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MEMORANDUM REPORT NO. 397

AN IMPROVED TOURMALINE AIR BLAST GAGE

by

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U.S. ARMY ABERDEEN RESEARCH AND DEVELOPMENT CENTER
BALLISTIC RESEARCH LABORATORY
ABERDEEN PROVING GROUND, MARYLAND

BALLISTIC RESEARCH LABORATORY

MEMORANDUM REPORT NO. 397

Ordnance Research and Development Center Project No. 5336

Carr/Bakinowski/rw
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17 October 1945

AN IMPROVED TOURMALINE AIR BLAST GAGE

Abstract

In order to meet the requirements of a program for measuring blast pressures of large caliber bombs at the Aberdeen Proving Ground a piezoelectric tourmaline crystal blast gage has been developed and methods of producing it in large quantities have been worked out. Successive calibrations taken on individual gages show a standard deviation from the mean rarely exceeding 1%; and an output that shows no significant departure from linearity in the pressure range from three to sixteen pounds per square inch. Details of construction and calibration are given.

AN IMPROVED TOURMALINE AIR BLAST GAGE

I. INTRODUCTION

A. The Piezoelectric Blast Gage. Piezoelectric gages are used extensively in the measurement of the time variation of the air blast pressure from bombs and guns. Changes in the pressure applied to a gage produce proportional amounts of electric charge which charges up the capacity of the gage and connecting cable. The resulting voltage is amplified and recorded photographically as a function of time by means of a cathode ray oscillograph. If the oscillograph deflection with gage and cable attached is recorded for a known charge and the calibration constant for the gage (i.e. charge per unit pressure) is known from previous measurement, the gage record can readily be calibrated in units of pressure.

B. Types of Piezoelectric Crystal. The crystals most widely used in piezoelectric gages are quartz, tourmaline, Rochelle salt, and ammonium dihydrogen phosphate. Of these crystals quartz and tourmaline have proven most suitable for quantitative blast measurement. Quartz gages have the disadvantage that they must be constructed with a piston or diaphragm for directing the force to particular surfaces of the crystals, and other faces must be protected from the pressure changes. Unlike quartz, tourmaline is sensitive to hydrostatic pressure. Thus the mechanical design of a gage can be much simpler if tourmaline is used instead of quartz because no force-directing structure is necessary. A disadvantage of tourmaline is that it exhibits a pronounced pyroelectric sensitivity, whereas quartz does not. Despite the pyroelectric effect, however, the piezoelectric constant of tourmaline is independent of temperature. If the crystals in tourmaline gages are coated with a layer of thermal insulation, the pyroelectric sensitivity is not objectionable in the measurement of blast. In the development of a satisfactory gage at Ballistic Research Laboratory, Aberdeen Proving Ground, Md., it was found that the difficulties of tourmaline were more easily overcome than those of quartz.

C. The NDRC - Stanolind Tourmaline Gage. A tourmaline gage for air blast measurement was developed by Division 2, NDRC and was manufactured in improved form by the Stanolind Gas and Oil Co.[1] It consists of a stack of four to eight tourmaline discs soldered together, with electrodes between the crystals. A process was developed for soldering directly to the crystal surface. The stack is surrounded for a plastic heat insulating material and a flexible electrostatic shield. A lead of relatively non-microphonic shielded cable is connected with the crystal electrodes which are in parallel electrically.

(1) See OSRD Report No. 4619 "Development of Blast Gages & Recording Equipment" - T.I.B. No. 7549a.

The Stanolind gages were used by Ballistic Research Laboratory in testing bombs for about a year and very good results were obtained at first. However, the gages were fragile and when used constantly would deteriorate rapidly. Furthermore, there were often gages for which the calibration varied. These gages were almost always found to have loose electrodes, due to defects in the soldering.(2) Finally, a sufficient number of gages to satisfy the needs of Ballistic Research Laboratory could not be obtained from Stanolind. Due to these difficulties, it was decided to attempt the development at BRL of a rugged and relatively simple tourmaline gage.

D. The BRL Tourmaline Gage. After a long period of development, a satisfactory tourmaline gage was produced at BRL. Its sensitivity is approximately 75μμ C/psi. The gage combines ruggedness with constancy of calibration, and can easily be constructed in quantity. A large number of these gages have been in almost continous use for the past six months in testing bombs. With the exception of those hit by fragments, veryfew have developed any fault. Blast records obtained with them are of good quality and show no apparent gage frequencies.

II. GAGE CONSTRUCTION

A. General Description. Figure 1. is a photograph of the BRL tourmaline gage at several stages of construction. It contains four (3) tourmaline plates with five silver foil electrodes, plates and foils alternating. The plates and foils in the stack are cemented together with a thermosetting cement, monomeric butyl methacrylate (MBM). The stack is cemented to a steel block. A brass ring of the same outside diameter as the block and slightly higher than the stack is bolted to the same face of the block to which the stack is cemented. Thus the stack of crystals is fastened to the bottom of a cup-like metal housing.

The crystals are so arranged that the sides which are positive with compression are in the directions indicated in Figure 2a. Electrical connection is made to the foils by means of projecting tabs. The positive tabs project from the stack in one direction and the negative in another. The plates are circular except on one side, where the boundary is a chord of the circle. This flattened side (see Figure 2b) allows space for making the tab connections. The negative tabs which include the top and bottom ones of the entire stack are fastened to the steel block.

The cable is British Telconax. It is especially made for measuring blast with piezoelectric gages, and is practically free of the signal resulting from mechanical agitation which is encountered in other types. A length of about three feet is attached to the gage.

(2) It is understood that recent improvements have been made which may have eliminated these difficulties.

(3) Another model has eight plates, sensitivity 120 μμ C/psi.

It enters the gage housing through a brass sleeve in the side. The shield at the end is unbraided for a short distance and anchored under a notch in the ring and soldered to the outside of the ring, as shown in Figure 3. The central conductor is soldered to the positive tabs.

The material used for heat insulation is General Electric Cable Joint Compound No. 227. It is a high melting point wax similar to pitch in appearance. The wax is melted and poured over the stack until its surface is level with the top of the ring. It clings very tightly to the crystal and metal surfaces. The thickness of the ring is such that the layer of wax covering the stack is about 1/16 inch. The wax is relatively plastic in comparison with the crystal. Thus it can transmit hydrostatic pressure to the crystal. Evidence supporting this was obtained by a simple test. A gage which was calibrated with several different thicknesses of wax always gave the same calibration constant.

A disc of copper foil is attached to the top of the ring, in contact with the wax, to complete the electrostatic shielding of the stack.

The leakage resistance of the MBM cement is very high. Thus it does not matter if cement adheres to the edges of the crystals, bridging the gap between successive foils. A test was made to determine whether or not cement between the crystals contributes to the piezoelectric output. A dummy gage was made of glass plates instead of crystal and was calibrated. It gave no charge, indicating that the cement is inactive. It is believed that in this type of gage soldering crystals together has no advantage over cementing.

Detailed construction information is presented in the appendix.

III. CALIBRATION RESULTS

A. Method of Calibration. Most of the calibrating has been done oscillographically. From one to four gages are calibrated at a time. They are placed in a small pressure tank with a cellophane window. The air pressure in the tank is raised, and its value read with a Bourdon gage. The pressure is then released very suddenly by puncturing the cellophane window. A multi-trace oscillograph record taken at the time of release gives the deflection for each gage. The charge liberated by each gage is determined from the ratio of this deflection to that produced by a standard charge. (4) The calibration constant is the ratio of the initial tank pressure (excess above atmospheric) to the liberated charge. Pressure oscillations persist within the tank until about five to eight milliseconds after release. The deflection is measured at a point on the record ten milliseconds after release, since within ten milliseconds all oscillation is completely damped.

(4) The method for applying the standard charge is similar to that described in OSRD Report No. 4619.

B. Consistency of Calibrations. Nine successive calibration records are taken for each gage constructed, all at approximately 20 psi. The standard deviation of individual measurements from the mean for the nine corresponding values of calibration constant is almost always less than 1%. Definite trends in a series of values never appear, although with the Stanolind gages this often occurred. When a gage which has been used for several months is recalibrated, its constant almost always agrees with the originally determined value to within 2%.

C. Linearity. No evidence of nonlinearity has ever been found. Table I gives mean values of a calibration constant measured at several defferent pressures, with the standard deviation of the mean for each value. There are no significant differences.

TABLE I

Gage 44

Pressure psi.	Sensitivity μμ C/psi
3	74.0 ± 1.5
6	74.7 ± 0.3
10	74.8 ± 0.2
16	74.7 ± 0.07

D. Temperature Dependence. Gages were calibrated at two widely separated temperatures. The observed differences in calibration constant are not significant. The data is given in Table II.

TABLE II

Gage	Sensitivity at 25° C. μμ C/psi	Sensitivity at 40° C. μμ C/psi
T42	78.8 ± 0.3	77.7 ± 0.3
T68	63.8 ± 0.4	65.4 ± 0.5

Thomas D. Carr, Physicist

Mary A. Bakinowski, T/4
Laboratory Technician

APPENDIX I

Details of Gage Construction

APPENDIX I

Details of Gage Construction

1. Preparation of Crystal Plates

Cutting: Tourmaline crystal plates were cut from the following specifications:[1] Crystal stock to be supplied by the Government. Plates to be cut perpendicular to crystal axis for maximum piezoelectric response to compression 0.060 inch plus or minus 0.02 inch thick and ground flat plus or minus 0.0001 inch, uniform in thickness, natural size and shape. Finish fine ground.

The cutting to gage size is done in the laboratory as follows:

> A "biscuit cutter" is constructed of 1-3/4" I.D. copper tubing and 1/32" wall thickness for use in a drill press.[2] Four notches are filed in grinding edge of the biscuit cutter with abrupt leading side and sloping trailing side.

Silicon Carbide Abrasive Grain is used as cutting agent. Mix 2/5 of size 220 with 3/5 of size 100; add water until of loose paste consistency.

Use melted wax to attach crystal to a steel plate for cutting. Cool wax thoroughly before cutting. Place plate on drill press table and fix biscuit cutter in drill chuck. Adjust plate position until biscuit cutter projects slightly beyond the edge of the crystal plate in order to cut out a piece of crystal of approximate dimensions as shown in Figure 2.

Clamp plate to drill press table. Attach weights and spring to handle of drill press in such a way that constant pressure will be applied in cutting. Start drill press, using medium speed. Apply compound to crystal, bring cutter into contact with crystal. As cutting progresses, add compound and water when necessary. Cutting process takes from 3 to 5 minutes.

To remove cut crystal from plate, heat back of plate until wax is melted. Remove with spatula. Do not force. Clean excess wax off plate and repeat the process for next crystal.

Cleaning Crystals. Remove excess wax and compound with razor blade. Clean with carbon tetrachloride and cotton. Clean thoroughly.

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(1) This was done for BRL by Reeves Sound Laboratory, New York.
(2) Method is described in Strong, "Procedures in Experimental Physics"

Testing for Polarity. A cathode ray oscilloscope is used to determine crystal polarity. Lay crystal on metal block which is connected to oscilloscope ground. On crystal, place electrode connected by shielded cable to input. Lay a piece of thin sheet bakelite on electrode and tap with pencil eraser. Deflection is upward or downward, depending on whether top side of crystal is positive or negative. Mark negative side with pencil.

2. Preparation of M. B. M.

Partially polymerized Monomeric Butyl Methacrylate (3) is used as a cement for securing stacks of crystals and foils together and to the base of the gage.

Precaution! M.B.M. must be kept in a dry ice refrigerator when not in use. Dissolve 3 or 4 grains of benzoyl peroxide catalyst in a 25 c.c. beaker of M.B.M.

Lay a metal sheet over gas burner and use a moderate gas flame for cooking. Lay a piece of paper toweling over metal sheet.

Pour mixture into glass cooking vessel and put over flame.

Stir constantly with thermometer, watching temperature rise.

Material can be heated to about 150° C. initially, and then cooled to 100° C. for partial polymerization.

Once the polymerization reaction has started, it is exothermic and must be watched. To keep under control it is necessary to lower the flame just as the temperature reaches 150° C. In the case of persistent rise in temperature, turn out flame or remove from stove at 150° C.

Keep stirring until temperature comes down to 100° C. Pour into glass container. Preparation is ready to use. 25 c.c. of this preparation is enough for approximately 25 gages of 4 crystals each.

M.B.M is good for about one week when left standing.

3. Assembly of Gage

Preparation of Gage Base

The metal parts of the gage are made according to Figure 3. Clean gage base of oil and grit. Screw tinned soldering lug to base for negative terminal.

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(3) Purchased from Rohm and Haas, Philadelphia, Pa.

Preparation of Crystals and Foils

Electrodes for crystals are made of 0.001" silver foil. Select 4 crystal plates and cut foil to match each plate. Leave tab projecting from straight side. Cut tab at such an angle that it will fit over its proper terminal. (See Figure 2 b) Clean foils with carbon tetrachloride.

Steps in Cementing Stack and Baking

Mark gage base by setting brass ring in its proper position and going around the inside of it with a scribe. This mark serves as a guide for placing the stack. When stack is centered, there should be a space of about 1/8" between edge of stack and the mark.

A small paint brush is best for applying the cement (M.B.M).

Paint negative foil and place directly on the gage base. Adjust it so that tab will lie over negative terminal and that negative side of the crystal plate will fit over it.

Immediately paint negative side of the first crystal and place it over the silver foil. Apply pressure with the fingers, beginning in the center of plate and moving outward to the edges to force out the air bubbles.

Top of crystal is positive. Paint top and lay positive matching silver foil over it with tab projecting from side opposite to the negative one. Use pressure as before. It is preferable that pressure is applied over cheesecloth or a metal block in order to keep finger prints and perspiration off parts. Lay the painted positive side of another plate on the positive silver foil.

Plates are always laid with adjacent sides of polarity as shown in Figure 2 a.

Top surface is now negative. Continue process until all are stacked. Stack is completed with a negative crystal surface and foil on top.

When stack is completed, place brass ring in position and make it secure with screws. Fill space around with a material that will stand heat, to keep stack from sliding during the final polymerization. Folded sheets of cellophane has been found to be useful as a filler.

Cover stack with a sheet of cellophane and set a weight on it. Weight should fit into the inside diameter of ring. Distribute weights evenly.

Let air dry for an hour. Then place gage with weights in an oven of a constant temperature of 68° C. (155° F.).

For a stack of 4 crystals of 1-3/4" diameter bake for 24 hours.

Bake a longer or shorter time depending upon the area and height of stack.

Remove from oven, remove ring and weights. Take care in removing cellophane which may be stuck to top silver foil.

Cut excess M.B.M. from around stack with razor blade.

Clean with carbon tetrachloride all excess cement that cannot be cut.

Solder negative tabs to terminal lug.

Test leakage resistance from positive to negative tabs with voltohmist. Should be infinite ($\gg 10^9 \Omega$)

4. Connecting Cable and Filling of Gage

The cable (British type) is inserted through the brass tube inside of gage base. Use 3 feet of cable for each gage.

The following method is best for threading the cable through the tube:

Strip about 2-1/2" of the rubber cover exposing shielding. Slip shielding back and bare inside lead for 1". Slide shield back in place and use it as a guide for pulling cable through. Pull until rubber covering of cable is all the way in the brass tube.

Shielded part of cable is now on gage base. Unweave shielding threads and bring out between ring and base to be soldered to outside of ring for contact.

Strip and cut inside conductor to suitable length and solder to positive silver foil.

Test terminals for infinite resistance.

File a little hollow in brass ring, enough to permit unbraided shielding to pass through. Screw ring in position and solder shielding to ring.

Prepare a copper foil diaphragm .002" in thickness and of the same diameter as gage base. Cut a tab for contact to one side of the outside of ring. Tin contact points.

Assembled gage is ready for filling, providing resistance is infinite.

If voltohmist shows low resistance, examine silver foils around edges to make sure there is no contact. If low resistance persists it may be due to humidity. Heating or placing gage in jar to which Calcium Chloride (CaCL2) grains have been added will help.

Wax (G.E. Cable Joint Compound No. 227) is used to fill the gage.

Melt wax over gas burner. Heat gage slightly so that hot wax will flow better for filling.

Use toothpick. Start at one point and work around and around layers until gage is filled a little above level of ring.

Watch for air bubbles while filling. Eliminate all.

Remove gage from heat and let cool a little before placing copper diaphragm.

Lay diaphragm over gage and press out excess pitch with block of wood over paper toweling. Apply even pressure and wipe off excess. Repeat until all excess has been forced out and diaphragm is level with ring. Allow to cool and test for infinite resistance.

5. Finishing Touches

Clean outside of gage with carbon tetrachloride or benzine.

Solder contact of diaphragm to ring.

To make air tight and prevent leaks apply adhesive (M 3) [4] at cable entrance into tube. Force some of it into tube and paint around cable. Allow to harden overnight. Two or three thin applications are better than one thick one.

Place label made from copper sheeting stamped with number of gauge about one foot away from brass tubing on cable.

Gage is finished and ready for calibrating.

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(4) Purchased from Minnesota Mining & Mfg. Co.

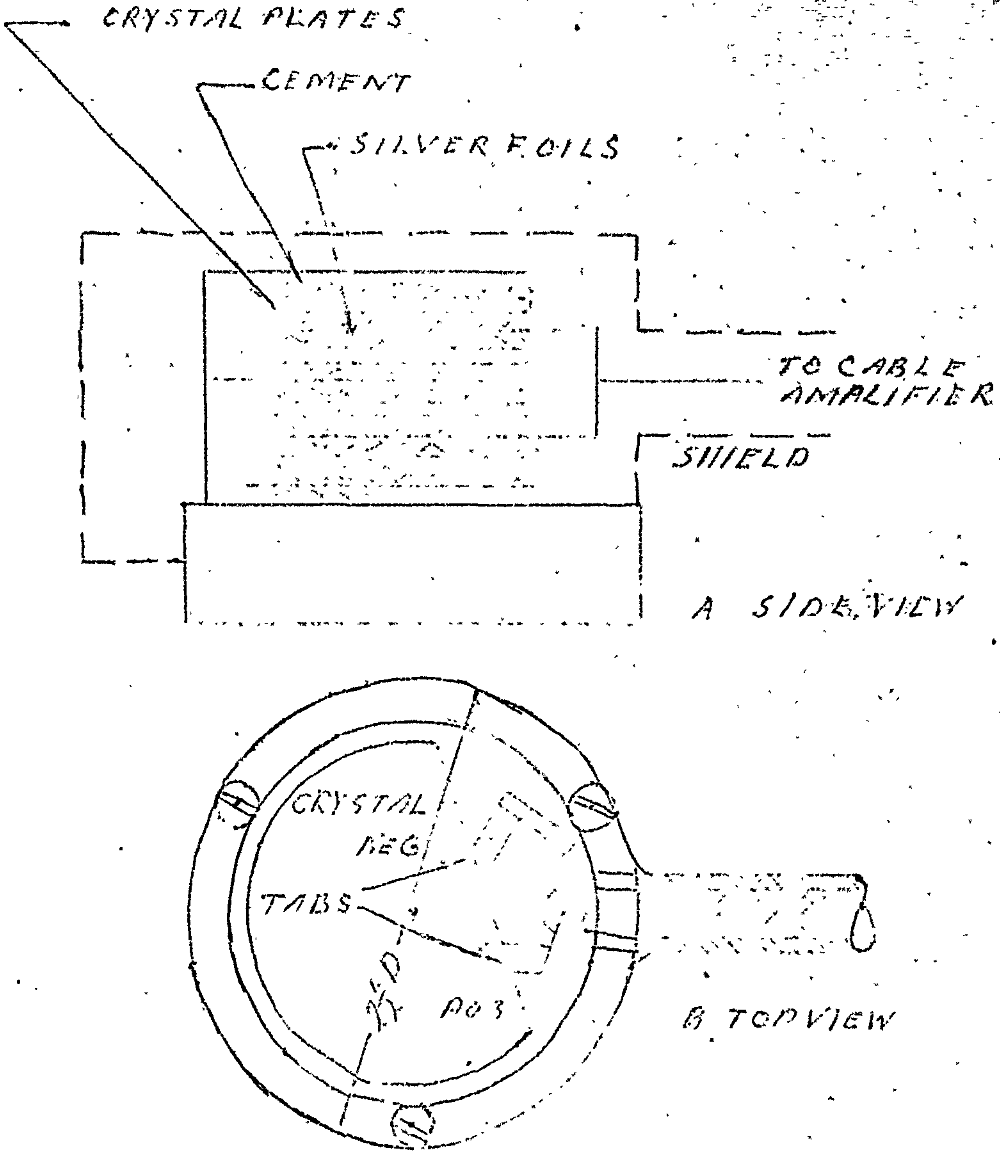
APPENDIX II

Photographs and Drawings

Fig. 1 · APG No. A32901 - Gages at several stages of construction.

Fig. 2 - Drawing BG 211 - Diagram of Gage

Fig. 3 - Drawing BG 210 - Tourmaline Blast Gage



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BALLISTIC MEASUREMENT

FIG 2 DIAGRAM OF GAGE

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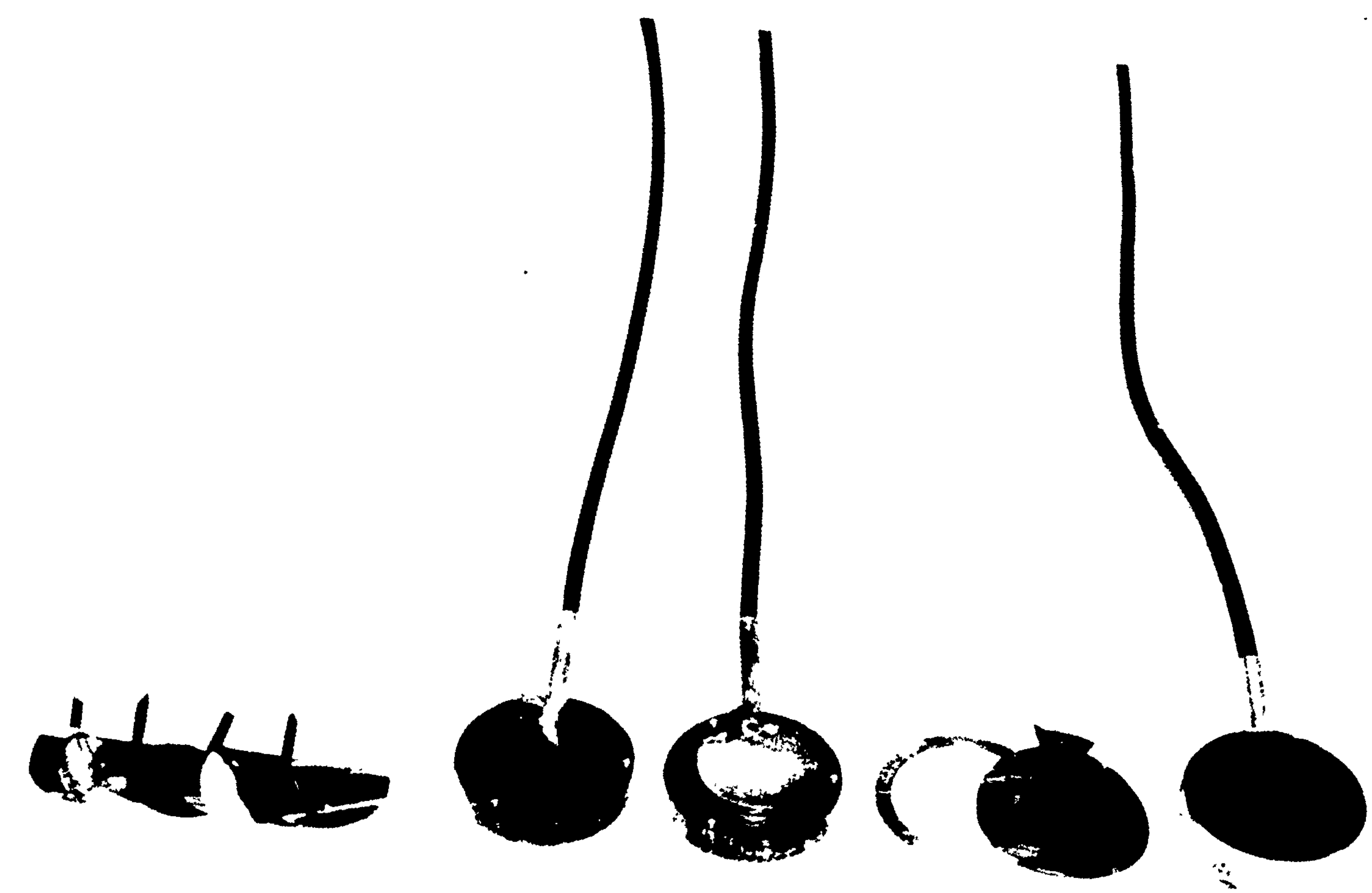
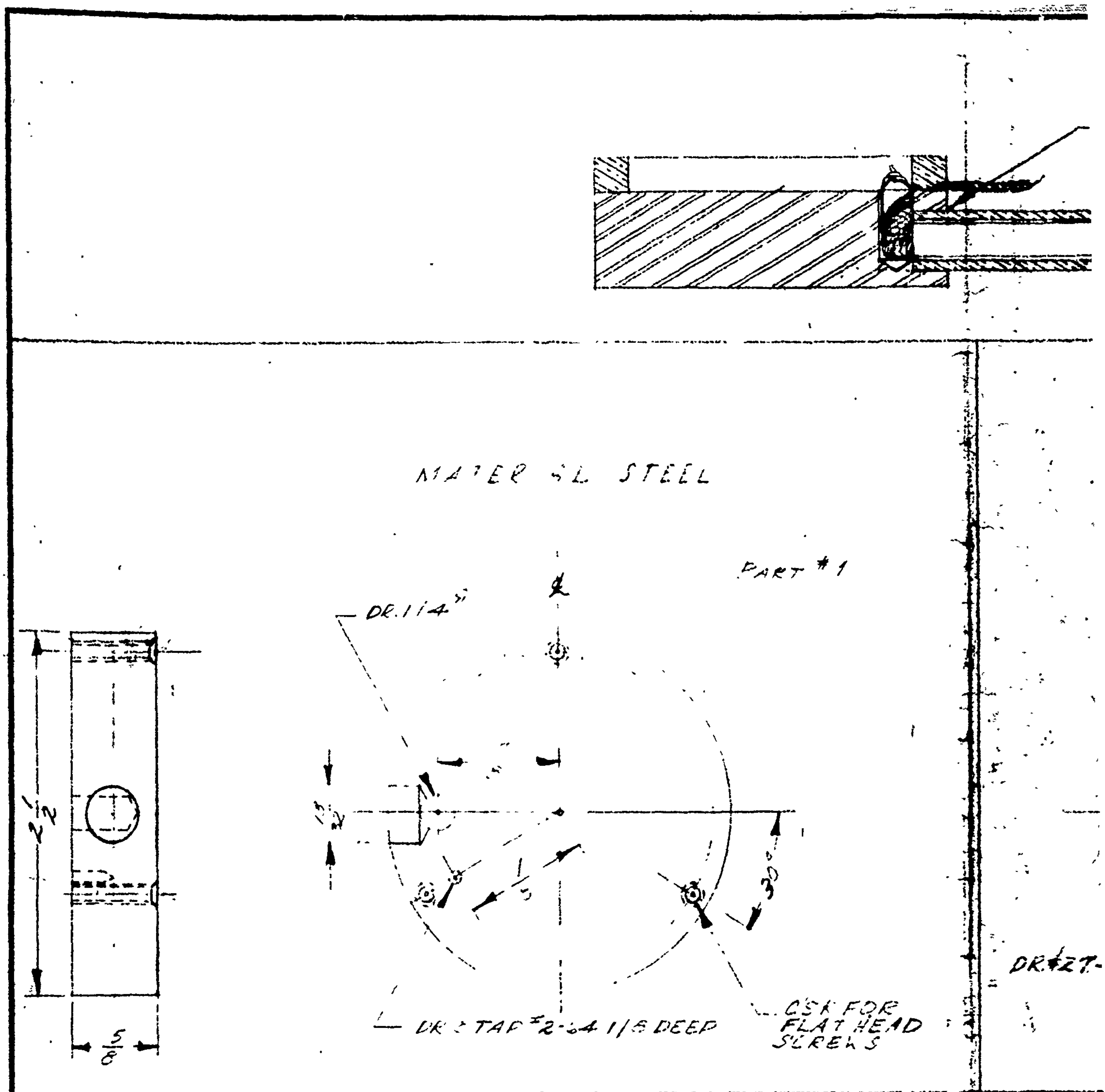
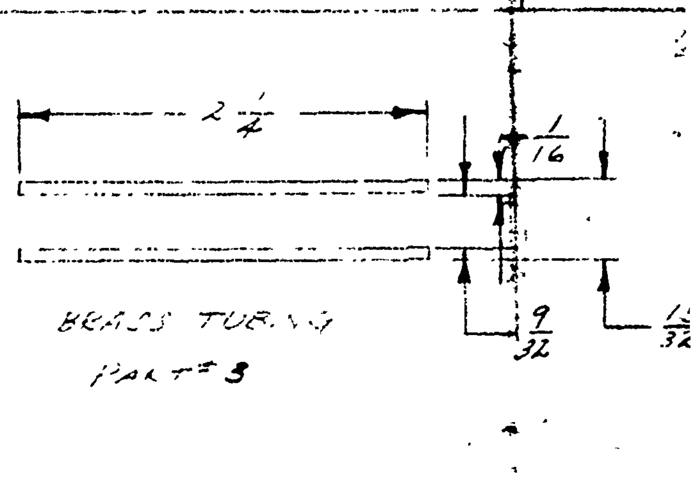


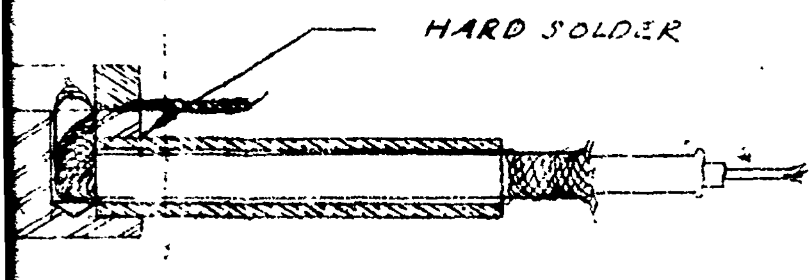
A32101 — ABERDEEN PROVING GROUND — 27 Sep 43

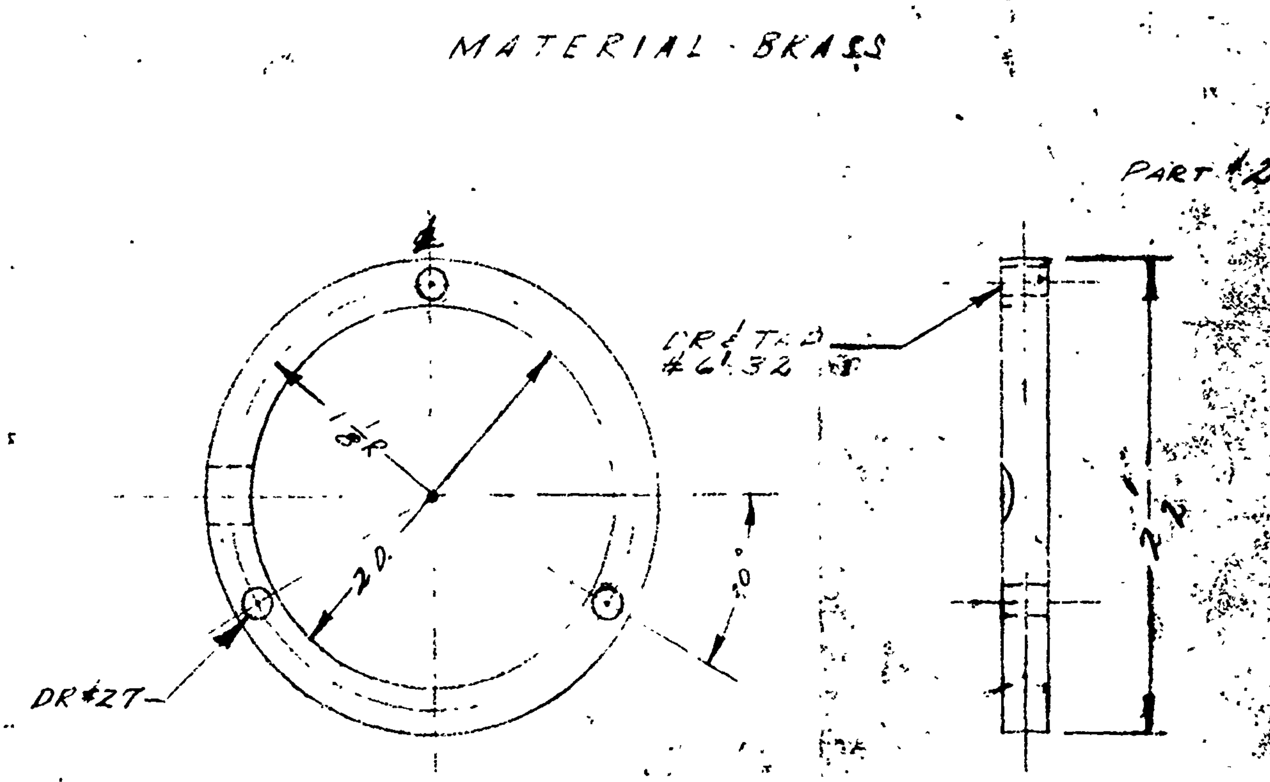
Project No. [illegible]. Figure #1. [illegible] at several stages of construction.

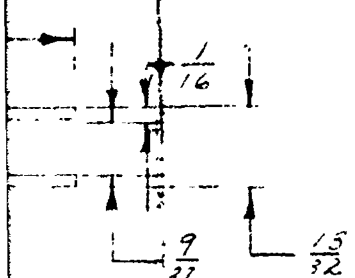

MATER AL STEEL
PART #1
DR.114"
DR & TAP #2-64 1/8 DEEP
CSK FOR FLAT HEAD SCREWS
2 1/2
5/8
30°
DR #27-


2 1/4
1/16
9/32
BRASS TUBING
PART #3

1







TOURMALINE BLAST GAGE
FIG 3

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BALLISTIC MEAS.

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1. References:

a. Ballistic Research Laboratory Memorandum Report No. 397, "An Improved Tourmaline Air Blast Gage", by T. D. Carr and M. A. Bakinowski, October 1945, AD number 494667, UNCLASSIFIED, enclosed.

b. Ballistic Research Laboratories Memorandum Report No. 1778, "Detonation Pressure Measurements in TNT and OCTOL", by R. Jameson and A. Hawkins, August 1966, AD number 802251, UNCLASSIFIED, enclosed.

c. Ballistic Research Laboratory Memorandum Report No. ARBRL-MR-03115, "Blast Computations over a Hemicylindrical Aircraft Shelter", by J. Wortman, July 1981, AD number B058960, UNCLASSIFIED, enclosed.

d. Ballistic Research Laboratory Memorandum Report No. ARBRL-MR-03125, "Combinatorial Geometry Computer Models of Sitting and Standing Crew Personnel" by L. R. Kruse and C. H. Lee, August 1981, AD number B060185, UNCLASSIFIED, enclosed.

e. Ballistic Research Laboratories Report No. 734, "Response of Air Blast Gauges of Various Shapes as a Function of Pressure Level", by S. T. Marks, August 1950, AD number 801219, UNCLASSIFIED, enclosed.

f. Ballistic Research Laboratories Report No. 775, "Response of Air Blast Gauges of Various Shapes to One-Pound Spherical Pentolite Charges as a Function of Pressure Level", by S. T. Marks, September 1951, AD number 801726, UNCLASSIFIED, enclosed.

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3. Our action officer is Douglas Kingsley, X36960.

Encl

Benjamin E. Bruso
BENJAMIN E. BRUSO
Team Leader, Security/CI Office

CF Dir, CISD, ATTN: Dr. N. Radhakrishna