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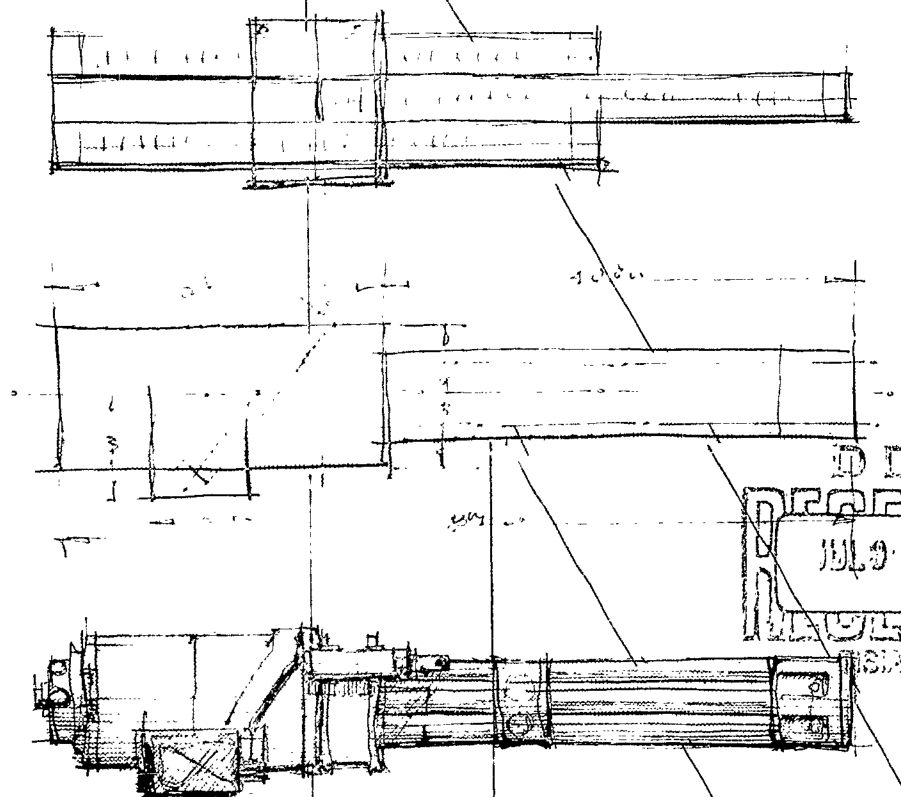
PROGRESS REPORT 39



Project Vulcan..
RESEARCH and DEVELOPMENT

MISSILE AND ARMAMENT DEPARTMENT
GENERAL ELECTRIC
BURLINGTON, VERMONT

63APB25

1 MAY 1963

PROJECT VULCAN
RESEARCH and DEVELOPMENT

PROGRESS REPORT NUMBER 39

CONTRACT DA - 19 - 020 - ORD - 5455

1 FEBRUARY 1963 TO 31 MARCH 1963

BOSTON ORDNANCE DISTRICT

DEPARTMENT OF THE ARMY

MISSILE AND ARMAMENT DEPARTMENT

GENERAL ELECTRIC

BURLINGTON, VERMONT

Approved by ______________

P. A. Lyon
Project Engineer

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LIST OF TABLES

SECTION I

GENERAL

Contract DA-19-020-ORD-5455, awarded to the General Electric Company by the Department of the Army, Boston Ordnance District, provides for the continuation of research and development on the M61 Vulcan Gun.

This report describes the work performed through the period 1 February 1963 to 31 March 1963. The following projects and studies are discussed:

Gun Gas Drive.

Gun Gas Drive Spring Starter.

Improved Parts Life: front track bolts.

Gun Components: bolt insulation, bolt body modification.

Boresighting and Target Study: production guns.

Range Firing Records.

SECTION II

GUN GAS DRIVE

The gun gas drive has completed the first part (14, 266 rounds) of a 30, 000 round endurance test without malfunction or maintenance. The drive was not cleaned and the same hardware was used throughout the test. Table 2-1 is a breakdown of the accumulated rounds on the components being used for the test.

TABLE 2-1. ACCUMULATED ROUNDS ON GAS DRIVE COMPONENTS

Component	Designation	Rounds
Cam follower Support	"A"	14,722
Cam follower (carbide)	#1	14,266
Drive cam	"G"	14,266
Cylinder	"E"	15,362
Cylinder cap, front	"G"	15,362
Cylinder cap, rear	"H"	14,266
Spline shaft	#1	16,266
Ball spline	#2	21,486
LFS drum	#1	27,608
LFS exit unit	#1	23,983
LFS elements		14,722
Bearing, rear		14,266
Rotor	#1532	53,622

Inspection of the components revealed the following:

- The cam follower showed only a nominal amount of wear.
- The cam track showed a definite wear pattern. The surface was smooth and did not show signs of galling (Figure 2-1).
- The clamps, cylinder, end caps, ball spline and rear bearing showed only minor signs of wear.
- The ball spline shaft showed a minor widening of the spline track. However, this was anticipated and a ball spline design to minimize this condition is now complete. The new ball spline is designed to distribute the torque loads between 6 ball bearing raceways instead of the present 3 ball bearing raceways. The new design will not be incorporated in the endurance test. Such incorporation would complicate the evaluation of the drive, considering the present assumption of no maintenance or parts replacement unless absolutely necessary.

During this test there were several ammunition feed system problems. These are detailed in Table 2-2.

The endurance test is being run to coincide with the gun maintenance schedule. Testing will continue through 45,000 rounds and evaluation of the drive system components will continue.

The firing schedule of the endurance test consists of loading the linkless feed system with 1,200 rounds and firing burst of 125 rounds at "D" Rate, 60 seconds apart until the full complement is fired out. Minor inspections are performed after each 1,100 round complement. The gas drive is powering both the gun and the linkless feed system.

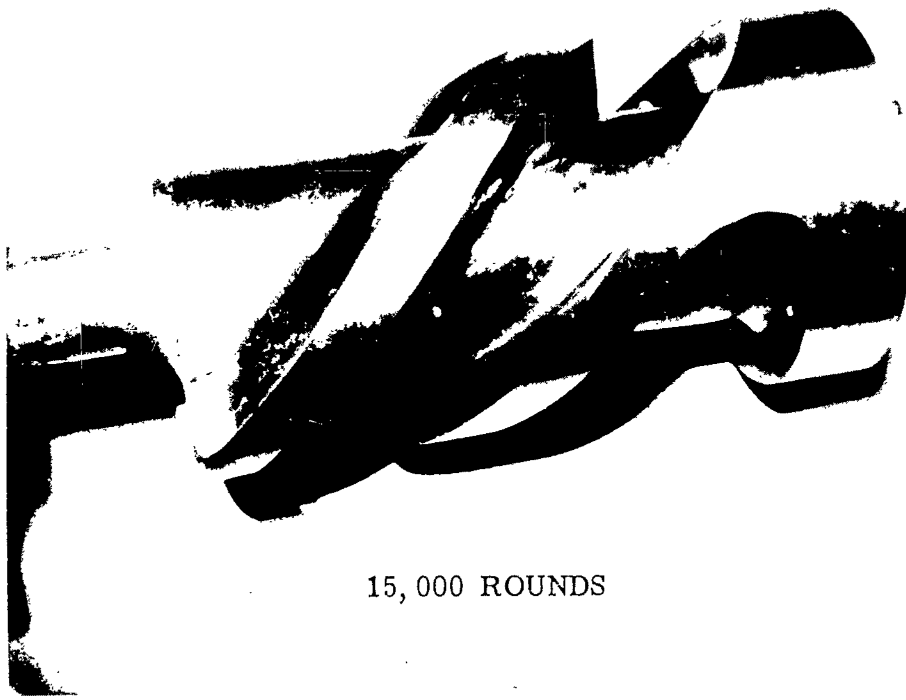


Figure 2-1. Cam Track

TABLE 2-2. FEED SYSTEM PROBLEMS

3/14/63	4169 accumulated rounds on the gas drive system. A pin was sheared and a gear tooth was broken on the exit sprocket. This was caused by a round being out of control transferring from the linkless feed drum to the exit unit. (Cause of the out of control round was not determined at this time.)
3/18/63	5794 accumulated rounds on the gas drive system. An element failure caused a round to be loaded into the feeder out of control causing a feeder jam. The damaged element was replaced.
3/18/63	5919 accumulated rounds on the gas drive system. A photographers power cord was caught in the chuting.
3/25/63	11,098 accumulated rounds on the gas drive system. The spline drive from the gun feeder to the linkless feed gear box failed when end caps failed to contain the raceway ball bearings. This caused the feeder to drive the feed system through the elements thereby causing a feeder jam.
3/27/63	12,260 accumulated rounds on the gas drive system. Same type of failure as 3/14/63. The condition has been corrected by modifying the exit unit. A spring was added to keep rounds up against retainer partitions during the feeding of rounds from the drum to the exit unit.
3/29/63	14,266 accumulated rounds on the gas drive system. A damaged round had been reloaded into the system and due to its crushed condition was out of control in the feeder and jammed the system.

The following changes were made on the gas drive system before starting the endurance test.

(1) The inner clamp and roller support were changed to make it possible to remove the cam follower without removing the gun barrels (Figure 2-2).

(2) The cam follower is now made of tungsten carbide. This change has resulted in an increase in the life of the follower from less than 1,000 rounds to more than 20,000 rounds.

(3) The drive cam is now a high nickel alloy steel. This has resulted in an increase in the life of this part from about 5,000 rounds to over 20,000 rounds.

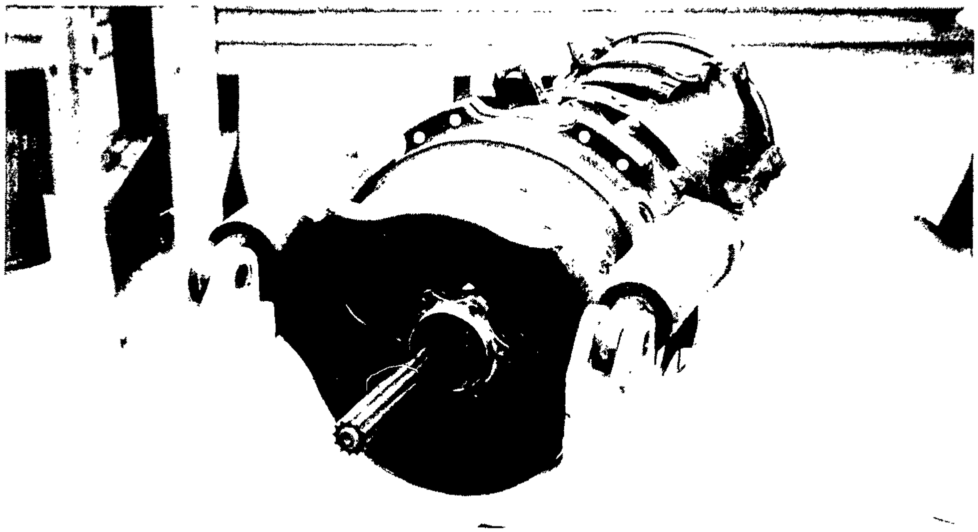
The following pages show the method of assembling the gas drive to the M61 gun.

OLD STYLE

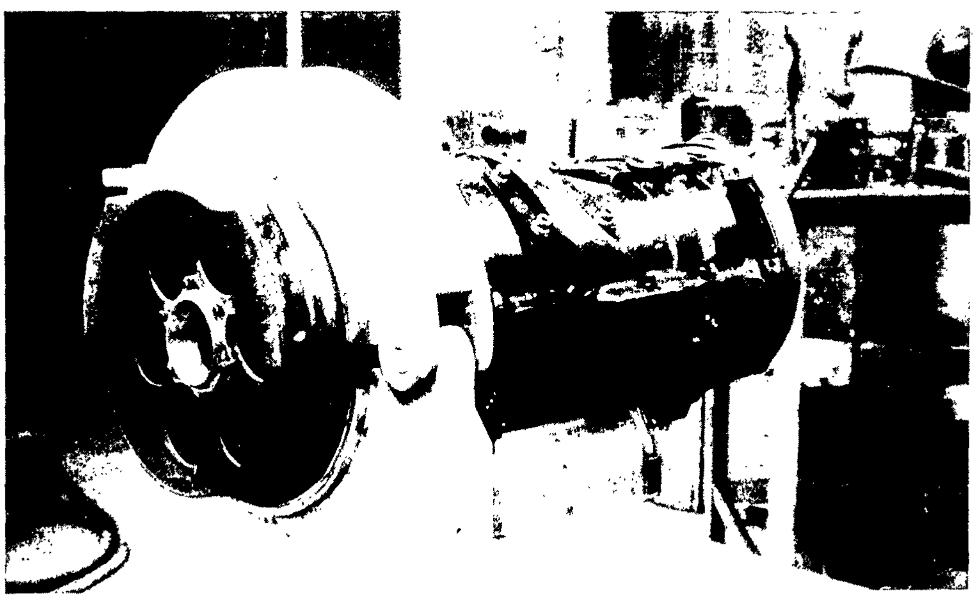
NEW STYLE

Figure 2-2. Inner Clamp and Roller Support

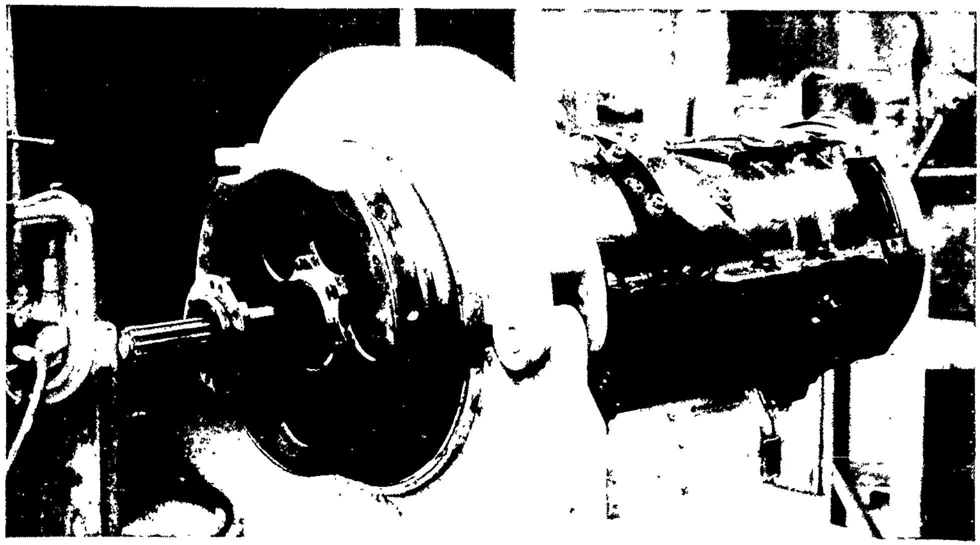
METHOD OF ASSEMBLING GAS DRIVE TO M61 GUN



1. Assemble modified stub rotor to standard gun (modification consists of the addition of a bronze bearing as shown).

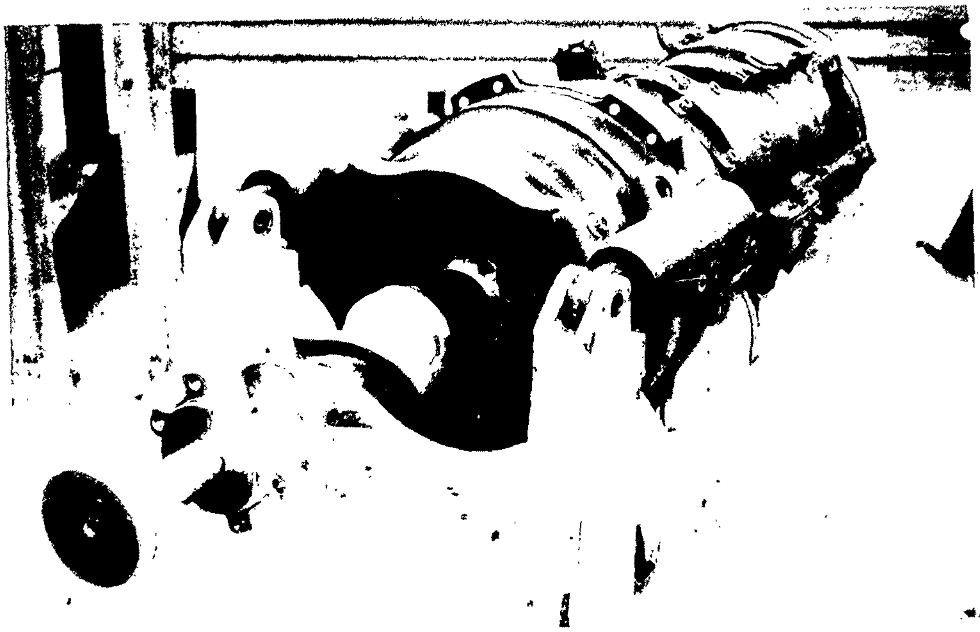


2. Assemble spline shaft to back plate and insert into rotor.



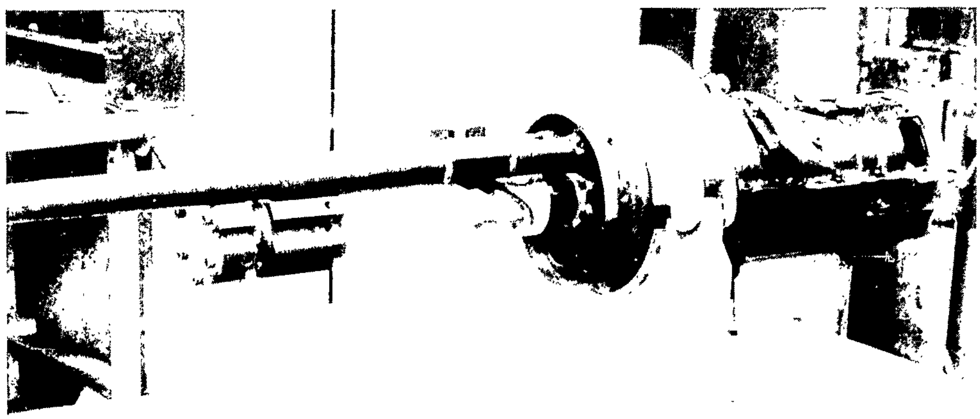
3. Slide ball spline onto spline shaft flange side facing outward.

4. Bolt and dowel the cam-piston to the ball spline.

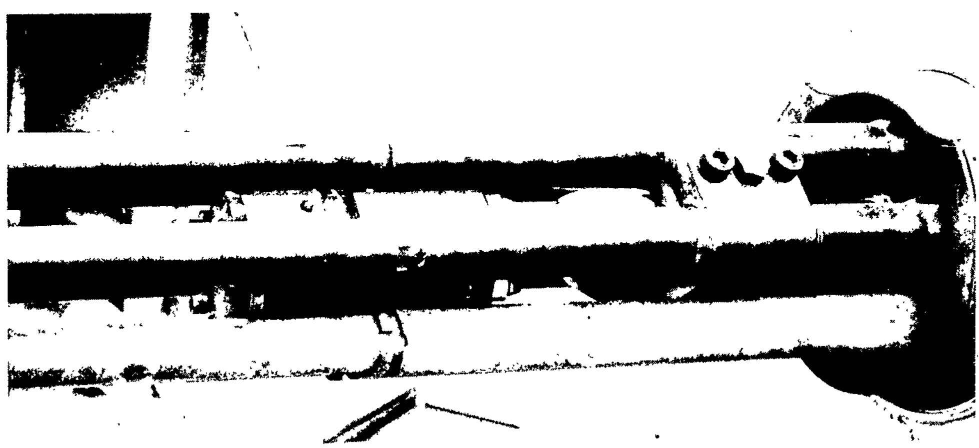


5. Place split end cap onto piston rod.

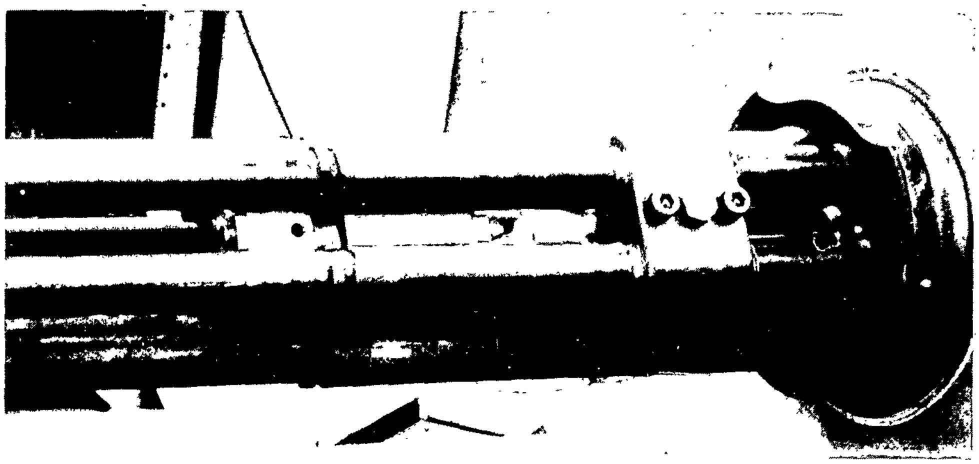
6. Place cylinder onto piston and bolt end cap into place.



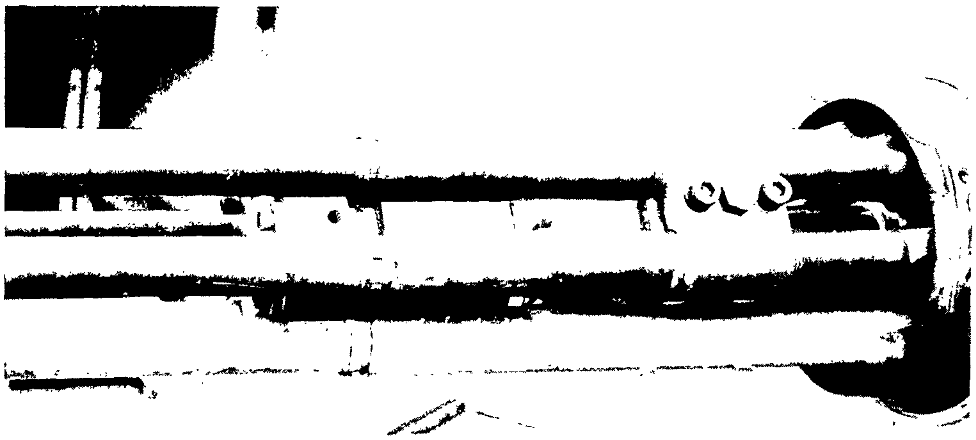
7. Place barrels #1 & #6 onto cylinder and slide into rotor. Push cam against stub rotor, insert inner clamp between barrels. (This is done over a relieved section of the cam for clearance.) Slide cam forward and insert roller into cam path. Assemble outer clamp and roller stud.



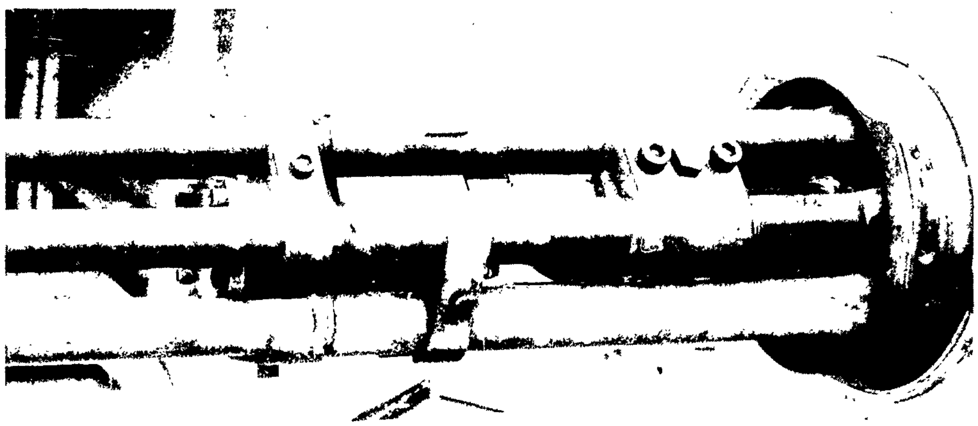
8. Assemble remaining four barrels.



9. Push cylinder rearward until locking tabs on the cylinder are behind the locking rings on the gun barrel.



10. Lock barrels in rotor (outer clamp must be loosened to do this).



11. Assemble clamps and tighten all bolts. (Photo shows Allen Head cap screws. The proper bolts are external wrenching.)

SECTION III

GUN GAS DRIVE SPRING STARTER

The spring starter (Figure 3-1) designed for use with the gas drive is a split torque tube type which utilizes the space between the 1.0 inch outer diameter of the gas drive shaft and the 2.25 inch inner diameter of the rotor. The starter system will weigh 12 pounds.

There are five split tubes (Figure 3-2), one inside the other and fastened together at the ends in a series combination to make a 32.35 inch effective spring length. The spring is presently a permanent assembly which can be replaced as a unit. Slots are used in the end connections (Figure 3-3) to allow for the axial movement of the torque tube corners when torque is applied.

Equal spring gradients for the five tubes are maintained by varying their thicknesses from 0.070 inch on the outer tube to 0.080 inch on the inner tube. Total spring weight is 4.14 pounds. A superior spring steel (A1S1 8740) is used for the tubes.

Face clutch gears which mate with identical gears on the rotor are attached to each end of the spring (Figure 3-3). These gears provide the means of transmitting power from the spring to

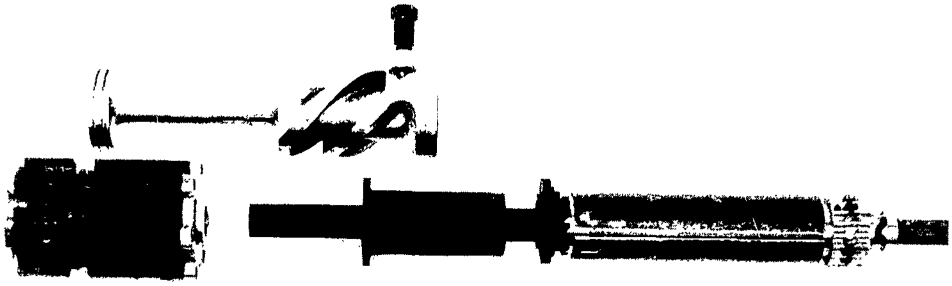


Figure 3-1. Spring Starter System

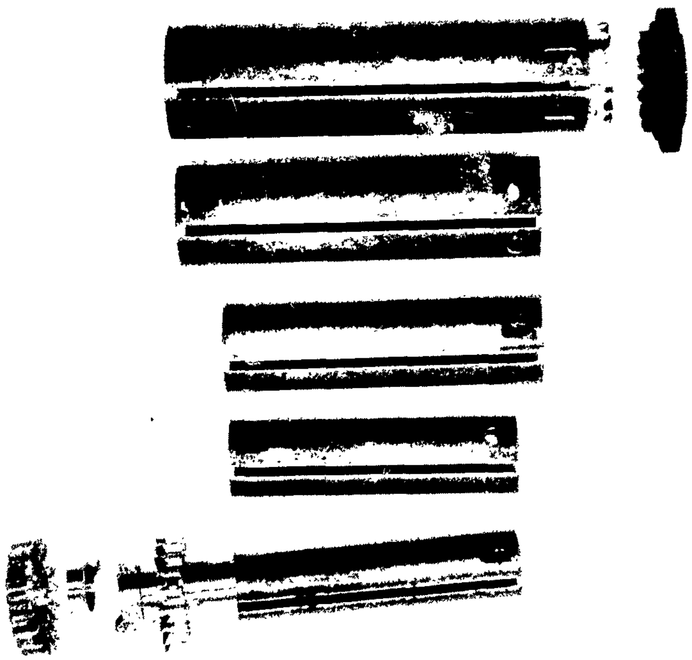


Figure 3-2. Split Tubes

Figure 3-3. Mating of Face Clutch Gears

the rotor for starting, and from the rotor to the spring for rewind. Helical spines on the inner diameter of each spring gear are the means of grounding the spring to mating splines on the gas drive shaft.

Cams on each end of the shaft are used to initiate de-clutching the spring and rotor gears and engaging the helical splines (Figure 3-3).

The actuator mounts on the gun backplate, protruding three inches rearward. A solenoid operates a cam follower which imperts axial, back and forth motion to the spring for starting and rewind. The cam is connected to the spring by means of two push rods which protrude through the end plate. The solenoid is the same type as used for clearing and operates on 23 amps at 28 volts.

A torque tube is one of the most efficient mechanical means of storing energy. The slotted tube being used allows the required deflection necessary in a very short length. The spring gradient is 240 inch-pounds/radian. It develops 1, 500 inch-pounds when wound up one revolution. However, due to clearances, helix unwind and gear mesh, a minimum of 1, 345 inch-pounds of torque may be applied to the gun for starting. Maximum shear stress on the springs will be 170, 000 psi. Stress analysis revealed that 75 percent of each spring is being stressed.

Nominally, 4,050 inch-pounds of energy will be delivered to the gun rotor when the spring is engaged to the rotor for starting. The spring alone will accelerate the gun and feed system to 1,500 spm in 0.15 second. Starting with a cleared gun, the gas drive will contribute power after 180 degrees of rotation and will accelerate the gun to 6,000 spm in 0.52 second.

A torsion rod spring simulating a spring starter, was affixed to a gun having a gas drive. The torsion rod was wound up 160 degrees with 1,500 inch-pounds of torque. This is about one half the energy (2,090 inch-pounds) available in the proposed split torque tube design. After 135 degrees of rotation, the gas drive began delivering power and the gun was accelerated to a steady state rate of 5,100 spm in 0.9 second.

Engaging the spring for rewind will reduce the gun speed from 6,400 to 5,700 spm. Since it is desirable to fire as many rounds as possible during deceleration, a brake will be applied until the gun is in clearing, then the brake will be released to allow a minimum of three rounds to be cleared. Based on a computer study, a 1,000 inch-pound brake will be required to achieve a 0.4 second stop time. If the firing voltage is cut off when the trigger is released and the spring cuts in between 6,400 and 4,000 spm, stop time would be between 0.3 and 0.4 second.

SECTION IV

IMPROVED PARTS LIFE

FRONT TRACK BOLT

A study of the rate at which the front track bolts loosen up in use has been conducted on a new gun and the data in Table 4-1 collected.

TABLE 4-1. FRONT TRACK BOLT DATA

Rounds	Avg. Breakaway Torque to Loosen Bolt (in-lbs)
4,000	454
8,000	304
11,000	566
15,000	662
19,000	340
22,000	1,370
25,000	1,311
29,000	1,425

Each time the torque was checked the bolts were retorqued to 1,500 ± 50 inch-pounds. After 15,000 rounds the bolts were removed, the tracks replaced and the same bolts returned to the same holes. It should be noted here that the tracks did not crack so severely during the second 15,000 rounds.

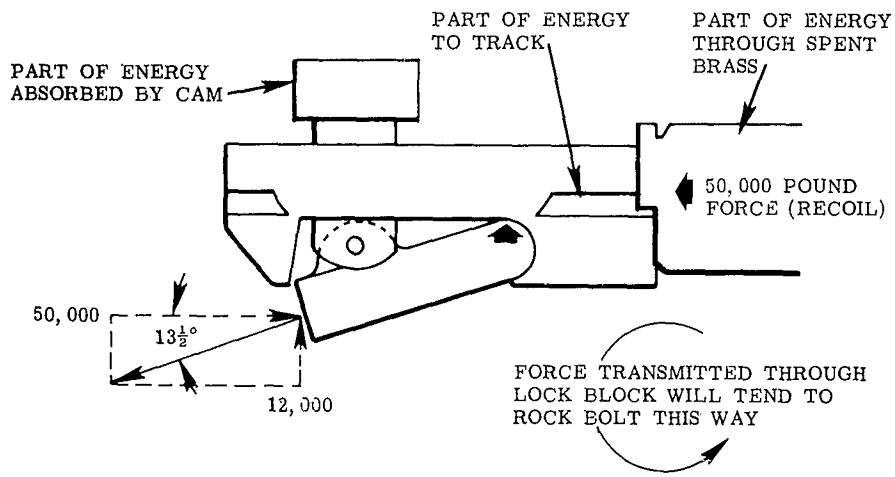
It is evident that loosening does not occur from the bolts turning. In order to have such large torque losses the safety wire would have to break. It is fairly certain then, that devices to keep the bolt from turning will not correct the problem.

Analysis of the forces on the gun bolt during firing show that the track bolt is severely shock loaded in tension with a force of approximately 12,000 pounds (Figure 4-1).

The data shows improvement in the loosening effect as the rotor accumulates additional thousands of rounds. This would indicate a possible permanent deformation of metal in some area. Photomicrograph studies of the bolt, rotor and track in the sections in question showed the following effects:

(1) There was a buildup of silver plate from the track on the edge of the bolt head imprint. This could have occurred at the time the bolts are torqued down but there would have to be a deformation of an order of magnitude greater than there is to account for the amount of torque loss.

(2) Bolt threads showed strain and evidence of plastic deformation, but this is expected because the threads are rolled onto the bolt shaft after heat treatment. They showed no measurable (at 70 magnification) demensional deviation, after use, from new threads.



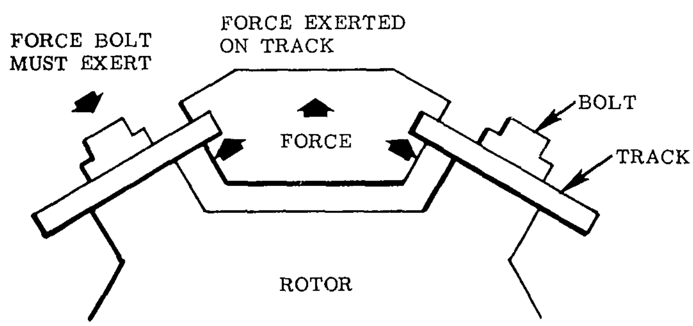


Figure 4-1. Front Track Bolt Forces

(3) There was no visible evidence of bolt stretching, although this is a possible but unlikely sourse of the trouble.

(4) There was excellent grain structure in the rotor and no evidence of heat treat problems which could contribute to the loss of torque. There was definite measurable distortion at the rotor threads which became more pronounced as the threads get nearer the top (toward the bolt head). Figure 4-2 shows a microphotograph of rotor threads.

(5) One other point that should be brought out is that there was a substantial difference in the yield strengths of the bolt and of the rotor. The bolt has a yield strength of 180,000/200,000 psi while the rotor has 95,000/110,000 psi. This would indicate that source of the trouble is in the rotor.

A longer bolt would not solve the problem. There is enough force to stretch the bolt and the last threads on the bolt are not affected in use. Tighter (interference) tolerances would tend to keep the torque from ever dropping to zero, but as the rotor threads deform the torque will drop.

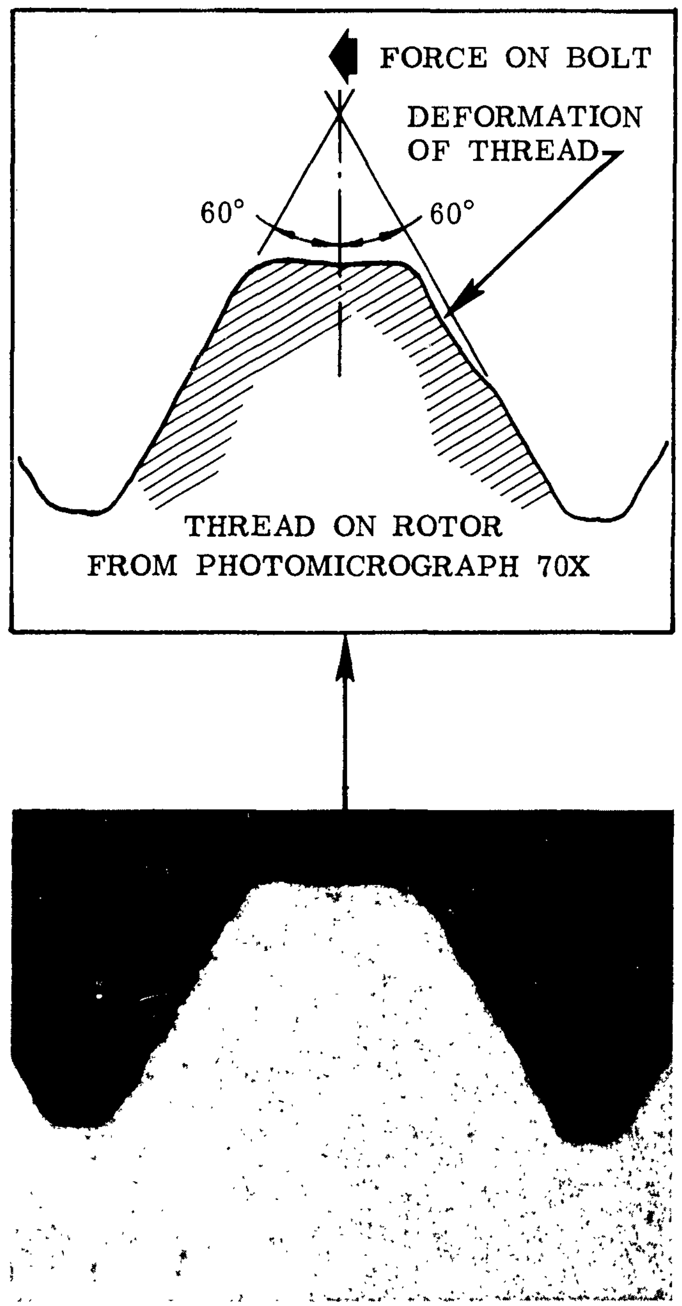


Figure 4-2. Microphotograph of Rotor Threads

If the rotor could be brought up to an equal strength with the bolts, then probably the problem would be eliminated. Local hardening is one possibility but does not lend itself readily to use in this application. Another possibility would be to change the rotor material to a maraging (18% nickel), super strength steel. Neither of these alternatives would offer a solution on guns already in use.

Probably the best and easiest solution is the use of a non-standard bolt thread. There is a thread available called "Lock Thread" which has wide and satisfactory application in similar problems on jet engines and turbines.

This thread is a modification of the standard thread and due to metal-to-metal interference at the thread root, the tendency of the bolt is to tighten rather than loosen in use. It is possible that no change in the rotor configuration would have to be made in order to incorporate use of this bolt. Samples of these bolts are being obtained for testing.

SECTION V

GUN COMPONENTS

BOLT INSULATION

During this reporting period six bolt assemblies with molded in place Kel-F insulation were tested at Aberdeen Proving Grounds. Three of the bolt assemblies had the spring steel washer molded in the Kel-F, three did not. The six sub assemblies were tested for a total of 16,313 rounds (Figure 5-1) at normal temperature and at "D" rate (6,000 spm).

The insulations without the washers cracked in the protrusion area after approximately 8,000 rounds. Misfires occurred at 13,393 rounds and then exceeded one percent during the next 2,920 rounds. At the completion of the test one insulation was completely without the protrusion. There were deep impact marks on the surface of the other two insulations. It is felt that this plastic deformation may have caused some sticking of the firing pin.

The insulations with the spring steel washers showed some severe cracking from the front of the protrusion toward the rear, but there was no indication that these insulations were the cause of misfires.

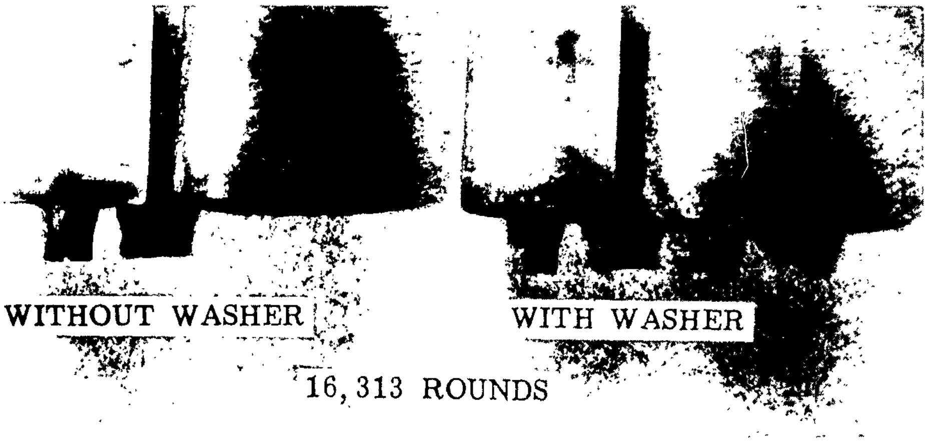


Figure 5-1. Insulations Fired 16,313 Rounds

Concurrent with the tests at Aberdeen Proving Grounds, a test of bolt assemblies with replaceable inserts of Kel-F plastic and spring steel washers was conducted at the General Electric Firing Range.

Five of the bolt bodies had radial lightening cuts (See Bolt Body Modification section of this report) and one was made from maraging (18% nickel) steel. Maraging (18% nickel) steel roller shafts were used in all assemblies. The firing pins and stop pins used were standard and the firing cam pins were standard except that the diameters were ground undersized in the area of the camming surface (Figure 5-2) to enable the parts to function freely after deformation from use. The lock blocks had polished radii around the elongated hole in the lobe. The bolts were not disassembled throughout the test. Firing was conducted at "D" rate and at room temperature.

At 11,854 rounds the stop pin plastic had broken loose in one of the bolt bodies and the stop pin had to be replaced. No other parts were changed or disassembled throughout the duration of testing.

The bolts were fired a total of 19,662 rounds. At this time a rear track lug on the bolt body made from maraging steel failed.

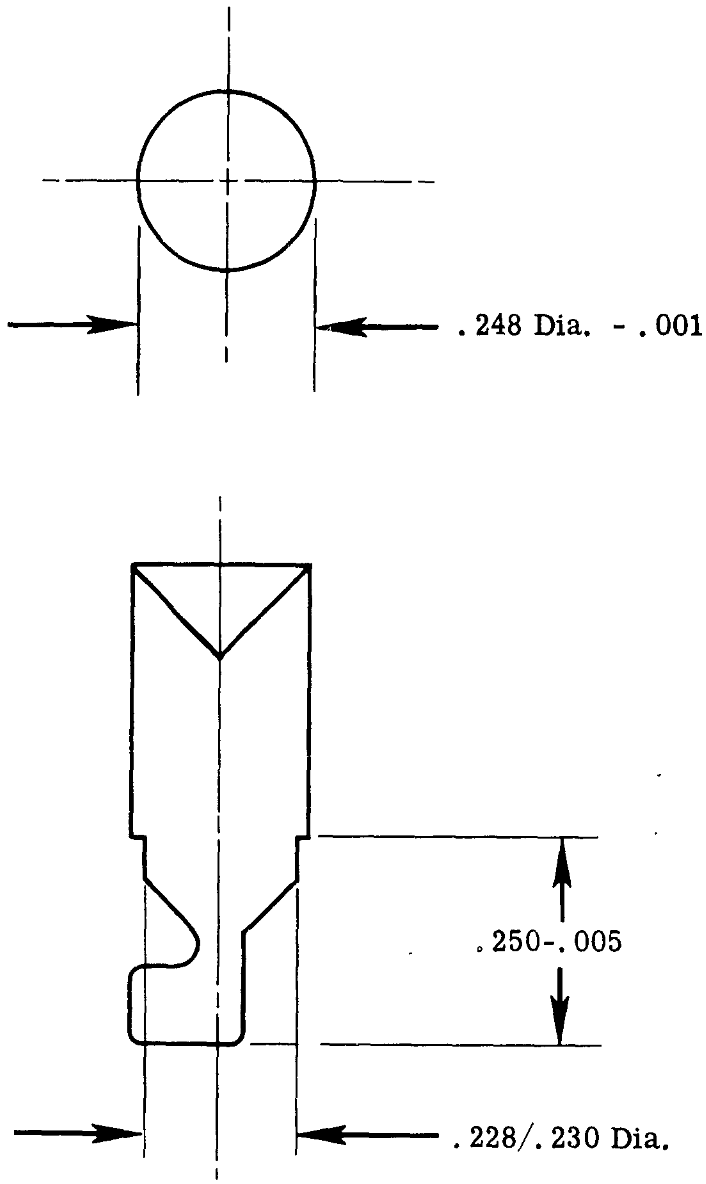


Figure 5-2. Decreased Diameter of Pin, Cam Firing

However, all other components were still useable at the end of testing.

There was no indication of cracking on the radial-cut rear track lugs or on the roller shafts. At the conclusion of the test, rolls pins on the two that were disassembled showed less than nominal amount of wear. The firing cam pins had free movement.

Four of the assemblies have been returned to the range for continued firing. These four still have not been disassembled.

Figure 5-3 shows the molded-in-place washer insert after 19, 662 rounds at "D" rate, standard molded insulation with 9, 536 rounds, and a standard, unfired insulation.

BOLT BODY MODIFICATION

The standard bolt body is subject to failure of the rear lug as its use is extended over the recommended limit. The crack extends across the smallest section (Detail A-Figure 5-4). This cracking occurs much more rapidly when the gun is fired under extreme cold conditions (i. e., 65°F).

In order to increase the reliability of the bolt as the useful life is increased toward 15, 000 rounds, and to increase the parts life in cold conditions, the lightening and clearance cut (Figure 5-4) on the back of the bolt was modified. The weak area is now

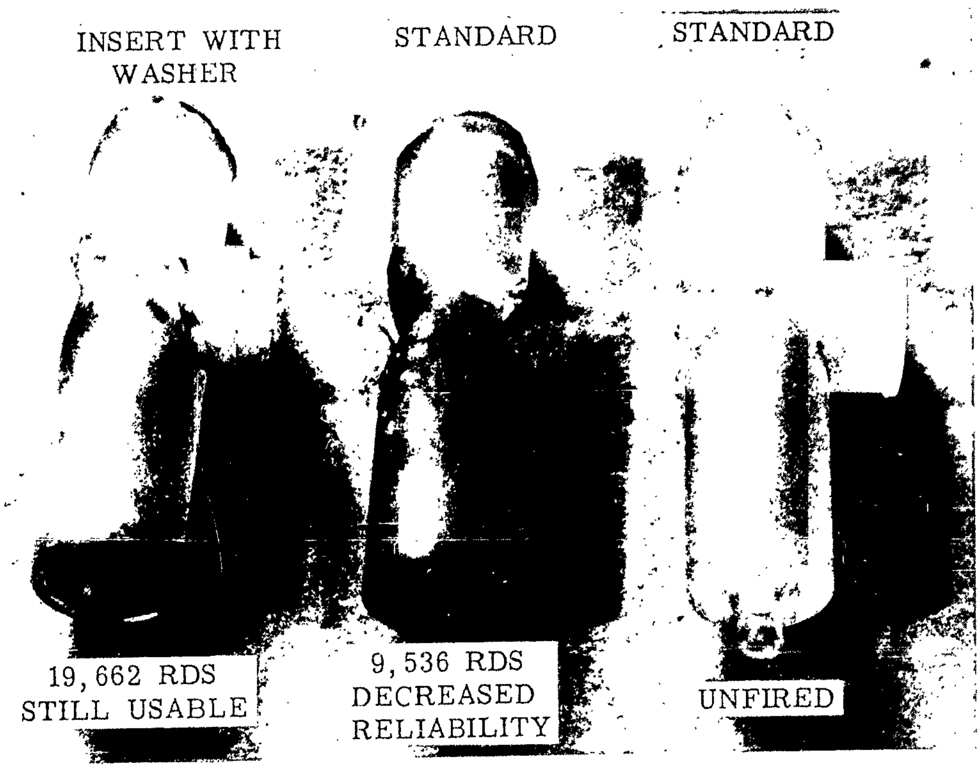


Figure 5-3. Insulations

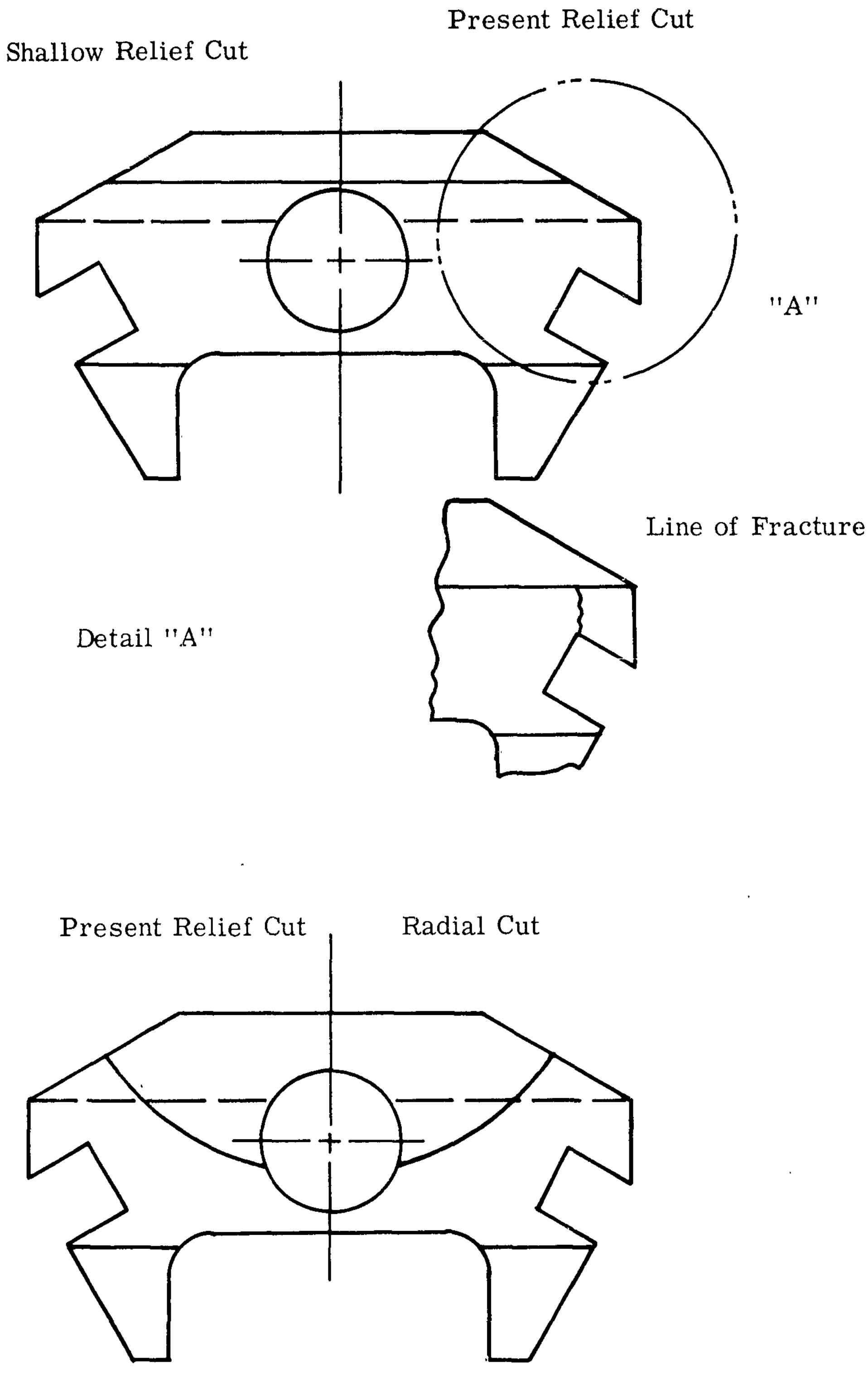


Figure 5-4. Bolt Body Modification

strengthened. An additional desireable condition is produced by this radial cut. The weight of the bolt is reduced slightly and this will give a slight decrease of torque in guns using the modified bolt body.

SECTION VI

BORESIGHTING AND TARGET STUDY

PRODUCTION GUNS

Data has been collected on targeting of production guns. A comparison of the new data and that of the past 18 months appears below. All firing was accomplished at "D" rate (6,000 spm).

	18 Month Average	February	March
No. of guns tested	--------	56	52
Distance from average boresight to average center of impact area (mils)	0.15 left 0.129 down	0.48 right 0.40 down	0.61 right 0.47 down
Average dispersion (mils)			
80% circle	5.0	5.1	5.5

SECTION VII

RANGE FIRING RECORDS

GUN FI ING REPORT

Engineering Testing
R & D Product Improvement

FIRING RECORD

GUN TYPE M61

SER. NO. 1495

DATE 5/10/63

FACILITY GE Burlington

PERIOD FROM 3-1-63 TO 3-3-63

NO. (1)	PURPOSE OF TEST (2)	TEST CONDITIONS (3)	TYPE AMMO & LOT NO. (4)	TYPE LINKS & LOT NO. (5)	TYPE DRIVE (6)	CUM. GUN ROUNDS (7)	RDS. PER TEST CONDITION (8)	MIS-FIRES (9)	TYPE STOPPAGE (10)
	TEST DESCRIPTION					ROUNDS FIRED			STOPPAGES
	Modified large radius Vertical contacts		KOP147-98	M14	T46 E1	151,394	1004	0	0
	Induction of hardened rotor wells						1004		
	Radial lightening cut on rear of bolt body						1004		
					TOTAL (11)	152,398	1004	0	0

STOPPAGE SCHEDULE

STOPPAGE (12)	GUN (13)	AMMO (14)	LINK (15)	PERSONNEL (16)	INSTAL. (17)	SPECIAL (18)	UNKNOWN (19)	(20)	TOTAL (21)
THIS PERIOD	0	0	0	0	0	0	0	0	0
TOTAL TO DATE	0	0	0	0	0	2	1	2	5

STOPPAGE CODING

A.	H.
B.	I.
C.	J.
D.	K.
E.	L.
F.	M.
G.	N.

024-247(10-60)

GUN FIRING REPORT

Engineering Testing
R&D Product Improvement
FIRING RECORD

GUN TYPE M61

SER. NO. 1532

DATE 5/9/63

FACILITY GE Burlington

PERIOD FROM 4/1/63 TO 4/30/63

TEST DESCRIPTION						ROUNDS FIRED			STOPPAGES
1 NO.	2 PURPOSE OF TEST	3 TEST CONDITIONS	4 TYPE AMMO & LOT NO.	5 TYPE LINKS & LOT NO.	6 TYPE DRIVE	7 CUM. GUN ROUNDS	8 RDS. PER TEST CONDITION	9 MIS-FIRES	10 TYPE STOPPAGE
	Self Bleed Gas Drive		147-47 M55A1 22-339 M55A2	One Ended Linkless Feed	Gas Drive	53,603	13,655	0	0
					TOTAL 11	67,288	13,655	0	0

STOPPAGE SCHEDULE

STOPPAGE 12	GUN 13	AMMO 14	LINK 15	PERSONNEL 16	INSTAL. 17	SPECIAL 18	UNKNOWN 19	20	TOTAL 21
THIS PERIOD	0	0	0	0	0	0	0	0	0
TOTAL TO DATE	0	0	0	0	0	0	0	0	0

STOPPAGE CODING

A.	H.
B.	I.
C.	J.
D.	K.
E.	L.
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024-247(10-60)

GUN FIRING REPORT

Engineering Testing
R & D Product Improvement

FIRING RECORD

GUN TYPE M61
SER. NO. 1532
DATE 5/9/63

FACILITY GE Burlington
PERIOD FROM 3/1/63 TO 3/31/63

TEST DESCRIPTION						ROUNDS FIRED			STOPPAGES
1 NO.	2 PURPOSE OF TEST	3 TEST CONDITIONS	4 TYPE AMMO & LOT NO.	5 TYPE LINKS & LOT NO.	6 TYPE DRIVE	7 CUM. GUN ROUNDS	8 RDS. PER TEST CONDITION	9 MIS-FIRES	10 TYPE STOPPAGE
	Self bleed gas drive		147-47 M55A1	One End Linkless Feed	Gas Drive	40056	13,547	0	0
	Bolt bodies with washer molded into insulations		22-339 M55A2				13,547		
	Ni Mark steel roller shafts						13,547		
					11 TOTAL	53603	13,547	0	0

7-4

STOPPAGE SCHEDULE

12 STOPPAGE	13 GUN	14 AMMO	15 LINK	16 PERSONNEL	17 INSTAL.	18 SPECIAL	19 UNKNOWN	20	21 TOTAL
THIS PERIOD	0	0	0	0	0	0	0	0	0
TOTAL TO DATE	0	0	0	0	0	0	0	0	0

STOPPAGE CODING

A.	H.
B.	I.
C.	J.
D.	K.
E.	L.
F.	M.
G.	N.

024-247(10-60)

GUN TYPE M61

SER. NO. 0438

DATE 5/10/63

GUN FIRING REPORT

Engineering Testing
R & D Product Improvement

FIRING RECORD

FACILITY GE Burlington

PERIOD FROM 4/1/63 TO 4/30/63

TEST DESCRIPTION						ROUNDS FIRED			STOPPAGES
1 NO.	2 PURPOSE OF TEST	3 TEST CONDITIONS	4 TYPE AMMO & LOT NO.	5 TYPE LINKS & LOT NO.	6 TYPE DRIVE	7 CUM. GUN ROUNDS	8 RDS. PER TEST CONDITION	9 MIS-FIRES	10 TYPE STOPPAGE
	Case ejector		KOP147-47	M14	T46 E1	61564	1400	0	0
					11 TOTAL	62964	1400	0	0

STOPPAGE SCHEDULE

12 STOPPAGE	13 GUN	14 AMMO	15 LINK	16 PERSONNEL	17 INSTAL.	18 SPECIAL	19 UNKNOWN	20	21 TOTAL
THIS PERIOD	0	0	0	0	0	0	0	0	0
TOTAL TO DATE	2	0	1	0	0	2	0	2	7

STOPPAGE CODING

A.	H.
B.	I.
C.	J.
D.	K.
E.	L.
F.	M.
G.	N.

024-247(10-60)

VULCAN

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General Electric Company, Burlington, Vermont
PROJECT VULCAN RESEARCH AND DEVELOPMENT
PROGRESS REPORT

G. E. Report 63APB May 1963 pp-incl. tables, curves
Unclassified Report

This report describes the work performed through the period 1 February 1963 to 31 March 1963. The following projects and studies are discussed: (1) Gun Gas Drive. (2) Gun Gas Drive Spring Starter. (3) Improved Parts Life: front track bolts. (4) Gun Components: bolt insulation, bolt body modification. (5) Boresighting and Target Study: production guns. (6) Range Firing Records.

UNCLASSIFIED

1. Automatic Gun, 20mm, M61
2. Automatic Gun, 20mm, T171E3

I. Title: Vulcan
II. Contract DA-19-020-ORD-5455
III. DA Project No. SA-7663

AD ____________ Accession No. ____

General Electric Company, Burlington, Vermont
PROJECT VULCAN RESEARCH AND DEVELOPMENT
PROGRESS REPORT

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