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THE DAVID W. TAYLOR MODEL BASIN

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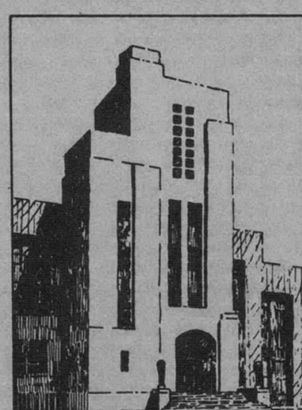
THE MEASUREMENT OF PERFORMANCE OF THE TRAINING SYSTEM OF THE 8-INCH 55-CALIBER PILOT TURRET

by

Vincent J. Mildenberg



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1 Chief of Ordnance, U.S. Army, SPOTX-AR, Technical Reports, Washington 25, D.C.

FOREWORD

The new main-battery turret for the CA139-Class cruisers incorporated many novel structural and mechanical features which rendered it capable of firing its three 8-inch 55-caliber guns more rapidly than any of its predecessors. To check its operation, perhaps the most extensive structural investigation ever conducted on turrets was performed. A 1/10-scale structural model was fabricated and tested at the David Taylor Model Basin, and a full-scale pilot turret was tested at the Naval Proving Ground. The results have subsequently been checked by structural firing trials conducted on the USS DES MOINES (CA134), the first naval vessel to carry these new turrets. As its part of the over-all program, the David Taylor Model Basin was given the responsibility of measuring (a) the performance of the turret structure and roller track, (b) the behavior of the recoil-counterrecoil system, (c) the operation of the training buffer, and (d) the motion of the guns and turret during elevating and training exercises.

Apart from the primary objective of confirming the safety and the satisfactory performance of the new turret in advance of construction of the ships themselves, secondary objectives were established to derive experimentally information which could be employed to confirm or invalidate design criteria for guns and turrets, and for structural assemblies which are similarly loaded.

The results of tests of the turret training-gear system are given in this report. The other results are given in additional reports and memoranda, as follows:

1. "Description of Test of Hydraulic Training Buffer of CA139-Class Pilot Turret," TMB RESTRICTED Report C-38, February 1948.

2. "An Elastic-Tube Gage for Measuring Static and Dynamic Pressures," TMB Report 627, May 1948.

3. "Description of Instruments Employed in the Operational Tests of the Gun-Elevating Systems of the CA139-Class Pilot Turret," TMB RESTRICTED Report C-29, October 1947.

4. "The Measurement of Performance of the Gun-Elevating System of the 8-Inch 55-Caliber Turret," TMB RESTRICTED Report C-163 (in preparation).

5. "Experimental Analysis of the Recoil System of the 8-Inch 55-Caliber Guns Mark 20, Mod 1," TMB RESTRICTED Report C-165, March 1950.

6. "The Dynamical Response of the Rotating Structure of Turrets with Particular Reference to the 8-Inch 55-Caliber Size," TMB RESTRICTED Report C-81 (in preparation).

7. "Structural Design Studies of a 1/10-Scale Model of the 8-Inch Gun Girder on the CA139-Class Cruisers," Thesis, Department of Naval Architecture and Marine Engineering, Massachusetts Institute of Technology, 1949.

8. "Schedule of Measurements to be Made by the David Taylor Model Basin during Tests of the CA139 Pilot Turret," TMB Memo 2, CA139-Class/S72-1 of 13 November 1945 (Revised 25 April 1947).

9. "Experimental Analysis of Stress and Deformation of a 1/10-Scale Model 8-Inch Gun Turret for the CA139-Class Cruisers," TMB RESTRICTED Report 571, February 1948.

10. "The Elastic Behavior of the Rotating Structure of the CA139-Class Pilot Turret with Static Loading," TMB RESTRICTED Report C-166, March 1950.

11. "The Elastic Behavior of the Rotating Structure of the CA139-Class Pilot Turret with Gunfire Loading," TMB RESTRICTED Report C-231 (in preparation).

12. "Natural Frequencies Measured on the CA139-Class Pilot Turret," TMB RESTRICTED Report C-82, December 1948.

Whereas the experimental and theoretical analyses were conducted for this turret investigation to obtain specific data regarding performance, a vast amount of general information was obtained pertaining to the behavior of hydraulic energy-absorbing systems and to the elastic behavior of complex structures subjected to dynamic loading. It is now planned to present these more general results in two separate reports:

1. Considerations for the Design of Complex Structures Subjected to Dynamic Loads, as Derived from Experimental Analysis.

2. New Considerations for the Design of Hydraulic Buffers as Derived from Experimental Analysis.

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ABSTRACT

Torque in the training-pinion shaft, angular acceleration of the turret, and the recoil forces developed through gunfire were measured by the David Taylor Model Basin during proof tests of the training-gear system of the 8-inch 55-caliber pilot turret. Supplemental measurements of the angular position of the turret and the closing of the gun firing circuit were also taken. Additional measurements on the electric-hydraulic power unit were made simultaneously by the Naval Proving Ground. Bonded wire-resistance strain gages were cemented to the pinion shaft to determine the torque and a Statham accelerometer was employed to measure the angular acceleration. During the training tests involving gunfire, the recoil forces were measured by means of TMB elastic-tube pressure gages.

This report includes a discussion of the instrumentation and procedures employed during the test and a summary of important results.

The maximum torque in the pinion shaft measured during a nonfiring training test amounted to 2470 kip-in.; this is to be compared with a torque of 2250 kip-in., the maximum measured during a firing trial.

The maximum angular acceleration measured was $82^{\circ}/\text{sec}^2$, which was recorded during a nonfiring test. The maximum recorded during a firing trial was $41^{\circ}/\text{sec}^2$.

The observed torque in the training-pinion shaft is not related to the rotational acceleration of the turret according to laws of rigid-body dynamics because of the effects of elasticity of the training system.

Specified training velocities and accelerations were achieved.

INTRODUCTION

Heavy cruisers of the CA139-Class differ from ships of the older CA68-Class primarily in the use of 8-inch gun turrets incorporating rapid-firing guns capable of being loaded at any elevation. The efficacy of gunfire was further improved by increasing the acceleration and rate of training of the turret which, with the increased weight of this turret over its predecessors, necessitated a larger, more powerful electric-hydraulic training-drive unit and sturdier mechanical gearing.

Even though the same type of training system has been used by the Navy on various sizes and types of turrets over a period of many years, very little experimental data concerning their operation have been compiled. Therefore, modifications made in the training mechanism of this type of turret were felt to warrant full-scale proof trials.

The primary objective of the full-scale trials was the confirmation of the strength and satisfactory performance of the training mechanism. Secondary objectives were also established to derive experimentally data which would confirm or invalidate existing theory and practice in the design of training mechanisms.

Accordingly, the Bureau of Ordnance directed that proof tests be conducted on the training gear of the pilot turret installed at the Naval Proving Ground, Dahlgren, Virginia.[1] The Taylor Model Basin was requested to determine the response of the mechanical gearing to various training exercises, both with and without gunfire. In reply to the request of the Bureau of Ordnance, a schedule[2] was formulated by the Taylor Model Basin in which the measurements to be made by the Model Basin during the tests were listed and the details of the necessary instrumentation were set forth. The schedule was confirmed by the Bureau of Ordnance in Reference 3. For the same trials, the Naval Proving Ground was asked to make simultaneous measurements in the electric-hydraulic driving unit. The Bureau of Ordnance requested that the analyzed oscillograms be submitted to them by both activities for correlation and for evaluation of the over-all performance of the training gear.

This report contains a brief discussion of the turret-training mechanism and of some of the design considerations; there are also given objectives of the test, a description of the instruments employed by the Taylor Model Basin in making the measurements, and a tabulated summary of important recorded data and of the results. Briefly stated these results are:

1. The maximum torque developed in the training-pinion shaft during these tests was recorded in Test 12, a nonfiring test;* it amounted to 2470 kip-in. The highest torque measured during a test with gunfire** was 2250 kip-in. In tests of the hydraulic training buffer of this same turret,[4] torques as high as 5600 kip-in. were measured in the same training-pinion shaft.

2. The highest acceleration measured was 82°/sec^2, recorded in Test 12, Run 6. The highest acceleration during a test with gunfire was 41°/sec^2. In the tests on the hydraulic training buffer,[4] a deceleration of 43°/sec^2 was measured.

3. Simulated pitch and roll motions of the turret developed negligible response in the training gear.

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[1]All references are listed on page 23 of this report.

*This test was conducted by displacing the turret 1/2° from target train position and releasing it, while in automatic control.

**This test was conducted by training to left at constant velocity of 1°/sec and firing the left gun.

DESCRIPTION OF THE TRAINING-GEAR SYSTEM

The training gear drives and controls the turret train movement and serves as a brake when guns are asymmetrically discharged. Figure 1 shows the general arrangement of the training mechanism. (In the following description the numbers in parentheses refer to this figure.)

The training motion of the turret is induced and controlled through the use of a hydraulic transmission of the Waterbury speed-gear type, driven by a 125-hp induction-type electric motor (18). This motor drives the hydraulic pump (or A-end*)(13), which is the source of fluid under high pressure for driving the two hydraulic motors (or B-ends**)(17) of the transmission system. A worm gear, located between the B-ends and coupled directly to them, engages a worm wheel in a housing (9) on one end of the pinion shaft. The training pinion (11) on the other end of this shaft meshes with a rack (10) attached rigidly to the stool or circular foundation of the gun turret. The speed reduction of the B-end shaft to the rack is 448 to 1.

Changes in the position of the turret or of angular velocity of train are the results of changes in the direction or rate of flow of fluid in the hydraulic transmission system. This variation of flow, except for the slight change in the speed of the electric motor, is produced entirely by a controlling device in the A-end.

The control device provides, by changing the angle of the tilt plate in the A-end, a means of changing the length of the piston stroke from zero to maximum, in either direction, thus varying the pumping capacity and direction of flow of oil from the A-end in accordance with the varying turret-train requirements.

The maximum speed of train is 5°/sec; maximum design acceleration rates are $40°/sec^2$.

DESIGN ANALYSIS

A certain relationship must exist between the different components of the training system during any movement of the turret. For example, this motion, as produced by the torque in the training-pinion shaft and as indicated by the angular velocity and acceleration, can be correlated with the pressures in the main hydraulic lines and with the power input to the system through the electric motor.

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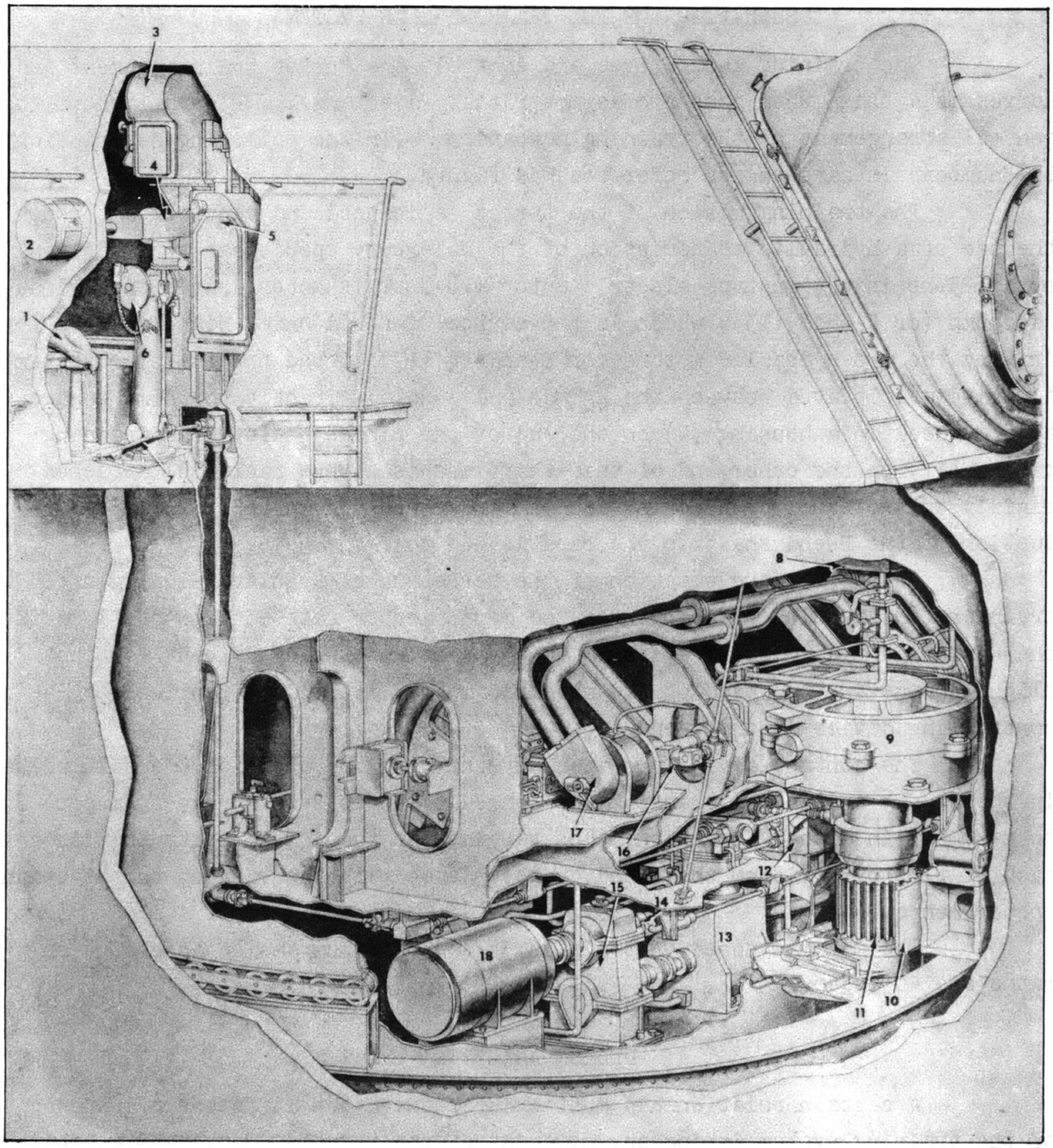
*Manufacturer's size 75.

**Manufacturer's size 50.



1. Trainer's seat
2. Telescope hood
3. Sight setter's indicator
4. Telescope holder
5. Train indicator
6. Trainer's handwheels
7. Foot control for elevation of trainer's line of sight
8. Expansion tank
9. Worm-wheel housing
10. Training rack
11. Training pinion
12. Receiver regulator
13. A-end assembly
14. Replenishing pump
15. Reduction gear
16. B-end response gear
17. Right B-end motor
18. Main electric motor

Figure 1 - General Arrangement of the Training Mechanism

The quantities for which such correlation can be made are:

1. B-end torque from measurement of B-end pressures and by direct measurement of torque in the pinion shaft.

2. Acceleration of the rotating structure as directly measured and as calculated from the torque in the pinion shaft.

3. Horsepower transmitted by the A-end shaft (which can be determined from the pressures in the main line, the speed of the A-end, and ratio of the angle of the tilt plate to the maximum angle of tilt) and horsepower in the A-end shaft as determined from the power input to the electric motor.

4. Horsepower at the pinion shaft (determined from torque in the pinion shaft and the pinion shaft speed) and horsepower transmitted by the B-end shaft.

Mathematically the above relationships as expressed by the Waterbury Tool Company[5] are

$$T_B = \frac{S_B P_B \times 63}{12 \times 100} \qquad [1a]$$

or

$$T_B = \frac{T_s}{32 \times 2} \qquad [1b]$$

where T_B is the torque of the B-end shaft in ft-lb,
T_s is the torque of the pinion shaft in ft-lb,
S_B is the size of the B-end (manufacturer's designation),
P_B is the B-end pressure in psi,
32 is the mechanical advantage between the B-end shaft and the training-pinion shaft, and
2 is the number of B-ends.

From mechanics (with the rotating turret structure assumed to be a rigid body and with friction neglected)

$$T_S = \frac{1}{14} I\alpha = \frac{1}{14} \frac{Wk^2}{g} \alpha \qquad [2a]$$

or

$$\alpha = \frac{14 T_s g}{Wk^2} \qquad [2b]$$

where I is the mass moment of inertia in lb-ft/sec^2,
k is the radius of gyration in ft,
α is the angular acceleration in radians/sec^2,

g is the acceleration of gravity in ft/sec^2,
W is the weight of rotating structure in lb, and
14 is the ratio of the pitch radius of the rack to that of the pinion.

Since the turret structure is slightly flexible, its torsional stiffness must be considered. An approximate analysis can be made if the turret is assumed to be a single-degree-of-freedom system (actually it has many degrees of freedom). The equation of motion may then be written

$$14T_s = I\alpha + s\phi \qquad [2c]$$

where $\alpha = \ddot{\phi}$,
s is the torsional stiffness, and
ϕ is the angular displacement.

The solution of this equation is treated in detail for various shapes of actuating torque in Reference 6 and will not be treated further here. It is evident, however, that the angular acceleration of the turret is a function of the torsional stiffness and that it need not be in phase with the applied torque.

Relationships for the horsepowers, as derived by the Waterbury Tool Company,[5] are

$$\text{Horsepower at A-end, } H_A = \frac{P_A S_A N_A}{100{,}000} \times \frac{\sin \theta}{\sin 20^\circ} \qquad [3a]$$

or

$$H_A = 0.746\ K \qquad [3b]$$

where P_A is the A-end pressure in psi,
S_A is the size of the A-end (manufacturer's designation),
N_A is the speed of the A-end in rpm,
K is the power in kilowatts, and
θ is the angle of tilt of the tilt box in degrees (20° maximum).

$$\text{Horsepower at Pinion Shaft, } H_S = \frac{T_s \times 2\pi N_s}{33{,}000} \qquad [4a]$$

where N_s is the speed of the pinion shaft in revolutions per minute.

$$\text{Horsepower at B-end, } H_B = \frac{P_B S_B N_B}{100{,}000} \qquad [4b]$$

where P_B is the A-end pressure in psi,
S_B is the size of the B-end (manufacturer's designation), and
N_B is the speed of the B-end in rpm.

Formulas [3b] and [4a] are generally used for the computation of horsepower.

MEASUREMENTS MADE IN THE OPERATIONAL TESTS

Measurements were made with sensitive instruments to detect any possible malfunctioning which could not be otherwise observed and, if necessary, to provide a rational basis by which remedial measures could be taken. Furthermore, this same information would be of value in checking the relationships between the various design parameters, as set forth previously, and would provide a basis for establishing conditions of maximum demand for power or strength of the training system. Thus, apart from the check on torque developed in the pinion shaft as related to acceleration and power, during training exercises and during gunfire, magnitude of torque is required to be known for strength design of the pinion shaft and gears and of the structural foundations of driving machinery. The acceleration would also be useful to determine shock effects on instruments located in the turret and on personnel.

Thus, to evaluate the performance of the training-gear mechanism, the following measurements were deemed necessary: 1) Torque in the training-pinion shaft, 2) angular acceleration of the turret, 3) angular displacement of the turret, 4) recoil forces developed by gunfire, 5) electrical power input to the electric training motor, and 6) pressures in the hydraulic units. All the quantities were to be measured by the Taylor Model Basin except the last two, which were to be obtained by the Naval Proving Ground. A schematic diagram of the instrumentation for the nonfiring tests is shown in Figure 2.

A brief description follows of the devices employed by the Taylor Model Basin in obtaining measurements during the training exercises. The location of these instruments in the turret is shown in Figure 3.

TORQUE IN THE TRAINING-PINION SHAFT

The torque in the training-pinion shaft was determined from the shear strain in the shaft by means of wire-resistance strain gages; the location of these gages is shown in Figure 4.

The strain gages installed in 1945 for torque measurement were used during the training-buffer test[4] in 1947 but later became inoperative and could not be used for the training tests. Because of the time and difficulty involved in removing the pinion shaft for the installation of new gages, the replacements were made with the shaft already assembled in the worm-gear housing. The electrical cables connecting the gages to the amplifying equipment

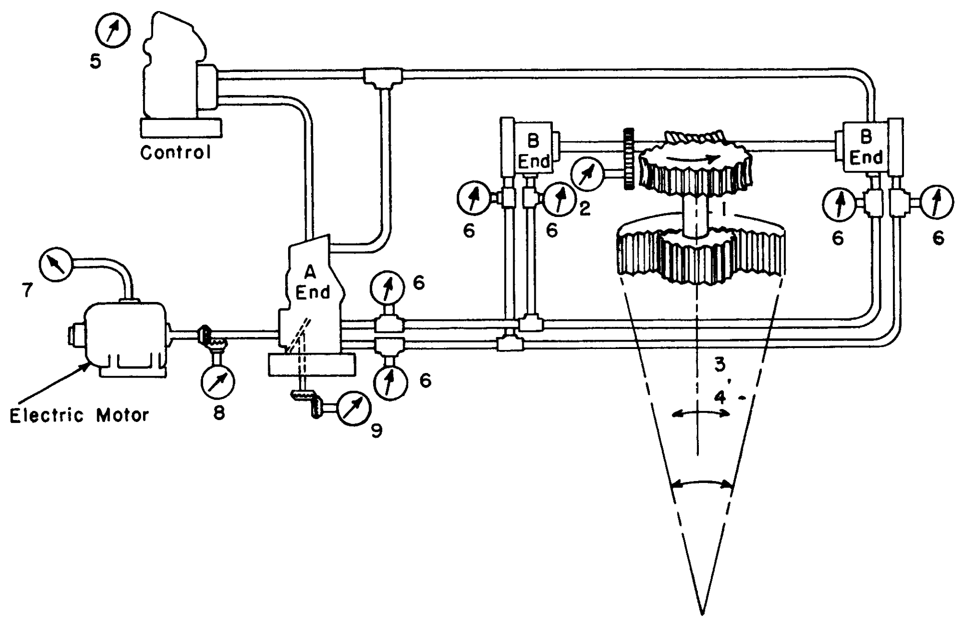


Figure 2 - Schematic Diagram of the Training Mechanism Showing Positions at Which Measurements Were Recorded during the Nonfiring Tests

1. Torque in pinion shaft
2. Angular position
3. Angular velocity
4. Angular acceleration of turret
5. Error indicator
6. Pressure in hydraulic lines between A- and B-end
7. Electrical input
8. Speed of A-end
9. Angle of tilt plate on A-end

were allowed to wind around the portion of the shaft just above the pinion, as the shaft rotated. Slack in the cables was taken up by weights suspended on the cables; swinging of the weights was prevented by guide wires. Since the shaft rotated only three revolutions in moving the turret through its full angle of train, limited here to 80°, this arrangement was considered more suitable than the use of electrical slip rings.

Four gages were mounted on the pinion shaft approximately 3 in. above the pinion; the gages were placed in pairs, 180° between pairs. The angle between the axes of the gages in each pair was 90°, and the axis of all gages was oriented at an angle of 45° with the axis of the shaft. It is at this angle that torsion in the shaft produces a tension in one gage of the pair and an equal compression in the other gage.

The tension gage from one pair of the strain gages and the compression gage from the other pair were connected so as to form the adjacent arms of a Wheatstone bridge. This arrangement made the circuit insensitive to axial strains, doubled the output signal, and provided automatic temperature compensation of the gages. The two separate bridge circuits so formed

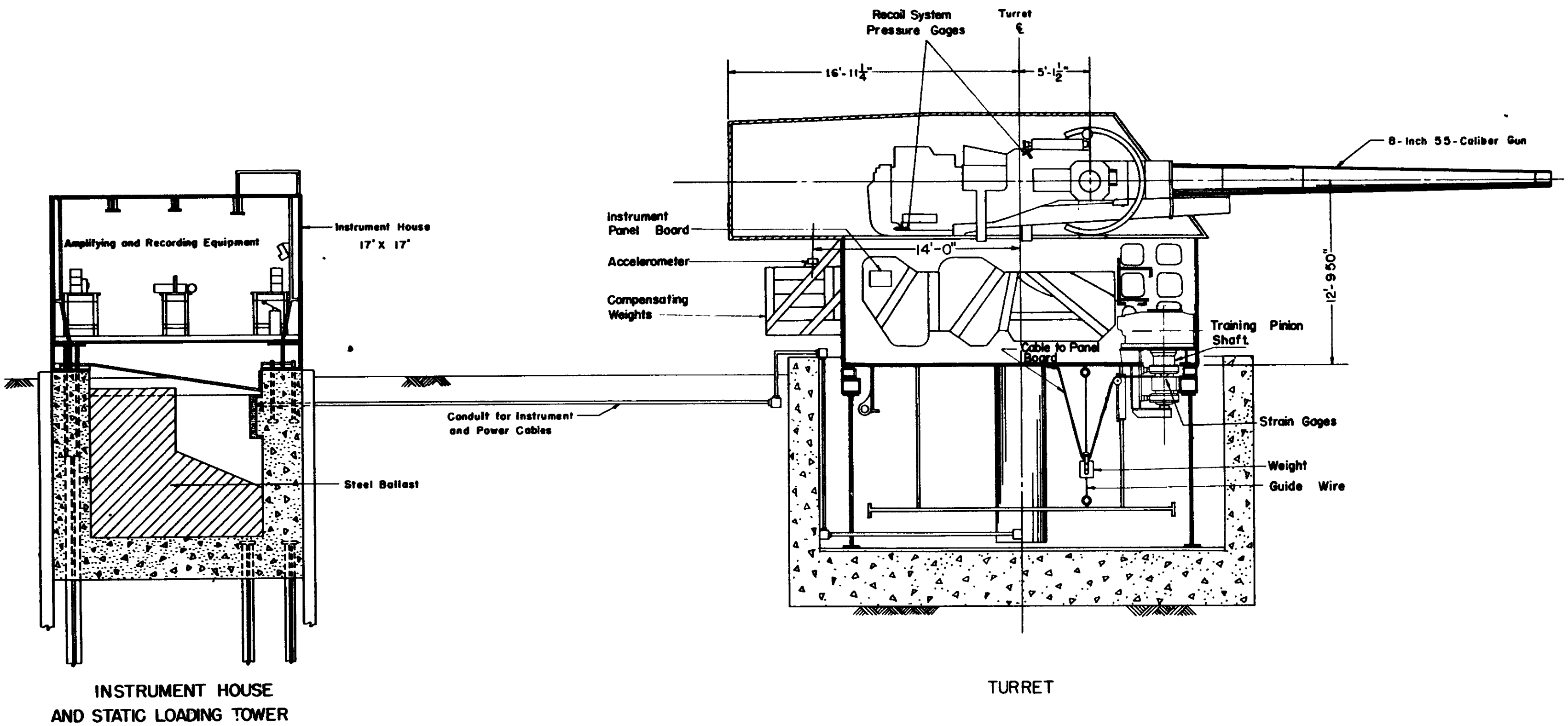


Figure 3 - General Arrangement of the Pilot Turret Showing Location of Gages

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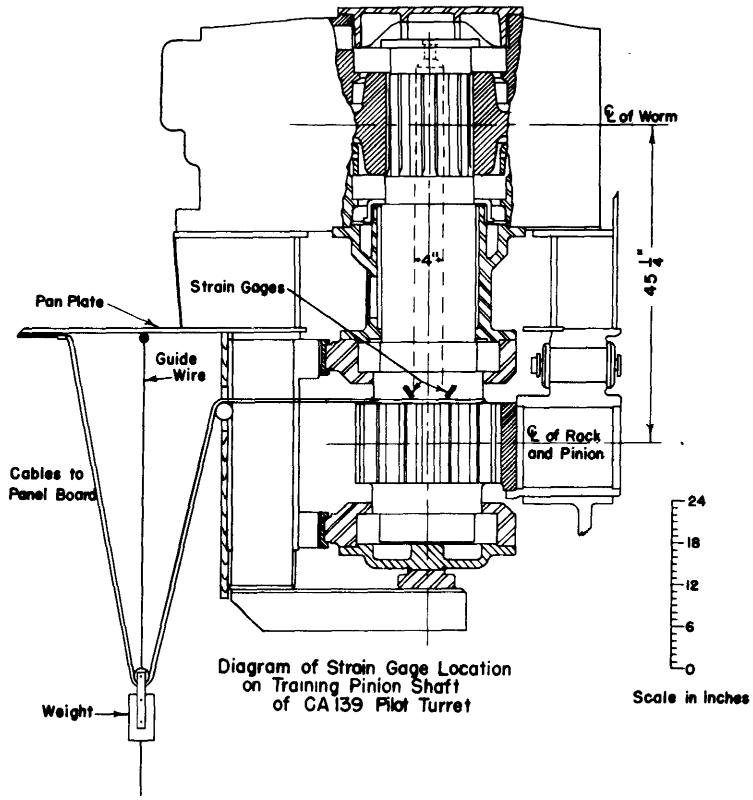

Figure 4 - Diagram of Strain-Gage Locations on the Training-Pinion Shaft

responded identically to all strains except those due to bending, and so served as a good check on each other. The true torque, however, was obtained by averaging the two values.

While the two active gages formed adjacent arms in the Wheatstone bridge, the remaining two arms were incorporated in a TMB Type-1A strain indicator,[7] designed and built at the Taylor Model Basin specifically for dynamic strain measurements. This instrument acts as a source of voltage for the bridge, amplifies the bridge output signal, and provides a means of electrical calibration. Its response is uniform to signals with frequencies within the range of 0 to 200 cps. The output of the strain indicator was recorded on a Consolidated string oscillograph.

The amplitude scale in terms of linear strain units was established by an electrical calibration before each run was made. This calibration was obtained by introducing, by means of a switch on the strain indicator, a known change of resistance into one arm of the Wheatstone-bridge circuit—the known change of resistance corresponding to a known magnitude of equivalent strain. The resulting unbalance of the bridge was recorded as a "step" on the string-oscillograph record, and the magnitude of the strain recorded during a test was determined by comparing directly the height of the record with that of the calibration step.

The measured linear strain in the pinion shaft was then converted to torque by the formula (the small hole in the center of the shaft being neglected)

$$T = \frac{\pi G d^3 e}{16}$$

where T is the torque in lb-in.,

G is the shear modulus of the shaft in psi,

d is the diameter of the shaft in inches, and

e is the measured linear strain in in/in. as recorded on the oscillograph (e is equal to twice the linear strain measured by one gage since the bridge circuit in which the gages operated combined their responses).

This procedure was checked during the static tests on the turret,[8] where a known torque was applied to the pinion shaft by loading one of the wing guns, and the change in torque was recorded on a string oscillograph. The B-end was locked for this test. The torque applied to the shaft (determined from a load dynamometer) and the measured torque (deduced from the oscillograph records) were in excellent agreement.

ANGULAR ACCELERATION OF THE TURRET

The linear tangential acceleration of a particular point in the horizontal plane of the turret was measured directly by means of a 1 1/2-g Statham accelerometer. The measured linear acceleration, designated in terms of g, the acceleration of gravity, was converted to angular acceleration in degrees per second squared by multiplying by a factor of 130. This factor was established by the location of the accelerometer during these tests, which was 170 in. from the center of rotation of the turret. At this distance, while training through an angle of 1 radian, the gage would travel through an arc of 170 in., and 1° would subtend an arc of 2.97 in. With this relationship established, a measured linear acceleration of g, which is 386.4 in./sec^2, would correspond to 130°/sec^2 of angular acceleration. The position of the accelerometer on the turret is shown in Figure 3.

The Statham accelerometer (shown in Figure 5) makes use of a guided mass, or inertia element, supported in space by strain-sensitive wires. The wires are connected so as to comprise all four arms of an electrical bridge circuit. When the mass is subjected to an acceleration, the electrical

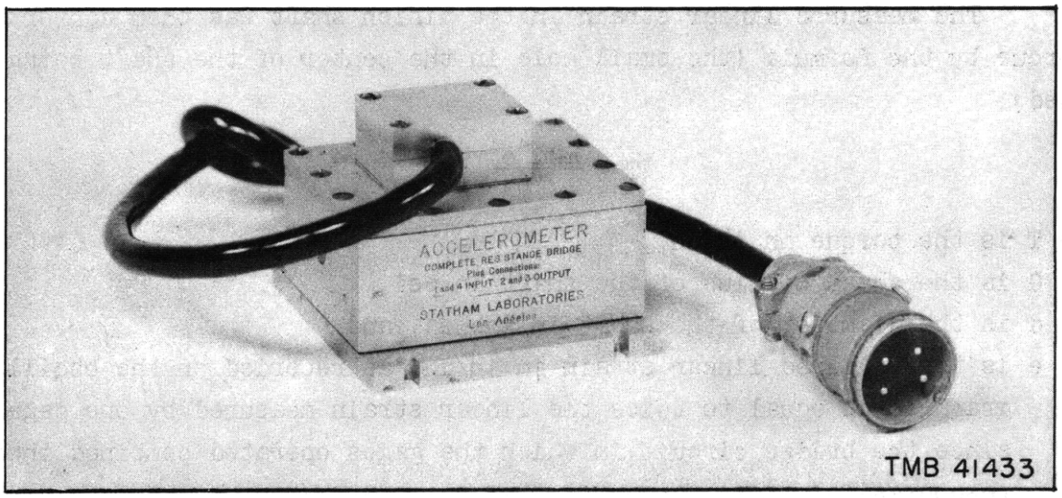

Figure 5 - The Statham Accelerometer

resistances of the wires are changed so as to unbalance the bridge. The signal produced by this unbalance was amplified by a TMB Type-1B strain indicator and recorded on the Consolidated string oscillograph.

The TMB-1B strain indicator is identical with the TMB-1A strain indicator except that all four arms of the bridge circuit are external. Like the 1A, the 1B also has a device for electrical calibration of the equipment. This calibration, which was taken before each record, was obtained by shunting one arm of the bridge with a known resistance, the known resistance corresponding to a known value of acceleration. The resulting voltage output appeared as a calibration step on the oscillograph record. The acceleration during the test was determined by comparing the height of the record above the base line with the height of the calibration step.

The accelerometer itself was calibrated statically. Employing the same strain indicator as was used during the tests, the accelerometer was rotated 90°, thus changing the acceleration by 1 g, and the voltage output was read. One arm of the bridge was then shunted with a known resistance, and again the output was read. This was a direct calibration of the accelerometer and the strain indicator together.

The natural frequency of the gage is 115 cps.

It was found during early tests that the accelerometer was excessively sensitive to vibrations caused by the electric motors in the turret when installed on the skirt plate, so it was subsequently relocated on the compensating weights at the rear of the turret. The large mass of the weights attenuated the vibrations from the electrical equipment, and the records taken from this location gave a more accurate picture of the acceleration of the turret.

While the acceleration curves from the records obtained during gunfire are, from all indications, reliable, frequently during the nonfiring exercises the inertia element used in the accelerometer stuck in an off-center position causing an unbalanced condition in the bridge circuit. As the acceleration computed from the oscillograph records depends on the position of the zero or base line, the acceleration could be in error by the amount the base line is deflected due to the signal produced by the unbalanced bridge condition of the instrument. This fault could be remedied in future applications through the use of a small vibrator with a frequency above the natural frequency of the accelerometer employed.

RECOIL FORCE OF GUNFIRE

The recoil force of gunfire was obtained from the fluid pressures measured in the recoil mechanisms which were multiplied by the appropriate piston areas. The separate components of recoil force were then added to obtain the total recoil force.

TMB elastic-tube pressure gages[9] were used for measuring both the hydraulic pressure in the recoil buffer and the air pressure in the counterrecoil cylinder. This type of pressure gage consists of an elastic tube divided into two sections by an integrally formed plug. One section is exposed to the fluid pressure in the buffer cylinder and is the active portion of the gage. The other section is open to the atmosphere. The dividing plug is drilled and tapped for a small screw which may be removed to bleed air from the gage after the gage has been installed.

Two wires, each of 120-ohm resistance, are cemented to the outer surface of the tube. One wire is wrapped around the active part of the tube to indicate the pressure. The second wire is similarly mounted on the open section of the tube to compensate for strains due to changes in temperature. These two strain elements are connected so as to form the adjacent arms of a Wheatstone-bridge circuit. Pressure inside of the tube expands the closed section of the tube and produces circumferential strains resulting in a change in resistance which is then amplified and recorded.

The amount of strain developed was found by comparing the height of the record above the base line with the height of the calibration step. The pressure was equal to the measured strain multiplied by the sensitivity of the gage. Each gage had been calibrated statically in the laboratory to determine its sensitivity in terms of microinches per inch of strain per 1000-psi pressure.

The shape and magnitude of the recoil force resulting from gunfire are discussed in detail in TMB Report C-165,[10] which deals with the recoil investigation of the 8-in. 55-cal. guns of this type turret.

AUXILIARY MEASUREMENTS

The number of measurements involved in the test required the use of more than one recording oscillograph, and synchronization of all records was obtained by placing a 60-cps wave signal, emitted from a timing device, on one channel of each oscillograph. Once each second this wave signal was interrupted and, since each interruption was indicated on all simultaneous recordings by a break in the wave form, it could be used as a point of departure.

The closing of the firing circuit was obtained on the oscillograph record directly from the current passing through a shunt resistance in the circuit. As the key was closed, a step was indicated on the record.

Naval Proving Ground personnel obtained the position of the turret in train by recording the output of an instrument installed on the B-end shaft of the training-gear system. The instrument consists of a transformer whose primary coil is geared to the rotating B-end shaft and whose secondary coil is fixed. A 60-cycle alternating current is passed through the primary coil, and the amplitude of the 60-cycle current induced in the fixed secondary coil varies as the primary coil is rotated by the movement of the turret. The magnitude of the output 60-cycle wave varies as a sine curve, which, because of the gearing system, passes through a node with every 5° change in the angle of train. The gage was regulated so that the nodes occurred at turret positions of 0°, 5°, 10°, and so on, and hence from a known position at one point on the record the location of the turret could be obtained for any other point.

The output of the strain indicators was recorded with a Consolidated 14-channel string oscillograph. Each galvanometer of the oscillograph has a uniform response to current variations of frequency ranging from zero to 400 cps. These variations are recorded through an optical system on moving photographic paper.

TEST SCHEDULE

The test schedule[2] followed by the Taylor Model Basin during the training-gear tests of the CA139 pilot turret at the Naval Proving Ground is presented in Table 1.

It was believed that this schedule of tests included all the possible training exercises to which the turret would be subjected in service, and thus would provide a realistically severe test of the system.

TEST PROCEDURE

The tests of the training-gear system were conducted with automatic control of the power drive. During TMB Test 12, the first part of the test program, which was without gunfire, the dummy director transmitted a stationary order of 0° and the turret was displaced by successive increasing angles of error up to 10°, which was considered great enough to allow the turret to attain its maximum acceleration and velocity. During this test and the succeeding nonfiring exercises, torque, acceleration, turret position, and the 60-cycle timer were recorded on the oscillograph by the Taylor Model Basin.

To determine the reaction of gunfire on the training mechanism the guns were fired both singly and in two-gun salvos while the turret was stationary or following a signal transmitted from the dummy director as outlined in the test program. During these firing trials the same type data recorded for the nonfiring tests were again obtained. In addition measurements of the recoil force and the closing of the firing circuit were also simultaneously recorded.

TEST RESULTS

A complete set of photostats of the oscillograms recorded by the Taylor Model Basin during these training tests was forwarded to the Bureau of Ordnance.[11,12]

Figure 6 is a sample oscillogram recorded during the nonfiring trials. Figure 7 is a replot of the data taken during a test with gunfire; it includes the data recorded by the Naval Proving Ground on this test.

The principal results of the tests are summarized in Tables 2 and 3.

The results of Test 12, a nonfiring test, are summarized in Table 2. In this test, with the dummy director transmitting a stationary order of 0°, the turret was displaced by successively increasing angles of error and then released. Torque in the pinion shaft and angular acceleration were measured; these are listed in Table 2. The "first peak" designated in the table denotes the torque and acceleration developed at the time the turret is set in motion.

TABLE 1

Schedule of TMB Training-Gear Tests

TMB Test Number	Test Directive*	Turret Operation**	Method of Training Turret	Gun Operation	
				Elevation	Gunfire
12	0-19a s-e	With dummy director transmitting stationary order, displace turret by successively increasing angles of error, and release turret.	Variable velocity, increment of error to be approx. 5°.	0	None
13	0-19c s-e	Train with turret following simple harmonic signals simulating roll.	Run 1; 25° in 12 sec Run 2; 5° in 12 sec Run 3; 10° in 18.8 sec	0	None
14	0-19d s-e	Same as Test 13 except signals simulate pitch.	Run 1; 25° in 9 sec	0	None
15	0-19e s-e	Train at constant velocity 320° through 40°	Run 1; 1°/sec Run 2; 3°/sec Run 3; 5°/sec	0	None
16	0-19f s-e	Train to right as in Test 15; fire left gun.	Run 1; 1°/sec Run 2; 3°/sec Run 3; 5°/sec	0°-30'	Automatic; single
17	0-19g s-e	Repeat Test 16; train to left	Run 1; 1°/sec Run 2; 3°/sec Run 3; 5°/sec	0°-30'	Automatic; single
18	0-19h s-e	Repeat Test 16.	Run 1; 1°/sec Run 2; 3°/sec Run 3; 5°/sec	Max. compatible with range	Automatic; single
19	0-19i s-e	Repeat Test 16; fire both guns.	Run 1; 1°/sec Run 2; 3°/sec Run 3; 5°/sec	0°-30'	Automatic; simultaneously
20	0-19j	Repeat Test 19.	Run 1; 1°/sec Run 2; 3°/sec Run 3; 5°/sec	Max.	Automatic; simultaneously
21	0-19k R-2 s-e Part 1	Turret stationary; fire left gun.	0	a-0°30' b-Max.	Manual; single
22	0-19k R-2 s-e Part 2	Turret stationary; fire right gun.	0	a-0°30' b-Max.	Manual; single
23	0-19k R-2 s-e Part 3	Turret stationary; fire both guns.	0	a-0°30' b-Max.	Manual; simultaneously
24	0-19n R-2 s-e Part 1	Train to right with turret following simple harmonic signals simulating 5° roll with a period of 12 sec. Fire left gun.	Variable velocity	a-0°30' b-Max.	Automatic; single
25	0-19n R-2 s-e Part 2	Same as Test 24; train to left; fire left gun.	Variable velocity	a-0°30' b-Max.	Automatic; single
26	0-19n R-2 s-e Part 3	Same as Test 25; fire both guns	Variable velocity	a-0°30' b-Max.	Automatic; simultaneously

*These symbols refer to paragraph numbers in Reference 1.

**The training-gear power drive was in automatic control for all tests.

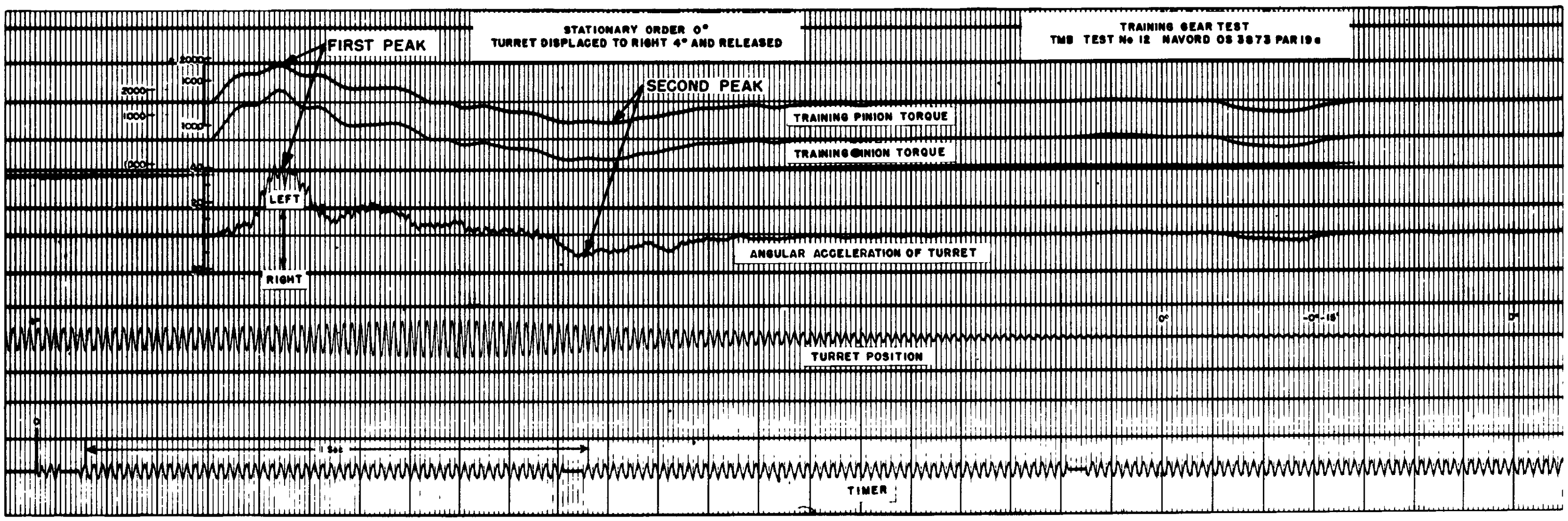

Figure 6 - A Typical Oscillogram from a Nonfiring Test

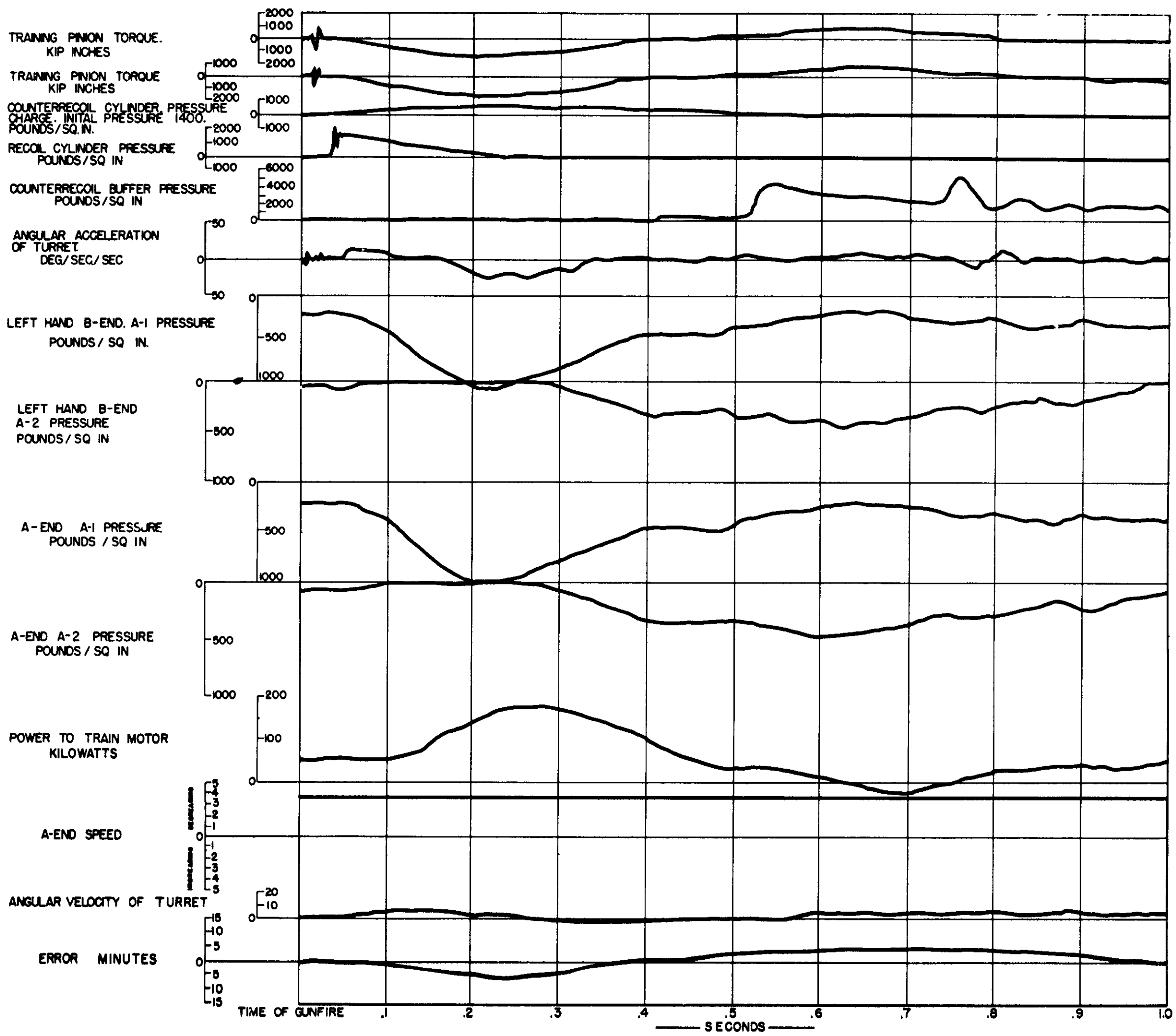

Figure 7 - Data Replotted from the Oscillograms Taken by Both TMB and NPG during a Test with Gunfire

The values listed under "second peak" are those observed during the deceleration of the rotating structure upon reaching the stationary order transmitted by the director. These peaks are indicated in Figure 6.

In Tests 13, 14, and 15, which were nonfiring tests designed to determine the effects of roll, pitch, and training at constant velocity, the measured torque and acceleration were too small to read, i.e., torque was below 400 kip-in. and acceleration was below 10°/sec^2.

Tests 16 through 26 were designed to determine the effects of gunfire upon the training mechanism. Table 3 shows the maximum torque and angular acceleration for these tests and the time of their occurrence in relation to the closing of the firing key. In this table, the "first peak" refers to the maximum torque and the corresponding accelerations which were recorded

TABLE 2

Torque and Acceleration Measured during Nonfiring Tests

Test and Run Number	Angle of Error Before Release of Turret degrees	Torque kip-in. (First Peak)	Acceleration deg/sec^2 (First Peak)	Torque kip-in. (Second Peak)	Acceleration deg/sec^2 (Second Peak)
12 - 1	0.5 L	1370	23.1	2470*	65.5*
12 - 2	0.5 R	1470	18.6	2220*	58.3*
12 - 3	1.0 L	1520	21.2	2320*	56.4*
12 - 4	1.0 R	1520	20.5	2240*	34.6*
12 - 5	1.5 L	1390	30.1	1540*	53.8*
12 - 6	1.5 R	1560	41.0	1630*	82.0*
12 - 7	2.0 L	1320	30.8	720	20.5
12 - 8	2.0 R	1560	59.3	1220*	25.0*
12 - 9	2.5 L	1480	48.7	860*	15.4*
12 - 10	2.5 R	1700	31.3	1490	34.7
12 - 11	3.0 L	1570	47.0	1020	23.0
12 - 12	3.0 R	1620	33.2	800	12.5
12 - 13	4.0 L	1590	44.0	860	12.8
12 - 14	4.0 R	1840	37.4	900	12.5
12 - 15	5.0 L	1550	24.2	1000	23.8
12 - 16	5.0 R	1780	29.4	1190	20.8
12 - 17	7.5 L	1450	24.2	920	23.0
12 - 18	7.5 R	1600	38.5	780	12.3
12 - 19	10.0 L	1530	36.2	2010	55.2
12 - 20	10.0 R	1550	45.1	1890	48.0
13	Negligible torque and acceleration				
14	Negligible torque and acceleration				
15	Negligible torque and acceleration				

*Reading taken after passing zero degrees.

after gunfire. A "second peak" of torque is also listed; this refers to the torque exerted to bring the turret back to the signal supplied by the dummy director; see Figure 7.

Immediately after gunfire, the acceleration record shows an appreciable acceleration which is not reflected in the torque record (Figure 7); this acceleration is also listed in Table 3.

TABLE 3

Torque and Acceleration Measured during Gunfire Tests

Test and Run Number	First Peak				Second Peak			
	Torque kip-in.	Time sec	Acceleration deg/sec^2	Time sec	Torque kip-in.	Time sec	Acceleration deg/sec^2	Time sec
16 - 1	1750	0.22	20.2	0.23	660	0.64	10.7	0.07
2	1500	0.24	21.4	0.28	640	0.68	11.9	0.07
3	1385	0.26	16.5	0.28	590	0.78	11.8	0.06
17 - 1	2250	0.23	41.3	0.25	950	0.42	15.6	0.09
2	1800	0.22	32.0	0.26	700	0.43	14.1	0.07
3	1720	0.23	34.5	0.23	540	0.61	19.2	0.09
18 - 1	1660	0.24	27	0.26	375	0.53	14.5	0.07
2	1340	0.23	22	0.23	290	0.73	14.5	0.06
3	1230	0.22	23	0.25	480	0.79	14.5	0.06
19 - 1, 2, 3	Negligible torque and acceleration							
20 - 1, 2, 3	Negligible torque and acceleration							
21 - 1	1660	0.17			380	0.62		
2	1460	0.22			220	0.45		
22 - 1	1710	0.21			300	0.43		
2	2010	0.22	32.3	0.25	380	0.43	32.3	0.25
23 - 1, 2	Negligible torque and acceleration							
24 - 1	1600	0.22	25.3	0.21	860	0.65	25.3	0.21
2	1380	0.24	13.6	0.09	Negligible		13.6	0.09
25 - 1	2000	0.23	32.6	0.26	480	0.45	32.2	0.26
2	1620	0.16	13.6	0.12	420	0.35	13.6	0.12
26 - 1, 2	Negligible torque and acceleration							

Recoil forces are not listed in Table 3; a value of 200,000 lb is believed to be the best average value of recoil force developed when a gun is fired at 0° elevation. When a gun is fired at 40° elevation, a figure of 220,000 lb applies; the component in the horizontal direction is, however, only about 170,000 lb. These figures are the average results of measurements taken during this test and the recoil investigation.[10]

DISCUSSION OF RESULTS

The maximum torque recorded during the training-gear investigation was 2470 kip-in.; this torque was developed in Test 12, Run 1, in which the turret was displaced 30 minutes from the stationary order transmitted by the dummy director, and then shifted into automatic control. The turret overran the stationary order; the high torque was then observed as the turret accelerated approaching the signal the second time. This value of 2470 kip-in. is to be compared with 2250 kip-in., the highest torque developed due to the effects of gunfire (Test 17, Run 1).

Similar measurements of torque in this same pinion shaft were made during the test of the hydraulic training buffer of the turret.[4] It is therefore of interest to note that the greatest amplitude of torque recorded during the training test is less than one-half of the 5600 kip-in. recorded in the course of the buffer investigation.

The maximum angular acceleration recorded was 82°/sec^2 (Test 12, Run 6). The maximum value recorded during a gunfire test was 41°/sec^2, recorded in Test 17, Run 1. In the tests on the hydraulic training buffer,[4] a maximum acceleration of 43°/sec^2 was measured.

It was noted in design formula [2a] that a direct relationship was taken to exist between torque in the training-pinion shaft and angular acceleration of the turret. This relationship was not found to exist experimentally.

Whereas the errors in acceleration data may be partly responsible for lack of correlation between these two quantities, it is more likely that the elasticity of the structural system made up of the training pinion, B-end foundations, etc., requires a more sophisticated analysis than that of pure rigid-body mechanics. The behavior of an elastic system, as given by Equation [2c], is the simplest expression of such an elastic system, and analyses should be made on that basis. The constant expressing flexibility of the system should be determined by static tests during which measurements of displacement and torque are made simultaneously.

No analysis of data involving records obtained by the Naval Proving Ground is given here. However, Figure 7 is introduced as a sample record of the complete data taken on the tests. These data may be correlated to check the design formulas given earlier.

Of additional interest is the recording of the error between the actual position of the turret and the position of the turret if it had responded exactly as dictated by the dummy director. In Figure 7, when the left gun was fired, this maximum error was 5 minutes.

CONCLUSIONS

The turret was observed to meet specified training rates and accelerations.

Performance of the instruments employed in these tests was found satisfactory, but records of acceleration may be in error as much as 15 percent.

The use of the training-pinion shaft as the elastic element in the measurement of torque transmitted by the shaft was found to be entirely satisfactory.

The strength of the training-gear mechanism is considered to be adequate.

No direct relationship was observed between torque in the training-pinion shaft and angular acceleration of the turret, and it is believed that elasticity of the system must be considered in any rational analysis. The data in this report and data taken by the Naval Proving Grounds can be used to verify mathematical relationships.

ACKNOWLEDGMENTS

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