Exp1 Hysteresis Magnetometer

Object

To understand magnetization and ferromagnetic hysteresis loop.

Introduction

The apparatus is designed for the examination of specimens in the form of a rod. The length of the specimen should be large in comparison with the diameter, in order to reduce the self-demagnetizing effect to a minimum. The sample (soft iron), 330 mm long and 1 to 1.5 mm diameter, are supplied with the apparatus and are intended to enable the wide difference in the behavior of ferromagnetic materials to be demonstrated.

Using the apparatus, a small error in locating the lower pole of specimen causes such a small difference in the magnetometer reading that a knowledge of the exact position of the pole is unnecessary. However, if desired, the pole can be placed exactly in the plane of the magnetometer needle by moving the specimen vertically until maximum defection for a given magnetizing force is obtained.

Theory

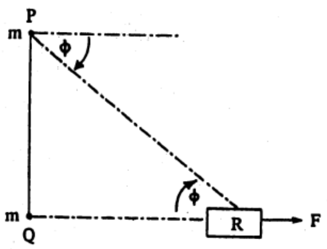


Fig. 1

If a long magnetized specimen (PQ in Fig. 1) of pole strength m is placed vertically, then the resultant horizontal force F acting perpendicularly to the horizontal component of the earth's magnetic field H_o at a point R in Fig.1 is given by

$$F = \frac{m}{(QR)^2} - \frac{m}{(PR)^2}\cos\emptyset = \frac{m}{(QR)^2} - \frac{m}{(PR)^2}\left(\frac{QR}{PR}\right)$$

$$= \frac{m}{(QR)^2}\left[1 - \left(\frac{QR}{PR}\right)^3\right] \qquad (1)$$

Clearly, for a long magnetized specimen, this force will be due mainly to the lower pole of the specimen. If the deflection of a magnetometer needle placed at R, due to the magnetized specimen is θ, then

$$\tan\theta = \frac{F}{H_o} = \frac{m}{H_o}\frac{1}{(QR)^2}\left[1 - \left(\frac{QR}{PR}\right)^3\right]$$

or $$m = \frac{H_o(QR)^2}{\left[1-\left(\frac{QR}{PR}\right)^3\right]}\tan\theta \qquad (2)$$

If the cross-sectional area of the magnetized specimen is A, the intensity of magnetization M is given by

$$M = \frac{m}{A} = \frac{H_o(QR)^2}{A\left[1-\left(\frac{QR}{PR}\right)^3\right]}\tan\theta \qquad (3)$$

the value of Ho varies worldwide and the value for a particular location can be found from tables. In London, for example, H_o=15Am^{-1}. Thus, for a given magnetized specimen at a particular location, the expression

$$\frac{H_o(QR)^2}{A\left[1-\left(\frac{QR}{PR}\right)^3\right]}$$

is constant. If this constant is α, i.e. $$\alpha = \frac{H_o(QR)^2}{A\left[1-\left(\frac{QR}{PR}\right)^3\right]} \qquad (4)$$

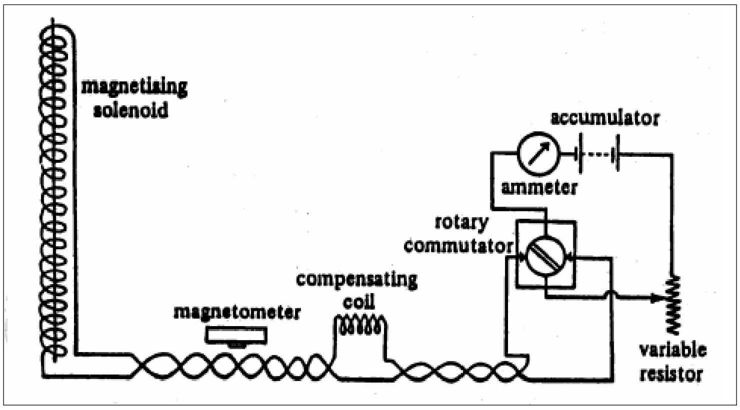
and $$M = \alpha\tan\theta \qquad (5)$$

The intensity of magnetization M of the specimen can, therefore, be readily calculated. If the field H . Used to magnetize the specimen, is obtained by passing a current I through a solenoid of n turns per meter, then

$$H = n\cdot I \qquad (6)$$

and this can also be easily determined. A hysteresis loop can then be plotted showing the relationship between M and H. If preferred, tanθ may be plotted against I or since $B = \mu_o(H + M)$ where μ_o is the permittivity of free space, B may be calculated and plotted against H. The general shape of the hysteresis loop will be the same in all three cases.

Setting Up



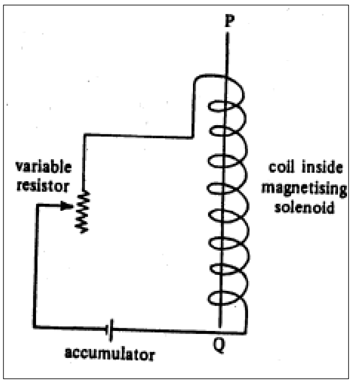


Fig.2 Fig.3

Locate the magnetizing solenoid in the hole provided at one end of the base and plug the shorter pair of leads into the sockets in the end of the base. Place the compensate coil in position and plug the connecting leads into the pair of sockets in the back of the base. This coil is used to compensate for the effect **AT THE MAGNETOMETER** of the **HORIZONTAL COMPONENT** of the field due to the current flowing in the **MAGNETISING SOLENOID**.

The pair of sockets in the end of the base farthest from the magnetizing solenoid should be connected to a rotary commutator, 6 or 8V accumulator, 0 to 2A ammeter and a variable resistor (e.g. 11.6 ohm, 2A) in a circuit as shown in Fig.2. Twin-twisted flexible wire should be used and the ammeter should be arranged some distance from the magnetometer so that its external field does not affect the magnetometer readings.

Connect the longer pair of leads from the magnetizing solenoid in series with a 2V accumulator and a variable resistor as shown in Fig.3. This circuit is used to annul the magnetizing effect on the specimen of the **VERTICAL COMPONENT** of the **EARTH'S MAGNETIC FIELD**. For clarity, this circuit has been omitted from Fig.2.

Level the base using the spirit level and adjustable feet. Rotate the base until the magnetometer needle is pointing directly towards the magnetizing solenoid; then rotate the magnetometer until the needle is on the zero mark.

Pass a current of about 1 A through the magnetizing solenoid and adjust the distance of the magnetometer from the magnetizing solenoid to be 7 to 10 cm. If a deflection of the magnetometer needle occurs, slide the compensating coil along its guides to a suitable position to annul it. It may be found necessary to reverse the connections of the plugs in the sockets in the base.

Insert a specimen in the glass tube in the magnetizing solenoid and demagnetize it by rapidly reversing the rotary commutator whilst simultaneously reducing the current to zero. Before proceeding, ensure that the current in the magnetizing solenoid is switched off. If the magnetometer needle still shows a deflection, then the field due to the compensating circuit of Fig.3 is additive to that of the vertical component of the earth's magnetic field instead of being in opposition to it. In this case, reverse the connections to the 2V accumulator and repeat the demagnetization procedure.

However, if the deflection decreases but not to zero, this is due to the vertical component of the earth's magnetic field being of a value other than 33.4 Am^{-1}, which the circuit of Fig.3 is designed to annul. In this event, replace the 2V accumulator with one able to provide 4V. Complete compensation can then be obtained using the variable resistor. Generally, however, a reduction to 10% is sufficient for the experiment.

Switch on the current to the circuit of Fig.2 again and increase to its maximum value of 2 A. Should the deflection of the magnetometer needle be in excess of 60^o, adjust the position of the magnetometer along its guides so that the maximum deflection is between 45^o and 60^o.

If this adjustment is found to be necessary, remove the specimen, pass a current of about 1A through the magnetizing solenoid an slide the compensating coil along its guides to annul the deflection of the magnetometer needle as previously. Re-insert the specimen and repeat he demagnetization procedure as described earlier.

When these adjustments have been completed, the apparatus is ready for use.

Procedure

Initially with the variable resistor in Fig.2 set to its maximum value, switch on the current to the circuit and then adjust the value to 0.1A. Note the deflection indicated by each end of the magnetometer needle and calculate the mean value.

In making his adjustment, the current **MUST NOT BE REDUCED**, (i.e.) if the value should rise to 0.22A, the reading must be taken at this value. **DO NOT REDUCE** to a more convenient figure of say 0.2A.

Proceed in this manner until the deflection remains constant with increase in current. The specimen is then magnetically saturated. A current of 2A will, in most cases, be sufficient.

Then, reduce the current in similar steps to zero, taking magnetometer needle readings, as before, at each stage.

At zero current, reverse the commutator and continue using negative current in steps until the magnetometer needle deflection is again constant, giving magnetic saturation of the specimen in the opposite sense.

Then, again, adjust the current in similar steps back to zero, taking magnetometer needle readings, as before, at each stage.

Reverse the commutator again and proceed to the former magnetic saturation condition.

IMPORTANT

In traversing the cycle, the current must not be cut off at any point except zero. Record, at each stage, the value of the current I, the deflection of the magnetometer needle θ and the subsequent evaluations of the intensity of magnetization M and the magnetizing field H, in a table as shown in the following specimen result. Hysteresis loops similar to those illustrated in Fig.4 can then be plotted.

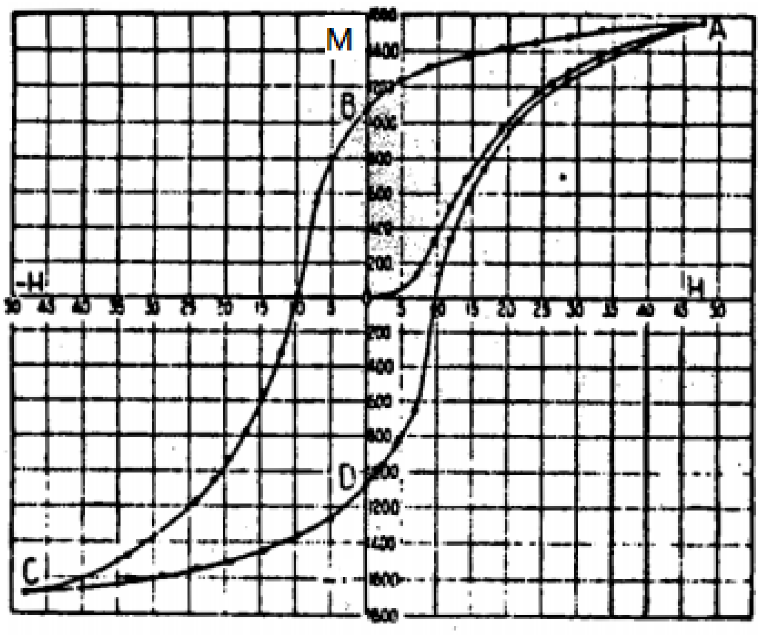


Fig.4

Typical results

Specimen	Silver steel
Length	330 mm
Mean diameter	1.01 mm
Distance between poles of magnetized specimen (taken to be three-quarters of the actual length)	247.5 mm
Distance of magnetimeter from specimen	80 mm
Horizontal component of the earth's magnetic field (in London)	15 Am^{-1}
Number of turns per meter on solenoid	1900

Thus from Eq. (4), we have

$$\alpha = \frac{H_o(QR)^2}{A\left[1-\left(\frac{QR}{PR}\right)^3\right]}$$

$$= \frac{15 \times (80 \times 10^{-3})^2}{\frac{\pi}{4} \times (1.01 \times 10^{-3})^2 \left[1-\left(\frac{80 \times 10^{-3}}{[(247.5 \times 10^{-3})^2 + (80 \times 10^{-3})^2]^{1/2}}\right)^3\right]}$$

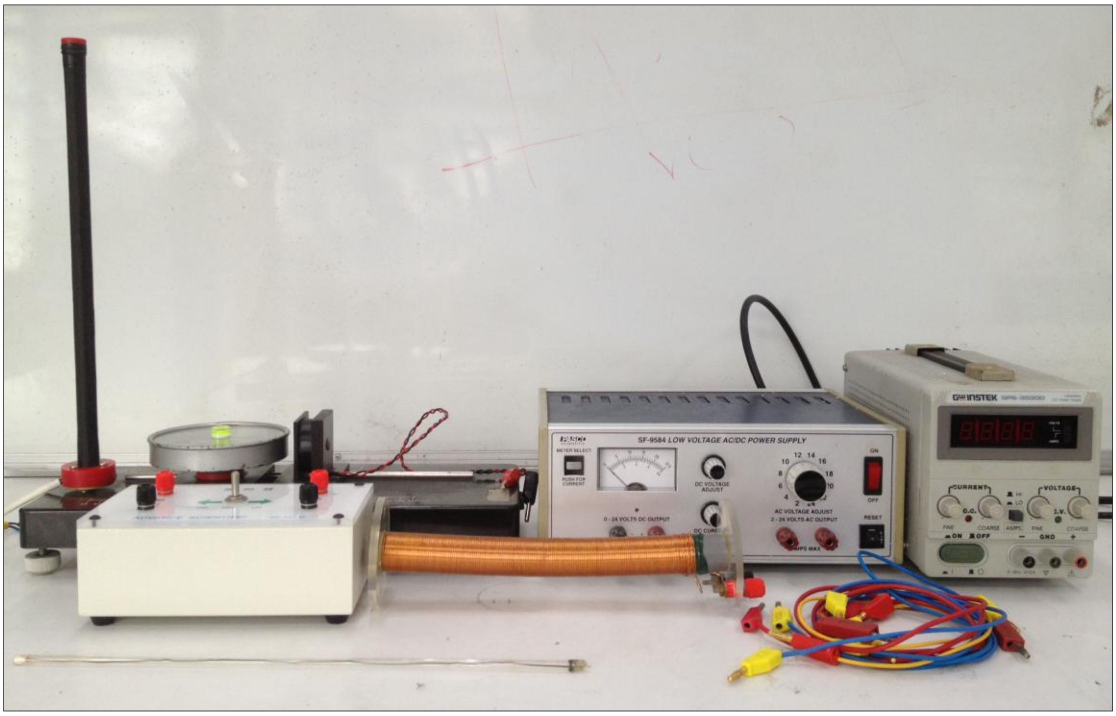
$$= 123.46 \times 10^3$$

from Eq. (5), i.e.

$$\mathrm{M} = \alpha \tan\theta = 123.46 \times 10^3 \tan\theta \ lines\ m^{-2}$$

and from Eq. (6), $\mathrm{H} = \mathrm{n} \cdot \mathrm{I} = 1900\mathrm{I}$

Equiments



I	Mean θ	$\tan\theta$	M(lines m^{-2})	H(Am^{-1})
0.0				
0.1				
0.2				
0.3				
0.4				
0.5				
0.6				
0.7				
0.8				
0.9				
1.0				
1.2				
1.4				
1.6				
1.8				
2.0				
1.6				
1.4				
1.2				
1.0				
0.8				
0.6				
0.4				
0.2				
0.0				
-0.2				
-0.3				
-0.4				
-0.5				
-0.6				
-0.7				
-0.8				
-0.9				
-1.0				
-1.2				
-1.4				
-1.6				

I	Mean θ	$\tan\theta$	M(lines m^{-2})	H(Am^{-1})
-1.8				
-2.0				
-1.8				
-1.6				
-1.4				
-1.2				
-1.0				
-0.8				
-0.6				
-0.4				
-0.2				
0.0				
0.1				
0.2				
0.3				
0.4				
0.5				
0.6				
0.7				
0.8				
0.9				
1.0				
1.2				
1.4				
1.6				
1.8				
2.0				