U. S. Department of Commerce
National Bureau of Standards

Research Paper RP1986
Volume 42, May 1949

Part of the Journal of Research of the National Bureau of Standards

An Electric Gage for Measuring the Inside Diameter of Tubes

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An electric gage has been developed for measuring the bores of small guns or tubes of about ½-inch inside diameter. Its operation depends on the mutual inductance of two coils. The instrument has a solenoid mounted on each prong of a fork. The current induced in the secondary varies inversely with the distance between the primary and secondary coils. The gage is calibrated with rings of known diameter, and the diameter of a tube or gun bore is read directly on the dial of the instrument.

I. Introduction

In experimental work on electroplating the bore of small gun barrels, a method of measuring bore diameters was needed. The gages available for the purpose were sufficiently accurate but were not always convenient to use. For this reason, an electric gage was designed that had some advantages over the standard types of gages. This gage is also applicable for measuring the inside diameter of tubes.

The gage most widely used commercially for gaging production quantities of small-caliber gun barrels is the air gage. This gage is a continuous reading instrument, which is comparatively easy to operate. A short description of this instrument is given to make clear in what respects it did not meet the needs of research. The measurement involves the passing of a spindle through the gun bore. Air under pressure passes out through two holes in the spindle. The rate of escape of air from the spindle is dependent upon the clearance between the jet and the bore, that is, upon the difference between the diameter of the spindle of known size and the diameter of the bore. This difference, measured in terms of the quantity of air flow, is registered by the relative height of a float in a transparent indicator tube.

The main disadvantage of this gage is that even under the most favorable conditions each spindle can be used over only a limited range, for example, 0.005 in. if an accuracy of ± 0.0002 in. is desired. If a bore is tapered, the spindle must be changed in order to cover the range of diameter; this operation is time-consuming. Different spindles must be used for the land and for the groove readings when gaging a gun bore. Special difficulties arose in gaging heavily plated tubes, because a single small nodule or deformation in the plate prevented the spindle from passing through. Another minor inconvenience is that a line pressure of 25 lb/in.^{2} is required to operate the air gage. The air escaping through the holes in the spindle causes the gaging operation to be very noisy. The assumption is made that the air pressure is constant after passing through a pressure compensator. However, as the gage is affected by air pressure changes, it is necessary to calibrate the gage before using, and any fluctuations in the pressure during operation cause inaccuracies in the readings.

Another extensively used instrument is the star gage, which consists of a pair of pins between which a cone is forced, thus separating the pins. These pins continue to spread until the cylindrical wall is reached. The dial type of instrument is sensitive to ± 0.0002 in., but a gage that has been used for a time can be relied on to this degree only over a region within 0.005 in. of the diameter of the ring used for calibrating because of the wear of the cone. The main disadvantage of the star gage lies in the fact that it permits a reading to be taken at only a single diameter at a time. The measurements are time consuming because the pins must be retracted and released for each reading, and it is not feasible to make sufficient readings to give a complete record of the profile of the bore. Both the air and star gages are very astisfactory for production control but not for research work.

The development of an electronic gage for gun bores has been reported.[1] The instrument consists of a wire strain gage mounted on a flexible beam to which one of the gage points is attached. The beam is bent by a variable amount, determined by the position of the gage point, and the flexure is measured by the strain gage and an electronic amplifier. This gage is a continuous-reading instrument with an accuracy reported to be ± 0.00005 in., but no further information is available on it.

There are a number of very sensitive electrical amplifying gages on the market, but they are too large to be used in a tube ½ in. in diameter. The spatial limitation imposed by this diameter was the main difficulty in developing a suitable gage.

II. Description and Operation of the New Instruments

The continuous-reading electric gage was developed to meet our requirements for ease of operation, width of range, and accuracy of measurement. The gage operates on the principle of mutual inductance of two solenoids. If a constant voltage is maintained in the primary coil, the current induced in the secondary is a measure of the distance between the two coils. As seen in figure 1, the two solenoids, *K* and *L*, are attached by screws to the fork, *J*, opposite each other. When the gage points, *G* and *H*, which are screwed on to the fork, are squeezed together the poles of the two solenoids approach each other. The spring, *I*, is placed between the ends of the fork to cause the points to seek the maximum diameter.

The current that is induced in the secondary coil from a 60-cycle current in the primary coil is converted to direct current by a rectifier. This current is partially annulled by a counter emf from the bucking circuit, and the resultant current is read on a properly calibrated microammeter. If a 1,000-cycle current is used, the sensitivity of the instrument is tripled. It has been found that the distance between the two coils varies with the induced current in a nonlinear and reproducible manner. A range of 0.02 in. was covered by the gage with a sensitivity of 0.0002 in. without requiring recalibration at any place in the range. This range is readily extended to a larger diameter by unscrewing one set of gage points and replacing them with shorter points to give the desired range. The difference in the length of the points is taken into consideration when the reading is made. A gage for tubes of larger diameter can be constructed to have a larger range with a given set of gage points. The gage is centered in the bore by two tubes with four phosphor bronze fins, *B* and *N* in figure 1.

[1] Chem. and Eng. News **23** No. 23 (Dec. 10, 1945).

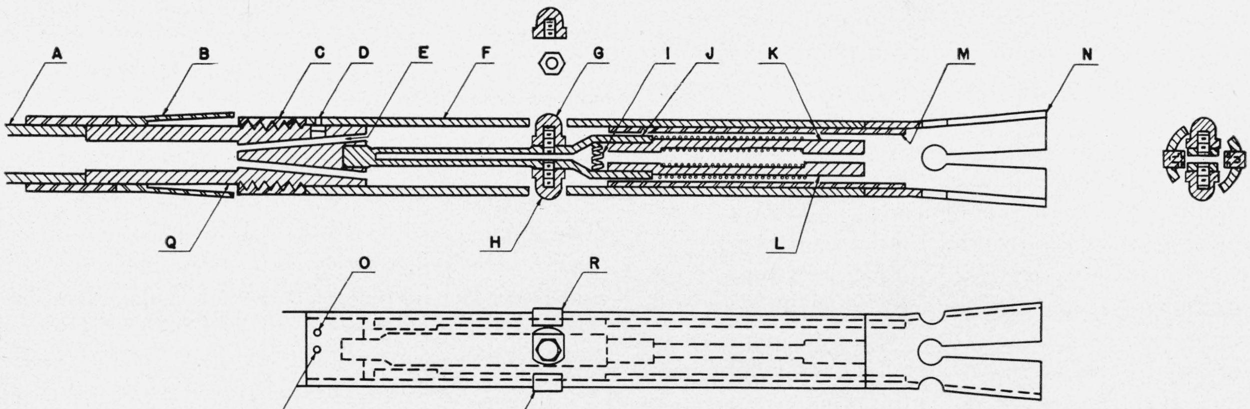

FIGURE 1. *The top drawing is a cross section of the gage, and the bottom drawing is a schematic diagram of a view taken approximately at right angles to that of the top drawing.*

A, Bakelite handle; B, phosphor bronze centering flange; C, locknut; D, pin and spring for orienting the guides R and S; E, wire conduits; F, steel case; G, gage point; H, gage point; I, spring; J, fork; K, Mu-metal solenoid; L, Mu-metal solenoid; M, Mu-metal magnetic shield; N, phosphor bronze centering flange; O and P, hole and pin for orienting guides R and S; Q, stainless steel base for fork; R, guide; S, guide.

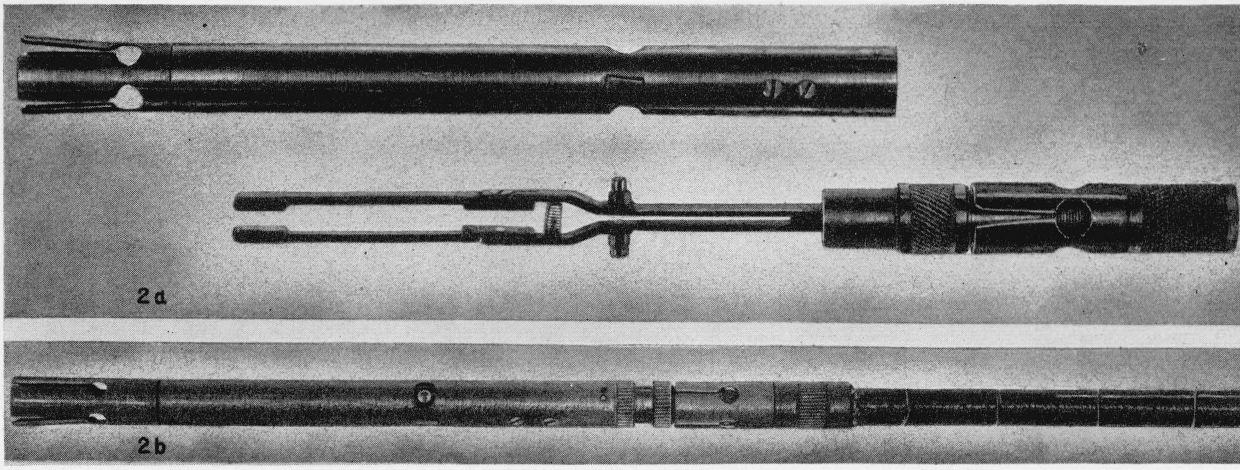

FIGURE 2. *Electric gage head.*

a, With case removed; b, assembled for operation.

The experimental gage was constructed for the purpose of gaging 0.50-caliber gun barrels, which necessitated certain additional features that are not required for gaging smooth bore tubes. The points must be maintained either on the lands or in the grooves by guides, *R* and *S*. These guides are made of tempered steel to hold the gage firmly oriented in the gun bore but flexibly enough to allow the gage to move along easily. The same gage points are used for both lands and grooves, and the method for shifting gage points from one to the other is simple. The locknut, *C*, is unscrewed a short distance, and the pin, *D*, is pressed down with the thumb so that the tube, *F*, may be rotated 22½ degrees to the adjacent hole (see *O* and *P*). This operation will rotate the tube with the guides into the alternate position with respect to the points. A 36-in. Bakelite tube, *A*, is screwed on to the end of the gage so that it may be pushed through the gun bore. The holes, *E*, hold the wires that pass from the solenoids to the box containing the electrical equipment.

The cores of the solenoids are made of Allegheny "Mu metal", which has a high permeability at a low field strength. In the experimental model these cores are 1/16 in. thick, 5/32 in. wide, and 1¼ in. long at the portion where the winding is done. After being annealed to restore the permeability that was possibly lost by machining, each core is wound with eight layers of number 42 enameled copper wire comprising about 3,700 turns per solenoid. The layers of wire are insulated from one another by coats of polystyrene. A tube of Mu metal with a wall 0.02 in. thick, *M*, is inserted in the tube in the proximity of the solenoids to shield them from possible magnetic effects outside of the gage. When a steel tube is passed over the gage this shield prevents a change in excess of 1 microampere. Figure 2, a, shows the gage with the outer case removed, and figure 2, b, the gage ready for use.

The electrical circuit, as seen in figure 3, is simple. The current is fed into the primary coil, 5, by a constant voltage transformer, 1. The induced current is partially annulled by a counter emf, called the bucking circuit, from a 4.5-volt portable battery, 12, and the difference is read on the 100-microampere ammeter, 8. As the current does not change linearly with the distance of separation of the coils, the scale is not linear. It is expedient to have several resistances, *X*, *Y*, and *Z* in the primary circuit, and X^1, Y^1, and Z^1 in the secondary circuit so that the total range, which is broken into three ranges, is open enough to be read to 0.0001 in. By using a multiple gang switch the various resistances for the primary, 4, and the corresponding resistance for the secondary, 10, may be thrown in simultaneously.

Occasionally a small shift in the calibration may result from wear of the points or changes in the electrical constants of the circuit. This may be readjusted with variable resistances. Should the ranges shift away from each other, resistance 3 may be varied to bring them back into adjustment with each other. If all the ranges shift proportionally, resistance 2 may be used to correct the

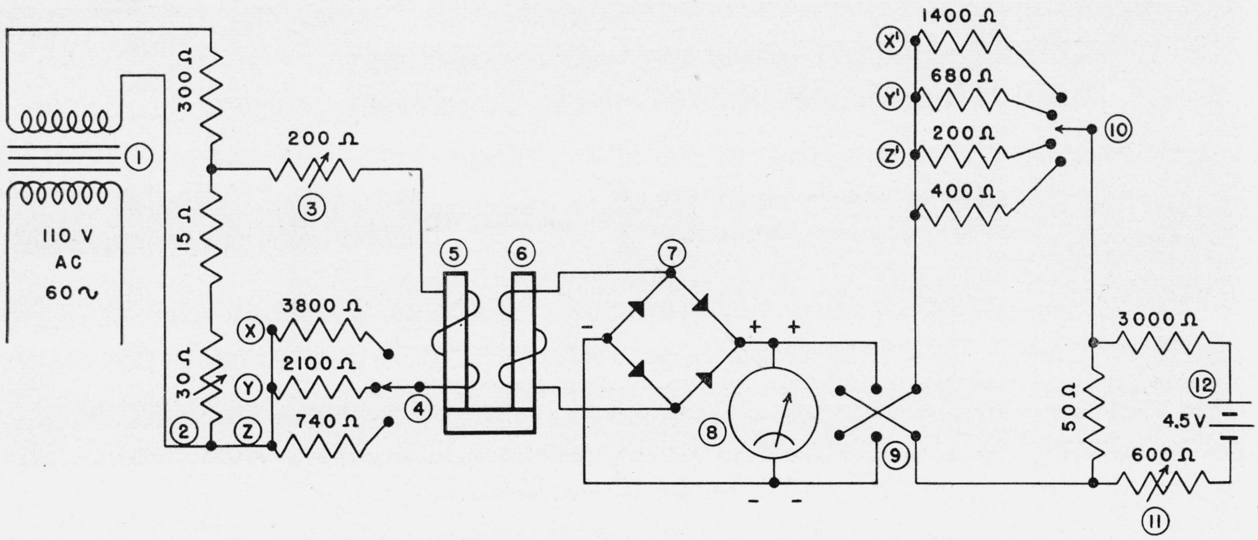

FIGURE 3. *Electrical circuit used with the electric gage.*

1, Constant voltage transformer; 2, resistance for adjusting ranges; 3, resistance for synchronizing ranges; 4, resistances for regulating the current through the primary for the three ranges; 5, primary coil; 6, secondary coil; 7, instrument rectifier; 8, microammeter; 9, reversing switch to check the bucking circuit; 10, resistances to regulate the bucking current for the three ranges, including a 400-ohm resistance to check the bucking circuit current; 11, resistance for adjusting bucking circuit; 12, battery for bucking circuit.

error. Sometimes it becomes necessary to readjust the current of the bucking circuit; for example, because of deterioration of the dry cell. To test for a shift occurring in the bucking circuit, the reversing switch, 9, and the switch opening the primary circuit, both of which are connected to the multiple gang switch, are thrown. At this position on the gang switch, a special 400-ohm resistance (see 10) is thrown in series with the bucking circuit to give a definite reading on the scale. If the resultant reading shows that the bucking current has changed, it may be readjusted by the variable resistance, 11. The gage may be checked quickly with two standard gage rings, and if a shift does occur it may be remedied easily with the use of the gang switch and the adjustable resistances.

The electric gage has several advantages. (1) It is a quick and accurate method of determining the diameter. (2) As it is a continuous-reading instrument, the profile of the entire bore may be scanned and the deviations revealed. (3) The sensitivity of 0.0002 in. holds over the entire range of 0.02 in. without recalibration. (This is a larger range than the air gage or the star gage will cover with comparable accuracy.) (4) The electrical circuit operates from a 60-cycle source and is comparatively simple, requiring no specialized equipment, such as an electronic amplifier. (5) The total range of 0.02 in. may be extended without requiring recalibration by exchanging the gage points for another pair and taking the difference in height of the points into consideration. (6) The gage is relatively inexpensive. (7) The total range is broken into three short ranges. The ranges are quickly shifted by the turn of a switch, and they do not require recalibration when this is done.

The electric gage has been in intermittent use for about 3 years, and it has remained in good working order during that time except for an occasional renewal of the battery. Various modifications of the gage can be made to increase its range or its sensitivity. The nearer the gage points are situated to the Y of the fork, the greater will be the mechanical magnification of their motion by the solenoids. One gage was built with the gage points situated on the ends of the prongs of the fork, in order to obtain a wider range with, however, a reduced sensitivity. Another variation in the use of the gage was to connect the output to a recording potentiometer instead of to the microammeter. In this way a continuous record of the profile of the bore of a tube can be obtained. This feature of the instrument has not been fully developed.