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ARMAMENT RESEARCH ESTABLISHMENT

MEMO No. 16/50

WEAPONS RESEARCH DIVISION

The Design of a Piezo-Electric Gauge for Closed Vessel No. 21

H. A. Flint and N. Lockett

Fort Halstead,
Kent.

September,
1950

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MEMO. NO. 16/50

(Weapons Research Memo. No. 8/50)

The Design of a Piezo-Electric Gauge for Closed Vessel No. 21

H. A. Flint and N. Lockett

Summary

This report is the third and final one of a series describing Closed Vessel apparatus in use in the A.R.E., the other two dealing respectively with Closed Vessel design (Ref. 1.) and the development of the recording apparatus (Ref. 3).

Since it was first introduced for routine purposes in the present connection, the design of Piezo-Electric gauge, employing tourmaline as the pressure-sensitive element, has closely followed that developed by the Gun Experimental Section for the recording of pressure-time phenomena in guns.

A brief account of modifications, mainly in the method of attaching the crystal to its electrodes, which have been made in recent years is followed by a description of the present gauge design and the manner in which it is calibrated.

Further developments are envisaged in the method of gauge assembly, and anticipated changes in calibration technique, to enable the Closed Vessel dP/dt pressure recorder to be employed in the determination of gauge sensitivity, are briefly outlined.

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1. Introduction

A brief account of the trends in the design of gauges used in Closed Vessel recording in the Armament Research Establishment is given in a previous report (Ref. 1), in which it was explained that, although Piezo-Electric gauges had been designed and used for this purpose as far back as 1927, they did not come into general use for Closed Vessel recording in this Establishment until 1942. Much experience had been gained in the use of tubular spring manometers in the recording of high and rapidly-varying pressures in stationary apparatus, and this system was considered to be superior, on accuracy grounds, to the Piezo-Electric method in its early stages of development. With advances in technique, however, it became evident that the electrical method possessed its own particular advantages, perhaps the most important being the ability to record the event in terms of rate of change of pressure.

For the recording of pressure-time phenomena in guns, the advantage of the Piezo-Electric method over the mechanical gauge is self-evident, and it had reached an advanced stage of development by the Gun Experimental Section by the time it was adopted for routine Closed Vessel recording. It was natural, therefore, for advantage to be taken of this accumulated experience in the design of a Piezo-Electric gauge for routine use in Closed Vessel No. 21, and for later improvements effected by the Gun Experimental Section to be incorporated in this design also.

It is well known that the Piezo-Electric property is shared by a comparatively large number of crystalline substances, but in practice the choice of a material suitable for use as the pressure-sensitive element for measuring high and rapidly-varying pressures, being dependent upon such considerations as mechanical strength and electrical output per unit volume, narrows down to two, viz. quartz and tourmaline. In the case of quartz it is necessary to use a piston as intermediary between the gas pressure and the pressure-sensitive element. Such a system is open to criticism on grounds of piston friction and the need for ensuring no escape of hot propellant gases past the piston. In these respects tourmaline is a superior material, as it is Piezo-Electrically sensitive to hydrostatic pressure and therefore does not require a piston. Also, the effects of secondary stresses due to end constraint are less serious with tourmaline than with quartz. In the absence, then, of any other overriding consideration, tourmaline is preferred to quartz for the present purpose. It is appreciated, however, that the latter material has its own particular advantages in certain applications, and has, in fact, been used in the A.R.E. as the pressure-sensitive element in gauges for measuring pressures in small-arms (Ref. 2).

In the early designs of Piezo-Electric gauge for both the gun and the Closed Vessel, the pressure-sensitive material used was black tourmaline cut into cylinders in such a manner that the electrical charges generated on the application of pressure appeared on the flat surfaces. It was considered, apparently without experimental verification, that continuous metallic films across the end-faces of the crystal were necessary for the collection of all the charge generated, and these surfaces were accordingly sputtered with platinum. After sputtering, the technique was to increase the thickness of the metallic film with an electrolytic deposit of copper, and then to cement the crystal into suitable electrodes. As an adhesive for this purpose, various types of cement have been employed, the one common factor being that they were made electrically conducting by the addition of colloidal graphite. For some years the satisfactory adhesion of the crystal to its electrodes remained an unsolved problem, the strength of the bond inevitably being degraded by the presence of the graphite in the cement. Adhesives containing a solvent were found to be unsatisfactory as they became permeable to oil following evaporation of the solvent, and frequently became unstuck during the process of calibration.

It should be explained here that the crystal is calibrated by measuring its electrical output during the release from it of an accurately known hydrostatic pressure, and that oil is used as the pressure medium.

Due to a combination of circumstances, there was some degradation in reliability of the gauge in use at one period during the early stages of the 1939-1945 war. An important contributory factor in this connection was the exhaustion of the original supply of black tourmaline, the source of which had become inaccessible. A fresh stock, obtained from an alternative source, was of inferior quality and had poor mechanical properties. Hair-line cracks on the crystal surface were common, and frequently led to fracture during sputtering, cementing, calibration and firing. In addition, difficulties in obtaining adequate insulation resistance were frequently encountered, due to penetration of sputtered metal and/or electrolyte into the cracks. Thus, a high proportion of crystals was rejected before reaching the final process in gauge make-up, and even those which survived up to this stage were not entirely reliable in later use.

It was at about this time that the Piezo-Electric method was adopted for routine use in Closed Vessel recording. In this application, the cement then in use was found to be unsatisfactory at elevated firing temperatures (e.g. 120°F.), and efforts were made to develop a more positive means for fixing the crystal to its electrodes. As a first step, some experimental work on the technique of the sputtering of metals was carried out. In this connection platinum has obvious advantages and was usually used, but films of other metals (e.g. copper) were successfully sputtered when certain precautions were taken. The strength of the metal to crystal bond was found to be considerably dependent upon the initial cleanliness of the crystal surfaces, and it was necessary to adopt elaborate cleaning techniques. For the sputtering of copper, it was found advantageous to allow a slight leakage of hydrogen into the bell-jar in which the process was carried out in order to avoid oxidation of the sputtered metal. Sputtering was usually carried out with a current of 15 milliamps at 2000 volts for a period of 6 hours. Both ends of the crystal were treated in this manner, and were then electroplated with copper to form a metallic layer of reasonable thickness. For soldering the crystal to its electrodes, a solder containing bismuth, lead and tin in the proportions of 40:40:20, and having a nominal melting temperature of 113°C, was employed, using zinc chloride solution as flux. To form a ready key for the solder, the surfaces to be joined were sometimes given an electrolytically-deposited coating of tin or lead.

The above method came into limited use, and was preferred to various similar techniques which were tried. It was necessary to exercise some care during the electrolytic deposition process, as, it is understood, this can be very effective in the removal of metallic coatings; such was, indeed, the experience in the present connection. The major difficulty, however, arose through the penetration of sputtered metal, electrolytic deposit, electrolyte and soldering flux into surface cracks in the inferior crystals available at that time, causing considerable degradation in insulation resistance of the made-up gauge, with consequent leakage of charge during its use.

The direct soldering of the copper-sputtered crystal to its electrodes (i.e. without the intermediate electroplating process) was performed successfully, but the joint could not be broken without causing severe damage to the sputtered film.

Alternative supplies of tourmaline were being sought, and the Gun Experimental Section ultimately acquired some crystals of gem quality. The specification for these crystals called for a matt finish on the ends to assist adhesion, and a polished finish on the curved surfaces to facilitate cleaning after assembly. Owing to its superior mechanical properties and general performance, this material soon supplanted the black variety previously used. Very few of the gem crystals were, however, free from internal cracks, but this did not appear to have any adverse effect on their functioning.

The question of whether metallic coatings on the crystal ends are, in fact, essential for efficient collection of the charge had meanwhile been given some consideration, and experiments had been carried out with gauges assembled with the omission of the sputtering operation. The main effect appeared to be a slight loss in gauge sensitivity, with no significant change in repeatability.

Some consideration had also been given to the validity of the argument that the adhesive used for cementing the crystal to the electrodes must be electrically conducting for efficient collection of the charge. Experiments designed to investigate this question had been carried out with the inferior grade of black tourmaline, using bitumen as cement, without arriving at any definite conclusion. This subject was reopened when the superiority of gem tourmaline had become established, and it was found that, with this material, satisfactory results could be obtained by using bitumen or resin as adhesive, thus indicating that it is not, in fact, necessary for the cement to be electrically conducting. The thickness of the cement layer was, however, found to be an important factor, making it desirable to employ the minimum amount necessary for adequate bonding. It was also found that the use of a non-conducting adhesive reduced the crystal sensitivity by an amount depending on thickness employed. However, it was clear that the thickness of the layer could be reduced to very small proportions by grinding the contacting faces of crystal and electrode to a high degree of flatness, and there was the further point that the omission of graphite was beneficial to the adhesive properties of the cement. There is, however, the important disadvantage that the use of an insulating cement leads to the build-up of a large voltage difference across the crystal faces, and this may result in charge leakage due to insulation break-down.

On balance it was concluded that the objection to an insulating cement outweighed its advantages, and that a conducting cement was to be preferred. Both resin and bitumen had been found to have excellent adhesive and manipulative properties, and, in addition, contain no highly volatile material. Also, it was found that they could be made sufficiently conducting by the addition of graphite without serious loss of adhesive properties. The final choice was a mixture of powdered resin and colloidal graphite in the proportion of 2:1 by volume, and this type of cement was used for some years with satisfactory results.

In attempting to assess the effect of gauge assembly on its performance, some uncertainty arises due to errors associated with the calibrating press and the recording equipment. The magnitudes of these errors are unknown, but it was considered that reversion to the use of a ballistic galvanometer, instead of the more recent arrangement of oscillograph and electronic equipment, for measuring gauge output during calibration should lead to some improvement in accuracy for the same expenditure of time. A ballistic galvanometer was therefore used, to a limited extent, in some assessments of gauge repeatability with various methods of sticking. In particular, the effect of the above-mentioned resin-carbon cement was investigated in this manner. As an example, gauge E, of gem quality tourmaline, was sputtered first with lead and then with copper, and was then soldered to the electrodes without having been copper plated. In the calibration runs, using the ballistic galvanometer for the measurement of output, the spread in sensitivity was 3.9% and the standard deviation of a single determination was 1.2%. This gauge was selected on this particular occasion because it had previously given somewhat variable results.

After the present calibration the gauge was broken down, the sputtering was removed, and the crystal was then re-cemented with the resin-carbon adhesive. In the further calibration runs the spread in sensitivity was 4% and the standard deviation was 1% - a result not appreciably different from the first. Assuming the first determination of mean sensitivity to be 100, this second mean came out at 98.2 i.e., nearly 2% less than the first, a figure which has high statistical significance. The contacting surfaces of crystal and electrodes were then ground flat, and the gauge was reassembled without the use of cement and with the contacting surfaces dry. The spread in sensitivity, again in the calibration was now 2.6%, the standard deviation was 0.6% and the sensitivity had increased to 100.6. This sensitivity is not significantly different from the first determination, but there is some improvement in regularity. Further calibrations were carried out with this same gauge assembly, the variant on this occasion being that the crystal ends were lubricated with a suspension of graphite in oil. This increased the spread in sensitivity to 3.2%, the standard deviation to 1.1%, and the sensitivity to 102.3. Compared with the first determination, this increase in sensitivity is statistically significant, and the inference is that the lubrication may have modified the stress distribution in the pressure-loaded crystal due to a reduction in end-constraint. The evidence here is not, however, conclusive, there remaining the possibility that the increase in sensitivity was brought about by the presence of the conducting medium. Removal of the lubrication and the use of mineral jelly in place of press oil around the crystal reduced the sensitivity to 99.5, the spread being 4.9% and the standard deviation 1.4%.

In experiments with gauge U, the use of resin-carbon cement instead of direct contact between the lapped crystal and electrode surfaces reduced the sensitivity by only 0.7%. At the same time the spread was reduced from 2.4% to 1.4%, and the standard deviation decreased from 0.7% to 0.6%. In view of the magnitudes of the deviations, this apparent difference in sensitivity can not be regarded as having any great significance.

It is clear that, for very accurate work, further attention must be given to the effect on sensitivity of the method of gauge assembly. So far, the experimental evidence indicates that the difference in gauge sensitivity due to change in assembly is consistently maintained, but, in the absence of a complete explanation of this phenomenon, some measure of doubt must remain regarding a gauge assembled in such a fashion that it does not develop its maximum output. Thus, it may be necessary ultimately to return to the sputtering technique, or to dispense with an adhesive and rely upon the adequacy of lapped crystal and electrode surfaces. In any event, improvement in gauge accuracy and reliability would appear to be dependent upon the availability of sufficiently accurate apparatus for the measurement of gauge output during calibration.

Apart from sputtering, little work on the application of metallic films to Piezo-Electric crystals has been carried out in the A.R.E. Crystals coated with silver by a volatilisation process have been tried with a considerable measure of success, but the possibility of failure was not entirely removed. Another well-known method of applying a silver deposit is to paint the crystal surface with a suspension of silver, and to melt the silver and drive off the carrier by baking at an elevated temperature. It is understood that "Hanovia" Burnish Silver Paste No.38 is suitable for this purpose, and that the rate of heating during the baking process should be such that the maximum temperature of 500°C, is reached in $1\frac{1}{2}$ hour. It is anticipated, however, that the gem tourmaline at present available would react unfavourably to this heating process, due to the presence of internal cracks.

2. Design of Piezo-Electric Gauge for Closed Vessel No. 21

This design is shown in Fig. 1. The pressure-sensitive element (detail 20) is a cylinder of gem-quality tourmaline approximately 0.5 in. in diameter and 0.25 in. long, with polished curved surface and matt-finished ends. A mixture of resin and carbon, in the proportion of 2:1 by volume, is used to cement the crystal into an electrode (detail 14) and to cement an earth-cap (detail 15) to its reverse end. For electrical insulation, the head of the electrode seats on a mica washer (detail 19), and the electrode stem is insulated by the surrounding sleeve of an insulating material such as ebonite or tufnol (detail 16). The electrode terminal nuts (detail 18) provided for connection to the recording apparatus are insulated by a washer of appropriate material (detail 22). A terminal (detail 17) screwing directly into the body of the gauge block is provided for earth return.

The axial orientation of the tourmaline crystal is such that the positive charge generated by the application of pressure is collected by the electrode to which it is cemented. The positive charge is collected by the earth-cap and conducted to earth by the spring-steel strip (detail 21) which is secured through screws (detail 25) at its ends to the gauge block body and bears on the cap. As well as providing a path to earth for the negative charge, the spring strip serves the secondary purpose of maintaining a rigid crystal-electrode assembly, an arrangement which was necessary with cements less reliable than that in present use.

It will be observed that the gauge electrode obturation is of the unsupported-area type. The pressure in the vessel chamber operates on the full cross-sectional area of the electrode head (0.283 sq. ins.), whereas the electrode head seats on an area which is smaller than this (only 0.234 sq. ins.). Thus, the sealing pressure is always some 20% greater than the pressure in the vessel. However, an occasional failure of this obturation has been experienced, and it is for this reason that the gauge electrode is mounted in a renewable bush (detail 5). A failure to obturate inevitably results in damage to the steel seating, and it is simpler to replace the bush than to repair this damage. The bush, also, is sealed by the unsupported-area principle, and seats on a copper washer (detail 24) for obturation purposes.

To assemble a gauge, the crystal seatings in the electrode and earth-cap are sprinkled with the resin-carbon mixture referred to above, and heat is gradually applied until the cement forms a continuous molten layer. Over-rapid and excessive heating will cause frothing of the cement, and this is to be avoided. The crystal is then assembled between the electrode and earth-cap in the jig shown in Fig. 3, during which time the cement has probably solidified. Further heat is applied very gradually until the cement again becomes molten, when surplus cement is forced out, under the influence of the spring, through the castellations provided for this purpose. After cooling, surplus cement is scraped away, and the gauge is then ready for use.

3. Gauge Calibration

The gauge is calibrated by subjecting it to an accurately-known hydrostatic pressure and measuring its electrical output when this pressure is released. Thus, it is assumed that the crystal sensitivity (i.e. its electrical output per unit of pressure) is the same for pressure application as for pressure release.

For the purpose of calibration, the unit comprising gauge electrode, tourmaline crystal and earth-cap is transferred from the vessel gauge-block to an adaptor (see Fig. 4) fitting the calibrating press, in which pressure is applied to the crystal through the medium of castor oil. The pressure is applied first by a hand-pump of limited range, and then by a screw-operated ram for higher pressures and final adjustment. The calibrating pressure of 5 tons/sq. in. is reached when the appropriate load on the measuring piston is counterbalanced by the oil-pressure on the piston end, and the piston commences to float. The piston is then rotated to eliminate frictional effects. The pressure is suddenly released by the rapid opening of a screw-down type of valve in the gauge adaptor, and the amount of charge developed by the crystal during this process is measured by recording the voltage build-up across the plates of a condenser connected in series with the crystal. This voltage, after amplification, is applied to the deflecting plates of a cathode-ray tube, and the resultant deflection of the spot is photographed, using a rotating-drum camera.

Immediately prior to the release of pressure from the crystal a series of accurately-known voltages is applied, through the amplifier, to the cathode-ray tube, for amplifier calibration. Thus, the photographed trace (see Fig. 5(a)) commences with a series of five steps corresponding to known voltages, followed by a signature corresponding to the release of the calibrating pressure from the crystal. It is then a simple matter to interpret, in terms of a voltage, the height of the pressure-release curve, and hence, knowing the capacity of the gauge-loading condenser, to calculate the gauge output.

The calibrating pressure of 5 tons/sq. in. is used as a matter of convenience, and a linear relationship between pressure and gauge output is assumed. The justification for this assumption lies in the results of past experiments, which had failed to detect any significant departure from linearity. It is usual to express gauge sensitivity in terms of micro-coulombs per ton/sq. in. of pressure applied. For the size of tourmaline crystal at present in use, (viz. 0.5 in. in diameter and 0.25 in. long), the sensitivity is usually between 0.004 and 0.005 micro-coulomb per ton/sq.in.

4. Further Developments

Experiments have recently been carried out by the Gun Experimental Section with a thermo-setting synthetic resin for cementing the tourmaline crystal to its electrodes. This material has been found to be more satisfactory than the resin-carbon cement, and will therefore be used in future in the making-up of Closed Vessel gauges.

The particular type of synthetic resin in question was developed by Messrs. Ciba Ltd., of Basle, Switzerland, and is marketed in Great Britain by Messrs. Aero Research Ltd., of Duxford, Cambridge, under the name of "Araldite" Type 1. In the present application, the powder form is used. In order to make it electrically conducting it is mixed with powdered graphite, in the proportion, by volume, of two parts of resin to one of graphite. This inevitably reduces the effectiveness of the adhesive, but the remaining mechanical strength appears to be ample for the present purpose.

The surfaces to be joined are cleaned, and sufficient of the powder mixture to ensure a continuous film of adhesive in the final joint is sprinkled on the seating surfaces on the electrode and the earth-cap, which are then gently warmed to a temperature between 100 and 120°C. This temperature is sufficient to melt the Araldite and cause it to flow easily over the metal surfaces. The electrode, crystal and earth-cap are then assembled together, and further heat is gradually applied to raise the temperature to the 100 - 120°C. level. This temperature is maintained for a few minutes to facilitate penetration by the molten adhesive, during which process it is necessary to ensure that the surfaces to be joined are held together by some suitable means e.g. the fixture shown in Fig.3. The joint is then cured by heat-treatment for 40 minutes at a temperature of 200°C.

The strength of this adhesive is such that if it is employed to bond together two materials with markedly different thermal expansion properties, (e.g. brass and tourmaline), it is capable of transmitting thermal stresses, on cooling down from the temperature of curing, to fracture the weaker of the two (i.e. the tourmaline).

It is possible to break this type of joint by heating it beyond 200°C, when the adhesive becomes plastic.

Further improvements in gauge design are largely dependent upon the development of techniques for the more accurate assessment of gauge sensitivity. One objection to the present method of gauge calibration is that it employs a pressure-time recorder, and not the dP/dt-pressure recorder (Ref.3) which is used in Closed Vessel firings. This arrangement was an interim measure, adopted on the grounds of convenience, whilst efforts were being made to develop a technique enabling calibration signals to be recorded by the Closed Vessel recorder. It is obviously desirable to use the same recording apparatus for both gauge calibration and Closed Vessel firings. The first difficulty encountered is that the C.V. recorder is designed for operation only by a positive signal. The gauge design, therefore, is such that the application of pressure, as in the C.V., causes a positive electrical charge to be delivered to the recorder. The calibration signal, however, is produced by the removal of pressure from the crystal, and this is therefore of reversed polarity compared with the C.V. signal and can not be recorded. The obvious way of overcoming this difficulty is to reverse the crystal end-for-end in its electrodes for calibration purposes, but this involves breaking the cemented joints, with the possibility of some change in gauge sensitivity. An alternative method, which so far has been used for experimental purposes only, is to cement steel discs, of the same diameter as the crystal, to the crystal ends, making it unnecessary to cement the crystal to the electrode. The polarity can then be reversed without having to break cemented joints, and calibration signals can then be directly recorded. This method has given more satisfactory results than one in which a special design of calibrating adaptor was used to enable the charge to be collected from the earth-cap.

A satisfactory method of reversing gauge polarity having been developed, it became possible to use the C.V. recorder for recording calibration signals. Further difficulties now arose due to the peculiar relationship between pressure and time during pressure release in the calibrating press. This will be readily understood on referring to Fig. 5(a) from which it can be seen that, in this particular instance, a pressure pulse in the hydraulic system of the press was recorded. In such circumstances the electronic switch-gear in the recorder is capable of blacking-out the C.R.T. and operating the calibration circuits at the first return of dP/dt to zero, with loss of the remaining portion of the signal.

A further difficulty is that the apparatus was designed to record a limited family of curves, and blacking-out of the C.R.T. can occur before the maximum pressure deflection is reached, as in Fig. 5b. The pressure pulse was eliminated by alterations to the hydraulic system, and by operating the pressure release valve through a system of lever, rope, pulley and weights. In this way the record drawn in Fig. 5c was obtained. It will be seen that in this case also the spot was blacked out before the maximum deflection in the pressure direction was reached. Fig 5d is a similar record, with longer exposure of the spot to enable the complete curve to be recorded. This curve is obviously unsatisfactory for the accurate measurement of pressure deflection. This conclusion could, of course, be forecast from the shape of the pressure-time curve (Fig. 5a), the slope of this curve decreasing very gradually as the maximum deflection is approached. In making the Fig. 5d recording, the spot ultimately becomes stationary at the point of maximum pressure deflection, and this leads to considerable thickening of the trace, making it impossible to make the necessary measurement with any reasonable degree of accuracy.

It is apparent then, that for satisfactory recordings of calibration signals to be made on the dP/dt-pressure apparatus, a considerable modification in type of signal is necessary. For accurate definition of the maximum pressure deflection, the path of the spot should be parallel (or nearly so) to the pressure calibration grid, and the spot writing speed should be equal (or nearly equal) to that employed in applying the calibration grid, towards the end of the event. In other words, the rate of pressure release from the calibrating press should increase to a maximum and then decrease almost instantaneously to zero. No doubt these conditions could be approached by suitable modifications to the hydraulic system and the method of pressure release, but it was felt that this would involve considerable experimentation and expenditure of time. It was considered that a solution to this problem could be obtained more rapidly by using only the pressure signal from the crystal, and employing a signal from a separate source for providing deflection in the dP/dt direction. In initial experiments the secondary signal was obtained by inducing a current in a coil by the movement near it of a magnet attached to the pressure release system. Thus, there was no difficulty in synchronizing the two signals, but the secondary signal was not of the appropriate form, as can be seen from Fig. 5e.

The appropriate type of dP/dt sweep is obtainable from the Closed Vessel signal simulator, but the difficulty here would be in synchronizing the signals. Promising results have, however, been obtained using two gauges which are subjected to the same calibrating pressure, the gauge under test supplying the sweep in the pressure direction, and the secondary gauge giving the dP/dt sweep. Connection between the secondary crystal and the differential amplifier is through a condenser, i.e., the resultant deflection of the spot in both directions is in terms of pressure. Thus, if the two gauges have the same characteristics, the C.R.T. spot will be deflected in a straight line when the calibrating pressure is released. The spot will ultimately become stationary upon the completion of pressure release, and after this stage will drift back along its previous path due to leakages. This type of record would be no better than that shown in Fig. 5d, but the conditions are capable of adjustment through the circuit of the secondary gauge, the sole purpose of which is to provide a sweep. The circuit of the secondary gauge is provided with a leak to earth, with the result that, towards the end of the event, as the maximum pressure deflection is approached, the electrical charge causing deflection in the dP/dt direction leaks away and the C.R.T. spot travels rapidly in the direction of zero dP/dt. The leak in the circuit of the secondary gauge is, of course, operating during the whole of the event, and this reduces the amount of charge available for maximum dP/dt excursion, but the available range of dP/dt gain is adequate to deal with this.

The dP/dt gain is, in fact, adjusted so that only the beginning and end of the event are recorded on the photographic paper, so that the desired end conditions are obtained. A specimen record of this type is shown in Fig.5f; the zero drift, which is believed to be associated with the additional circuitry employed in these experiments, is not important in the present connection, as the only measurement required is the maximum deflection in the pressure direction.

Summarising the above, there is now available a method of using the Closed Vessel dP/dt-pressure recorder in the calibration (i.e. sensitivity determination) of tourmaline pressure gauges. This method involves the cementing of metal discs to the crystal ends so that the polarity of the gauge may be reversed without breaking cemented joints. The gauge may then be calibrated by employing a second crystal, operated upon by the same calibrating pressure as the first, to provide the necessary sweep in the dP/dt direction. To date, there is no information regarding the possibility of slight changes in sensitivity occurring due to the reversal of polarity, but experiments are being carried out with an alternative method which makes this operation unnecessary. This method employs a total of three crystals, which are cemented to their electrodes in the normal manner. The first gauge is the one which is to be calibrated, and is of the appropriate polarity for Closed Vessel recording. The second crystal is of reversed polarity compared with the first, and its sensitivity may therefore be determined by the two-gauge method outlined above. For this purpose a third gauge, of the same polarity as the second, is required for providing the dP/dt sweep. The sensitivity of the second crystal is greater (by say, 10%) than that of the first, and is determined accurately by an appropriately large number of calibration runs, as it is to serve as a standard. Gauges one and two are then assembled in the same calibrating adaptor as the first, so that the same calibrating pressure can be applied to the two gauges simultaneously, and are connected together so that their inputs are in opposition. Gauge two has the greater sensitivity, and its output will therefore predominate over that of gauge one. The polarity of the resultant signal will be of correct polarity for operation of the Closed Vessel recorder. As it is merely a difference which is to be recorded, the relationship with time will be linear, and it will be possible to obtain a suitable shape of recorded curve, using the differentiating circuit of the Closed Vessel recorder. The curve should, of course, be rectangular in shape, and it should be possible to measure its width (which represents the difference in sensitivity between the two gauges) to a high degree of accuracy.

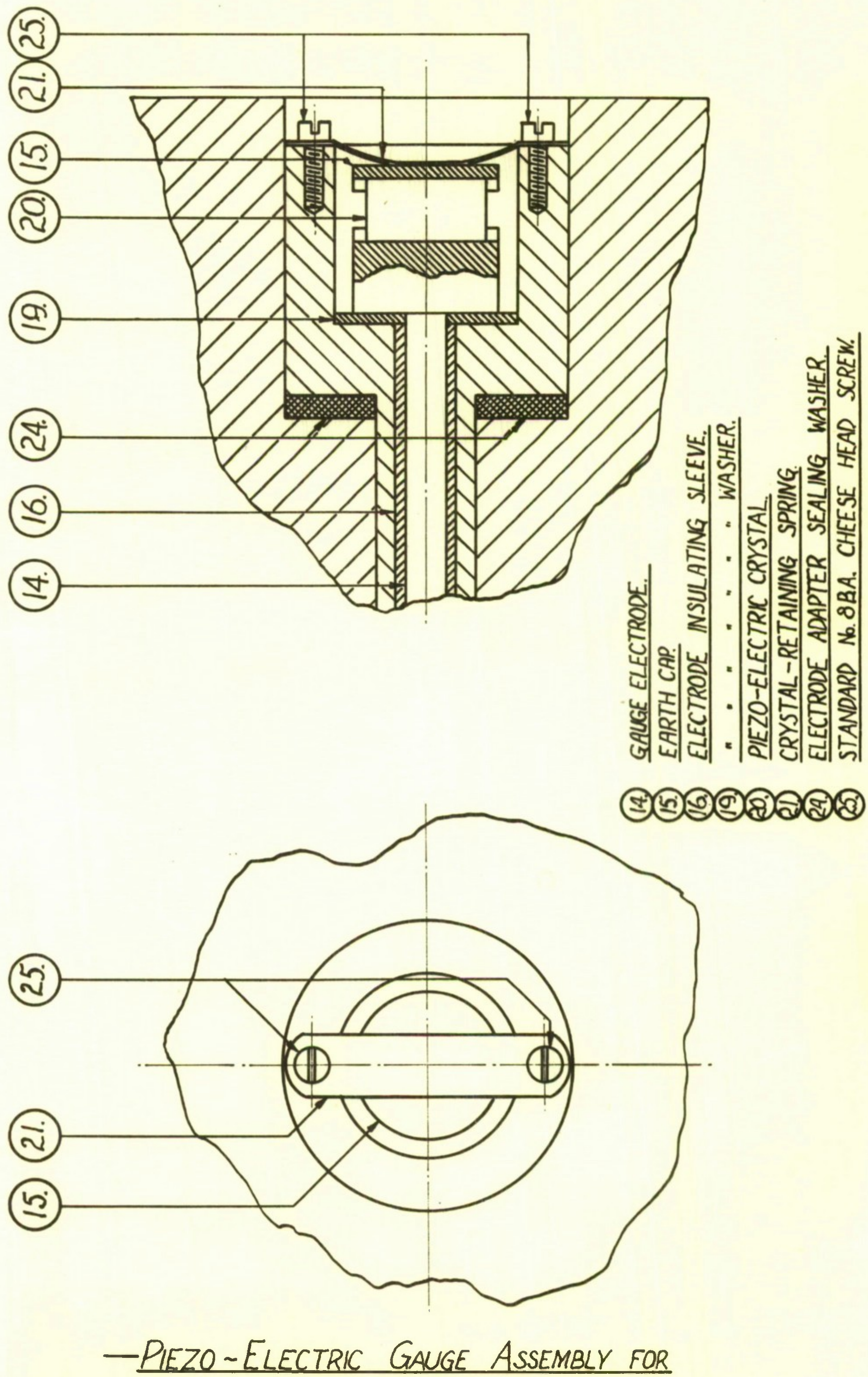
5. Bibliography

(1) H.A. Flint "The design of a Closed Vessel (No.21) for routine examination of propellants for guns". A.R.E. Memo. No. 15/50.

(2) S.P. Hillson and J.E. Brickell. "A Piezo-Electric gauge for the measurement of pressures in small arms". A.R.E. Terminal Ballistics Report No.4/44.

(3) H.A. Flint. "The development of a Closed Vessel Piezo-Electric recording equipment". A.R.E. Report No.18/50.

-FIG. 1-



—PIEZO-ELECTRIC GAUGE ASSEMBLY FOR CLOSED VESSEL No. 21.—

-CONFIDENTIAL-

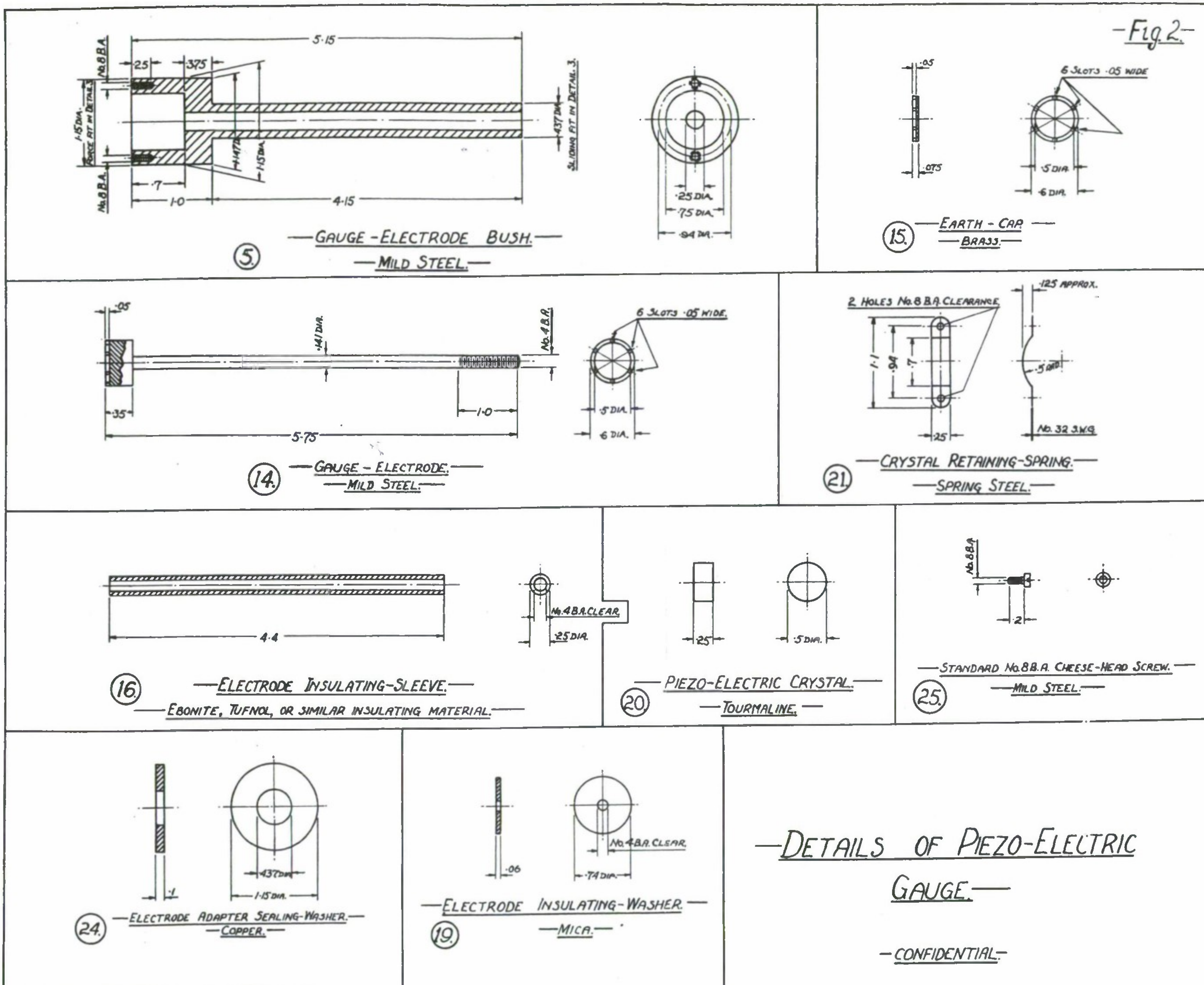


Fig. 2.

DETAILS OF PIEZO-ELECTRIC GAUGE.

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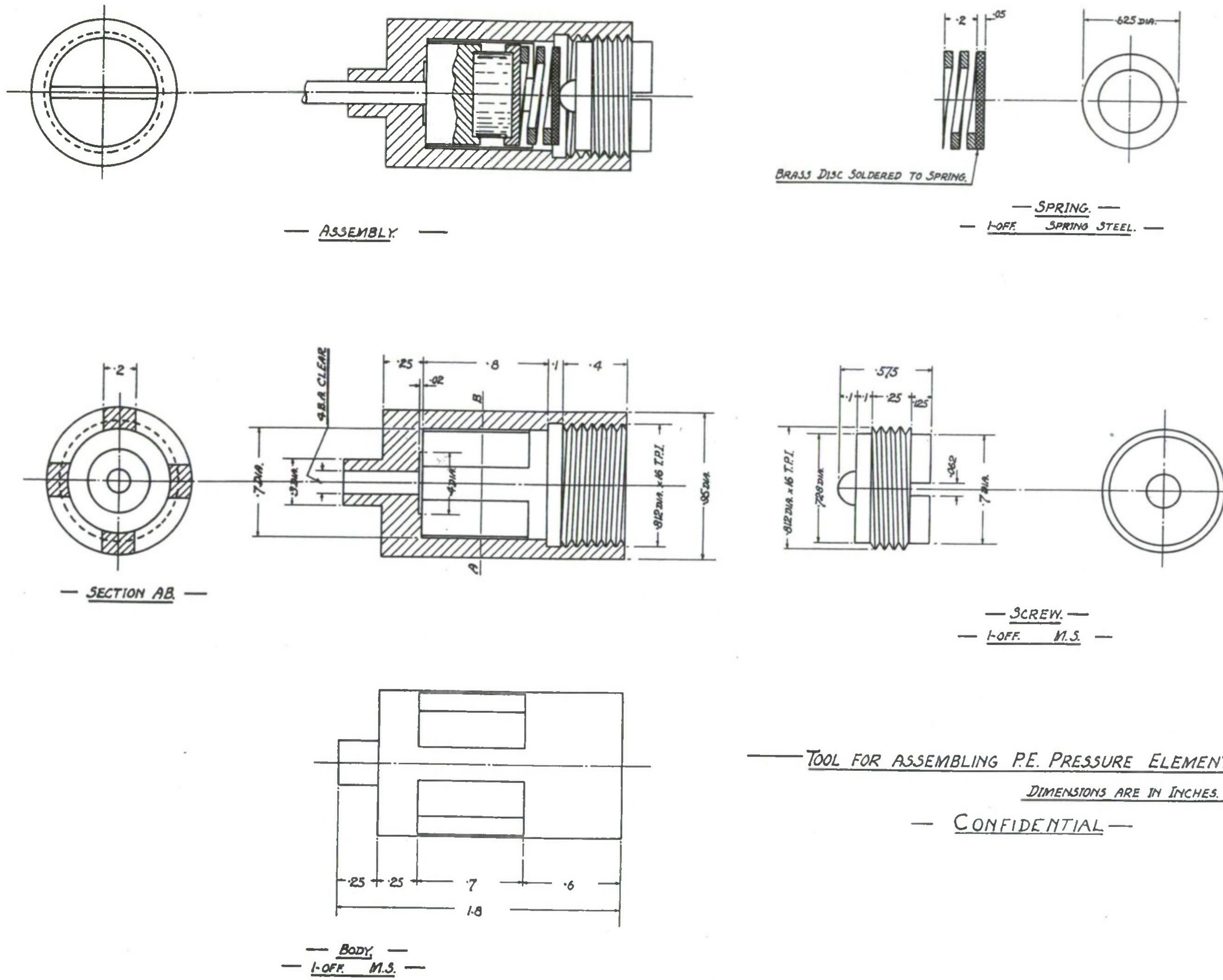
Fig 3

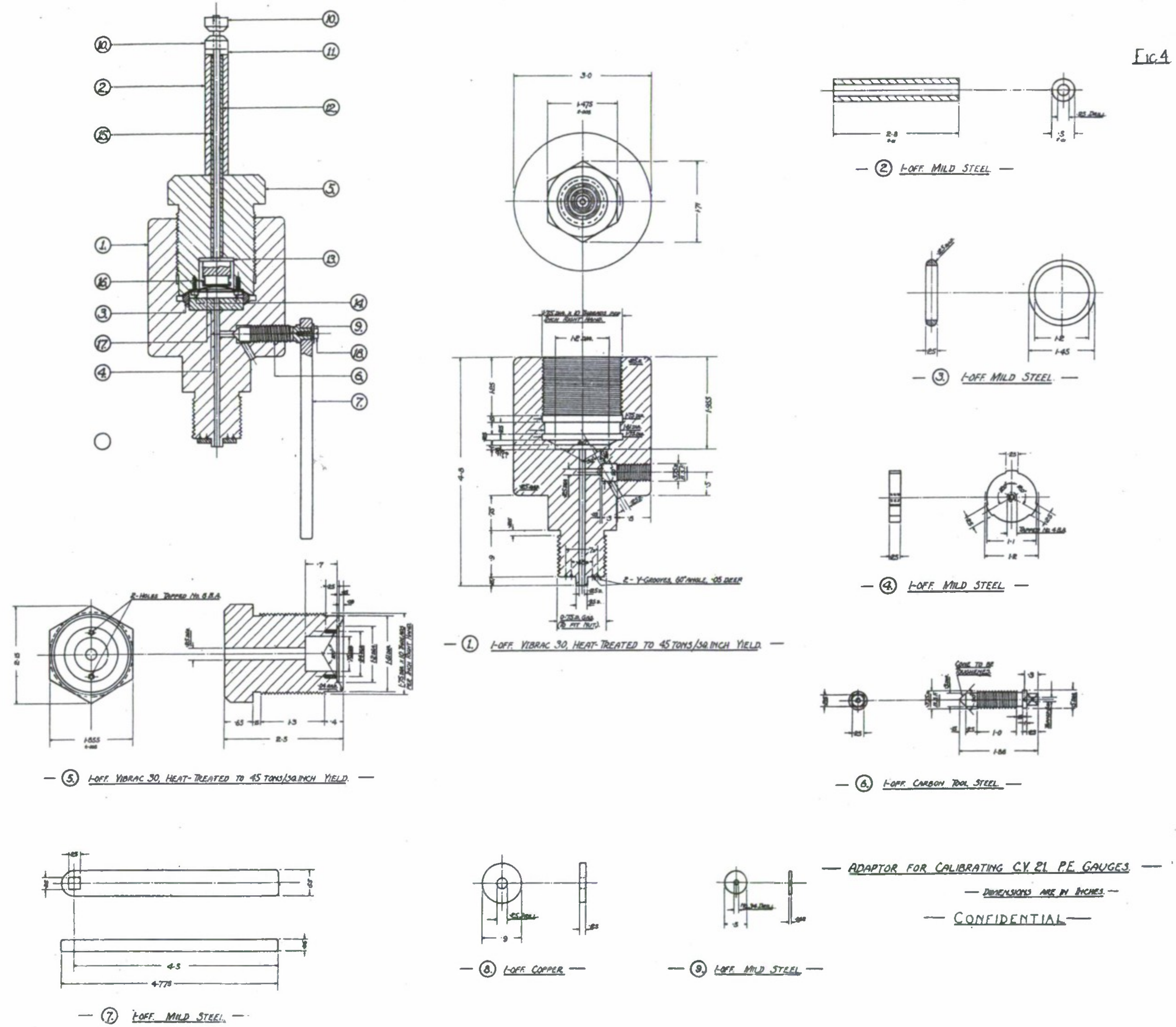


— TOOL FOR ASSEMBLING P.E. PRESSURE ELEMENTS. —

DIMENSIONS ARE IN INCHES.

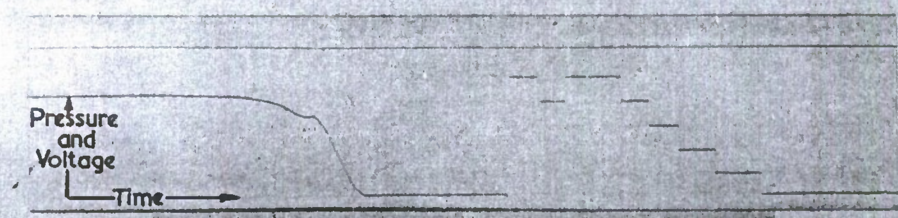
— CONFIDENTIAL —

Fig 4

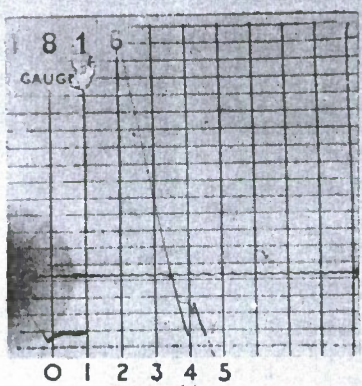


— ② 1-OFF. MILD STEEL. —
— ③ 1-OFF. MILD STEEL. —
— ④ 1-OFF. MILD STEEL. —
— ⑥ 1-OFF. CARBON TOOL STEEL. —
— ① 1-OFF. VIBRAC 30, HEAT-TREATED TO 45 TONS/SQ.INCH YIELD. —
2 - V-GROOVES, 60° ANGLE, ·05 DEEP
— ⑤ 1-OFF. VIBRAC 30, HEAT-TREATED TO 45 TONS/SQ.INCH YIELD. —
2-HOLES TAPPED No. 6 B.A.
— ⑦ 1-OFF. MILD STEEL. —
— ⑧ 1-OFF. COPPER. —
— ⑨ 1-OFF. MILD STEEL. —
— ADAPTOR FOR CALIBRATING C.V. 21 P.E. GAUGES. —
— DIMENSIONS ARE IN INCHES. —
— CONFIDENTIAL —

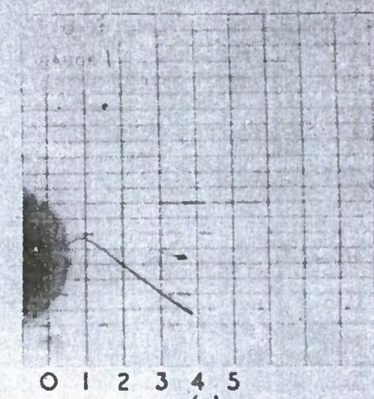
Fig. 5.



(a). PRESSURE-TIME CALIBRATION CURVE.

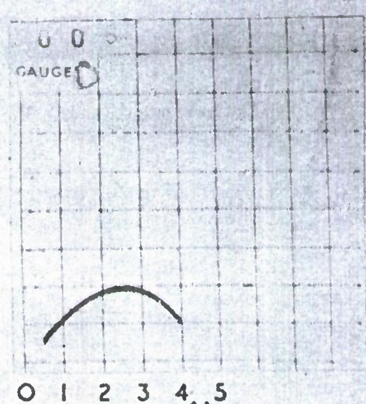


(b).

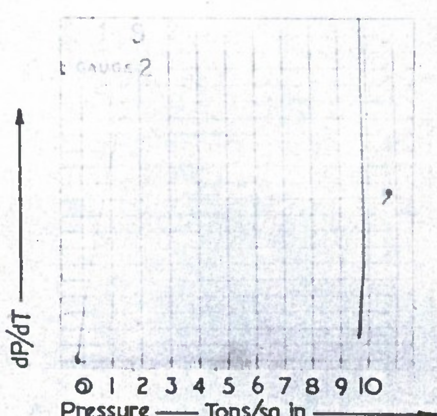


(c).

(d).



(e).



(f).

b.c.d.e & f:- dP/dT - PRESSURE CALIBRATION CURVES.

NOTE:- For records (b), (c), & (d) dP/dT deflection was provided by the crystal under test.

For (e) & (f) a separate signal was used to provide the "dP/dT" sweep.

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Covering dates 1950
Availability Open Document, Open Description, Normal Closure before FOI Act: 30 years
Former reference (Department) Memo No 16/50
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