000 R 000524 FC        0000 R 000602 FCD       0000 R 000545 FCDDT     0000 R 000252 FD
  0000 R 000335 FDT       0000 R 000273 FG        0000 I 000607 I         0000 I 000615 K         0000 I 000610 L
  0000 I 000031 M         0000 R 000021 PA        0000 R 000503 PC        0000 R 000641 RVEC      0000 R 000146 S
  0000 R 000625 SP        0000 R 000637 SXP       0000 R 000634 S1        0000 R 000535 S2        0000 R 000000 T
  0000 R 000125 V         0000 R 000644 VA        0000 R 000042 VB        0000 R 000442 VC        0000 R 000613 VCO
  0000 R 000441 VE        0000 R 000167 VS        0000 R 000626 W         0000 R 000530 WC        0000 R 000420 WCM
  0000 R 000377 WM        0000 R 000104 X         0000 R 000623 XP        0000 R 000620 XI        0000 R 000621 X2


 00101    1.      DIMENSION T(17),PA(17),VB(17),FA(17),X(17),V(17),S(17),VS(17),          3
 00101    2.     1DV(17),DVS(17),FD(17),FG(17),F(17),FDT(17),DX(17),WM(17),WCM(17),       4
 00101    3.     2VE(17),VC(17),PC(17),FC(17),FCDDT(17),DS(17)                           5
 00103    4.      READ 350, (T(I), I=2,17)                                               6
 00111    5.      READ 350, (PA(I), I=2,17)                                              7
 00117    6.      READ 350, (VB(I), I=2,17)                                              8
 00125    7.  350 FORMAT (8F9.0)                                                         9
 00126    8.  500 L = I                                                                  10
 00127    9.      AO = 0.042                                                             11
 00130   10.      FA(1) = 680.0                                                          12
```

```
00131   11.      1 IF(L.G..50)STOP                                                    13
00133   12.      2 PRINT 10, AO                                                       14
00136   13.        FO(I) = 85.0                                                       15
00137   14.        X(1) = 0.0                                                         16
00140   15.        V(1) = 0.0                                                         17
00141   16.        S(1) = 0.0                                                         18
00142   17.        VS(1) = 0.0                                                        19
00143   18.        T(1) = 0.0                                                         20
00144   19.        DV(1) = 2.0                                                        21
00145   20.        EME = 0.2285                                                       22
00146   21.        VCO = 0.50                                                         23
00147   22.     10 FORMAT(1HI/16X,7HTABLE 5-12 COMPUTED RECOIL AND OPERATING CYLINDE  24
00147   23.       1R DATA FOR ORIFICE AREA OF F5.3,6H SQ IN//21X,8HAVERAGE     PROP  25
00147   24.       2          URIVING     RESULT                    DIFFER        DIF  26
00147   25.       3FER/12X,10HBORE    BORE      GAS     ADAPTER    SPRING,     RECO  27
00147   26.       4IL    RECOIL    RECOIL    RECOIL    RECOIL    RECOIL/117H   TIME  28
00147   27.       5  VOLUME   PRESSURE    FORCE     FORCE     FORCE     FORCE    IMPUL 29
00147   28.       6SE     VEL       VEL     TRAVEL    TRAVEL/115H  MILSEC     CU IN  30
00147   29.       7   PSI        LB        LB        LB        LB        LB-SEC   IN/SE 31
00147   30.       8C    IN/SEC      IN        IN)                                    32
00150   31.        DO 100  I=2,17                                                     33
00153   32.        DT =(T(I)-T(I-1))/1000.0                                           34
00156   33.        FC(I) = 0.515*PA(I)                                                35
00155   34.        K = 0                                                              36
00156   35.      3 DVI = DV(I-1)                                                      37
00157   36.      4 DVK = DVI                                                          38
00160   37.        X1 =  V(I-1)*DT                                                    39
00161   38.        X2 = 0.5*DVK*DT                                                    40
00162   39.        DXP= X1 + X2                                                       41
00163   40.        XP = DXP + X(I-1)                                                  42
00164   41.        FA(I) = FA(I-1) + 1760.0*DXP                                       43
00165   42.        IF(1.GT.2)GO TO 15                                                 44
00167   43.        FO(I) = FO(I-1) + 40.0*DXP                                         45
00170   44.        F(I) = FG(I)-FA(I)/0.45-FO(I)/0.80                                 46
00171   45.        FDT(I) = F(I)*DT                                                   47
00172   46.        DVI = 4.025*FDT (I)                                                48
00173   47.        K = K+1                                                            49
00174   48.        IF(K.GT.3C)STOP                                                    50
00176   49.       85 DIFV =  ABS((DVI-DVK)/DVI)                                       51
00177   50.        IF(DIFV.GT.0.003)GO TO 4                                           52
00201   51.      6 DV(I) = DVI                                                        53
00202   52.        DX(I) = DXP                                                        54
00203   53.        DVS(I) = DV(I)                                                     55
00204   54.        DS(I) = DX(I)                                                      56
00205   55.        SP = XP                                                            57
00206   56.        WM(1) = 0.0                                                        58A
00207   57.        WCM(1) = 0.0                                                       58B
00210   58.        VE(1) = 0.0                                                        58C
00211   59.        VC(1) = 0.0                                                        58D
00212   60.        PC(1) = 0.0                                                        58E
00213   61.        GO TO 97                                                           59
00214   62.       15 WM(I) = 1.42*AO*PA(I)                                            60A
00215   63.        W = WM(I)/1000.0                                                   60B
00216   64.        DWC = W*DT                                                         61
00217   65.        WCM(I) = WCM(I-1) + 1000.0*DWC                                     62A
00220   66.        WC = WCM(I)/1000.0                                                 62B
00221   67.        VE(I) = 19.2*WC*VB(I)                                              63
00222   68.        M = 0                                                              64
```

A-8. (Con't.)

```
00223   69.      15 DVSI = DVS(I-1)
00224   70.      14 DVSK = DVSI + DVI
00225   71.         S1 =  VS(I-1)*DT
00226   72.         S2 = 0.5*DVSK*DT
00227   73.         DSP= S1 + S2
00230   74.         SP = DSP + S(I-1)
00231   75.         SXP = SP - XP
00232   76.         DSX = DSP - DXP
00233   77.         VC(I) = VC0 + 1.767*SXP
00234   78.         RVEC = (VE(I)/VC(I))**1.5
00235   79.         IF(RVEC.GT.1.0)GO TO 17
00237   80.      16 PC(I) = PA(I)*RVEC
00240   81.         GO TO 18
00241   82.      17 PC(I) = PA(I)
00242   83.      18 FC(I) = 1.767*PC(I)
00243   84.         FD(I) = FD(I-1) + 40.0*DSP
00244   85.         FCD = FC(I) - FD(I)/0.80
00245   86.         FCDOT(I) = FCD*DT
00246   87.         DVSI = 35.127*FCDOT(I)
00247   88.         M = M+1
00250   89.         IF(M.GT.30)STOP
00252   90.      95 DIFVS =  ABS((DVSI - DVSK+ DVI)/DVSI  )
00253   91.         IF(DIFVS.GT.0.002)GO TO 14
00255   92.      96 F(I) = FG(I) - FA(I)/0.45 - FC(I)
00256   93.         FDT(I) = F(I)*DT
00257   94.         DVI = 4.546*FDT(I)
00260   95.         K = K+1
00261   96.         IF(K.GT.30)STOP
00263   97.      35 DIFV =  ABS((DVI-DVK)/DVI)
00264   98.         IF(DIFV.GT.0.003)GO TO 4
00266   99.       7 DV(I) = DVI
00267  100.         DX(I) = DXP
00270  101.         DVS(I) = DVSI
00271  102.         DS(I) = DSP
00272  103.      97 V(I) = V(I-1) + DV(I)
00273  104.         VS(I) = VS(I-1) + DVS(I)
00274  105.         X(I) = XP
00275  106.      100 S(I) = SP
00277  107.         GWRITE(6,98)(T(I),VB(I),PA(I),FG(I),FA(I),FD(I),F(I),FDT(I),
00277  108.        1DV(I),V(I),DX(I),X(I),I=2,17)
00320  109.         WRITE(6,99)
00322  110.         GWRITE(6,101)(T(I),WM(I),RCM(I),VE(I),VC(I),PC(I),FC(I),FCDOT(I),
00322  111.        1DVS(I),VS(I),DS(I),S(I),I=2,17)
00343  112.      98 FORMAT(F6.3,F10.1,2F10.0,2F9.0,F10.0,F10.2,2F10.1,2F10.4)
00344  113.      990FORMAT(7/14X,73HGAS      OPER      EQUIV      OPER      OPER      0      CYL
00344  114.        1PER      OPER    DIFFER,13X,7H DIFFER/12X,105H FLOW      CYL      SLIDE
00344  115.        2 CYL      CYL      CYL      PISTON      CYC      SLIDE      VOLUME
00345  116.        3  SLIDE      SLIDE/117H  TIME      RATE      GAS      VEL      TRAVEL
00345  117.        4VOLUME      PRES      FORCE      IMPULSE      VEL      CU IN      CU IN
00346  118.        5  TRAVEL/115H  MILSEC    LB/SECXM    LBX4      IN/SEC      IN      IN/ 1
00346  119.        6 PSI      LB      LB-SEC      IN/SEC      IN/SEC      IN      IN/ 1
00345  120.      101 FORMAT (F8.3,F10.1,1PF10.3,2F10.0,F9.3,2F10.1,2F10.3)
00346  121.         VA =  ABS(V(I7))
00347  122.         IF(VA.LT.0.5)GO TO 103
00351  123.      105 DFA =0.30*EXP(V(I7)/(T(I7)/1000.0))
00352  124.         FA(I) = FA(I)*DFA
00353  125.         L = L+1
00354  126.         GO TO 1
```

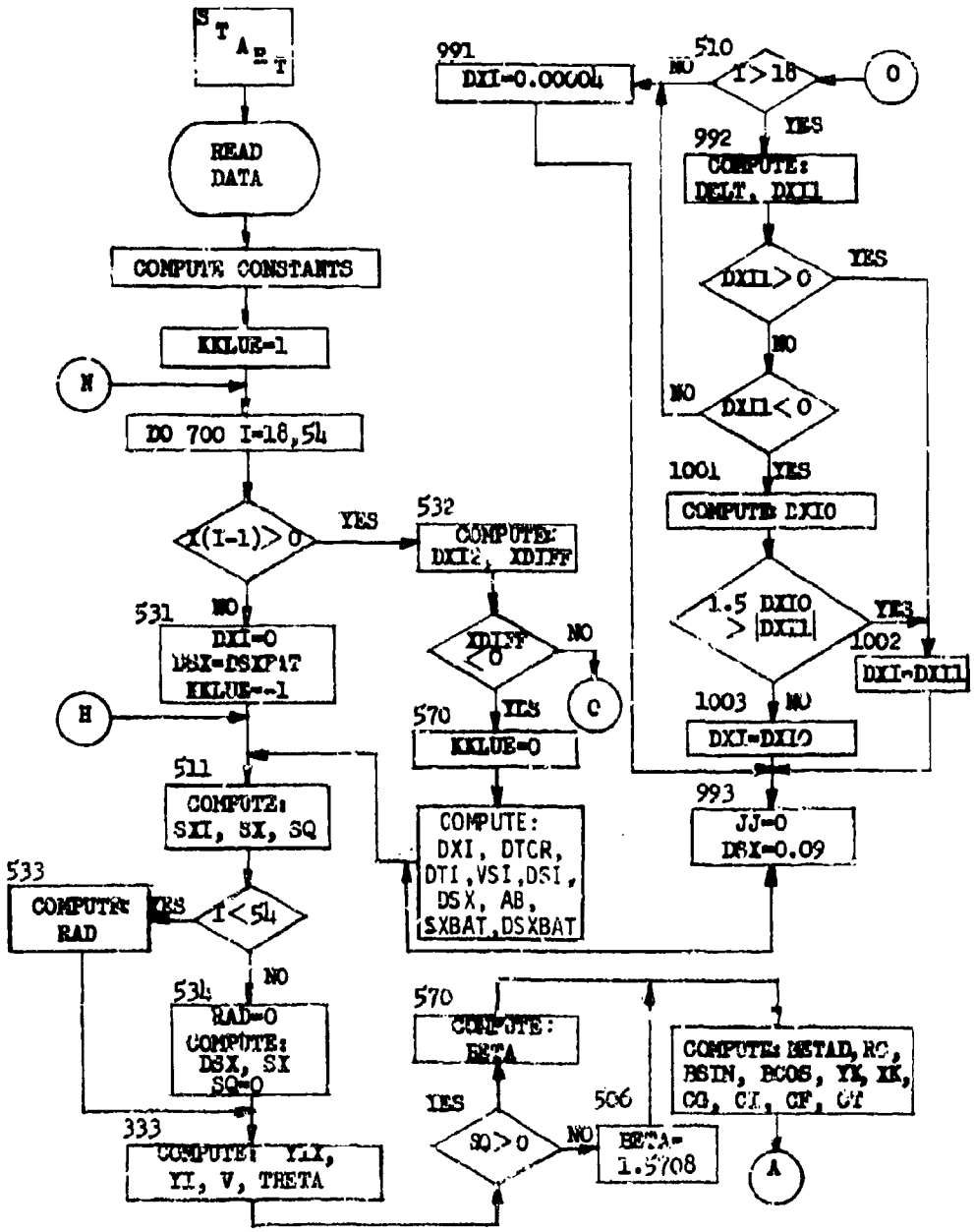
A–8. (Con't.)

```
00355   127.      103 OSN = S(17)-1.67                                    122
00356   128.          OSA =  ABS(OSN)                                     123
00357   129.          IF(OSA.LT.0.034)STOP                                124
00361   130.      115 AO = AO*(1.0 - OSN/1.67)                            125
00362   131.          L = L + 1                                           126
00363   132.          GO TO 1                                             127
00364   133.      900 STOP                                                128
00365   134.          END                                                 129

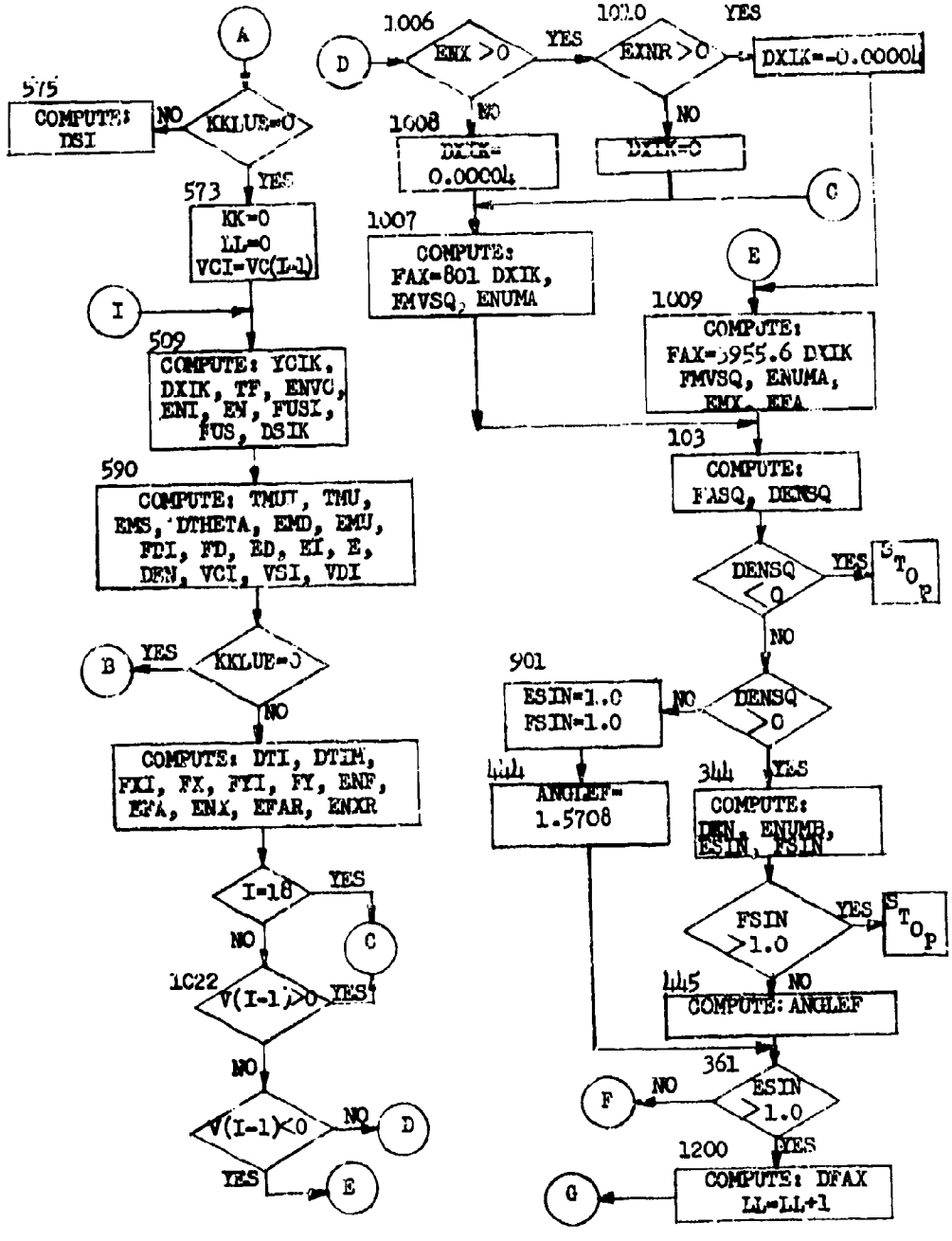
        END OF LISTING.      0 *DIAGNOSTIC* MESSAGE(S).
PHASE 1 TIME =    2 SEC.
PHASE 2 TIME =    0 SEC.
PHASE 3 TIME =    3 SEC.
PHASE 4 TIME =    0 SEC.
PHASE 5 TIME =    2 SEC.
PHASE 6 TIME =    2 SEC.

TOTAL COMPILATION TIME =    9  SEC
```

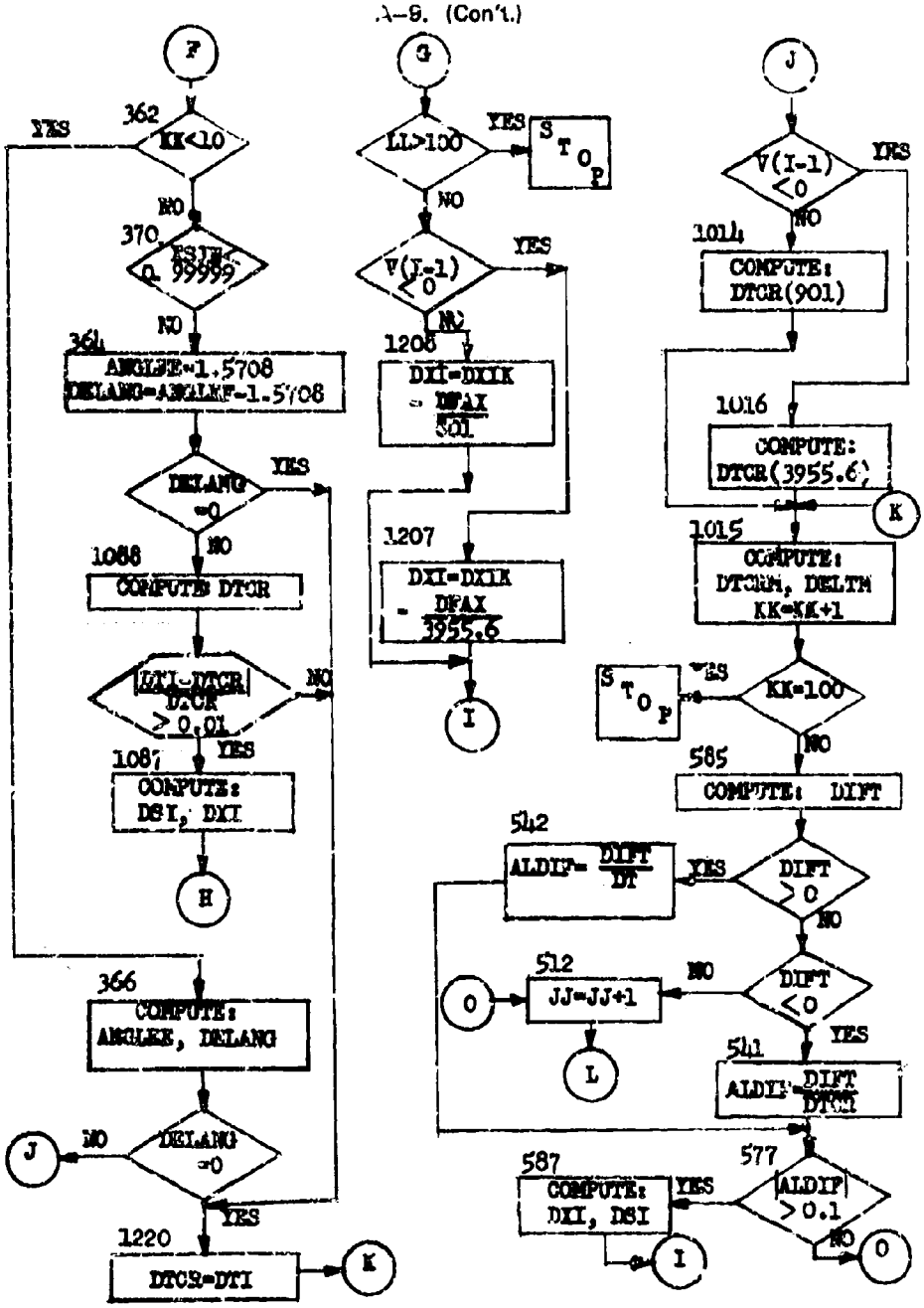
A--9. FLOW CHART FOR CAM AND DRUM DYNAMICS DURING RECOIL



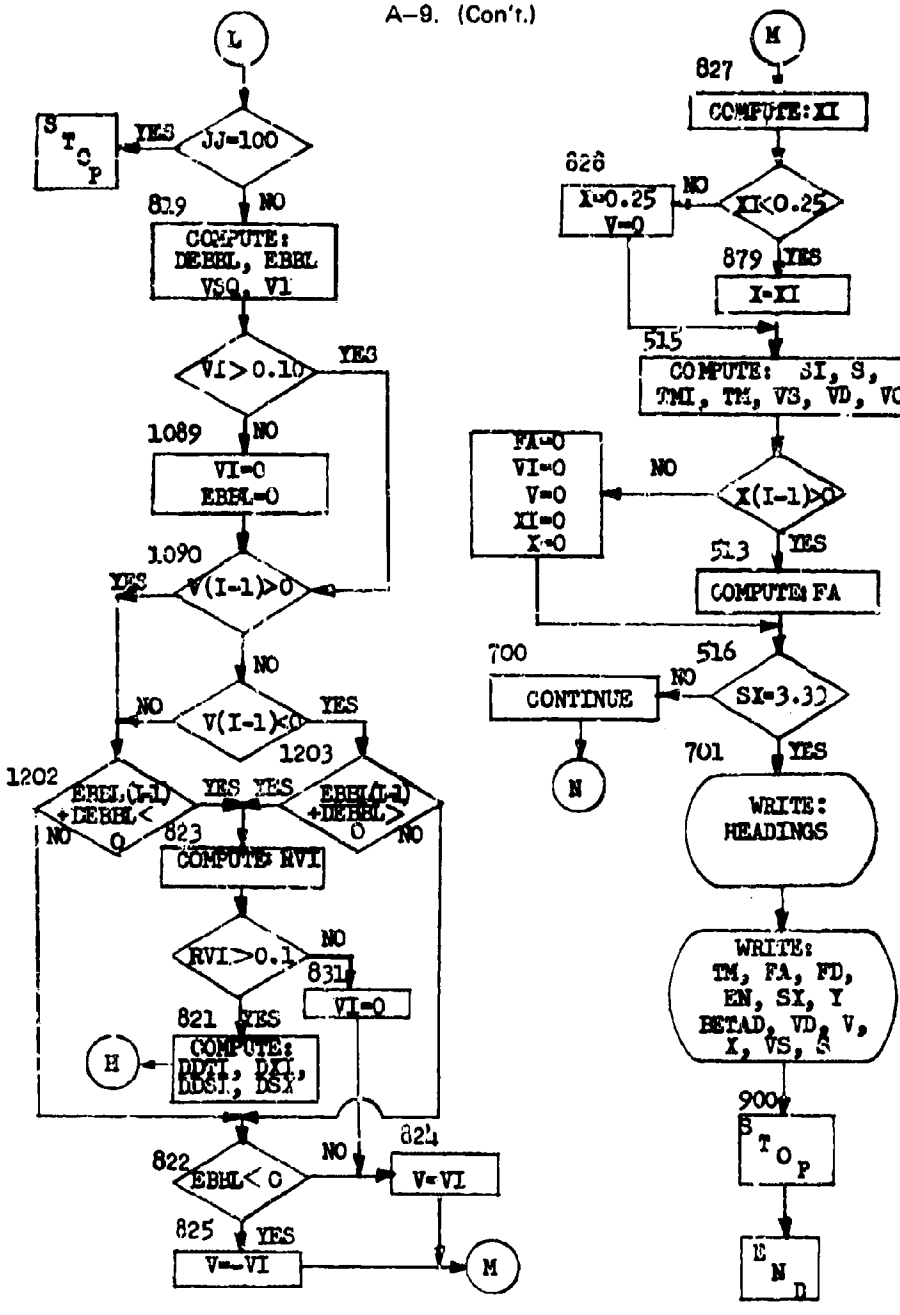
A--9. (Con't.)


A
575
COMPUTE: DSI
NO
KKLUE=0
YES
573
KK=0
LL=0
VCI=VC(L-1)
I
509
COMPUTE: YCIK, DXIK, TF, ENVC, ENI, EN, FUSI, FUS, DSIK
590
COMPUTE: TMUT, TMU, EMS, DTHETA, EMD, EMU, FDI, FD, ED, EI, E, DEN, VCI, VSI, VDI
B
YES
KKLUE=0
NO
COMPUTE: DTI, DTIM, FXI, FX, FYI, FY, ENF, EFA, ENX, EFAR, ENXR
I=18
YES
NO
C
1022
V(I-1)>0
YES
NO
V(I-1)<0
NO
D
YES
E
D
1006
ENX>0
YES
NO
1008
DXIK=0.00004
1010
EXNR>0
YES
NO
DXIK=-0.00004
DXIK=0
C
1007
COMPUTE: FAX=801 DXIK, FMVSQ, ENUMA
E
1009
COMPUTE: FAX=3955.6 DXIK FMVSQ, ENUMA, EMX, EFA
103
COMPUTE: FASQ, DENSQ
DENSQ<0
YES
STOP
NO
901
ESIN=1.0
FSIN=1.0
NO
DENSQ>0
YES
444
ANGLEF=1.5708
344
COMPUTE: DEN, ENUMB, ESIN, FSIN
FSIN>1.0
YES
STOP
NO
445
COMPUTE: ANGLEF
361
F
NO
ESIN>1.0
YES
1200
COMPUTE: DFAX
LL=LL+1
G

A-8. (Con't.)


F
362
KK<10
YES
NO
370
DSIN<0.99999
NO
361
ANGLEE=1.5708
DELANG=ANGLEF-1.5708
DELANG=0
YES
NO
1088
COMPUTE DTCR
DTI-DTCR/DTCR > 0.01
NO
YES
1087
COMPUTE: DSI, DXI
H
366
COMPUTE: ANGLEE, DELANG
DELANG=0
NO
J
YES
1220
DTCR=DTI
K
G
LL>100
YES
STOP
NO
V(J-1)<0
YES
NO
1208
DXI=DXIK - DFAX/501
1207
DXI=DXIK - DFAX/3955.6
I
J
V(I-1)<0
YES
NO
1014
COMPUTE: DTCR(901)
1016
COMPUTE: DTCR(3955.6)
K
1015
COMPUTE: DTCRM, DELTM
KK=KK+1
KK=100
YES
STOP
NO
585
COMPUTE: DIFT
542
ALDIF=DIFT/DT
YES
DIFT>0
NO
512
JJ=JJ+1
NO
DIFT<0
YES
O
L
541
ALDIF=DIFT/DTCR
587
COMPUTE: DXI, DSI
YES
I
577
ALDIF>0.1
NO
O

A–9. (Con't.)


L
JJ=100
YES
NO
829
COMPUTE: DEBBL, EBBL VSQ, VI
VI>0.10
YES
NO
1089
VI=0
EBBL=0
1090
V(I-1)>0
YES
NO
NO
V(I-1)<0
YES
1203
1202
EBBL(I-1) +DEBBL< 0
EBBL(I-1) +DEBBL> 0
YES
YES
NO
NO
823
COMPUTE RVI
RVI>0.1
NO
831
VI=0
821
YES
COMPUTE: DDT, DXT, DDS, DSX
H
822
EBBL< 0
NO
824
V=VI
825
YES
V=-VI
M
M
827
COMPUTE: XI
828
X=0.25 V=0
NO
XI<0.25
879
YES
X=XI
515
COMPUTE: SI, S, TMI, TM, VS, VD, VC
FA=0 VI=0 V=0 XI=0 X=0
NO
X(I-1)>0
513
YES
COMPUTE FA
700
CONTINUE
N
516
NO
SI=3.33
701
YES
WRITE: HEADINGS
WRITE: TM, FA, FD, EN, SI, Y BETAD, VD, V, X, VS, S
900
STOP
END

A–10. LISTING FOR CAM AND DRUM DYNAMICS DURING RECOIL

```
0002 P 002331 FDI       0000 R 002367 FMVSQ     0000 R 002334 FSIN      0000 R 001210 FUS       0000 R 002322 FUSI
0000 R 002302 FX        0000 R 002337 FXI       0000 R 002370 FY        0000 R 002340 FYI       0000 I 002255 I
0000 I 002266 JJ        0000 I 002312 KK        0000 I 002254 KKLUE     0000 I 002313 LL        0000 R 002277 RHO
0000 R 002303 RC        0000 R 002244 RO        0000 R 002372 RVI       0000 R 000066 S         0000 R 002376 SI
0005 R 000600 SIN       0000 R 002276 SQ        0003 R 000000 SWKT      0000 R 000660 SX        0000 R 002278 SXBAT
0000 R 002275 SXI       0000 A 002317 TF        0000 R 002245 T6        0000 R 001452 THETA     0000 R 000572 TM
0000 R 002377 TMI       0000 R 001276 TMU       0000 R 002324 TMUI      0000 R 000154 V         0000 R 001540 VC
0000 R 002314 VCI       0000 R 002315 VCIK      0000 R 001626 VD        0000 R 002335 VDI       0000 R 002371 VI
0000 R 000242 VS        0000 R 002271 VSI       0000 R 002370 VSQ       0000 R 000030 X         0000 R 002262 XDIFF
0000 A 002375 XI        0000 R 002305 XK        0000 R 000746 Y         0000 R 002301 YI        0000 R 002306 YIK
0000 R 002304 YK
```

```
00101    1.      DIMENSION X(54),S(54),V(54),VS(54),FA(54),FD(54),EN(54),TM(54),                1
00101    2.     1SX(54),Y(54),BETAD(54),DSIN(54),FUS(54),TMU(54),E(54),THETA(54),               2
00101    3.     2VC(54),VD(54),BCOS(54),FX(54),FY(54),EBBL(54)                                  3
00103    4.      READ(5,360)ND,TG,EMA,DIE,CY,CX,DF,EMSL,X(16),X(17),S(17),VS(17),               4
00103    5.     1VC(17),FA(17),FD(17),TM(17)                                                    5
00125    6.  360 FORMAT (8F10.0)                                                                 6
00126    7.      V(17) = 0.0                                                                    7
00127    8.      EN(17) = 0.0                                                                   8
00130    9.      SX(17) = 0.0                                                                   9
00131   10.      E(17) = 0.5*EMSL*VS(17)**2                                                    10
00132   11.      FA(17) = 0.0                                                                  11
00133   12.      FY(17) = 0.0                                                                  12
00134   13.      Y(17) = 0.0                                                                   13
00135   14.      FUS(17) = 0.0                                                                 14
00136   15.      TMU(17) = TG                                                                  15
00137   16.      EBBL(17)=0.0                                                                  16
00140   17.      KKLUE = 1                                                                     17
00141   18.      DO 700  I = 16,54                                                             18
00144   19.      IF(X(I-1).GT.0.0)GO TO 532                                                    19
00146   20.  531 DXI = 0.0                                                                     20
00147   21.      DSX = DSXBAT                                                                  21
00150   22.      KKLUE = -1                                                                    22
00151   23.      GO TO 511                                                                     23
00152   24.  532 DXI2 = 2.0*(X(I-2)-X(I-1))                                                    24
00153   25.      XDIFF=X(I-1)-DXI2                                                             25
00154   26.      IF(XDIFF.LT.0.0)GO TO 570                                                     26
00156   27.  510 IF(I.GT.18)GO TO 992                                                          27
00160   28.  991 DXI = 0.00004                                                                 28
00161   29.      GO TO 993                                                                     29
00162   30.  992 DELT = (TM(I-1)-TM(I-2))/1000.0                                               30
00163   31.      DXI1 = V(I-1)*DELT                                                            31
00164   32.      IF(DXI1.GT.0.0)GO TO 1002                                                     32
00166   33.      IF(DXI1.LT.0.0)GO TO 1001                                                     33
00170   34.      GO TO 991                                                                     34
00171   35.  1001 DXI0 = 0.25-X(I-1)                                                          35
00172   36.      IF(1.5*DXI0.GT.ABS(DXI1))GO TO 1002                                           36
00174   37.  1003 DXI = DXI0                                                                  37
00175   38.      GO TO 993                                                                     38
00176   39.  1002 DXI = DXI1                                                                  39
00177   40.  993 JJ=0                                                                         40
00200   41.      DSX = 0.09                                                                   41A
00201   42.      GO TO 511                                                                    41B
00202   43.  570 KKLUE = 0                                                                    42
```

A–10. (Con't.)

```
00203   44.          DXI   = XI[I-1]                                          43
00204   45.          DTCR = DXI/V(I-1)                                        44
00205   46.          DTI = DTCR                                               45
00206   47.          VSI = VS(I-1)                                            46
00207   48.          DSI = VSI*DTI                                            47
00210   49.          DSX = DSI + DXI                                          48
00211   50.          AB = 1                                                   49
00212   51.          SXBAT = 54.0 - AB                                        50
00213   52.          DSXBAT = (5.0 - SX(I-1) - DSX)/SXBAT                     51
00214   53.      511 SX I = SX(I-1) + DSX                                     52
00215   54.          SX(I) = SXI                                              53
00216   55.          SQ = 11.6889 - SX(I)**2                                  54
00217   56.          IF(I.LT.54)GO TO 533                                     55
00221   57.      534 RAD = 0.0                                                56
00222   58.          DSX=3.33-SX(53)                                          57
00223   59.          SX(I)=3.33                                               58
00224   60.          SW = 0.0                                                 59
00225   61.          GO TO 335                                                60
00226   62.      533 RAD=SQRT(SQ)                                             61
00227   63.      333 YIX= 0.6856*RAD                                          62
00230   64.          YI  = 2.15 - YIX                                         63
00231   65.          Y(I) = YI                                                64
00232   66.          THETA(I) = 29.6987*Y(I)                                  65
00233   67.          IF(SW.GT.0.0)GO TO 507                                   66
00235   68.      506 BETA = 1.5708                                            67
00236   69.          GO TO 508                                                68
00237   70.      507 BETA =  ATAN(0.6856*SX(I)/RAD)                           69
00240   71.      508 BETAD(I) = 57.296*BETA                                   70
00241   72.          RC = (11.6889 - 0.5831*SX(I)**2)**1.5/7.1595             71
00242   73.          DSIN(I) =  SIN(BETA)                                     72
00243   74.          DCOS(I)=  COS(BETA)                                      73
00244   75.          XK = DCOS(I)- 0.05*DSIN(I)                               74
00245   76.          AK = DSIN(I) + 0.05*DCOS(I)                              75
00246   77.          CG = CT*YK - CX*XK                                       76
00247   78.          CI = DIE*DCOS(I)/TRO*RC*CG)                              77
00250   79.          CF = 0.15*YK                                             78
00251   80.          CT = CX*AK + 0.1*YK                                      79
00252   81.          IF(XKLUE.GE.0)GO TO 573                                  80
00254   82.      575 DSI = DSX - DXI                                          81
00255   83.      573 AK = 0                                                   82
00256   84.          CL = 0                                                   83
00257   85.          VCI = VC(I-1)                                            84
00260   86.      509 VCIK = VCI                                               85
00261   87.          DXIK = DXI                                               86
00262   88.          TF = TG/CG                                               87
00263   89.          ENVC = CI*VCIK**2                                        88
00264   90.          ENI = ENVC + TF                                          89
00265   91.          EN(I) = ENI                                              90
00266   92.          FUSI  = CF*EN(I)                                         91
00267   93.          FUS(I) = FUSI                                            92
00270   94.          DSIK = DSI                                               93
00271   95.      590 TMUI  = CF*EN(I) + TG                                    94
00272   96.          TMU(I)= TMUI                                             95
00273   97.          ENS = 0.5*(FUS(I-1) + FUS(I))*DSIK                       96
00274   98.          DTHETA = (Y(I) - Y(I-1))/RD                              97
00275   99.          ENU = 0.5*(TMU(I-1) + TMU(I))*DTHETA                     98
00276  100.          ENU = ENS + ENU                                          99
00277  101.          FUI   = FU(I-1) + 40.0*DSIK                             100
```

A-10. (Con't.)

```
00330  102.          FD(I) = FDI                                                    101
00331  103.          ED = (FD(I-1) + FD(I))*0.5*DSIK                                102
00332  104.          EI = E(I-1) - EMU - ED                                         103
00333  105.          E(I) = EI                                                      104
00334  106.          DEN = 0.5*(CMSL*BCOS(I)**2+DIE*(SIN(Y/RU)**2)                  105
00335  107.          VCI = SQRT(E(I)/DEN)                                           106
00336  108.          VSI = VCI*BCOS(I)                                              107
00337  109.          VDI = VCI*BSIN(I)                                              108
00340  110.          IF(KKLUC.EQ.0)GO TO 512                                        109
00342  111.      572 DTI = DSIK/( (VSI + VS(I-1))*0.5)                              110
00345  112.          DTIK = 1000.0*DTI                                              111
00346  113.          FXI = EN(I)*XK                                                 112
00346  114.          FX(I) = FXI                                                    113
00347  115.          FYI = EN(I)*YK                                                 114
00350  116.          FY(I) = FYI                                                    115
00351  117.          EMF = 0.5*(FX(I-1)+FX(I))                                      116
00352  118.          EFA = 0.45*FA(I=1)                                             117
00353  119.          ENX = EMF-EFA                                                  118
00354  120.          EFAR = FA(I-1)/0.45                                            119
00355  121.          ENXR = EMF - EFAR                                              120
00356  122.          IF(I.EQ.10)GO TO 1007                                          121
00357  123.     1022 IF(V(I-1).GT.0.0)GO TO 1007                                    122
00361  124.          IF(V(I-1).LT.0.0)GO TO 1009                                    123
00363  125.     1006 IF(ENX.GT.0.0)GO TO 1010                                       124
00365  126.     1008 DXIK=0.00004                                                   125
00366  127.          GO TO 1007                                                     126
00367  128.     1010 IF(ENXR.GT.0.0)GO TO 1012                                      127
00371  129.     1011 DXIK = 0.0                                                     128
00372  130.          GO TO 1007                                                     129
00373  131.     1012 DXIK=-0.00004                                                  130
00374  132.     1007 FAX = 801.0*DXIK                                               131
00375  133.          FMVSQ = 801.0*EMR*V(I-1)**2                                    132
00376  134.          ENUMA= FAX + ENX                                               133
00377  135.          GO TO 1013                                                     134
00400  136.     1009 FAX = 3955.6*DXIK                                              135
00401  137.          FMVSQ = 3955.6*V(I-1)**2*EMR                                   136
00402  138.          ENUMA = FAX + ENXR                                             137
00403  139.          ENX = ENXR                                                     138
00404  140.          EFA = EFAR                                                     139
00405  141.     1013 FASQ = ENX**2                                                  140
00406  142.          DENSQ = FASQ + FMVSQ                                           141
00407  143.          IF(DENSQ.LT.0.0)STOP                                           142
00411  144.          IF(DENSQ.GT.0.0)GO TO 344                                      143
00413  145.      901 ESIN = 1.0                                                     144
00414  146.          FSIN =1.0                                                      145
00415  147.          GO TO 446                                                      146
00416  148.      344 DENOM = SQRT(DENSQ)                                            147
00417  149.          ENUMB = ENX                                                    148
00420  150.          ESIN  = ABS(ENUMA/DENOM)                                       149
00421  151.          FSIN  = ABS(ENUMB/DENOM)                                       150
00422  152.      350 IF(FSIN.GT.1.0)STOP                                            151
00424  153.      445 ANGLEF= ASIN(FSIN)                                             152
00425  154.          GO TO 351                                                      153
00426  155.      446 ANGLEF = 1.5708                                                154
00427  156.      351 IF(ESIN.GT.1.0)GO TO 1200                                      155A
00431  157.          GO TO 362                                                      1558
00432  158.     1200 DFAX  = TENOMA - DENOM                                         156
00433  159.          LL = LL+1                                                      157
```

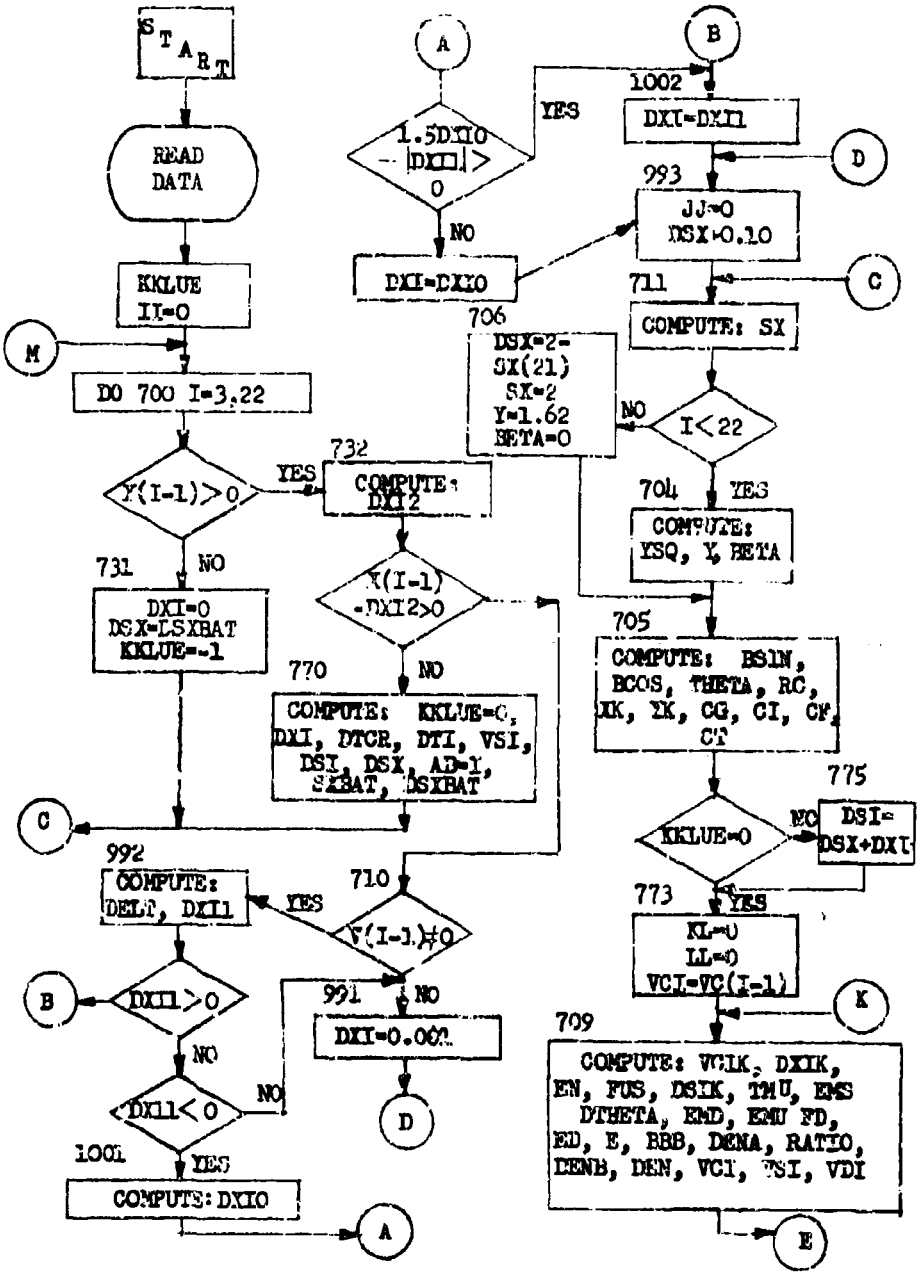
```
00404   160.          IF(LL.EQ.100)STOP                                    158
00406   161.    1201 IF(V(I-1).LT.0.0)GO TO 1207                           159
00410   162.    1208 DXI = DXIK - DFAX/801.6                               160
00411   163.         GO TO 509                                             161
00412   164.    1207 DXI = DXIK - DFAX/3955.6                              162
00413   165.         GO TO 509                                             163
00414   166.     362 IF(KK.LT.10)GO TO 366                                 164
00416   167.     370 IF(ESIN.LT.0.999990)GO TO 366                         165
00420   168.     364 ANGLEE = 1.5708                                       166
00421   169.         DELANG=ANGLEF-1.5708                                  167
00422   170.         IF(DELANG.GT.0.0)GO TO 1088                           168
00424   171.         IF(DELANG.LT.0.0)GO TO 1088                           169
00426   172.         GO TO 1220                                            170
00427   173.    1088 DTCR= (SQRT(EMR/801.0))* ABS(DELANG)                  171
00430   174.         IF((ABS(DTI-DTCR)/DTCR).GT.0.01)GO TO 1087            172
00432   175.         GO TO 1220                                            173
00433   176.    1087 DSX=DTCR*(VS(I-1)+VSI)/2.0                            174
00434   177.         DXI =V(I-1)*DTCR/2.0                                  175
00435   178.         GO TO 511                                             176
00436   179.     366 ANGLEE=ASIN(ESIN)                                     177
00437   180.     446 DELANG = ANGLEF - ANGLEE                              178
00440   181.         IF(DELANG.GT.0.0)GO TO 1017                           179
00442   182.         IF(DELANG.LT.0.0)GO TO 1017                           180
00444   183.    1220 DTCR=DTI                                              181
00445   184.         GO TO 1015                                            182
00446   185.    1017 IF(V(I-1).LT.0.0)GO TO 1016                           183
00450   186.    1014 DTCR = (SQRT(EMR/801.0))* ABS(DELANG)                 184
00451   187.         GO TO 1015                                            185
00452   188.    1016 DTCR= (SQRT(EMR/3955.6))* ABS(DELANG)                 186
00453   189.    1015 DTCRK = 1000.0*DTCR                                   187
00454   190.         DELTM = DTIM - DTCRM                                  188
00455   191.         KK = KK + 1                                           189
00456   192.         IF(KK.EQ.100)STOP                                     190
00460   193.     585 DIFT = DTI - DTCR                                     191
00461   194.         IF(DIFT.GT.0.0)GO TO 542                              192
00463   195.         IF(DIFT.LT.0.0)GO TO 541                              193
00465   196.         GO TO 512                                             194
00465   197.     541 ALDIF =     (DIFT/DTCR)                               195
00467   198.         GO TO 577                                             196
00470   199.     542 ALDIF =     (DIFT/DTI)                                197
00471   200.     577 IF(ABS(ALDIF).GT.0.01)GO TO 587                       197A
00473   201.         GO TO 512                                             197B
00474   202.     587 DXI = DXIK*(1.0 + ALDIF/4.0)                          198
00475   203.         DSI = DSX + DXI                                       199
00476   204.         GO TO 509                                             200
00477   205.     512 JJ=JJ+1                                               201
00500   206.         IF(JJ.EQ.100)STOP                                     202
00502   207.     819 DEBBL =  ABS(DXIK)*(-ENUMA)                           203
00503   208.         EBBL(I) = EBBL(I-1) + DEBBL                           204
00504   209.         VSQ = 2.0*EBBL(I)/EMR                                 205
00505   210.         VI = SQRT(ABS(VSQ))                                   206
00506   211.         IF(VI.GT.0.10)GO TO 1090                              207
00510   212.    1089 VI=0.0                                                208
00511   213.         EBBL(1)=0.0                                           209
00512   214.    1090 IF(V(I-1).GT.0.0)GO TO 1202                           210
00514   215.         IF(V(I-1).LT.0.0)GO TO 1203                           211
00516   216.         GO TO 822                                             212
00517   217.    1202 IF(EBBL(I-1)+DEBBL.LT.0.0)GO TO 823                   213
```

A–10. (Con't.)

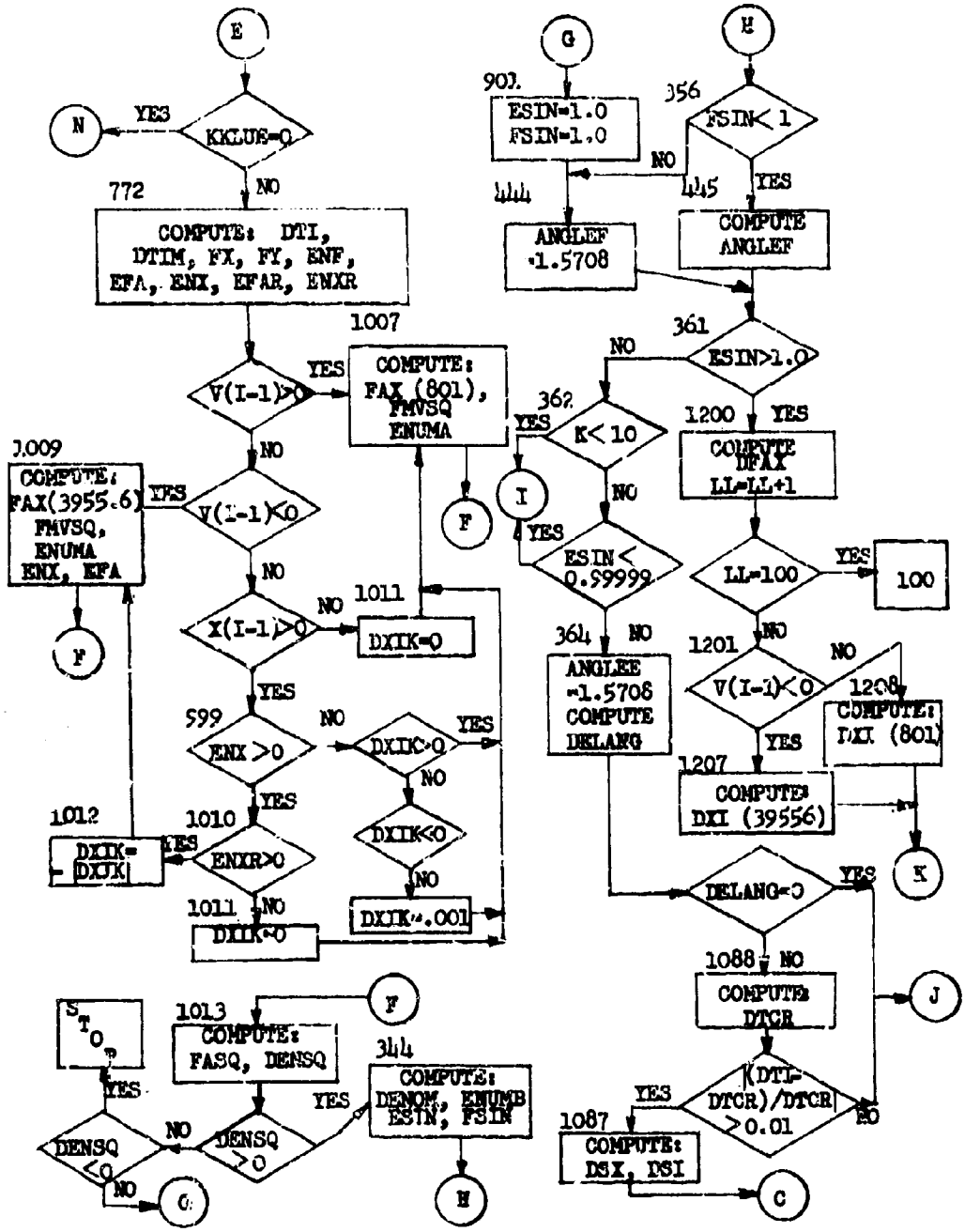
```
00521  218.        GO TO 822
00522  219.    503 IF((EBBL(I-1)*EBBL).GT.0.0)GO TO 823
00524  220.        GO TO 822
00525  221.    822 RVI = VI/ABS (V(I-1))
00526  222.        IF(RVI.GT.0.10)GO TO 821
00530  223.    831 VI = 0.0
00531  224.        GO TO 824
00532  225.    821 DOTI = DTI*(1.0 - ( ABS(V(I-1))/(( ABS(V(I-1)) + VI)+4.6)))
00533  226.        DXI = V(I-1)*DOTI
00534  227.        DOSI = VS(I-1)*DOTI
00535  228.        DSI = DOSI * DXI
00536  229.        GO TO 515
00537  230.    822 IF(EBBL(I).LT.0.0)GO TO 825
00541  231.    824 V(I) = VI
00542  232.        GO TO 827
00543  233.    825 V(I) = -VI
00544  234.    827 XI = X(I-1) - DXI
00545  235.        IF(XI.LT.0.25)GO TO 829
00547  236.    828 X(I) = 0.25
00550  237.        V(I) = 0.0
00551  238.        GO TO 515
00552  239.    829 X(I) = XI
00553  240.    515 SI = S(I-1) + DSIK
00554  241.        S(I) = SI
00555  242.        TMI = TM(I-1)+ 1000.0*DTI
00556  243.        TM(I) = TMI
00557  244.        VS(I) = VSI
00560  245.        VD(I) = VDI
00561  246.        VC(I) = VCI
00562  247.        IF(X(I-1).GT.0.0)GO TO 513
00564  248.    514 FA(I) =   0.0
00565  249.        VI = 0.0
00566  250.        V(I) = VI
00567  251.        XI = 0.0
00570  252.        X(I) = XI
00571  253.        GO TO 516
00572  254.    513 FAI = 680.0 + 1780.0*X(I)
00573  255.        F(I) = FAI
00574  256.    516 IF(SX(I).GT.3.33)GO TO 701
00576  257.    700 CONTINUE
00600  258.    701 WRITE(6,110)
00602  259.    110 FORMAT(1H1/38X,46HTABLE 5-13 CAM AND DRUM DYNAMICS DURING RECOIL//
00602  260.       1132X,48HRECOIL   DRIVING   NORMAL    AXIAL    PERIPH/22X,17HCOUNT
00602  261.       2ER   COUNTER/12X,105H ADAPTER   SPRING      CAM          CAM       CAM
00602  262.       3      CAM      DRUM    RECOIL    RECOIL    SLIDE      SLIDE/
00602  263.       43X,114H TIME      FORCE     FORCE     FORCE     TRAVEL     TRAVEL
00602  264.       5 SLOPE     VEL       VEL      POSITION    VEL       TRAVEL/
00602  265.       62X,113H MILSEC     LB        LB        LB        IN         IN
00602  266.       7 DEGREE    IN/SEC    IN/SEC      IN      IN/SEC     IN/)
00603  267.         WRITE(6,702)(TM(I),FA(I),FD(I),EN(I),SX(I),V(I),BETAD(I),VD(I),
00603  268.        1V(I),X(I),VS(I),S(I),I=1,N)
00624  269.    7020FORMAT (F10.5,F9.0,F9.1,F11.0,2F10.4,F8.1,F10.1,2F10.4,F10.1,
00624  270.        1F10.3)
00625  271.    900 STOP
00626  272.        END

      END OF LISTING.      0 DIAGNOSTIC MESSAGE(S).
PHASE 1 TIME =   4 SEC.
```

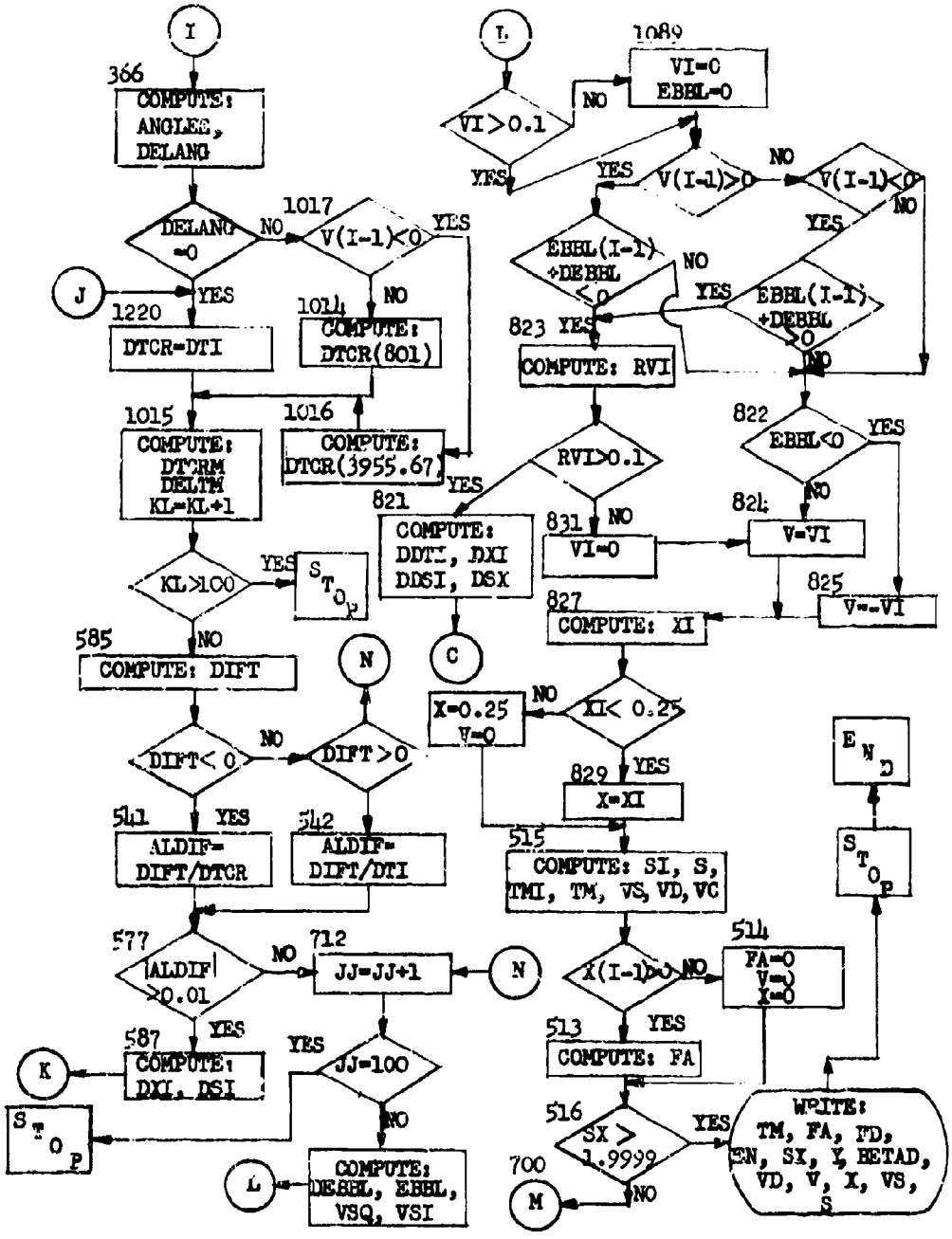
A–11. FLOW CHART FOR CAM AND DRUM DYNAMICS DURING COUNTERRECOIL



A-11 (Con't.)


E
N
YES
KKLUE=0
NO
772
COMPUTE: DTI, DTIM, FX, FY, ENF, EFA, ENX, EFAR, ENXR
V(I-1)>0
YES
1007
COMPUTE: FAX (801), FMVSQ ENUMA
NO
1009
COMPUTE: FAX(3955.6) FMVSQ, ENUMA ENX, EFA
V(I-1)<0
YES
NO
F
X(I-1)>0
NO
1011
DXIK=0
YES
599
ENX>0
NO
DXIK>0
YES
NO
1012
DXIK=DXIX
YES
1010
ENXR>0
DXIK<0
NO
1011
DXIK=0
DXIK=.001
F
1013
COMPUTE: FASQ, DENSQ
344
COMPUTE: DENOM, ENUMB ESIN, FSIN
YES
DENSQ<0
NO
DENSQ>0
YES
NO
G
H
G
903
ESIN=1.0 FSIN=1.0
444
ANGLEF =1.5708
H
356
FSIN<1
NO
445
YES
COMPUTE ANGLEF
361
ESIN>1.0
NO
YES
362
K<10
YES
NO
I
ESIN<0.99999
YES
364
NO
ANGLEE =1.5708 COMPUTE DELANG
1200
YES
COMPUTE DFAX LL=LL+1
LL=100
YES
100
NO
1201
V(I-1)<0
NO
YES
1208
COMPUTE: DXI (801)
1207
COMPUTE: DXI (39556)
K
DELANG<0
YES
1088
NO
COMPUTE: DTCR
J
(DTL-DTCR)/DTCR >0.01
YES
NO
1087
COMPUTE: DSX, DSI
C

A–11. (Con't.)


I
366
COMPUTE: ANGLEE, DELANG
DELANG =0
NO
1017
V(I-1)<0
YES
J
YES
1220
DTCR=DTI
NO
1014
COMPUTE: DTCR(801)
1015
COMPUTE: DTCRM DELTM KL=KL+1
1016
COMPUTE: DTCR(3955.67)
KL>100
YES
STOP
NO
585
COMPUTE: DIFT
DIFT< 0
NO
DIFT>0
N
541
YES
ALDIF= DIFT/DTCR
542
ALDIF= DIFT/DTI
577
ALDIF >0.01
NO
712
JJ=JJ+1
N
YES
587
COMPUTE: DXI, DSI
K
YES
JJ=100
NO
STOP
L
COMPUTE: DEBBL, EBBL, VSQ, VSI
L
1089
VI=0 EBBL=0
VI>0.1
NO
YES
YES
V(I-1)>0
NO
V(I-1)<0
NO
YES
EBBL(I-1) +DEBBL <0
NO
YES
EBBL(I-1) +DEBBL >0
NO
823
YES
COMPUTE: RVI
RVI>0.1
YES
821
COMPUTE: DDTI, DXI DDSI, DSX
C
831
NO
VI=0
822
EBBL<0
YES
NO
824
V=VI
825
V=-VI
827
COMPUTE: XI
XI< 0.25
NO
X=0.25 V=0
YES
829
X=XI
515
COMPUTE: SI, S, TMI, TM, VS, VD, VC
X(I-1)>0
NO
514
FA=0 V=0 X=0
YES
513
COMPUTE: FA
516
SX > 1.9999
YES
700
M
NO
WRITE: TM, FA, FD, EN, SX, Y, BETAD, VD, V, X, VS, S
STOP
END

A–12. LISTING FOR CAM AND DRUM DYNAMICS DURING COUNTERRECOIL

```
0000 R 001040 FAS0      0004 R 001035 FAX       0008 R 000306 FD        0010 R 001036 FNS0      0014 R 001040 FNS1
0018 R 000342 FUS       001C R 000342 FX        0020 R 000370 FY        0024 I 000756 I         0028 I 000756 II
002C I 000776 JJ        0030 I 000754 KKLUE     0034 I 001004 LL        0038 I 001007 LL1       003C R 001005 NNTYP
0040 R 000777 RC        0044 R 000734 RD        0048 R 001061 RVI       004C R 000054 S         0050 R 001065 SI
0054 R 000777 SIGMA     0058 R 000000 SIGMT     005C R 001002 SX        0060 R 000770 SXBAT     0064 R 000706 T0
0068 R 000040 SIN       006C R 000000 SIMT      0070 R 001004 THI       0074 R 000410 THU       0078 R 000412 V
007C R 001130 THETA     0080 R 000436 TM        0084 R 001004 TMI       0088 R 000414 VD        008C R 001005 VDY
0090 R 000340 VC        0094 R 001010 VCI       0098 R 001011 .CIK      009C R 000414 VS        00A0 R 000000 X
00A4 R 001040 VI        00A8 R 000566 VS        00AC R 000765 VSI       00B0 R 001057 V26       00B4 R 000000 Y
00B8 R 001004 XI        00BC R 001004 XK        00C0 R 000026 Y         00C4 R 001001 YK        00C8 R 000776 YSI
```

```
00101    1.      0DIMENSION X(22),Y(22),S(22),SX(22),THETA(22),BETAD(22),BSIN(22),                    1
00101    2.      1BCOS(22),FA(22),FD(22),EN(22),FUS(22),YMU(22),TM(22),E(22),V(22),                   2
00101    3.      2VC(22),VS(22),VD(22),FX(22),FY(22),EBBL(22)                                         3
00103    4.       RE(0)=5.37D)/RD,T0,EPR,DIS,CY,CX,DF, DMELN,XI2),SI2),SX(2),                         4
00103    5.      1FA(2),FD(2),EN(2),V(2),VC(2),VS(2),FX(2),FY(2),FUS(2),YU(2),E(2),                   5
00103    6.      2TM(2),TMU(2),Y(2),BETAD(2),TM(1),X(1)                                               6
00141    7.    370 FORMAT (6F12.0)                                                                    7
00142    8.        KKLUE = 1                                                                          8
00143    9.        II = 0                                                                             9
00144   10.        DO 700 I = 3,22                                                                   10
00147   11.        IF(X(I-1).GT.0.0)GO TO 732                                                        11
00151   12.    731 DXI = 0.0                                                                         12
00152   13.        DSX = DSXBAT                                                                      13
00153   14.        KKLUE = -1                                                                        14
00154   15.        GO TO 711                                                                         15
00155   16.    732 DXI2 = 2.0*(X(I-2)-X(I-1))                                                        16
00156   17.        IF((X(I-1)-DXI2).GT.0.0)GO TO 710                                                 17
00160   18.    770 KKLUE = 0                                                                         18
00161   19.        DXI = X(I-1)                                                                      19
00162   20.        DTCR = DXI/V(I-1)                                                                 20
00163   21.        DTI = DTCR                                                                        21
00164   22.        VSI = VS(I-1)                                                                     22
00165   23.        DSI = VSI*DTI                                                                     23
00165   24.        DSX = DSI - DXI                                                                   24
00167   25.        AB = I                                                                            25
00170   26.        SXBAT = 22.0 - AB                                                                 26
00171   27.        DSXBAT = (2.0 - SX(I-1) - DSX)/SXBAT                                              27
00172   28.        GO TO 711                                                                         28
00173   29.    710 IF(V(I-1).GT.0.0)GO TO 992                                                        29
00175   30.        IF(V(I-1).LT.0.0)GO TO 992                                                        30
00177   31.    991 DXI = 0.001                                                                       31
00200   32.        GO TO 993                                                                         32
00201   33.    992 DELT = (TM(I-1)-TM(I-2))/1000.0                                                   33
00202   34.        DXI1 = V(I-1)*DELT                                                                34
00203   35.        IF(DXI1.GT.0.)GO TO 1002                                                          35
00205   36.        IF(DXI1.LT.0.0)GO TO 1001                                                         36
00207   37.        GO TO 991                                                                         37
00210   38.   1001 DXI0 = 0.25-X(I-1)                                                                38
00211   39.        IF((1.5*DXI0-ABS(DXI1)).GT.0.0)GO TO 1002                                         39
00213   40.   1003 DXI = DXI0                                                                       40
00214   41.        GO TO 993                                                                         41
00215   42.   1002 DXI = DXI1                                                                       42
00216   43.    993 JJ=0                                                                             43
00217   44.        DSX = 0.10                                                                        44
00220   45.    711 SX(I) = SX(I-1) + DSX                                                            45
```

```
00221   46.          IF(I.LT.22)GO TO 704
00223   47.    706 DSX = 2.0 - SX(21)
00224   48.          SX(I) = 2.0
00225   49.          Y(I) = 1.62
00226   50.          BETA = 0.0
00227   51.          GO TO 705
00230   52.    704 YSQ =  SQRT(4.0-(2.0 - SX(I))**2)
00231   53.          Y(I) = 0.81*YSQ
00232   54.          BETA =  ATAN(0.81*2.0-SX(I))/YSQ)
00233   55.          BETAD(I)=57.296*BETA
00234   56.    705 BSIN(I) =  SIN(BETA)
00235   57.          BCOS(I) =  COS(BETA)
00236   58.          THETA(I) = 19.0587*((Y(I)*2.15)
00237   59.          RC = (4.0 - 0.3439*(2.0-SX(I))**2)**1.5/3.24
00240   60.          XK = BSIN(I) -0.05*BCOS(I)
00241   61.          YK = BCOS(I) +0.05*BSIN(I)
00242   62.          CG = CT*YK - CX*XK
00243   63.          CI = DIE*BCOS(I)/(PD*RC*CG)
00244   64.          CF = 0.15*YK
00245   65.          CT = CX*XK + 0.1*YK
00246   66.          IF(KKLUE.EQ.0  )GO TO 775
00250   67.    775 DSI = DSX +DX1
00251   68.    773 KL = 0
00252   69.          LL = 0
00253   70.          VCI = VC(I-1)
00254   71.    709 VCIK = VCI
00255   72.          DXIK = DXI
00256   73.          EN(I)= ABS(CI*VCIK**2 + TG/CG)
00257   74.          FUS(I) = CF*EN(I)
00260   75.          DSIK = DSI
00261   76.          TMU(I) = CT*EN(I) + TG
00262   77.          EMS = 0.5*(FUS(I-1) + FUS(I))*DSIK
00263   78.          DTHETA = (Y(I) - Y(I-1))/RD
00264   79.          EMD = 0.5*(TMU(I-1)+ TMU(I))*DTHETA
00265   80.          EMU = EMS + EMD
00266   81.          FD(I) = FD(I-1) - &0.0*DSIK
00267   82.          ED = (FD(I-1)*FD(I))*0.50*DSIK
00270   83.          E(I) =E(I-1)+ED-EMU
00271   84.          BBB=BCOS(I)
00272   85.          DENA=EMSLR*BBB**2
00273   86.          RATIO=BSIN(I)/RD
00274   87.          DENB=DIE*RATIO**2
00275   88.          DEN=0.5*(DENA*DENB)
00276   89.          VCI =  SQRT(E(I)/DEN)
00277   90.          VSI = VCI*BCOS(I)
00300   91.          VDI = VCI*BSIN(I)
00301   92.          IF(KKLUE.EQ.0)  GO TO 712
00303   93.    772 DTI = DSIK/( (VSI + VS(I-1))*0.5)
00304   94.          DTIM = 1000.0*DTI
00305   95.          FX(I) = EN(I)*XK
00306   96.          FY(I) = EN(I)*YK
00307   97.          ENF = 0.5*(FX(I-1)+FX(I))
00310   98.          EFA = 0.65*FA(I-1)
00311   99.          ENX = ENF-EFA
00312  100.          EFAR = FA(I-1)*0.45
00313  101.          ENXR = ENF - EFAR
00314  102.          IF(V(I-1).GT.0.0)GO TO 1007
00316  103.          IF(V(I-1).LT.0.0)GO TO 1009
```

A-12. (Con't.)

```
00320  104.  1006 IF(X(I-1).GT.0.0)GO TO 999
00322  105.       GO TO 1011
00323  106.   999 IF(ENX.GT.0.0)GO TO 1010
00325  107.  3007 IF(DXIK.GT.0.0)GO TO 1007
00327  108.       IF(DXIK.LT.0.0)GO TO 1012
00331  109.  3008 DXIK=0.001
00332  110.       GO TO 1007
00333  111.  1010 IF(ENXR.GT.0.0)GO TO 1012
00335  112.  1011 DXIK = 0.0
00336  113.       GO TO 1007
00337  114.  1012 DXIK = - ABS(DXIK)
00340  115.       GO TO 1009
00341  116.  1007 FAX = 801.0*DXIK
00342  117.       FMYSQ = 801.0*ENR*V(I-1)**2
00343  118.       ENUMA= FAX + ENX
00344  119.       GO TO 1013
00345  120.  1009 FAX = 3955.6*DXIK
00346  121.       FMYSQ = 3955.6*V(I-1)**2*ENR
00347  122.       ENUMA = FAX + ENXR
00350  123.       ENX = ENXR
00351  124.       EFX = EFAR
00352  125.  1013 FASQ = ENX**2
00353  126.       DENSQ = FASQ + FMYSQ
00354  127.       IF(DENSQ.GT.0.0)GO TO 344
00356  128.       IF(DENSQ.LT.0.0)STOP
00360  129.       GO TO 901
00361  130.   344 DENOM =  SQRT(DENSQ)
00362  131.       ENUMB = ENX
00363  132.       ESIN  = ABS(ENUMA/DENOM)
00364  133.       FSIN  = ABS(ENUMB/DENOM)
00365  134.       GO TO 356
00366  135.   901 ESIN = 1.0
00367  136.       FSIN =1.0
00370  137.       GO TO 444
00371  138.   356 IF(FSIN.LT.1.0)GO TO 445
00373  139.   444 ANGLEF = 1.5708
00374  140.       GO TO 361
00375  141.   445 ANGLEF =ASIN(FSIN)
00376  142.   361 IF(ESIN.GT.1.0)GO TO 1200
00400  143.       GO TO 362
00401  144.  1200 DFAX   = (ENUMA - DENOM)
00402  145.       LL = LL+1
00403  146.       IF(LL.EQ.100)STOP
00405  147.  1201 IF(V(I-1).LT.0.0)GO TO 1207
00407  148.  1208 DXI = DXIK - DFAX/801.0
00410  149.       GO TO 709
00411  150.  1207 DXI = DXIK - DFAX/3955.6
00412  151.       GO TO 709
00413  152.   362 IF(KL.LT.10)GO TO 360
00415  153.  1370 IF(ESIN.LT.0.999999)GO TO 366
00417  154.   364 ANGLEE = 1.5708
00420  155.       DELANG=ANGLEF-1.5708
00421  156.       IF(DELANG.GT.0.0)GO TO 1088
00423  157.       IF(DELANG.LT.0.0)GO TO 1088
00425  158.       GO TO 1220
00426  159.  1088 DTCR= (SQRT(ENR/801.0))* ABS DELANG)
00427  160.       IF((ABS(DTI-DTCR)/DTCR).GT.0.01)GO TO 1087
00431  161.       GO TO 1220
```

```
00432  162.    1587 DSX=DTCR*(VS(I-1)+VSI)/2.0                                  158
00433  163.         DXI =V(I-1)*DTCR/2.0                                        159
00434  164.         GO TO 711                                                   160
00435  165.     366 ANGLEE=ASIN(ESIN)                                           161
00436  166.     446 DELANG = ANGLEF - ANGLEE                                    162
00437  167.         IF(DELANG.GT.0.0)GO TO 1017                                 163
00441  168.         IF(DELANG.LT.0.0)GO TO 1017                                 164
00443  169.    1220 DTCR=DTI                                                    165
00444  170.         GO TO 1015                                                  166
00445  171.    1017 IF(V(I-1).LT.0.0)GO TO 1016                                 167
00447  172.    1014 DTCR = (SQRT(EMR/80))*ABS(DELANG)                           168
00450  173.         GO TO 1015                                                  169
00451  174.    1016 DTCR= (SQRT(EMR/3955.67))* ABS(DELANG)                      170
00452  175.    1015 DTCRM = 1000.0*DTCR                                         170
00453  176.         DELTM = DTIM - DTCRM                                        171
00456  177.         KL = KL +1                                                  172
00455  178.         IF(KL.GE.100)STOP                                           173
00457  179.     585 DIFT = DTI - DTCR                                           174
00470  180.         IF(DIFT.LT.0.0)GO TO 541                                    175
00462  181.         IF(DIFT.GT.0.0)GO TO 582                                    176
00464  182.         GO TO 712                                                   177
00465  183.     541 ALDIF =     (DIFT/DTCR)                                     178
00466  184.         GO TO 577                                                   179
00467  185.     542 ALDIF =     (DIFT/DTI)                                      180
00470  186.     577 IF( ABS(ALDIF).GT.0.01)GO TO 587                            181
00472  187.         GO TO 712                                                   182
00473  188.     587 DXI = DXIK*(1.0 + ALDIF/2.0)                                183
00474  189.         DSI = DSX + DXI                                             184
00475  190.         GO TO 709                                                   185
00476  191.     712 JJ=JJ+1                                                     186
00477  192.         IF(JJ.EQ.100)STOP                                           187
00501  193.     819 DEBBL =  ABS(DXIK)*(-EMUMA)                                 188
00502  194.         EBBL(I) = EBBL(I-1) + DEBBL                                 189
00503  195.         VSQ = 2.0*EBBL(I)/EMR                                       190
00504  196.         VI=SQRT(ABS(VSQ))                                           191
00505  197.         IF(VI.GT.0.10)GO TO 1090                                    192
00507  198.    1089 VI=0.0                                                      193
00510  199.         EBBL(I)=0.0                                                 194
00511  200.    1090 IF(V(I-1).G.-0.0)GO TO 1202                                 195
00513  201.         IF(V(I-1).LT.0.0)GO TO 1203                                 196
00515  202.         GO TO 822                                                   197
00516  203.    1202 IF((EBBL(I-1)+DEBBL).LT.0.0)GO TO 823                       198
00520  204.         GO TO 822                                                   199
00521  205.    1203 IF((EBBL(I-1)+DEBBL).GT.0.0)GO TO 823                       200
00523  206.         GO TO 822                                                   201
00524  207.     823 RVI = VI/ ABS(V(I-1))                                       202
00525  208.         IF(RVI.GT.0.10)GO TO 821                                    203
00527  209.         GO TO 831                                                   204
00530  210.     821 DDTI = DTI*(1.0 -  (ABS(V(I-1))/(( ABS(V(I-1)) + VI)*4.0)))  205
00531  211.         DXI = V(I-1)*DDTI                                           206
00532  212.         DDSI = VS(I-1)*DDTI                                         207
00533  213.         DSX = DDSI + DXI                                            208
00534  214.         GO TO 711                                                   209
00535  215.     831 VI = 0.0                                                    210
00536  216.         GO TO 824                                                   211
00537  217.     822 IF(EBBL(I).LT.0.0)GO TO 825                                 212
00541  218.     824 V(I) = VI                                                   213
00542  219.         GO TO 827                                                   214
```

A—12. (Con't.)

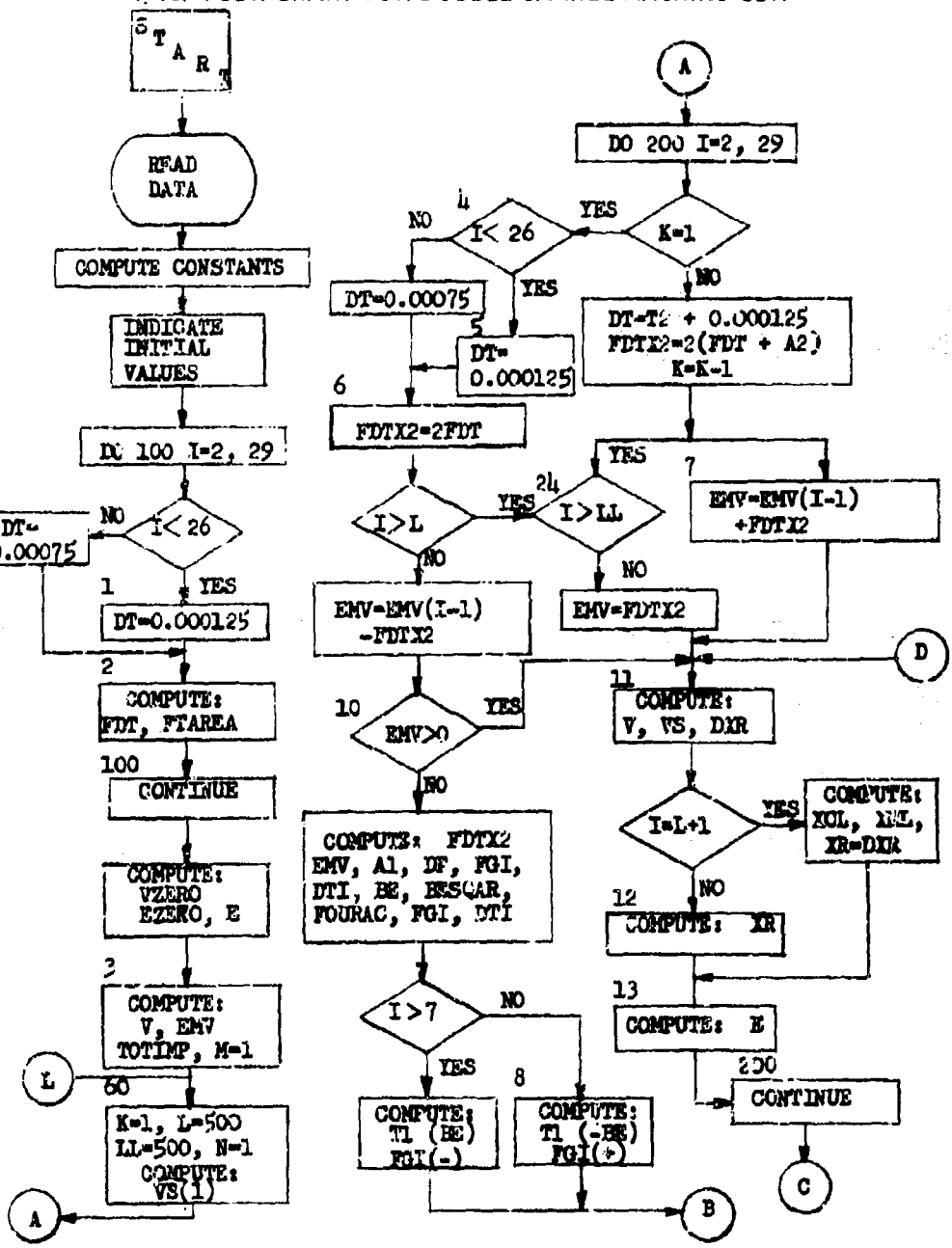
```
00543   220.      825 V(I) = -VI                                                  215
00544   221.      827 XI = X(I-1) - DXI                                           216
00545   222.          IF(XI.LT.0.25)GO TO 829                                     217
00547   223.      828 X(I) = 0.25                                                 218
00550   224.          V(I) = 0.0                                                  219
00551   225.          GO TO 515                                                   220
00552   226.      829 X(I) = XI                                                   221
00553   227.      515 SI = S(I-1) - DSIK                                          222
00554   228.          S(I) = SI                                                   223
00555   229.          TMI = TM(I-1)+ 1000.0*DTI                                   224
00556   230.          TM(I) = TMI                                                 225
00557   231.          VS(I) = VSI                                                 226
00560   232.          VD(I) = VDI                                                 227
00561   233.          VC(I) = VCI                                                 228
00562   234.          IF(X(I-1).GT.0.0)GO TO 513                                  229
00564   235.      514 FA(I) =   0.0                                               230
00565   236.          V(I) = 0.0                                                  231
00566   237.          X(I) = 0.0                                                  232
00567   238.          GO TO 516                                                   233
00570   239.      513 FA(I)=880.0 + 1780.0*X(I)                                   234
00571   240.      516 IF(SX(I).GT.1.9999)GO TO 701                                235
00573   241.      700 CONTINUE                                                    236
00575   242.      701 WRITE(6,170)                                                237
00577   243.      170 FORMAT(1H1/34X,53HTABLE 5-14 CAM AND DRUM DYNAMICS DURING COUNTERR  238
00577   244.         1ECOIL//13X,85HRECOIL   DRIVING    NORMAL    AXIAL     PERIPH  239
00577   245.         2                  COUNTER   COUNTER/                        240
00577   246.         3                12X,105H ADAPTER   SPRING     CAM       CAM       CAM  241
00577   247.         4      CAM          DRUM      RECOIL   RECOIL     SLIDE     SLIDE/    242
00577   248.         53X,115H TIME      FORCE     FORCE    FORCE      TRAVEL    TRAVEL    243
00577   249.         6 SLOPE    VEL       VEL      POSITIONN   VEL      TRAVEL/           244
00577   250.         72X,113H MILSEC      LB        LB        LB        IN        IN     245
00577   251.         8 DEGREE   IN/SEC    IN/SEC    IN        IN/SEC    IN)             246
00600   252.          WRITE(6,702)(TM(I),FA(I),FD(I),EN(I),SX(I),V(I),BETAD(I),VD(I),  247
00600   253.         1V(I),X(I),VS(I),S(I),I=3,22)                                243
00621   254.      702 FORMAT(F10.5,F9.0,F9.1,F10.0,F10.3,F11.4,F8.1,F10.1,F10.4,F10.4,  249
00621   255.         1F10.1,F10.3)                                                250
00622   256.      900 STOP                                                        251
00623   257.          END                                                         252

        END OF LISTING.      0 *DIAGNOSTIC* MESSAGE(S).

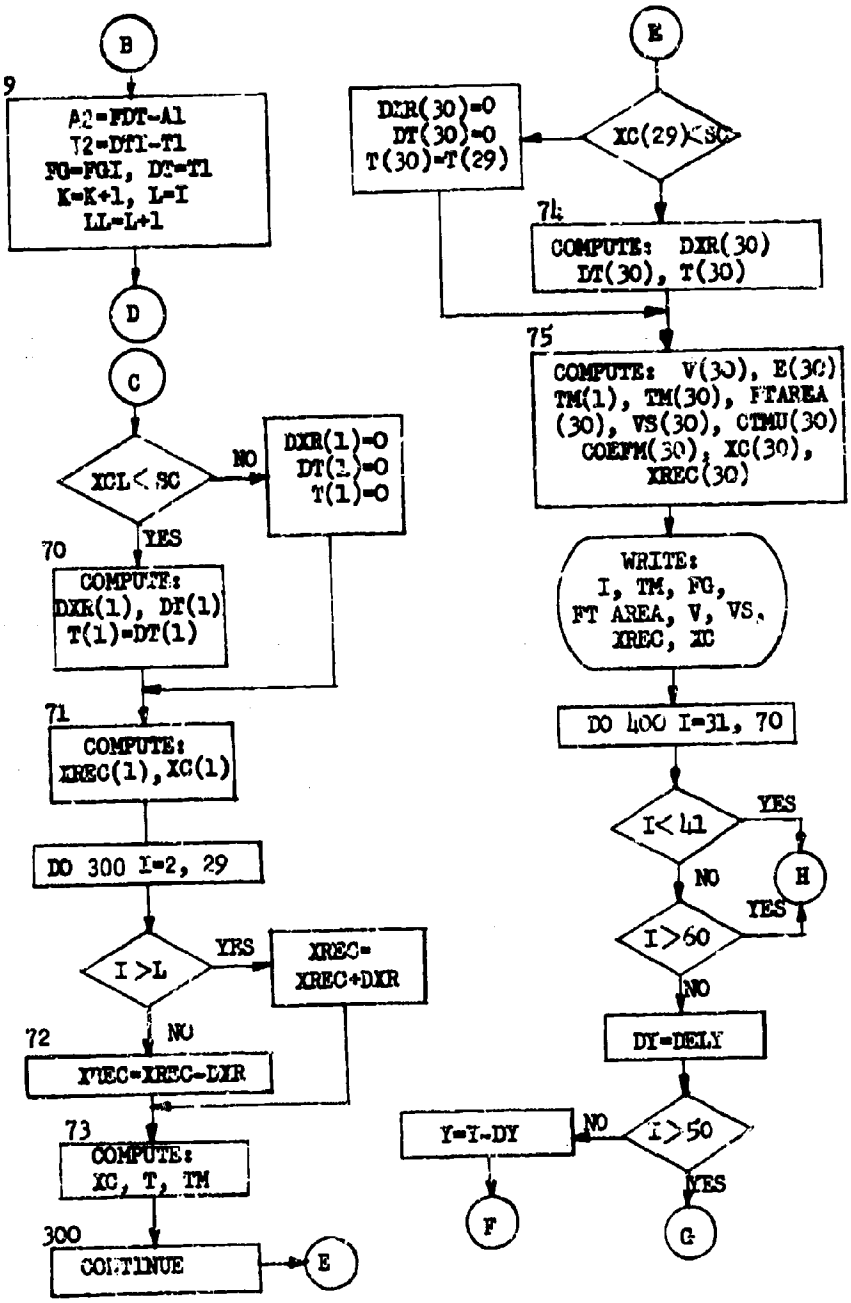
PHASE 1 TIME =   3 SEC.
PHASE 2 TIME =   0 SEC.
PHASE 3 TIME =   4 SEC.
PHASE 4 TIME =   1 SEC.
PHASE 5 TIME =   3 SEC.
PHASE 6 TIME =   3 SEC.

TOTAL COMPILATION TIME =  14  SEC
```

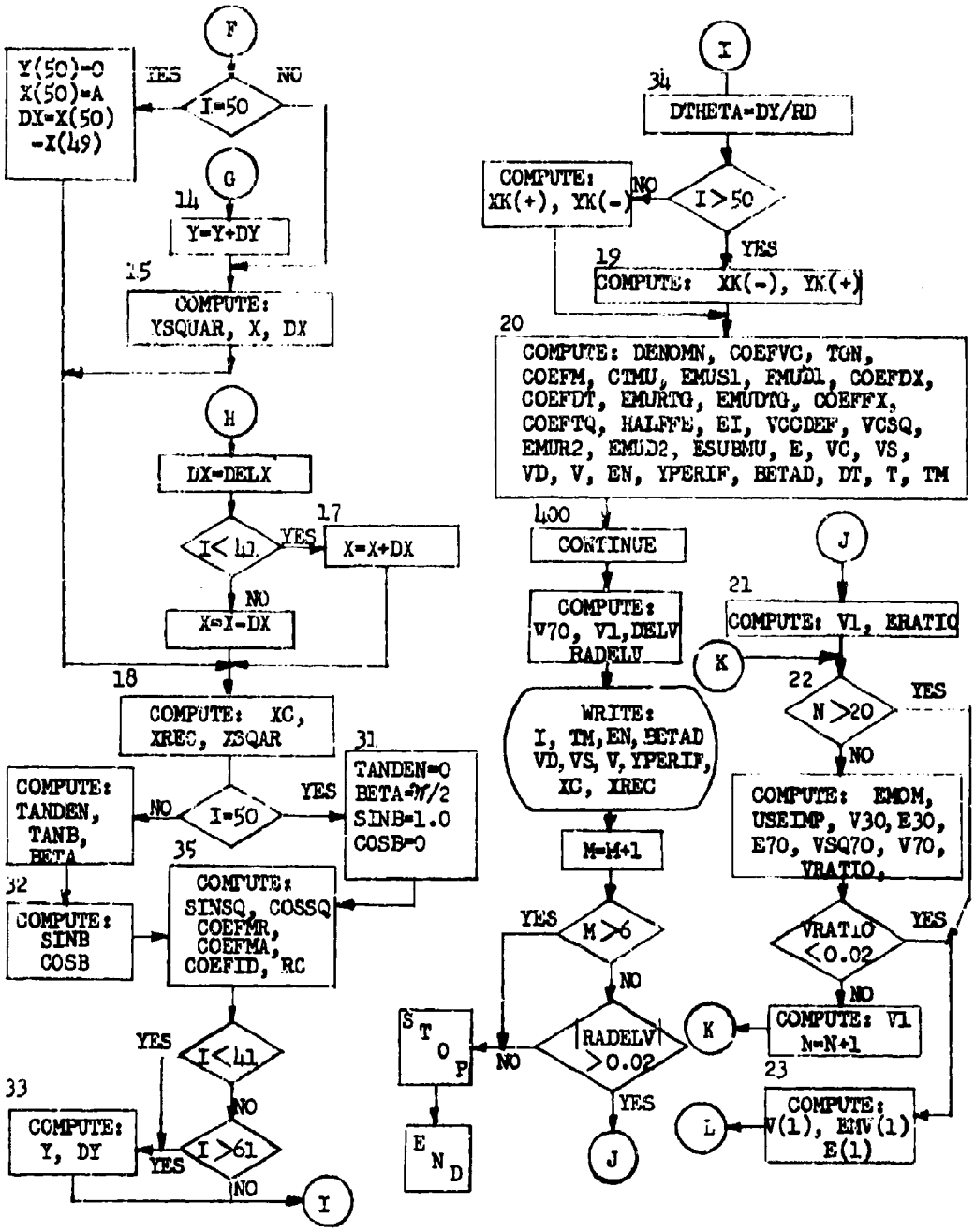
A–13. FLOW CHART FOR DOUBLE BARREL MACHINE GUN



A–13. (Con't.)


B
9
A2=FDT-A1
T2=DT1-T1
FG=FGI, DT=T1
K=K+1, L=I
LL=L+1
D
C
XCL<SC
NO
DXR(1)=0
DT(1)=0
T(1)=0
YES
70
COMPUTE:
DXR(1), DT(1)
T(1)=DT(1)
71
COMPUTE:
XREC(1), XC(1)
DO 300 I=2, 29
I>L
YES
XREC=
XREC+DXR
NO
72
XREC=XREC-DXR
73
COMPUTE:
XC, T, TM
300
CONTINUE
E
E
DXR(30)=0
DT(30)=0
T(30)=T(29)
XC(29)<SC
74
COMPUTE: DXR(30)
DT(30), T(30)
75
COMPUTE: V(30), E(30)
TM(1), TM(30), FTAREA
(30), VS(30), CTMU(30)
COEFM(30), XC(30),
XREC(30)
WRITE:
I, TM, FG,
FT AREA, V, VS,
XREC, XC
DO 400 I=31, 70
I<41
YES
NO
H
I>60
YES
NO
DY=DELY
Y=Y-DY
NO
I>50
YES
F
G

A—13. (Con't.)


F
Y(50)=0
X(50)=A
DX=X(50)
-X(49)
YES
I=50
NO
G
14
Y=Y+DY
15
COMPUTE:
YSQUAR, X, DX
H
DX=DELX
I<41
YES
17
X=X+DX
NO
X=X-DX
18
COMPUTE: XC,
XREC, YSQAR
31
TANDEN=0
BETA=π/2
SINB=1.0
COSB=0
COMPUTE:
TANDEN,
TANB,
BETA
NO
I=50
YES
32
COMPUTE:
SINB
COSB
35
COMPUTE:
SINSQ, COSSQ
COEFMR,
COEFMA,
COEFID, RC
YES
I<41
NO
33
COMPUTE:
Y, DY
I>61
YES
NO
I
I
34
DTHETA=DY/RD
COMPUTE:
XK(+), YK(-)
NO
I>50
YES
19
COMPUTE: XK(-), YK(+)
20
COMPUTE: DENOMN, COEFVC, TGN,
COEFM, CTMU, EMUS1, FMUD1, COEFDX,
COEFDT, EMURTG, EMUDTG, COEFFX,
COEFTQ, HALFFE, EI, VCCDEF, VCSQ,
EMUR2, EMUD2, ESUBMU, E, VC, VS,
VD, V, EN, YPERIF, BETAD, DT, T, TM
400
CONTINUE
COMPUTE:
V70, V1, DELV
RADELV
WRITE:
I, TM, EN, BETAD
VD, VS, V, YPERIF,
XC, XREC
M=M+1
YES
M>6
NO
RADELV
>0.02
NO
STOP
END
YES
J
J
21
COMPUTE: V1, ERATIO
K
22
N>20
YES
NO
COMPUTE: EMOM,
USEIMP, V30, E30,
E70, VSQ70, V70,
VRATIO,
VRATIO
<0.02
YES
NO
K
COMPUTE: V1
N=N+1
23
L
COMPUTE:
V(1), EMV(1)
E(1)

A-14. PROGRAM LISTING FOR DOUBLE BARREL MACHINE GUN

```
0000 I 003353 M          0000 I 003357 N          0000 R 003404 RADCLV     0000 R 003354 RB
0000 R 003343 RCFRAC     0000 R 003307 RCH        0000 R 003313 RD         0000 R 003330 RDSQ
0000 R 003344 RHOSQ      0000 R 003301 RL         0000 R 003310 RP         0000 R 003332 RPORR
0000 R 003312 RT         0000 R 003333 SC         0005 R 000000 SIN        0000 R 003403 STIME
0003 R 000000 SQRT       0000 R 003517 SR         0000 R 002373 T          0000 R 003402 TANB
0000 R 003325 TG         0000 R 003428 YBAR       0000 R 003047 TM         0000 R 003352 TOTIME
0000 R 003360 T2         0000 R 003447 USEIMP     0000 R 000454 V          0000 R 003440 VC
0000 R 003434 VCSQ       0000 R 002135 VD         0000 R 003554 VRATIO     0000 R 003432 VS
0000 R 003350 VZERO      0000 R 003442 V1         0000 R 003450 V30        0000 R 003441 VTB
0000 R 003276 WR         0000 R 001356 X          0000 R 002506 XC         0000 R 003373 XCL
0000 R 001615 XR         0000 R 002621 XREC       0000 R 003374 XRL        0000 R 003433 XSQUAR
0000 R 003415 YK         0000 R 003162 YPERIF     0000 R 003377 YSQUAR
```

```
00101    1.      DIMENSION F6(75),FDT(75),DT(75),E(75),V(75),FMV(75),OXR(75),XR(75)                    3A
00101    2.     1      ,EN(75),Y(75),X(75),BETA(75), COEFM(75),CTMU(75),YS(75),VD(7                   3B
00101    3.     25),          BETAD(75),T(75),VC(75),XREC(75),FTAREA(75),                             3C
00101    4.     3TM(75), YPERIF(75)                                                                   3D
00103    5.      RLAD 50,(F6(I), I=1,29)                                                              4
00111    6.      READ 50,WR, WA, DI, RL, CL, A, B, RHO, RB, RCH, RP, RR, RT, RD,                      5A
00111    7.     1FGRES ,EMU ,G,SR                                                                     5B
00135    8.     50 FORMAT(6F12.0)                                                                     6
00136    9.      EMR=WR/G                                                                             7A
00137   10.      EMA=WA/G                                                                             7B
00140   11.      RPORR=RP/RR                                                                          7C
00141   12.      CTRIG=EMU*RPORR                                                                      2
00142   13.      CID=DI/RD                                                                            9
00143   14.      TG=FGRES*(RCH-EMU*RB)*EMU                                                            10
00144   15.      CY=RD - EMU*RB                                                                       11
00145   16.      CX=EMU*(RT+RD*RPORR)                                                                 12
00146   17.      RDSQ=RD**2                                                                           13
00147   18.      EMURB=EMU*RB                                                                         14
00150   19.      CMUF=EMU*(RPORR-1.0/RHO)                                                             15
00151   20.      SC =CL-A                                                                             16
00152   21.      DELY=0.0866025*B                                                                     17
00153   22.      DELX=A/20.0                                                                          18
00154   23.      ASQUAR=A*A                                                                           19
00155   24.      BSQUAR=B*B                                                                           20
00156   25.      AOVERB=A/B                                                                           21
00157   26.      BOVERA=B/A                                                                           22
00160   27.      AB=A*B                                                                               23
00161   28.      RCFRAC=(ASQUAR - BSQUAR)/ASQUAR                                                      24
00162   29.      RHOSQ=RHO**2                                                                         25
00163   30.      EFMR  =G.5*EMR/RHOSQ                                                                 26
00164   31.      EFMA  =0.5*EMA/RHOSQ                                                                 27
00165   32.      EFID=0.5*DI/(RDSQ + RHOSQ)                                                           28
00166   33.      XR(1)=0.0                                                                            29
00167   34.      T(1)=0.0                                                                             30
00170   35.      EN(30)=0.0                                                                           31
00171   36.      EN(70)=0.0                                                                           32
00172   37.      F6(30)=0.0                                                                           33
00173   38.      FTAREA(30)=0.0                                                                       34
00176   39.      VD(30)=0.0                                                                           35
00175   40.      YPERIF(30)=0.0                                                                       36
00176   41.      BETAD(30)=0.0                                                                        37
00177   42.      COEF M(30)=0.0                                                                       38
```

A–14. (Con't.)

```
00200    43.          CTMU(30)=0.0                                          39
00201    44.          Y(30)=8                                               40
00202    45.          X(30)=0.0                                             41
00203    46.          FTAREA(1)=0.0                                         42
00204    47.          DO 100 I=2,29                                         43
00207    48.          IF(I.LT.26)GO TO 1                                    44
00211    49.          DT(I)=0.00075                                         45
00212    50.          GO TO 2                                               46
00213    51.        1 DT(I)=0.000125                                        47
00214    52.        2 FDT(I)  =0.5*(FG(I)+FG(I-1))*DT(I)                   48
00215    53.          FTAREA(I)=FTAREA(I-1)+FDT(I)                          49
00216    54.      100 CONTINUE                                              50
00220    55.          VZERO=FTAREA(29)/EMR                                  51
00221    56.          EZERO = 0.5*EMR*VZERO**2                              52
00222    57.          E(1)=0.7*EZERO                                        53
00223    58.        3 V(I)=SQRT(2.0*E(1)/EMR)                               54
00224    59.          EMV(1)=EMR*V(1)                                       55A
00225    60.          TOTIME = 2.0*FTAREA(29)                               55B
00226    61.          M=1                                                   56
00227    62.       60 K=1                                                   57
00230    63.          L=500                                                 58A
00231    64.          LL=500                                                58B
00232    65.          N = 1                                                 58C
00233    66.          VS(1)=V(1)*RHO                                        59
00234    67.          DO 200 I=2,29                                         60
00237    68.          IF(K.EQ.1)GO TO 4                                     61
00241    69.          DT(I)=T2*0.000125                                     62
00242    70.          FDTX2=2.0*(FDT(I)*A2)                                 63
00243    71.          K = K-1                                               64
00244    72.          GO TO 7                                               65
00245    73.        4 IF(I.LT.26)GO TO 5                                    66
00247    74.          DT(I)=0.00075                                         67
00250    75.          GO TO 6                                               68
00251    76.        5 DT(I)=0.000125                                        69
00252    77.        6 FDTX2 = 2.0*FDT(I)                                    70
00253    78.          IF(I.GT.L)GO TO 24                                    71
00255    79.          EMV(I)=EMV(I-1)-FDTX2                                 72
00256    80.          GO TO 10                                              73A
00257    81.       24 IF(I.GT.LL)GO TO 7                                    73B
00261    82.          EMV(I)=FDTX2                                          73C
00262    83.          GO TO 11                                              73D
00263    84.        7 EMV(I)=EMV(I-1)+FDTX2                                 73E
00254    85.          GO TO 11                                              76
00265    86.       10 IF(EMV(I).GT.0.0)GO TO 11                             75
00267    87.          FDTX2 = EMV(I-1)                                      76
00270    88.          EMV(I)=0.0                                            77
00271    89.          A1=FDTX2/2.0                                          78
00272    90.          DF= ABS(FG(I)-FG(I-1))                                79A
00273    91.          FGI = FG(I)                                           79B
00274    92.          DTI=DT(I)                                             79C
00275    93.          BE= FGI*DTI/DF                                        80
00276    94.          BESQAR=BE**2                                          81
00277    95.          FOURAC=2.0*DTI*A1/DF                                  82
00300    96.          FGI=FG(I-1)                                           83
00301    97.          DTI=DT(I)                                             84
00302    98.          IF(I.LE.7)GO TO 8                                     85
00304    99.          T1=BE-SQRT(BESQAR-FOURAC)                             86
00305   100.          FGI=FGI-DF*T1/DTI                                     87
```

A-14. (Cont'd.)

```
00306  101.          GO TO 9                                                  88
00307  102.        8 T1=-BE+SQRT(BESQAR+FOURAC)                               89
00310  103.          FGI=FGI+DF*T1/DTI                                        90
00311  104.        9 A2=FDT(I)-A1                                             91
00312  105.          T2=DT1-T1                                                92
00313  106.          FG(I)=FGI                                                93
00314  107.          DT(I)=T1                                                 94
00315  108.          K=K 1                                                    95
00316  109.          L=I                                                      96A
00317  110.          L=L+1                                                    96B
00320  111.       11 V(I)=EMV(I)/EMR                                          97A
00321  112.          VS(I)=V(I)*RHO                                           97B
00322  113.          DXR(I)=0.5*(V(I-1)+V(I))*DT(I)                           9E
00323  114.          IF(I.NE.(L+1))GO TO 12                                   99A
00325  115.          XCL=XR(L)*RHO                                            99B
00326  116.          XRL=XR(L)                                                99C
00327  117.          XR(I)=DXR(I)                                             99D
00330  118.          GO TO 13                                                 100
00331  119.       12 XR(I)=XR(I-1)+DXR(I)                                     101
00332  120.       13 E(I)=EMR*V(I)**2/2.0                                     102
00333  121.      200 CONTINUE                                                 103
00335  122.          IF(XCL.LT.SC)GO TO 70                                    104
00337  123.          DXR(1)=0.0                                               105A
00340  124.          DT(1)=0.0                                                105B
00341  125.          T(1)=0.0                                                 105C
00342  126.          GO TO 71                                                 105D
00343  127.       70 DXR(1)=SR-XRL                                            105A
00344  128.          DT(1)=DXR(1)/V(1)                                        106B
00345  129.          T(1)=DT(1)                                               106C
00346  130.       71 XREC(1)=XRL                                              107A
00347  131.          XC(1)=XREC(1)*RHO                                        107B
00350  132.          DO 300 I=2,29                                            108A
00353  133.          IF(T.LE.L)GO TO 72                                       108B
00355  134.          XREC(I)=XREC(I-1)+DXR(I)                                 108C
00356  135.          GO TO 73                                                 108D
00357  136.       72 XREC(I)=XREC(I-1)-DXR(I)                                 108E
00360  137.       73 XC(I)=XREC(I)*RHO                                        108F
00361  138.          T(I)=T(I-1) +DT(I)                                       1086
00362  139.          TM(I)=1000.0*T(I)                                        108H
00363  140.      300 CONTINUE                                                 108I
00365  141.          IF(XC(29).LT.SC)GO TO 74                                 109A
00367  142.          DXR(30)=0.0                                              109B
00370  143.          DT(30)=0.0                                               109C
00371  144.          T(30)=T(29)                                              109D
00372  145.          GO TO 75                                                 109E
00373  146.       74 DXR(30)=SR     -XR(29)                                   110A
00374  147.          DT(30)=DXR(30)/V(29)                                     110B
00375  148.          T(30)=T(29)+DT(30)                                       110C
00376  149.       75 V(30)=V(29)                                              110D
00377  150.          E(30)=E(29)                                              110E
00400  151.          TM(I)=1000.0*T(I)                                        110F
00401  152.          TM(30)=1000.0*T(30)                                      1106
00402  153.          FTAREA(30)=0.0                                           110H
00403  154.          VS(30)=VS(29)                                            110I
00404  155.          CTMU(30)=CX*CTRIG+CMUKB                                  110J
00405  156.          COEFM(30)=CMUF                                           110K
00406  157.          XC(30)=SC                                                111A
00407  158.          XREC(30)=XC(30)/RHO                                      111B
```

```
00470   159.       PRINT 105,(I,TM(I),FG(I),FTAREA(I),V(I),VS(I),XREC(I),XC(I),
00470   160.      1I=1,30)
00425   161.    105 FORMAT(1H1/12X,47H TABLE 2-11  DOUBLE BARREL MACHINE GUN DYNAMICS
00425   162.      1       //14X,11H PROPELLANT,19X,6H AXIAL,13X,6H AXIAL/17X,4H GA
00425   163.      2S,14X,33H RECOIL    CAM      RECOIL     CAM/70H  I    TIME      FOR
00425   164.      3CE    IMPULSE     VEL       VEL      TRAVEL    TRAVEL/68H        MSEC
00425   165.      4      LB        LB-SEC    IN/SEC    IN/SEC     IN          IN//
00425   166.      5(13,F9.3,F11.1,F9.2,2F9.1,2F10.4))
00426   167.       DO 400  I=31,70
00431   168.       IF(I.LT.41)GO TO 16
00433   169.       IF(I.GT.60)GO TO 16
00435   170.       DY=DELY
00435   171.       IF(I.GT.50)GO TO 14
00440   172.    25 Y(I)=Y(I-1)-DY
00441   173.       IF(I.NE.50)GO TO 15
00443   174.       Y(50)=0.0
00446   175.       X(50)=A
00445   176.       DX = X(50) - X(49)
00446   177.       GO TO 18
00447   178.    14 Y(I)=Y(I-1)+DY
00450   179.    15 YSQUAR=Y(I)**2
00451   180.       X(I)=AOVERB*SQRT(BSQUAR-YSQUAR)
00452   181.       DX = ABS(X(I-1) - X(I))
00453   182.       GO TO 18
00454   183.    16 DX=DELX
00455   184.       IF(I.LT.41)GO TO 17
00457   185.       X(I)=X(I-1)-DX
00460   186.       GO TO 18
00461   187.    17 X(I)=X(I-1)+DX
00462   188.    18 XC(I)=SC    +X(I)
00463   189.       XREC(I)=XC(I)/RHO
00464   190.       XSQUAR=X(I)**2
00465   191.       IF(I.EQ.50) GO TO 31
00467   192.       TANDEN=SQRT(ASQUAR-XSQUAR)
00470   193.       TANB=BOVERA*X(I)/TANDEN
00471   194.       BETA(I)=ATAN(TANB)
00472   195.       GO TO 32
00473   196.    31 TANDEN=0.0
00474   197.       BETA(I)=1.570755
00475   198.       SINB=1.0
00476   199.       COSB=0.0
00477   200.       GO TO 35
00500   201.    32 SINB=SIN(BETA(I))
00501   202.       COSB=COS(BETA(I))
00502   203.    35 SINSQ=SINB**2
00503   204.       COSSQ=COSB**2
00504   205.       COEFMR=EFMR*COSSQ
00505   206.       COEFMA=EFMA*SINSQ
00506   207.       COEFID=EFID*SINSQ
00507   208.       RC=(ASQUAR-XSQUAR*RCFRAC)**1.5/AB
00510   209.       IF(I.LT.41)GO TO 33
00512   210.       IF(I.GT.60)GO TO 33
00514   211.       GO TO 34
00515   212.    33 Y(I)=BOVERA*TANDEN
00516   213.       DY=ABS(Y(I-1)-Y(I))
00517   214.    34 DTHETA=DY/RO
00520   215.       IF(I.GT.59)GO TO 19
00522   216.       XK=SINB*CTRIG*COSB
```

A–14. (Con't.)

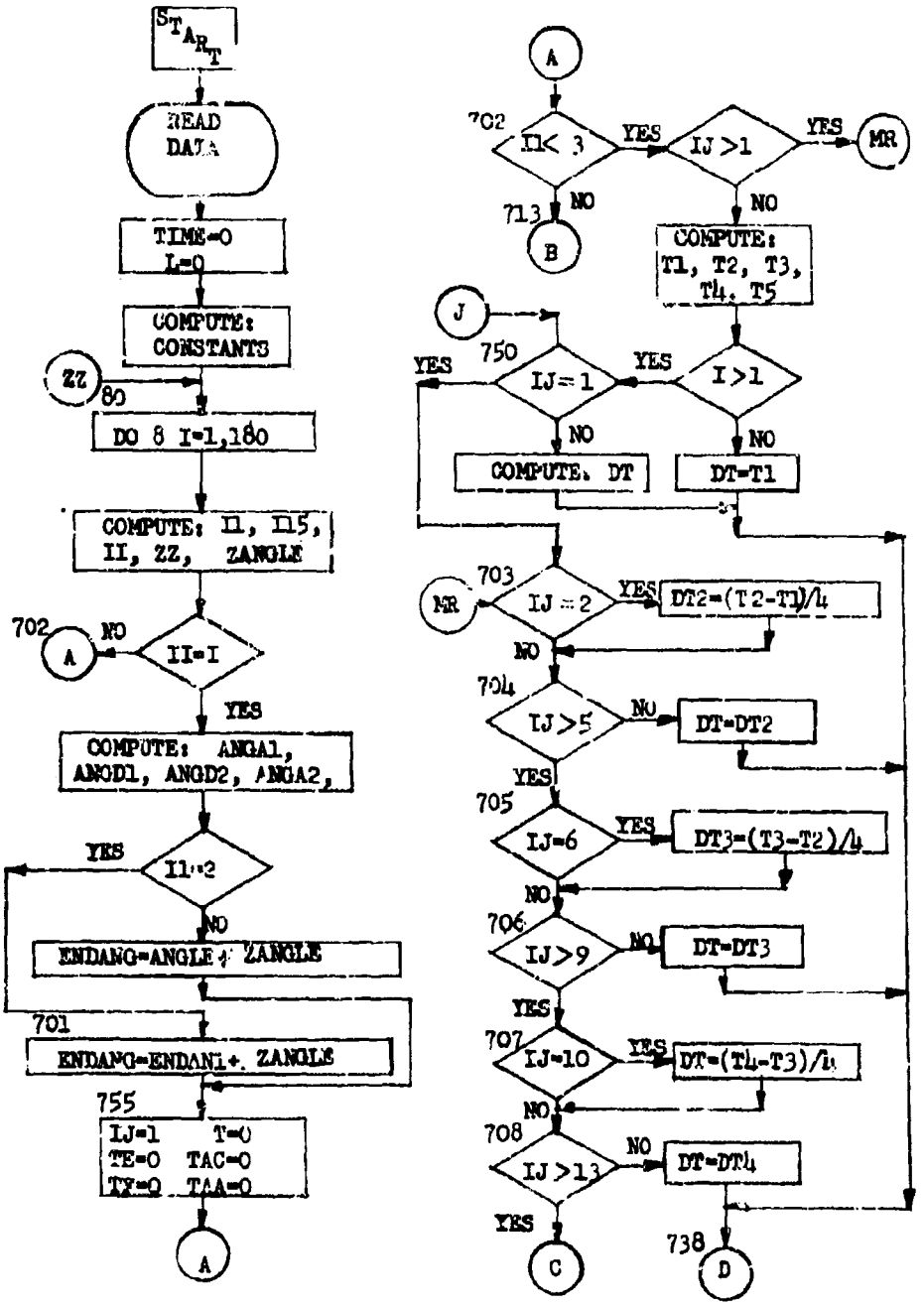
```
00523  217.        YK = COSB - CTRIG*SINB                                          142
00524  218.        GO TO 20                                                        143
00525  219.     19 XK=SINB-CTRIG*COSB                                              144
00526  220.        YK=COSB+CTRIG*SINB                                              145
00527  221.     20 DENOMN=ABS(CY*YK-CX*XK)                                         146
00530  222.        COEFVC=CID*COSB/(RC*DENOMN)                                     147
00531  223.        TGN=TG/DENOMN                                                   148
00532  224.        COEFM(I)=CMUF*YK                                                149
00533  225.        CTMU(I)=(CX*XK + EMURB*YK)                                      150
00534  226.        EMUS1=COEFM(I-1)*EN(I-1)*DX/2.0                                 151
00535  227.        EMUD1=CTMU(I-1)*EN(I-1)*DTHETA/2.0                              152
00536  228.        COEFDX=COEFM(I)*DX/2.0                                          153
00537  229.        COEFDT=CTMU(I)*DTHETA/2.0                                       154
00540  230.        EMURTG=(COEFDX+COEFDT)*TGN                                      155
00541  231.        EMUDTG=TG*DTHETA                                                156
00542  232.        COEFFX=COEFDX*COEFVC                                            157
00543  233.        COEFTG=COEFDT*COEFVC                                            158
00544  234.        HALFFE=EMUS1+EMUD1+EMURTG+EMUDTG                                159
00545  235.        EI=E(I-1)+HALFFE                                                160
00546  236.        VCCOEF=COEFMR+COEFMA+COEFID+COEFFX+COEFTG                       161
00547  237.        VCSQ=EI/VCCOEF                                                  162
00550  238.        EMUR2=COEFFX*VCSQ                                               163
00551  239.        EMUD2=COEFTG*VCSQ                                               164
00552  240.        ESUBMU=HALFFE + EMUR2 + EMUD2                                   165
00553  241.        E(I)=E(I-1) - ESUBMU                                            166
00554  242.        VC=SQRT(VCSQ)                                                   167
00555  243.        VS(I)=VC*COSB                                                   168
00556  244.        VD(I)=VC*SINB                                                   169
00557  245.        V(I)=VS(I)/RHO                                                  170
00560  246.        EN(I)=COEFVC*VCSQ + TGN                                         171
00561  247.        YPERIF(I)=YPERIF(I-1)+ABS(DY)                                   172
00562  248.        BETAD(I)=57.296*BETA(I)                                         173
00563  249.        DT(I)=2.0*DX/(VS(I-1) + VS(I))                                  174
00564  250.        T(I)=T(I-1) + DT(I)                                             175
00565  251.        TM(I)=1000.0*T(I)                                               176A
00566  252.     400 CONTINUE                                                       176B
00570  253.        V70=V(70)                                                       176C
00571  254.        V1=V(1)                                                         176D
00572  255.        DELV=V1-V70                                                     176E
00573  256.        RADELV=DELV/V1                                                  176F
00574  257.        IF(ABS(RADELV).GT.0.02)GO TO 36                                 176G
00576  258.     36 PRINT 110,(I,TM(I),EN(I),BETAD(I),VD(I),VS(I),V(I),YPERIF(I)    177
00576  259.       1,XC(I),XREC(I),I=31,70)                                         178
00615  260.     110 FORMAT(1H1/20X,53H TABLE 2-11 CONT.  DOUBLE BARREL MACHINE GUN DYN  179
00615  261.       1AMICS      //16X,7H NORMAL,11X,15H PERIPH    AXIAL,12X,17H PERIPH  180
00615  262.       2  AXIAL/19X,71H CAM       CAM       DRUM      CAM      RECOIL     DRUM   181
00615  263.       3       CAM      RECOIL/90H  I       TIME      FORCE     SLOPE      VEL   182
00615  264.       4      VEL       VEL      TRAVEL     TRAVEL   TRAVEL/88H           MSEC  183
00615  265.       5       LB        DEG      IN/SEC    IN/SEC    IN/SEC      IN         IN  184
00615  266.       6       IN//(13,F (.4,F10.1,F9.2,3F9.1,3F10.4))                  185-6
00616  267.        M=M+1                                                           187
00617  268.        IF(M.GT.6) GO TO 30                                             188
00621  269.        IF(ABS(RADELV).GT.0.02)GO TO 21                                 189
00623  270.        GO TO 99                                                        190
00624  271.     21 V1= (V1+V70)/2.0                                                191
00625  272.        ERATIO = E(70)/E(30)                                            192
00626  273.     22 IF(N.GT.20)GO TO 23                                             193
00630  274.        EMOM=V1*EMR                                                     194
```

```
00631   275.          USEIMP=TOTIMP-EMOM                                    195
00632   276.          V30=USEIMP/EMR                                        196
00633   277.          E30=EMR*V30**2/2.0                                    197A
00634   278.          E70=ERATIO*E30                                        197B
00635   279.          VSQ70=2.0*E70/EMR                                     197C
00636   280.          V70=SQRT(VSQ70)                                       197D
00637   281.          VRATIO=ABS(1.0-V1/V70)                                197E
00640   282.          IF(VRATIO.LT.0.02)GO TO 23                            197F
00642   283.          V1=(V1+V70)/2.0                                       197G
00643   284.          N=N+1                                                 198
00644   285.          GO TO 22                                              199
00645   286.       23 V(I)=V1                                               200
00646   287.          EMV(I)=EMR*V(I)                                       201
00647   288.          E(I)=EMR*V(I)**2/2.0                                  202
00650   289.          GO TO 60                                              203
00651   290.       30 PRINT 80,V(I),T(70),RADELV,M,N                        204
00660   291.       80 FORMAT(////3E18.8,2I5)                                205
00661   292.       99 STOP                                                  206
00662   293.          END                                                   207

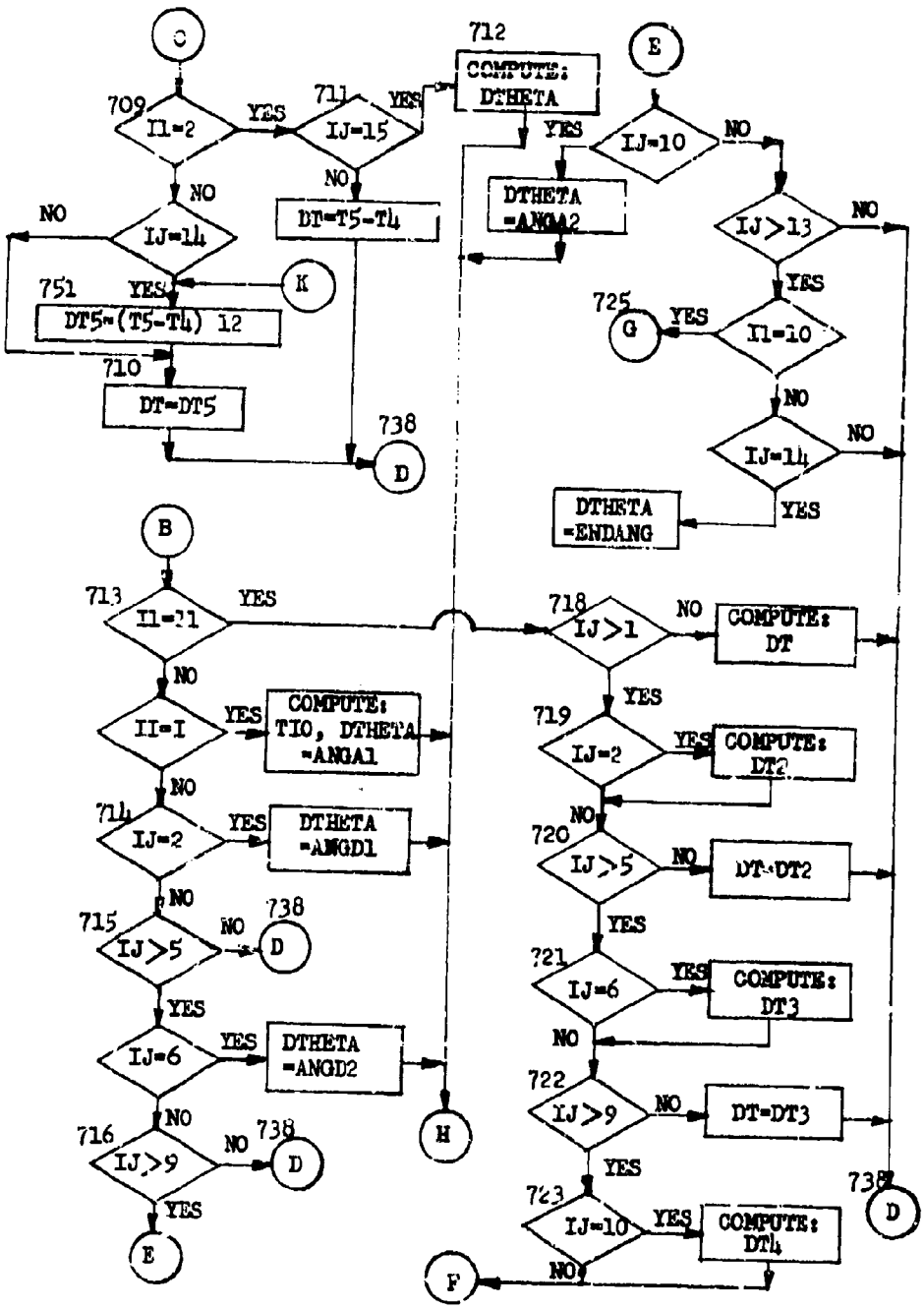
        END OF LISTING.      0 *DIAGNOSTIC* MESSAGE(S).
PHASE 1 TIME =    3 SEC.
PHASE 2 TIME =    1 SEC.
PHASE 3 TIME =    5 SEC.
PHASE 4 TIME =    0 SEC.
PHASE 5 TIME =    4 SEC.
PHASE 6 TIME =    4 SEC.

TOTAL COMPILATION TIME =  17  SEC
```

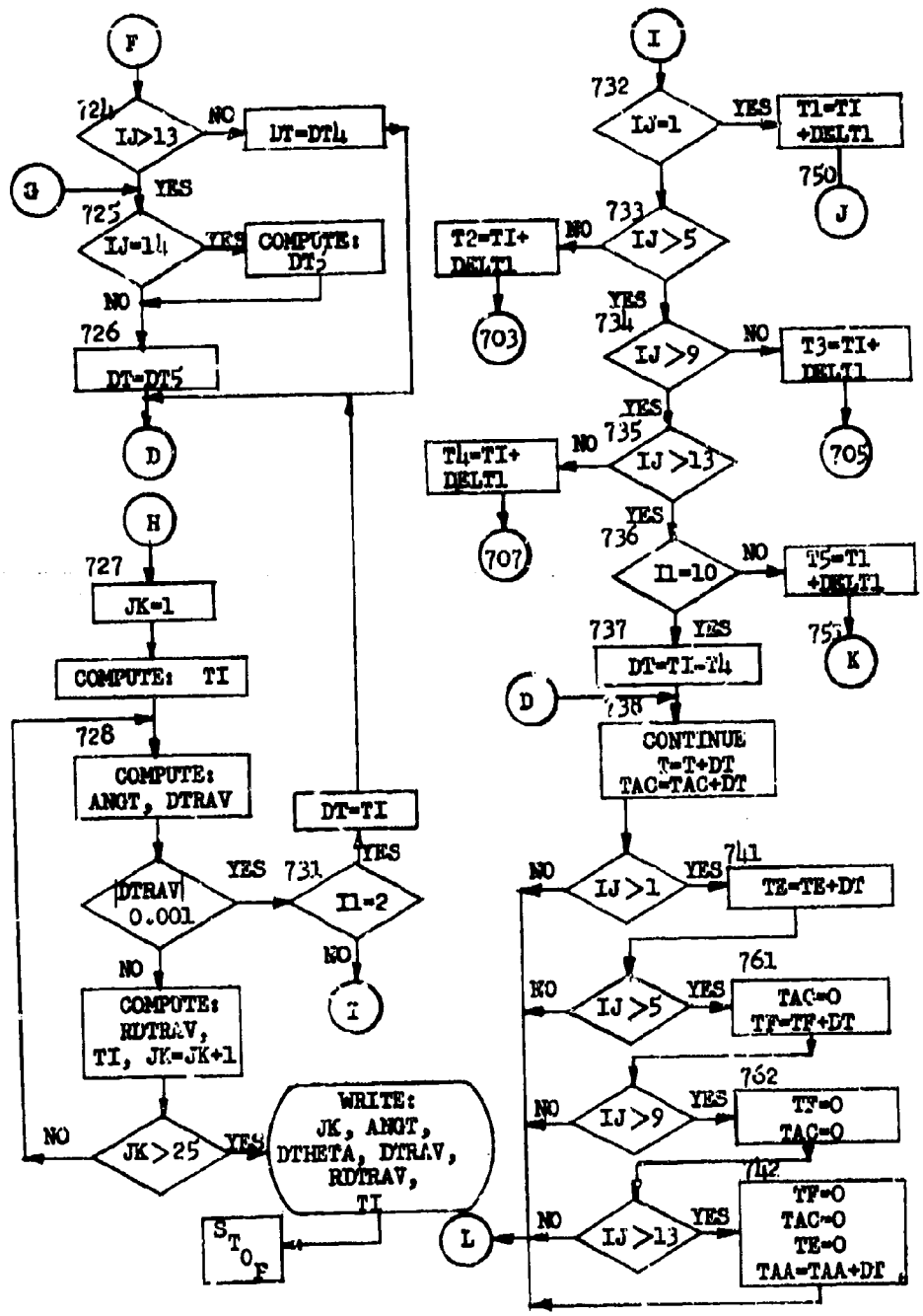
A–15. FLOW CHART FOR MULTIBARREL POWER



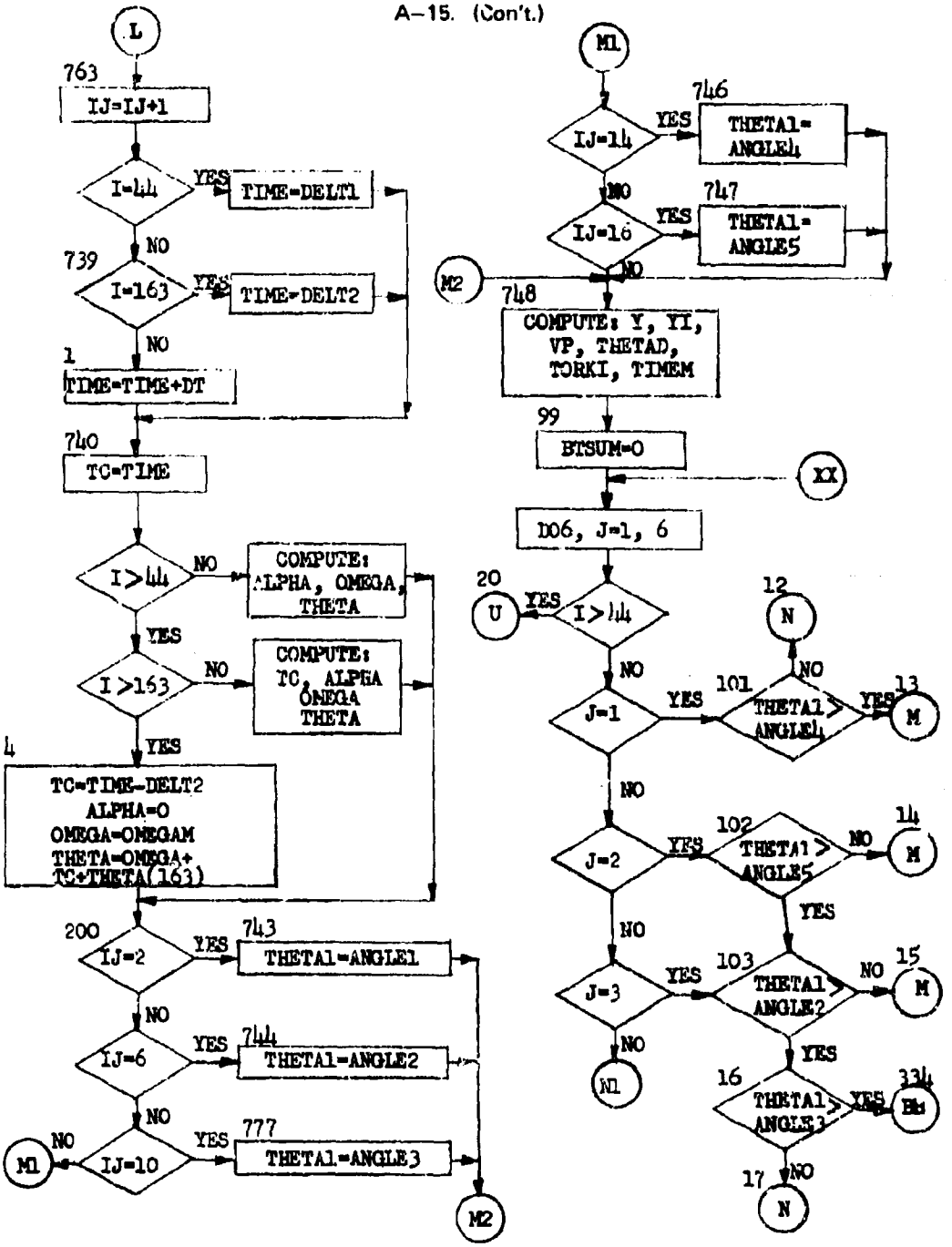
A–16. (Con't.)


C
709
I1=2
YES
711
IJ=15
YES
712
COMPUTE: DTHETA
NO
NO
IJ=14
NO
DT=T5-T4
751
YES
K
DT5=(T5-T4) 12
710
DT=DT5
738
D
E
IJ=10
NO
DTHETA =ANGA2
YES
IJ>13
NO
YES
725
G
YES
I1=10
NO
IJ=14
NO
YES
DTHETA =ENDANG
B
713
I1=11
YES
718
IJ>1
NO
COMPUTE: DT
NO
YES
II=I
YES
COMPUTE: TIO, DTHETA =ANGA1
719
IJ=2
YES
COMPUTE: DT2
NO
714
IJ=2
YES
DTHETA =ANGD1
NO
720
IJ>5
NO
DT=DT2
NO
738
715
IJ>5
NO
D
YES
721
IJ=6
YES
COMPUTE: DT3
YES
IJ=6
YES
DTHETA =ANGD2
NO
722
IJ>9
NO
DT=DT3
NO
738
716
IJ>9
NO
D
H
YES
723
IJ=10
YES
COMPUTE: DT4
738
D
YES
E
NO
F

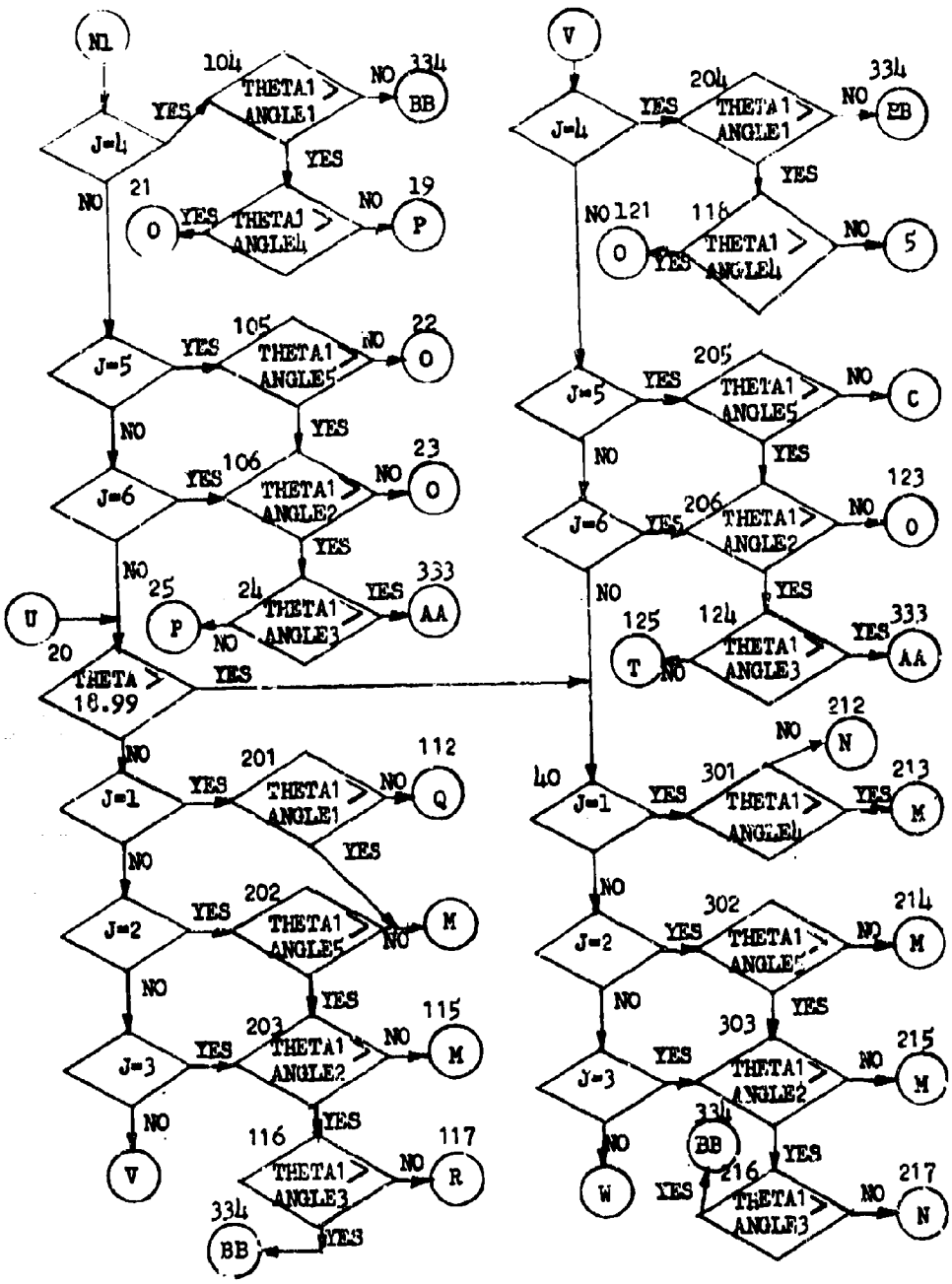
A—15. (Con't.)


F
724
IJ>13
NO
DT=DT4
3
YES
725
IJ=14
YES
COMPUTE: DT5
NO
726
DT=DT5
D
H
727
JK=1
COMPUTE: TI
728
COMPUTE: ANGT, DTRAV
DTRAV 0.001
YES
731
II=2
YES
NO
I
NO
COMPUTE: RDTRAV, TI, JK=JK+1
JK>25
NO
YES
WRITE: JK, ANGT, DTHETA, DTRAV, RDTRAV, TI
STOP
DT=TI
I
732
IJ=1
YES
T1=TI+DELT1
750
J
733
IJ>5
NO
T2=TI+DELT1
703
YES
734
IJ>9
NO
T3=TI+DELT1
705
YES
735
IJ>13
NO
T4=TI+DELT1
707
YES
736
II=10
NO
T5=T1+DELT1
751
K
737
YES
DT=TI-T4
D
738
CONTINUE
T=T+DT
TAC=TAC+DT
741
IJ>1
NO
YES
TE=TE+DT
761
IJ>5
NO
YES
TAC=0
TF=TF+DT
762
IJ>9
NO
YES
TF=0
TAC=0
742
IJ>13
NO
YES
TF=0
TAC=0
TE=0
TAA=TAA+DT
L

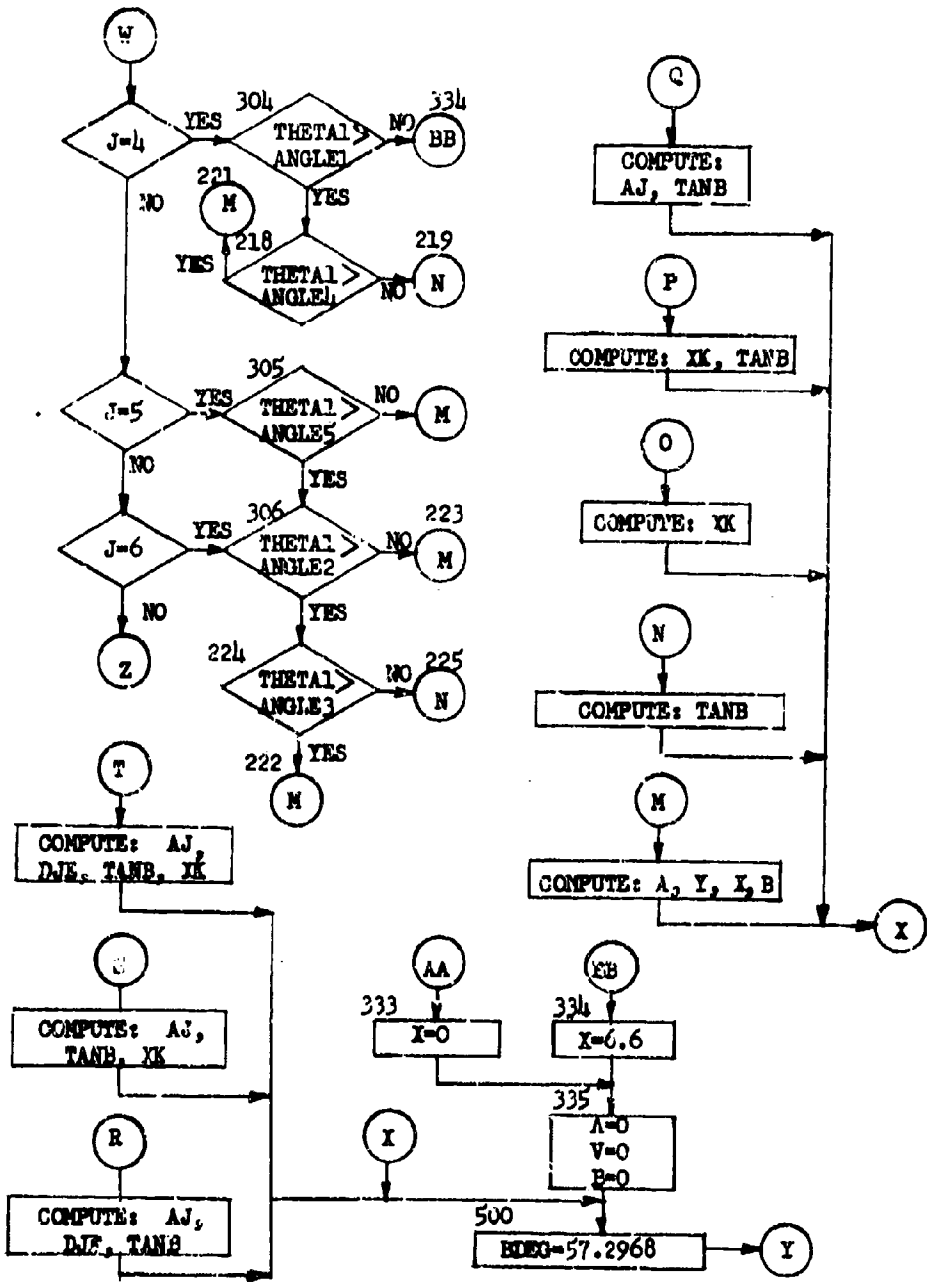
A-15. (Con't.)


L
763
IJ=IJ+1
I=44
YES
TIME=DELT1
NO
739
I=163
YES
TIME=DELT2
NO
1
TIME=TIME+DT
740
TC=TIME
I>44
NO
COMPUTE: ALPHA, OMEGA, THETA
YES
I>163
NO
COMPUTE: TC, ALPHA OMEGA THETA
YES
4
TC=TIME-DELT2
ALPHA=0
OMEGA=OMEGAM
THETA=OMEGA+TC*THETA(163)
200
IJ=2
YES
743
THETA1=ANGLE1
NO
IJ=6
YES
744
THETA1=ANGLE2
NO
IJ=10
NO
M1
YES
777
THETA1=ANGLE3
M2
M1
IJ=14
YES
746
THETA1=ANGLE4
NO
IJ=16
YES
747
THETA1=ANGLE5
NO
M2
748
COMPUTE: Y, YI, VP, THETAD, TORKI, TIMEM
99
BTSUM=0
XX
DO6, J=1, 6
20
U
YES
I>44
12
N
NO
J=1
YES
101
THETA1>ANGLE4
NO
YES
13
M
NO
J=2
YES
102
THETA1>ANGLE5
NO
14
M
YES
NO
J=3
YES
103
THETA1>ANGLE2
NO
15
M
YES
NO
M1
16
THETA1>ANGLE3
YES
334
Bm
NO
17
N

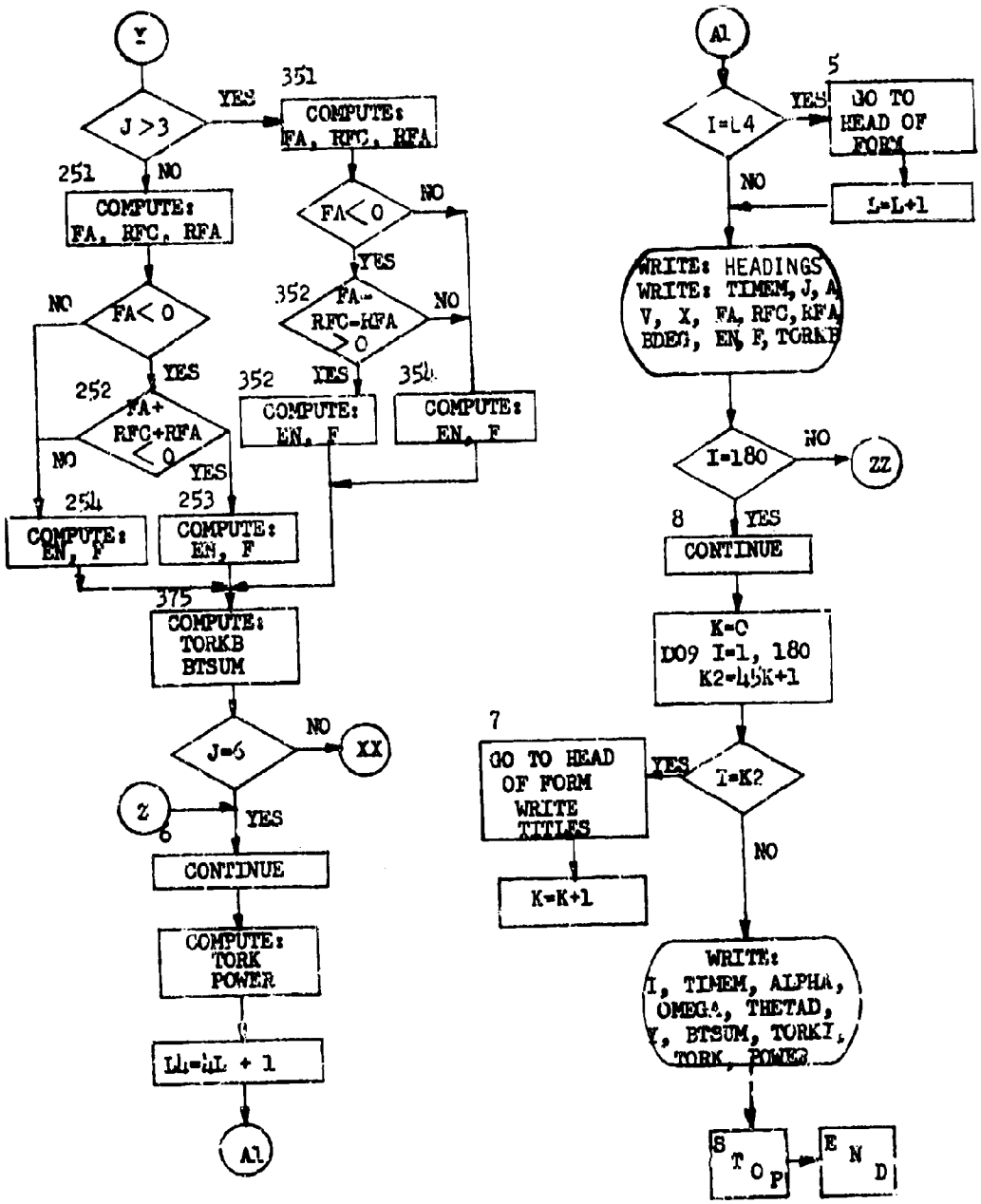
A-15. (Cont'd)


N1
104
THETA1 > ANGLE1
YES
NO
334
BB
J=4
YES
NO
21
O
YES
THETA1 > ANGLE4
NO
19
P
105
J=5
THETA1 > ANGLE5
22
O
106
J=6
THETA1 > ANGLE2
23
O
U
25
P
24
THETA1 > ANGLE3
333
AA
20
THETA > 18.99
201
J=1
THETA1 > ANGLE1
112
Q
202
J=2
THETA1 > ANGLE5
M
203
J=3
THETA1 > ANGLE2
115
M
V
116
THETA1 > ANGLE3
117
R
334
BB
V
204
J=4
THETA1 > ANGLE1
334
BB
121
O
116
THETA1 > ANGLE4
5
205
J=5
THETA1 > ANGLE5
C
206
J=6
THETA1 > ANGLE2
123
O
125
T
124
THETA1 > ANGLE3
333
AA
40
J=1
301
THETA1 > ANGLE4
213
M
212
N
302
J=2
THETA1 > ANGLE5
214
M
303
J=3
THETA1 > ANGLE2
215
M
W
334
BB
216
THETA1 > ANGLE3
217
N

A-1b. (Con't.)


W
J=4
YES
304
THETA1 > ANGLE1
NO
334
BB
NO
221
M
YES
218
THETA1 > ANGLE4
219
N
J=5
YES
305
THETA1 > ANGLE5
NO
M
NO
YES
J=6
YES
306
THETA1 > ANGLE2
223
NO
M
NO
YES
Z
224
THETA1 > ANGLE3
NO
225
N
222
YES
M
T
COMPUTE: AJ, DJE, TANB, XK
U
COMPUTE: AJ, TANB, XK
R
COMPUTE: AJ, DJE, TANB
Q
COMPUTE: AJ, TANB
P
COMPUTE: XK, TANB
O
COMPUTE: XK
N
COMPUTE: TANB
M
COMPUTE: A, Y, X, B
X
AA
333
X=0
BB
334
X=6.6
335
A=0
V=0
B=0
X
500
RDEG=57.2968
Y

A-15. (Con't.)


Y
J >3
YES
351
COMPUTE: FA, RFC, RFA
NO
251
COMPUTE: FA, RFC, RFA
FA< 0
NO
YES
352
FA-RFC-RFA > 0
NO
YES
352
COMPUTE: EN, F
350
COMPUTE: EN, F
NO
FA< 0
YES
252
FA+RFC+RFA < 0
NO
YES
254
COMPUTE: EN, F
253
COMPUTE: EN, F
375
COMPUTE: TORKB BTSUM
J=6
NO
XX
Z
6
YES
CONTINUE
COMPUTE: TORK POWER
L1=4L + 1
A1
A1
I=L4
YES
5
GO TO HEAD OF FORM
NO
L=L+1
WRITE: HEADINGS
WRITE: TIMEM, J, A, V, X, FA, RFC, RFA, EDEG, EN, F, TORKB
I=180
NO
ZZ
YES
8
CONTINUE
K=C
DO9 I=1, 180
K2=45K+1
7
GO TO HEAD OF FORM WRITE TITLES
YES
I=K2
NO
K=K+1
WRITE: I, TIMEM, ALPHA, OMEGA, THETAD, V, BTSUM, TORKI, TORK, POWER
STOP
END

A--15. PROGRAM LISTING FOR MULTIBARREL POWER

		INPUT CARD COUNT
DIMENSION TIMEM(180),ALPHA(180),OMEGA(180),THETA(180),THETAD(180),	3	1
1BTSON(180),TORKT(180),TORK(180),X(6), V(6),A(6),Y(180),BDEG(6),	4	2
2FA(6),RPC(6),RFA(6),EN(6),F(6),B(6),TORKB(6),POWER(180)	5	3
3READ(5,75)AFK,DFK, AEK, DEK, AK, C1 , C2, C3, ANGLE1,	6	4
1 ANGLE2, ANGLE3, ANGLE4, ANGLE5, EL, R, RC, WB, WST,	7	5
2BSE, COEFC1, COEFC2, COEFS1,COEFS2,ALPHA0,OMEGAM,YIF, Y2F,	8+9	6
3 X1F, X2F, TANBF, TANBE, Y1E, Y2E, X1E, X2E, G,	10	7
4 DELT1, DELT2,ENDAN1, EMUR, EMUS, EMUT, EYE, BF1, BE1	11	8
75 FORMAT (9F8.0)	12	9
TIME = 0.0	13	10
L = 0	14	11
RCA1 = RC*ANGLE1	15A	12
RCTF = RC*TANBF	15B	13
RCTE = RC*TANBE	15C	14
RSQ = RC**2	15D	15
VJF = OMEGAM*RCTF	15F	16
VJE = -OMEGAM*RCTE	15G	17
AJA3 = 2.0*RC**3*OMEGAM**2	15H	18
AJAF = AJA3/AFK	15I	19
AJDF = -AJA3/DFK	15J	20
AJAE = -AJA3/AEK	15K	21
AJDE = AJA3/DEK	15L	22
AJAP = RCTF*ALPHA0	15M	23
AJAN = -RCTE*ALPHA0	15N	24
XK1F = RCTF*(ANGLE5-ANGLE4)	15O	25
XK1E = RCTE*(ANGLE5-ANGLE4)	15P	26
XK2F = RCTF*(2.0*ANGLE5-ANGLE4)	15Q	27
XK2E = RCTE*(2.0*ANGLE5-ANGLE4)	15R	28
XK3F = XK2F + RCTF*ANGLE2	15S	29
XK3E = XK2E + RCTE*ANGLE2	15T	30
YF2 = 2.0*Y2F*RC	15U	31
YE2 = 2.0*Y2E*RC	15V	32
AJF2 = YF2*ALPHA0	15W	33
AJE2 =-YE2*ALPHA0	15X	34
AJ3 = 3.0*RC**2*ALPHA0**2	15Y	35
AJ3F = AJ3/AFK	15Z	36
AJ3E = AJ3/AEK	15AA	37
DJ2F = AYF2/DFK	15AB	38
DJ2E = AYE2/DEK	15AC	39
DJ3F = AJ3/DFK	15AD	40
DJ3E = AJ3/DEK	15AE	41
AJT4 = 5.0*RSQ*AK**2/6.0	15AF	42
AJT3 = 10.0*RSQ*AK*C1/3.0	15AG	43
AJT2 = RSQ*(4.0*AK*C2 +3.0*C1**2)	15AH	44
AJT1 = 2.0*RSQ*(AK*C3 + 3.0*C1*C2)	15AI	45
AJT0 = 2.0*RSQ*(C1*C3 + C2**2)	15AJ	46
BX=C2/C1	15AK	47
BSQ=BX**2	15AL	48
CX=2.0/C1	15AM	49
80 DO 8 I=1,180	16	50
I1 = (I-1)/15	A1	51
II5 = 15*I1	A2	52
II = I15 + 1	A3	53
ZZ = II	A4	54
ZANGLE = ZZ*ANGLE5	A5	55

A—16. (Con't.)

```
      IF(II.NE.1)GO TO 702                                          A6      56
      ANGA1 = ANGLE1 + ZANGLE                                       A7      57
      ANGU1 = ANGLE2 + ZANGLE                                       A8      58
      ANGU2 = ANGLE3 + ZANGLE                                       A9      59
      ANGA2 = ANGLE4 + ZANGLE                                       A10     60
      IF(II.EQ.2)GO TO 701                                          A11     61
      ENDANG = ANGLE5 + ZANGLE                                      A12     62
      GO TO 755                                                     A13     63
  701 ENDANG = ENDAN1 + ZANGLE                                      A14     64
  755 IJ = 1                                                        A15A    65
      T=0.0                                                         A15B    66
      TE=0.0                                                        A15C    67
      TAC=0.0                                                       A15D    68
      TF=0.0                                                        A15E    69
      TAA=0.0                                                       A15F    70
  702 IF(II.GE.3)GO TO 713                                          A16     71
      IF(IJ.GT.1)GO TO 703                                          A17     72
      T1 = SQRT(2.0*ANGA1/ALPHA0)                                   A18     73
      T2 = SQRT(2.0*ANGD1/ALPHA0)                                   A19     74
      T3 = SQRT(2.0*ANGD2/ALPHA0)                                   A20     75
      T4 = SQRT(2.0*ANGA2/ALPHA0)                                   A21     76
      T5 = SQRT(2.0*ENDANG/ALPHA0)                                  A22     77
      IF(I.GT.1)GO TO 750                                           A23A    78
      DT = T1                                                       A23B    79
      GO TO 738                                                     A23C    80
  750 IF(IJ.NE.1)GO TO 703                                          A23D    81
      DT = T1 - TIMEM(I-1)/1000.0                                   A24     82
      GO TO 738                                                     A25     83
  703 IF(IJ.NE.2)GO TO 704                                          A26     84
      DT2 = (T2-T1)/4.0                                             A27     85
  704 IF(IJ.GT.5)GO TO 705                                          A28     86
      DT = DT2                                                      A29     87
      GO TO 738                                                     A30     88
  705 IF(IJ.NE.6)GO TO 706                                          A31     89
      DT3 = (T3-T2)/4.0                                             A32     90
  706 IF(IJ.GT.9)GO TO 707                                          A33     91
      DT = DT3                                                      A34     92
      GO TO 738                                                     A35     93
  707 IF(IJ.NE.10)GO TO 708                                         A36     94
      DT4 = (T4-T3)/4.0                                             A37     95
  708 IF(IJ.GT.13)GO TO 709                                         A38     96
      DT = DT4                                                      A39     97
      GO TO 738                                                     A40     98
  709 IF(II.EQ.2)GO TO 711                                          A41     99
      IF(IJ.NE.14)GO TO 710                                         A42     100
  751 DT5 = (T5-T4)/2.0                                             A43     101
  710 DT = DT5                                                      A44-5   102
      GO TO 738                                                     A46     103
  711 IF(IJ.EQ.15)GO TO 712                                         A47     104
      DT = T5-T4                                                    A48     105
      GO TO 738                                                     A49     106
  712 DTHETA = 3.0*ANGLE5                                           A50     107
      GO TO 727                                                     A51-2   108
  713 IF(II.EQ.11)GO TO 718                                         A53     109
      IF(II.NE.1)GO TO 714                                          A54     110
      TIO=TIMEM(I-1)/1000.0-DELT1                                   A55     111
      DTHETA = ANGA1                                                A56     112
      GO TO 727                                                     A57-8   113
```

```
      714 IF(IJ.NE.2)GO TO 715                                          A59   114
          DTHETA = ANGD1                                                A60   115
          GO TO 727                                                     A61   116
      715 IF(IJ.LE.5)GO TO 738                                          A62   117
          IF(IJ.NE.6)GO TO 716                                          A63   118
          DTHETA = ANGD2                                                A64   119
          GO TO 727                                                     A65   120
      716 IF(IJ.LE.9)GO TO 738                                          A66   121
          IF(IJ.NE.10)GO TO 717                                         A67   122
          DTHETA = ANG42                                                A68   123
          GO TO 727                                                     A69   124
      717 IF(IJ.LE.13)GO TO 738                                         A70   125
          IF(IJ.EQ.10)GO TO 725                                         A71   126
          IF(IJ.NE.14)GO TO 745                                         A72   127
          DTHETA = ENDANG                                               A73   128
          GO TO 727                                                     A74   129
      745 GO TO 738                                                     A75-8 130
      718 IF(IJ.GT.1)GO TO 719                                          A79   131
          DT = ANGLE1/OMEGAM                                            A80   132
          GO TO 738                                                     A81   133
      719 IF(IJ.NE.3)GO TO 720                                          A82   134
          DT2 = (ANGLE2 - ANGLE1)/(2.0*OMEGAM)                          A83   135
      720 IF(IJ.GT.5)GO TO 721                                          A84   136
          DT = DT2                                                      A85   137
          GO TO 738                                                     A86   138
      721 IF(IJ.NE.6)GO TO 722                                          A87   139
          DT3 = (ANGLE3 - ANGLE2)/(2.0*OMEGAM)                          A88   140
      722 IF(IJ.GT.9)GO TO 723                                          A89   141
          DT = DT3                                                      A90   142
          GO TO 738                                                     A91   143
      723 IF(IJ.NE.10)GO TO 724                                         A92   144
          DT4 = (ANGLE4 - ANGLE3)/(2.0*OMEGAM)                          A93   145
      724 IF(IJ.GT.13)GO TO 725                                         A94   146
          DT = DT4                                                      A95   147
          GO TO 738                                                     A96   148
      725 IF(IJ.NE.14)GO TO 726                                         A97   149
          DT5 = (ANGLE5 - ANGLE4)/ (2.0*OMEGAM)                         A98   150
      726 DT = DT5                                                      A99   151
          GO TO 738                                                     A100  152
      727 JK = 1                                                        A101  153
          TI=SQRT(BSG+CX*(DTHETA-C3))-BX                                A102  154
      728 ANGT = AK*TI**3/6.0 + C1*TI**2/2.0 + C2*TI + C3               A103  155
          DTRAV = DTHETA - ANGT                                         A104  156
          IF(ABS(DTRAV).LT.0.001)GO TO 731                              A105  157
          RDTRAV = DTRAV/(DTHETA-C3)                                    A106  158
          TI =TI*(1.0 + RDTRAV)                                         A107  159
          JK = JK+1                                                     A108  160
          IF(JK.GT.25)GO TO 729                                         A109  161
          GO TO 728                                                     A110  162
      729 WRITE(6,730)JK,ANGT,DTHETA,DTRAV,RDTRAV,TI                    A111  163
      730 FORMAT(I3,5E15.8)                                             A112  164
          GO TO 900                                                     A113  165
      731 IF(IJ.NE.2)GO TO 732                                          A114  166
          DT = TI - T5                                                  A115  167
          DT=TI                                                         A116  168
          GO TO 738                                                     A117  169
      732 IF(IJ.NE.1)GO TO 733                                          A118  170
          T1 = TI*DELTI                                                 A119  171
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A—16. (Con't.)

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      GO TO 750                                                          A119   172
  733 IF(IJ.GT.5)GO TO 734                                               A120   173
      T2 = TI*DELT1                                                      A121   174
      GO TO 703                                                          A122   175
  734 IF(IJ.GT.9)GO TO 735                                               A123   176
      T3 = TI*DELT1                                                      A124   177
      GO TO 705                                                          A125   178
  735 IF(IJ.GT.13)GO TO 736                                              A126   179
      T4 = TI*DELT1                                                      A127   180
      GO TO 707                                                          A128   181
  736 IF(IJ.EQ.10)GO TO 737                                              A129   182
      T5 = TI*DELT1                                                      A130   183
      GO TO 751                                                          A131   184
  737 DT = TI-T4                                                         A132   185
  738 CONTINUE                                                           A133   186
      T=T+DT                                                             A134   187
      TAC=TAC+DT                                                         A135   188
      IF(IJ.GT.11)GO TO 741                                              A136A  189
      GO TO 703                                                          A136B  190
  741 TE=TE+DT                                                           A136C  191
      IF(IJ.GT.5)GO TO 761                                               A137   192
      GO TO 703                                                          A138   193
  761 TAC=0.0                                                            A139   194
      TF=TF+DT                                                           A140   195
      IF(IJ.GT.9)GO TO 762                                               A141   196
      GO TO 703                                                          A142   197
  762 TF=0.0                                                             A143   198
      TAC=0.0                                                            A144   199
      IF(IJ.GT.13)GO TO 742                                              A145   200
      GO TO 703                                                          A146   201
  742 TF=0.0                                                             17A    202
      TAC=0.0                                                            17B    203
      TE=0.0                                                             17C    204
      TAA=TAA*DT                                                         17D    205
  763 IJ=IJ+1                                                            17E    206
      IF(I.NE.44)GO TO 739                                               17F    207
      TIME = DELT1                                                       17G    208
      GO TO 740                                                          17H    209
  739 IF(I.NE.163)GO TO 1                                                17I    210
      TIME = DELT2                                                       17J    211
      GO TO 740                                                          17K    212
    1 TIME = TIME+DT                                                     18     213
  740 TC= TIME                                                           19A    214
      IF(I.GT.44)GO TO 2                                                 19B    215
      ALPHA(I) = ALPHA0                                                  20     216
      OMEGA(I) = ALPHA(I)*TC                                             21     217
      THETA(I) = OMEGA(I)*TC/2.0                                         22     218
      GO TO 200                                                          23     219
    2 IF(I.GT.163)GO TO 4                                                24-5   220
      TC= TIME - DELT1                                                   26     221
      ALPHA(I) = AK*TC+ C1                                               27     222
      OMEGA(I)=AK*TC**2/2.+C1*TC+C2                                      28     223
      THETA(I)=AK*TC**3/6.+C1*TC**2/2.+C2*TC*C3                          29     224
      GO TO 200                                                          30     225
    4 TC= TIME - DELT2                                                   31-2   226
      ALPHA(I) = 0.0                                                     33     227
      OMEGA(I) = OMEGAM                                                  34     228
      THETA(I) = OMEGA(I)*TC+ THETA(163)                                 35     229
```

```
200 IF(IJ.EQ. 2)GO TO  743                                      36A  230
    IF(IJ.EQ. 6)GO TO  744                                      36B  231
    IF(IJ.EQ.10)GO TO  777                                      36C  232
    IF(IJ.EQ.14)GO TO  746                                      36D  233
    IF(IJ.EQ.16)GO TO  747                                      36E  234
    THETA1 = THETA(I)-ZANGLE                                    37A  235
    GO TO 748                                                   37B  236
743 THETA1 = ANGLE1                                             38A  237
    GO TO 748                                                   38B  238
744 THETA1 = ANGLE2                                             38C  239
    GO TO 748                                                   38D  240
777 THETA1 = ANGLE3                                             39A  241
    GO TO 748                                                   39B  242
746 THETA1 = ANGLE4                                             39C  243
    GO TO 748                                                   39D  244
747 THETA1 = ANGLE5                                             39E  245
748 Y(I) =RC*THETA1                                             40A  246
    YI = Y(I)-RC*ANGLE2                                         40B  247
    VP = RC*OMEGA(I)                                            40C  248
    THETAD(I) = 57.296*THETA(I)                                 41   249
    TORX(I) = EYE*ALPHA(I)                                      42   250
    TIMEM(I) = 1000.0*TIME                                      43   251
 99 BTSUM(I)=0.0                                                44   252
    DO 6   J=1,6                                               45   253
    IF(I.GT.44)GO TO 20                                         46   254
 10 GO TO (101, 102, 103, 104, 105, 106),J                      47   255
101 IF(THETA1.GT.ANGLE4)GO TO 13                                48   256
 12 A(J)=AJAF*T  **2                                            49   257
    TANB = 2.0*Y(I)/AFK                                         50A  258
    V(J)=VP*TANB                                                50B  259
    X(J) = Y(I)*2/AFK                                           51   260
    B(J) = ATAN (TANB)                                          52   261
    GO TO 500                                                   53   262
 13 A(J) = AJAP                                                 54   263
    V(J) = TANBF*VP                                             55   264
    X(J) = X1F + ((Y(I)-Y1F)*TANBF)                             56   265
    B(J) = BF1                                                  57   266
    GO TO 500                                                   58   267
102 IF(THETA1.GT.ANGLE5)GO TO 103                               59   268
 14 A(J) = AJAP                                                 60   269
    V(J) = TANBF*VP                                             61   270
    X(J) = Y(I)*TANBF + X1F + XK1F                              62   271
    B(J) = BF1                                                  63   272
    GO TO 500                                                   64   273
103 IF(THETA1.GT.ANGLE2)GO TO 16                                65   274
 15 X(J) = Y(I)*TANBF + X1F + XK2F                              66   275
    A(J) = AJAP                                                 67   276
    V(J) = VP*TANBF                                             68   277
    B(J) = BF1                                                  69   278
    GO TO 500                                                   70   279
 16 IF(THETA1.GT.ANGLE3)GO TO 334                               71   280
 17 A(J)=DJ2F-DJ3F*TE **2                                       72   281
    TANB = 2.0*(Y2F-YI)/DFK                                     73A  282
    V(J)=   TANB*VP                                             73B  283
    X(J)=X2F-(Y2F-YI)**2/DFK*XIF+XK3F                           74   284
    B(J) = ATAN (TANB)                                          75   285
    GO TO 500                                                   76   286
104 IF(THETA1.LE.ANGLE1)GO TO 334                               77   287
```

A—16. (Con't.)

```
      18 IF(THETA1.GT.ANGLE4)GO TO 21                                  78                285
      19 A(J) = -AJ3E*TF **2                                           79                289
         TANB = 2.0*(Y(I)-RCA1)/AEX                                    80A               290
         V(J) = -TANB*VP                                               80B               291
         XK = (Y(I)-RCA1)**2/AEK                                       81                292
         X(J) = EL-XK                                                  82                293
         B(J) = ATAN (TANB)                                            83                294
         GO TO 500                                                     84                295
      21 A(J) = AJAN                                                   85                296
         V(J) = -TANBE*VP                                              86                297
         XK   = X1E + ((Y(I)-Y1E-RCA1)*TANBE)                          87                298
         X(J) = EL-XK                                                  88                299
         B(J) = BE1                                                    89                300
         GO TO 500                                                     90                301
     115 IF(THETA1.GT.ANGLE5)GO TO 106                                 91                302
      22 A(J) = AJAN                                                   92                303
         V(J) = -TANBE*VP                                              93                304
         XK = X1E + Y(I)*TANBE + XK1E                                  94                305
         X(J) = EL - XK                                                95                306
         B(J) = BE1                                                    96                307
         GO TO 500                                                     97                308
     106 IF(THETA1.GT.ANGLE2)GO TO 24                                  98                309
      23 A(J) = AJAN                                                   99                310
         V(J) = -TANBE*VP                                              100               311
         XK = X1E+XK2E-(Y(I)*TANBE)                                    101               312
         X(J) = EL-XK                                                  102               313
         B(J) = BE1                                                    103               314
         GO TO 500                                                     104               315
      24 IF(THETA1.GT.ANGLE3)GO TO 333                                 105               316
      25 A(J)=-DJ2E*DJ3E*TF **2                                        106               317
         TANB = 2.0*(Y2E-YI)/DEK                                       107A              318
         V(J)=-TANB*VP                                                 107B              319
         XK=X1E+XK2F+X2E-(Y2E-Y1)**2/DEK                               108               320
         X(J) = EL-XK                                                  109               321
         B(J) = ATAN (TANB)                                            110               322
         GO TO 500                                                     111               323
      20 IF(I.GT.163)GO TO 40                                          112               324
      30 GO TO (201,202,203,204,205,206),J                             113               325
     201 IF(THETA1.GT.ANGLE4)GO TO 113                                 114               326
         AJ = AJT4*T**4 + AJT3*T**3 + AJT2*T**2 + AJT1*T + AJT0        116A              327
         A(J)= AJ/AFK                                                  116B              328
         TANB = 2.0*Y(I)/AFK                                           117               329
         V(J)= TANB*VP                                                 118               330
         X(J) = Y(I)**2/AFK                                            119               331
         B(J) = ATAN (TANB)                                            120               332
         GO TO 500                                                     121               333
     113 A(J)=RCTF*(AK*TAA+C1)                                         122               334
         V(J) = VP*TANBF                                               123               335
         X(J) = X1F+(Y(I)-Y1F)*TANBF                                   124               336
         B(J) = BF1                                                    125               337
         GO TO 500                                                     126               338
     202 IF(THETA1.GT.ANGLE5)GO TO 203                                 127               339
         A(J)=RCTF*(AK*T  +C1)                                         128               340
         V(J) = VP*TANBF                                               129               341
         X(J) = X1F + Y(I)*TANBF + XK1F                                130               342
         B(J) = BF1                                                    131A              343
         GO TO 500                                                     131B              344
     203 IF(THETA1.GT.ANGLE2)GO TO 116                                 132               345
```

```
      A(J)=RCTF*(AK*TAC+C1)                                          133
      V(J) = VP*TANBF                                                134
      Y(J) = XJF + Y(I)*TANBF + XK2F                                 135
      B(J) = BF1                                                     136
      GO TO 500                                                      137
  116 IF(THETA1.GT.ANGLE3)GO TO 334                                  138
  117 DJF = YF2*(AK*TF+C1)                                           139
      AJ = AJT4*TF**4 + AJT3*TF**3 + AJT2*TF**2 + AJT1*TF + AJT0     140
      A(J) = (DJF - AJT/DFK                                          141
      TANB = 2.0*(Y2F-YI)/DFK                                        142
      V(J) = VP*TANB                                                 143
      X(J)=X2F-(Y2F-YI)**2/DFK+X1F+XK3F                              144
      B(J) = ATAN (TANB)                                             146
      GO TO 500                                                      147
  204 IF(THETA1.LE.ANGLE1)GO TO 334                                  148
  118 IF(THETA1.GT.ANGLE4)GO TO 121                                  149
      AJ = AJT4*TE**4 + AJT3*TE**3 + AJT2*TE**2 + AJT1*TE + AJT0     150
      A(J) = -AJ/AEK                                                 151
      TANB = 2.0*(Y(I)-RCA1)/AEK                                     152
      V(J) = -VP*TANB                                                153
      XK=(Y(I)-RCA1)**2/AEK                                          154
      X(J) = EL-XK                                                   155
      B(J) = ATAN (TANB)                                             156
      GO TO 500                                                      157
  121 A(J)=-RCTE*(AK*TAA+C1)                                         158
      V(J) =-VP*TANBE                                                159
      XK = X1E + (Y(I)-Y1E-RCA1T*TANBE                               160
      X(J) = EL-XK                                                   161A
      B(J) = BE1                                                     161B
      GO TO 500                                                      162
  205 IF(THETA1.GT.ANGLE5)GO TO 206                                  163
      A(J)=-RCTE*(AK*T  +C1)                                         164
      V(J) =-VP*TANBE                                                165
      XK = X1E + Y(I)*TANBE + XK1E                                   166
      X(J) = EL-XK                                                   167
      B(J) = BE1                                                     168
      GO TO 500                                                      169
  206 IF(THETA1.GT.ANGLE2)GO TO 124                                  170
      A(J)=-RCTE*(AK*TAC+C1)                                         171
      V(J) =-VP*TANBE                                                172
      XK = X1E+XK2E +(Y(I)*TANBE )                                   173
      X(J) = EL-XK                                                   174
      B(J) = BE1                                                     175
      GO TO 500                                                      176
  124 IF(THETA1.GT.ANGLE3)GO TO 333                                  177
      AJ = AJT4*TF**4 + AJT3*TF**3 + AJT2*TF**2 + AJT1*TF + AJT0     178
  125 DJE = YE2*(AK*TF +C1)                                          179
      A(J) = (DJE + AJ)/DEK                                          180
      TANB = 2.0*(Y2E-YI)/DEK                                        181
      V(J)=-VP*TANB                                                  182
      B(J)=ATAN(TANB)                                                183
      XK=X1E+XK3E+2E-(Y2E-YI)**2/DEK                                 184
      X(J) = EL-XK                                                   185
      GO TO 500                                                      186
   30 GO TO (301,302,303,304,305,306),J                              187
  301 IF(THETA1.GT.ANGLE4)GO TO 213                                  188
  212 A(J) = AJAF                                                    189
      TANB = 2.0*Y(I)/AFK                                            190A
```

A—16. (Con't.)

```
      V(J) = VP*TANB                                                    1908
      X(J) = Y(I)**2/AFK                                                191
      B(J) = ATAN (TANB)                                                192
      GO TO 500                                                         193
  213 A(J) = 0                                                          194
      V(J) = VJF                                                        195
      X(J) = X1F + (Y(I)-Y1F)*TANBF                                     196
      B(J) = BF1                                                        197
      GO TO 500                                                         198
  302 IF(THETA1.GT.ANGLE5)GO TO 303                                     199
  214 A(J) = 0                                                          200
      V(J) = VJF                                                        201
      X(J) = Y(I)*TANBF + X1F  + XK1F                                   202
      B(J) = BF1                                                        203
      GO TO 500                                                         204
  303 IF(THETA1.GT.ANGLE2)GO TO 216                                     205
  215 A(J) = 0                                                          206
      V(J) = VJF                                                        207
      X(J) = Y(I)*TANBF + X1F + XK2F                                    208
      B(J) = BF1                                                        209
      GO TO  500                                                        210
  216 IF(THETA1.GT.ANGLE3)GO TO 334                                     211
  217 A(J) = AJDF                                                       212
      TANB = 2.0*(Y2F-YI)/DFK                                           213A
      V(J) = VP*TANB                                                    213B
      X(J)=X2F-(Y2F-YI)**2/DFK+X1F+XK3F                                 214
      B(J) = ATAN (TANB)                                                215
      GO TO 500                                                         216
  304 IF(THETA1.LE.ANGLE1)GO TO 334                                     217
  218 IF(THETA1.GT.ANGLE4)GO TO 221                                     218
  219 A(J)= AJAE                                                        219
      TANB = 2.0*(Y(I)-RCA1)/AEK                                        220A
      V(J)=VP*TANB                                                      220B
      X(J)= EL-(Y(I)-RCA1)**2/AEK                                       221
      B(J)= ATAN (TANB)                                                 222
      GO TO 500                                                         223
  221 A(J) = 0                                                          224
      V(J) =VVE                                                         225
      X(J) = EL-(X1E + (Y(I)-Y1E-RCA1)*TANBE)                           226
      B(J) = BE1                                                        227
      GO TO 500                                                         228
  305 IF(THETA1.GT.ANGLE5)GO TO 306                                     229
  222 A(J) = 0                                                          230
      V(J) =VVE                                                         231
      X(J) = EL - (X1E + Y(I)*TANBE + XK1E)                             232
      B(J) = BE1                                                        233
      GO TO 500                                                         234
  306 IF(THETA1.GT.ANGLE2)GO TO 224                                     235
  223 A(J) = 0                                                          236
      V(J) =VVE                                                         237
      X(J) = EL - (X1E+XK2E+Y(I)*TANBE)                                 238
      B(J) = BE1                                                        239
      GO TO 500                                                         240
  224 IF(THETA1.GT.ANGLE3)GO TO 333                                     241
  225 A(J) = AJDC                                                       242
      TANB = 2.0*(Y2E-YI)/DEK                                           243
      V(J) = VP*TANB                                                    244
      X(J)=EL-X1E-XK3E-X2E+(Y2E-YI)**2/DEK                              245
```

```
      B(J) = ATAN (TANB)                                                  246
      GO TO 500                                                           247
  333 X(J) = 0.0                                                          248A
      GO TO 335                                                           248B
  334 X(J) = 6.6                                                          248C
  335 V(J) = 0.0                                                          249
      A(J) = 0.0                                                          250
      B(J) = 0.0                                                          251
  500 BDEG(J) = 57.296*B(J)                                               252
      IF(J.GT.3)GO TO 351                                                 253
  251 FA(J) = ATJ*(WB+WST)/6                                              254
      RFC(J) = R*OMEGA(I)**2*(EMUT*WB+EMUS*WST)/6                         255
      RFA(J) = R*ALPHA(I)*(EMUT*WB+EMUS*WST)/6                            256
      IF(FA(J).GE.0.)GO TO 254                                            257
  252 IF (FA(J)+RFC(J)+RFA(J))253,253,254                                 258
  253 EN(J)=(FA(J)+RFC(J)+RFA(J))/(-COEFC2*COS (B(J))-COEFS2*SIN (B(J)))  259
      F(J) =EN(J)*(EMUR*COS (B(J))-SIN (B(J)))                            260
      GO TO 375                                                           261
  254 EN(J)=(FA(J)+RFC(J)+RFA(J))/(COEFC1*COS (B(J))-COEFS1*SIN (B(J)))   262
      F(J) =EN(J)*(SIN (B(J))+EMUR*COS (B(J)))                            263
      GO TO 375                                                           264
  351 FA(J) = A(J)*(WB + WSE)/6                                           265
      RFC(J) = R*OMEGA(I)**2*(EMUT*WB+EMUS*WSE)/6                         266
      RFA(J) = R*ALPHA(I)*(EMUT*WB+EMUS*WSE)/6                            267
      IF(FA(J).GE.0.0)GO TO 354                                           268
  352 IF(FA(J)-RFC(J)-RFA(J))354,354,353                                  269
  353 EN(J)=(FA(J)-RFC(J)-RFA(J))/(COEFC2*COS (B(J))+COEFS2*SIN (B(J)))   270
      F(J)=EN(J)*(EMUR*COS (B(J))-SIN (B(J)))                             271A
      GO TO 375                                                           271B
  354 EN(J)=(FA(J)-RFC(J)-RFA(J))/(COEFS1*SIN (B(J))-COEFC1*COS (B(J)))   272
      F(J)=EN(J)*(SIN (B(J))+EMUR*COS (B(J)))                             273
  375 TORKB(J) = F(J)*RC                                                  274
      BTSUM(I) = BTSUM(I)+TORKB(J)                                        275A
    6 CONTINUE                                                            275B
      TORK(I) = BTSUM(I) + TORKI(I)                                       276
      POWER(I) = TORK(I)*OMEGA(I)/6600.0                                  277
      L3 = L*3+1                                                          278
  803 IF(I.NE.L3)GO TO 56                                                 279
    5 WRITE(6,501)                                                        280
      L = L+1                                                             281
  501 FORMAT(1H1/37X,43HTABLE 6-2 OUTPUT OF EACH BOLT AT GIVEN TIME//)    282
   66 WRITE(6,601)TIME(I),(J,A(J),V(J),X(J),FA(J),RFC(J),RFA(J),BDEG(J)   283
     1,EN(J),F(J),TORKB(J),J=1,6)                                         284
  601 FORMAT(  /41X,15HCAM DYNAMICS AT F7.2,13H MILLISECONDS//33X,7HBOLT  285
     1    AXIAL    NORMAL   ANGULAR     CAM        CAM        CAM       286
     2BOLT/108H BOLT      BOLT        BOLT      AXIAL    INERTIA   FRICTI 287
     3ON  INERTIA   CURVE   NORMAL    DRIVING   DRIVING/108H  NO  ACCE    288
     4LERATION   VELOCITY   TRAVEL    FORCE     FORCE     FORCE     ANGL  289
     5E     FORCE     FORCE     TORQUE/7X,10HRIN/SEC/SEC     IN/SEC      290
     6INCH      POUND      POUND      POUND     DEGREE     POUND     POUND 291
     7   LB=IN//(I5,F12.0,F12.2,F10.3,F9.0,2F10.3,F10.3,3F10.0))         292
    8 CONTINUE                                                            293A
      K = 0                                                               293B
      DO 9 I = 1,180                                                      293C
      K2 = K*45+1                                                         293D
      IF(I.NE.1)GO TO 1051                                                293E
      WRITE(6,1052)                                                       293F
      GO TO 1054                                                          293G
```

A–16. (Con't.)

```
1052 FORMAT(1H1/33X,29HTABLE 6-3 GUN OPERATING POWER/)                    293H
 802 FORMAT(1H1/30X,35HTABLE 6-3 CONTD GUN OPERATING POWER/)              2931
1051 IF(I.NE.KZTGO TO 9                                                   294
   7 WRITE(6,802)                                                         295A
1054 WRITE(6,1053)                                                        2958
     K = K+1                                                              296
   9 WRITE(6,801)I, TIMEN(I),ALPHA(I),OMEGA(I),THETAD(I),Y(I),BTSUM(I)    297
     1,TORK(I),TORK(I),POWER(I)                                           298
1053 FORMAT (                                                             299
                                                    1X,56HROTOR     ROTOR 300
     1  ROTOR      BOLT      TOTAL/5H  IN-,13X,78HANGULAR     ANGULAR   AN 301
     2GULAR  PERIPHERAL    CAM      ROTOR   REQUIRED   REQUIRED/95H CRI-  302
     3 TIME    ACCELERATION  VELOCITY   TRAVEL     TRAVEL     TORQUE   TORQ 303
     4UE    TORQUE      HORSE-794H MENT  MILSEC   RAD/SEC/SEC   RAD/SEC  304
     5DEGREE      INCH      LB-IN     LB-IN      LB-IN        POWER/ )     305
 601 FORMAT (I4,F9.3,2F11.2,F11.1,F10.3,3F9.0,F11.1)                      306
 900 STOP                                                                 307
     END
```

APPENDIX B

AUTOMATIC CONTROL OF ROUNDS IN A BURST FOR WEAPON EFFECTIVENESS

Since it is not generally possible to automatically vary the number of rounds in a burst from modern automatic weapons, it is of interest to know whether or not advantage could be taken of such a capability to increase the cost effectiveness of such weapons.

In the most general case, hit probability $(Pr)_{eh}$ is a variational problem because hit probability is represented as

$$(Pr)_{eh} = 1 - \int_0^1 \left[1 - \frac{A}{2\pi\sigma_d^2} \, x^{\,\sigma_b^2/\sigma_d^2} \right]^n dx \qquad \text{(B-1)}$$

where

$(Pr)_{eh}$ = engagement hit probability

A = area of target

σ_d^2 = variance of dispersion

σ_b^2 = variance of bias

n = number of rounds in burst (each round assumed independent)

$x = \exp\left[r^2 / 2\sigma_b^2 \right]$

r = radial distance from target center

The reference for Eq. B-1 and its derivation is Eq. 4-413, AMCP 706-327, *Fire Control Systems – General.*

Observe that $(Pr)_{eh}$ is a function of, among other parameters, n. Thus, there is an optimum value of n for a burst. To exceed this optimum value of n increases the use and cost of rounds without appreciably increasing the hit probability. Use of an n smaller than the optimum value decreases hit probability, thereby, decreasing the effectiveness of the weapon.

Extensive studies to date with plotted curves for various values of n have shown that, in terms of $(Pr)_{eh}$, a tight control of n should reduce an excess use of ammunition. Since the value of n is generally under the trigger control of the gunner who cannot concentrate on or control discrete number of rounds in most circumstances, it appears logical that consideration should be given to the evaluation and design of a capability in the trigger or sear area to easily preselect an automatic number of rounds in a burst. Fig. B-1 illustrates the nature of $(Pr)_{eh}$ in relation to the number of rounds n in a burst. In interpreting this figure

$$\alpha = \frac{A}{2\pi\sigma_d^2}$$

$$R = \frac{\sigma_b^2}{\sigma_d^2}$$

For additional information on effectiveness vs the number of rounds in a burst for point fire refer to

1. *Summary of Test Data and Effectiveness Evaluation for Special Purpose Individual Weapon,* Ballistic Research Laboratories Technical Note 1542, Aberdeen Proving Ground, Md., August 1964.

2. *Dispersions for Effective Automatic Small Arms Fire and a Comparison of the M14 Rifle With a Weapon Yielding Effective Automatic Fire,* Ballistic Research Laboratories Technical Note 1372, Aberdeen Proving Ground, Md., January 1961.

The methods for automatically controlling the number of rounds in a burst are limited only by the ingenuity of the designer. Several methods that have been successfully employed are described briefly:

a. The M61A1 Vulcan Machine Gun employs a burst length control device which is essentially an electrical accessory that is preset by the operator. The accessory controls the length of time that power is supplied to the gun drive and firing circuits. The original design required

bursts of 10, 30, 60, and 100 rounds. These were later reduced to 10 and 60 because of operational difficulties.

b. A second type which performed successfully is a burst circuit located on the side of the gun cradle, which counts the number of rounds and then cams the trip lever down on the last round fired to end the burst. As the gun returns to full battery position, a torsion spring is activated which sets the circuit for the next burst. The number of rounds per burst is manually set only once. On the assumption that the circuit is set for a 10-round burst and the trigger is released after 6 rounds have been fired, the lug will cam the lever down and the sear will move over the trip lever. The gun will now settle into full battery position, and the circuit reset and ready to count 10 rounds. The trigger must be pulled and released for each burst.

c. A third type, more applicable to self-powered guns, consists of an escapement mechanism which is preset to some desired number of rounds up to maximum capacity. As each round is fired, the escapement rotates closer to zero or to stopping the gun through holding of the sear or trigger control.

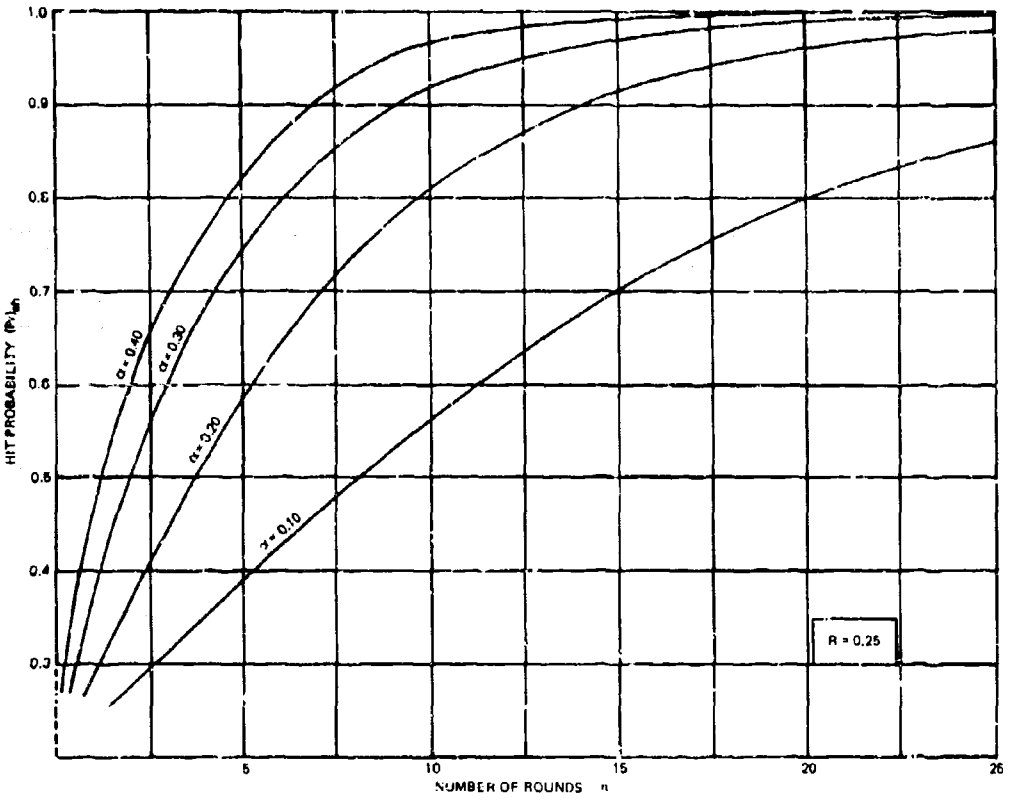


Figure B–1. Hit Probability vs Number of Rounds in a Burst

GLOSSARY

accelerator. A cam arrangement that converts barrel momentum to bolt momentum thereby increasing bolt velocity and decreasing time.

automatic weapon. A rapid, self-firing weapon.

barrel spring. The driving spring equivalent for the barrel.

belt, ammunition. Fabric or metal band with loops for carrying cartridges that are fed from it to an automatic weapon.

belt, disintegrating. An ammunition belt whose empty links are detached as the individual rounds are removed.

blowback. The class of automatic weapon that uses the propellant gas pressure on the cartridge case base to force the bolt open, barrel and receiver remaining relatively fixed.

blowback, advanced primer ignition. A blowback gun that fires before the round is fully chambered.

blowback, delayed. A blowback gun that keeps the bolt locked until the projectile leaves the muzzle.

blowback, retarded. A blowback gun that has a linkage to provide a large, early resistance to recoil.

blowback, simple. A blowback gun that relies on bolt inertia for early recoil resistance.

breech closure. Complete closing of the breech by bolt or breechblock.

buffer spring. A spring that augments either driving or barrel spring during the last stages of either bolt or barrel travel.

compression time. The time during which a spring becomes compressed.

cutoff. The closing of the gas port between bore and operating cylinder.

cutoff expansion system. An expansion system that has a valve to close the gas inlet port after the operating piston moves a prescribed distance.

counterrecoil time. Time required for a counterrecoiling part to return to battery.

critical pressure. The pressure on the discharge end of a nozzle at which flow rate becomes independent regardless of how much the down stream pressure is reduced.

cycle, time of. The time required for a gun to negotiate the firing cycle.

driving spring. The spring that stores some of the bolt recoil energy, stops the recoiling bolt, then drives it into the in-battery position.

ejector. A device in the breech mechanism which automatically throws out an empty cartridge case or unfired cartridge from the breech or receiver.

expansion system. An operating cylinder of a machine gun that has an initial expansion chamber at the gas inlet port

external power unit. A unit that drives some or all operating components of an automatic weapon by deriving its power from a source other than the propellant gases.

extractor. A device in the breech mechanism that pulls an empty cartridge case or unfired cartridge from the chamber.

firing cycle. The sequential activity that takes place from the time a round is fired until the next round is about to be fired.

firing mechanism. The mechanism that actuates and controls the firing of a gun.

firing pin. The component of a firing mechanism that contacts the primer and relays the detonating energy of the firing mechanism to the primer.

flexibility. The flexing of an ammunition belt so that it will assume a fan-like attitude or form a helix.

flexibility, base fanning. The fan-like flexibility where the cartridge case bases form the inner arc.

flexibility, free. The flexibility that becomes available by taking up the slack provided by the accumulated clearances of the links.

flexibility, helical. The flexibility that forms a helix.

flexibility, induced or forced. The flexibility that is derived from the elastic deflection of the individual links.

flexibility, nose fanning. The fan-like flexibility where the cartridge noses form the inner arc.

gas filling period. The time of gas activity in the operating cylinder.

gas-operated. The class of automatic weapon that uses propellant gases vented through the barrel wall to operate all moving components.

hammer. The striking component of a firing mechanism.

impingement system. A gas-operated gun that has no initial expansion chamber at the gas inlet port.

link. The unit of an ammunition belt that firmly holds and carries one round.

link, extracting type. A link from which the round is removed axially by pulling it rearward.

link, push through type. A link from which the round is removed axially by pushing it forward by bolt or rammer.

link, side stripping type. A link from which the round is removed perpendicular to the axis.

locking cam, bolt. The cam that controls the locking and unlocking of the bolt.

locking period. The time needed to lock the bolt in its closed position.

machine gun. An automatic weapon that can sustain relatively long bursts of firing.

magazine, box. A magazine, usually detachable, of rectangular construction and of small capacity.

magazine, drum. A magazine of drum construction whose capacity is larger than that of the box magazine.

operating cylinder. The gas pressure system that powers a gas-operated machine gun

override. The clearance between bolt face and cartridge case base when the bolt is in its rearmost position.

propellant gas period. The time that propellant gas pressures are effective.

rate of fire. The number of rounds fired per minute.

recoil, long. A recoil-operated gun that has the barrel recoiling as far as the bolt, both recoiling as a unit but counter-recoiling separately.

recoil-operated. The class of automatic weapon that uses the energy of all recoiling parts to operate the gun.

recoil, short. A recoil-operated gun that has the barrel recoiling a short distance, with barrel and bolt moving as a unit for part of that distance, whereupon the bolt is released to continue its rearward motion.

recoil time. The time required for a recoiling part to negotiate its rearward travel.

recoil time, accelerating. The time required to accelerate the recoiling parts.

recoil time, decelerating. The time required to stop the recoiling parts.

sear. The component of a firing mechanism that releases the hammer.

safety. A locking or cutoff device that prevents a weapon from being fired accidentally.

semiautomatic. A gun that functions automatically except that each round fired must be triggered manually.

specific impetus. The unit energy, ft-lb/lb, of a propellant.

surge time. The period of time required for a compression wave to traverse a spring.

tappet system. An impingement system that has a very short piston travel.

trigger. The component of a firing mechanism that releases the sear to initiate all firing.

trigger pull. The force that is required to actuate the trigger.

unlocking period. The time needed to release the bolt from its closed position.

velocity of free recoil. The maximum velocity that a recoiling part would attain if left unimpeded during recoil.

wall ratio. The ratio of outer to inner diameter of a hollow cylinder.

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