# NATIONAL BUREAU OF STANDARDS REPORT

5381

# THE DETAILS OF CONSTRUCTION AND ASSEMBLY OF THE NBS DESIGN MANGANIN HIGH PRESSURE GAGE

by

H. A. Bowman
D. P. Johnson

Report to
Watertown Arsenal and Watervliet Arsenal
Ordnance Corps, Department of the Army

NBS

U. S. DEPARTMENT OF COMMERCE
NATIONAL BUREAU OF STANDARDS

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# FOREWORD

This report describes in detail the construction of a type of manganin wire pressure gage used successfully by the National Bureau of Standards for measurements of pressures up to 200,000 pounds per square inch.

The work was conducted in connection with a program for the improvement in techniques of high pressure measurements, supported initially by the Watertown Arsenal (Order No. TR3-3002) and later by the Watervliet Arsenal (Order No. TR3-0110).

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## 1. INTRODUCTION

The NBS design manganin wire high pressure gage, Figure 1, has given satisfactory service to pressures of 200,000 psi in use over an extended period of time at the National Bureau of Standards. This report provides detailed instructions for the fabrication of the various members of the gage, and a step-by-step description of the assembly of these members into the completed unit. Although not strictly a part of the gage assembly, there are described certain tools which facilitate the removal of the gage from the high pressure vessel.

The historical development of the gage, its calibration, methods of use, etc., are not reported on here since such topics are adequately covered elsewhere in high pressure literature (see bibliography at end of report). Also discussion of choices of materials and configurations are not included except insofar as are necessary to the proper understanding of the fabrication and assembly process.

The NBS gage is essentially a 4-terminal manganin wire resistor immersed in the high pressure fluid in a configuration wherein strains, other than hydrostatic, are minimized. It is designed to be contained in a Harwood Engineering Company high pressure vessel (Harwood drg D1082), and hence the Harwood jam nut (Harwood drg B1100) associated with the vessel is an integral part of the gage. This gage may be housed in any high pressure vessel with a bore one inch in diameter, 3 3/4 inches long, and whose jam nut contains a hole 1/2" in diameter.

For purposes of discussion the fabrication of the complete gage is divided as follows:

A. The ceramic mandrel

B. The manganin coil and its leads

C. The high pressure electrically insulated header

D. The assembly of the gage

E. Insertion for pressure seasoning

F. Removal of the gage from the high pressure vessel.

## 2. FABRICATION OF THE CERAMIC MANDREL

The mandrel is made of steatite (General Ceramics Company, type BN 3030) which may be formed into precisely dimensioned parts. It is obtained in the form of one-inch diameter rods which are first machined as shown in Figure 2. Upon completion of this lathe job, several small (No. 80 drill) holes are drilled in the end shanks, and floors of the grooves in order that the various wire members of the coil may be held firmly in place. The approximate locations of these holes are shown in Figures 3a and 3b. A hole is drilled in the floor of each groove at the upper end of the mandrel, and one hole is drilled in the wall of the shank at this end. The shank hole and one floor hole are shown in Figure 3a. Care must be exercised in drilling the shank hole to avoid breaking through the inner wall of the shank. At NBS these holes are drilled by hand with the No. 80 drill in a pin vice, it having been found that fewer green (i.e. unfired) steatite mandrels are broken when drilling by hand rather than with drill press and drilling jig. At the base end of the mandrel, four such shank holes are drilled, two on each side of the shank. Again, a single hole is drilled in the floor of each of the two grooves. Figure 3b shows two of the shank holes and a floor hole.

The steatite mandrel is next fired in a ceramic kiln as follows:

1. Increase temperature at the rate of 2°C per minute until a temperature of 1270°C is attained.
2. Hold this temperature for one hour.
3. Allow the furnace to cool slowly to room temperature (about 18 hours cooling time).

This schedule was worked out to reduce the green mandrel to a fairly dense unit with near zero porosity. The success of firing is easily checked by placing a small drop of Skrip fountain pen ink on the fired surface. If the ink remains in a small well defined spot the firing cycle was successful. If, on the other hand, the ink disperses, the material is still porous. It should be pointed out that the manufacturer of green steatite rod will usually fire the rod which they have made when requested by the purchaser, in which case, proper firing is almost certainly assured.

During the firing process, the mandrel will shrink about 16% radially and 8% longitudinally with respect to the axis of the original green rod.

## 3. FABRICATION OF THE MANGANIN COIL

The wire sensing element coil is made of B+S No. 36 (.005" diameter) manganin wire which is insulated by a double layer of silk. Depending upon the melt, it will have an ohmic resistance of 11-1/2 to 12 ohms per foot. Two lengths of wire are cut, each having a resistance of one-half of the desired total resistance of the completed unit plus about 2-1/2% plus 3/4 inch to allow for heat treatment and trimming.

These two pieces are formed into helices by winding, with turns touching, on a highly polished length of 3/64" diameter drill rod. Winding tension should be 8 to 10 ounces, and the outside diameter of the finished helix will be about 0.065". When the helix is removed from the mandrel a 1/2" length should be bared at one end and a 1-1/4" length at the other. Each wire is then stretched so that the helical portion is equal to about 3/4" less than is required to fill one of the spiral grooves in the ceramic mandrel. They are then mounted on the mandrel, passing the 1/2" bare length through the hole in the floor of the groove at the base end of the mandrel, and the 1-1/4" bare end through the floor hole at the opposite end. No effort should be made to stretch the helix to fill the entire length of the groove. Four short (about 1-1/2") lengths of 0.010" diameter gold wire are threaded through the #80 holes in the base end shank of the mandrel, and two are silver brazed to each free end of manganin at this end (see Figure 3b). This brazing process is best performed by a gas oxygen flame rather than a gas-air flame, since the higher temperatures thus developed will cause the silver brazing alloy to flow out more quickly, so there is less chance for damage to the manganin wire.

The brazing alloy bead should be rather large, and the three wires (2 of gold and one of manganin) which protrude from this bead should be separated by large angles. This eliminates any possibility of intermittent short circuiting of the leads in the immediate vicinity of the bead.

In this brazing process borax flux is used which may be removed by immersing the entire mandrel in boiling water for several minutes. The mandrel should be rinsed in another container of boiling water.

The mandrel and the supported wires are next placed in an oven at 130°C to 140°C for 48 hours, during which interval the resistance will decrease by somewhat less than 2% and the length of each helix will be increased by about 3/4". This slack may be taken up at the upper end of the mandrel, and each helix should now fill its groove almost perfectly. It is not desirable that the helix be wrapped tightly around the mandrel, so the free end of the manganin at the upper end of the mandrel should be adjusted in length to allow a slight amount of play of the helix. Ordinarily about 1/2 to 3/4 inches of wire will have to be removed from each piece.

One of the two free ends of manganin should be passed through the hole in the upper shank, and the two free ends silver-brazed together as shown in Figure 3a. The flux removal in this step is accompolished by playing a tiny stream of near-boiling water directly upon the flux covered brazing bead taking great care to prevent any wetting of the rest of the assembly.

The overall coil resistance should now be slightly above the desired final resistance.

## 4. FABRICATION OF THE ELECTRICALLY INSULATED HIGH PRESSURE HEADER

This member of the NBS high pressure gage assembly is made up of several individual elements which will be taken up individually.

A. MAIN BODY. This element is made of Vega Tool Steel (manufactured by the Carpenter Steel Company) and is hardened to Rockwell C57 to C59. The finished dimensions are shown in Figure 4. Unless otherwise indicated, tolerances of ±.003" are satisfactory. Requirements for finishing surfaces and corners are shown in Figure 5. Where no other requirement is called for NBS practice has been to grind exterior surfaces to a finish of 32 microinches. The element should be carefully checked for hardness after heat treatment and prior to the performance of any finish grinding. A radius (.005" - .010") should be left on all corners.

B. INSULATING BUSHING. These bushings, Figure 6, have been made from a number of materials (sapphire, quartz, etc.) all of which work satisfactorily. Present Bureau practice is to use Solenhofen Lithographic limestone. This material machines well; however, it should not be heated during machining since it is believed that the physical characteristics may be unfavorably altered by such heating.

After machining, the completed bushing is immersed in melted paraffin at a temperature of about 125°C. This temperature is maintained for several minutes and the paraffin is allowed to cool to solidification, at which time the bushings are removed from the cold paraffin with a knife. Paraffin remaining on the surface of the bushing and in the hole is removed by scraping (not heating). This process is intended to replace part of the water contained in the inter-crystalline spaces by paraffin and reduce the surface conductivity.

C. THE ELECTRODE. These elements are made of cold rolled steel as shown in Figure 7. In step 1, effort should be made to have the gold wire emerge from the pool of silver brazing alloy near the longitudinal axis of the cold rolled steel rod. In step 2, the piece is chucked up in a four jaw chuck and aligned so that the emergence of the gold from the brazing alloy is near the longitudinal axis of the .174" surface to be turned. In step 3, the piece is chucked up on the .174 diameter, cut to length and the finish-machining performed as indicated.

D. OUTER EXTRUSION RING. This square cross section ring fitting on the .815" diameter of the main body, Figure 4, is made of annealed 18-8 stainless steel. Its I.D. is .818" and its O.D. is .998". Its length is .090" (all dimensions ±.001").

E. O-RINGS. The small O-rings in the packing socket, Figure 8, are 1/4" OD x 1/8" ID. The large O-ring, adjacent to the outer extrusion ring, Figure 4, is 15/16" OD x 3/4" I.D. Both rings are commercially available (these are both standard sizes) in numerous materials. They should be made of a compound which is not affected by the hydraulic fluid to which they will be exposed.

F. EXTRACTION BOLT. This element, Figure 9A, is made of 3/16" x 9/16" stainless steel tubing. After machining as shown, a flat is milled on the 1/2" diameter and a 4-terminal soldering strip is attached as shown in Figure 9B.

## 5. FINAL ASSEMBLY OF THE GAGE

This process is best performed in the following steps:

1. Sweat 14" lengths of stranded #28 copper wire (teflon insulated) into the No. 70 hole in the electrode elements of the insulating high pressure header. Use 50-50 lead-tin rosin-core solder for this purpose. The outside diameter of the teflon insulation should be no greater than .050" (since it must pass through the hole in the bushing and the No. 55 holes in the main body of the header, see Figure 8).

2. The teflon insulation on the 14" length of wire is worked up the wire until it is flush against the tip of the electrode and no wire is visible (see Figure 8).
3. A limestone bushing is slipped over the free end of each wire and run up to the tapered surface of each electrode.
4. One of these wire-electrode-bushing assemblies is placed in each of the four packing sockets in the main body of the header as shown in Figure 8.
5. A 1/4" x 1/8" O-ring is inserted between the exposed portion of the electrode and the .283" diameter section of the packing socket. This will require care to avoid bending or breaking the gold wire attached to the end of the electrode. The 1/8" ID O-ring is stretched over the end of the electrode which causes the OD of the O-ring to become greater than the .283" space allotted. Hence, when the O-ring is forced into this opening a tight seal is formed.
6. A 1/2" x 20 TPI nut is placed on the extraction bolt, Figure 9, followed by a Harwood Engineering Company jam nut to fit their high pressure vessel.
7. The four teflan insulated wires protruding from the base of the main body of the header are pushed through the hole in the extraction bolt, and this bolt is firmly screwed into the main body base threads.

8. The ends of these four teflan insulated wires now protrude from the upper end of the extraction bolt, and they are soldered to the 4-terminal soldering strip attached to the upper end of this bolt as shown in Figure 9B.

9. Check the insulation resistance of each circuit to ground by a megohm bridge. It should be at least 1000 megohms in each circuit.

10. The following procedure is important and should be carefully followed. The final step in assembly is the attachment of the coil; however, the electrical resistance of each of the four circuites to ground should be checked out under pressure. The method of inserting and removing the coil from the pressure vessel are described in sections 6 and 7 of this report. A megohm bridge should be used in the measurements. The insulation resistance should increase from 1000 megohms with increasing pressure (probably due to the deformation of the O-ring). Use only non-conducting fluids such as gasoline or varsol. When it is established that the header functions properly under pressure the coil mandrel may be attached to the main body of the header by a 4-40 machine screw with the base end of the mandrel adjacent to the header. After trimming to a convenient length the four gold leads protruding from the shank holes in the mandrel base are fused to the four gold leads attached to the header electrodes using a very hot gas-oxygen flame.

No flux is necessary. These gold-to-gold fusion junctions are shown in Figure 3b. This fusion should be performed as rapidly as is possible to avoid any unnecessary heating of the assembly.

## 6. INSERTION FOR PRESSURE SEASONING

The insertion of the assembly into the high pressure vessel is readily accomplished and requires no tools. To do this, the following steps are followed:

1. Place an annealed stainless steel extrusion ring on the .815 diameter of the high pressure header main body.
2. Follow this extrusion ring with a 15/16" x 3/4" O-ring. When this O-ring is stretched onto the main body of the header, its outside diameter will be increased enough to make a slight interference fit with the I.D. of the pressure vessel.
3. Slide the jam nut back up to the upper end of the extraction bolt in order that the operator may visually check on the process, and push the main body of the header into the 1" I.D. portion of the pressure vessel.
4. Slide the jam nut forward (well lubricated) and screw it all the way home. If everything is fitted together properly, no wrench will be required.

Several applications of pressure should be applied to the manganin coil to well above the anticipated working pressure range. The coil resistance at atmospheric pressure should be noted between each high pressure application. There is a slight decrease in this atmospheric pressure resistance between the first few high pressure applications, however, this resistance valve will eventually become stable, at which time the coil may be assumed to be pressure seasoned. This "pressure seasoning" should be performed at a pressure as high as convenient, but in no case should it be less than 120,000 psi.

If the manganin coil resistance at atmospheric pressure becomes fixed at a value lower than desired, it can be increased by slightly scraping the loop of wire at the upper end of the mandrel. If it stabilizes at a value higher than desired, this loop of wire may be shortened, however, this latter procedure may alter the coil characteristics due to the high temperatures imposed when silver brazing the wires together again.

## 7. REMOVAL OF THE GAGE FROM THE HIGH PRESSURE VESSEL

When the gage is finally installed in its pressure vessel, it should not be unnecessarily removed.

With the proper tools, removal is easy. A slotted spacer made of cold rolled steel, Figure 10, is placed around the extraction bolt and its base rests upon the top of the Harwood jam nut. The 1/2" x 20 TPI nut on the extraction bolt is run down lightly against the top of this slotted spacer. With one wrench holding the spacer from rotating, a second wrench is used to back the jam nut out of the vessel. After several turns of the jam nut the assembly becomes loose and may be removed by hand. Caution: Do not attempt to remove the slotted spacer until play in the extraction bolt indicates that the main body of the header has been withdrawn from the square cross section extrusion ring. This should occur after the assembly has been raised 1-3/4" by jam nut rotation.

When the gage assembly is removed in this manner, the stainless steel extrusion ring and the 3/4" x 15/16" O-ring will ordinarily be left in the vessel. A bent wire hook can be used to lift out the O-ring, however, the extrusion ring will remain tightly wedged against the pressure vessel I.D. since the high pressure applications usually expand the OD of this ring. The extrusion ring extraction tool, Figure 11, will remove this ring in a minute or two. Although the gage assembly may be jacked out of the high pressure vessel by the contained hydraulic pressure, the mechanical shock on the manganin coil may have an adverse effect on its characteristics, hence, for the removal of the gage assembly, the procedure outlined herein is recommended.

## 8. FINAL CHECK-OUT

Prior to calibration of the gage by any of the methods listed in the bibliography, the following check-out procedure should be conducted:

A. The resistance between ground and any of the four lead wires should be a minimum of 250 megohms. This is equivalent to a minimum resistance of 1000 megohms for each individual circuit previously measured (section 5-10).

If the resistance is appreciably less than this amount the gold wires to the coil should be cut (they may be easily fused together again) and the resistance of each circuit rechecked to determine the malfunctioning circuit. The trouble, if any, will frequently be a partial short circuit between the lead wire and the header main body due to slippage of the teflon insulation away from the electrode. (Note that Figure 8 shows this insulation abutting the electrode). Another possibility of trouble is that certain portions of the assembly have become wet by atmospheric moisture or by water. This may be corrected by insertion of the assembly in a dessicator or it may be baked for several hours at 50°C.

B. Moisture in the assembly may exist but not affect insulation resistance. The assembly, when attached to a Mueller Bridge shows the presence of such moisture by causing a "wet kick" on the galvanometer associated with the bridge. Under such circumstances, when the bridge battery is keyed into the circuit, the galvanometer will exhibit a violent deflection in one direction, followed by a slow drift in the opposite direction. It is frequently possible to correct this difficulty by washing the moisture away from the assembly (by alcohol for example). If this fails a dessicator or heat should be used as explained above.

## BIBLIOGRAPHY

For readers interested in other phases of the manganin wire high pressure gage art, the following references are cited.

| Subject | Reference |
|---|---|
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| Manganin Gage Construction | (2) Ibid, pp. 72-73. |
|  | (3) "Construction and Properties of the Manganin Resistance Pressure Gage", Adams, Goranson and Gibson, R.S.I. 8, 230 (1937). |
| Calibration vs. Piston Gage | (4) "The Piston Gage as a Precise Measurements Instrument", Johnson and Newhall, ASME, 75, 3, 301 (1953). |
| vs. Water Freezing | (5) "The Utilization of the Phase Transition Between Water and Ice VI in the Calibration of a Manganin Wire Pressure Gage, NBS Report 4378, Bowman, Johnson, Cross, Ives and Hill. |
| vs. Mercury Freezing | (6) "The Use of Electrical Resistance in High Pressure Calibration", P. W. Bridgman, R.S.I. 24, May 1953, p. 401. |
| Pressure Seals in NBS Gage | (7) "A Versatile Closure for High Pressure Vessels", Johnson, Bowman, Cross, Hill and Ives, Jour. ISA 3, 7, 1956, pp. 2-3. |

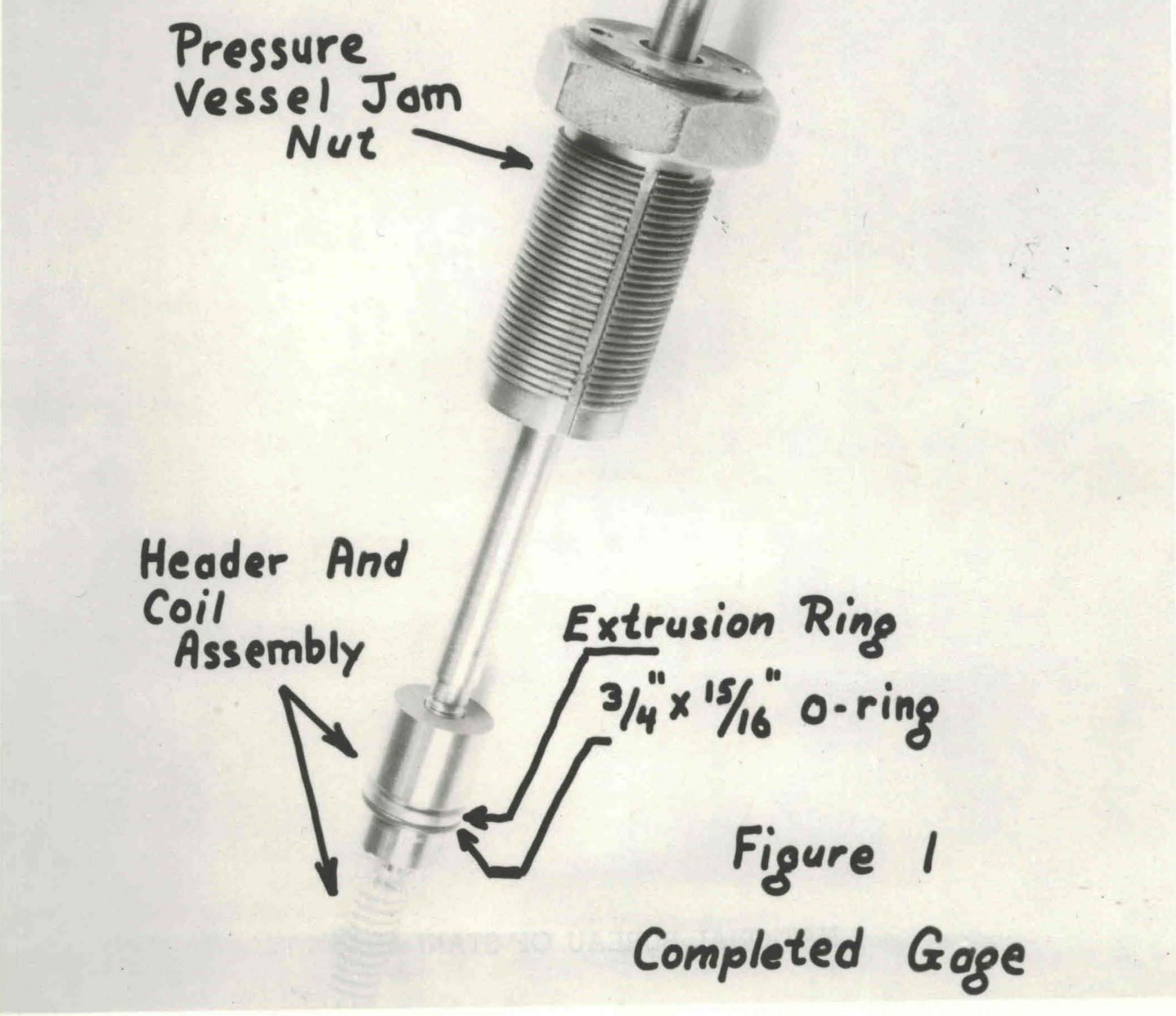
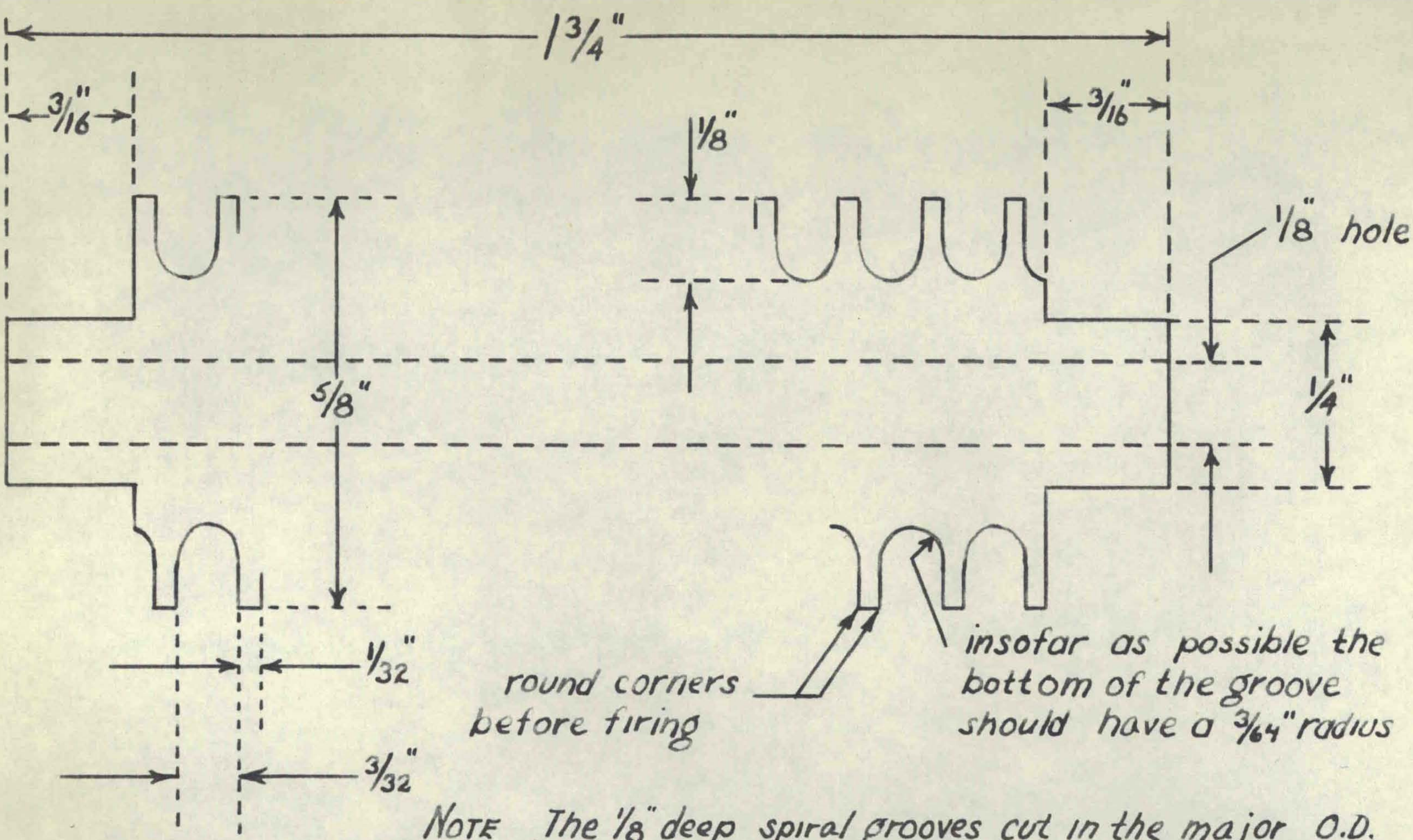


Figure 1

Completed Gage



NOTE The 1/8" deep spiral grooves cut in the major O.D. of the mandrel should be in the form of a double, or interlocking, 4 threads per inch configuration.

PRELIMINARY MACHINE WORK ON THE STEATITE MANDREL
(wire locking holes not shown here)

FIG. 2

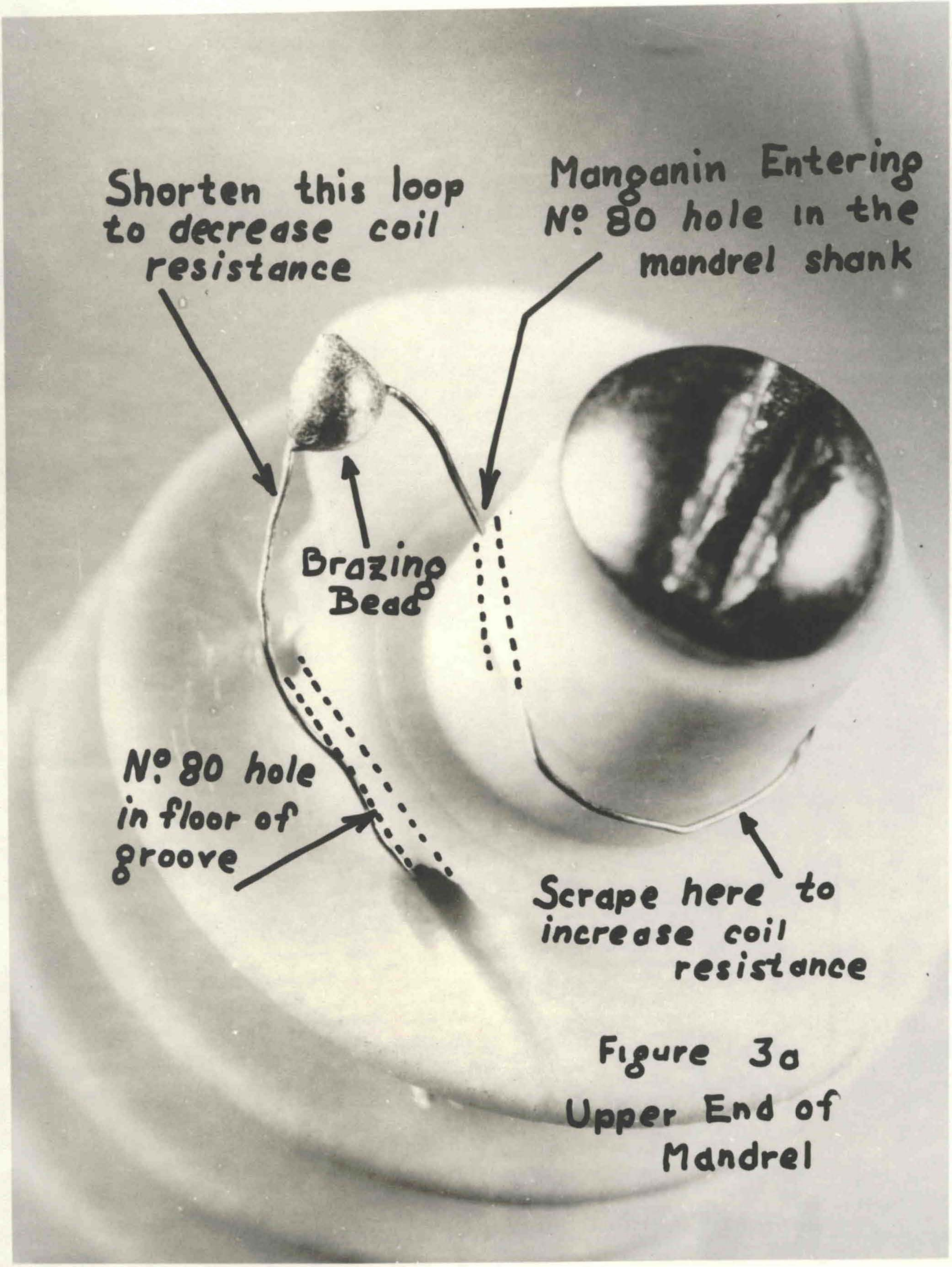


Figure 3a
Upper End of Mandrel

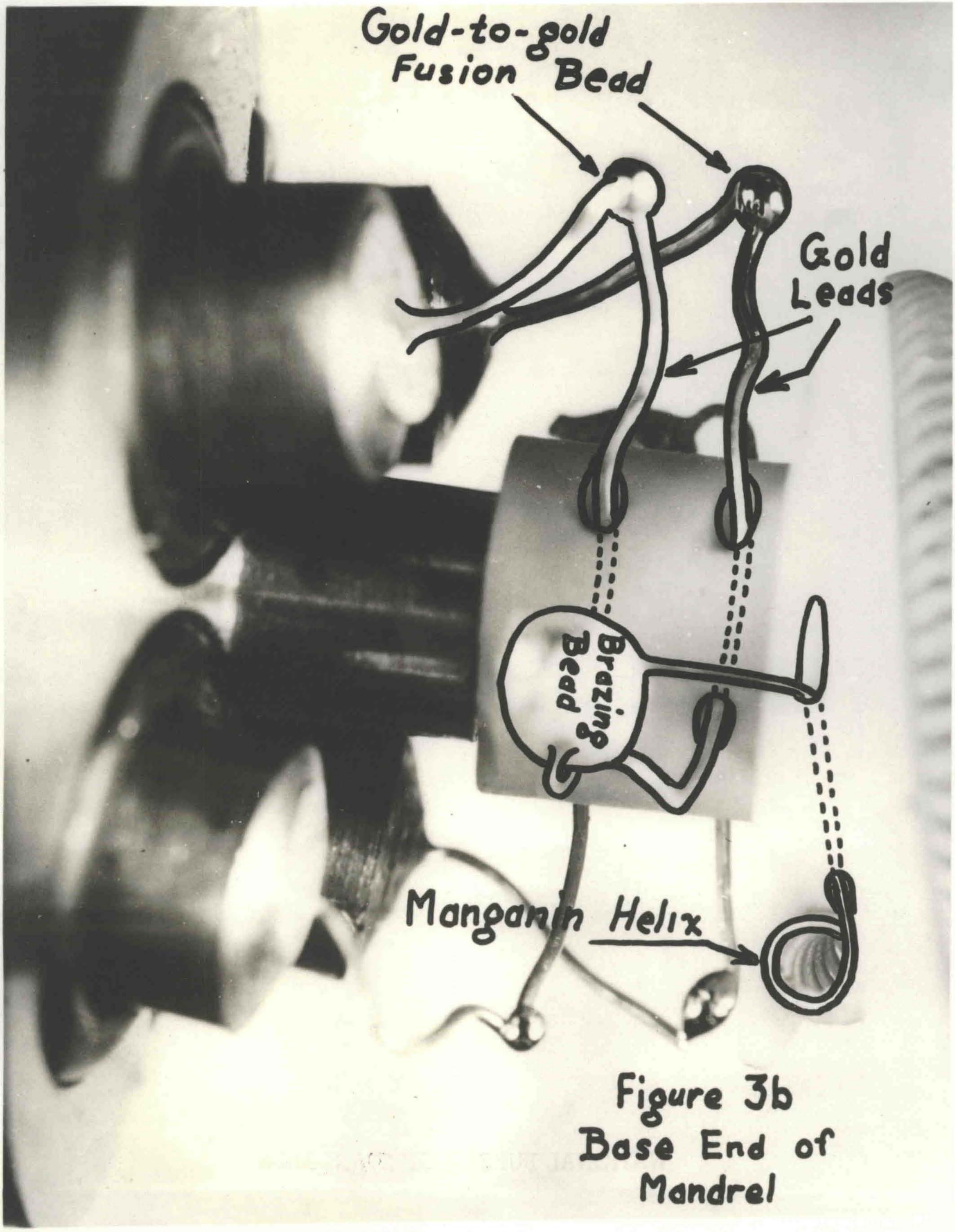
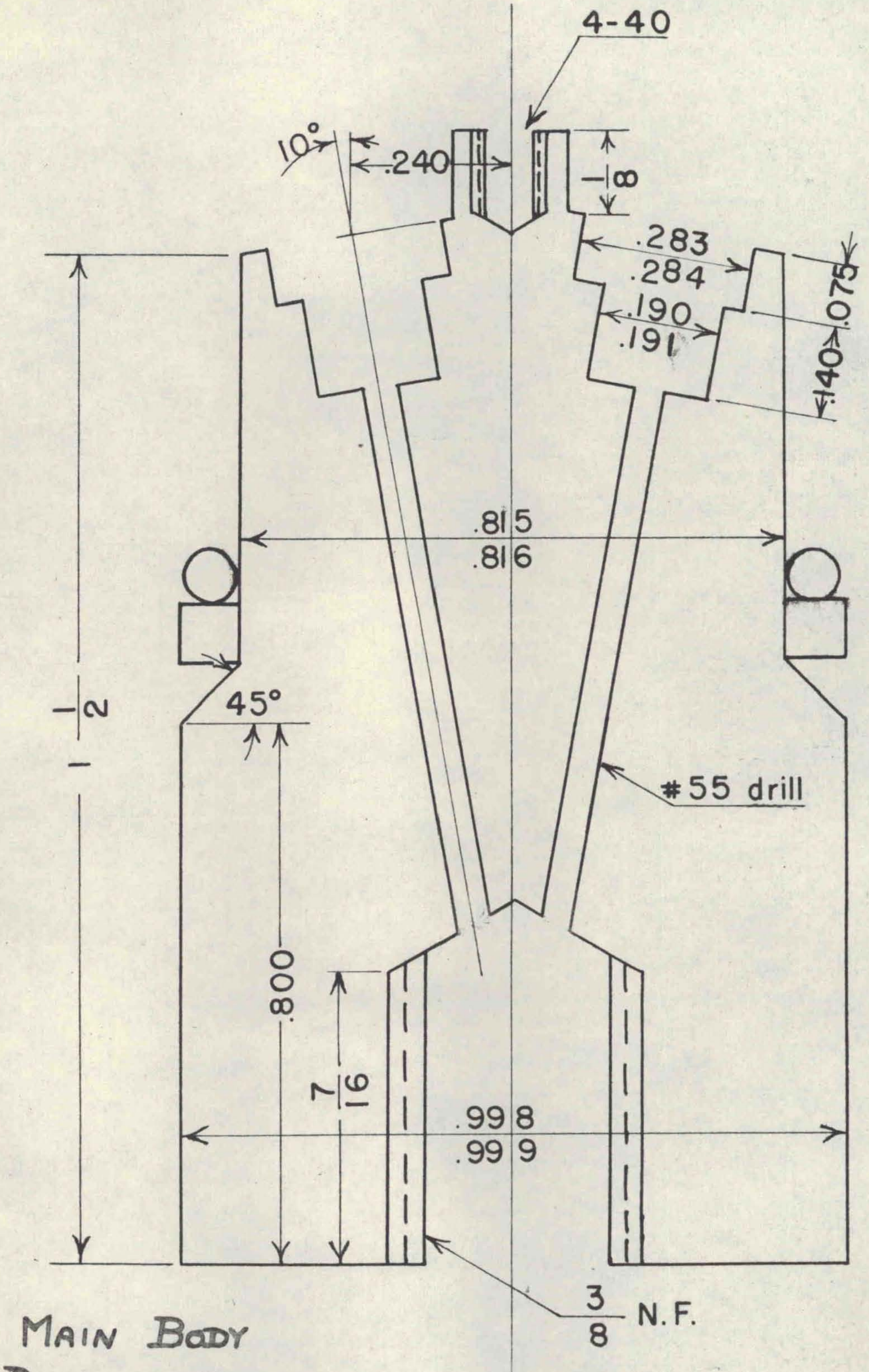
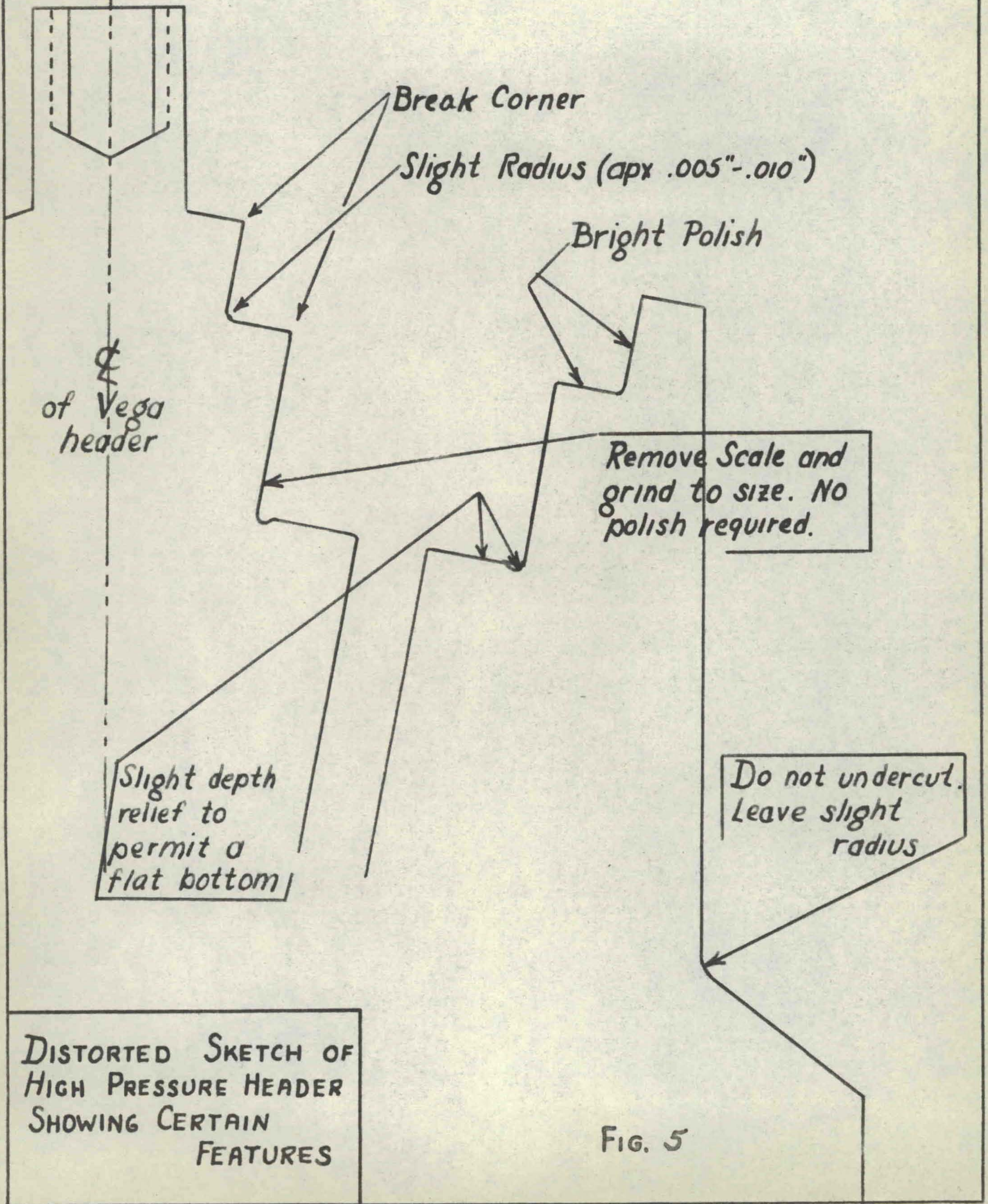


Figure 3b
Base End of Mandrel



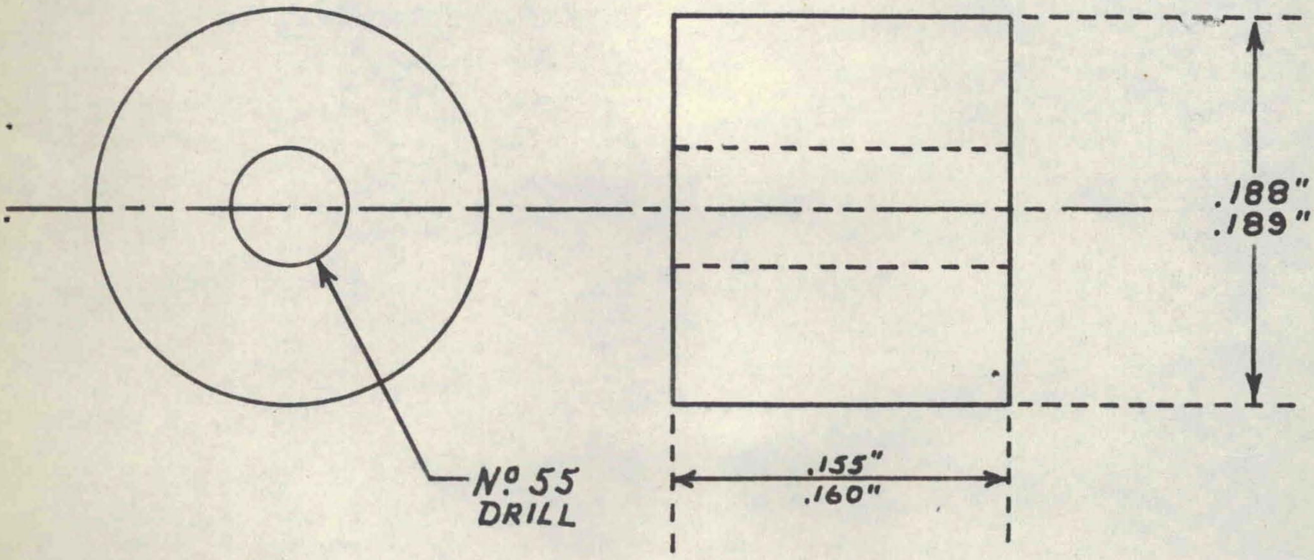
MAIN BODY DIMENSIONS

FIG. 4



DISTORTED SKETCH OF HIGH PRESSURE HEADER SHOWING CERTAIN FEATURES

FIG. 5



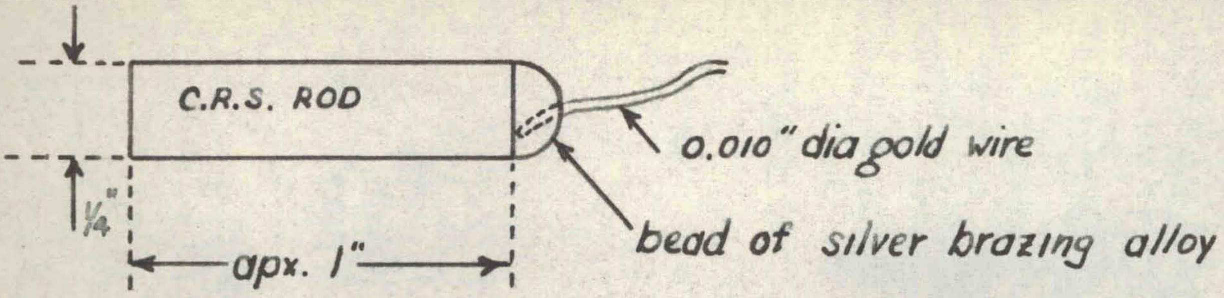
NOTES 1. Break all corners very lightly with paper

2. N.B.S. experience indicates that the O.D. and ends are best formed with high spindle speeds and very light cuts. Use carbide lathe tool with large clearance angle

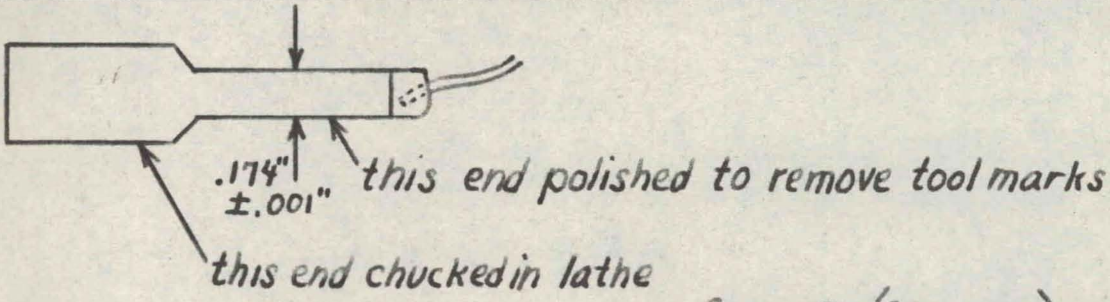
3. Avoid heating the work.

FIGURE 6

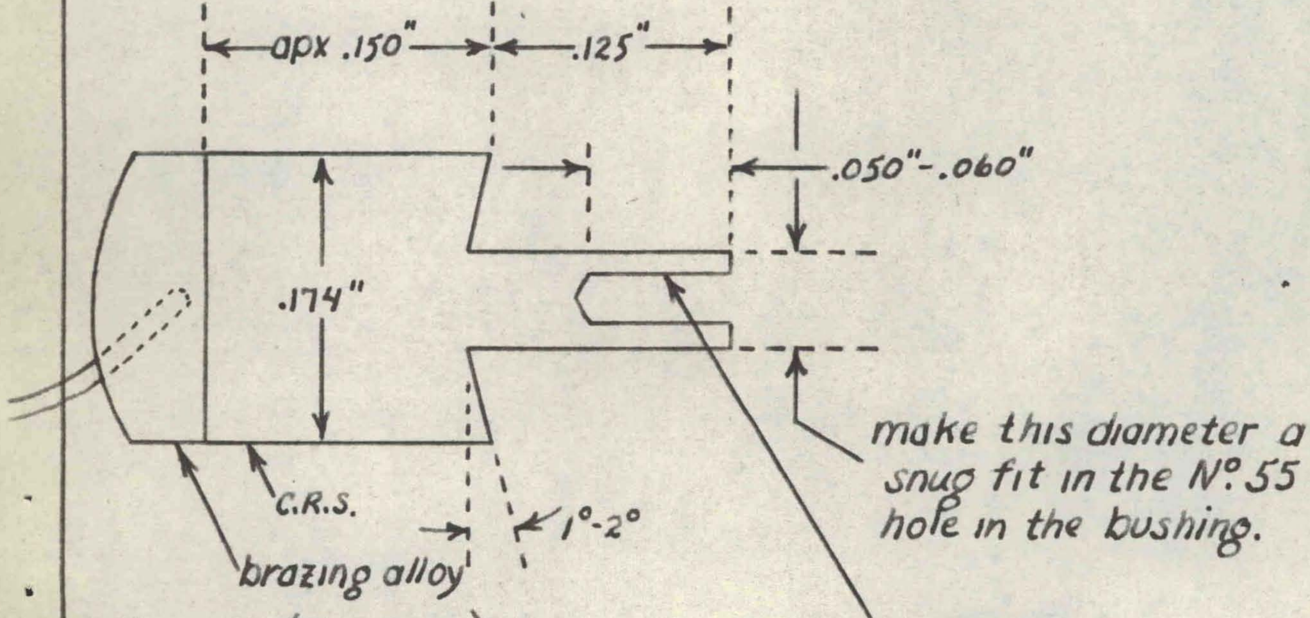
FABRICATION OF THE
LITHOGRAPHIC LIMESTONE
INSULATING BUSHING



STEP 1. BRAZING GOLD WIRE TO ROD (SEE TEXT)



STEP 2. (SEE TEXT)



STEP 3 (SEE TEXT)

FABRICATION OF THE ELECTRODE (SEE TEXT)

FIG. 7

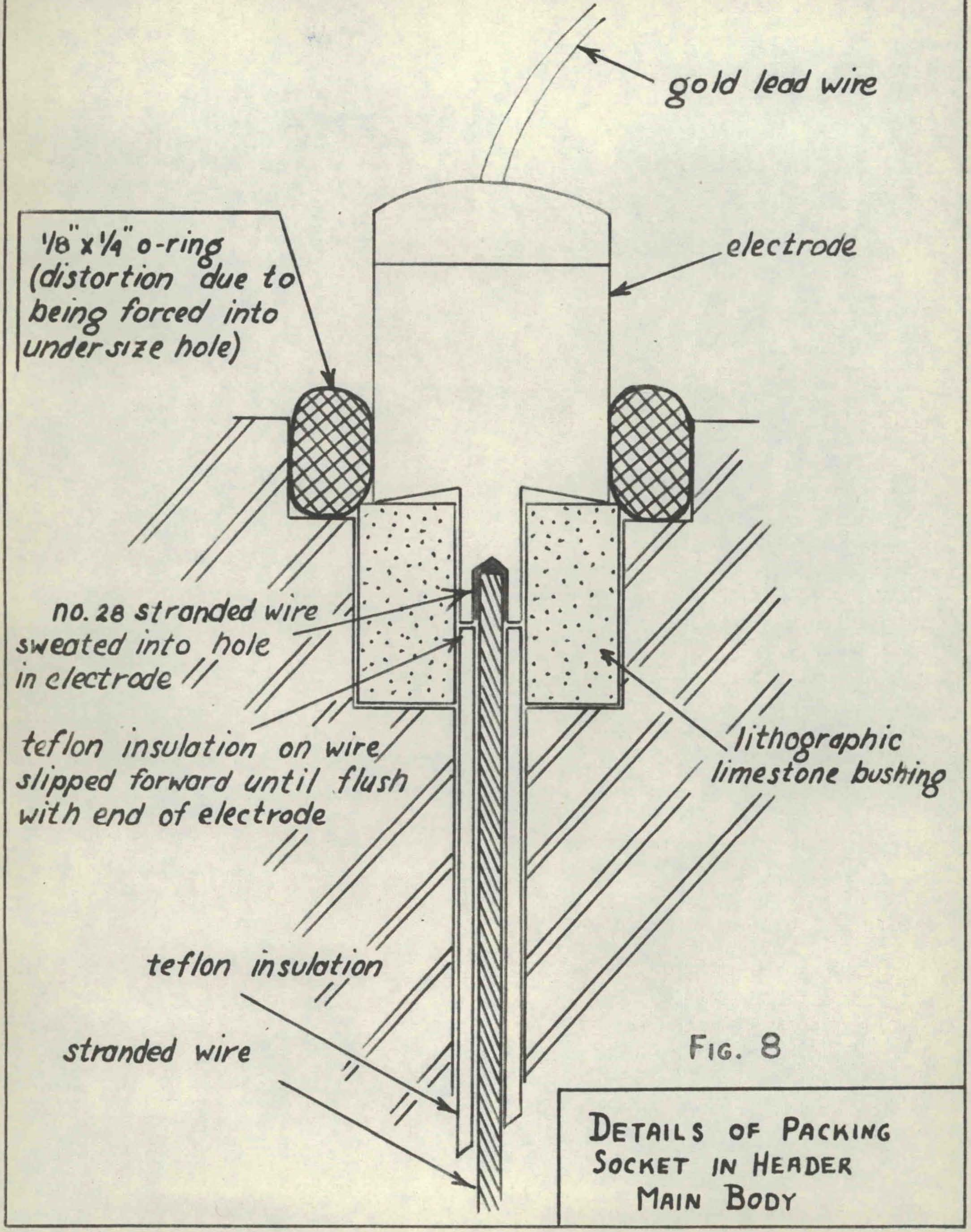
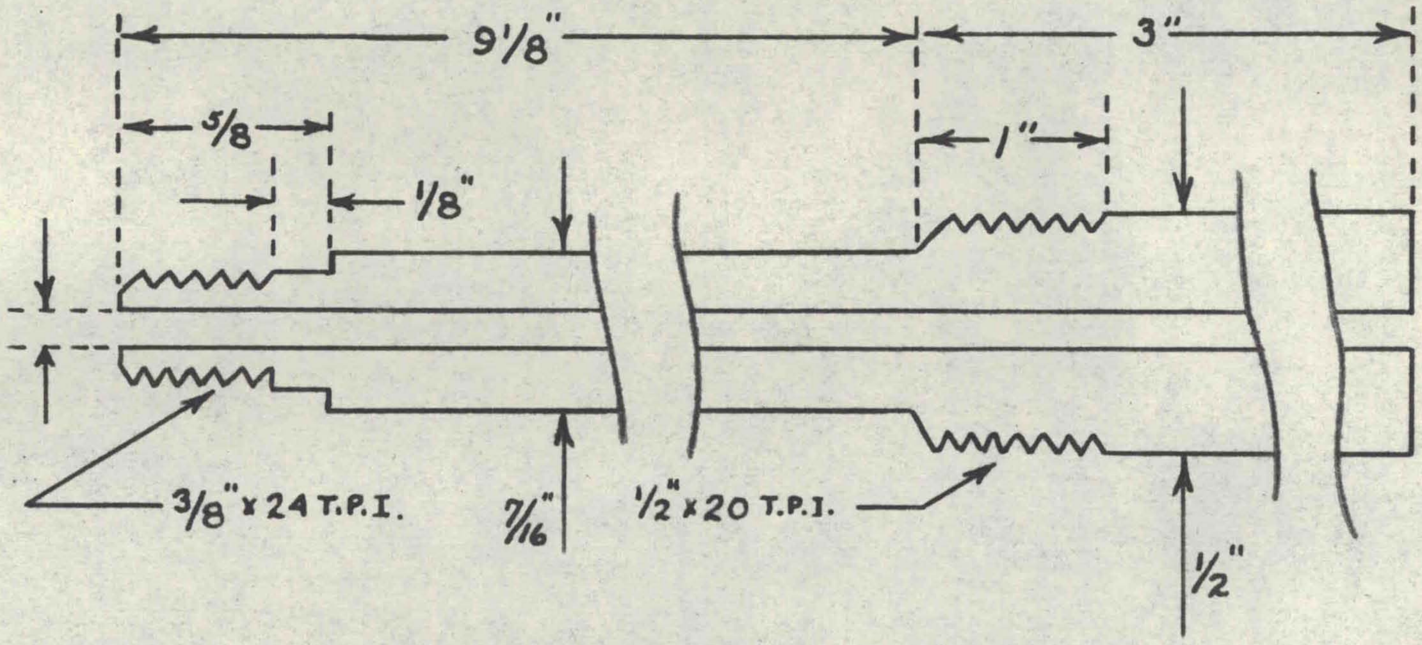


FIG. 8

DETAILS OF PACKING SOCKET IN HEADER MAIN BODY



NOTE: A flat is milled on the 1/2" diameter section to which is attached a 4-terminal soldering strip.

EXTRACTION BOLT
FIG. 9A

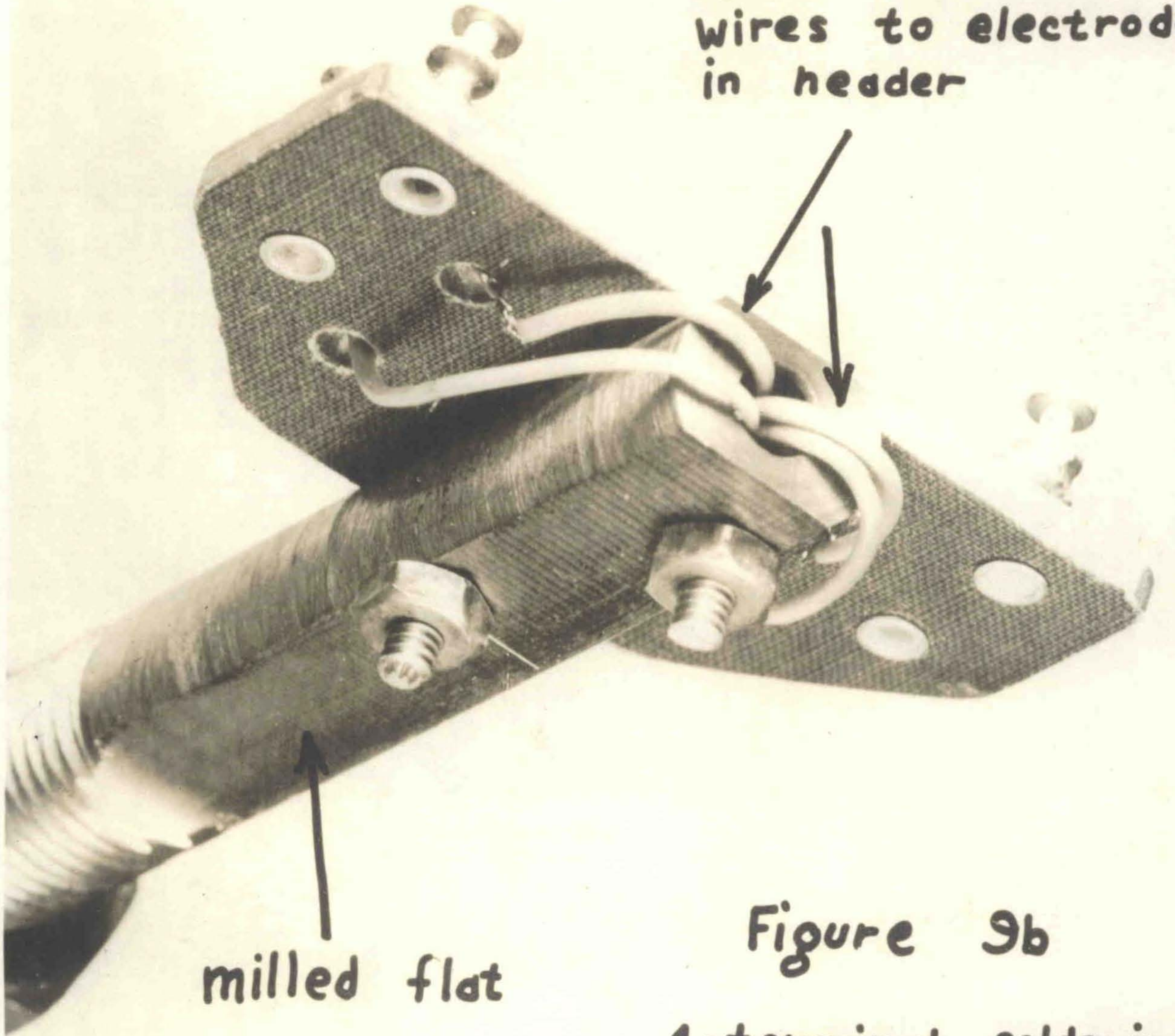
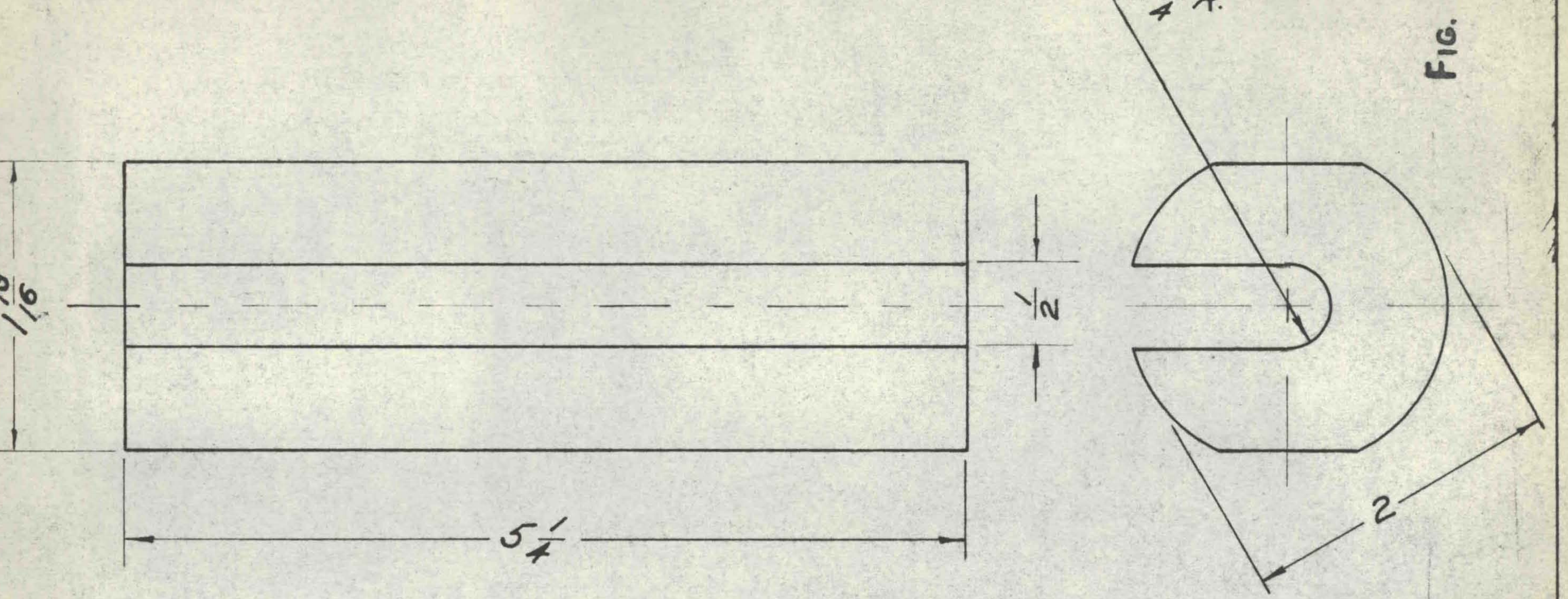


Figure 9b

4-terminal soldering strip at upper end of extraction bolt

FIG. 10



C.R.S.
SCALE 1-1

FIG 10

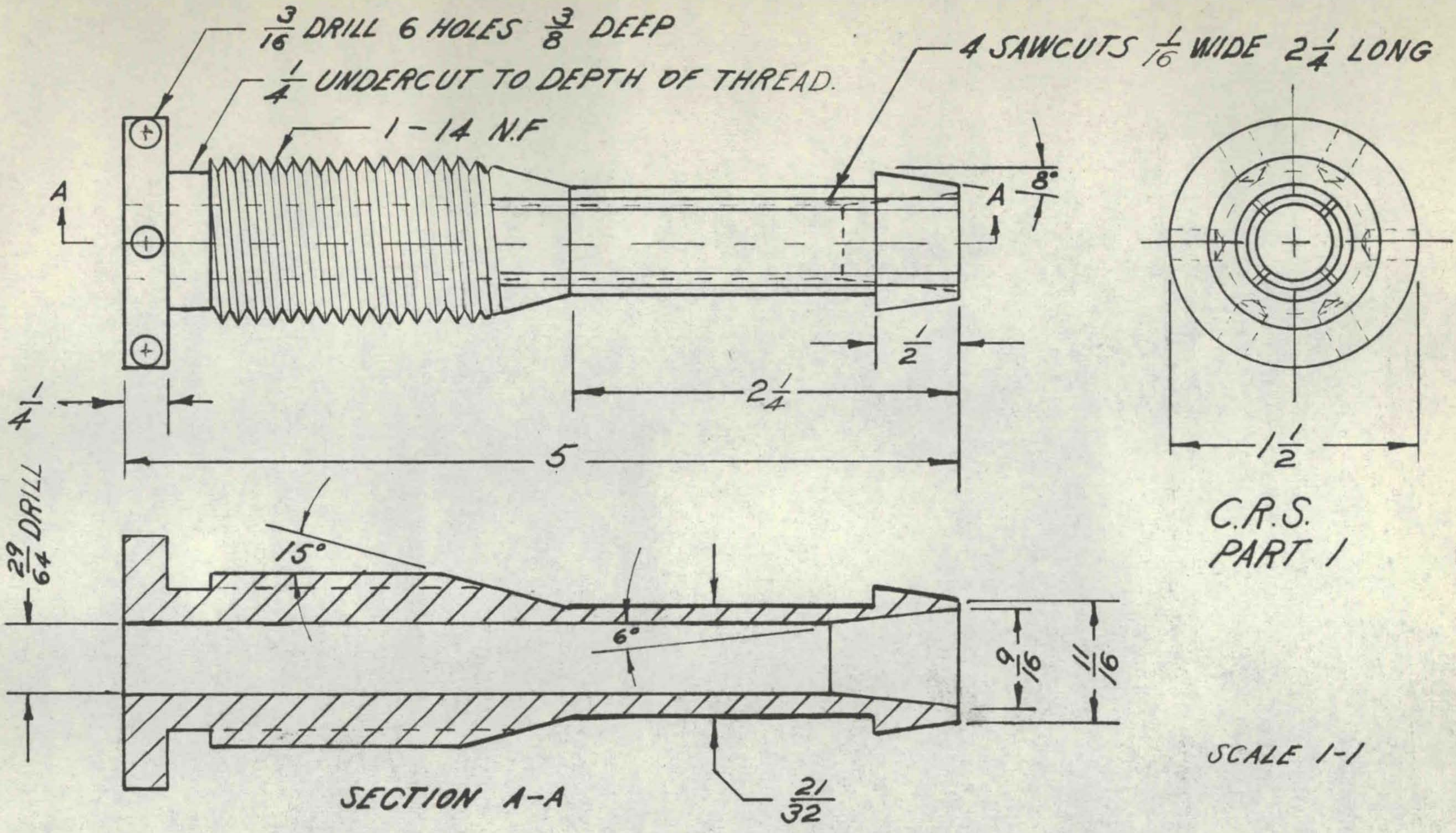
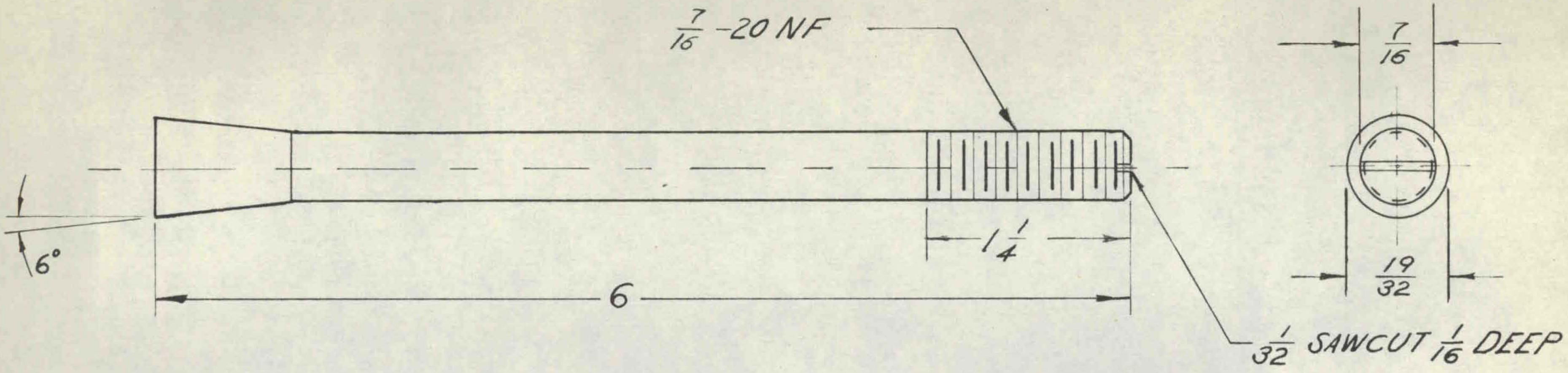


FIG. 11 A

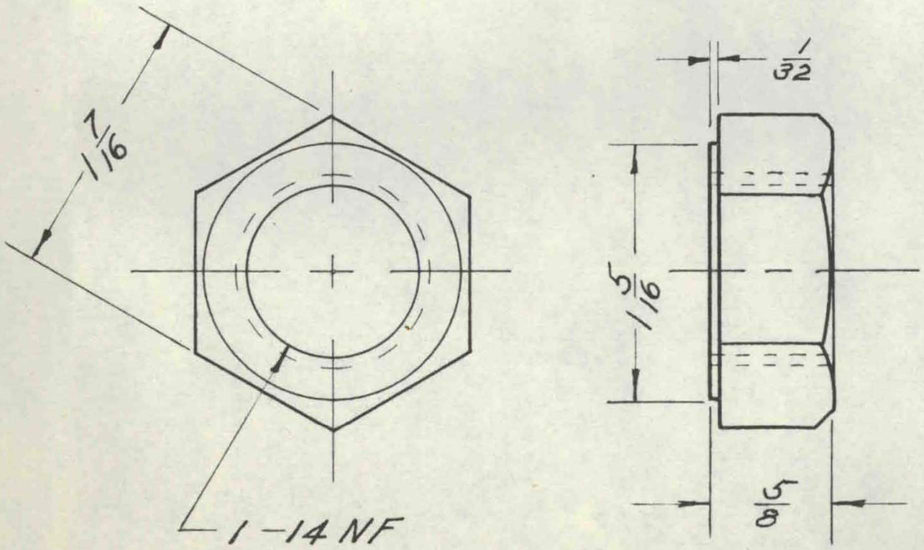
FIG 11-A

PART 2 C.R.S.

SCALE 1-1



PART 3 C.R.S.



PART 4 C.R.S.

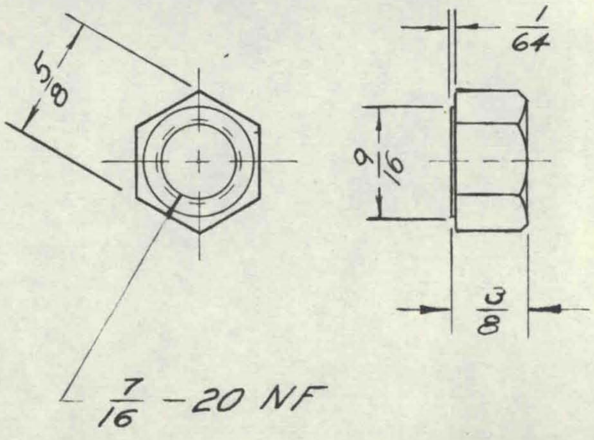


FIG. 11-B

FIG. 11-B

SCALE 1-1

SCALE 1-1

## THE NATIONAL BUREAU OF STANDARDS

### Functions and Activities

The functions of the National Bureau of Standards are set forth in the Act of Congress, March 3, 1901, as amended by Congress in Public Law 619, 1950. These include the development and maintenance of the national standards of measurement and the provision of means and methods for making measurements consistent with these standards; the determination of physical constants and properties of materials; the development of methods and instruments for testing materials, devices, and structures; advisory services to Government Agencies on scientific and technical problems; invention and development of devices to serve special needs of the Government; and the development of standard practices, codes, and specifications. The work includes basic and applied research, development, engineering, instrumentation, testing, evaluation, calibration services, and various consultation and information services. A major portion of the Bureau's work is performed for other Government Agencies, particularly the Department of Defense and the Atomic Energy Commission. The scope of activities is suggested by the listing of divisions and sections on the inside of the front cover.

### Reports and Publications

The results of the Bureau's work take the form of either actual equipment and devices or published papers and reports. Reports are issued to the sponsoring agency of a particular project or program. Published papers appear either in the Bureau's own series of publications or in the journals of professional and scientific societies. The Bureau itself publishes three monthly periodicals, available from the Government Printing Office: The Journal of Research, which presents complete papers reporting technical investigations; the Technical News Bulletin, which presents summary and preliminary reports on work in progress; and Basic Radio Propagation Predictions, which provides data for determining the best frequencies to use for radio communications throughout the world. There are also five series of nonperiodical publications: The Applied Mathematics Series, Circulars, Handbooks, Building Materials and Structures Reports, and Miscellaneous Publications.

Information on the Bureau's publications can be found in NBS Circular 460, Publications of the National Bureau of Standards ($1.25) and its Supplement ($0.75), available from the Superintendent of Documents, Government Printing Office. Inquiries regarding the Bureau's reports and publications should be addressed to the Office of Scientific Publications, National Bureau of Standards, Washington 25, D. C.

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