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# THE DAVID W. TAYLOR MODEL BASIN

UNITED STATES NAVY

## DESCRIPTION OF INSTRUMENTS EMPLOYED IN THE OPERATIONAL TEST OF THE GUN-ELEVATING SYSTEMS OF THE CA139 CLASS PILOT TURRET

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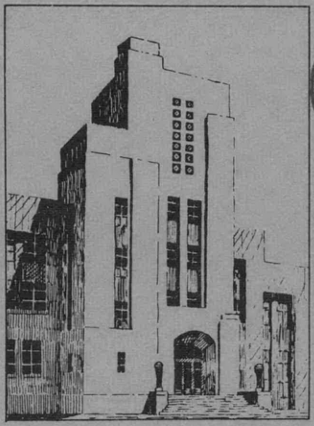

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# PERSONNEL

The instruments described in this report were developed by Lt. R.S. Thatcher, USNR, E. Larson, Jr., W.D. Hunter, and L.M. DeLand. The equipment was operated at the Naval Proving Ground by W.D. Hunter, S. Davidson, and M. Dean under the supervision of L.M. DeLand who is also the author of this report. General guidance for tests of the pilot turret was given by E. Wenk, Jr.

# DESCRIPTION OF INSTRUMENTS EMPLOYED IN THE OPERATIONAL TESTS OF THE GUN-ELEVATING SYSTEMS OF THE CA139 CLASS PILOT TURRET

## ABSTRACT

For proof tests of the elevating-gear systems of the 8-inch 55-caliber pilot turret instruments were required to measure the torque transmitted by the elevating-pinion shaft, and the angular acceleration of the gun. Metalectric strain gages were mounted on the shaft to determine the torque. A Statham accelerometer, which uses the strain-sensitive wire principle, was used to measure the acceleration. The output signals of these gage systems were amplified by electronic equipment and recorded on a string oscillograph. Supplemental indications of gun position, of the closing of the firing circuit, and of the starting of recoil were also recorded directly on the oscillograph. A brief description of these instruments is given in this report.

## INTRODUCTION

Heavy cruisers of the projected CA139 Class differ from ships of the CA68 Class now in service primarily in the use of rapid-firing guns that can be loaded at any elevation. Among the mechanical features incorporated in the 8-inch turrets for the first time is an arc-and-pinion drive located in the final gearing of the elevating system to move the guns. To determine the operating characteristics of this system and the performance of all of its components, full-scale field tests were deemed necessary. Accordingly, the Bureau of Ordnance directed (1)* that proof tests of the elevating gear be conducted on the pilot turret installed at the Naval Proving Ground, Dahlgren, Virginia. The Proving Ground was requested to study the driving elements through measurements of the electrical power input and pressures in the hydraulic units. The David Taylor Model Basin was requested to determine the response of the system to specific signals from a dummy director by measuring the torque transmitted by the elevating-pinion shaft and the angular acceleration developed by the moving gun. To confirm this request, the Taylor Model Basin issued a schedule (2) listing instrumentation it would furnish during these tests.** The performance of these instruments during the tests appeared satisfactory and records obtained are considered reliable.

This report contains a brief description of the elevating system under study and of the instruments employed to measure torque and acceleration, with general comments about the apparatus which provides supplemental data and about the auxiliary electronic and recording equipment. Additional instruments and

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* Numbers in parentheses indicate references on page 7 of this report.

** Instrumentation has been developed under Project C200, TMB file C-CA139 Class/S72-1.

apparatus to be used in further tests of the pilot turret will be described in a series of similar reports to be issued at the completion of the various portions of the tests.

The general arrangement of the instruments and of the auxiliary equipment provided for the complete test program of the turret is shown in Figure 1.

More complete descriptions of the test equipment together with analyses of the operation of the equipment and of the action of the systems under study will be included in more comprehensive reports to be issued later.

## DESCRIPTION OF THE ELEVATING-GEAR SYSTEM

Motion of each gun installed in the CA139 Class pilot turret is derived from an independent closed hydraulic system powered by an electric motor. This motor drives, at a constant speed, a hydraulic pump of the Waterbury speed gear type, termed the A-end, which is the source of fluid for driving a hydraulic motor, called the B-end. A worm gear located on the B-end shaft engages a worm wheel on one end of the elevating-pinion shaft. On the other end of the latter shaft, the elevating pinion engages an arc which is rigidly attached to the gun-slide assembly.

Changes in gun elevation or in angular velocity are accomplished by operation of the B-end through variation of the direction or rate of fluid flow from the A-end. Variations in fluid flow from the A-end are produced entirely by changes of the angle of the tilt plate in that unit.

It is apparent that, during movement of the gun, certain relationships must exist between the power input to the electric motor and pressures in the hydraulic system, on the one hand, and the behavior of the gun as produced by the torque transmitted through the elevating-pinion shaft and indicated by its displacement, velocity, and acceleration, on the other.

Superposed on the dynamics of this system during elevating exercises are the effects which accompany gunfire. In this case, an overturning moment of the gun about the trunnion is created by the gun recoiling out of battery. A restraint to motion of the gun is effected by the braking action of the B-end applied through the worm drive.

Previous to this test, very little experimental data existed for the variables involved in this type of elevating system, and it was the purpose of this test to obtain data to establish such relationships to serve as a basis for designing future gun-elevating systems.

## INSTRUMENTS EMPLOYED IN THE OPERATIONAL TESTS

A brief description follows of each of the instruments or devices employed by the Taylor Model Basin during the tests on the elevating system to obtain records of behavior of the guns during dynamic exercises.

### TORQUE TRANSMITTED BY THE ELEVATING-PINION SHAFT

Inasmuch as torsion in the pinion shaft is known to be accompanied by proportional elastic strains, metalectric strain gages were installed on both the right and left shafts as means of measuring the torque in each. Four gages were mounted on each shaft between the worm wheel and pinion, as shown in Figure 2. These gages were placed in pairs oriented 180 degrees apart. The angle between the gages in each pair is 90 degrees with the axis of each individual gage at an angle of 45 degrees with the axis of the shaft. It is at this angle that a pure torque produces tension in one gage and equal compression in the other gage of the pair.

Each pair of strain gages was connected so as to form two adjacent arms of an electrical bridge circuit. When a torque is applied to the shaft, the induced strain causes a change in resistance in the gages which creates an unbalance in the bridge circuit. This unbalance produces an output signal which can be measured to determine the amount of torque. The use of two active gages strained in opposite directions doubles the output of the system. In addition, the use of the metalectric strain gages in pairs produces automatic compensation for temperature effects that would otherwise produce errors. The output signal resulting from the unbalance of the circuit is too small to be satisfactorily recorded directly, so it is amplified by passing it through a TMB Type 1A strain indicator, acting as a carrier-type amplifier, and it is recorded on a Hathaway string oscillograph. This auxiliary equipment is described later in this report.

Holes in the pinion shaft, as shown in Figure 2, were provided for the electrical leads from the strain gages. The gages were mounted in August 1945 before the shafts were installed in the worm-drive housings, and were waterproofed with a bitumastic compound known commercially as Ozite B. Operation of the gages was still satisfactory in October 1947.

Cables which connect the electrical leads from the gages to the electronic equipment are left slack after leaving the shaft to permit twisting as the shaft rotates. This arrangement was considered suitable since rotation of the shaft is only 1.8 revolution while the gun moves through its complete range of elevation.

The presence of holes in the pinion shaft as well as variations in cross section in the vicinity of the strain gages were believed to produce such an irregular stress distribution as to make invalid any computed relationships between applied torque and strain. Consequently, a calibration was performed to obtain the relation of torque to strain developed on the surface of the shaft. This was accomplished by applying a load on the barrel normal to the axis of the gun while the gun was locked in position at zero elevation by having the B-end of the hydraulic drive running at idling speed. This load was measured with a TMB tension dynamometer with an error believed to be less than 2 per cent. By plotting the observed strain in the pinion shaft versus applied force or moment, a straight-line relationship was established between the applied torque and the observed strain for each pair of gages. A sensitivity of 510 inch-pounds of torque per microinch per inch of strain was obtained for one pair of gages whereas a sensitivity of 670 inch-pounds of torque per microinch per inoh of strain was obtained for the other pair. This difference is due to bending moment in the shaft at the calibrating position. These calibrations are used to convert to torque the strains measured during the tests.

During a test, variations in resistance of the metalectric gages produced by torsion in the shaft are recorded photographically on an oscillograph as a function of time. The amplitude scale in terms of strain units is established by an artifical calibration before each gun operation, as follows: A calibration step is obtained by introducing a known resistance into the electrical bridge system by means of a switch in the TMB Type 1A strain indicator. This resistance causes an unbalance of the bridge productive of an output electrically equal to that of the original system with one gage under a strain of 400 microinches per inch. Since both active gages are connected to give double output, the value of the calibration strain is one-half of that recorded when both gages are equally strained. The magnitude of the strain recorded is determined by comparing directly the height of the record above the base line with the height of a calibration step equivalent, in this particular case, to strain of 400 microinches per inch.

Two pairs of gages were mounted directly opposite each other on the pinion shaft so that bending of the shaft could be either ascertained or balanced out. The actual torque transmitted by the shaft would be the average of the two values. Bending is evidenced by the variations in the ratio of torque obtained with one pair of gages and that obtained with the second pair. Since the calibration for the strain-torque relation was made at zero gun elevation, torque values computed from both pairs of gages are equal at that elevation. This is also true at a 25-degree gun elevation when the gages and the elevating pinion have made one complete revolution and are in the same relative position as when the gun elevation is zero. However, at intermediate angles of gun elevation from zero to 25 degrees and on up to 40 degrees the ratio of the values of torque varies as a sine curve.

The use of the shaft itself as the pickup element of the measuring system was considered the best method of obtaining the torque measurement and proved to be very satisfactory.

## ANGULAR ACCELERATION OF GUN

The angular acceleration of the gun while elevating or depressing was measured with a Statham 1 1/2-g accelerometer. This instrument incorporates a mass or inertia element supported in space by a strain-sensitive wire. 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 strain wires are changed in length so as to unbalance the bridge. The signal produced by this unbalance is amplified by a TMB Type 1B strain indicator and recorded on the string oscillograph. The natural frequency of the instrument is 115 cycles per second, which is well above the frequencies anticipated during elevating tests.

The Statham accelerometer used during these exercises was so located on the gun that it could measure accelerations only in a direction normal to the axis of the gun. Since the component in this direction of the weight of the floating mass depends on the elevation of the gun, the true acceleration when elevating would be indicated only when the gun is horizontal. At any elevation other than zero, the signal produced by the instrument is in error. This error, which varies as the angle of elevation, is equal to one minus the cosine of the angle. It is cancelled by displacing the base line by an amount equal to the error corresponding to the particular gun elevation. This process may result in a curved base line. At small angles of gun elevation the correction is negligible.

The values of accelerations are obtained from the records in a manner similar to that used in obtaining the values of torque, namely, by comparing the height of the record above the base line with the height of a calibration step. The values thus obtained are in terms of "g," the acceleration of gravity, and are converted to accelerations in terms of degrees per second per second by multiplying by a factor of 130. This factor was determined by the location of the accelerometer during these tests. It was mounted on the counterweight on the gun slide at 170 inches from the centerline of the trunnion. At this distance, an angle of 1-radian amplitude at the axis of the trunnion would subtend an arc of 170 inches and 1 degree would subtend an arc of 2.97 inches. With this relationship of angular and linear displacement of the instrument, the value of "g," which is 386.4 inches per second per second, would become 130 degrees per second per second.

The accelerometer is calibrated in the laboratory by placing it on a table vibrating in simple harmonic motion with a known amplitude and period. The acceleration to which the instrument is subjected can be computed from these factors. Records of output signals of the accelerometer and amplifier were obtained at several values of acceleration as induced by the vibrating table. The ratio of the magnitude of these output signals to the signal at an acceleration of unity, 1 g, establishes the values of the calibration steps used to evaluate records obtained during tests. In general, the Statham accelerometer performed satisfactorily, although small errors were believed to exist because of sticking of the mass at low accelerations with frequencies below 10 CPS.

### CLOSING OF THE FIRING CIRCUIT

The closing of the firing circuit was recorded and taken to be the time that the gun was fired. This circuit was closed by operation of the firing key. An oscillograph record was obtained directly of the current passing through a shunt resistance in the circuit. As the key was closed, a step was indicated on the record.

### START OF RECOIL

The start of the recoiling motion of the gun resulting from gunfire was determined by means of a microswitch mounted on the stationary forward portion of the gun slide. A rod was attached to the breech housing which is on the recoiling portion of the gun. This rod pressed the arm of the switch to hold an open circuit when the gun was in battery. The instant recoil started, pressure was released from the arm of the switch, closing the circuit and placing a step on the oscillograph record.

## GUN POSITION

The position of the gun in elevation was obtained by recording the output of an instrument installed in the regulator of the elevating system by the Naval Proving Ground. The instrument consists of two coils, one fixed and one free to rotate about a transverse axis. 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 gun. The magnitude of the output 60-cycle wave varies as a sine curve, which, as the result of a gearing system, passes through a node every 5 degrees change of gun elevation. The gage was regulated so that the nodes occurred at gun elevations of 0 degree, 5 degrees, 10 degrees, and so on, and hence from a known elevation at one point on the record the elevations could be obtained for any other point.

## ELECTRONIC EQUIPMENT

The output signal of the strain-gage systems used for the measurements mentioned earlier cannot be recorded on a string oscillograph without amplification. This amplification is provided by TMB Type 1A strain indicators. The strain indicator contains fixed resistors which are connected to the external strain gages to form a Wheatstone bridge circuit. This bridge circuit is excited by a 2200-CPS carrier from a vacuum-tube oscillator. Mechanical strain in the gages produces a change in resistance which alters the balance of the bridge. This electrical unbalance, which appears as an output voltage, is amplified by vacuum tubes in the amplifier circuit of the indicator. The signal from the amplifier is then passed through the output stage which bypasses the carrier frequency and delivers a current which is directly proportional to the input signal and thus to the strain being measured. This output current can be used to drive the recording galvanometer of the oscillograph. The indicator also provides a method for accurately balancing the bridge circuit and calibrating the gage system. The design and operation of this instrument are described in detail in a separate report (3).

The arrangement of gages used for the measurement of elevating-pinion-shaft torque places two arms of the bridge circuit, external to the TMB 1A strain indicator while the other two arms of the bridge are located in the indicator. For the measurement of angular gun acceleration, the Statham accelerometer used contains all four arms of the bridge circuit. With this complete external bridge, amplification was obtained by means of a TMB Type 1B strain indicator. The fundamental difference between the Type 1A and Type 1B indicators lies in the arrangement of the electrical bridge system.

The frequency range of these strain indicators is linear from zero to about 200 CPS.

## RECORDING EQUIPMENT

The output of the strain indicators and other electrical equipment was recorded with a Hathaway Type S8 12-channel string oscillograph. The galvanometer of the oscillograph responds to current variations in output of the gage systems. These variations are recorded through an optical system on moving photographic paper. The average linear frequency range of the galvanometers is 500 CPS.

## CONCLUSION

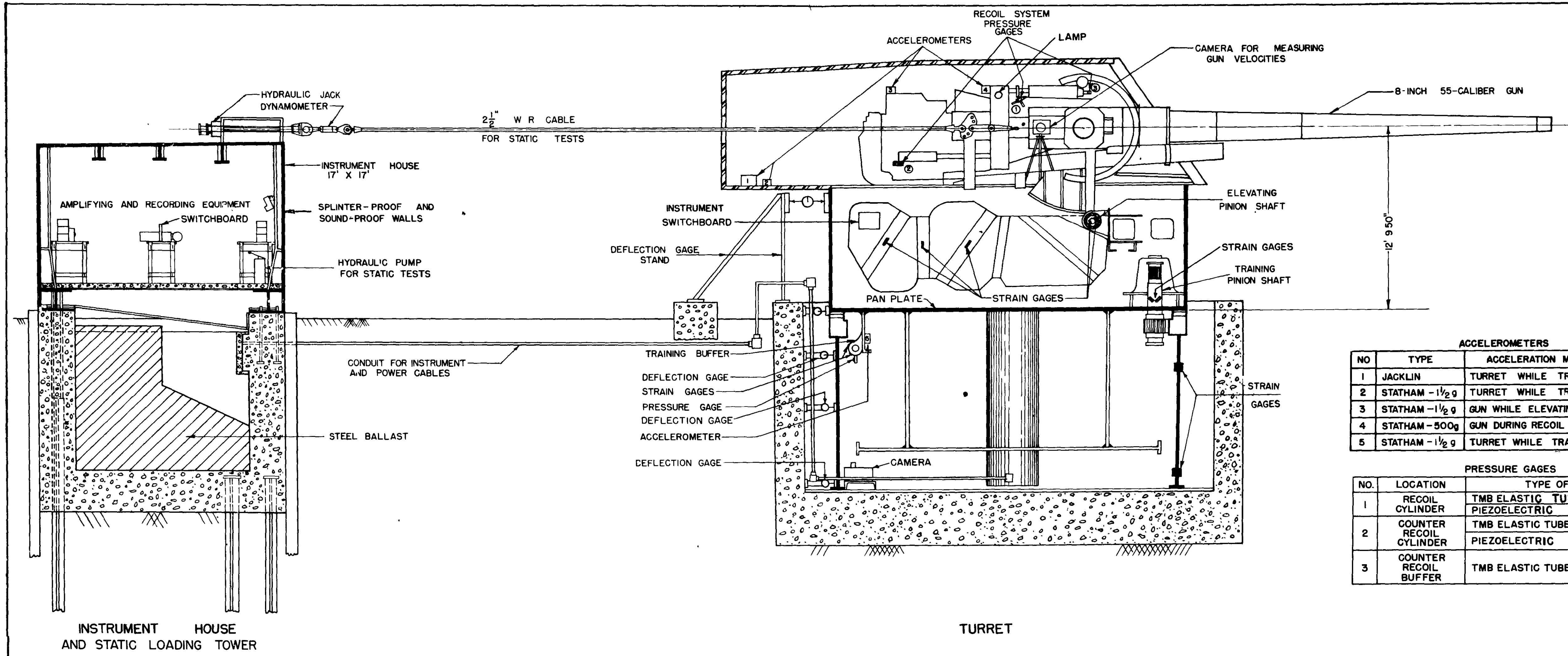
The instruments described in this report, and the records obtained are considered satisfactory.

## REFERENCES

(1) NAVORD OS3873 "General Specifications to Cover the Tests to be Conducted on the 8"/55 Caliber Pilot Turret CA139 Class," dated 10 October 1945 (Revision of 25 September 1946).

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

(3) "A Carrier-Type Strain Indicator," by George W. Cook, TMB Report 565, November 1946.



INSTRUMENT HOUSE AND STATIC LOADING TOWER

TURRET

ACCELEROMETERS

| NO | TYPE | ACCELERATION MEASURED |
|---|---|---|
| 1 | JACKLIN | TURRET WHILE TRAINING |
| 2 | STATHAM - $1\frac{1}{2}$ g | TURRET WHILE TRAINING |
| 3 | STATHAM - $1\frac{1}{2}$ g | GUN WHILE ELEVATING OR DEPRESSING |
| 4 | STATHAM - 500g | GUN DURING RECOIL |
| 5 | STATHAM - $1\frac{1}{2}$ g | TURRET WHILE TRAINING |

PRESSURE GAGES

| NO. | LOCATION | TYPE OF GAGES |
|---|---|---|
| 1 | RECOIL CYLINDER | TMB ELASTIC TUBE<br>PIEZOELECTRIC |
| 2 | COUNTER RECOIL CYLINDER | TMB ELASTIC TUBE<br>PIEZOELECTRIC |
| 3 | COUNTER RECOIL BUFFER | TMB ELASTIC TUBE |

FIGURE 1 – GENERAL ARRANGEMENT FOR STATIC AND FIRING TESTS OF CA139 PILOT TURRET

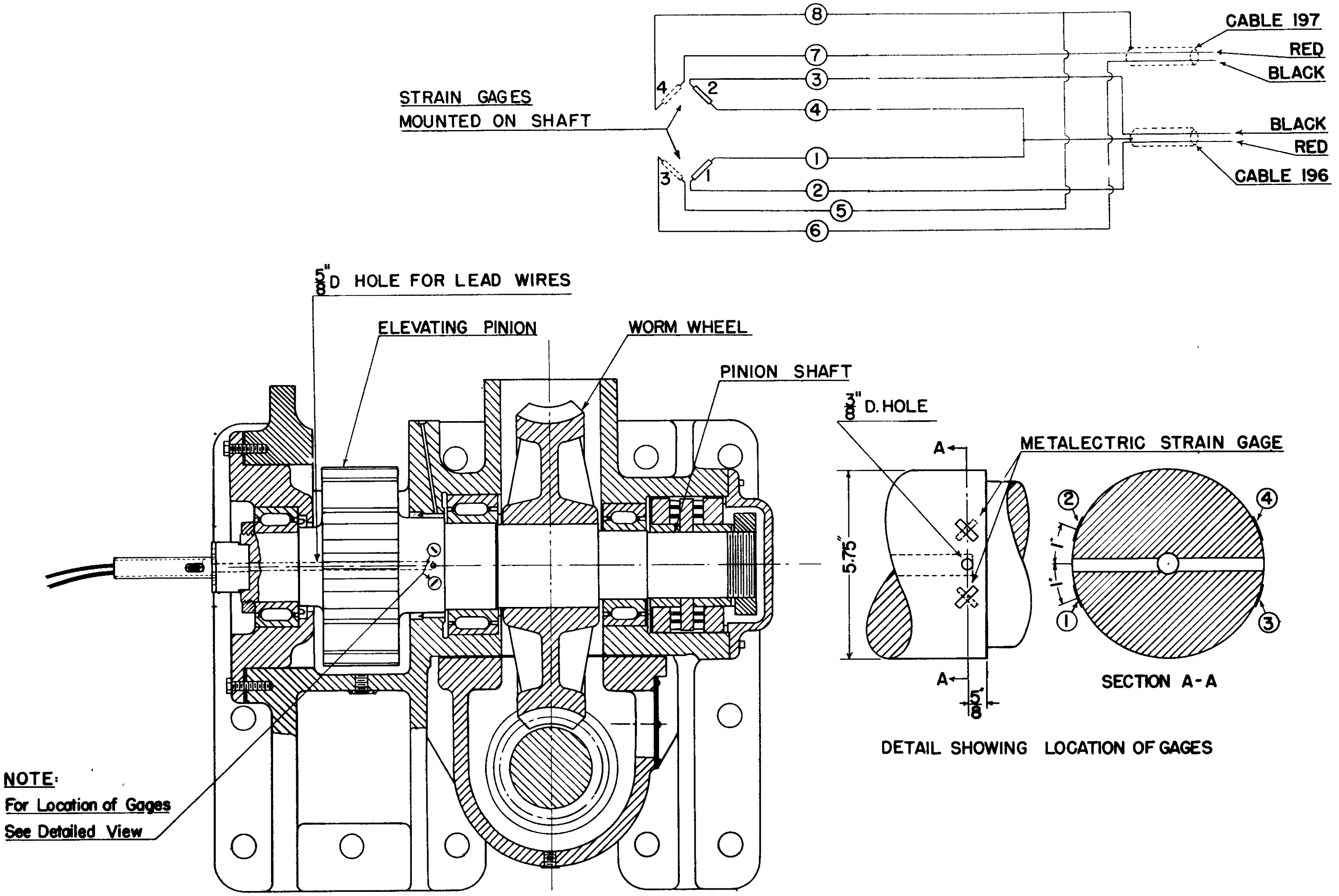


FIGURE 2- ARRANGEMENT FOR MEASURING TORQUE IN THE RIGHT ELEVATING-PINION SHAFT FOR THE CA139 CLASS PILOT TURRET

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