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| Dynamic Pressure Generators | Pressure Measurements |
| Electrical Transducers | Projectiles |
| Gages | Weapon Pressure |

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This document describes instrumentation and procedures for measuring pressure within weapon chambers during firing tests.

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US ARMY TEST AND EVALUATION COMMAND
TEST OPERATIONS PROCEDURE

DRSTE-RP-702-102
*Test Operations Procedure 3-2-810 21 January 1982
AD No.

# WEAPON CHAMBER PRESSURE MEASUREMENTS

1. SCOPE. This TOP describes instrumentation and procedures for measuring the pressure within weapon chambers during firing tests. Such measurements provide data for evaluating the design and performance of projectiles, propellants, ignition systems, and cannon.

2. INSTRUMENTATION.

| ITEM | RANGE OF MEASUREMENT | MAXIMUM PERMISSIBLE ERROR OF MEASUREMENT** |
|---|---|---|
| Crusher gages | 14,000 to 799,796.8 kPa<br>(2,000 to 116,000 psi) | ±3% of reading[a] |
| Pressure transducers | pressure to 689,000 kPa<br>(100,000 psi) | ±2% of reading[a] |

[a] The overall precision and accuracy of current measurement systems are estimates that may be revised when an ongoing study is completed.

*This TOP supersedes TOP 3-2-810 dated 5 October 1979.

**Footnote numbers correspond to reference numbers in Appendix D.

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## 3. PREPARATION FOR MEASUREMENTS.

3.1 Selection of Instrumentation. Select the appropriate instrumentation from the following two categories:

a. Crusher gages - used primarily when only peak chamber pressure is required (see Appendix A for description)
b. Electrical pressure transducers - used when pressure time and maximum pressure data are required for weapon chambers or recoil systems (see Appendix B for description)

### 3.2 Crusher Gages.

3.2.1 Cleanliness. This is very important to the reliable and precise performance of these gages. The following specific procedures are to be followed:

a. Scrub gage body in hot soap and water as necessary to remove salt deposits.
b. Disassemble the gage and remove sphere for measurement.
c. Assure piston and springs are removed from the gage body.
d. Place in cleaning trays with all components of each gage kept together.
e. Soak in bore cleaner for at least 4 hours.
f. Place tray of gages in ultrasonic cleaner for at least 30 minutes.
g. Change trichloroethane in ultrasonics cleaner whenever gages appear to be insufficiently clean; recycle dirty gages.
h. Clean new gages received from supply in accordance with step f to remove packing oil and grease.

3.2.2 Assembly.

a. Before assembly, identify and record the copper lot of spheres being used.
b. Visually inspect each component to ensure that it is not defective, e.g., gas wash, evidence of rust and/or heavy pitting. Set aside all suspect gages and return to the appropriate facility for survey, repair, or discard.
c. Be sure that the standard rust-inhibiting oil usually used as a preservative for long-term storage is entirely removed before the gage is used.
d. Assemble gage body, piston, spring, and washer. (Do not interchange gage components with those from other gages.)
e. Ensure that the piston moves freely in the gage body cylinder and that the washer is properly centered by using a brass or wooden dowel. Do not force piston movement.
f. Inspect ball spring, and replace as necessary.
g. Center ball in cap, assemble to gage body, and torque as prescribed.
h. Before using the gages, place them in a sealed container with an efficient desiccant for at least 24 hours to remove all traces of moisture from the gage interiors. Do not seal the gages with silicone grease until after removal from the container.
i. Put silicone grease in the end of the gage body where the piston is exposed, ensuring that all air bubbles are removed from the grease.
j. In preparing the gages for service, assemble them without applying any lubricant to the components, except the piston opening which is sealed with the silicone grease.

3.2.3 Taraging. Calibration of the gage is accomplished by compressing copper spheres on a dynamic pressure generator at pressures ranging from 55,000 kPa (8,000 psi) through 386,000 kPa (56,000 psi). The standard gage used as a reference is a tourmaline piezoelectric transducer. Following calibration, tarage (calibration) tables, which show chamber pressure as a function of the remaining height of the spheres, are prepared, based on data acquired. Tarage tables are also extrapolated to approximately 11,700 kPa (1,700 psi) and to 800,000 kPa (116,000 psi). Separate calibrations must be made for each lot of spheres, and tarage tables issued for each size of piston.

3.2.4 Installation.

a. Placement of gages in the chamber area and uniformity of gage location is of utmost importance in acquiring reliable, precise peak pressure measurements. For bagged, separate-loading propelling charges, the internal crusher gages (see Figure 1) should be placed in the cusp formed by the intersection of the propelling charge outside surface and the cannon chamber inside surface. One gage is placed on either side of the charge as far rearward as possible (preferably at the 10 and 2 o'clock positions), with the piston facing the muzzle. The gages should not be placed under the charge since this raises the base end of the charge and alters the normal alignment between the axis of the charge and the primer hole in the breech. The gages should not be placed behind the charge since this may change the normal standoff between the base of the charge and the breech face.

b. Gages for cased ammunition, both fixed and semifixed, should be placed in the bottom of the cartridge case, with the piston facing the mouth of the case, before the propellant is loaded. When possible, secure the gages to the primer tube to prevent their shifting or exiting the tube. When using gages conditioned to extreme temperatures, simultaneously condition the gages with the propellant charges, and fire the rounds within 5 minutes after removing the propellant charges and gages from the packing container. This will minimize the effect of ambient temperature on gage temperature. NOTE: Never leave crusher gages in a shell case during vibration, rough-handling, loose cargo, or drop tests because of safety reasons and because the gages may break up some of the propellant grains or damage the primer.

c. Mount the external crusher gage (see Figure 2) on the weapon by threading it into a tapped hole in the chamber wall. The bottom of the hole is vented into the chamber.

d. For greater precision and reliability, use at least two crusher gages on all rounds requiring maximum pressure measurements.

e. Record the temperature at which pressure gages are stored, conditioned, or exposed before firing. These gage temperatures are essential in determining pressure corrections from correction tables (available from the Commander, US Army Aberdeen Proving Ground, Maryland 21005).

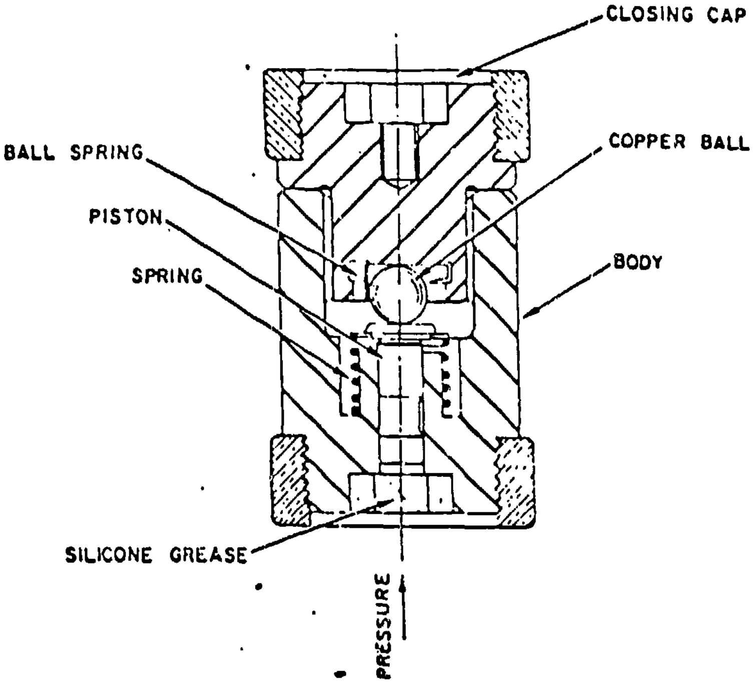

Figure 1. Cross section of internal crusher gage (M11).

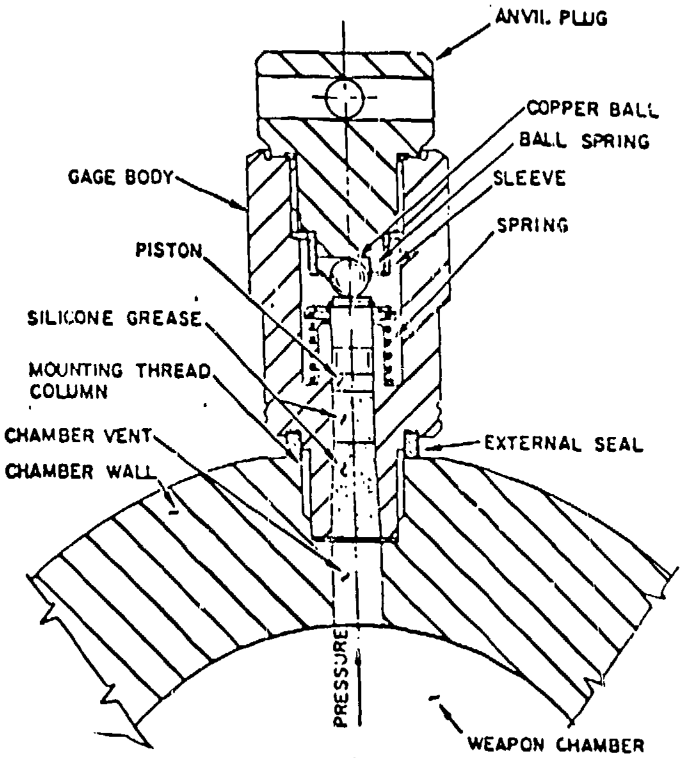

Figure 2. Cross section of external crusher gage (T14).

3.3 Electrical Transducers.

3.3.1 Cleanliness. These gages generally do not require a detailed cleaning process; however, after each firing cycle, the silicone grease must be cleaned from the gage and new silicone grease or silicone-mica mixture repacked at the sensing element.

3.3.2 Assembly. Procedures do not apply to commercially manufactured quartz transducers due to their self-contained welded diaphragm construction. Tourmaline gages occasionally are damaged during testing and therefore must be carefully inspected to determine any damaged points. Particular attention should be directed to APG tourmaline gages used in high pressure (340,000 kPa [50,000 psi] and above) chamber firings due to the tendency of the ground band to fracture.

3.3.3 Transducer Calibration.

a. After storing in desiccant to remove the moisture, calibrate the transducers as follows:

(1) Install the pressure transducer in the dead weight tester. Connect the electrical output lead from the transducer to a charge amplifier, and connect the charge amplifier output to a device for measuring short-duration peak voltage. The amplifier should have a band width exceeding 20 kHz and linearity less than 0.2% full scale.

(2) When pressure from the dead weight tester is applied to or released from the transducer, a charge is developed across the two faces of the crystal element. This charge is fed into the charge amplifier where it is converted to voltage and indicated on the reading/recording system.

(3) The desired pressure is applied to the transducer and the charge amplifier is then shorted by momentarily depressing the ground button on the charge amplifier. The pressure is then quickly released from the transducer by a release valve having a release time in the order of 15 to 20 milliseconds, and the output is read and recorded. When design constraints permit, make sure the quick release valve is as close to the transducer as practical, so that fluid inertia and flow will not cause a delay in pressure reduction. To provide greater precision and accuracy, at least three measurements are taken at each pressure level. An average of the readings is to be used.

(4) The number of calibration steps and the values of the increments are determined by the test requirements. Normally, five to ten points are measured (10 or 20% increments or at increments of 69,000 kPa [10,000 psi] for a 340,000-kPa [50,000-psi] transducer).

(5) The above gage calibration should be traceable to the National Bureau of Standards, Washington, D.C.

b. After calibrating the piezo transducers, store them in desiccators until they are to be used if they are subject to moisture problems. Strain resistance transducers are sealed by the manufacturer, and present no moisture problems.

3.3.4 Installation.

a. Generally, the piezoelectric pressure gages should be situated at the extreme ends of the weapon chamber space available to the propelling charge.

This will put one gage in the breech face and the other in the sidewall of the chamber just behind the base of the projectile. Experience has shown that this placement will generally prevent blockage of the gage hole with parts of the charge components, thus ensuring that correct values of initial negative pressure gradient are recorded. The variation in the projectile seating distance and length of boattail in the various projectile families while in the rest position make selection of one forward gage position a compromise. For example, locating the forward pressure port at 95.8 cm (37.7 inches) from the rear face of the 155-mm M199 tube places the port forward from the base and over the boattail for the M483 projectile.

b. Mounting the gage is very important if accurate, precise pressure measurements are to be obtained. Determine the exact position at the breech where the gage will be mounted. Drilling and tapping are not to be done by hand but should be performed in such a manner to ensure a correct, precise orientation and seating of the gage. All drilling and tapping procedures are to follow applicable appropriate ASTM standards. Following drilling and tapping, clean the mounting cavity with degreaser spray, and inspect the gage seating surface for burrs, scratches, or other damage that would affect sealing. Reject damaged gages. Clean the gage threads and apply a light coat of grease. Check the mica-silicone packing and asbestos disc on the APG tourmaline gage. Seat gages carefully to avoid misthreading. Tighten to a torque of 95 ±7 newton meters (70 ±5 pound-force feet). Follow the manufacturer's recommendations for installing commercial gages.

c. For cannon chamber pressure measurements, use two pressure transducers to measure pressure-time histories at each end of the chamber to detect pressure abnormalities described in Appendix B.

d. Use a suitable low-noise coaxial cable to connect the transducer output to the signal conditioning and recording equipment. (Figure 3 shows a typical instrumentation setup.) Be sure that ringnuts on all cable connectors are tight to ensure good connection.

The signal-conditioning equipment should consist of amplifiers meeting the following minimum specifications:

(1) Charge amplifier:
Band width: -3 dB at 80 kHz
Linearity: 0.1% full scale

(2) DC amplifier, wideband differential instrumentation:
Band width: -3 dB at 100 kHz
Common mode rejection: 120 dB
Input impedance: 10 MΩ
Linearity: 0.1% full scale

e. Perform a field calibration of the electrical measuring system to ensure the validity of the relationship of pressure to electrical output using the known charge or resistance methods.

f. Protect the installed transducers and cable connections against inclement weather because moisture within the transducer or connector affects its electrical characteristics.

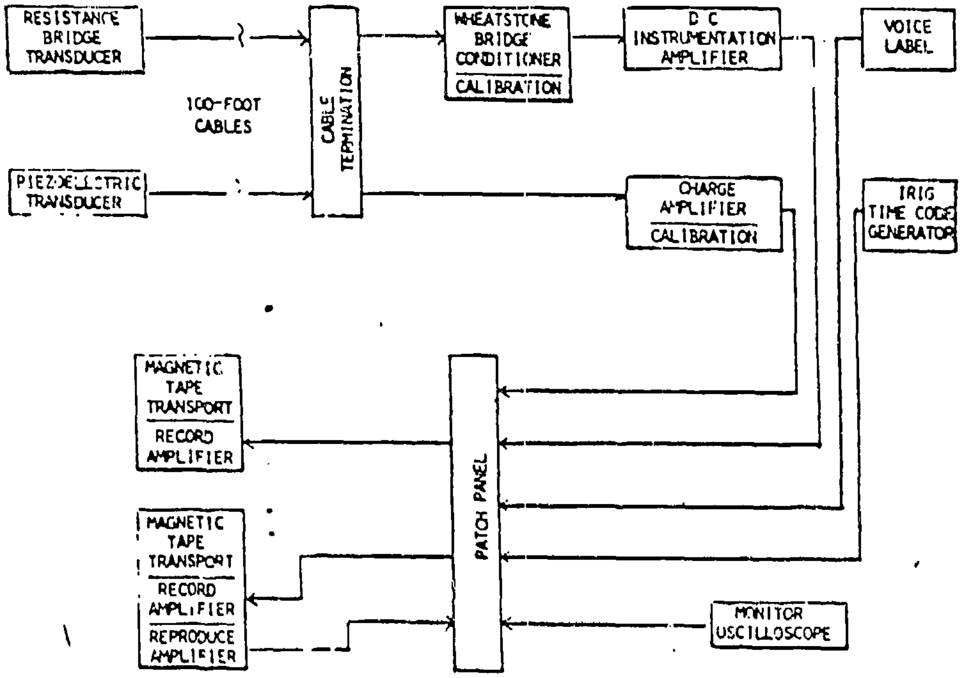

Figure 3. Typical instrumentation setup.

## 4. MEASUREMENT CONTROLS.

a. Assemble and disassemble each type of crusher gage according to the appropriate SOP to ensure the reliability and reproducibility of the crusher gage pressure measurements.

b. Calibrate electrical transducers in accordance with paragraph 3.3.3 before and after each test. Depending upon the type of gage and measurement to be made, additional calibrations may be required at intermediate intervals during the test to maintain measurement reliability. These intervals should be based on calibration history and field experience.

c. Handle calibrated transducers carefully to avoid incurring damage that might change the calibration factor.

## 5. PRESSURE MEASUREMENT.

Fire the weapon to obtain pressure measurements as prescribed by the particular firing program and perform the following after-fire procedures according to the type of instrumentation used.

### 5.1 Crusher Gages.

a. Retrieve the internal crusher gages from inside the weapon or the ground in front of the weapon, or remove the externally mounted gages, as applicable.

Do not use bare hands to handle the gages after firing since the gage body becomes hot and may be covered with corrosive residue.

b. When a gage is retrieved, immediately scrub it with clean water and wipe it completely dry before returning it to the gage room for disassembly. If not cleaned with water, gages may be immersed in bore cleaner to prevent corrosion before being returned to the gage room. If gages are opened at the firing position to make pressure readings, they should be partially reassembled as soon as possible and coated with bore cleaner. Gage components exposed to air too long after a firing tend to rust rapidly.

c. When a gage is opened, inspect the closing threads, closing plugs, ball, piston and cylinder for evidence of gas leakage and erosion. (Leaks and erosion that occur in a gage may not greatly affect recorded pressure for a particular round, but the accumulated damage over a number of rounds may ruin primary gage components. When a leak occurs, there is always evidence in the form of a propellant residue within the gage housing.)

(1) To trace a leakage path to its source, note whether the closing plug surfaces, piston, or piston vent walls are blackened.

(2) Record any evidence of gas leakage in the pressure data tabulations.

d. Remove the piston and crusher spheres from the gage bodies. It is imperative that the individual gage components be kept together for reassembly in the same gage housing. For thorough cleaning, the piston must be completely removed from the gage. Lack of proper cleaning is one of the most common causes of gage problems.

(1) Before measuring a used crusher sphere, wipe the compression surfaces lightly on surface of a sheet of hard-finish paper to remove dirt.

(2) Examine the compression surfaces to ensure that they are flat. When the gage is subjected to pressure exceeding its design limits, a ridge may be formed around the compression surface and may thus prevent obtainment of an accurate measurement.

(3) Examine the brass sleeve for the anvil plug used in T13, T14, and T15 gages to be certain that it is properly seated and not deformed. Deformed or loose sleeves should be replaced.

e. Measure the compressed heights of the copper spheres at 21° C (70° F) and enter them in the gage record by gage number. For this measurement, use a micrometer with the smallest scale interval no larger than 0.0025 mm (0.0001 inch) and with anvils of sufficient surface area to completely include the end faces of any compressed sphere being measured.

## 5.2 Electrical Transducers.

a. Never disassemble transducers in the field or allow unauthorized personnel to disassemble them.

b. Gage seals for commercial piezoelectric gages should always be replaced when the gage is removed.

c. Renew the materials used to protect the transducer's pressure-sensing element from thermal transients (asbestos disc, silicone grease, luting compound, modeling clay, etc.) at sufficient intervals to prevent damage to the transducers and avoid errors in pressure data. Base these intervals on the design of the transducer and field experience.

d. Retain transducer output records for data reduction.

## 6. DATA REDUCTION AND PRESENTATION.

### 6.1 Crusher Gages.

a. After testing and removal, measuring the deformation of the copper sphere is a very important and exacting operation. Follow the ensuing procedure carefully:

(1) Make sure the copper is at approximately 21° C.

(2) Exercise the electronic micrometer several times to minimize drift by sliding the spindle the full length of travel. Or, if a mechanical micrometer is used, be sure that the rachet type is used.

(3) Make sure the anvil and spindle mating surfaces are clean by wiping, using hard white paper. This is accomplished by closing the spindle against the anvil and paper and pulling the paper through the anvil and spindle several times.

(4) Clean carbon from the sphere by wiping on hard white paper before measurement.

(5) Make sure the micrometer is zeroed before measurement.

(6) Check measurement against proper tarage tables to acquire pressure reading.

(7) Set aside gages and spheres having pressure differences exceeding 5% variation between gage pairs for further evaluation and confirmation of findings. NOTE: All temperature-conditioned gages not used as originally scheduled should be disassembled and recleaned before use.

b. For each round fired for chamber pressure measurement, use the measured height of the crusher gage sphere (corrected for temperature, if applicable) to determine the chamber pressure from the appropriate tarage table (see Appendix A).

c. Before placement and firing, enter the round and gage numbers on the test director's field data sheet, together with the other variables of the specific test. After firing, remove the gages and store in racks for measurement. Data to be recorded in the pressure gage measurements are:

(1) Test director's name
(2) Weapon number
(3) Date of firing test
(4) Model number and serial number of copper crusher gage
(5) Round number
(6) Copper crusher gage lot number
(7) Conditioning temperature
(8) Individual gage data:
    Copper sphere measurements
    Temperature correction, if appropriate
(9) Measured chamber pressure

### 6.2 Electrical Transducers.

a. At the instant of firing and ignition, the buildup of chamber pressure is registered on the transducer sensing element. The sensing element transduces the pressure into electrical signals that are recorded along with calibration data. Subsequent data-reduction programs can compare pressure history output to calibration data to obtain true pressures.

b. The pressure output may take the form of a graphical plot and/or a numerical printout. Visual examination can be made of the plot histories to ascertain any questionable data. The following output-type print format may be used to present the pressure data:

| | Chamber Pressure, kPa | | | Differential Pressure, kPa | | |
|---|---|---|---|---|---|---|
| (Milliseconds) | Pos 1 | Pos 2 | Pos N | 2-1 | N-1 | N-2 |
| 0.0 | | | | | | |
| 0.05 | | | | | | |
| 0.10 | | | | | | |
| 0.15 | | | | | | |
| 0.20 | | | | | | |
| 0.25 | | | | | | |
| etc. | | | | | | |
| 25.0 | | | | | | |

The differential pressure column can be examined to determine if there is an initial negative differential pressure resulting between the start of propellant burning and the time of maximum chamber pressure. When using two gages for differential pressure measurements, take care to ensure that the two gage systems are both linear and uniform before summation in the differential amplifier.

c. Upon removal of the gage, recalibrate it in accordance with the procedure specified in 3.3.3. The pressure ranges are to be the same as those covered in the initial calibration of the gage before usage in the weapon. This is to verify that the sensitivity of the gage has not changed. Following calibration and cleaning, the gage is again ready for use.

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## APPENDIX A
## CRUSHER GAGES

Peak chamber pressures are usually measured with a mechanical crusher gage that consists of a housing, a piston, a crushable element (sphere), and an anvil. The piston of the gage is exposed to the weapon chamber. The chamber pressure moves the piston which compresses and slightly flattens the crusher sphere permanently. Chamber pressure as a function of the final height of the crusher sphere is obtained by entering a tarage (calibration) table that lists chamber pressure that corresponds to a measured decrease in crusher sphere height as a result of firing. This table is prepared for each lot of crusher spheres by subjecting samples of the spheres to a representative range of deforming loads using dynamic pressure generators (Appendix C) that simulate firing conditions. Four calibrated tourmaline piezoelectric pressure transducers are used to monitor and record the pressure transients developed in the fluid chamber of the generators. The average load (average pressure of the tourmaline transducers times the crusher gage piston area) is plotted against the final height of the crusher spheres to form a curve from which a tarage table is computed.

Crusher gages may be of the internal or external type (see Figures 1 and 2). The internal type is used for proof testing production weapons since these weapons cannot be drilled and tapped to accept external crusher gages or electrical pressure transducers. (Internal gages are also used for production and developmental testing of ammunition.) Both types of crusher gages are available in various sizes and pressure ranges (Table A-1). Materials other than copper may be used for the crusher spheres to expand their measurement ranges: aluminum to extend the lower limits and ingot iron to extend the upper limits.[2]

Table A-1
Approximate Range of Pressure Measurement of Crusher Gages

| Gage Model | Piston Area, (sq cm) | Type | Copper Spheres Usable Range (kPa) | Aluminum Spheres Usable Range (kPa) | Ingot Iron Spheres Usable Range (kPa) |
|---|---|---|---|---|---|
| T18 | .645 | Internal | 13,789.6 to | 5,515.8 to | |
| T13 | .645 | External | 131,001.2 | 53,090 | |
| T17 | .43 | Internal | 20,684.4 to | 8,273.76 to | |
| | | | 137,896 | 75,842.8 | |
| T19 | .215 | Internal | 41,368.8 to | 16,547.5 to | 86,185 to |
| T14 | .215 | External | 399,898.4 | 158,580.4 | 503,320.4[a] |
| M11(T20) | .108 | Internal | 82,737.6 to | | 172,370 to |
| T15 | .108 | External | 482,636 | | 1,006,640.8[a] |

[a] Upper limits extrapolated from laboratory tests that do not exceed 482,636 kPa (70,000 psi).

## APPENDIX B
## ELECTRICAL TRANSDUCERS

Pressure versus time data for interior ballistic studies of weapon systems are obtained using electrical pressure transducers such as the piezoelectric or strain resistance type. Piezoelectric pressure transducers employ the properties of tourmaline, quartz, and similar crystals to generate a charge proportional to an applied pressure, whereas the strain resistance pressure transducers use applied pressure to vary the electrical resistance of a bridge circuit that becomes unbalanced to produce a signal proportional to the applied pressure. The signals produced by these transducers are amplified and recorded on magnetic tape along with a timing signal on a second channel. A time-expanded plot of the pressure-time data is obtained by playing back the recorded signals at a reduced speed to a galvanometer oscillograph. The analog tape may also be digitized for computer processing. The types of transducers most frequently used are described below.

B1. Tourmaline Pressure Transducers. Tourmaline piezoelectric pressure transducers (Figure B-1) are often used when pressure-time data are required in the ballistic testing of cannon. The transducers in use at Aberdeen Proving Ground are two sizes: 3.81 cm (1.5 in) long by 2.54 cm in diameter, and approximately 10 cm (4 in) long by 2.86 cm (1.125 in) in diameter. They have a relatively high natural frequency, a short response time, and a capacity greater than 689,000 kPa (100,000 psi). The sensing element consists of a Z-cut tourmaline crystal placed in a suitable steel body. The cavity that surrounds the sensing element is completely filled with a silicone grease. Tourmaline crystals, unlike quartz crystals, are isostatically sensitive to pressure. This isostatic sensitivity is an advantage because it eliminates the need for a piston (or similar mechanism for the application of pressure to certain crystal faces); the pressure is transmitted by the silicone grease directly to the tourmaline sensing element.

The pressure transducers in use at Yuma Proving Ground also use the tourmaline crystal; however, due to a unique assembly procedure involving encapsulation of the crystal, the transducer is much more rugged and can be adapted to a wider variety of applications, including small arms weapons in which miniaturization of the transducer is required. Figure B-2 shows one of these transducers (Model T8) which is used in larger weapons. The external dimensions are the same as the APG gage shown in Figure B-1. The pressure transducer (Part No. 7, Fig. B-2) in the model T8 gage assembly can be electrically insulated from the weapon, which reduces ground loop problems. This gage assembly also has a needle valve (Part No. 5, Fig. B-2) which makes it possible to replenish the grease around the pressure-sensing element without having to remove the gage from the weapon, and no other thermal shielding materials are required. Another type of YPG tourmaline pressure transducer (Model 50E and 100E) is shown in Figure B-3. This transducer is considerably smaller than model T8, and was originally designed for use in the smaller weapons such as the 30mm gun shown. The assembly in Figure B-3 also includes a needle valve for replenishing the grease around the pressure-sensing element. It is not, however, an integral part of the transducer.

For cannon chamber pressure measurements, two pressure transducers are used to measure the pressure-time histories at different locations within the chamber (Figure B-4) so as to detect pressure abnormalities. Pressure is measured at each end of the chamber and if possible at the middle. With normal propellant burning, the instantaneous pressure gradient in the chamber is always positive; i.e., the pressure at the breech end is greater than the pressure farther forward, particularly just behind the projectile. If pressure waves are generated during propellant burning, reversals in this gradient (i.e., pressure at the projectile base greater than at the breech) may appear. These reverse pressure gradients are due to localized improper ignition and propellant burning which introduce wave fronts or oscillations within the chamber. If the reverse differential is great enough, a dangerous condition exists that could cause the breech to blow out. Low amplitude pressure waves can cause small changes in the absolute values of muzzle velocity and chamber pressure and can affect muzzle velocity reproducibility.

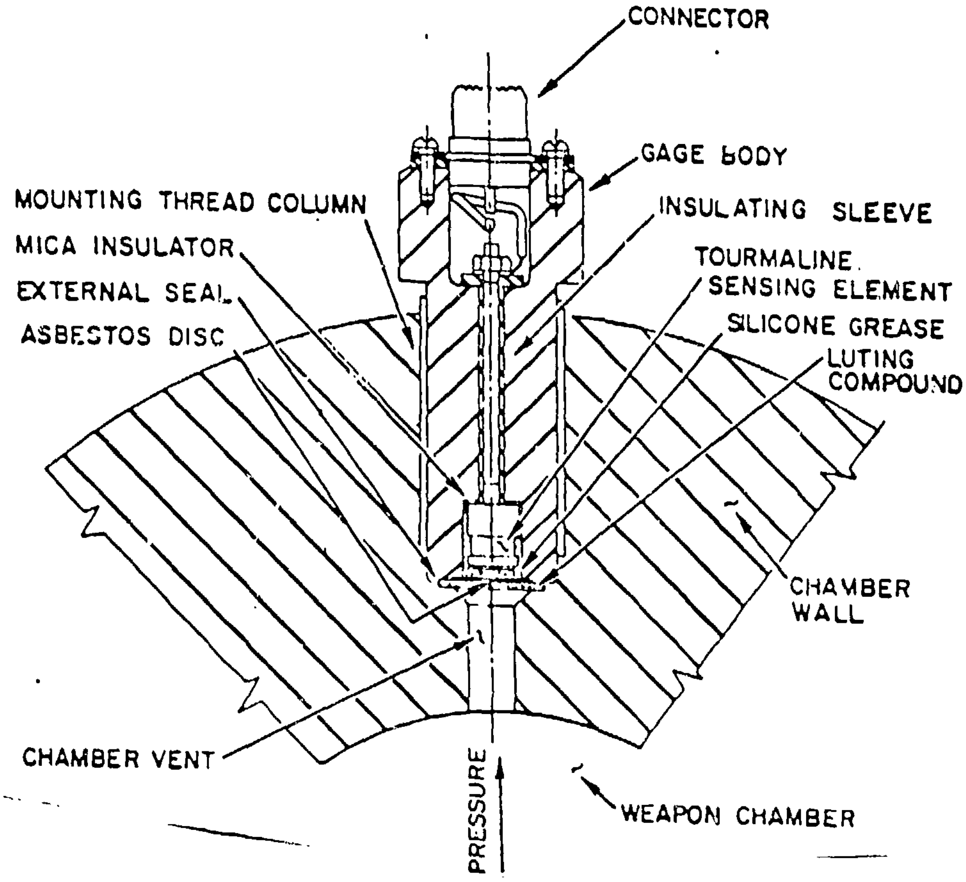

Figure B-1. Cross-section of piezoelectric (tourmaline) pressure transducer (external type)

For a quick-look capability, transducer outputs are fed to a differential amplifier and recorded on magnetic tape. Since tourmaline transducers are not linear, it is important that the transducers selected have matching or similar calibration factors. For a precise quantification of the pressure differential magnitude within the chamber, a digital computer is used to process each transducer output channel independently and calculate the instantaneous differences between the transducer outputs (relative to the breech end) at common points in time (Figure B-5). Negative difference values indicate reverse pressure gradients ($-\Delta P$). For each test condition, the maximum instantaneous negative differential ($-\Delta P$) is determined for each round, and the average and standard deviations for all the rounds fired are computed. For purposes of these calculations, a zero value is used for $-\Delta P$ when a round does not show a negative

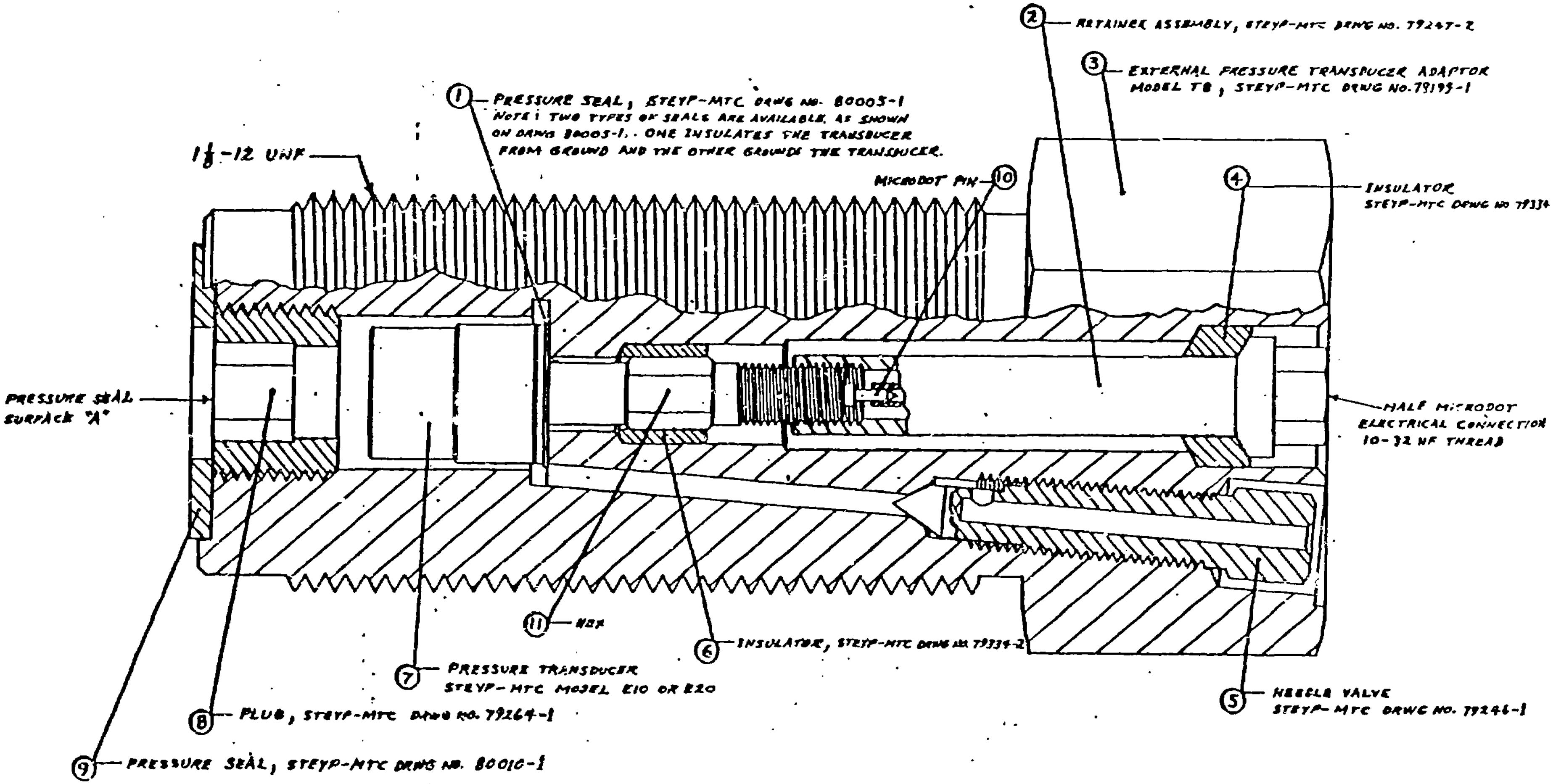① PRESSURE SEAL, STEYP-MTC DRWG NO. 80005-1
NOTE: TWO TYPES OF SEALS ARE AVAILABLE, AS SHOWN ON DRWG 80005-1. ONE INSULATES THE TRANSDUCER FROM GROUND AND THE OTHER GROUNDS THE TRANSDUCER.
② RETAINER ASSEMBLY, STEYP-MTC DRWG NO. 79247-2
③ EXTERNAL PRESSURE TRANSDUCER ADAPTOR MODEL T8, STEYP-MTC DRWG NO. 79195-1
④ INSULATOR STEYP-MTC DRWG NO 79334-1
⑤ NEEDLE VALVE STEYP-MTC DRWG NO. 79246-1
⑥ INSULATOR, STEYP-MTC DRWG NO. 79334-2
⑦ PRESSURE TRANSDUCER STEYP-MTC MODEL E10 OR E20
⑧ PLUG, STEYP-MTC DRWG NO. 79264-1
⑨ PRESSURE SEAL, STEYP-MTC DRWG NO. 80010-1
⑩ MICRODOT PIN
⑪ NUT
1 1/8-12 UNF
PRESSURE SEAL SURFACE "A"
HALF MICRODOT ELECTRICAL CONNECTION 10-32 NF THREAD

Figure B-2.

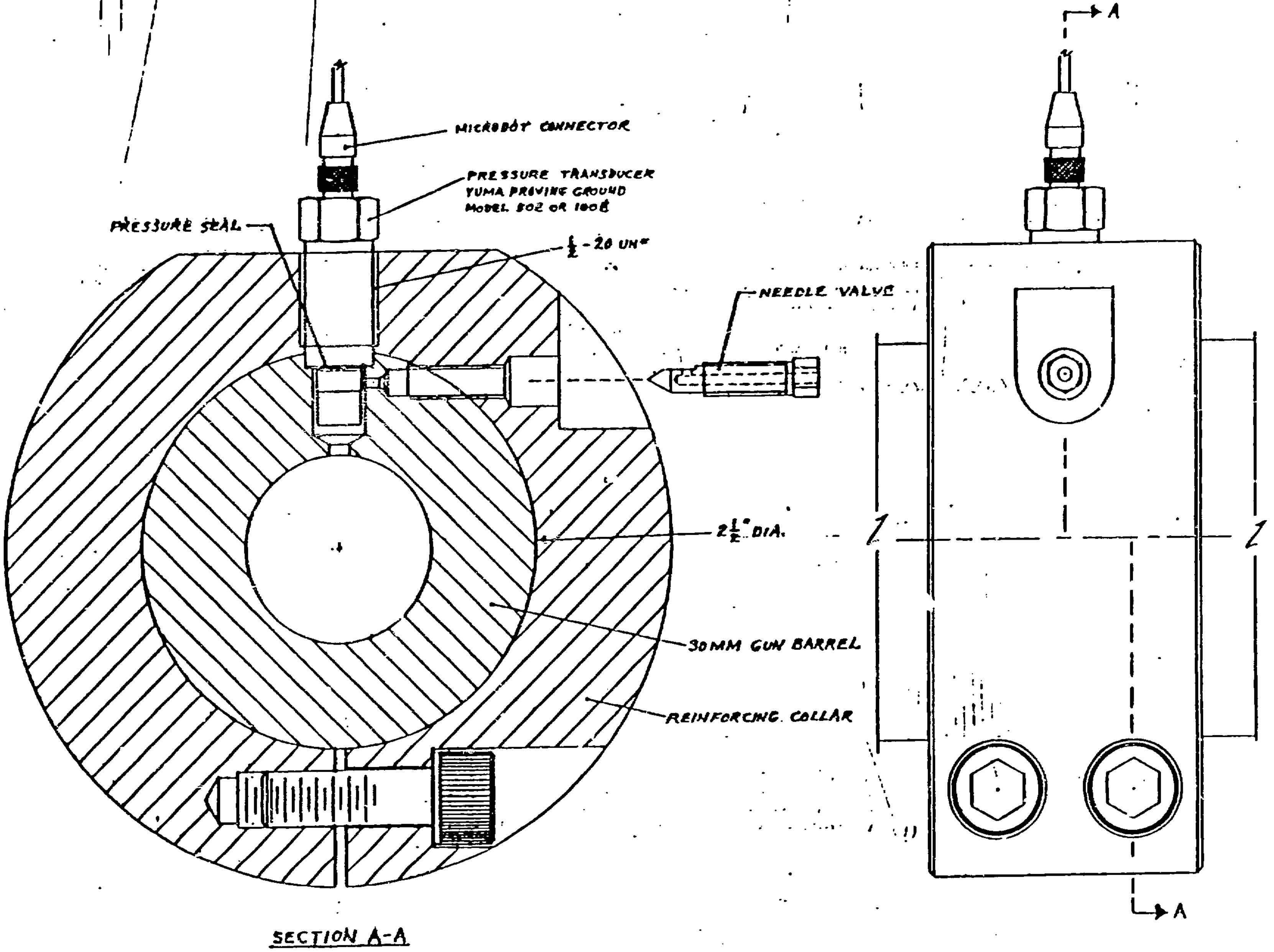
MICROBOT CONNECTOR
PRESSURE TRANSDUCER
YUMA PROVING GROUND
MODEL 802 OR 100B
PRESSURE SEAL
½-20 UN"
NEEDLE VALVE
2½" DIA.
30MM GUN BARREL
REINFORCING COLLAR
A
A
SECTION A-A

Figure B-3.

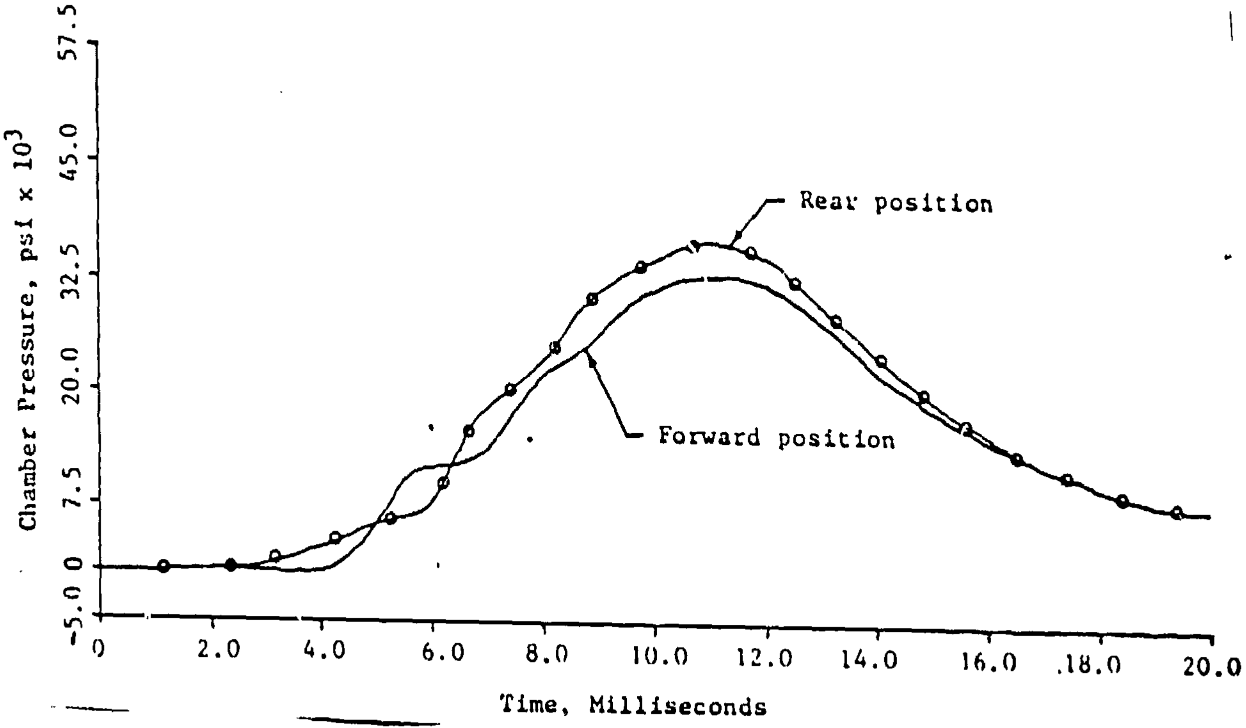

Figure B-4. Pressure-time history at different locations.

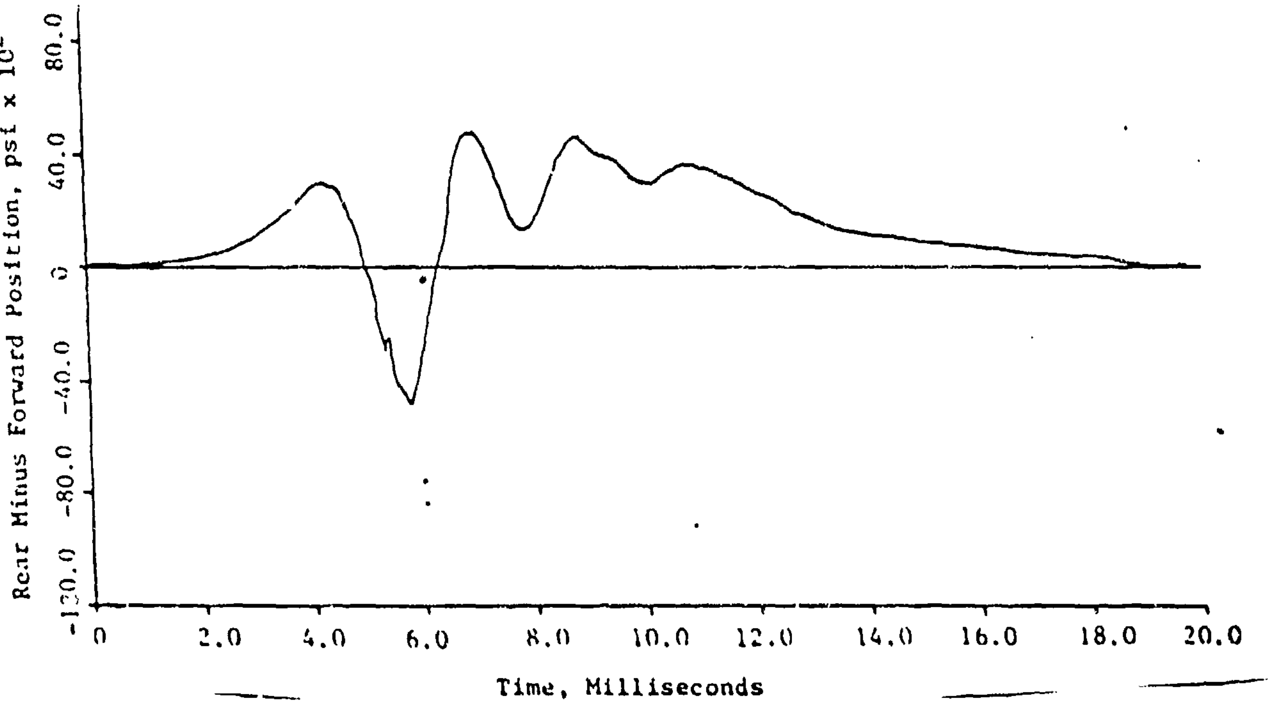

Figure B-5. Pressure differential.

pressure gradient. A more detailed discussion of negative differential pressure is contained in TOP 4-2-504.[3]

B2. Commercial Quartz Pressure Transducers. These transducers are frequently used for ballistic pressure measurement. They are typically 1.9 cm (.75 in) long by 0.95 cm (0.375 in) in diameter, with capacities ranging to 827 mPa (120 kpsi). Some versions have internal impedance converters providing a low impedance/voltage output, rather than the conventional high impedance charge output.

B3. Strain Resistance Pressure Transducers. Strain resistance pressure transducers such as the CEC* pressure transducer (Figure B-6) and the BRL minihat gage (Figures B-7, B-8, and B-9) are generally used in ballistic tests of rocket motors and for measuring the transient pressures produced in recoil and counter-recoil systems. The sensing element of the CEC-type transducer is a strain-gaged tube whose active end is covered by a catenary diaphragm. Two strain gage windings one longitudinal and the other circumferential, are bonded to the tube. When pressure is applied to the outside of the diaphragm, the strain tube is compressed along its axis and expanded around its circumference. This decreases the length of the longitudinal winding, thus decreasing its resistance, and increases the length of the circumferential winding, thus increasing its resistance. The windings form two legs of a Wheatstone bridge circuit. Since both windings are at about the same temperature due to intimate mechanical contact, resistance changes caused by temperature variations are essentially canceled.

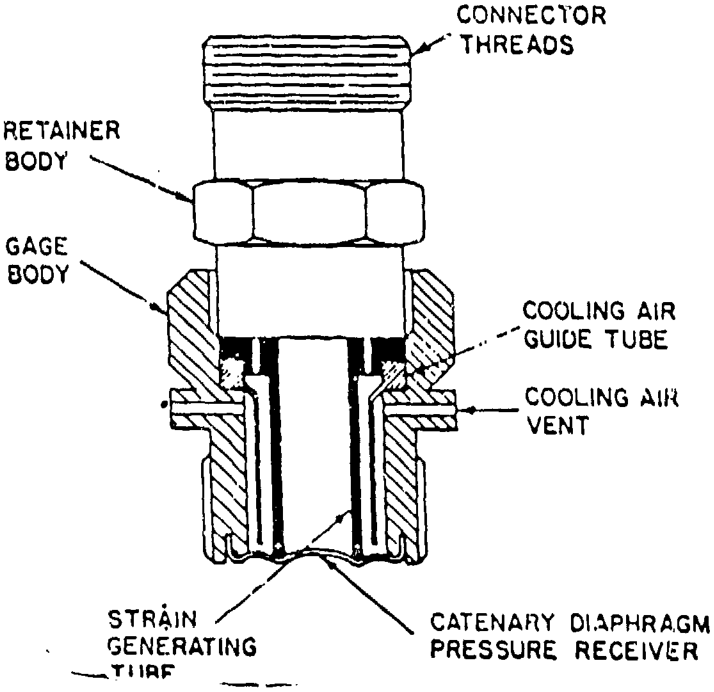

Figure B-6. Cross-section of a typical strain resistance wire transducer

*Term derived from the original manufacturer, and commonly used to distinguish this transducer from other types of strain resistance transducers.

The minihat is the latest product of more than 40 years of pressure transducer development and experimentation at BRL. The gage, known as the "hat" due to its resembling a derby, features a strain sensing element inside a cylindrical cavity. Pressure on the outside of the structure results in strain on the inner surface. For a given pressure, there is greater strain on the inner surface than on the outer. Therefore, it is possible to make a smaller, higher frequency gage with the sensing element on the inside of a cylinder. The hoop strain is measured by suitably mounted foil-type strain gages. The hat gage is mounted inside cartridge cases and on spindles of large caliber weapons. The minihat gage was developed to achieve the miniaturization required for use in small arms and for downbore gages in the walls of large caliber guns. In the minihat gage, the principle of externally applied pressure measured as strain on the inner wall of a hollow structure is maintained, but the cylindrical shape is replaced with a hollow conical member with a constant wall ratio along the sensing area.

The originators of the thick wall conical sensing element concept felt that by analogy with thick wall cylinder theory, given a constant wall ratio and a fixed external pressure on the outer surface of the cone, there should be a constant hoop strain along the inner cone surface. A change in the external pressure will result in a proportional change in hoop strain at the inner surface. By contouring a strain patch so as to follow parallel hoop strain contours along the inner surface (Figure B-8), a well-behaved gage of reasonable linearity characteristics should be achieved. The minihat transducer has been used successfully for more than 15 years. Output and response characteristics (linearity and hysteresis) are at least as good as the best commercial ballistic pressure transducers. The modified minihat gage (Figure B-9) is designed for pressure in the 1000-mPa (145-kpsi) range.

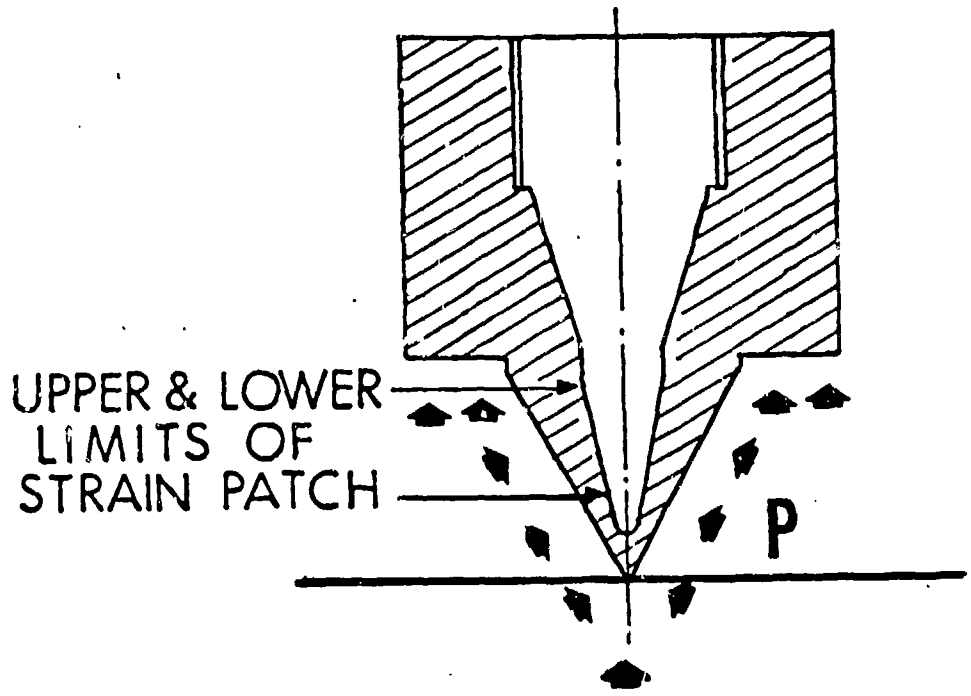

Figure B-7 Schematic of minihat pressure gage before modification for 145K psi (1000-MPa) use (pressure loading, P, indicated).

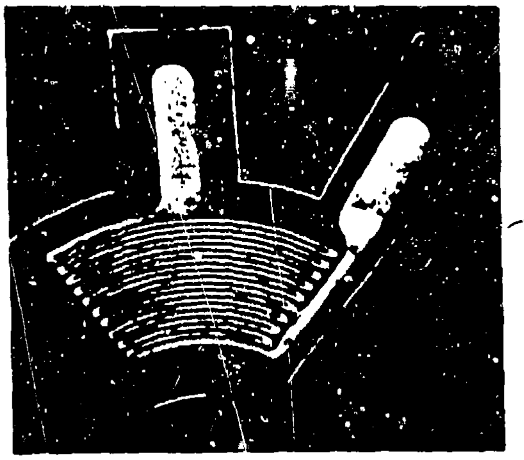

Figure B-8 Photograph of strain patch used in minihat gage.

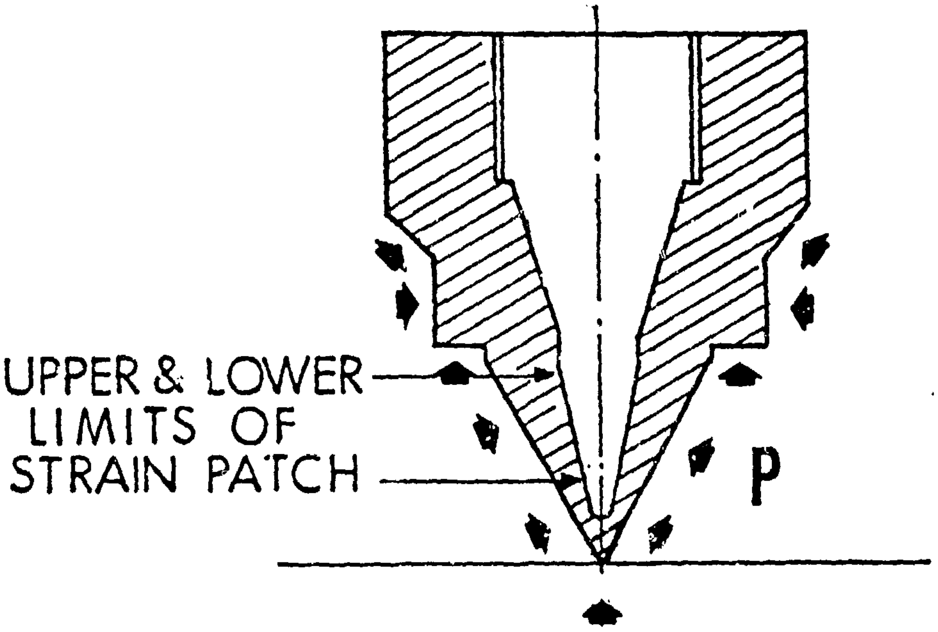

Figure B-9 Schematic of minihat gage modified for 145K psi (1000-MPa) use (pressure loading, P, indicated).

# APPENDIX C
# DYNAMIC PRESSURE GENERATORS*

C1. Drop Weight Pressure Generator. This consists of a dual track 2.44 m (8 ft) high, a movable carriage, and a hydraulic chamber at the base of the dual track. This machine is mounted on a solid concrete base 86.4 cm (34 in) deep by 101.6 cm (40 in) wide by 88.9 cm (35 in) high. Of the total height (88.9 cm), 45.7 cm (18 in) are below floor level and 43.2 cm (17 in) are above. The falling mass, which consists of a suitable carriage and weights, can be varied from 2.72 to 29.48 kg (6 to 65 lb).

The hydraulic system consists of a cylindrically shaped fluid chamber that contains a piston vent and close-fitting piston. The fluid chamber contains 10 equally spaced tapped holes located radially around its outer circumference in a plane normal to the direction of piston motion. The chamber can accommodate any combination of 10 electrical pressure transducers and mechanical crusher gages.

The movable carriage has been provided with several safety features to prevent the carriage's accidentally falling. It also has a device that stops the carriage after it has rebound upward from the chamber, thus preventing it from striking the chamber piston again.

The drop-weight pressure generator provides semi-sinusoidal pressure pulses of variable amplitudes from 3,400 to 137,000 kPa (500 to 20,000 psi) at pulse widths of 1 to 12 milliseconds.

C2. Hydrodynamic Pressure Generator. This consists essentially of two major elements, the energy source and the high-pressure hydraulic system. The energy source consists of a controlled air reservoir, a horizontal acceleration tube, and a large mass or slug driven in the acceleration tube. The high-pressure hydraulic system consists of an oil-filled chamber containing a piston vent and a close-fitting piston. Three different chamber geometries are used to provide ranges of pressure amplitude from 97,000 to 507,000 kPa (14,000 to 75,000 psi) and pulse widths of 3.25, 6.6, and 25 milliseconds.

Each of the three chambers can accommodate four external electrical pressure transducers and four to six US internal-type crusher gages that are exposed simultaneously to the same pressure transients. This permits direct comparisons of the gages and further permits observation of the ability of electrical pressure transducers to trace and reproduce the developed pressure transients.

C3. Dynamic Pressure Generating System. This consists of a pressure vessel about 0.035 cu m (1.25 cu ft) in volume designed to take reservoir pressure to 10,342.2 kPa (1,500 psi), a 3.7-m (12-ft) barrel with a 5.08-cm (2-in) bore, a high pressure cap, and a 38.1-cm (15-in) -long free piston. The system is operated using nitrogen gas as both the driving force behind the piston and as the compressible fluid for generating pressures between 60 and 120 Kpsi at a pulse width of about 3 milliseconds.

The high pressure end cap will accommodate two APG-type piezoelectric tourmaline gages and two crusher gages of either the M11 or T20 configuration. Both types of gages are exposed simultaneously to the same pressure; thus, direct comparisons are made. Pressure-time information is obtained through automatic processing of the electrical signals received from the piezoelectric gages.

## APPENDIX D
## REFERENCES

1. Calibration Procedures for Proving Ground Instrumentation: Part I, Report DPS-1864; Part II, Report DPS-2352, Aberdeen Proving Ground, Maryland.

2. Special Study of EC Aluminum and Ingot Iron Pressure Spheres for Use in Mechanical Crusher Gages, John R. Vigliante, TECOM Project No. 9-CO-001-000-002, Aberdeen Proving Ground, Md., Report APG-MT-3764.

3. Test Operations Procedure (TOP) 4-2-504, Safety Evaluation - Artillery, Mortar, and Recoilless Rifle Ammunition, 1 April 1979.