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INSTRUCTIONS FOR THE USE OF
No. 2597 PERMEAMETER

Manufactured by
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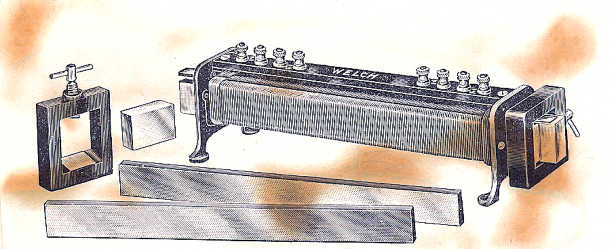

No. 2597. (1/5)

The Double-Bar Permeameter, designed by Professor Arthur W. Smith of the University of Michigan, is intended to meet the needs of those laboratories that wish to give instruction in the measurement of the magnetic qualities of iron and steel, and yet do not wish to install the more expensive forms of apparatus for this purpose.

The standard method for magnetic testing is the ring method, since a ring circuit is uniform throughout its length and there are no ends to introduce disturbing factors. The various forms of permeameters have magnetic circuits that more or less satisfactorily approach the form of a ring circuit. In the double-bar permeameter the magnetic circuit consists of two rectangular bars, 1 cm x 3 cm in cross section and 36 cm in length. The ends of these bars are connected by two flat blocks of very soft iron having a small reluctance. Yokes provided with set screws are placed around each end as shown above so as to clamp the bars firmly together and reduce the air gap between them to a negligible quantity. The magnetic circuit is thus closed, and consists almost entirely of the bars that are being tested. As will be seen from the full cut of the apparatus shown above, the bars thread through two brass tubes of rectangular section slightly larger than 1 cm x 3 cm, mounted on end brackets and upon which are wound three layers of well insulated wire. Considerable care has been exercised to insure the uniform spacing of the turns of wire in those coils, and the number of turns per centimeter is constant. It will be noticed from Fig. 2 that a part of the magnetic circuit lies beyond the ends of the coils, where it would be practically impossible to wind the coils. The number of turns that should go on the end portions of the magnetic circuit has been experimentally determined, and these turns are wound as extra turns at each end of both long coils. The two long solenoids and the four extra end coils are all joined in series, forming a single

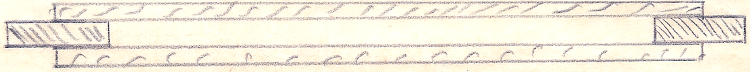

Fig. 1. Showing the iron bars and blocks that form the closed magnetic circuit of the Double-Bar Permeameter.

electric circuit that extends over the entire length of the magnetic circuit.

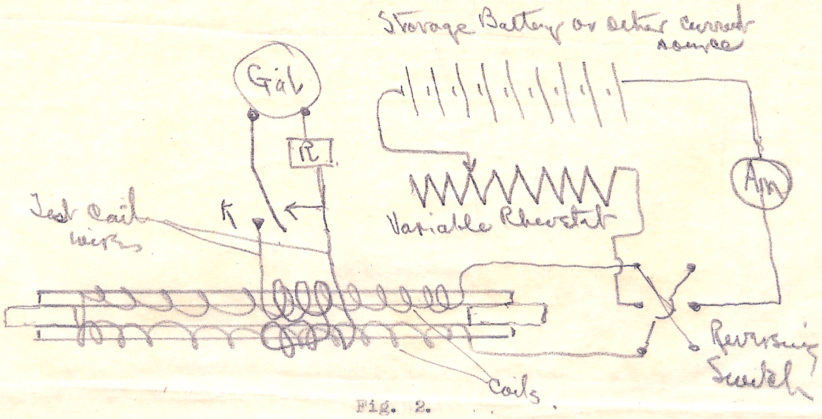

Fig. 2.

When in use the electrical circuit is connected to a storage battery or some other source of steady, direct current of sufficient E. M. F. that, when coupled with a suitable variable resistance, will force through the coils a current of any desired value from 2 amperes down to 0.1 of an ampere, or even to 0.01 ampere in some cases. There should be an ammeter in this circuit to measure the amount of the current. There should also be a reversing switch connected as shown in Fig. 2 so that the current in the coil can be quickly reversed from a steady value in one direction to the same steady value in the opposite direction.

The steel bars are magnetized by the current in the solenoids, and when the current is reversed the magnetization of the bars is reversed also. This magnetization of the steel bars is expressed in terms of *magnetic flux*, which is measured by means of a small test coil of twenty turns of wire wound around the middle part of the bars--ten turns around each bar. When the magnetic flux in the bars is reversed, there is induced in the test coil a transient electromotive force. If this coil is connected to a ballistic galvanometer, it produces a fling or throw of the movable coil that is proportional to the amount of magnetic flux that was reversed.

Relations in the Magnetic Circuit

The magnetic circuit of the permeameter is the closed iron path consisting of the two bars and the small blocks of iron connecting their ends. The amount of the *magnetic flux* in this circuit depends upon a number of factors, being proportional, for one thing, to I the *current* in the solenoids and N the *number of times* this current goes around the solenoid. It also depends upon the quality of the material in the bars as measured by μ the *permeability* of the steel. The total amount of the flux φ depends on the size of the bars, being greater in bars of greater cross-section A, and less for circuits of greater length L. Putting all of these factors together gives

$$\varphi = \mu(A/L)(4\pi NI) \quad \textit{maxwells}$$

If all of these quantities are measured in the usual magnetic (C.G.S.) units, the numerical factor 4π shown in the equation is necessary to make this relation an equality. The various factors can be rearranged in different ways to suit various purposes. Usually we are more interested in *B* the *density* of the magnetic flux than in φ the *total amount* of this flux. From the idea of density we have

$$B = \frac{\varphi}{A} \textit{ gausses}$$

or *maxwells per square centimeter.*

The magnetizing influence of the current is called the *magnetomotive force,* and denoted by the letters M. M. F. The amount of the M.M.F. is sometimes given in *ampere-turns,* that is, NI the product of I, the number of amperes of current in the coils multiplied by N, the number of times this current goes around the bars. This unit, an ampere-turn, while simple, does not fit in with the other units of the C.G.S. ~~sysxxxx~~ system that are used in magnetic measurements. The C.G.S. unit of M.M.F. is called a *gilbert,* and it is about eight-tenths as large as one ampere-turn. The M.M.F. due to NI ampere-turns in a coil is

$$\text{M.M.F.} = \frac{4\pi}{10} NI \textit{ gilberts}$$

Usually the total M.M.F. is not as important as the amount of M.M.F. per centimeter *length of the circuit.* This is called the *magnetic intensity,* and its value is denoted by *H.*

$$H = \frac{\text{M.M.F.}}{L} \textit{ oersteds}$$

or *gilberts per linear centimeter.*

Normal Magnetization Curve

The usual magnetic test of a steel is the determination of the *normal magnetization curve,* Fig. 3. This curve shows the relation between H, the *magnetic intensity* due to I, the *current* in the magnetizing coils, and B, the *magnetic flux density* due to the combined effect of the current and the steel. If the steel were absent, $B = H$. When the steel is present, *B* is increased several hundred or even thousand times the value that it would have been in air.

After testing one pair of bars, the bars of another grade of steel can be inserted easily and tested without disturbing the test coils or the solenoids that carry the magnetizing current,

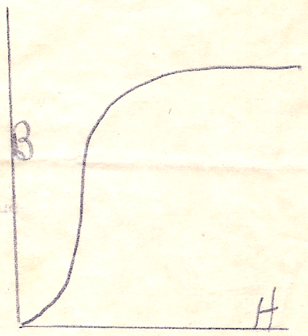

Fig. 3. Curve Showing The Normal Magnetization of Steel.

Computation of the Value of *H*

The coils that carry the magnetizing current are wound on rectangular forms that fit closely around the steel bars. The turns are uniformly spaced throughout the entire length of both coils, there being p turns of wire per cm. The magnetizing influence of a current of I amperes in both coils is

$$H = \frac{4\pi p}{10} \times I = h \times I \textit{ oersteds}$$

in which $p = N/L$ and $h = 4\pi N/10L$. N, the number of turns, will be found on the plate of the permeameter and, therefore, the value of h may be obtained by multiplying N by .0207. Its value is about 50.

Measurement of B

A ballistic galvanometer is connected to the test coil of 20 turns wound around the middle portions of both bars. When φ the *magnetic flux* through the bars is reversed by quickly reversing the current in the magnetizing coils, d the *galvanometer deflection* measures this change in the flux. This relation is

$$\varphi = \frac{c}{2n} d \textit{ maxwells}$$

where n is the *number of turns* in the test coil and c is the *magnetic ballistic constant* of the galvanometer circuit.

If the steel bar has a cross section of A sq. cm., B the *density of the flux* is

$$B = \frac{\varphi}{A} = \frac{c}{2An} d \textit{ maxwells per sq. cm., or gausses}$$

If the resistance of the galvanometer circuit is adjusted to make $c = 200 An$, then

$$B = 100 d \textit{ gausses}$$

and the galvanometer deflection measures B directly.

To Determine a Normal Magnetization Curve

1. Place the two bars of cold rolled steel (C.R.) inside the two solenoids of the permeameter. Clamp the bars firmly, and with good clean contact, against the small blocks of Armco iron at each end.

2. The current coils of both solenoids are connected in series and brought out to a single pair of binding posts plainly marked. Join these binding posts to the outgoing side of a reversing switch. Connect a storage battery, or other source of direct current, through a variable rheostat and ammeter to the ingoing side of the reversing switch. The rheostat and battery should be such that the current can be set at any desired value from 2.0 amperes down to 0.02 ampere. The reversing switch should be arranged to give a very quick reversal of the current in the solenoids of the permeameter. Our Nos. 2912 or 2913 or their equivalent will be satisfactory and the reversal should be accomplished without loss of time.

3. Connect the galvanometer through a resistance box of 10,000 ohms to the short-circuit binding posts of a contact and short-circuit key, our No. 2901 or No. 2915. Connect the tongue and contact binding posts of this key to the binding posts of the test coil on the permeameter. When this key is depressed the test coil, galvanometer, and resistance are all in

series. When the key is released the galvanometer and resistance are in series, but the test coil is out of the circuit.

4. Adjust the current through the solenoids to 1.00 ampere. If these bars have ever been subjected to a current larger than 1.00 ampere they must be demagnetized down to this point. With this current of 1.00 ampere the magnetic flux density, *B*, in the cold rolled steel bars is 14900 gausses *(maxwells per square centimeter)*. Reverse the current about once a second for 12 or 15 times, and stop with the switch closed and ready for another reversal. Close the galvanometer key and note the resting point on the scale. While still holding the galvanometer key closed, quickly reverse the current again, and observe the first throw of the galvanometer.

If this deflection of the galvanometer is not 149 scale divisions, release the galvanometer key, set the resistance in the galvanometer circuit smaller or larger than the 10,000 ohms, and repeat the reversal of the current. When the deflection *d* of the galvanometer has been brought to 149 scale divisions, the galvanometer is direct reading. The *flux density B* in the steel is now

$$B = 100\,d \quad \textit{gausses}$$

The galvanometer will now read directly the value of B for all bars of the same cross-section as these standard cold rolled bars. For bars of smaller section the factor 100 would be correspondingly increased.

5. The value of the *magnetic intensity H* is computed directly from the value of the *current I* as measured by the ammeter, by the relation

$$H = hI \quad \textit{oersteds}$$

gilbert per centimeter.

where an *oersted* is the same thing as a *gilbertper centimeter*.

The factor *h* is given with each permeameter as .0207 x N. It is about 50, and is the familiar $4\pi N/10L$, where *N* is the number of turns of wire in *L* centimeters length of the solenoids.

6, The current can now be changed a small amount, reversed 12 or 15 times, and values of *B* and *H* determined as before. And so on until as many points as desired are obtained. Values of *H* are usually plotted as abscissae and values of *B* as the corresponding ordinates.

<u>To Make the Galvanometer Direct Reading by the Use of a Mutual Inductance</u>

If a mutual inductance of a few millihenries is available, the galvanometer can be made direct reading without actually using the standard steel bar. When the magnetization of the steel bar is reversed the galvanometer is affected by a change in flux turns of

$$\Delta\varphi n = 2\varphi n = 2BAn$$

where *n* denotes the number of turns of wire in the test coil (20 in this permeameter) surrounding the total flux of φ maxwells in the bar. This same change in flux-turns can be obtained from a mutual inductance.

Let the primary coil of the mutual inductance be supplied with a current of I c.g.s. units, that can be quickly reversed from + I to -I.

(The same amount of current, but passing through the coil in the opposite direction.) This reversal means a change of 2I in the current through the coil. The flux-turns, φn, through the secondary coil of the mutual inductance of M c.g.s., units is MI, and when the current is reversed the change in flux turns is

$$\Delta\varphi n = 2MI$$

If M is measured in millihenries and I is measured in amperes the change in maxwell-turns is

$$\Delta\varphi n = 2MI \times 10^5$$

If this change is to be the same as when the magnetization of the standard bar is reversed, then

$$2MI \times 10^5 = 2BAn$$

and the current that will give this relation is

$$I = \frac{BAn}{M \times 10^5} \text{ amperes}$$

This means that a reversal of I amperes in the primary of a mutual inductance of M millihenries will give the same deflection to a galvanometer that is connected to the secondary as the reversal of a flux-density of B in the steel bar. If B is taken as 10,000 gausses, the deflection of the galvanometer should be 100 scale divisions.

After the resistance of the galvanometer circuit has been adjusted to give the desired deflection, it should not be changed until it is desired to change this factor of 100 gausses per scale division.

For more detailed information regarding magnetic testing see "Electrical Measurements in Theory and Application", pages 190-244, by Arthur W. Smith (McGraw-Hill Book Co., Inc., 370 Seventh Ave., New York, N. Y.) The method to be followed in obtaining an Hysteresis Curve is fully explained on pages 235-241.

If a user of the permeameter has difficulty in making measurements or adjustments he may write directly to Professor Smith, University of Michigan, Ann Arbor, Mich.

The importance of having good contact between the test bars and the pole pieces at the ends of the coils has been clearly brought out. Yokes with set screws are provided at each end so that this contact can be sufficiently tight to eliminate air films between the parts. It is, therefore, important that the bars and pole pieces be protected from rust during the times when the instrument is not in use. Therefore, oil or vaseline should be spread on the surfaces when the instrument is set away for the season, this film being carefully removed prior to taking observations. When this is done it is wise to leave the test bars out of the coils and remove the pole pieces from their mounting so that all parts of the iron can be thoroughly covered with the protecting coating.

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