RB-55

RECORDING FLUXMETER

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This bulletin describes the theory of operation and constructional details of a recording fluxmeter particularly well suited to measurements on ferrite materials. Measurement results are automatically plotted by an X-Y recorder on graph paper providing a permanent record.

Introduction

The most widely employed method of measuring the magnetic properties of materials requires the use of a ballistic galvanometer for obtaining discrete points which may be plotted on graph paper and connected to show a continuous curve. This method is accurate but requires as much as one hour or more to obtain the data, do the necessary calculations and plot the results. Where a large number of samples must be measured this method becomes impractical. For certain types of material where eddy currents are not a problem, a 60 cycle sweep circuit, with the proper integrator and oscilloscope may be used for making photographic records. Its use is limited by the material being tested and the difficulty of interpreting the results from relatively small graphs. The expense of the photographic material might also be a factor where many records are required.

It was felt that the most useful type of measuring equipment should make a permanent record on graph paper in a reasonable length of time and should be capable of measuring all types of magnetic material with good accuracy. A study of the literature showed several types of recording fluxmeters.[1,2,3] The resulting design utilized the best features of those investigated as well as several innovations for the purpose of improving and simplifying the operation.

General Description

The Recording Fluxmeter consists of a cabinet rack 22 inches wide by 19 inches deep by 7 feet high and an electromagnet weighing approximately 125 pounds. These two units are shown in Fig. 1.

The lowest panel has the main power switch and a five ampere fuse. The second panel from the bottom has a Variac which varies the magnetizing current supplied to the electromagnet and the primary of the toroid sample. The shelf above this panel holds a Moseley X-Y Recorder which plots the B-H curves.

The panel above this shelf has the controls for both integrators. A trap door in this panel gives access to a thermally insulated compartment in which the toroid samples are placed and the terminals to which the primary and secondary coils are connected.

The top panel has a power switch for the magnetizing current supply, a Variac for setting the maximum current supplied and a 3 ampere meter for indicating the current.

The power cord plugs into any standard 117 v 60 cycle outlet capable of supplying 5 amperes.

A rear view of the rack showing the arrangement of the components is shown in Fig. 2.

Theory of Operation

The method of flux measurements employed in this equipment is based on the fact that the integral of a voltage generated in a coil by a changing flux is proportional to the flux change.

$$e = \frac{dN\phi}{dt} \qquad (1)$$

$$\int_o^t e\,dt = \Delta N\phi \qquad (2)$$

The method actually used is based on the fact that the voltage developed across a capacitor is proportional to the time integral of the current flowing into it. If the coil is connected to a capacitor C through a resistor R as shown in Fig. 3 then $e = iR+V$ where i is the current flowing into the capacitor and e is the voltage generated across the coil, S, by a changing flux and V is the voltage appearing across the capacitor, C.

Assuming the capacitor has an initial voltage of zero it can be shown that the following relationship exists

$$\Delta N\phi = RCV + \int_o^t v\,dt \qquad (3)$$

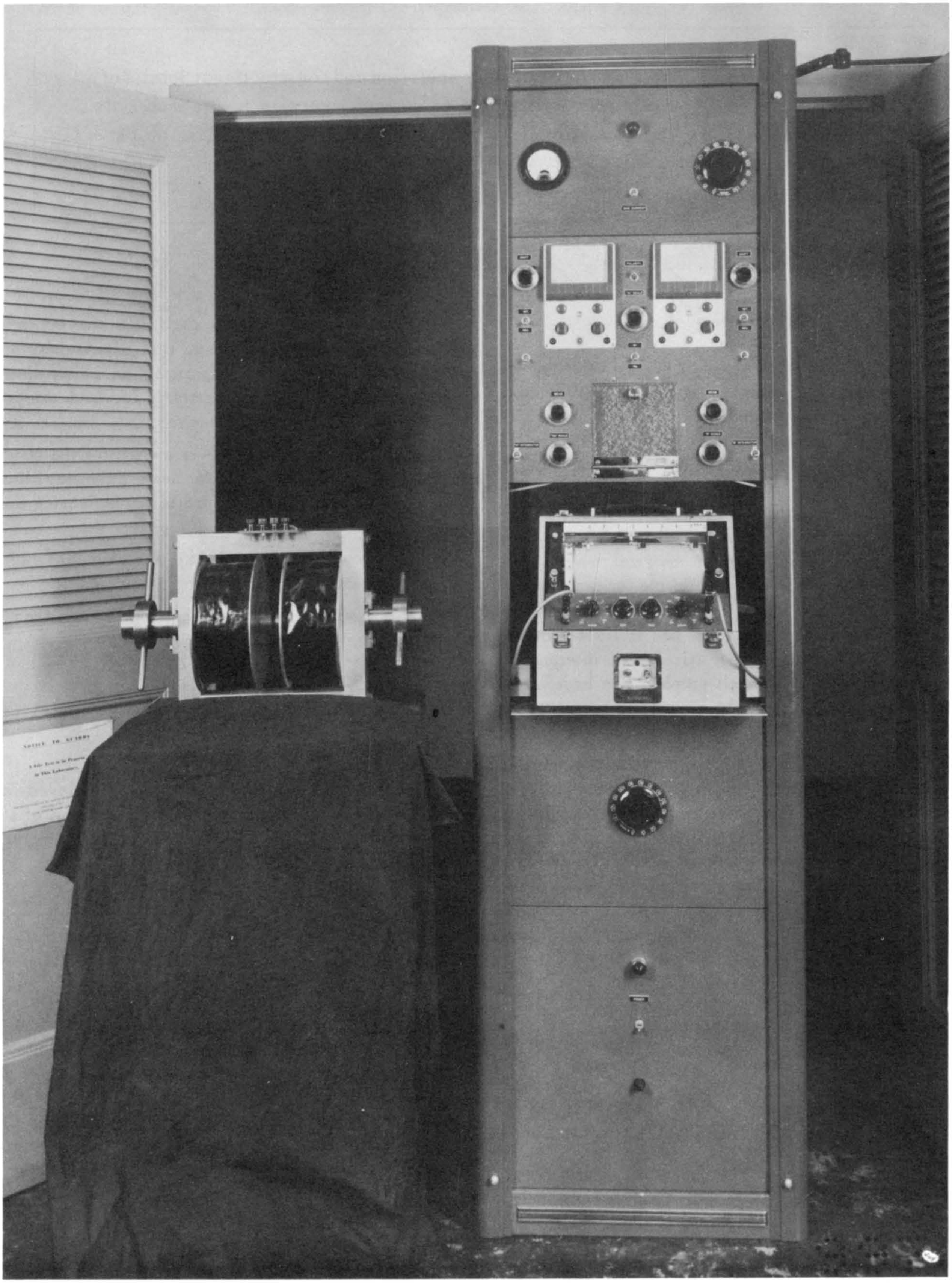

Fig. 1 – Cabinet Rack and Electromagnet.

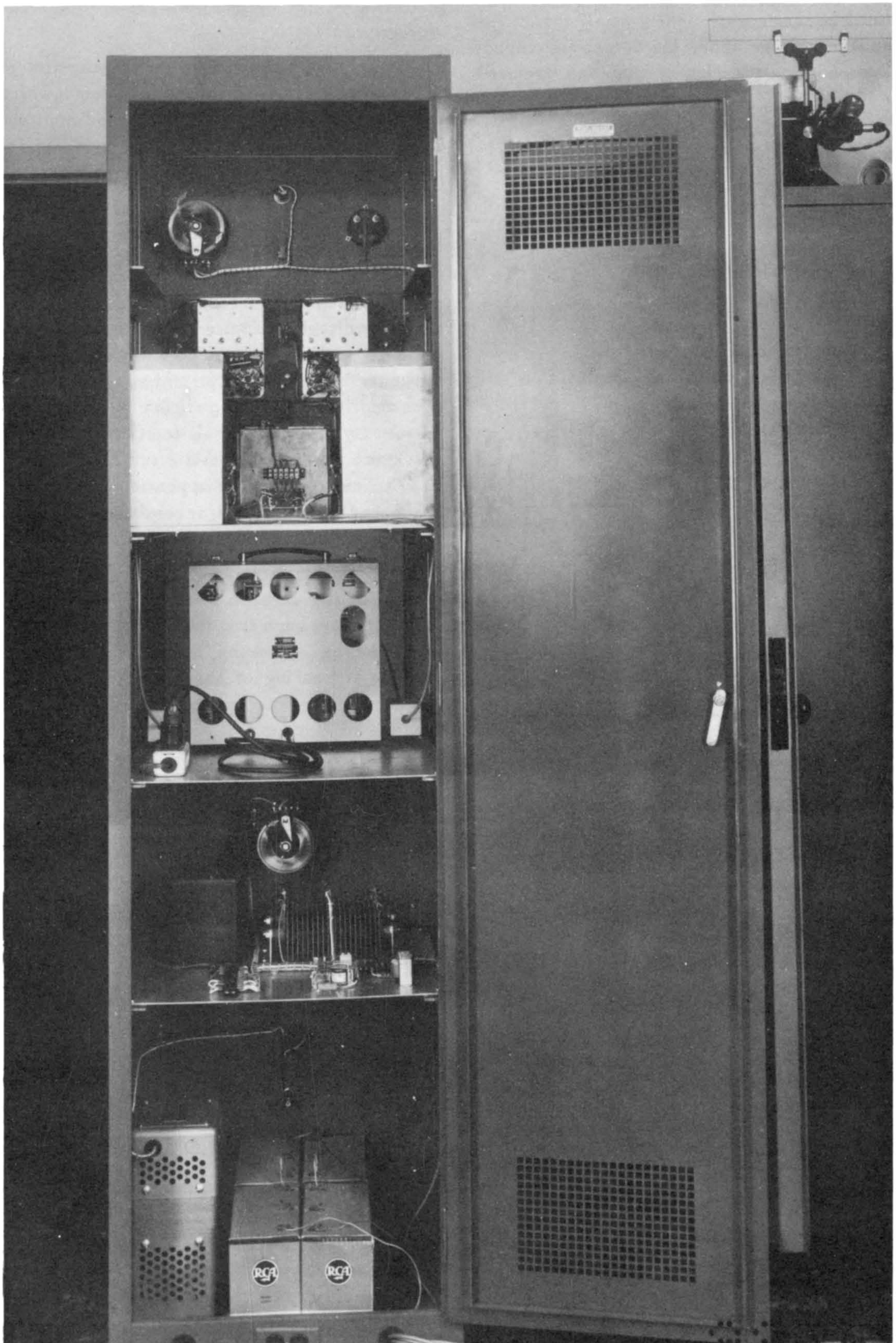

Fig. 2 – Cabinet Rack – Rear View.

If the time constant of RC is very long with respect to t then the last term becomes sufficiently small that it may be neglected and the voltage appearing across the capacitor is a measure of the flux change that has occurred. Therefore:

$$\Delta N\phi = RCV \times 100, \tag{4}$$

$$\text{and } B = \frac{RCV}{NA} \times 100 \tag{5}$$

where R = resistance in ohms
C = capacity in microfarads
V = voltage across capacitor
N = number of turns on coil S
A = area of cross section of sample in cm^2
B = flux density in gauss
ϕ = lines of flux

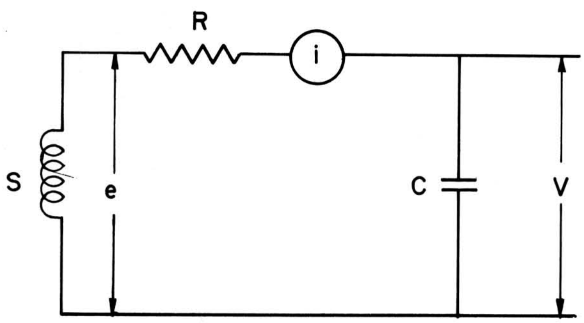

Fig. 3 – Basic Integrator Circuit.

If a time of one minute is required for the integration, then a time constant about 60 times as great as t will allow the last term to be neglected with an error not exceeding about one percent. However, an RC circuit having a time constant of one hour would have a sensitivity too low for practical application. One solution to this problem is to use a high gain d-c amplifier the output of which charges a capacitor through a resistor in the input circuit, the direction of the charging current opposing the current due to the input signal.

The effect of the feedback applied in this manner is to multiply the time constant RC by the gain of the amplifier. By using a relatively low R, in this case 55 ohms, a relatively high voltage appears across the capacitor. If the gain of the amplifier were infinite the input voltage would be zero, and the voltage across C and the output voltage of the amplifier would be equal.

However, if the gain of the amplifier is high enough ($>100 \times 10^6$) the difference in voltage is negligible and the output voltage may be taken as a measure of the voltage across C. With $R = 55$ *ohms*, $C = 1.0$ *microfarad*, and $G = 100 \times 10^6$ the time constant equals 5500 seconds or about 1½ hours.

Description of Circuits

Integrators

The d-c amplifier in each integrator consists of a Leeds and Northrup mirror galvanometer which is arranged so that it deflects a sharply defined spot of light across the cathodes of two photocells connected in series. The output of the junction of the photocells is connected to the grid of a cathode follower the output of which is measured by a voltmeter (see Fig. 4). The initial adjustment of the light beam is such that each photocell receives about the same amount of light so that the voltage at the junction is approximately half of the total applied voltage. A bias voltage is applied to the meter so that the reading is zero when the photocells are balanced. The meter is adjusted to read zero at mid-scale. The voltage gain of the amplifier in this condition is approximately 50×10^6 times. By feeding a small fraction of the cathode voltage back into the galvanometer circuit (see Fig. 5) in a direction to aid the voltage appearing across the coil, S, this gain may be increased several times. This is controlled by the potentiometer labeled Drift Control.

A one microfarad capacitor is connected from the output of the cathode follower to the input circuit of the galvanometer such that the voltage drop across R opposes the voltage appearing across the coil S. The voltage change appearing at the cathode is the integral of the voltage change across coil S and is proportional to the change of flux in coil S. The effective time constant of the integrator is:

$$T = RCG$$

T = time in seconds
R = resistance of series resistor in megohms
C = capacity in microfarads
G = voltage gain of amplifier

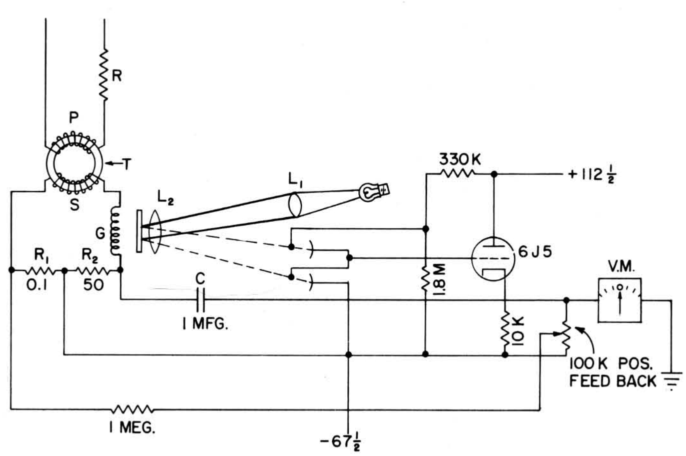

Fig. 4 – Schematic Diagram of Integrator.

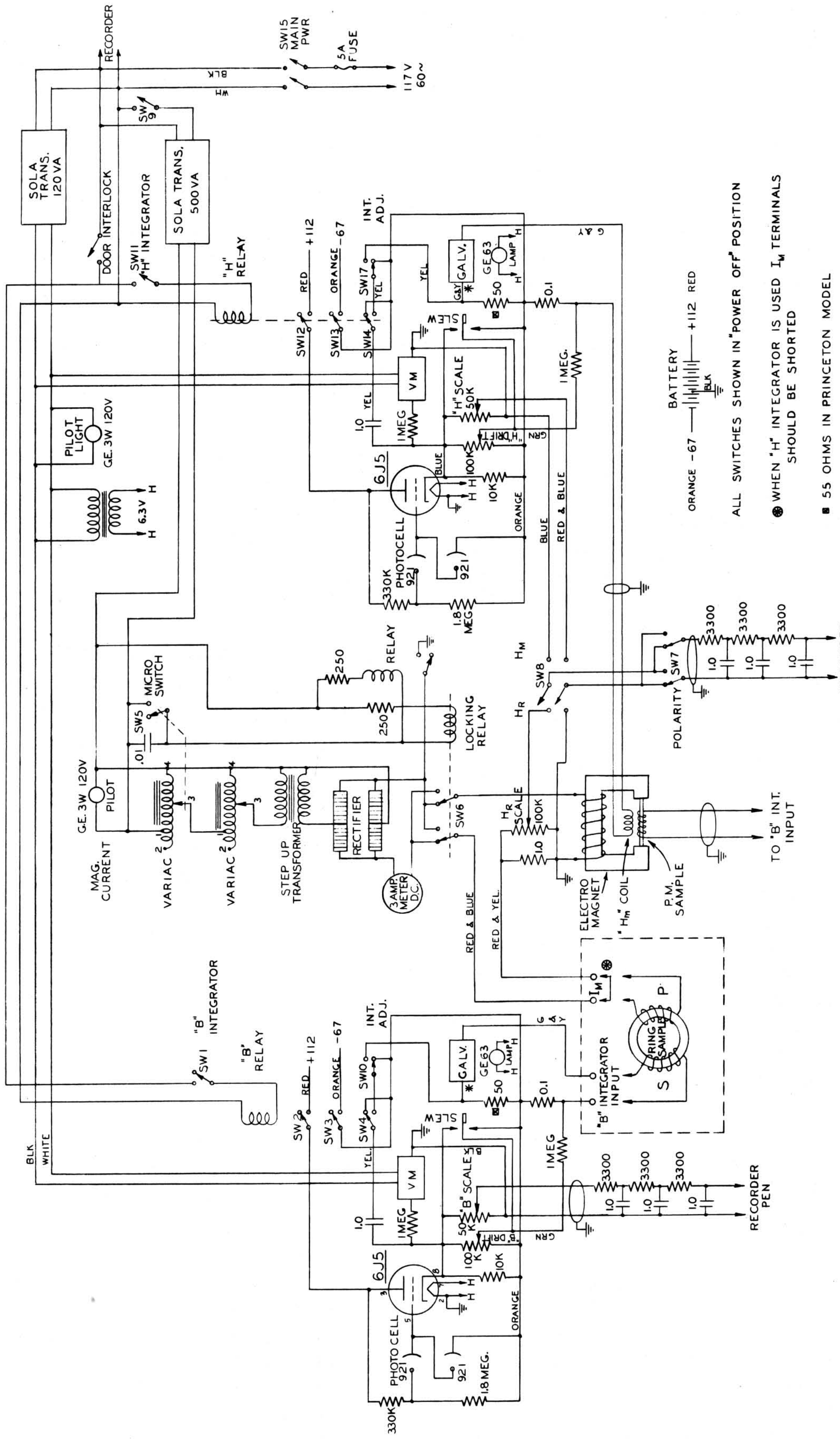

Fig. 5 — Wiring Diagram of Fluxmeter.

The "B" Integrator is used for measuring high permeability materials in the form of a toroid with a primary and a secondary winding. One requirement is that the primary must supply enough ampere turns to saturate the core. If the sample is too small to accommodate enough turns of sufficiently large wire for this purpose then the sample must be in the form of a bar and is wound with a secondary coil only. It is magnetized by placing it between the poles of the electromagnet. The winding on the sample is connected to the B Integrator and an air core coil placed in the gap near the sample is connected to the "H" Integrator. The output voltage of each Integrator is controlled by a ten turn helipot.

Electromagnet

The semi shell type magnetic structure of the magnet is made of Armco iron which has a low remanence.

The 1½ inch diameter pole pieces are both adjustable to provide a gap from zero up to 1¾ inches. Each pole piece has a coil of 4800 turns of No. 17 Formex insulated copper wire with a resistance of about 33 ohms. The coils are normally connected in series and supplied with a maximum current of 2.5 amperes. With this current the flux density in a 0.4 inch gap is about 12000 gauss and the leakage flux is quite low.

Two shielded cables, one from the B Integrator and one from the H Integrator terminate at two pairs of binding posts on a bakelite panel fastened to the magnet frame. The magnet current is supplied by another cable which goes directly to the coil terminals.

Moseley Recorder

This unit is a portable two axis graphic recorder. It contains two identical self balancing servo-mechanisms. One servo system positions a rotatable drum which carries the graph paper. The second servo system moves a pen across the paper. The input to the drum is a voltage representing H. In the measurement of a toroid this voltage is taken from the drop across a resistor in series with the primary winding. In the measurement of a bar sample in the electromagnet, the drum is supplied from the output of the H Integrator. The output of the B Integrator supplies the pen actuating voltage in both cases. Step attenuators on each of the servo inputs, in connection with the helipots at the outputs of the two integrators are used to adjust the scale factors of the X and Y axes.

Power Supplies

The electromagnet is supplied with a direct current of about 2.5 amperes maximum. A 500 volt-ampere Sola regulator transformer supplies 60 cycle power to the bottom Variac (No. 1) which in turn supplies power to the top Variac (No. 2). The 2nd Variac supplies the primary of a two to one step up transformer which feeds a bridge type selenium rectifier. The electromagnet is connected directly to the output of the rectifier through a 3 ampere d-c meter. Variac No. 2 is adjusted for the maximum magnetizing current required for the sample. Variac No. 1 is varied from zero to maximum and back to zero to obtain one half of the B-H loop. Each time this Variac returns to zero a cam operated switch operates a locking type reversing relay which changes the direction of current flow through the electromagnet. Thus a second excursion of Variac No. 1 from zero to maximum to zero will complete the B-H loop.

A 100 volt-ampere Sola transformer supplies constant voltage to the two Voltohmyst meters and to a transformer which supplies 6.3 volts to the 6J5 heaters and the galvanometer lamps.

The voltage for the cathode follower and photocell circuits is supplied by a 180 volt heavy duty "B" battery. The battery voltage is connected to the circuits through relays which are controlled by the a-c power switches on the Integrator panel.

USE OF EQUIPMENT

The main purpose of this equipment is to make static measurements of experimental samples of newly developed magnetic materials. This is usually done by plotting a B-H or hysteresis loop. In the case of a high permeability material the magnetizing force is supplied by means of a primary winding through which a d-c current may be passed. By making the sample in the form of a toroid the magnetizing force may be readily calculated.

$$H = \frac{0.4NI}{D}$$

where H = magnetizing force in Oersteds
N = number of turns on primary winding
I = current in amperes
D = average diameter of toroid in cm.

The primary of the toroid sample is connected in series with the electromagnet coils and the current is read on the d-c ammeter.

A secondary or pickup coil wound over the primary will have a voltage induced in it when the primary current is varied. This voltage is fed into the input of the B Integrator. The change in output voltage of the integrator is proportional to the change in flux in the toroid (see Eqs. (4) and (5)), and $B = RCV \times 100/NA$. In this case V = the voltage change appearing at the output of the integrator as indicated by the Voltohmyst when the primary current is varied from zero to maximum, and $RC \times 100 = 5500$. N = the number of turns on the secondary coil and

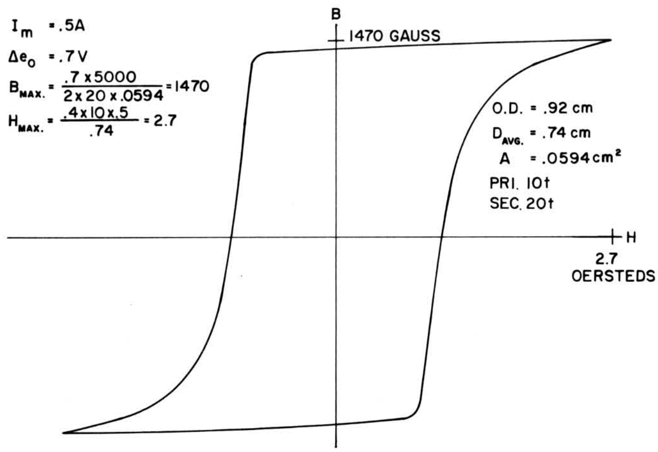

Fig. 6 – B-H Loop of Ferrite Switch Core.

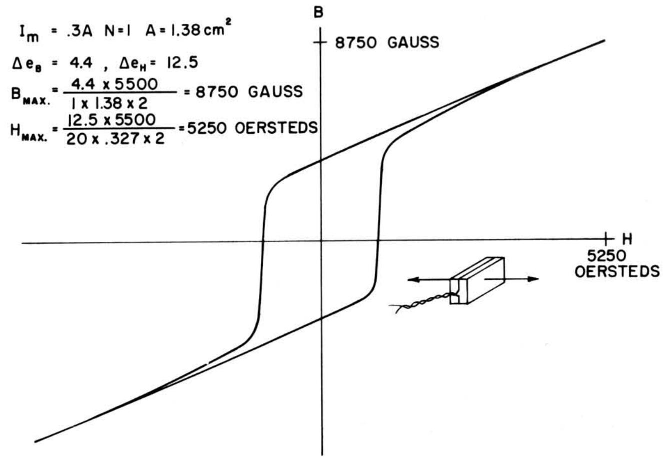

Fig. 7 – B-H Loop of Oxide Permanent Magnet Material.

A = the cross sectional area of the toroid in square centimeters. An example of a B-H loop of a ferrite switch core is shown in Fig. 6.

If the sample to be measured has low permeability as in the case of a permanent magnet material then it is not feasible to use a magnetizing coil wound directly on the sample. Generally it would not be physically possible to obtain enough ampere turns. In this case the sample is made in the form of a bar or cylinder about 0.4 inches long and 0.25 inches diameter. This is wound with a pick-up coil of about 5 to 10 turns and placed between the pole pieces of the electromagnet. The magnetizing force, H, is supplied by the electromagnet and the voltage developed across the coil by the change in flux is fed into the B Integrator. The voltage from an air core coil placed adjacent to the magnetic sample in the gap between the pole pieces, is fed into the H Integrator. The pen servo of the recorder is actuated by the output of the B Integrator and the drum servo is actuated by the output of the H Integrator. An example of a B-H loop of a permanent magnet material is shown in Fig. 7.

H. C. Allen

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