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**AN INVESTIGATION OF  
HIGH-FREQUENCY FLUCTUATIONS OF  
STRAIN GAUGE SIGNALS ASSOCIATED  
WITH THE PRESENCE OF LIQUIDS IN GUNS**



**U. S. NAVAL PROVING GROUND  
DAHLGREN, VIRGINIA**

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**Date: 25 June 1954**

**54AA 43320**

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U. S. Naval Proving Ground  
Dahlgren, Virginia

An Investigation of  
High-Frequency Fluctuations of  
Strain Gauge Signals Associated  
with the Presence of Liquids in Guns

by

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NPG REPORT NO. 1281

Foundational Research Project No.  
NPG-M-11016-13

25 June 1954

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54AA

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ABSTRACT

The occurrence of high-frequency oscillations on the pressure and strain oscillograms from guns using liquid propellants or liquid projectiles was investigated by recording the response of gauges under a variety of conditions during scheduled tests of two guns. The data and results are reported in detail in order to provide background information for planning future investigations of any of the phases which may warrant more intensive study. It was demonstrated that the high-frequency disturbance in the strain gauge signal is due only partially to strain fluctuations, with evidence that the remainder is due to magnetic pickup. A fluctuating magnetic field was shown to exist around the gun during firing. The potential of various points on the surface of the gun also fluctuates rapidly, but appears to have little effect on the signal.

It is concluded that:

The origin of the high-frequency disturbances observed lies in the violent agitation of the liquid contained within the gun. This agitation is attributed to the random impingement of the high-pressure combustion products on the gas-liquid interface.

The transmission of the disturbances to the gauge positions occurs through the medium of elastic waves in the gun, initiated by the pressures in the agitated liquid.

The disturbance appearing in the signal from the gauge consists of two components, one due to the direct effect of mechanical strain associated with the elastic waves and the other due to magnetic pickup. The magnetic field causing the latter component is attributed to the magnetostrictive effect of the elastic waves.

FOREWORD

The work reported herein was conducted under the Foundational Research Program of the Naval Proving Ground, under authority of reference (a). The project was initiated in June 1953 under the title "Investigation of Magnetic Effect on Strain Gauge Response". This is the final report on Foundational Research Project NPG-M-11016-13.

These tests were conducted by Mr. W. A. Dennison and Mr. P. E. Wine, Jr. of the Armament Laboratories Division.

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INTRODUCTION

In firings of liquid propellants in guns at the Naval Proving Ground, oscillations of very high frequency (30,000 cps and above) have been observed, superimposed on oscillograms of chamber pressure and barrel strain. In many cases these oscillations have been of sufficient amplitude to preclude accurate determination of pressures and strains. Transducers used in liquid propellant tests at the Naval Proving Ground employ bonded wire strain gauges as active elements; however, informal reports from other activities using piezo-electric transducers indicate that similar disturbances appear on oscillograms obtained with these.

In recent firings of a 5"/54 caliber gun, using water slugs in place of a conventional projectile, pressure and strain oscillograms contained high-frequency oscillations very similar to those encountered in the liquid propellant firings. The similarity of the oscillations under these two different sets of conditions, and the fact that the phenomena were not present in either gun when conventional propellants and projectiles were used, tend to support the hypothesis that the phenomena are directly associated with the presence of liquid in the gun, whether active, as propellant, or inert, as water.

It is a reasonable, though speculative, hypothesis that violent agitation of the liquid occurs during the ignition and burning of the propellant, and that this agitation manifests itself mechanically in the form of rapidly-changing pressures at the adjacent metal surfaces. Assuming that this is true, the mechanism by which pressure fluctuations at the inner surface of a gun or gauge tube affect the response of a strain gauge located on the outer surface is of interest.

Direct mechanical transmission, as strain, suggests itself as one possibility. In the absence of resonance, the strain at a point on the outer surface is influenced by the distribution of inner surface pressures over an appreciable area, rather than at a point; thus highly localized peaks at the inner surface should be attenuated. On the

other hand, if the pressure variations occur at a frequency which excites the tube or barrel at one of its natural frequencies, oscillations of the strain gauge trace may be of a higher amplitude than that commensurate with the oscillations of pressure within the tube. In neither case would the oscillations observed bear any quantitative relation to true pressures.

A second possibility is that of electromagnetic coupling. The guns, being of steel, are nearly always magnetized to a greater or lesser degree, either by stray fields, by the earth's magnetic field, or by firing magnetized projectiles used in velocity measurements. It is conceivable that rapidly fluctuating strains in the metal, originating as described above, could by magnetostriction produce a high-frequency alternating magnetic field which excited the strain gauge circuit by induction.

Variations in electrostatic potential of the metal adjacent to the gauge, with respect to instrument ground, can, under certain conditions, modify the true strain signal. Electrostatic coupling is, therefore, a third possible avenue for the production of oscillations.

The objective of this investigation was to determine, by means of exploratory tests, the conditions of occurrence of the high-frequency oscillations. Qualitative observations under a wide variety of conditions were desired in order to provide a background for possible future experiments of a specific nature. Certain tests were particularly directed toward observing the relative importance of the three means of transmission discussed above.

#### DESCRIPTION OF MATERIAL

The data for this investigation were obtained during regularly scheduled firings of two guns: a 40mm gun which was fired with both liquid and solid propellants in connection with the development of a liquid-propellant

round, and a 5<sup>n</sup>/54 caliber gun which was fired with slugs of water in place of a conventional projectile, in connection with the development of a special operational test procedure. A detailed description of the two guns follows:

a. 40mm Gun: This gun is a Mk A Mod 1 40mm barrel (#14934), assembled in a six-pounder mount. The gun used a hydrazine-type liquid propellant and fired a Mk 2 40mm projectile. The gun was drilled to accommodate two pressure gauges at three and ten inches from the breech face. Typical records containing rapid oscillation may be seen in Figure 1. Typical barrel strain records are presented in Figure 2. Percussion primers were used in firing the gun for these tests. Further details concerning the liquid propellant program may be had from reference (b).

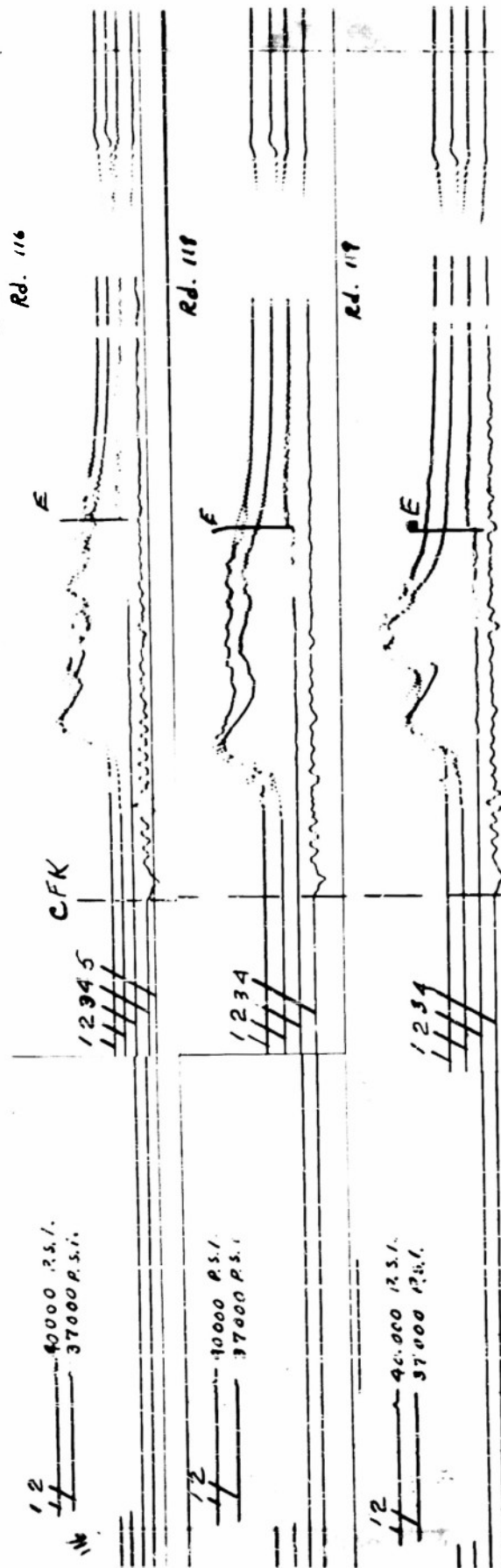
b. 5<sup>n</sup>/54 Caliber Water-Shot Gun: The program was fired using a Mk 16 Mod 0 barrel (#14751). The powder type and the charge weight were varied throughout the program to suit operational test requirements. The projectile was simulated by an equal or greater weight of water encased in wax-impregnated cylindrical cartons. Typical records showing high-frequency oscillations of the strain gauge traces appear in Figure 3. Further details concerning the water shot program may be obtained from reference (c).

#### DESCRIPTION OF TEST EQUIPMENT

Both guns were equipped with similar instrumentation consisting of wire resistance strain gauges for strain measurements on the barrel, and dynamic pressure gauges for pressure-time measurements. The pressure gauges employed, as active elements, wire resistance gauges similar to those used for strain recording.

In recording the pressures and strains, conventional recording circuits were used. A basic circuit is shown in Figure 4. In these circuits, the gauge was connected as the active arm of a Wheatstone bridge, the output of which was amplified by a d-c amplifier and recorded on a cathode-ray oscillograph. In addition, certain gauges were connected to the amplifier either directly or through

| Date     | Round No. | Charge Weight | Free Volume | % $N_2H_5NO_3$ | % $N_2H_4$ | % $H_2O$ |
|----------|-----------|---------------|-------------|----------------|------------|----------|
| 11/18/52 | 116       | 275 Grams     | 1.0%        | 15.0           | 30.5       | 4.5      |
| "        | 118       | 250 "         | 0.8%        | 18.0           | 76.2       | 5.8      |
| "        | 119       | 275 "         | 2.6%        | "              | "          | "        |



- Ch. 1: Expanding tube type pressure gage located 10" from breech face.  
 Ch. 2: " " " " " " " "  
 Ch. 3: Ejection strain gage.  
 Ch. 4: Close of Firing Key Indication (Percussion type primer).  
 Ch. 5: Reference line.

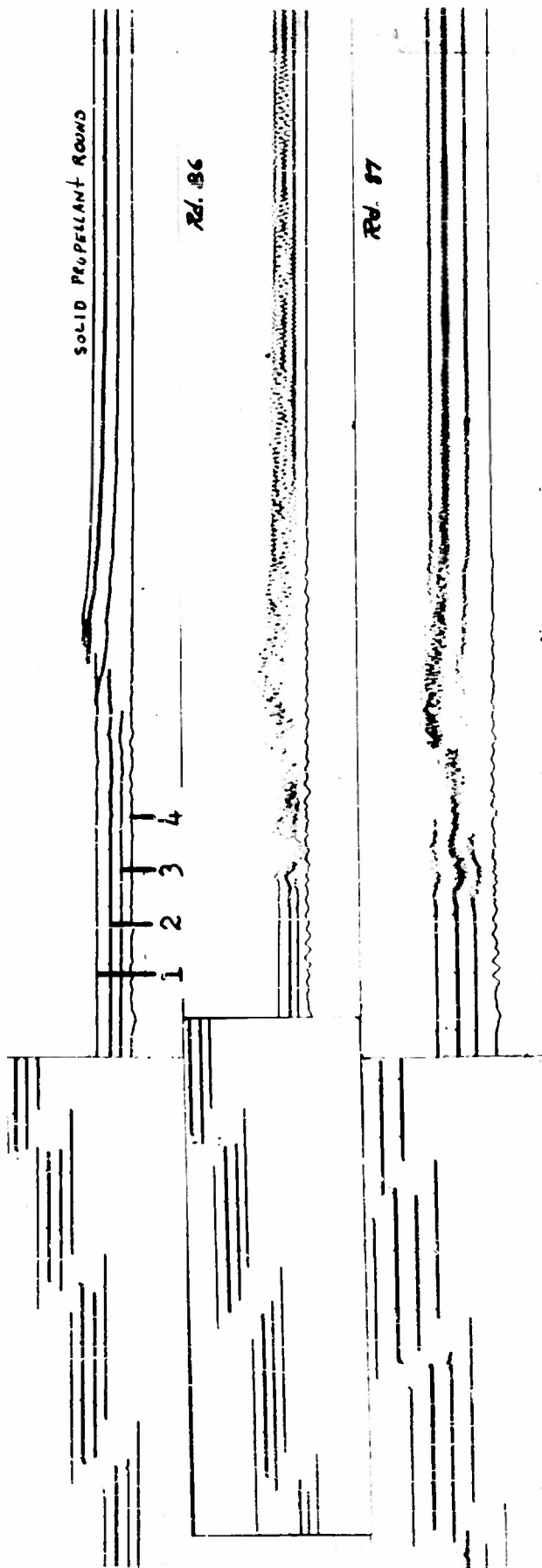
FIGURE 1

PRESSURE-TIME OSCILLOGRAMS

40 mm Liquid Propellant Gun

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|                         |                  |                      |                    |                                                   |                                     |                         |
|-------------------------|------------------|----------------------|--------------------|---------------------------------------------------|-------------------------------------|-------------------------|
| <u>Date</u>             | <u>Round No.</u> | <u>Charge Weight</u> | <u>Free Volume</u> | <u>% N<sub>2</sub>H<sub>5</sub>NO<sub>3</sub></u> | <u>% N<sub>2</sub>H<sub>4</sub></u> | <u>% H<sub>2</sub>O</u> |
| Solid Prop.<br>10/14/52 | 86               | 302.5 Grams          | 30.0%              | 18.0                                              | SPDN-8541                           | 5.8                     |
| "                       | 87               | 275                  | 20.0%              | "                                                 | 76.2                                | "                       |

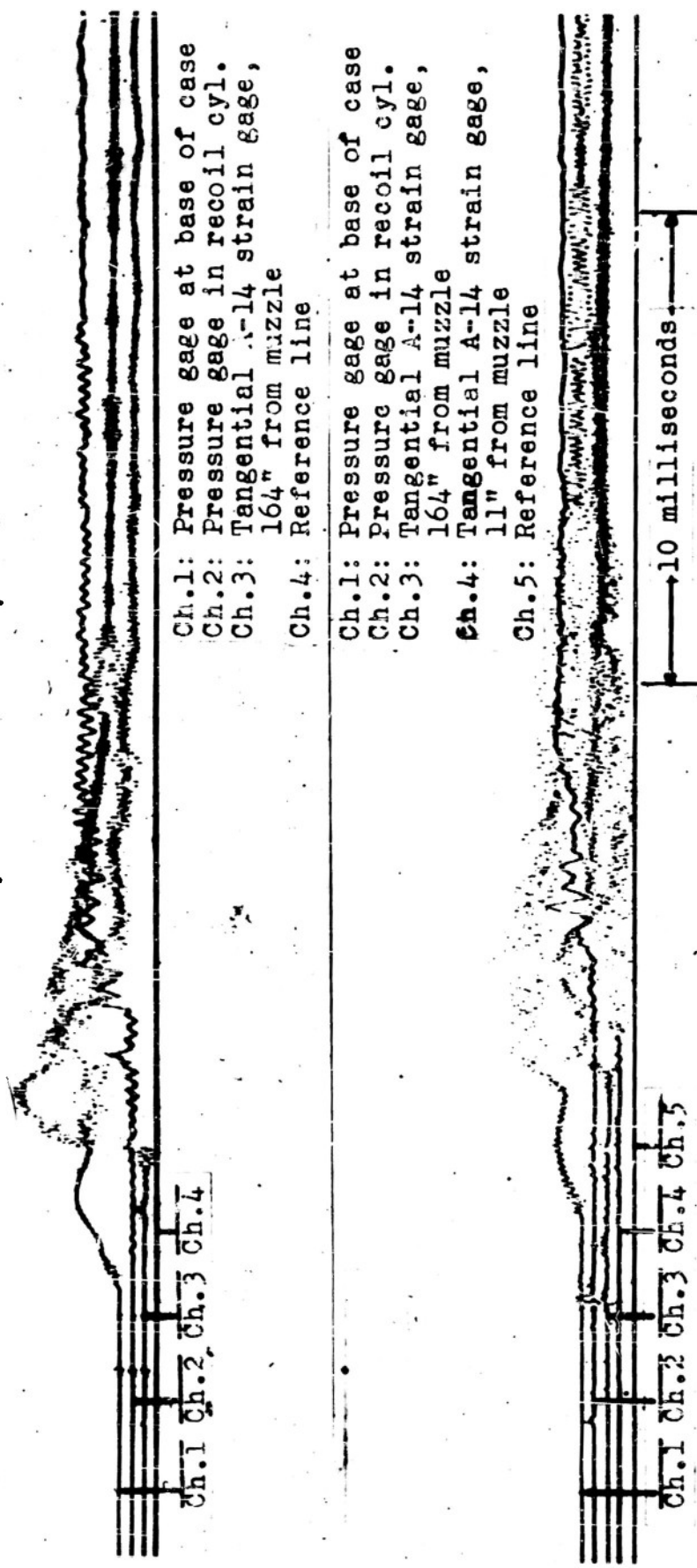


Ch. 1: Tangential A-14 strain gage located at 2.5" from the muzzle.  
 Ch. 2: Tangential A-14 strain gage located at 12.0" from the muzzle.  
 Ch. 3: Tangential A-14 strain gage located at 36.0" from the muzzle.  
 Ch. 4: Close of Firing Key Indication (Percussion type primer).

FIGURE 2

BARREL STRAIN OSCILLOGRAMS

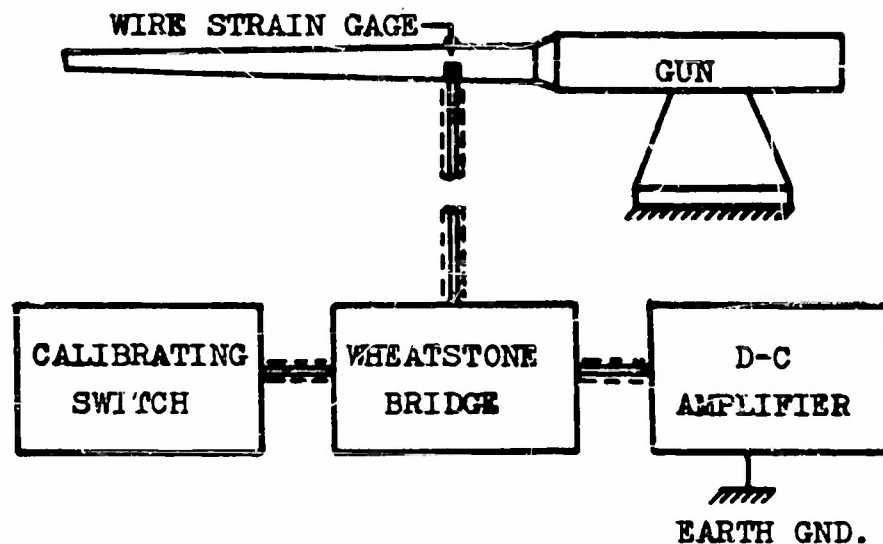
40 mm Liquid Propellant Gun



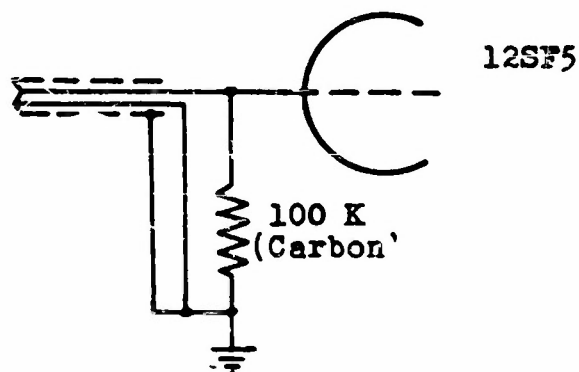
Ch.1: Pressure gage at base of case  
 Ch.2: Pressure gage in recoil cyl.  
 Ch.3: Tangential A-14 strain gage, 164" from muzzle  
 Ch.4: Reference line

Ch.1: Pressure gage at base of case  
 Ch.2: Pressure gage in recoil cyl.  
 Ch.3: Tangential A-14 strain gage, 164" from muzzle  
 Ch.4: Tangential A-14 strain gage, 11" from muzzle  
 Ch.5: Reference line

FIGURE 2  
5"/54 Water Shot Test  
Oscillograms



a. INTERCONNECTIONS



b. AMPLIFIER INPUT

FIGURE 1 - CONVENTIONAL STRAIN RECORDING CIRCUIT

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an unenergized bridge in order to separate the signal due to strain from that due to other disturbances. Coils used for magnetic pickup were fed directly to the amplifier input terminals. Further details of the instrumentation peculiar to specific tests are discussed in the section on PROCEDURE.

Details of the cables, amplifiers and recording equipment are as follows:

a. Cables: Two-conductor shielded. Shield normally grounded at laboratory and floating at gun. In certain tests later discussed, this grounding procedure was reversed to avoid ground loops or reduce undesired pickup.

b. Amplifiers:

|                     |                                                                                                               |
|---------------------|---------------------------------------------------------------------------------------------------------------|
| Type:               | Direct coupled.                                                                                               |
| Frequency Response: | Flat 0-30,000 cps.<br>Down 3 db at 100,000 cps.                                                               |
| Voltage Gain:       | 30,000 nominal.                                                                                               |
| Input Impedance:    | 100,000 ohms.                                                                                                 |
| Output:             | Direct to C-R tube deflection plates.                                                                         |
| Drift:              | 0.5 mv. equivalent input signal over 5-minute period.<br>5 mv. equivalent input signal over 30-minute period. |

c. Oscilloscopes:

|           |                                                                                                                                             |
|-----------|---------------------------------------------------------------------------------------------------------------------------------------------|
| Type:     | 4-channel with separate spot position controls for all channels.                                                                            |
| C-R Tube: | Four-gun with deflection plates, independently operated within a single envelope. 5" flat-face with short persistence blue (P-11) phosphor. |

- Sweep Circuit: None. Equivalent linear sweep is provided by relative motion of the recording medium.
- Timing Circuit: Internal pulse circuit superimposes timing "spikes" on all traces. May be driven by an external frequency standard, at operator's choice.
- d. Recording Camera: 60" circumference rotating drum with adjustable speed to 1800 rpm.
- e. Strain Gauges: Baldwin SR-4 Type A-14 used for all tests except as noted under "PROCEDURE".

#### PROCEDURE

Tests on the 5"/54 Gun: Three series of special tests were conducted on the 5"/54 caliber gun firing water slugs. These comprised four rounds to investigate the presence of a potential difference between different points on the gun and mount and its effect, if any, on the strain gauge signal; four rounds to check certain arbitrary variations in the strain gauge system, as described later; and two rounds to investigate the existence of a varying magnetic field near the gauge locations (a conventional projectile was fired on the second round of this series for comparison). On all of the water-shot firings, these special data were obtained concurrently with recordings of case pressure and strains, typical oscillograms of which appear in Figure 3. Details of the tests were as follows:

a. Electric Potential Tests:Test 1:

Purpose - To record potential difference during firing between a point on the barrel 160" from the muzzle and the base of the mount.

Channel 1 - Record of potential vs. time

Channel 2 - Reference line

Diagram - Figure 5a

Record - Figure 6 (T1)

Remarks - Instrument ground at base of mount.

Test 2:

Purpose - To obtain simultaneous recordings of potential between the base of the mount and a point on the barrel 160" from the muzzle, and of the response of an unbonded strain gauge on the barrel 160" from the muzzle.

Channel 1 - Record of potential vs. time

Channel 2 - Record from strain gauge

Record - Figure 6 (T2)

Remarks - Instrument ground at base of mount.

Test 3:

Purpose - To record potential difference between two adjacent points on the barrel (Separation of points 140).

Channel 1 - Record of potential vs. time

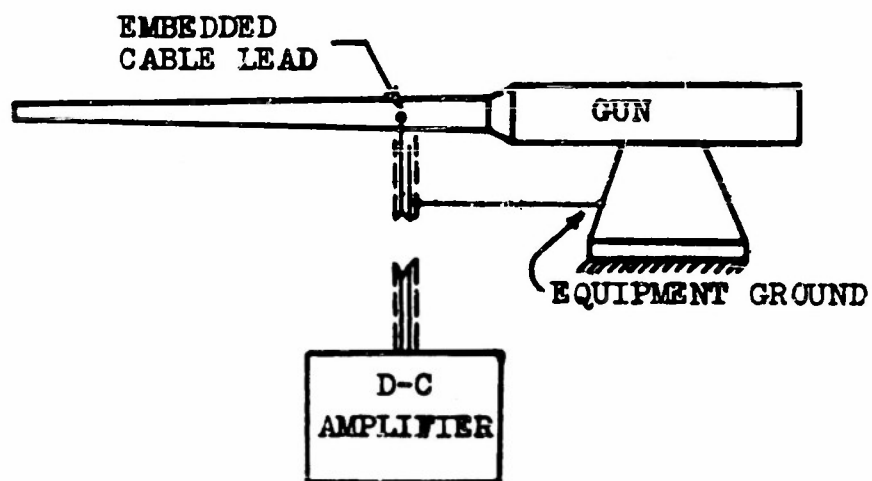
Channel 2 - Reference line

Diagram - Figure 5b

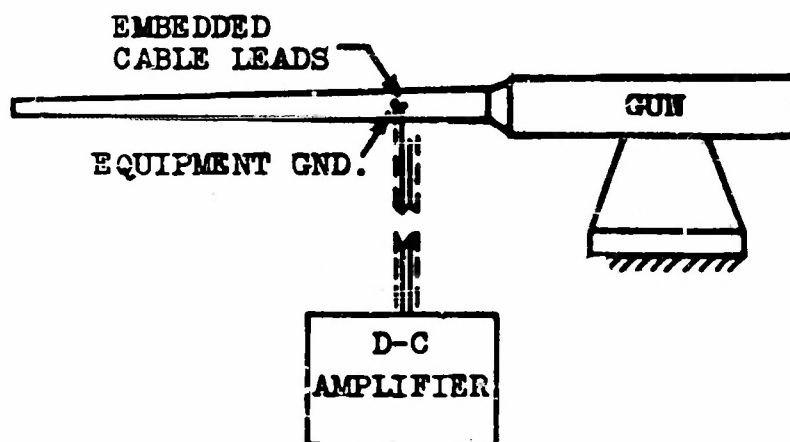
Record - Figure 6 (T3)

Remarks - Instrument ground adjacent to points of measurement;

Copper leads used at points of measurement.



a. CONNECTIONS FOR TEST 1



b. CONNECTIONS FOR TEST 3

FIGURE 5 - POTENTIAL TEST CONNECTIONS

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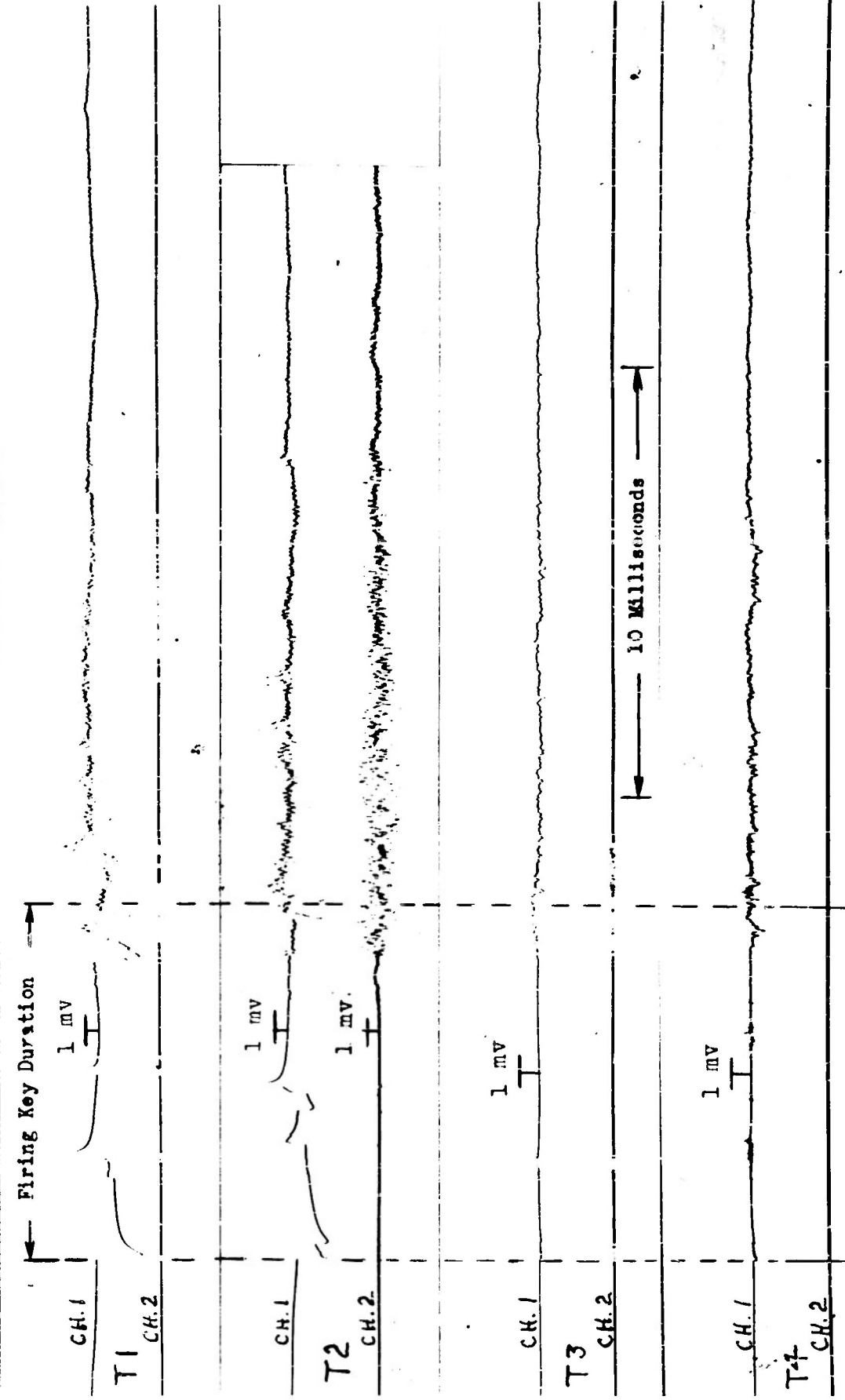


FIGURE 6 - Voltage Information Recorded on

the 5"/54 Water Shot Tests

Test 4:

Purpose - To duplicate Test 3, using steel leads, in order to determine whether the contact between dissimilar metals at points of measurement affects results.

Record - Figure 6 (T4)

Remarks - Same as Test 3 except that steel (music wire) leads were used.

b. Strain Gauge Tests:

Test 5:

Purpose - To record for reference the high-frequency oscillation from a normally energized, unbonded A-14 strain gauge 160" from the muzzle, and to observe the effect of locating the instrument ground adjacent to the gauge.

Channel 1 - Strain gauge trace

Channel 2 - Reference line

Diagram - Same as Figure 1a except that ground point was on gun, adjacent to gauge

Record - Figure 7, (T5)

Test 6:

Purpose - To record the high-frequency oscillation from an unenergized, unbonded A-14 strain gauge 160" from the muzzle.

Channel 1 - Strain gauge trace

Channel 2 - Reference line

Diagram - Figure 8

Record - Figure 7 (T6)

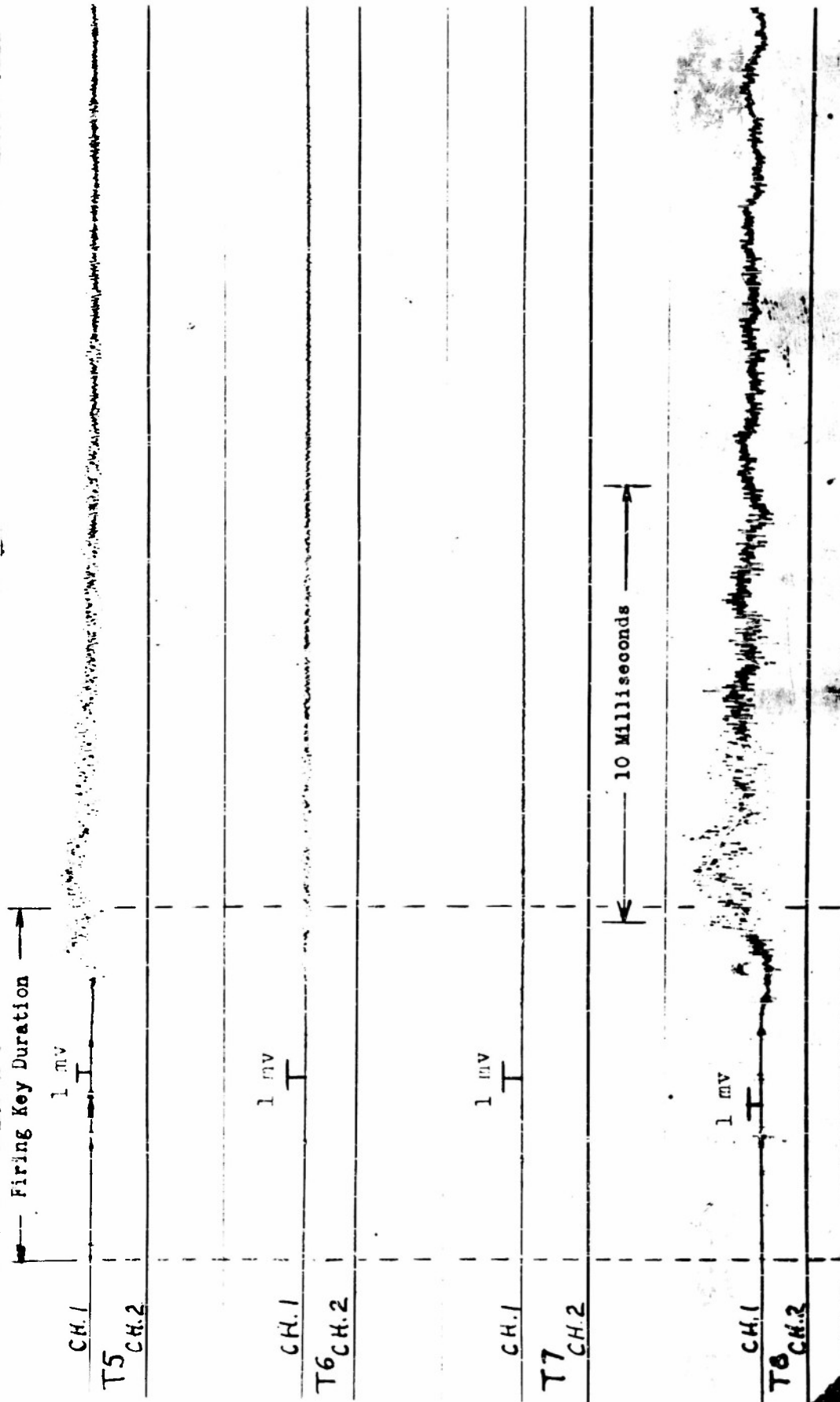


FIGURE 7

Strain Gage Information Recorded

on the 5"/54 Water Shot Tests

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Test 7:

Purpose - To observe effect of physical separation of the gauge from the metal of the gun.

Channel 1 - Strain gauge trace

Channel 2 - Reference line

Diagram - Figure 8

Record - Figure 7 (T7)

Remarks - Identical with Test 6 except that gauge was separated from contact with gun by a 0.005 mica sheet.

Test 8:

Purpose - To determine the practicability of cancellation of the undesired signal by using a second strain gauge in an adjacent arm of the Wheatstone bridge.

Channel 1 - Net output of the gauges

Channel 2 - Reference line

Record - Figure 7 (T8)

Remarks - Two gauges, oriented tangentially and longitudinally, respectively, were connected as adjacent arms of the Wheatstone bridge. With this connection the signal should be proportional to the difference between tangential and axial strain, and any superimposed signals due to magnetic or electrostatic pickup should cancel, if in phase.

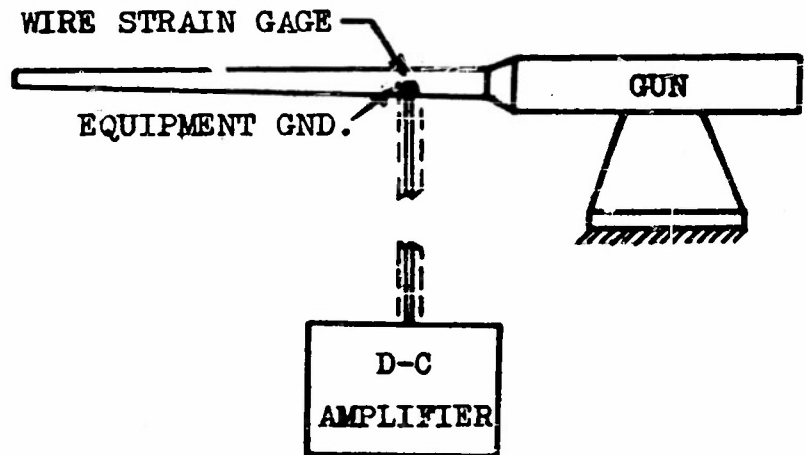


FIG. 8 - UNENERGIZED GAGE CONNECTION

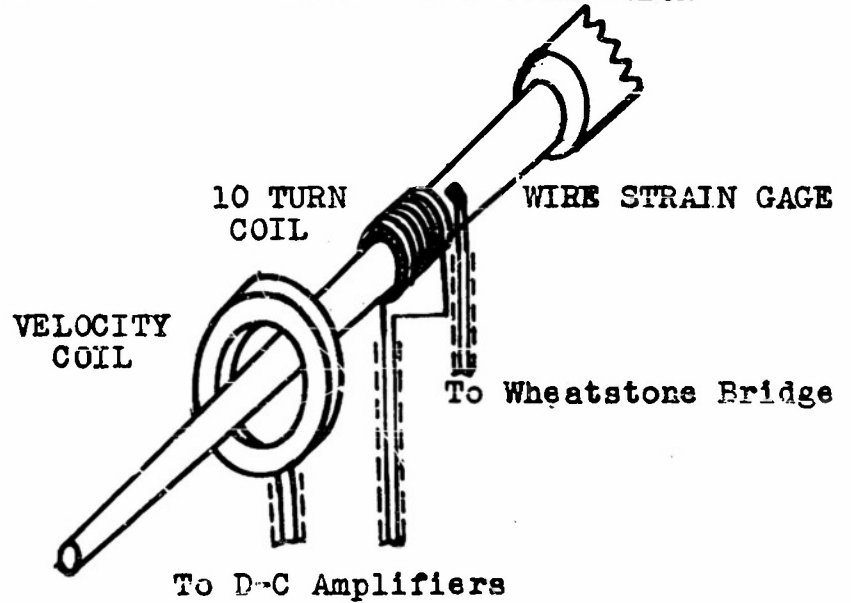


FIG. 9 - MAGNETIC PICKUPS

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c. Magnetic Field Tests:Test 9:

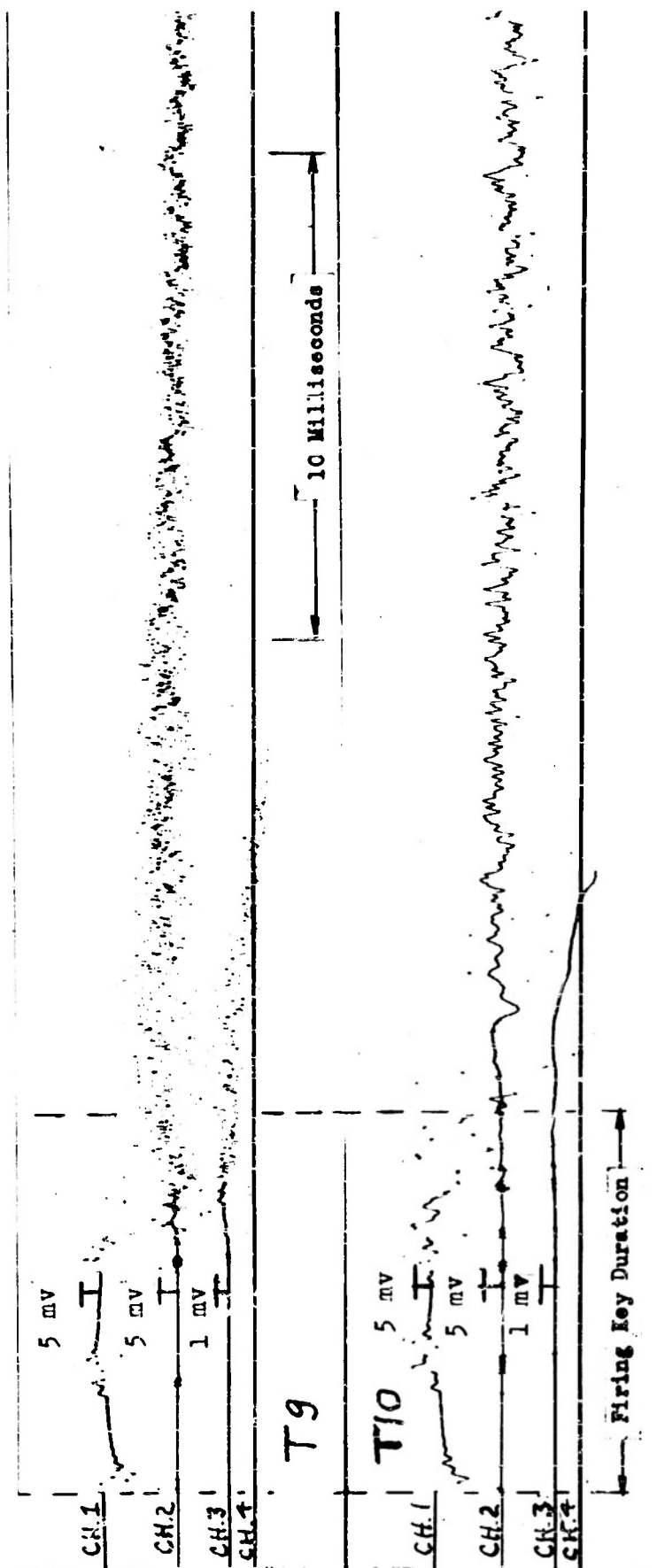
Purpose - To compare the high-frequency components of the strain gauge signal with those from magnetic pickup coils around the gun.

- Channel 1 - Output of conventional chronograph coil suspended around barrel at 100" from muzzle. Coil consists of 200 turns No. 22 copper wire on 24" diameter wooden form.
- Channel 2 - Output of a coil wound around the barrel over a foam rubber base at 160" from muzzle. Coil consists of ten turns No. 22 copper wire (approximate diameter 1270).
- Channel 3 - Strain gauge trace, unbonded A-14 gauge in conventional bridge, located adjacent to coil 160" from muzzle.
- Channel 4 - Reference line
- Diagram - Figure 9
- Record - Figure 10 (T9).

Test 10:

Purpose - To duplicate Test 9 using a conventional projectile instead of a water slug, as a basis of comparison.

- Channel 1 - Chronograph coil
- Channel 2 - Ten-turn coil
- Channel 3 - Strain gauge trace
- Channel 4 - Reference line
- Diagram - Figure 9
- Record - Figure 10 (T10)



**FIGURE 10**  
Magnetic Information Recorded on  
the 5W/54 Water Shot Tests

Tests on the 40mm Gun: A series of four rounds was fired to compare the response of individual strain gauges in a rosette pattern, one of the gauges being tangentially oriented, another longitudinal, and the third at 45 degrees. Simultaneously, the response of a fourth gauge, which was covered with a soft steel magnetic shield, was recorded. The first round of this series was fired with solid propellant for the purpose of comparison. Following this series, a test was conducted to investigate, on the same round, the response of bonded versus unbonded gauges, the effect of wrapping the shielded signal lead around the barrel, the magnetic pickup from a coil around the barrel, and the effect of changes in shape and size of strain gauge grids. Finally, the test of rosette gauges was repeated because the earlier tests had not produced high-frequency oscillations of sufficient magnitude for evaluation. Also on the final test, exploratory variations in bridge gain and amplifier gain were made in order to observe their effect on the amplitude of the high-frequency oscillations. Details of these tests were as follows:

Test 11:

Purpose - To record for reference the signals from the rosette gauges and the magnetically shielded gauge during firing of a solid propellant round in the 40mm liquid propellant gun.

Channel 1 - Longitudinal gauge in rosette

Channel 2 - 45-degree gauge in rosette

Channel 3 - Tangential gauge in rosette

Channel 4 - Steel-covered gauge

Channel 5 - Reference line

Record - Figure 11 (T11)

Remarks - Rosette location - 2940 from muzzle.  
Covered gauge location - 3640 from muzzle.

All gauges bonded to barrel.

All gauges unenergized.

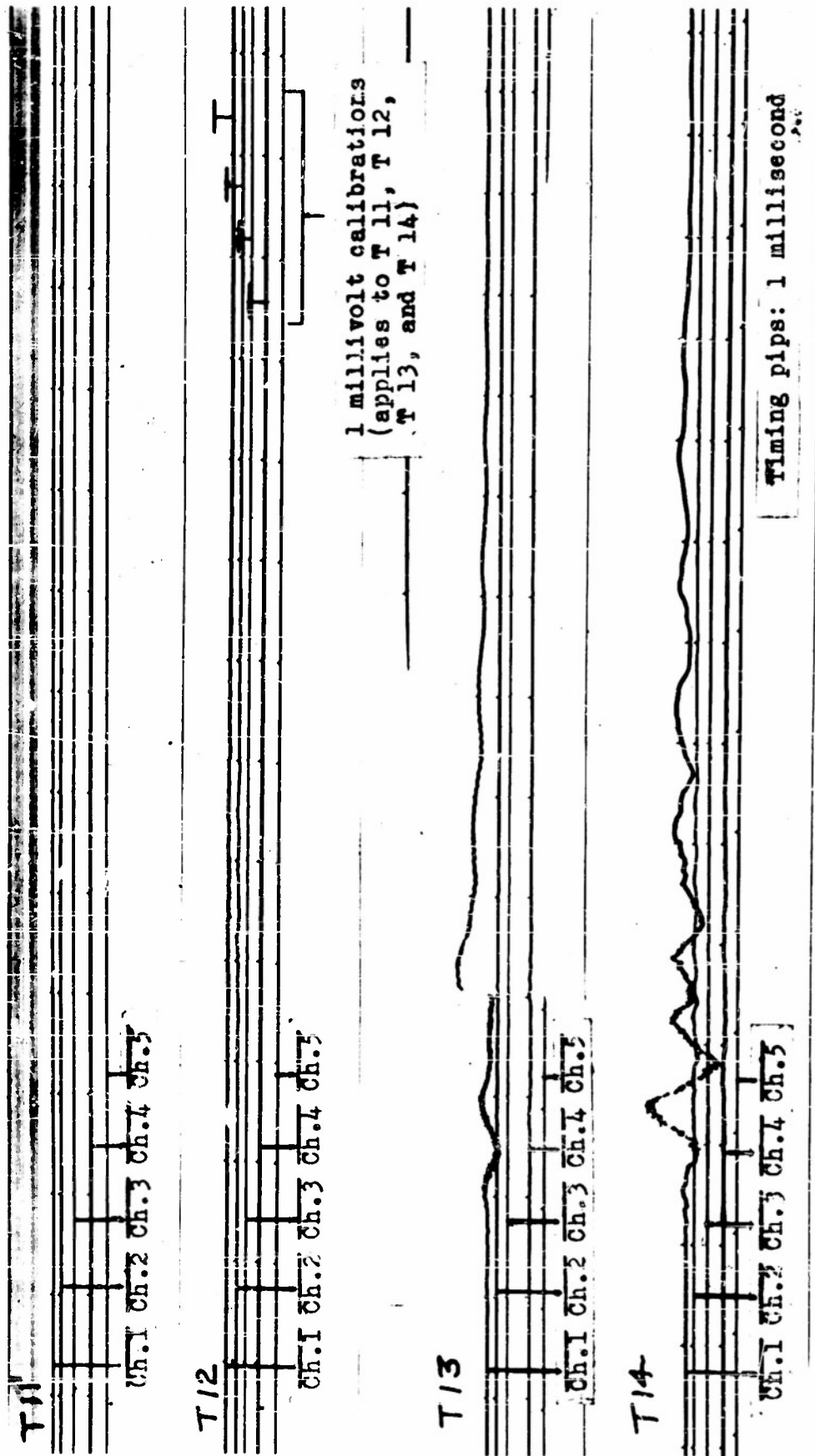


Figure 11

Strain Gage Information Recorded on

The 40 mm Liquid Propellant Gun

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Test 12:

Purpose - To repeat Test 11 using hydrazine-type liquid propellant for comparison.

Channel 1-5 - Same as above

Record - Figure 11 (T12)

Remarks - Conditions same as above except that a liquid propellant was used instead of solid propellant.

Test 13:

Purpose - To record the high-frequency components from an energized tangential gauge for comparison with the signal from the same gauge unenergized obtained on the previous round, and with the signals from other unenergized gauges obtained simultaneously.

Channel 1 - Tangential gauge in rosette (energized)

Channel 2 - 45-degree gauge in rosette

Channel 3 - Longitudinal gauge in rosette

Channel 4 - Steel-covered gauge

Channel 5 - Reference line

Record - Figure 11 (T13)

Remarks - Gauge locations same as Tests 11 and 12.  
All gauges bonded to barrel.  
Gauges unenergized except as noted.

Test 14:

Purpose - To repeat test 13 with the longitudinal rosette gauge energized.

Channel 1 - Longitudinal gauge in rosette (energized)

Channel 2 - 45-degree gauge in rosette

Channel 3 - Tangential gauge in rosette

Channel 4 - Steel-covered gauge

Channel 5 - Reference line

Record - Figure 11 (T14)

Remarks - Gauge locations same as Tests 11-13.  
All gauges bonded to barrel.  
Gauges unenergized except as noted.

Test 15:

Purposes - (a) To compare response of bonded versus unbonded gauges.

(b) To determine the effect of wrapping signal lead around barrel.

(c) To observe the output of a magnetic pickup coil around the barrel.

(d) To compare signals from strain gauges of varying shapes and dimensions.

Channel 1 - Reference line

Channel 2 - Unbonded tangential A-14 gauge 18" from muzzle

Channel 3 - Bonded tangential A-14 gauge 18" from muzzle

- Channel 4 - Same as above, except that the shielded lead from the gauge was wrapped three turns around the barrel
- Channel 5 - Same as Channel 3, except that shielded lead was wrapped one turn around the barrel
- Channel 6 - Magnetic pickup coil - four turns of No. 32 formvar-coated wire cemented to barrel 25475 from muzzle
- Channel 7 - Bonded tangential A-9 strain gauge 2345 from muzzle
- Channel 8 - Bonded tangential C-1 strain gauge 2240 from muzzle
- Channel 9 - Bonded tangential A-14 strain gauge (control) 2240 from muzzle
- Channel 10 - Reference line
- Record - Figure 12 (T15)
- Remarks - None of the gauges were energized.

Test 16:

Purposes - (a) To obtain further data from the unenergized rosette and steel-shielded gauges under the conditions of test 12 (required to verify the almost complete absence of high-frequency oscillations previously observed).

(b) To compare the response of two bonded tangential strain gauges energized at different levels.

(c) To obtain additional data on the output of a magnetic pickup coil around the barrel.

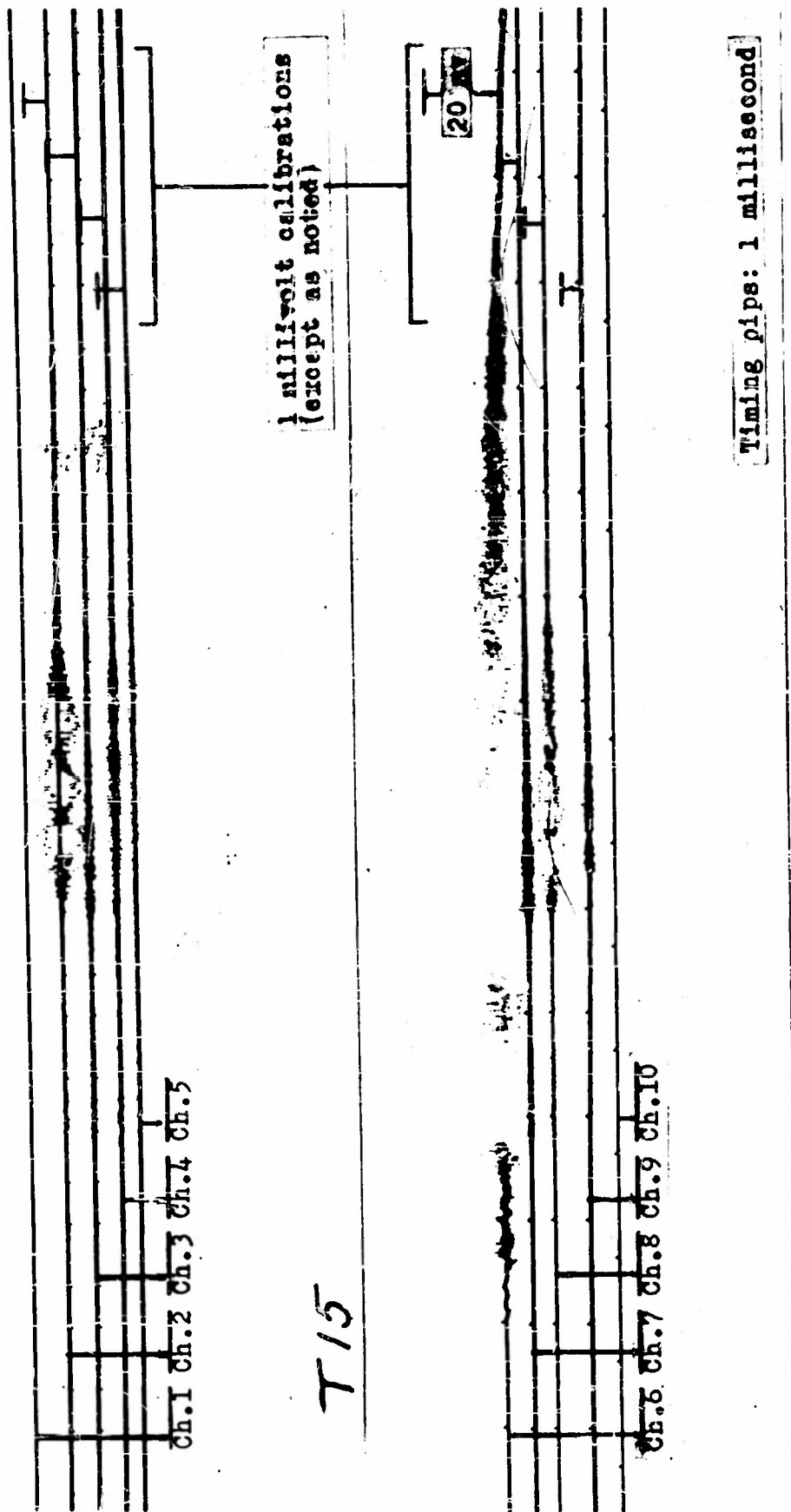


Figure 12  
Strain Gage Information Recorded on  
the 40 mm Liquid Propellant Gun

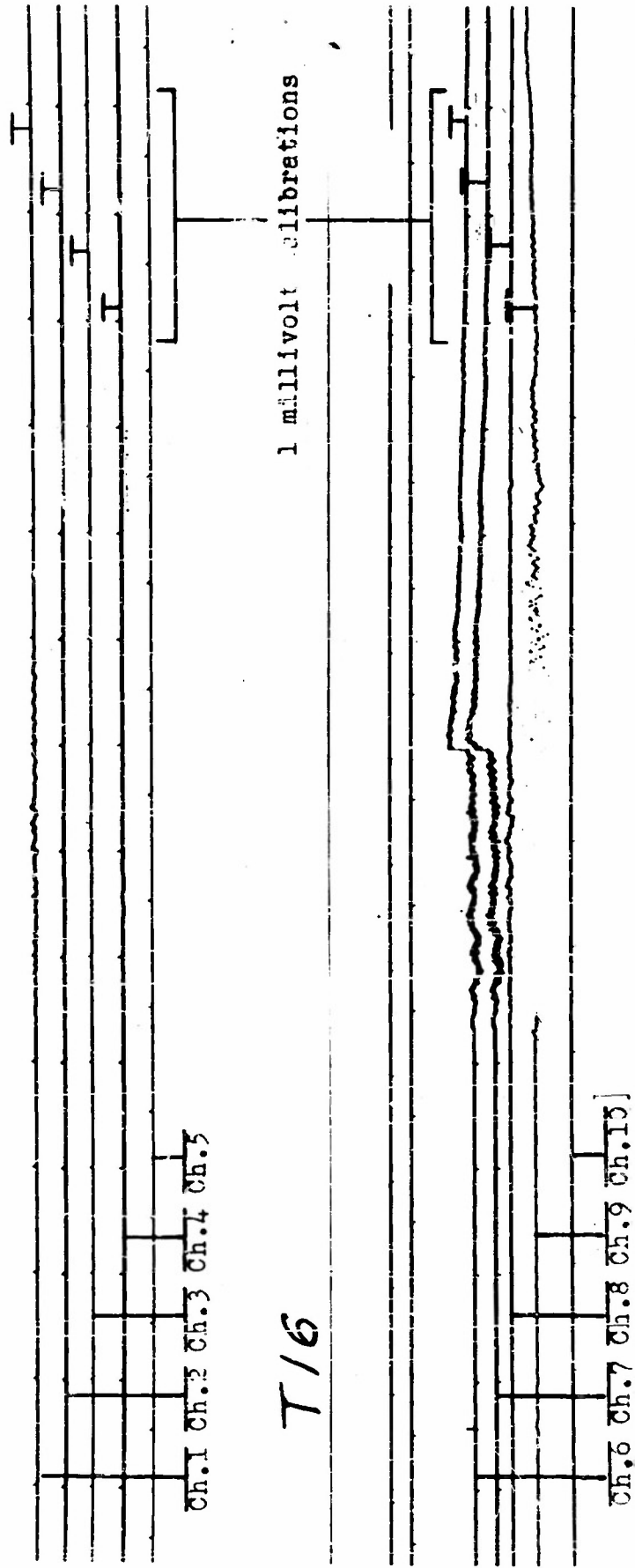
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- Channel 1 - Tangential gauge in rosette
- Channel 2 - 45-degree gauge in rosette
- Channel 3 - Longitudinal gauge in rosette
- Channel 4 - Steel-covered gauge
- Channel 5 - Reference line
- Channel 6 - Energized tangential strain gauge 1640 from muzzle. Amplifier gain reduced to 60% (approximately 15,000 voltage gain). Bridge current increased to yield same overall gain as Channel 7
- Channel 7 - Energized tangential strain gauge 1640 from muzzle. Amplifier gain 100% (approximately 24,000 voltage gain)
- Channel 8 - Unenergized tangential strain gauge 1840 from muzzle. (For comparison with Channel 1.)
- Channel 9 - Magnetic pickup coil four turns of formvar-coated wire cemented to barrel 2545 from muzzle
- Record - Figure 13 (T16)

### RESULTS AND DISCUSSION

The results of the tests described in the preceding section were as follows:

a. High frequency oscillations were found to be present in the signals from unenergized strain gauges on both guns. This effect is shown in the oscillograms of Test No. 6 for the 5"/54 gun firing water slugs, and Test No. 15 for the 40mm liquid propellant gun (Figure 7, T-6 and Figure 12, T-15). It also appears in the oscillograms



Timing pips: 1 millisecond

Figure 13

Strain Gage Information Recorded on  
the 40 mm Liquid Propellant Gun

from unenergized gauges used in Tests Nos. 12, 13, 14 and 16. The presence of these oscillations in the signals from gauges which are not energized indicates that direct mechanical strain is not solely responsible for the disturbance. The fact that the amplitude of the disturbance was only slightly greater when the gauge was energized (compare oscillograms of Tests 5 and 6) indicates that disturbances which are independent of strain form a significant part of the total signal. The effective impedance of the input circuit was 500 ohms in both types of tests. No decrease in the amplitude of oscillation was observed when the system ground was made at the gun, by comparison with prior tests in which the ground was made in the laboratory.

b. Rapidly fluctuating potential differences were found to exist between selected points on the 5"/54 gun and mount, but these showed poor correlation with fluctuations of the strain gauge signal. Tests No. 1 to 4, inclusive, were devoted to the potential tests, the oscillograms of which appear in Figure 6. The "channel 1" traces of the first two tests show the potential between the mount and a point on the barrel. The potential due to the firing current can be clearly distinguished as a series of pulses, each followed by a smooth decay in the region marked "firing key duration". Rapid fluctuations of the traces commence about one millisecond before breaking of the firing contacts, and continue, with diminishing amplitude, to the end of the record. The corresponding strain gauge trace is shown on Channel 2 of record No. T2. Although the high-frequency oscillations on this trace commenced at the same time as the potential oscillations, the wave form appears considerably different in character so that no direct correlation is possible, beyond the fact that the time of commencement of the fluctuations was the same. Record T2 does demonstrate, however, that a properly grounded strain gauge circuit is almost completely insensitive to variations of potential alone. This follows from the fact that the large potential pulses appearing on Channel 1 during firing circuit closure are barely perceptible on Channel 2. Records T3 and T4 show that fluctuating potential differences exist between

two points one inch apart on the barrel. Since similar traces were obtained on these test, using copper and iron leads, respectively, the possibility that any part of the disturbance could have resulted from contact potential between the steel gun and copper leads was ruled out.

c. Physical separation of the strain gauge from the surface of the gun by means of a 0.005 mica spacer reduced the amplitude of high-frequency oscillations appreciably. This is illustrated by a comparison of records T6 and T7, Figure 8. The strain gauge cannot, of course, record true strain when installed in this manner; however, this result may have significance in the light of the results of a later test (sub-paragraph g. below) from which it appears that the thickness of the coat of cement used to bond the gauge to the surface may be a factor in reducing undesired oscillation of the trace.

d. The attempt to reduce the amplitude of the high-frequency oscillations by connecting two gauges so that inphase components would cancel one another was unsuccessful. Referring to Figure 7, Record T8, the oscillogram shows that instead of being reduced, the amplitude of the oscillation was roughly doubled by comparison with the control test, Record T5. This result indicates that the disturbances on the two gauges were out of phase by an appreciable margin, and suggests either that the disturbance causing the oscillations varies in phase over short distances of the order of one inch (the distance between gauge centers) or that it varies with direction. The two gauges used in this test were oriented 90 degrees apart so that the system would be sensitive to directional effects. Further experiments are necessary to establish which of these two effects predominate. During Tests No. 11-14, inclusive, the signals from three strain gauges oriented tangentially and at 45° and 90° from the first, respectively, were recorded simultaneously in an attempt to obtain more data on directional

effect. However, because of the low level of the oscillator, disturbance on all of these tests, the results were inconclusive. These oscillograms are reproduced in Figure 11 as follows:

| <u>Test No.</u> | <u>Channels</u> |
|-----------------|-----------------|
| 11              | 1-3 incl.       |
| 12              | 1-3 incl.       |
| 13              | 2 and 3         |
| 14              | 1 and 3         |

No concrete explanation has yet been offered for the absence of disturbances on certain rounds fired under conditions which have, in past firings, produced disturbances, as was the case in these tests. It is hoped that observations made on routine firings in the future may shed further light on this phenomenon.

e. Solenoid coil tests demonstrated that a rapidly fluctuating magnetic field exists around the barrels during firings of liquid propellants or water slugs. The frequency and wave form of signals from the coils were similar to those of the disturbances observed on the strain gauge traces, but larger in amplitude. Conventional chronograph coils were not capable of reproducing high-frequency oscillation because of their high L-R-C constant. Coils consisting of a few turns of wire wound around the barrel were satisfactory. A control round, using a conventional projectile with solid propellant, also showed a fluctuating magnetic field, but the frequencies of fluctuation were appreciably lower. These data were obtained on Tests No. 9, 10, 15 and 16. Oscillograms appear on Figure 10 (T9 and T10), Figure 12 (T15, Channel 6), and Figure 13 (T16, Channel 9).

f. Tests 13 and 14 demonstrated that the high-frequency disturbance under investigation appears, in part, in the form of mechanical strain. For reasons as yet undetermined, the disturbance was completely absent from the unenergized channels on these tests, and appeared only when the gauges were energized so as to indicate strain. However, examination of the tangential strain (T13, Channel 1) and the axial strain (T14, Channel 1) shows that the component of disturbance appearing as strain is small and does not seriously effect the readability of the strain-time records. The frequency of the disturbance on these tests was 31,000 cps. approximately the same as previously observed.

g. The amplitude of the disturbance on an unbonded strain gauge was found to be appreciably greater than on a bonded gauge. Two adjacent gauges were used on Test 15 under identical conditions with the exception that one was bonded to the gun with a coat of nitrocellulose cement, and the other was tightly taped in contact with the gun. Referring to Figure 12, Channel 2 shows the signal from the unbonded gauge, and Channel 3 that from the bonded gauge. The maximum peak-to-peak amplitudes were 2.1 mv. and 0.45 mv., respectively, a ratio of approximately five to one.

h. Tests of several gauges of different physical dimensions showed small differences in the amplitude of high-frequency oscillation. The three gauges used for dimensional checks during Test 15 were tested under identical conditions on the same round. Results were as follows:

| Channel<br>(Fig. 12) | Gauge<br>Type | Resistance<br>Ohms | Loop<br>L/W* | Active Element |              |                                 | Max. Amplitude<br>of Disturbance<br>MV. peak-to-peak |
|----------------------|---------------|--------------------|--------------|----------------|--------------|---------------------------------|------------------------------------------------------|
|                      |               |                    |              | Length<br>in.  | Width<br>in. | Net<br>Area<br>in. <sup>2</sup> |                                                      |
| 7                    | A-9           | 300                | 192          | 6              | 1/32         | .187                            | 0.7                                                  |
| 8                    | C-1           | 500                | 27           | 1              | 3/16         | .094                            | 1.7                                                  |
| 9                    | A-14          | 500                | 67           | 3/8            | 9/32         | .053                            | 0.5                                                  |

\* Loop L/W is the ratio of length to width of individual loops in the active element.

The efficiency of a gauge as an inductive pickup should decrease with increasing values of L/W, and should increase with increasing values of the net area of the active element. If both of these relations are roughly proportional, the ratio

$$R = \frac{\text{Area}}{L/W}$$

should provide an index of the disturbance amplitude to be expected from magnetic pickup. This was found to be the case, within the limits of precision imposed by variables in gauge design and other factors. The C-1 gauge, for which R is greatest ( $3.48 \times 10^{-3}$ ), produced maximum disturbance. The A-9 and A-14 gauges ( $R = 0.97 \times 10^{-3}$  and  $0.80 \times 10^{-3}$  respectively) followed in descending order.

i. The effectiveness of a soft steel magnetic shield over the gauge, as a means of reducing magnetic pickup, was not confirmed because of the low level of disturbance encountered on the rounds where this shield was tested. Furthermore, the effectiveness of a high versus a low ratio of bridge gain to amplifier gain was not confirmed for the same reason.

j. No significant increase in the recorded disturbance was observed when the signal lead was wrapped one time around the barrel, as compared with a lead brought directly out; however, three turns of the signal lead produced a small but readily discernible difference. (Compare channels 3 and 4, Figure 12.)

#### CONCLUSIONS

On the basis of the tests reported, it is concluded that:

The origin of the high-frequency disturbance observed lies in the violent agitation of the liquid contained within the gun. This agitation is attributed to the random impingement of the high-pressure combustion products on the gas-liquid interface.

The transmission of the disturbances to the gauge positions occurs through the medium of elastic waves in the gun, initiated by the pressures in the agitated liquid.

The disturbance appearing in the signal from the gauge consists of two components, one due to the direct effect of mechanical strain associated with the elastic waves, and the other due to magnetic pickup. The magnetic field causing the latter component is attributed to the magnetostrictive effect of the elastic waves.

#### REFERENCES

- (a) BUORD ltr Rex-PMG:mdn/NP9 of 29 June 1953
- (b) NPG Conf Report No. 1200 of 13 November 1953
- (c) NPG Report No. 1175 of 30 September 1953

APPENDIX A

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Subject: An Investigation of High-Frequency Fluctuations  
of Strain Gauge Signals Associated with the  
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Dahlgren, Virginia 25 June 1954

### ABSTRACT

The occurrence of high-frequency oscillations on the pressure and strain oscillograms from guns using liquid propellants or liquid projectiles was investigated by recording the response of gauges under a variety of conditions during scheduled tests of two guns. The data and results are reported in detail in order to provide background information for planning future investigations of any of the phases which may warrant more intensive study. It was demonstrated that the high-frequency disturbance in the strain gauge signal is due only partially to strain fluctuations, with evidence that the remainder is due to magnetic pickup. A fluctuating magnetic field was shown to exist around the gun during firing. The potential of various points on the surface of the gun also fluctuates rapidly, but appears to have little effect on the signal.

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