VARIATION OF LOSS WITH SPECIMEN SIZE OF ALCOMAX III AT 50 HZ EXCITATION

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SYNOPSIS

No attempt appears to have been made previously to find the effect of specimen size on the loss measurements of hard magnetic materials with cyclic magnetization. Experimental investigation was carried out to examine the variation of loss in Alcomax III with variation of (a) Magnetizing current (b) Volume of Alcomax III. The loss measurements were done by two methods. Firstly, loss was measured by a differences method using a dynamometer wattmeter. A permeameter was designed by the author using Telmag 'C' cores for this purpose. The flux density of the iron core of the permeameter was made the same with & without the specimen by adjusting the air-gap of the permeameter. Secondly, loss was measured by the dynamic method, obtaining the B-H loop on the oscilloscope & measurring the area of B-H loop. The two methods agreed well with each other. For both of these methods it was observed that the loss in Alcomax III metal increases with increase of specimen size at higher values of magnetizing current. Moreover the B-H distribution is associated not only with the hysteresis but with eddy currents as well as other factors like viscous damping & magnetic viscosity etc.

1. Introduction

Magnetically hard materials such as Alcomax III & Alnico are used mainly in permanent magnets & the design is based on the static demagnetization curves. Little information is available about the alternating excitation of hard magnetic materials. A.C. excitation of hard magnetic materials is usually avoided because of large hystersis loss. Much information is available about the dynamic performance of soft magnetic materials such as grain-orientated silicon iron, but even here relatively large anomalous losses of doubtful origin occur (1-2).

Some of the work concerned with finding practical A.C applications for modern hard magnetic materials has been poineered by Alger(3). In his work Alger used hard magnetic materials in the leakage flux path of the rotor of the squirrel cage motor to improve its starting performance.

Previously (soft) low-loss materials had application as magnetic materials in circuits & motors to minimise losses. It is a relatively new idea to use a hard magnetic material for the purpose of deliberately inducing magnetic loss & so fa this has found only limited applications.

Hard magnetic materials, to a varying degree, have the ability to retain their magnetization under conditions which experience has shown to be unfavourable for retention. The development of these materials has to a great extent been empirical. Permanent magnetic materials are presently commercially available with a wide combination of magnetic & physical properties, which offer greater latitude to designer. Hard magnetic materials perform no new task but serve merely as sources of magnetic air gap-flux, a function which is equally accomplished with wound fields & electro magnets. Improved efficiency & stability of these materials make them preferred over wound fields & electromagnets. Another important factor, which has contributed to the increasing popularity of hard materials is their excellent stability, both metallurgical & magnetic.

A number of different types of hard magnetic materials are used as permanent magnets. Alcomax III is one of them. This is an alloy of (Fe-Co-Ni-Al) & is used for present investigation.

2. Magnetic Properties Of Hard Magnetic Material Alcomax III.

Many authors(4, 5) have worked on the magnetic properties of Alcomax III. It is found that small amounts of impurties or deliberate additions such as sulphur, silicon, niobium, tantalum, titanium & zirconium are allowable and give small advantages, but carbon must not be more than 0 3%. Anistropic Alcomax III alloys have usually an intrinsic saturation magnetization of about 14000 G, but remanence, coercivity & the general shape of the hysteresis loop are changed considerably by the precise heat treament to which the alloy is subjected. If it is cooled from 1250°C or more to 500°C or lower at a mean rate of about 1°C sec & subjected to a magnetic field of over 1000 oe in at least the range 850°-750°C, room temperature would give an extremely square hysteresis loop in the axis of the field heat treatment, with remanence about 13000 G and coercivity about 200 oe.

By prolonged tempering of the alloy in the range 600-550°C, the coercivity increases to 600-800 oe, dependent on the precise composition. Measurements on the direction perpendicular to that of the field treatment give a lean hysteresis loop with remanence about 4000 G & coercivity of 400 oe & (BH) max of 5 MGoe.

In fact, there are different views on the merits of the minor additions by different authors(3, 4). In general nioburium or tantalum increases coercivity with small reduction in remanence & BH (max), & also nullifies the harmful effects of inevitable small residue of carbon. Titanium gives even greater coercivity but with more marked reduction of remanence & (BH) max. Silicon & zirconium reinforce the loop squareness but with the reduction of coercivity.

3. Differences Method For Loss Measurement

The wide spread use of a.c. equipment, especially transformers & reactors, makes it desirable to have available methods of testing materials under a.c. conditions. In particular the engineer is concerned with the power losses that occur with alternating magnetization. Precise measurements are difficult to make, since in addition to the difficulties occuring in d.c. measurement, problems of waveform also arise to complicate the issue.

The principle uses of a.c testing methods are for determining (a) the permeability & energy losses of materials at low inductions & the inductance bridge is employed for this purpose, (b) energy losses at high inductions, usually B-1000 Gauss or 15000 Gauss using the Epstein method.

In interpreting the permeability & energy losses measured by a.c methods one must consider the apparent reduction of permeability due to skin effect or shielding caused by eddy currents as well as the separable losses attributable to eddy currents & hysteresis.

Hard magnetic materials such as Alcomax III are not available in toroidal form nor as thin laminae suitable for use in the Lloyd-Fisher square. A permeameter was built by the author using Telmag C core as shown in Fig. 1. A basic consideration in the design of the permeater was that the air-gap of the permeameter is adjustable. In the differences method of loss measurement for different size specimens of Alcomax III, the air-gap of the permeameter was adjusted such that the flux density in the iron core (C core) is the same with & without the specimen for the same magnetizing current. Since the copper losses in the magnetizing coil and the iron losses in the iron are then the same, the difference in power measurements represents the loss in the specimen. Power measurements were made directly by measuring the power into the magnetizing coil using a low power factor dynamometer wattmeter.

The scale of the design was determined mainly by the desire to achieve uniform field over the central test region-the gap, & also by the size of this test region necessary to permit reliable measurements of flux & field, Four Telmag (c) cores type TCSU are housed together with dimensions marked on the diagram. In the construction of this permeameter an important step towards ensuring good field uniformity in the test region was made by keeping the reluctance of the core small compared with the gap. The cross-section of the centre test region was made large to have uniform field throughout the area. In addition, it was found necessary to keep the magnetizing coils as near to the gap as possible that the total m.m.f applied to the permeameter should act across the gap. Two 215 turn magnetizing coils on the upper & lower sides of the centre limb of the permeameter were used in parallel. The effect of using them in parallel is to minimise the leakage reactance. The wire used forthe magnetizing coils is 13 swg. The 'C' cores have a permeability several hundred times that of the gap so that the core was considered as having zero reluctance.

To measure the flux density in the iron a search coil was wound around the centre limb concentric to one of the magnetizing coils. Four tappings were made on the coil, each having 100 turns.

$$B_{max} = \frac{E_{av}}{4\,fna} \quad \cdots\cdots\cdots (1)$$

Equation (1) is used for measuring the value of flux density Bmax in the iron by measuring the Eav by average voltmeter.

It is observed that the power loss measurement by the differences method failed to hold for the two smallest sizes of specimen i.e. 5.0 mm. × 5.0 mm. × 40.0 mm & 7.5 mm. × 7.5mm × 40. mm. Results which were obtained for these two specimen were not constant. For the large specimens this method holds good. At the low value of magentizing current eg 7 amps, the loss per unit volume decreased with increase in specimen size. It was found that the loss started to increase with increase in specimen size at the value of 12 amps of magnetizing current. The graph of loss per unit volume & magnetizing current is shown in Fig. 2 for different specimens.

4. Dynamic Method of Loss Measurement.

Dynamic measurements are those which for investigating the magnetic properties of materials, use time-varying fields. The properties of magnetic materials in time-varying fields generally depend on the way magnetic field varies with time, in other words, the field wave form has to be specified. The most important class of dynamic measurement is composed of a. c. measurements using sinusoidal excitation. Large amplitude excitation, in which the induction is a sinusoidal time function is also the basis of many industrial iron testing methods. Consider the average flux density on the specimen as

$$B = BO + \sum_{n=1}^{n=\alpha} B_{m1} \text{ Sin } (nwt + \theta n - \alpha n) \ldots\ldots (2)$$

and the total applied magnetizing field at the surface of the specimen of value

$$H_R = H_O + \sum_{n=1}^{n=\infty} H_{m1} \text{ Sin } (nwt + \theta n) \ldots\ldots (3)$$

where the subscripts m indicate the maximum values of each frequency component of the alternating quantities, n the order of the frequency, w the angular frequency of the fundamental alternating component, θ the angle of the nth harmonic component of H_R & αn the phase shift lag of the nth harmonic component of Ba behind that of H_R.

For the field intensity at the surface of specimen & average flux density in the material, Copeland (6) derived a relationship for energy loss per unit volume per cycle as

$$W = \int_{\text{lcycle}} H_R \, dBa \ldots\ldots (4)$$

and for the volume-average loss per cycle of the fundamental per unit volume as

$$W = \sum_{n=1}^{n=\infty} n\pi H_{mn} B_{mn} \text{ Sin } \alpha n \ldots\ldots (5)$$

If the alternating component of the applied field is of fundamental frequency only then

$$W = \pi B_{mn1} \; H_{mn1} \; \mathrm{Sin}\, \alpha n \quad \ldots\ldots (6)$$

In this case loss per cycle can be determined by measuring the peak values of the fundamentals & the phase shift between them.

If the applied field (in Equation 3) has harmonic terms, it would be necessary to measure the peak value of, & the phase shift between, the harmonics as well as the fundamental.

The B-H loop was obtained on the oscilloscope by the method shown in fig. 3. A polaroid camera was used to take the photographs of the B-H loops of different size specimens of Alcomax III at different values of magnetizing current.

The magnetizing force or magnetic intensity was calculated by the formula,

$$H = \frac{4\pi \, N I m \sqrt{2}}{10 \, l} \quad \ldots\ldots (7)$$

Where I_m is the magnetizing current in amperes, N the number of turns in the magnetizing coil, l the length of gap in centimeters. As the field in the gap was uniform i.e. there was not much leakage flux in the gap, the value of H measured by the search coil placed in the gap adjacent & parallel to the specimen was nearly the same as that calculated by the above formula.

The loss per cycle per unit volume can be measured by measuring the area of B-H loop. The area of the B-H loop was measured by polar planimeter & also mathematically by Simpson's Rule.

Fig. 4 shows the graph between Watt/cm^3 versus magnetizing current for different size of specimen.

It is observed that there is a decrease in loss with increase of specimen size at lower values of magnetizing current. Loss increases with size of specimen at 10 amps magnetizing current.

Fig. 5 shows the relation between magnetizing current and coercive force H_C for different sizes of specimen.

It is observed that W/cm^3 and Hc versus magnetizing current measured by the dynamic method have increased values compared with corresponding data obtained from static B-H loop shown in Fig 6.

5. Conclusions.

The present investigation has included two methods of loss measurements of Alcomax III hard magnetic material undergoing cyclic magnetization at 50 HZ frequency fot different size specimens.

Power measurement to the specimen was made by measuring directly the power into the magnetizing coils, using a dynamometer wattmeter. Using the differences method, the flux density of the iron core of the permeameter was made the same with & without the specimen, by adjusting the air-gap of the permeameter. The loss was also measured by obtaining dynamic B-H loop on the oscilloscope & measuring the area of that loop. Different size specimens of Alcomax III were employed & variation of loss with increase in specimen size was determined. The effect of loss on the Alcomax III metal was observed by varying two parameters i.e., magnetizing current & volume of the material.

The watt loss/cm^3, B_{max}, H_c, B_r, $H_{(gap)}$ were found from the dynamic B-H loop of the Alcomax III specimens. Watt loss/cm^3 was observed to increase with specimen size at higher values of magnetizing current.

It was observed that the value of coercive force increases with increase of specimen size. The coercive force was found to become greater under dynamic conditions than under static conditions. In fact, if H_c is the value of coercive force under static conditions, it would be $H_c + H_e$ where H_e is the additional field required to overcome the effect of eddy currents & other effects. As eddy currents are geometry dependent i. e. eddy currents effect increases with the increase in volume of the metal, therefore, it gives rise to increase in coercive force with increase in specimen size. As the section of specimen increased from 5.0mm × 5.0 mm × 40mm. to 25.0 mm × 25.00 mm. × 40 mm., the value of H_c increased by about 21.5% for the value of magnetizing current of 15 amps. It was discovered that average flux density in the metal decreased with the increase of specimen size for a fixed value of H. This may be caused by some mechanism of flux inhibition caused by eddy currents and other effects. The precise mechanism of this flux inhibition is not known.

It was determined that the loss measured by the differences method gave agreement within 10% with the loss measured from the area of dynamic B-H loop for higher value of magnetizing current. As loss calculated by measuring the area of the dynamic loop includes the loss due to hysteresis, eddy currents, magnetic viscosity, viscous damping etc., it is apparent that the loss measured by the differences method should be the same, as this also measures all the losses involved in the cyclic magnetization process.

REFERENCES

1. Brailsford, F & Fogg, R, Proc. IEE, Vol III, No. 8, 1964, PP. 1463-7.
2. Brailsford, F & Fogg, R, Proc. IEE, Vol. 113, No. 9 1966, PP. 1562-4.
3. Alger, PL, United States Patent Office, Patented December 20, 1966.
4. Brailsford, F, Proc. IEE, Paper No. 1947, February 1956 (103 A, 39).
5. Hadfield, D, 'Permanent magnets & magnetism' (book), John Wiley & Sons, New Yerk, I liffe Books Ltd. London.
6. Capeland, MA 'Losses in Alnico permanent magnet materials' PhD Thesis, University of Toronto, 1965.

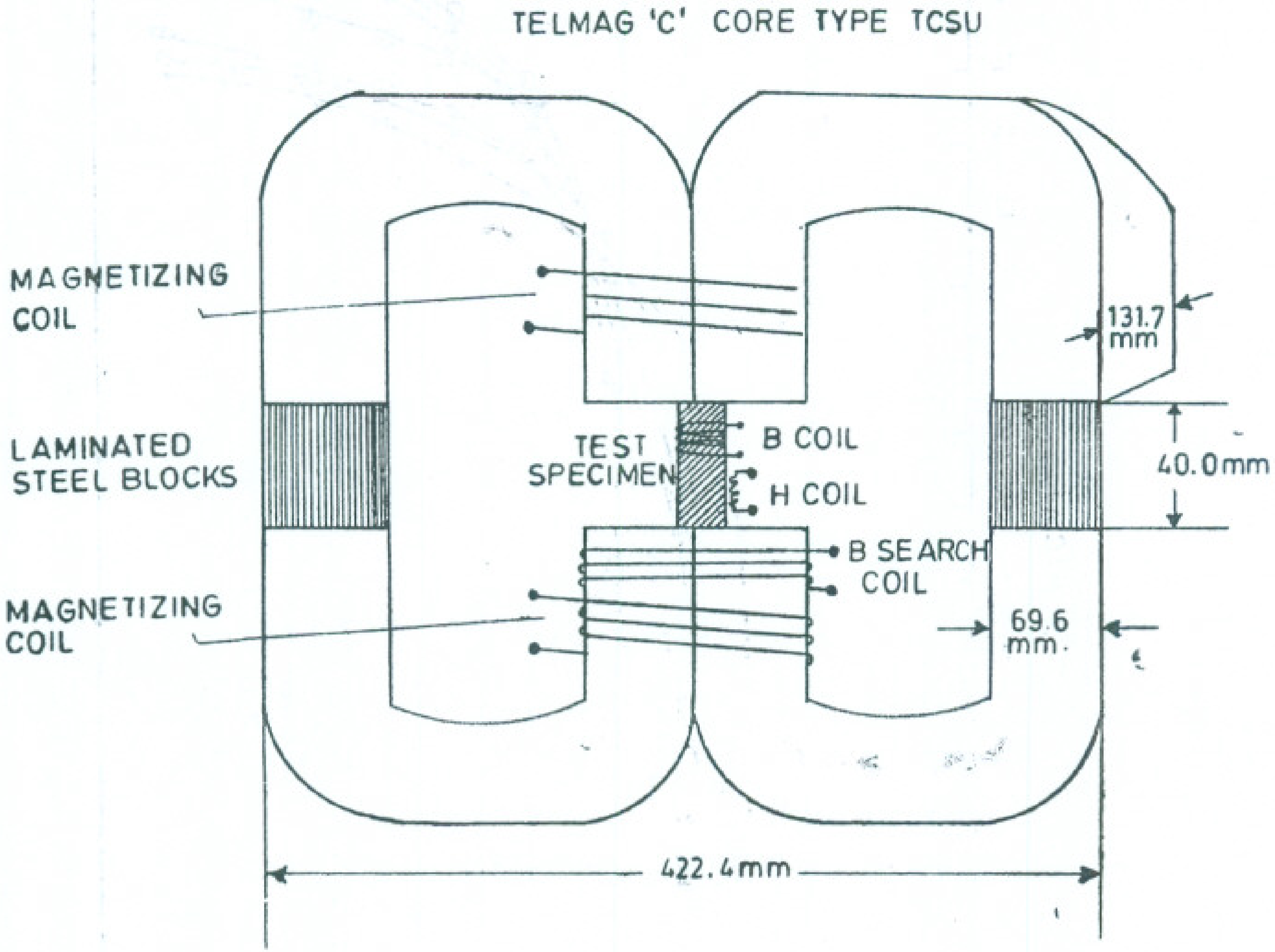

FIG.(1) SKETCH OF THE PERMEAMETER

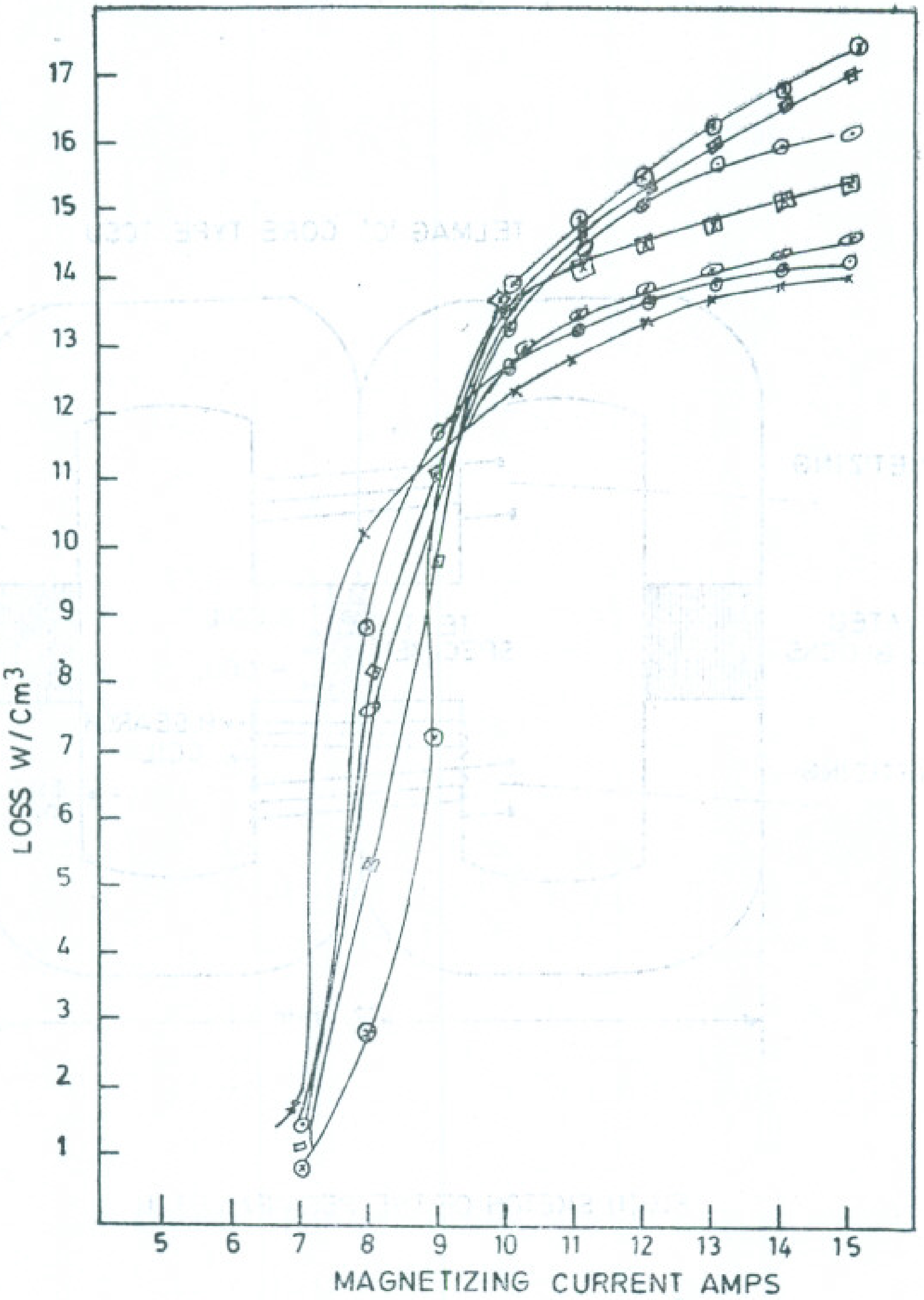

FIG.(5) VARIATION OF LOSS W/Cm^3 WITH MAGNETIZING CURRENT

SPECIMEN SIZE
× × × × 5.0mm X 5.0mm X 40mm
○ ○ ○ ○ 7.5mm X 7.5mm X 40mm
⊗ ⊗ ⊗ ⊗ 10.0mm X10.0mm X40mm
⊠ ⊠ ⊠ ⊠ 12.5mm X12.5mm X40mm
○ ○ ○ ○ 15.0mm X15.0mm X 40mm
□ □ □ □ 17.5mm X17.5mm X 40mm
⊘ ⊘ ⊘ ⊘ 25.0mm X25.0mm X 40mm

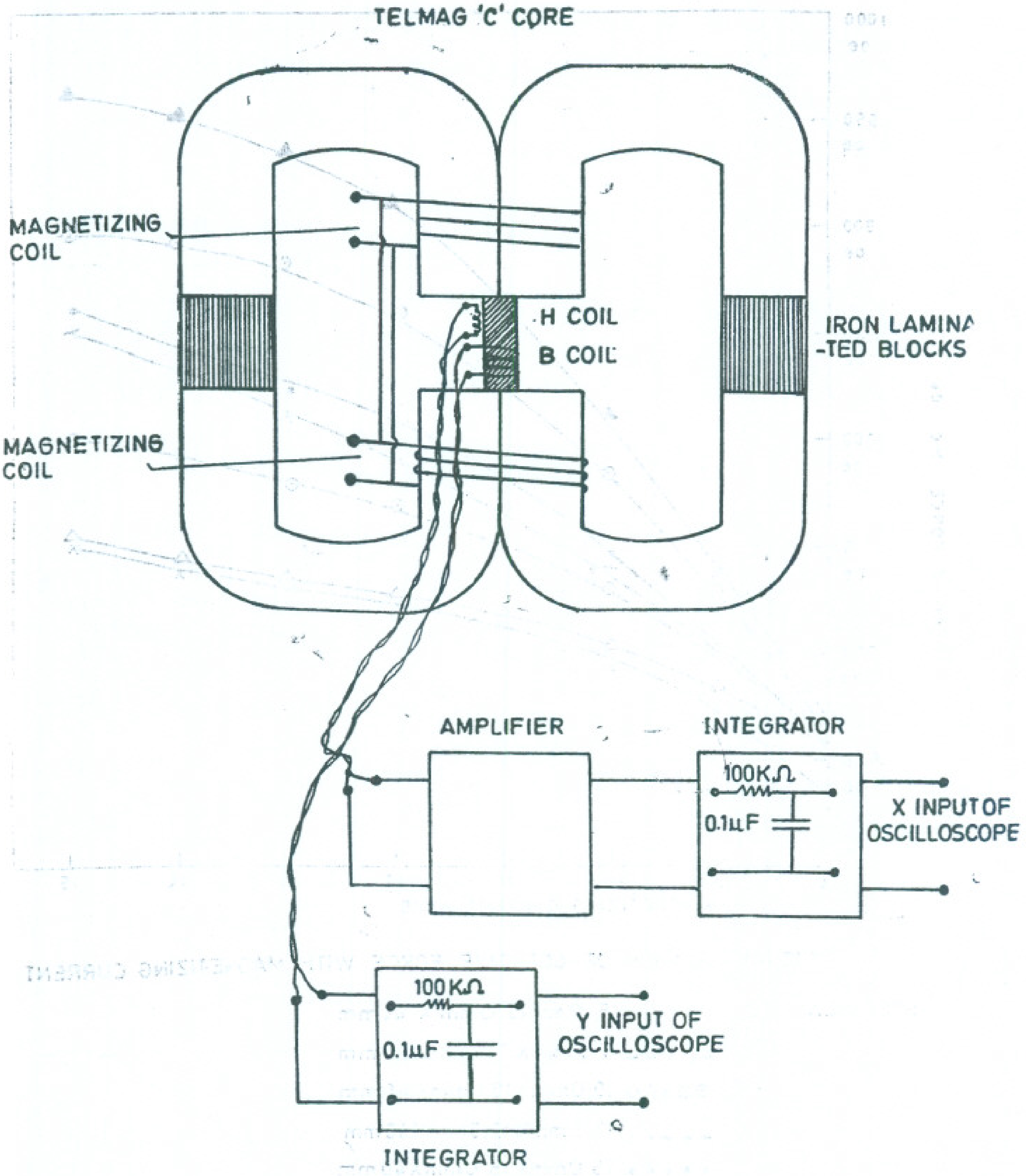

FIG. (3) MAGNETIZING APPARATUS FOR DYNAMIC - B-H LOOP

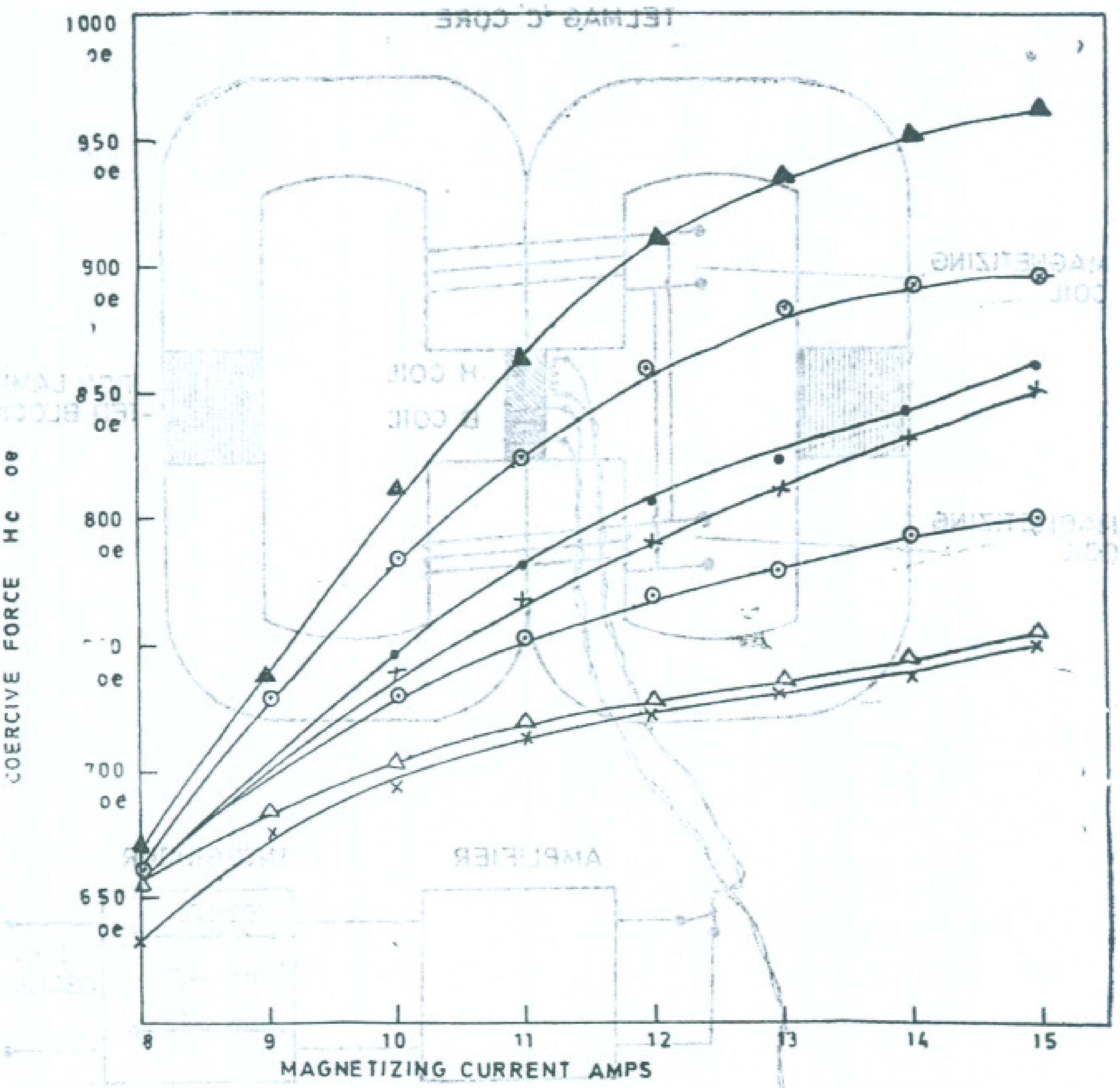

FIG.(4) VARIATION OF COERCIVE FORCE WITH MAGNETIZING CURRENT

SPECIMEN SIZE xxxxx 5.0mmX5.0mm X 40mm
△△△△△ 7.5mm X 7.5mm X 40mm
⊗⊗⊗⊗⊗ 10.0mmX10.0mmX 40mm
+++++ 12.5mmX12.5mmX40mm
••••• 15.0mmX15.0mmX40mm
⊙⊙⊙⊙⊙ 17.5mmX17.5mmX40 mm
△△△△△ 25.0mmX25.0mmX40mm

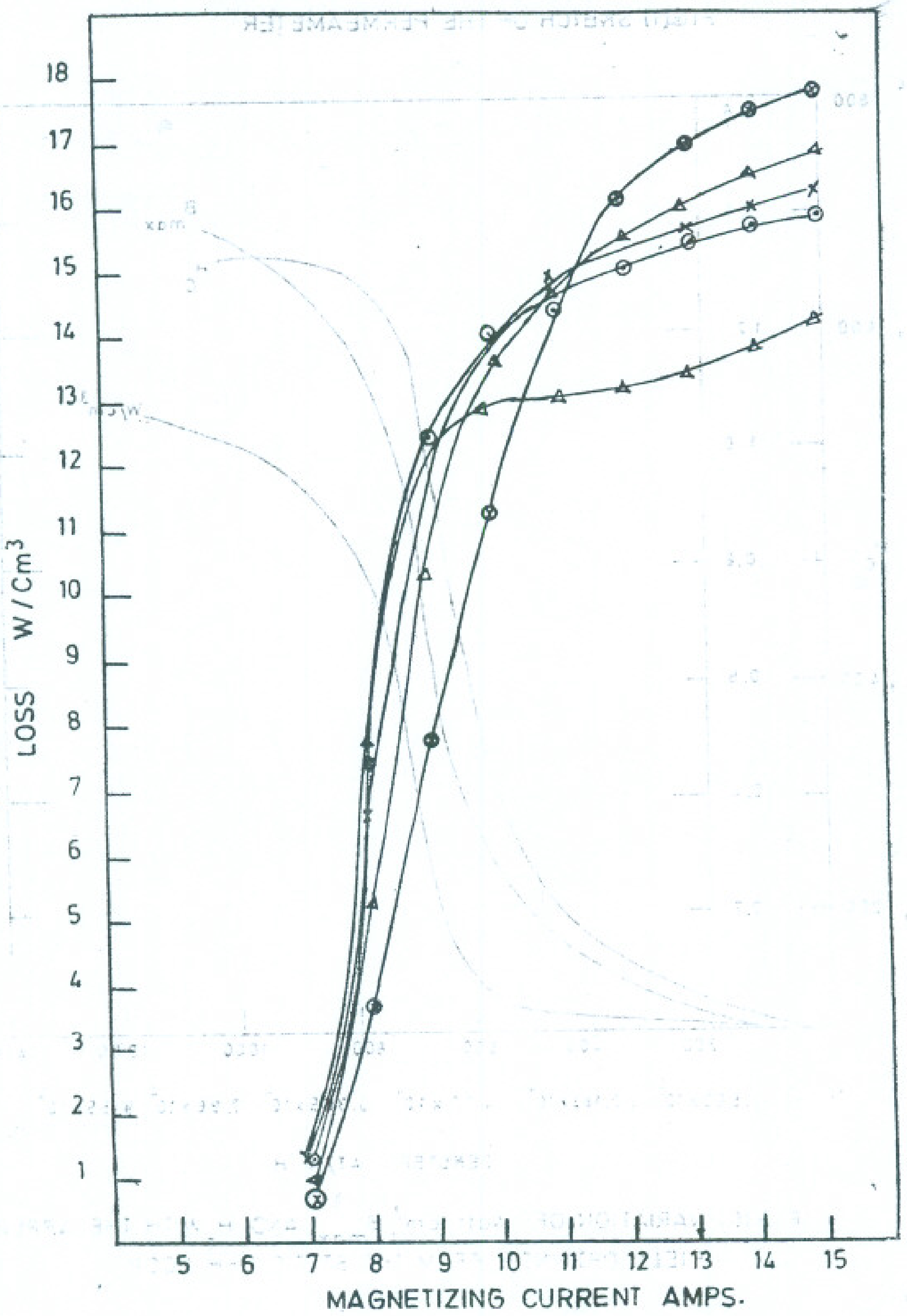

FIG.(2) VARIATION OF LOSS W/Cm^3 WITH MAGNETIZING CURRENT

SPECIMEN SIZE

▲ ▲ ▲ ▲	10.0mm X 10.0mm X 40mm
⊙ ⊙ ⊙ ⊙	12.5mm X 12.5mm X 40 mm
x x x x	15.0mm X 15.0mm X 40mm
△ △ △ △	17.5mm X 17,5mm X 40mm
⊗ ⊗ ⊗ ⊗	25.0mm X 25,0mm X 40mm

FIG(1) SKETCH OF THE PERMEAMETER

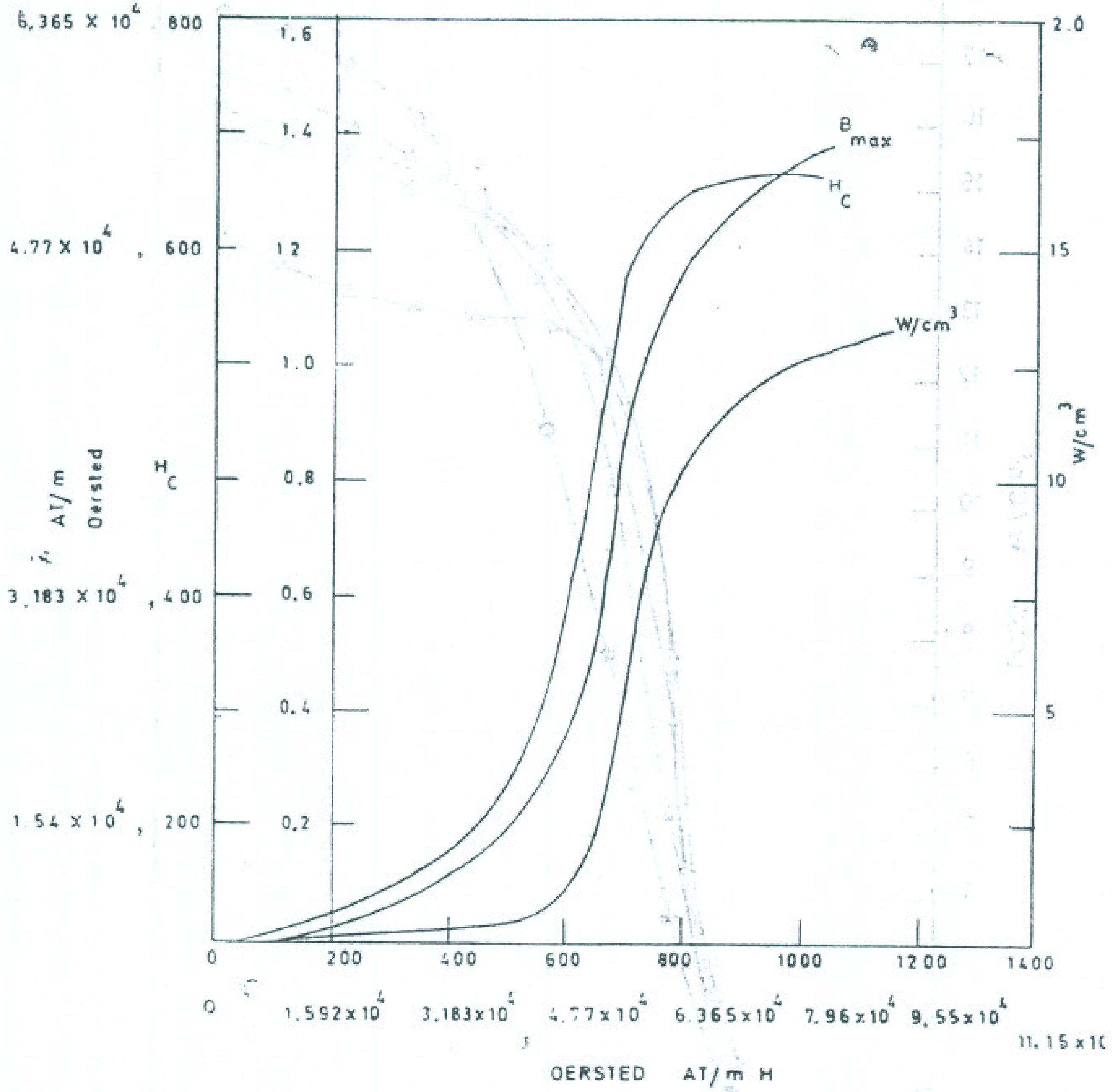

FIG.(6) VARIATION OF Watt/cm^3, B$_{max}$, AND H$_c$ WITH THE APPLIED FIELD OBTAINED FROM THE STATIC B-H LOOP