"CONSTRUCTION OF A SPECIAL PURPOSE ELECTROMAGNET AND MEASUREMENT OF MAGNETIC PROPERTIES OF IRON-SILICON ALLOYS".

BY

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CERTIFICATE

This is to certify that this work was done by me and it has not been submitted elsewhere for the award of any degree or for publication.

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BANGLADESH UNIVERSITY OF ENGINEERING AND TECHNOLOGY

DEPARTMENT OF PHYSICS

CERTIFICATION OF THESIS WORK

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has been accepted as satisfactory in partial fulfilment for the degree of Master of Philosophy in Physics and certify that the student demonstrated a satisfactory knowledge of the field covered by this thesis in an oral examination held on 30th March, 1991.

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ABSTRACT

A 8.6 kilo-gauss electromagnet has been constructed. Locally produced soft iron has been used for its construction. Chittagong Steel Mills (CSM) has supplied the material and its carbon content is 0.08%.

The construction work has mainly been done at different work-shops of BUET. Some work has also been done at Engineering workshops situated at Dholaikhal, Dhaka.

The electromagnet hae thoroughly been investigated. In order to know its characteristics, different parameters such as field-generation capacity at different current values, stability of the field with time, temperature conditions at different layers of the energising coils, residual magnetism etc. have been studied.

The magnetisation measurement of Iron sample (0.08%C) has been done. The same of a commercial Fe-Si alloy has also been done. Both the measurements were carried out with Vibrating Sample Magnetometer (VSM) installed at Magnetic Material Science Division of Atomic Energy Centre, Dhaka (AECD).

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CHAPTER - 1

INTRODUCTION

INTRODUCTION

Electromagnets constitute a powerful tool to create perturbations in materials and to study their magnetic response and they are of immense importance in fundamental research. Electromagnets are used in different forms and sizes in various electromechanical devices such as radio loudspeakers, tape-recorders, electromagnetic brakes etc. They are also used to lift heavy masses of magnetic materials and to attract movable parts of electric devices such as relays, clutches etc.

In industries and in energy conversion and transmission as also in information storage and processing, magnets play an indespensible role. The rapid development of many branches of physics, especially magnetic confinement of plasma, study and application of superconductivity, quantum optics, antiferromagnetism etc. demand powerful magnetic field. Magnetic fields are needed to determine the degree of splitting in radiation spectrum of various substances and to study properties of elementary particles in photographic emulsions. Magnets of different kinds are also used to control charged particles in particle accelerators, and also to study fermi surfaces in metals. Magnets have started taming the thermonuclear research. Magnetotheraphy is an important science to cure many a incurable disease.

The contribution of Electromagnets to material science is tremendous. They are cheap and conventional tools to study electronic structure and spin ordering of materials that are either ferromagnetic, paramagnetic or diamagnetic. The added advantage of electromagnets lies in their variability in respect of field strength and design.

Although commercial electromagnets are available, the prices of these magnets are quite high. And one has to pay for certain characteristics of these magnets which may not be essential for specific laboratory experiment. On the otherhand many of these expensive magnets may not possess the characteritics which are required for fundamental research purposes.

The aim of the present work is to tailor an electromagnet to the specific needs of our laboratory, and also to study the characteristics such as saturation field, flux-distribution, heat generation, residual field as affected by the design parameters. Locally produced iron containing 0.08% carbon bought from Chittagong Steel Mills has been used for constructing the electromagnet.

Over 8.5 kilogauss magnetic filed was obtained with the electromagnet. But 25 Kilogauss field can easily be generated if higher current can be supplied with a highly powerful d.c power supply which was not available. Maximum temperature developed in the electromagnet was $93.5^{0}C$ but this did not affect the field. Very small amount of residual field was present but in future if more carbon-free iron is available, residual magnetism could be minimised to a great extent.

Another aspect of the present work is the measurement of magnetisation of iron used for the construction of electromagnet and of iron-silicon alloy. The saturation magnetisation and residual field of electromagnet are determined by the magnetic properties of core and pole-face material. And so the study of the magnetisation process and magnetic properties of the constructional material was taken up. Iron -silicon alloy is an important material which has immense technological use and that is why its magnetisation process was also studied.

The magnetisation of the two above mentioned materials has been measured with Vibrating Sample Magnetometer (VSM) installed at magnetic material science division of Atomic Energy Centre, Dhaka (AECD).

Iron-Silicon alloys containing 0.5-5% silicon have high permeability, high electrical resistance and low hysteresis loss. Iron-Silicon steel electrical sheets are made commercially into two main categories: grain-oriented and non-oriented. The non-oriented steels may be subdivided into low, intermediate and high silicon classes. They are used in rotors and stators of motors and generators, reactors, relays, transformers and various types of communication equipments. Considering all these enqineering and applied research importnce of iron-silicon alloys, the magnetisation of a commercial sample of iron-silicon alloy was measured.

CHAPTER - 2

DEVELOPMENT OF ELECTROMAGNETS

A HISTORICAL VIEW

CHAPTER - 2

DEVELOPMENT OF ELECTROMAGNETS

A HISTORICAL VIEW

The first electromagnet was made by William Sturgeon[1].He demonstrated his new discovery to the Royal Society of Arts on 23rd May, 1825. It was a varnished rod of iron one foot long and half an inch in diameter. It had the form of a horse-shoe and was covered all over with a single layer of uninsulated copper wire. Sturgeon's electromagnet weighed 200 gm-force.

James Prescott Joule made the second electromagnet and that also in the year 1825. Joule's magnet's lifting capacity was 20 Kg-force.

Almost five years later in 1830 a third electromagnet was built by William Sturgeon. It had a lifting capacity of 550 kilograms. A year later iu 1831 Professor Joseph Henry of Yale University, U.S.A. constructed the fourth electromagnet of the world. Incidentally all these magnets had horse-shoe cores.

Research on design and construction of electromagnet gradually gained momentum, and in 1840 Joule came with his second magnet which was fifth in the serial. It consisted of a thick steel tube cut along its axis below the diameter. The magnet's lifting capacity was 1.3 tons. In the same year Joule built another electromagnet that attracted a load not by usual two poles but by a much larger numbers.

Electromagnet began to appear in great numbers in physics laboratories, in aristocratic salons and in doctor's surgeries. They even began to be used in clothing factories, and in concert halls as a part of the magnetic organ.

When material scientists, engineers and every one of other discipline were convinced of Electromagnet's strength, reliability, compactness, efficiency and convenience, new commercial companies came up with electromagnets of different sizes and designs. These electromagnets were widely used in steel works and engineering factories. Thomas Edison in 1880 invented a magnet and it was used as a magnetic seperator for cleaning grain in flour mills. The Horse-Tram and Omnibus company of U.S.S.R. used electromagnet to remove nails from the oats fed to the horses. The criminologist V.I. Sorokin made magnetic brush based on electromagnet-principle for taking finger prints of criminals. Professor Auguste Piccard used powerful electromagnet to explore ocean depths.

In 1910 Railway Engineers designed electromagnet to magnetise the wheels of wagons in order to improve the grip on the rails. The electromagnet trippled the coefficient of friction and consequently the load capacity. For some time magnetic road was used in Moscow to transport letters from Post-Offices.

In the 1930's a very large electromagnet was built for equipment used to destroy defective castings. Its capacity was enormous and that was around twenty tons. Within short time robust electromagnets were built capable of lifting 50 tons.

The Russian scientists E.K. Lentz and B.S. Jacobi and Englishmen John and Edward Hopkinson made an enormous contribution to the theory and design of modern electromagnet. Leading physicists and electrical engineers like Faraday, Becquerel and Thomson also made stupendous efforts to advance the design of modern electromagnets.

In the thirties in the U.S.A. the brilliant physicist Francis Bitter who dedicated his whole life to magnets and magnetism, built his 100 kilo-oersted magnet. The magnet had a series of copper discs, with radial slits and 600 (six hundred) holes for cooling water. The magnet is often called the First Bitter Solenoid. Before Bitter a 60 kilo-oersted magnet was working in Bellevure out side Paris and a 70 kilooersted magnet was at Uppsala University in Sweden.

Super-powerful magnetic fields were obtained in the 1960's and were put to use to different rapidly developing branches of physics. Special laboratories and installations were set up in the U.S.S.R., the U.S.A. and Great Britain to carry out research on magnet and magnetic field patterns.

In 1965 a field of 220 kilo-oersted was obtained at U.S. National Laboratory of Magnetism. The magnet had three co-axial solenoids. It had an inside diameter of ten centimeters and used 16 MW of power. The outside was wound with a hollow copper tyre of square-cross-section. The inside was filled with copper discs on which radial cooling channels had been etched. Later U.S. and Russian scientists succeeded in building 440 kilo and 700 kilo oersted electromagnets.

CHAPTER - 3

CONSTRUCTION OF ELECTROMAGNET

CHAPTER - 3

CONSTRUCTION OF ELECTROMAGNET

3.1 CONSTRUCTIONAL MATERIAL

The major parts of the electromagnet---rectangular yoke, the pole-pieces and pole-tips are constructed with soft-iron having a carbon composition of 0.08%. The iron is obtained from Chittagong Steel Mills (CSM).

The choice of this very low carbon iron is essential. It is well known that the yoke material is largely determined by the permissible residual field. If this must be reduced to an absolute minimum an iron forging carefully annealed with very low impurities is essential. In this way minimum remanence and highest saturation intensity will be achieved. The actual permeability is of secondary importance since the reluctance of the working air-gap is the main feature in controlling the field at low excitation. This reluctance also reduces the remanent field in the gap to a low value. But very low remanent field is not our main objective. Our actual purpose is to employ the magnet to measure saturation intensity of ferromagnetics and to determine the susceptibilities of para magnetic materials. For saturation intensity measurement of soft ferromagnetics, a high residual field would be intolerable whereas in susceptibility determination even a higher residual field is unimportant. Taking all these into consideration low carbon steel of around 0.08% carbon is chosen.

3.2 YOKE CONSTRUCTION

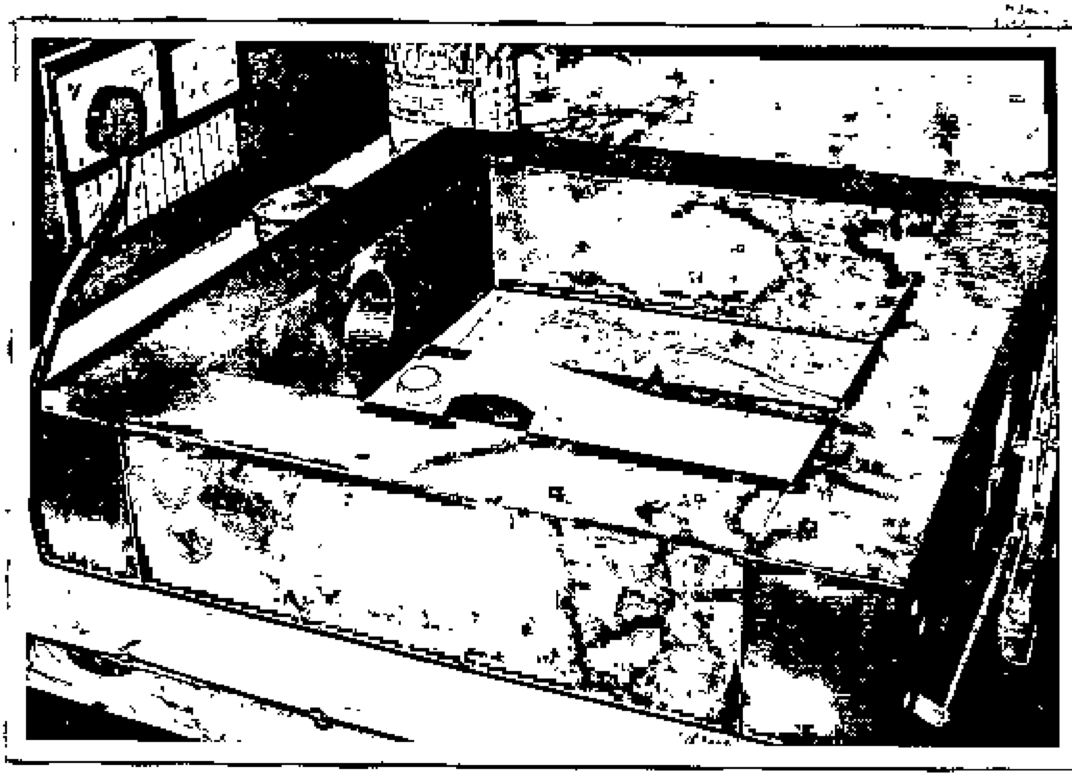
A rectangular yoke is made. The Chittagong Steel Mills has supplied three bars of dimension 1800 mm X 110 mm X 110 mm. At BUET machine shop, with the help of Electric-shaping machine, their sizes have been reduced to 104 mm X 104 mm. This reduction is necessary to free the material from all wears and tears and also make it fault-free. Next with the help of Bend-saws, two iron bars measuring 550 mm X 104 mm X 75 mm have been made. Another two bars measuring 510 mm X 104 mm X 75 mm are also made using Bend Saws. These four bars form the four arms of the yoke.

3.3 JOINING OF BARS

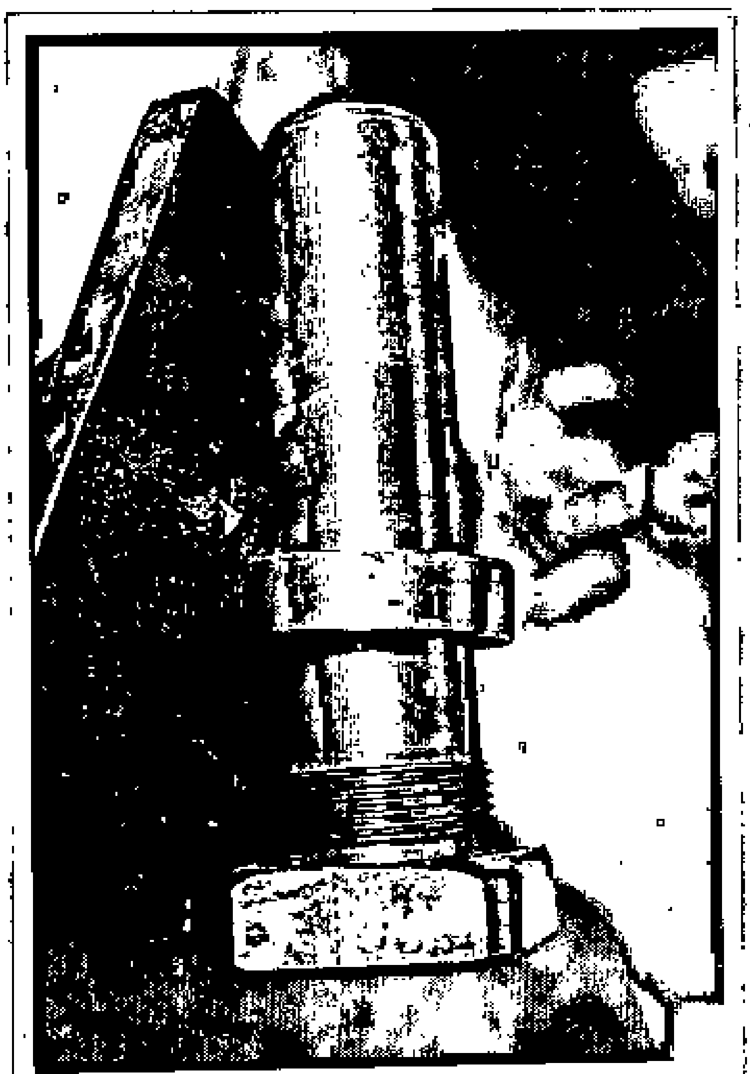
In order to join the bars, at the extreme ends of each bar, three holes of diameter 12.5 mm are made with the help of Electric Radial Drill Machine. Thus twelve holes have been drilled in four bars. Next twelve full threaded allen key bolts (10 cm X 1.25 cm) are used to join the bars and a rectangular yoke as shown in photography has been constructed.

3.4 POLE-PIECE CONSTRUCTION

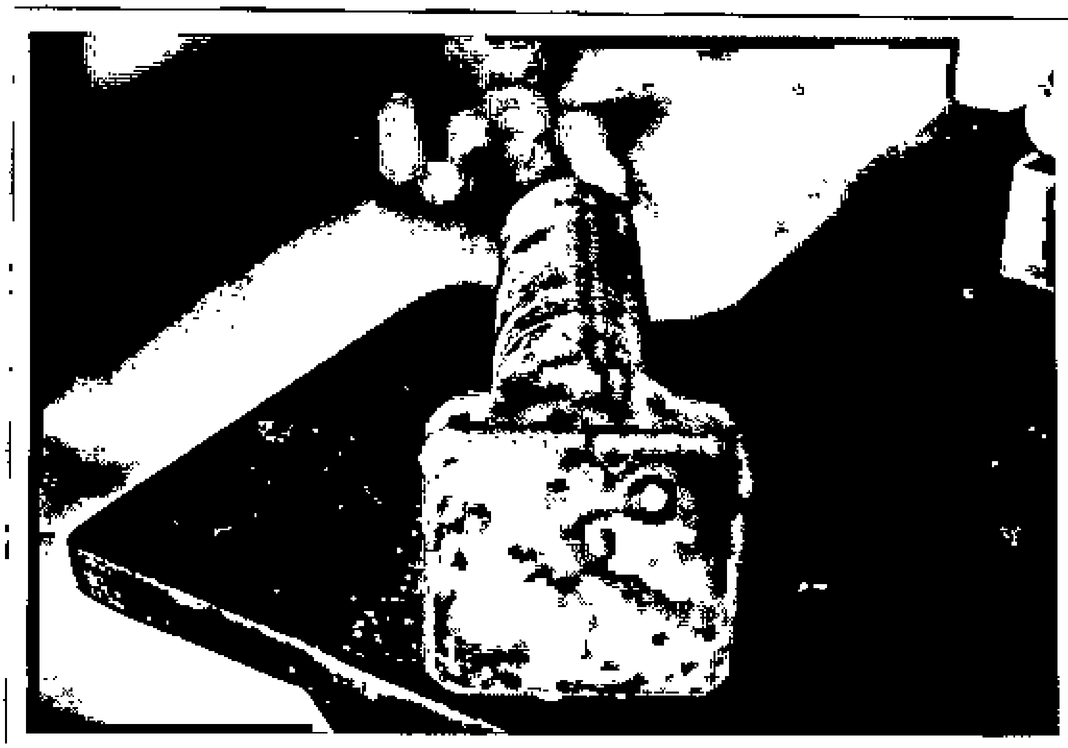
Lathe machine has been used to make the pole-pieces. Two pole pieces each of 250 mm length and around 75 mm diameter have been made. The pole-faces are bevelled out. The pole-pieces are secured to the yoke by making two holes of over 75 mm diameter at the centre of each 550 mm X 104 mm X 75 mm bars.



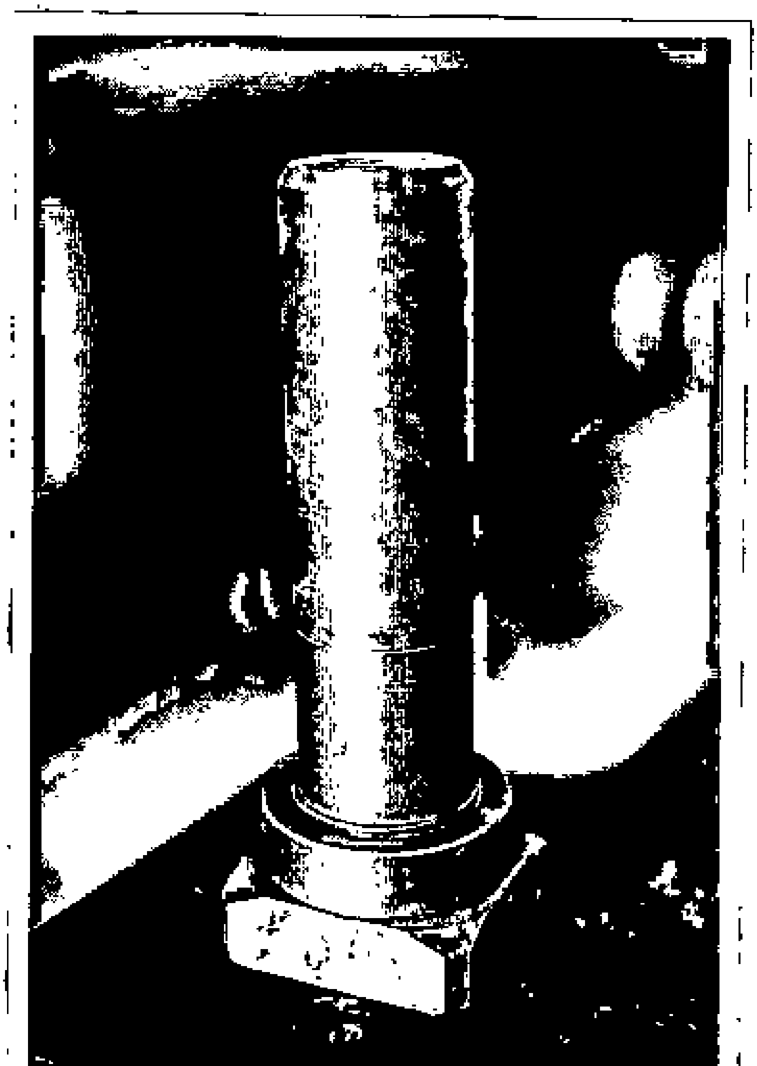
RECTANGULAR YOKE OF THE ELECTROMAGNET



THE EXTREME END OF THE POLE PIECE IS THREADED



THE POLE PIECE IS TERMINATED TO A RECTANGULAR BLOCK



SUCH TWO POLE PIECES ARE THERE IN THE ELECTROMAGNET

Provision has been kept for pole-gap adjustment. The extreme ends of the pole-pieces as shown in photograph are threaded so that the pole-pieces could be locked in any desired positions and thus different pole gaps could be obtained. The ends of the poles are terminated to a rectangular plate of dimension 9.18 cm X 9.18 cm X 3.18 cm as shown in the photograph.

3.5 COIL PREPARATION

Two coils for two pole-pieces have been made with insulated copper wire of No. S.W.G. 18. The resistance of each coil is 36 ohm as obtained from Avo-meter reading. The insulation resistance is 100 Mega-ohm.

First the wire is wound on a plastic core. But after giving a total of three thousand turns, the plastic core broke down. After this accident, the damaged core along with the wire was kept soaked in kerosene since each layer contained insulating varnish. When all the varnish got dilluted, the wires were wound on wooden frame as shown in figure 3.1.

Winding of the wire is done manually. This time also after each layer, insulating varnish is used. The coil has a total of fifty one layers, each layer having one hundred and fifteeu turns. So in total five thousand eight hundred and sixty five turns are given to each coil. The length of each coil is 152.4 mm. Outer diameter of each coil is 195 mm while inner diameter is 76.4 mm. Both the coils are wrapped with thick cotton cloths. Two coils are set in two pole pieces. They are connected in series.

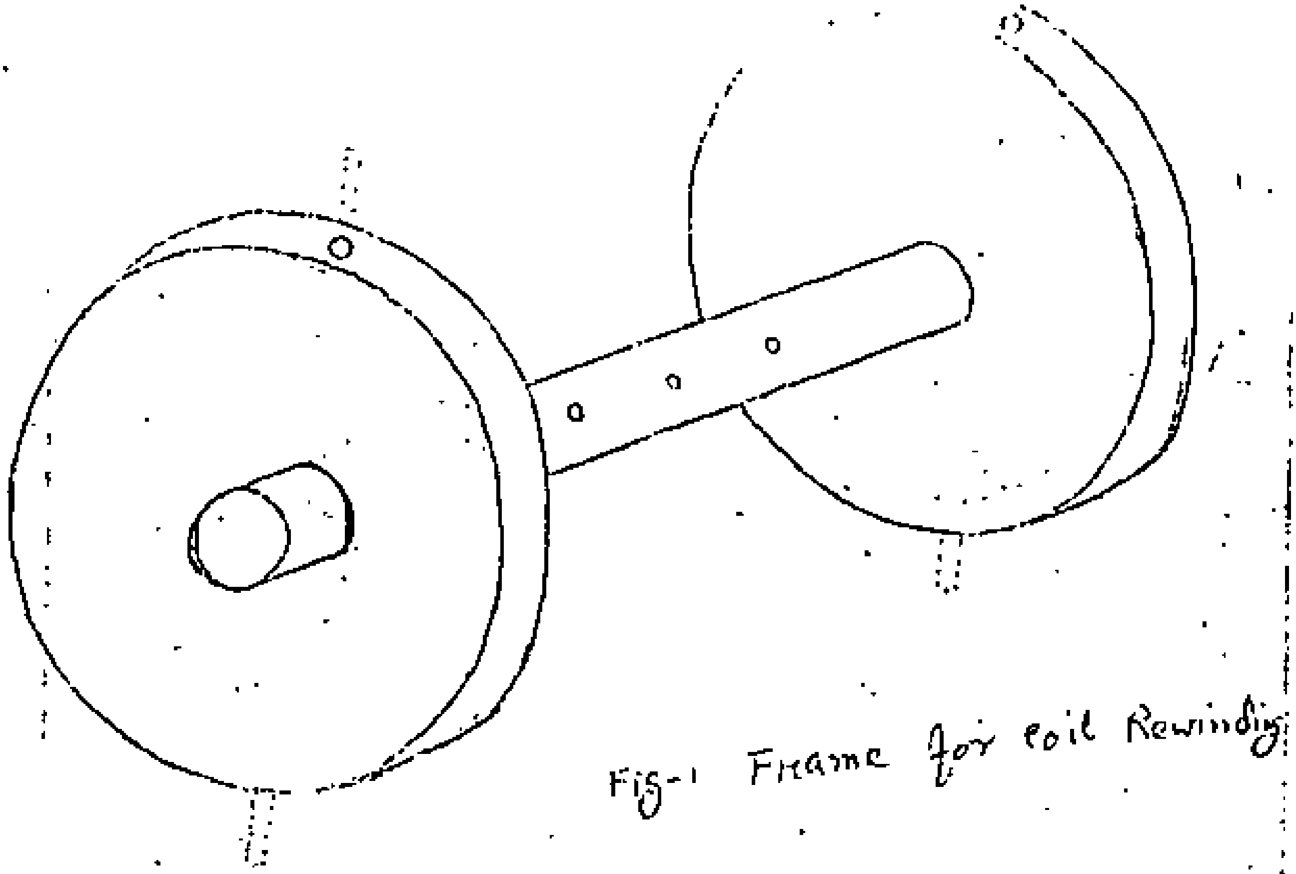


Fig-1 Frame for coil Rewinding

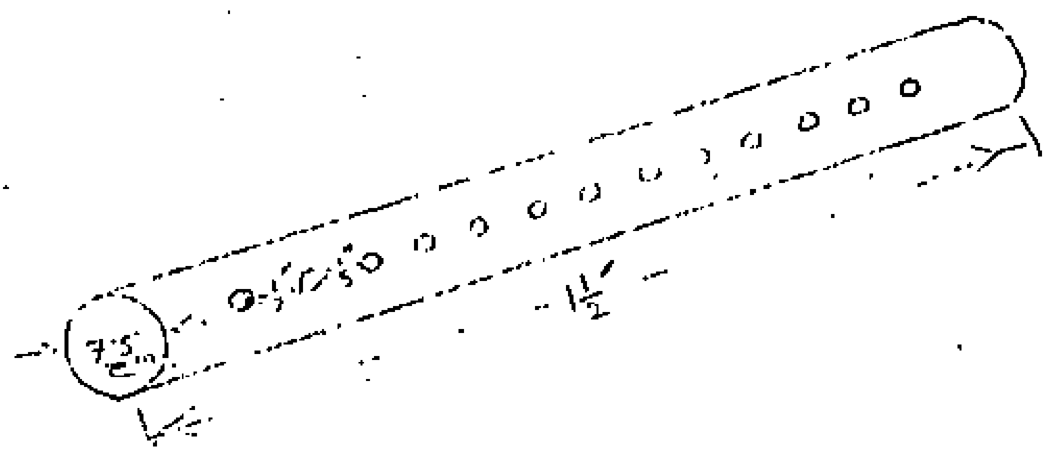


FIG. 2. ROLLER,
LENGTH - 1'-6''
DIA - 7.5 cm

HOLE - 0.5 cm

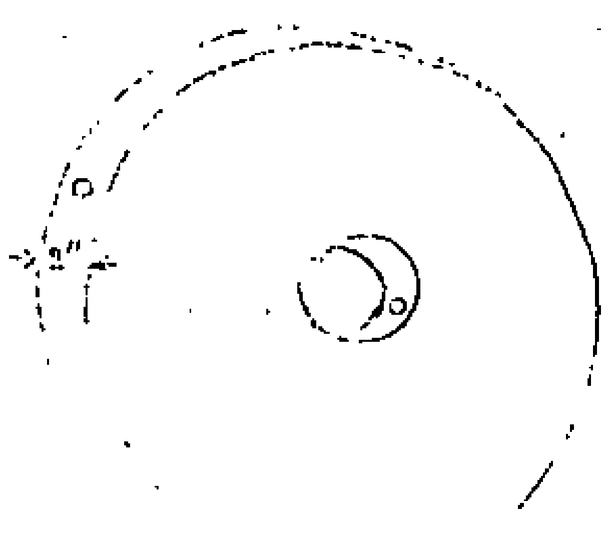
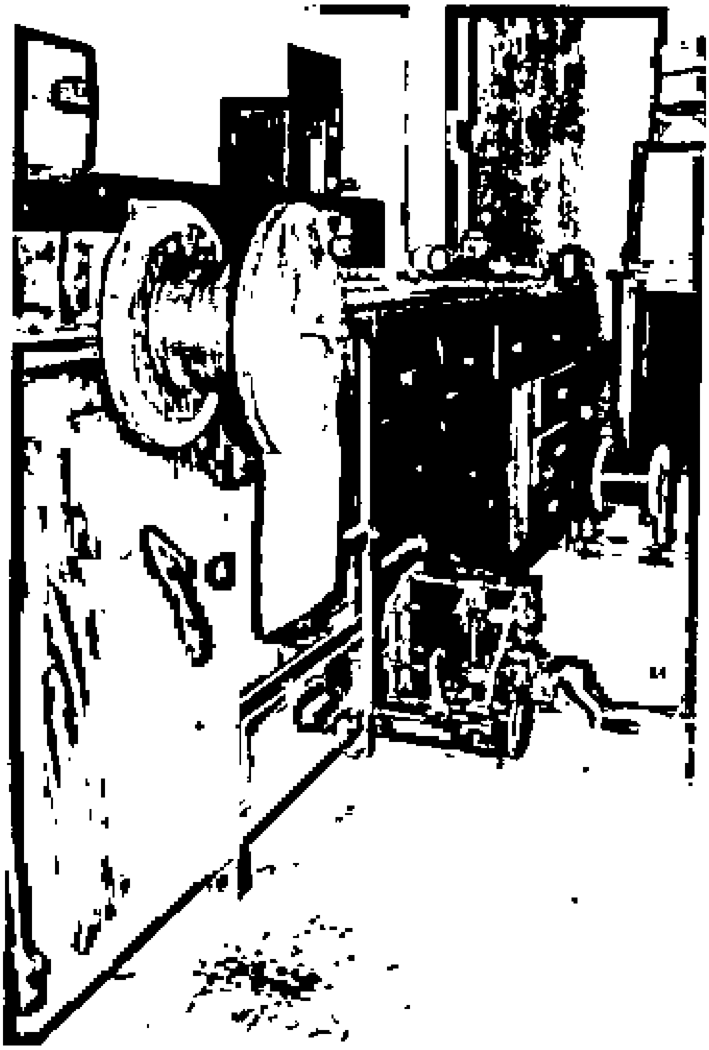
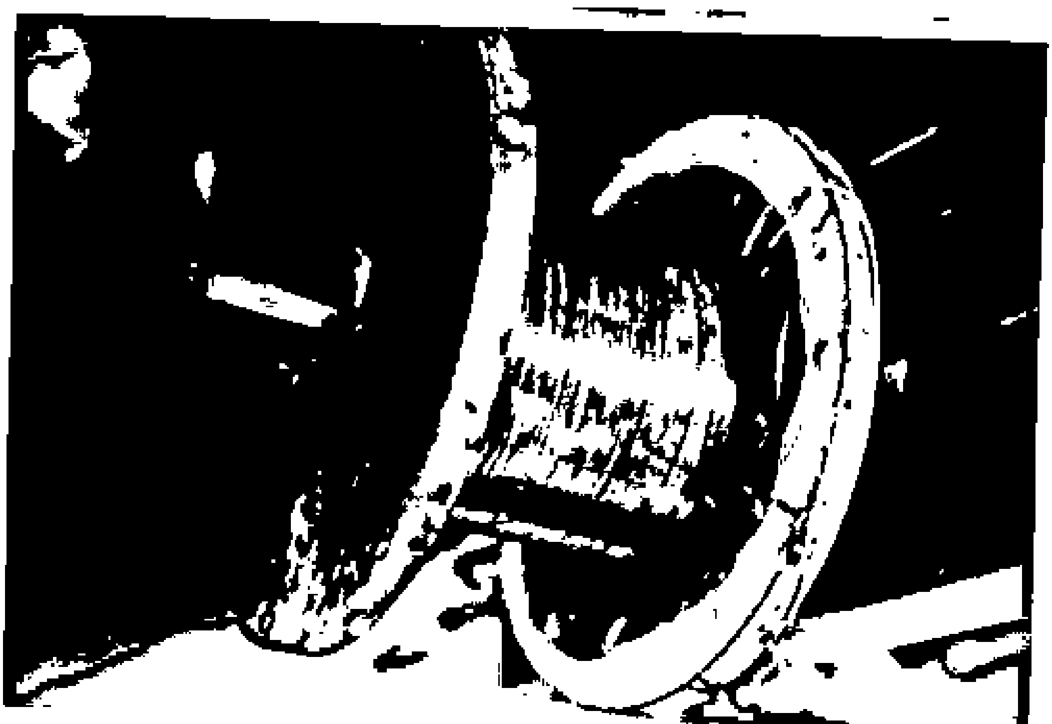


FIG. 3. SLIDE WHEEL,
THICKNESS - 2 ''
DIA - 1'

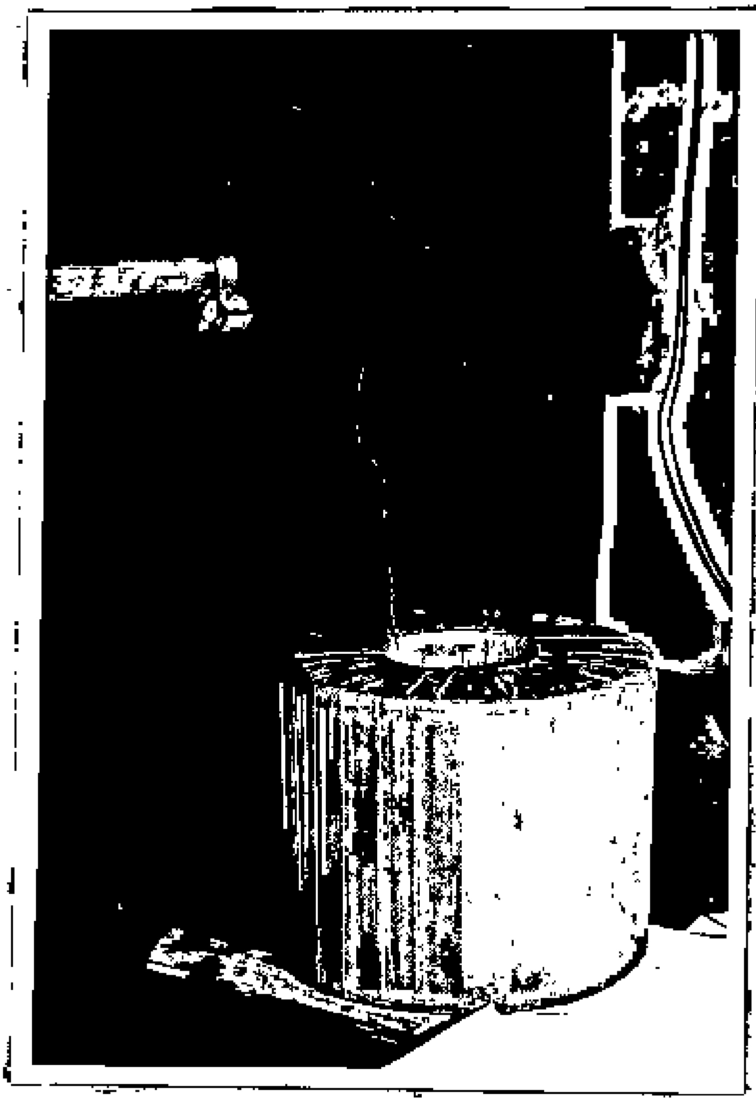
INNER HOLE
DIA - 0.5 cm



SET-UP FOR COIL-WINDING



WINDING IS DONE ON THE WOODEN CORE



SUC H TWO COILS ARE FOR TWO POLE PIECES

WINDING OF THE COIL IS DONE MANUALLY

Thus with yoke, pole-pieces and coils, the construction of electromagnet is almost complete.The whole assembly is mounted on an inclined seat, description of which is given next.

3.6 SEAT CONSTRUCTION

The electromagnet is mounted on an angular seat. It has four legs - two long legs and two short legs. The longer ones are thirty-one centimetres high each while the shorter ones are ten centimetres in height each. Each long and short leg form a pair and as such two pairs are obtained. Each pair is joined by an angular bar fifty-seven centimetres long. The angle between long leg and angular bar as seen from outside at the upper end is one hundred and fifteen degrees while that between short leg and bar at the lower end is seventy five degrees.

From the upper-end at a distance of seven centimetres an angle-bar of dimension 4 cm X 4 cm is placed cross-wise. Its length is sixty-eight and half centimetres. Another angle-bar is placed cross-wise at a distance of nine centimetres from the bottom end. Its length is also sixty-eight and half centimetres.

On the lower cross-bar a hole of diameter twelve and half mili-metres is drilled at a distance of twenty-three centimetres from the right extreme end. Another hole of same diameter is also drilled at a distance of tewnty-three centimetres from the left end. The upper cross-bar has aleo a hole of diameter twelve and half mili-metres drilled at its centre.

One of the two short arms of the rectangular yoke is bolted with upper-angle hole while the other short arm is bolted with two holes on the lower cross-arm.

In order to provide good support three cylindrical fibre pieces are used in-between the cross-bars and short-arms of the yoke. The height of each cylindrical fibre piece is thirty two millimetres while the diameter is fifty-nine milli-metres. Two fibre-pieces are placed on lower side arm while one is placed on upper side arm. Thus the rectangular yoke of the electromagnet is placed rigidly on the seat.

CHAPTER - 4

MAGNETIC CIRCUIT

CHAPTER - 4

MAGNETIC CIRCUIT

We can design magnetic circuits in analogy with electric-circuits by considering the basic equations of Electromagnetism[2,3] as follows :

$$\text{div } \beta = 0 \quad \text{------} \quad (1)$$

$$\Rightarrow \text{div } \mu(\text{grad } V_m) = 0 \quad \text{------} \quad (2)$$

Where V_m = magnetic potential

= magnetic flux-density

$= \mu H$

Since, μ is a constant,

We have, $\Delta^2(V_m) = 0$ - - - (3)

Total flux of the circuit is given by

$$\phi = \iint \beta_x ds \quad \text{------} \quad (4)$$

The magnetic reluctance is by definition

$$R_m = \int dl/MS \quad \text{------} \quad (5)$$

In magnetic circuit, the magnetomotive force (m.m.f) is given by

$$\mathcal{E}_m = \oint H_\ell dl \quad \text{------} \quad (6)$$

According to Ampere's theorem,

$$\oint H_\ell dl = 0.4 \; Ni \quad \text{------} \quad (7)$$

in c.g.s. unit

And again, $\oint H_{\ell} dl = Ni$, in SI unit.

Now we can write

$$
\begin{aligned}
M.M.F. &= \oint H dl \\
&= \oint B/\mu \, dl \\
&= \oint \phi \, dl/\mu s \\
&= \phi \int dl/\mu s \\
&= \phi R_m \quad \text{------------- (8)}
\end{aligned}
$$

Using some approximation, we can calculate the magnetising currents necessary to produce a particular magnetic field in an electro-magnet having a special arrangement of magnetic cores, poles, pole-faces solenoids etc.

If we have a coil of N-turns carrying a current of C-amperes and also a unit pole once around a closed path threading through the coil, the work done in opposition to the field is $4\pi/10NC$ ergs. We know that the work done in taking the unit pole over a short distance dl is Hdl and the total work over the complete path in $\int Hdl$. This is known as the line integral of magnetic force or magnetomotive force and is expressed in gilberts.

Then $\int Hdl = 4\pi/10 \; NC$

Field-intensities are sometimes defined in terms of gilbert/cm. The product NC is known as ampere-turns linked with the circuit. And in general when several coils are used, the complete statement is

$$
\begin{aligned}
M.F.F. &= \int H dl \\
&= 4\pi/10 \; NC \quad \text{--------- (9)}
\end{aligned}
$$

We may picture the M.F.F. of the coil system of an Electro-magnet as responsible for the flux of magnetism through the magnetic circuit. Now the quantity Hdl may be re-written as follows :

$$Hdl = B/\mu \, dl$$

$$= Ba/\mu a/dl$$

$$= d\phi/ \mu a/dl \text{ - - - - - - - - - } (10)$$

Where $d\phi$ is the flux through a small area a.

Hence $d\phi = Hdl/dl/\mu a \; = \; Hdl/dz$ - - - - (11)

Where dz is termed magnetic reluctance of an Element of the circuit of length dl and area of cross-section a and is analogous to resistance $R = \rho dl/a$ in electric case. the receiprocal of Z (1/z) is known as the magnetic conductance. The total flux ϕ through the circuit is given by

$$\phi = \int d\phi$$

$$= \int Hdl/ dz \; = \; M.M.F./z \text{ - - - - - - - - -} (12)$$

To take a straight forward example we consider an iron-ring of large mean radius R and radius of cross-section r in which a small gap of thickness g is cut. Then the total magnetic reluctance z is $2\pi R - g/\mu\pi r^2 + g/\pi r^2$, since the permeability of air is unity, it is assumed here that there is no magnetic leakage i.e. that lines of force are not found outside the gap. Here the m.m.f. required to give a total flux 0 across the gap is equal to $\phi\{ 2\pi R - g/ \pi r^2\mu \; + g/ \pi r^2\}$

Two points require comment; first the value of μ depends upon the m.m.f used and secondly, the term $g/\mu r^2$ maybe extremly large compared with other terms where μ is large showing that most of the reluctance is in the air gap.

In an electro-magnet, the total reluctance consists of the reluctance of the yoke plus the reluctance of the pole-pieces and pole-tips plus the reluctance of the air-gap. There are as many terms in the expression for the total reluctance as there are components in the magnetic circuit. In each portion of the circuit leakage occurs e.g. all lines of force from the coils do not enter the iron.

In gnereal we can write,

ϕ = M.M.F $\div$ $q_1 l_1/\mu_1 a_1 + q_2.l_2/\mu_2 a_2 + q_3.l_3/\mu_3 a_3$

Where q_1, q_2 ..... are leakage factors which are known either from theoretical consideration or from direct experiment.

If we have a cone of angle 2θ with uniform intensity of magnetisation I_o, then whole of the free magnetism upon the slant surface P of a ring between sections of radii r and r + dr is $M = I_o 2\pi r dr$. This magnetism produces a field at O parallel to axis, equal to

$M/OP^2 . OQ/OP = Mx/(r^2 + X^2)^{3/2} = f$ - - -- - - - (13)

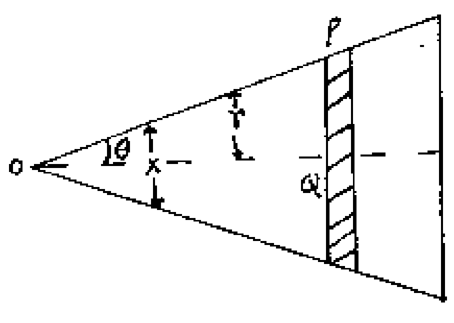


FIG.41

Now f is maximum when

$df/dx = M/(r^2 + x^2)^{3/2} - 3Mx^2/(r^2 + x^2)^{5/2} = 0$

i.e. $r^2 + x^2 - 3x^2 = 0$

or, $x = r/\sqrt{2}$

Where $\tan\theta = \sqrt{2}$ $\theta = 54^{\circ}44'$

Substituting (13) for M and putting OP = r/sinθ the field at O due to whole ring is

$I\sin\theta(2\pi r dr/\sin\theta)(\sin^2\theta/r^2)\cos\theta$

$= 2\pi I_o \sin^2\theta \cos\theta\, dr/r$ - - - - - - - - - - - (14)

Hence for a truncated cone of base "b" and gap face "a" the total field F is given by

$F = 2\pi I_o \sin^2\theta \cos\theta \int_a^b dr/r$ - - - - - - - - (15)

Remembering that there are two pole-tips, the field is 2f and equal to $4\pi I_o \sin^2\theta \cos\theta \log_e b/a$

Now, in practice the pole-pieces are not completely saturated and it is necessary to make θ somewhat greater. And 60° is usually chosen for which the value of the gap field for cobalt-steel pole tip with $I_o = 1900$ is

$4\pi(1900)^{3/8}2.303\log_{10} b/a$

$= 2.07 \times 10^4 \log_{10} b/a.$

CHAPTER - 5

PERFORMANCE OF THE ELECTROMAGNET

CHAPTER - 5

PERFORMANCE OF THE ELECTROMAGNET

The electromagnet has been tested to know its instant field generation capacity, to see the field conditions with different pole-gaps, to observe the field-duration with time, to study the temperature conditions of the exciting coils with time and current and also to study its remanence. All the above parameters have throughly been studied and results are presented in data and relevant graphs are also given.

5.1 INSTANT FIELD CALIBRATION

The electromagnet has first been supplied with current from a 30V-5A D.C. power source and the electrical connections have been checked. A simple series circuit consisting of the electromagnet, an ammeter the D.C power source is shown in figure 5A. After a satisfactory check of the electrical connections, the field pick-up probe of a gaussmeter was inserted across the pole gap of the electromagnet. Then very low current from the power source was allowed to flow through the exciting coil and the magnet began to generate field which was obvious from the gauss-meter reading. Then current was gradually increased by an small amount of 0.05 ampere and the magnetic field was noticed increasing. The resistance of the exciting coils in series was 72 Ohm and the magnet could not draw more than 0.4 ampere current. The maximum field obtained at this current was 4839 gauss. The distance between the pole-faces was 1 cm. The fields obtained at

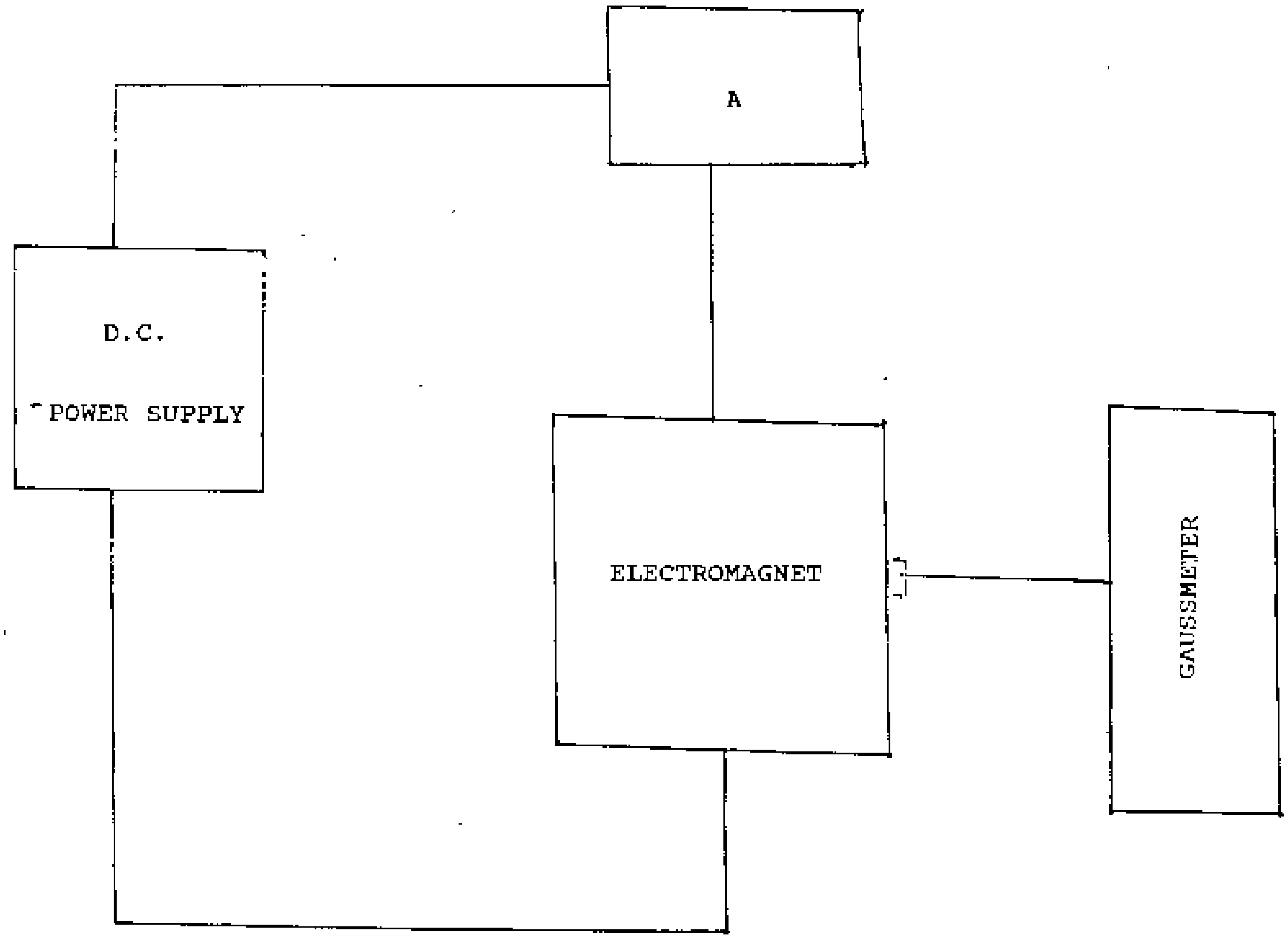
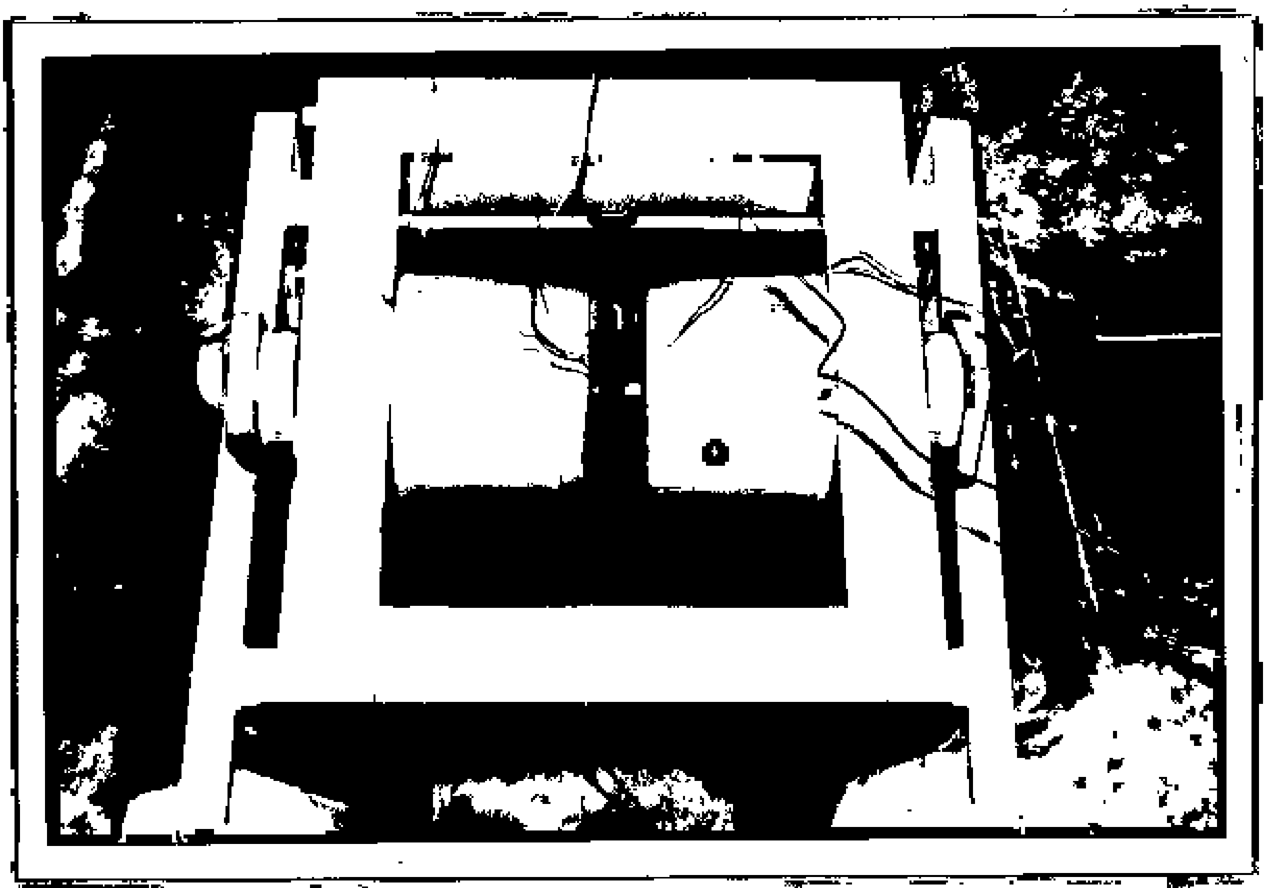
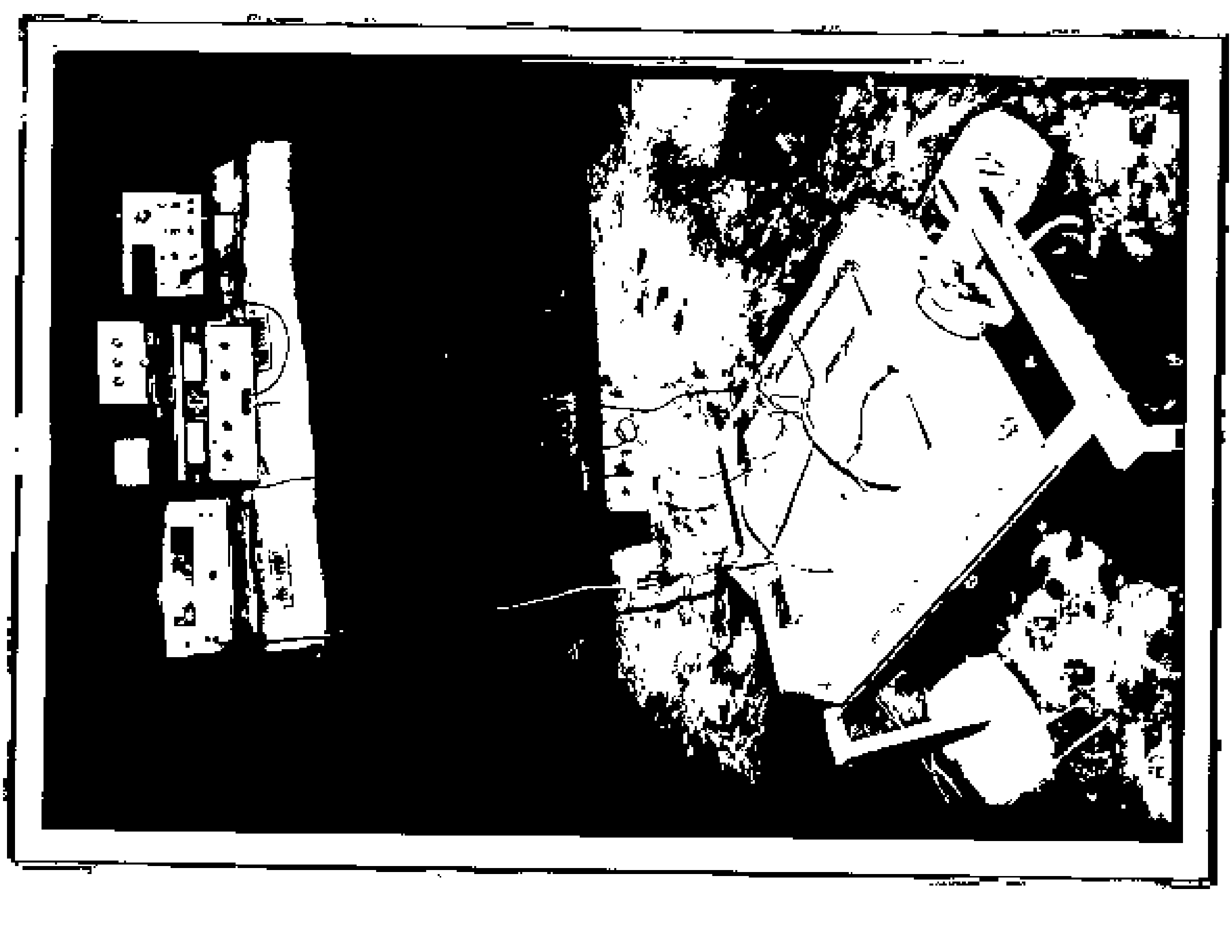


FIG. 5.A. SET-UP FOR MEASURING MAGNETIC FIELD GENERATED BY THE ELECTROMAGNET



THE ELECTROMAGNET



EXPERIMENTAL SET-UP TO STUDY THE ELECTROMAGNET different current values and pole gaps are presented in Tables 5.1, 5.2, 5.3, 5.4, 5.5. and 5.6 and figures 5.1, 5.2, 5.3, 5.4, 5.5 and 5.6 present the results in graphical forms. A family of curves is shown in figure 5.7 and the comprehensive data (table-5.7) is also given.

TABLE - 5.1

VARIATION OF MAGNETIC FIELD STRENGTH WITH CURRENT

Pole Gap = 1 cm.

Max. Current = 0.4 amp.

Voltage Range = 0-29.8 volts.

Current (I) (amp.)	Magnetic Field Strength (B) (Gauss)		
	Forward Value	Reverse Value	Average Value
00	57	61	59
0.05	696	693	694.50
0.10	1311	1330	1320.50
0.15	1870	1949	1909.50
0.20	2429	2536	2482.50
0.25	3019	3085	3052.00
0.30	3608	3659	3633.50
0.35	4210	4251	4230.50
0.40	4839	4839	4839.00

TABLE - 5.2

VARIATION OF MAGNETIC FIELD STRENGTH WITH CURRENT

Pole Gap = 1.5 cm.

Max. Current = 0.4 amp.

Voltage Range = 0-29.8 volts.

Current (I) (amp.)	Magnetic Field Strength (B) (Gauss)		
	Forward Value	Reverse Value	Average Value
00	49	50	49.50
0.05	488	493	490.50
0.10	853	907	880.00
0.15	1285	1304	1294.50
0.20	1672	1745	1708.50
0.25	2101	2131	2116.00
0.30	2514	2538	2526.00
0.35	2917	2900	2908.50
0.40	3355	3355	3355.00

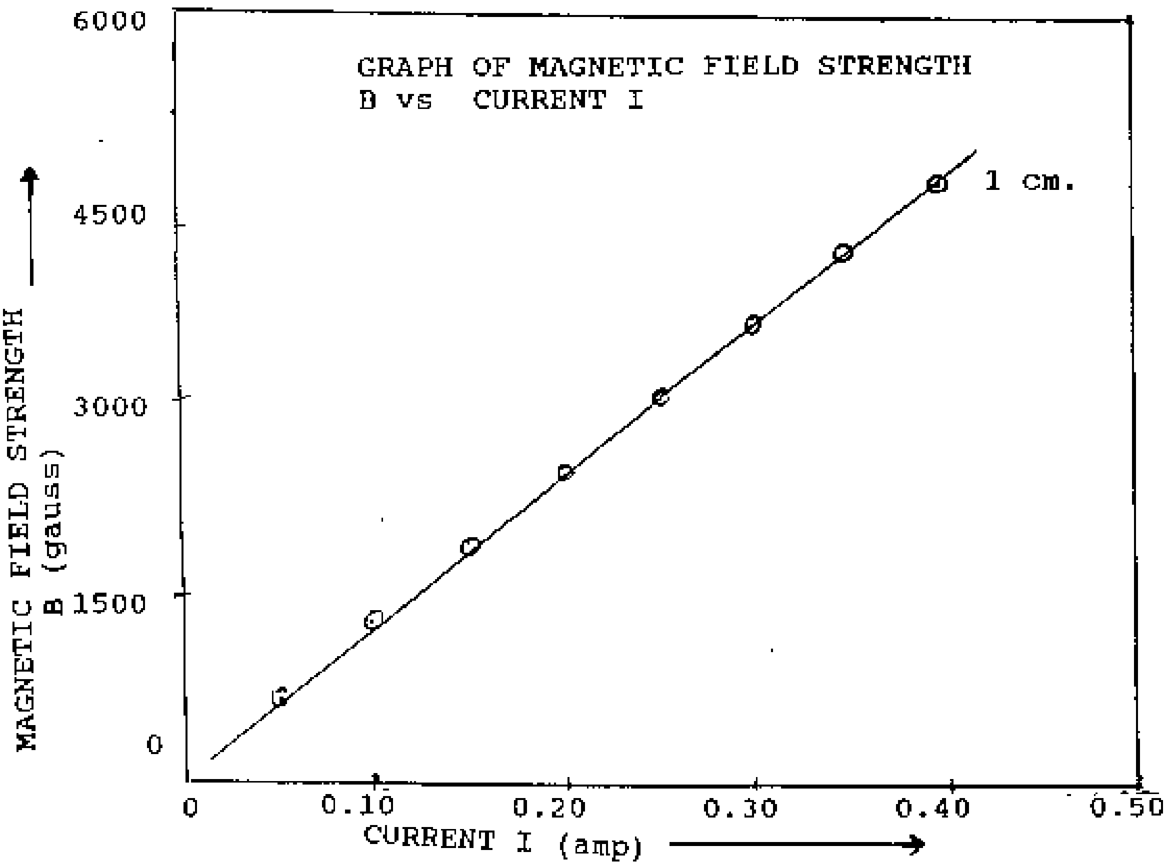


FIG. 5.1 VARIATION OF MAGNETIC FIELD STRENGTH WITH CURRENT AT POLE GAP 1 cm.

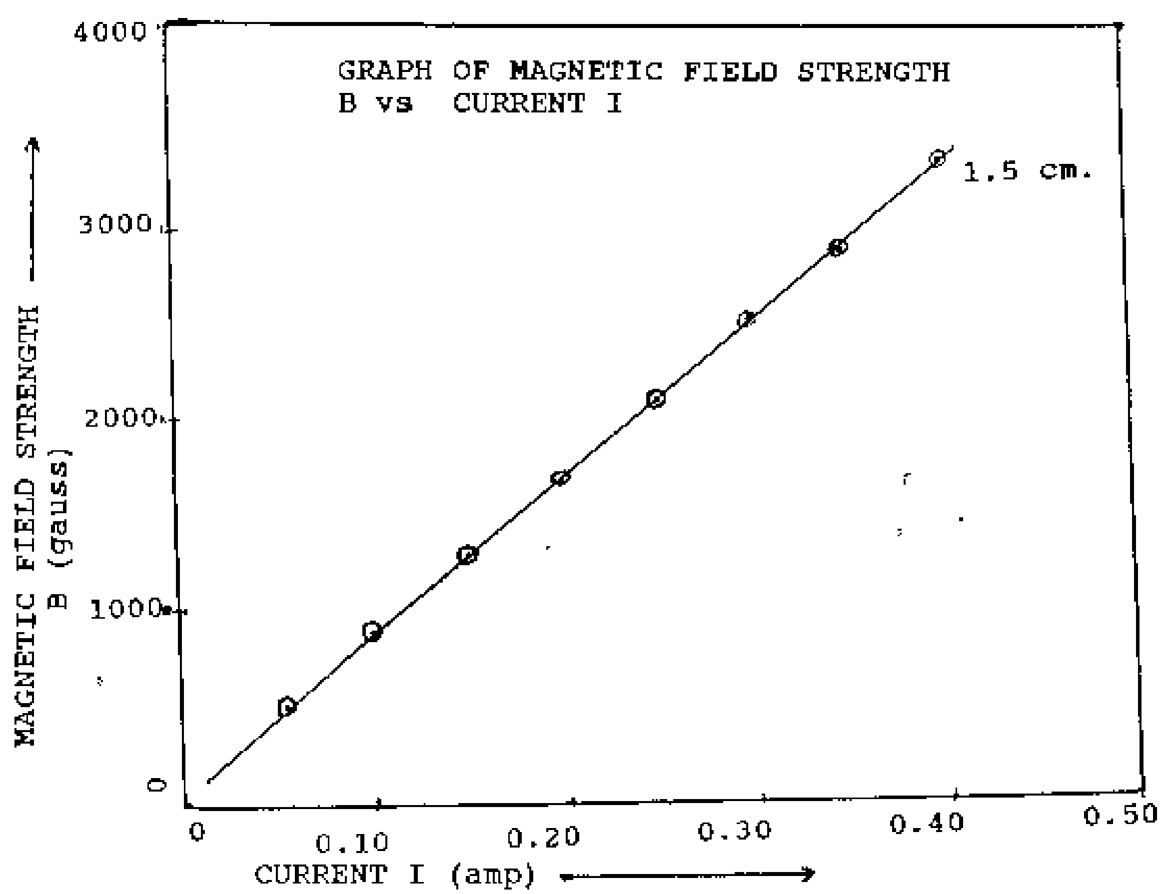


FIG. 5.2 VARIATION OF MAGNETIC FIELD STRENGTH WITH CURRENT AT POLE GAP 1.5 cm.

TABLE - 5.3

VARIATION OF MAGNETIC FIELD STRENGTH WITH CURRENT

Pole Gap = 2 cm.

Max. Current = 0.4 amp.

Voltage Range = 0-29.8 volts.

Current (I) (amp.)	Magnetic Field Strength (B) (Gauss)		
	Forward Value	Reverse Value	Average Value
00	33	34	33.50
0.05	361	377	369.00
0.10	667	694	680.50
0.15	992	998	995.00
0.20	1285	1313	1299.00
0.25	1610	1602	1606.00
0.30	1904	1950	1926.00
0.35	2259	2260	2259.50
0.40	2578	2578	2578.00

TABLE - 5.4

VARIATION OF MAGNETIC FIELD STRENGTH WITH CURRENT

Pole Gap = 2.5 cm.

Max. Current = 0.4 amp.

Voltage Range = 0-29.8 volts.

Current (I) (amp.)	Magnetic Field Strength (B) (Gauss)		
	Forward Value	Reverse Value	Average Value
00	22	23	22.50
0.05	300	307	303.50
0.10	541	546	543.50
0.15	782	826	804.00
0.20	1042	1069	1055.50
0.25	1299	1324	1311.50
0.30	1546	1569	1557.50
0.35	1793	1815	1804.00
0.40	2080	2080	2080.00

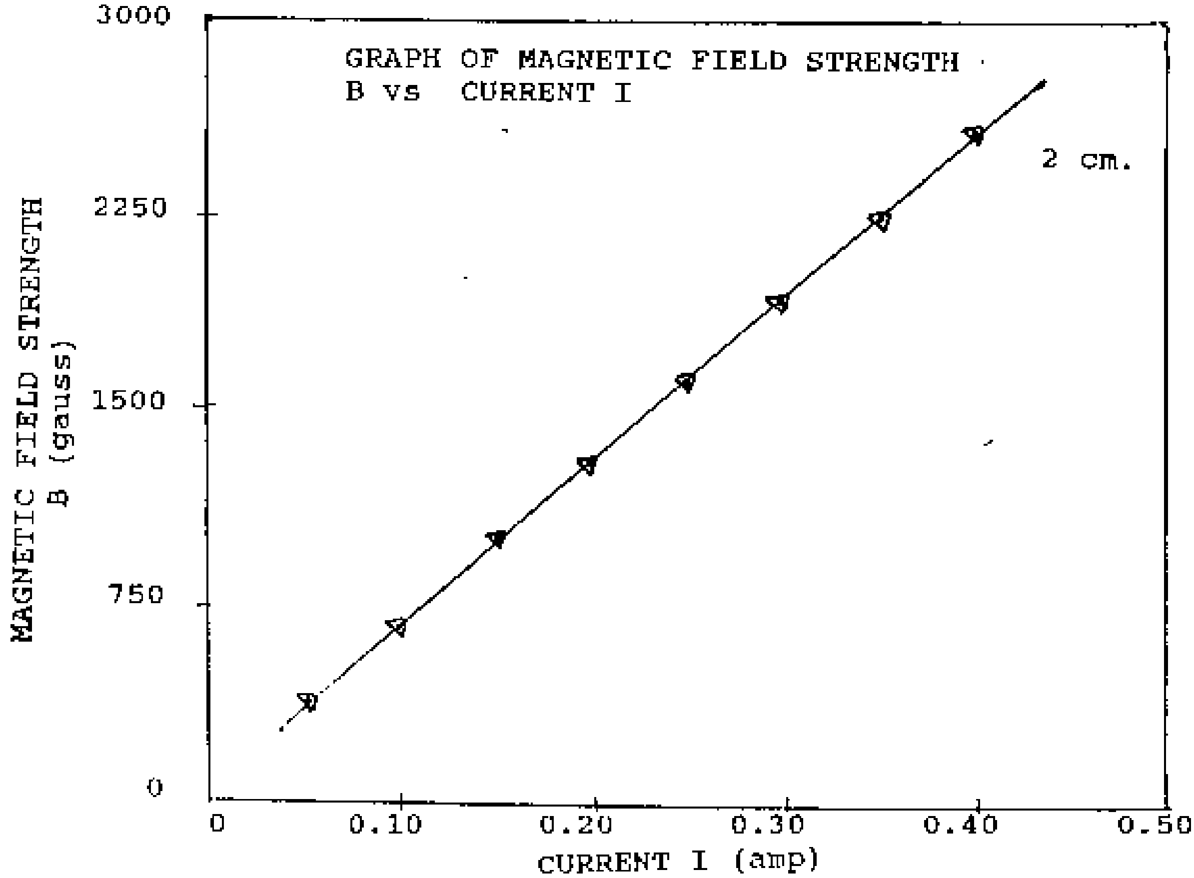


FIG. 5.3 VARIATION OF MAGNETIC FIELD STRENGTH WITH CURRENT AT POLE GAP 2 cm.

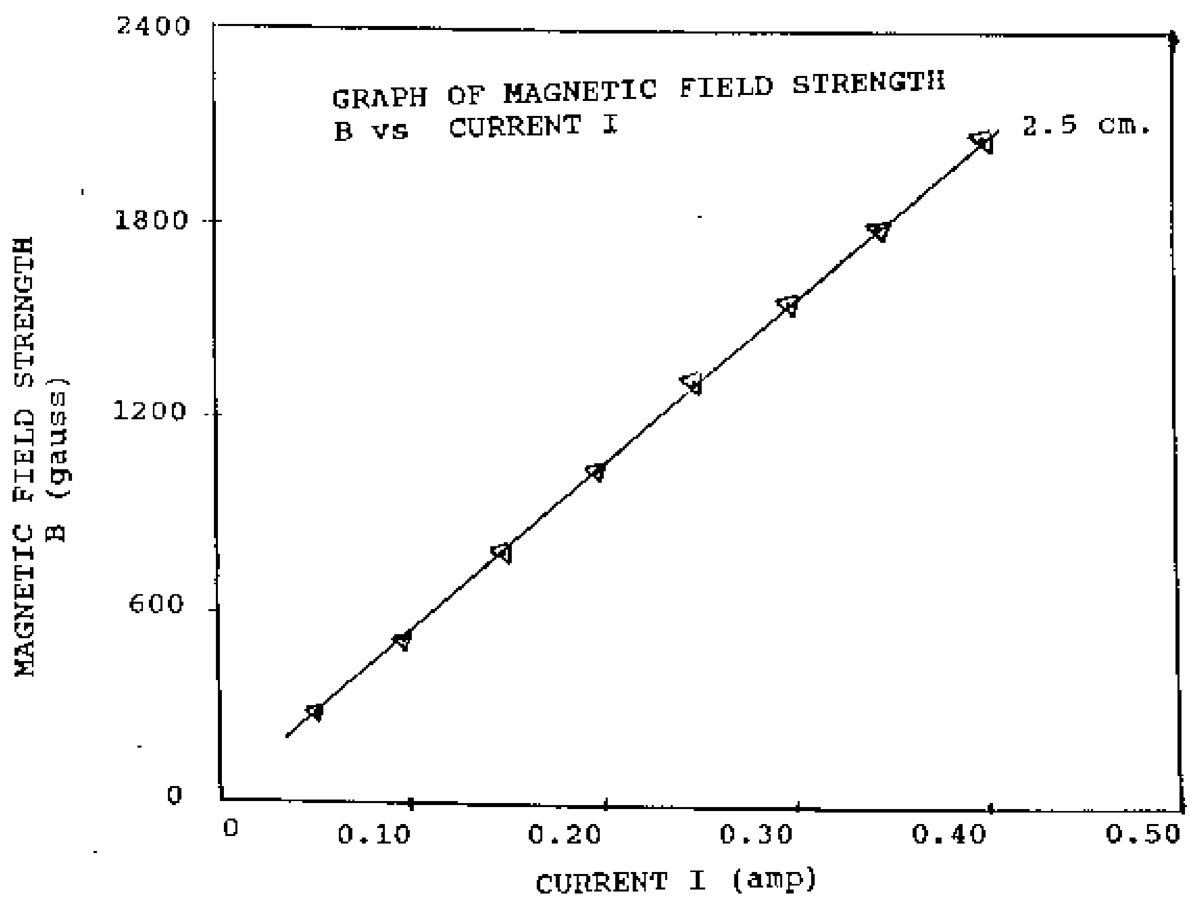


FIG. 5.4 VARIATION OF MAGNETIC FIELD STRENGTH WITH CURRENT AT POLE GAP 2.5 cm.

TABLE - 5.5

VARIATION OF MAGNETIC FIELD STRENGTH WITH CURRENT

Pole Gap = 3 cm.

Max. Current = 0.4 amp.

Voltage Range = 0-29.8 volts.

Current (I) (amp.)	Magnetic Field Strength (B) (Gauss)		
	Forward Value	Reverse Value	Average Value
00	15	16	15.50
0.05	245	245	245.00
0.10	455	456	455.50
0.15	668	670	669.00
0.20	860	875	867.50
0.25	1083	1095	1089.00
0.30	1295	1310	1302.50
0.35	1519	1522	1520.50
0.40	1754	1754	1754.00

TABLE - 5.6

VARIATION OF MAGNETIC FIELD STRENGTH WITH CURRENT

Pole Gap = 3.5 cm.

Max. Current = 0.4 amp.

Voltage Range = 0-29.8 volts.

Current (I) (amp.)	Magnetic Field Strength (B) (Gauss)		
	Forward Value	Reverse Value	Average Value
00	11	12	11.50
0.05	220	210	215.00
0.10	399	405	402.00
0.15	593	596	595.50
0.20	780	773	776.50
0.25	964	959	961.50
0.30	1148	1144	1146.50
0.35	1338	1350	1344.50
0.40	1549	1549	1549.50

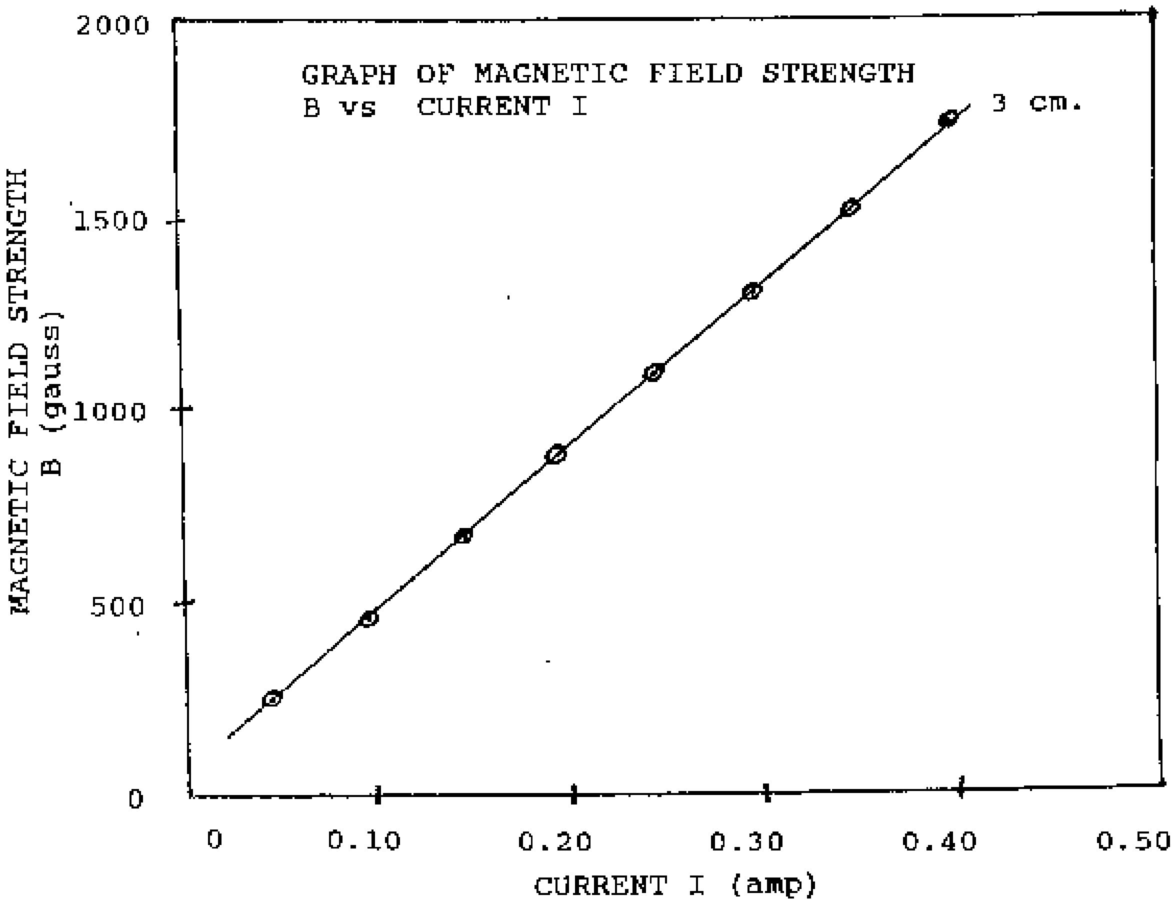


FIG. 5.5 VARIATION OF MAGNETIC FIELD STRENGTH WITH CURRENT AT POLE GAP 3 cm.

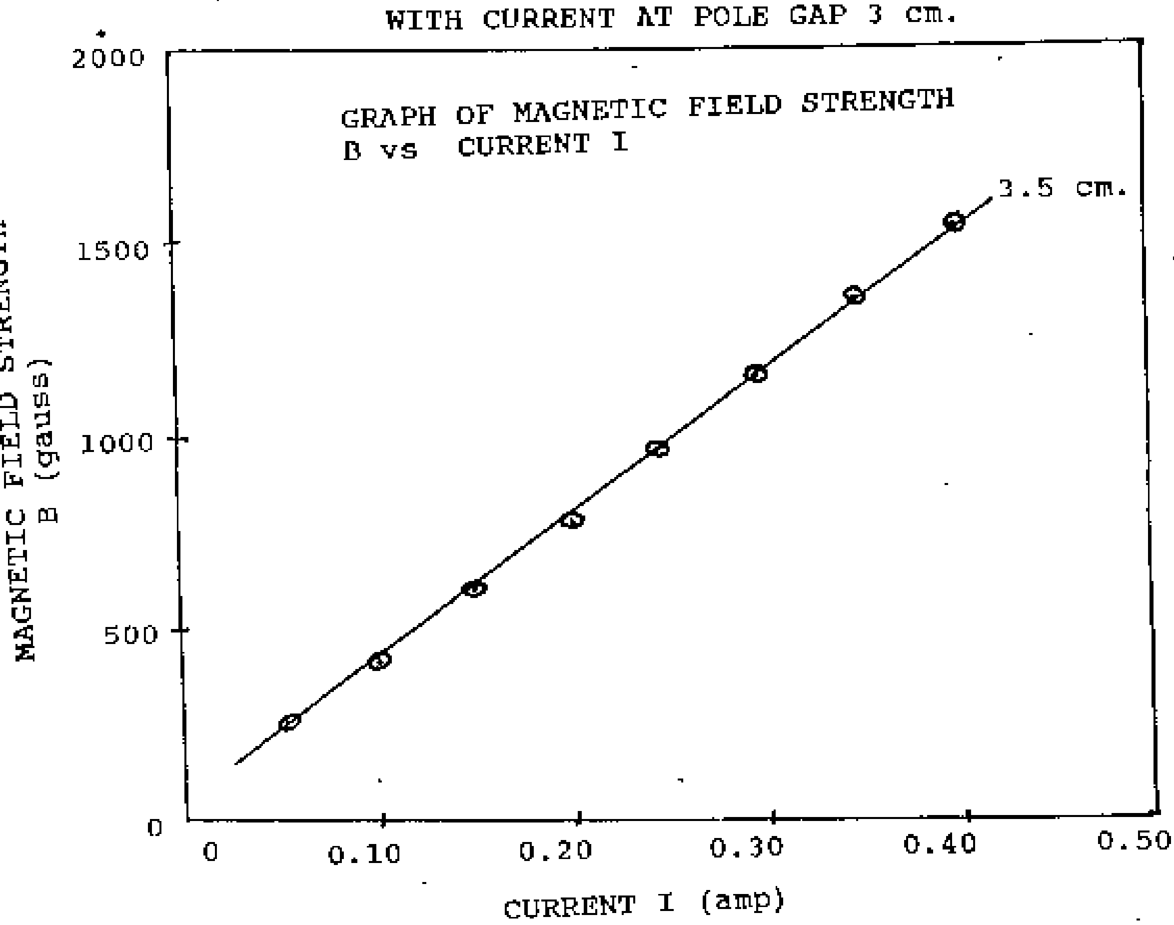


FIG. 5.6 VARIATION OF MAGNETIC FIELD STRENGTH WITH CURRENT AT POLE GAP 3.5 cm.

TABLE - 5.7

VARIATION OF FIELD (GAUSS) IN THE CENTRE OF GAP WITH EXCITATION AND GAP LENGTH

Max. Current : 0.4 A

Voltage Range : 0 - 29.8 V

POLE GAP (cm) / CURRENT (amp.)	1.0	1.5	2.0	2.5	3.0	3.5
00	59	49.50	33.50	22.50	15.50	11.50
0.05	694.50	490.50	369.00	303.50	245.00	215.00
0.10	1320.50	880.00	680.50	543.50	455.50	402.00
0.15	1909.50	1294.50	995.00	804.00	669.00	595.00
0.20	2482.50	1708.50	1299.50	1055.50	867.50	776.50
0.25	3052.00	2116.00	1606.00	1311.50	1089.00	961.50
0.30	3633.50	2526.00	1926.00	1557.50	1302.50	1146.00
0.35	4230.50	2908.50	2259.50	1804.00	1520.50	1344.00
0.40	4839.00	3355.00	2578.00	2080.00	1754.00	1549.00

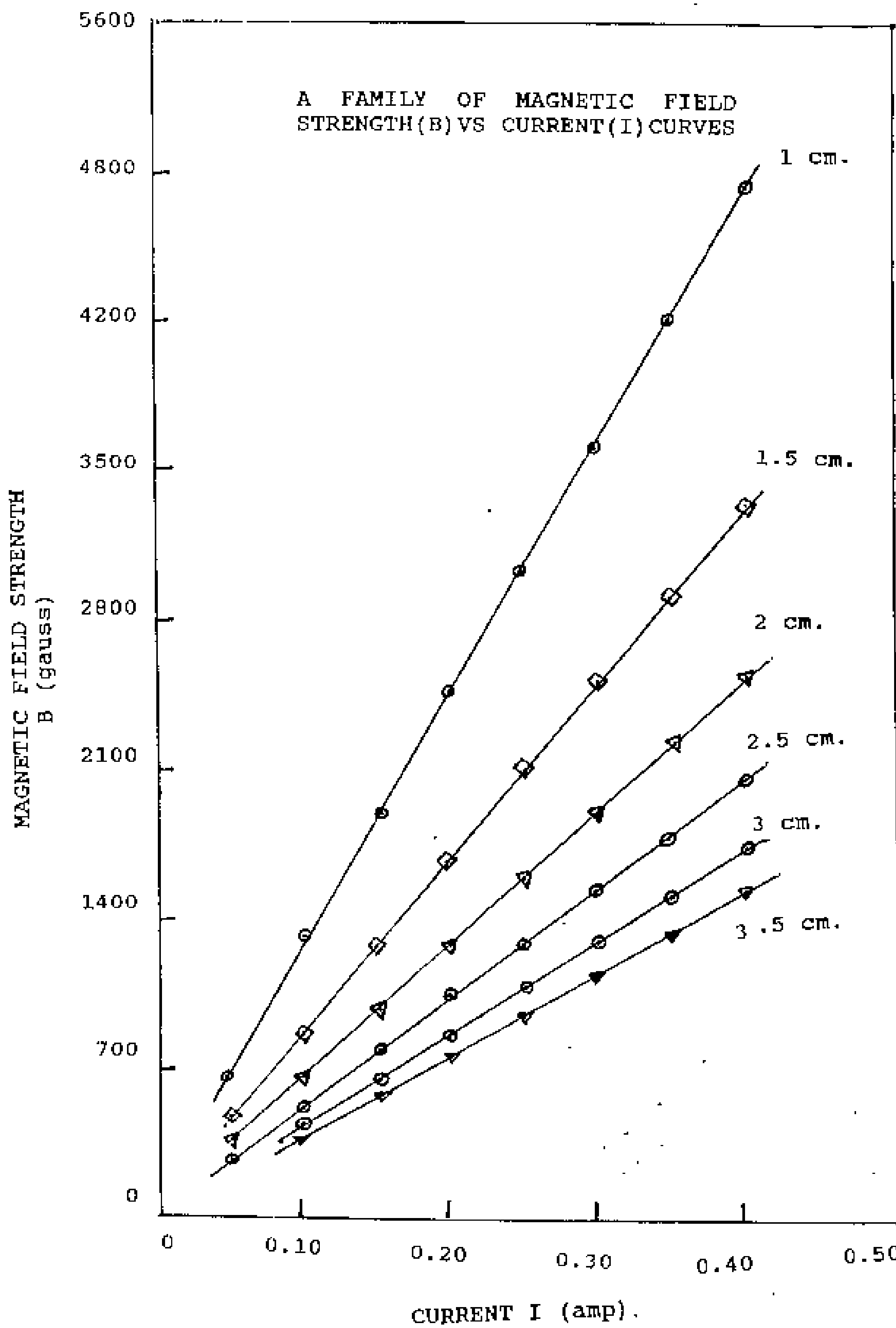


FIG. 5.7 VARIATION OF MAGNETIC FIELD STRENGTH WITH CURRENT AT DIFFERENT POLE GAPS.

The curves obtained at 0.4A are all linear. Because of the linearity, the 30V-5A power source was replaced by a 100V-5A power supply to provide the magnet with more current and hence to derive more field. The maximum current was incresed to 1.3 ampere from the previous value of 0.4A. The maximum field obtained at 1.3A current was 8688 gauss. The pole gap at this field was 1.5cm. The pole-gap was not further reduced because 1.5cm is the most convenient pole distance for all practical laboratory measurements of magnetic sample.. The fields obtained at different current values and pole-gaps are shown in Tables 5.8, 5.9, 5.10, 5.11 and 5.12. The results are presented in graphical forms in figures 5.8, 5.9, 5.10, 5.11 and 5.12. A family of curves is given in figure 5.13 and the comprehensive data (Table-5.13) is given. The curves obtained here also are linear. But the electromagnet could not be given more current due to non-availability higher rated power source. The trend of the curves indicatee that the electromagnet will be able to produce magnetic field in the range of 25 kilogauss when it ie supplied with higher current.

TABLE - 5.8

VARIATION OF MAGNETIC FIELD STRENGTH WITH CURRENT

Pole Gap = 1.5 cm.

Max. Current = 1.3 amp.

Voltage Range = 0 - 99 volts.

Current (I) (amp.)	Magnetic Field Strength (B) (Gauss)		
	Forward Value	Reverse Value	Average Value
00	59	63	61.00
0.10	974	970	972.00
0.20	1411	1410	1410.50
0.30	2643	2641	2642.00
0.40	3466	3464	3465.50
0.50	4266	4266	4266.00
0.60	5096	5098	5097.00
0.70	5885	5886	5885.50
0.80	6592	6594	6593.00
0.90	7219	7220	7119.50
1.00	7676	7678	7677.00
1.10	8011	8010	8010.50
1.20	8343	8341	8342.00
1.30	8688	8688	8688.00

TABLE - 5.9

VARIATION OF MAGNETIC FIELD STRENGTH WITH CURRENT

Pole Gap = 2 cm.

Max. Current = 1.3 amp.

Voltage Range = 0 - 99 volts.

Current (I) (amp.)	Magnetic Field Strength (B) (Gauss)		
	Forward Value	Reverse Value	Average Value
00	43	45	44
0.10	733	731	732.00
0.20	1320	1320	1320.00
0.30	1903	1900	1901.50
0.40	2648	2648	2648.00
0.50	3257	3258	3257.50
0.60	3769	3769	3769.00
0.70	4454	4456	4455.00
0.80	4984	4988	4986.50
0.90	5576	5574	5575.00
1.00	6140	6142	6141.00
1.10	6519	6520	6519.50
1.20	6801	6799	6800.00
1.30	7122	7122	7122.00

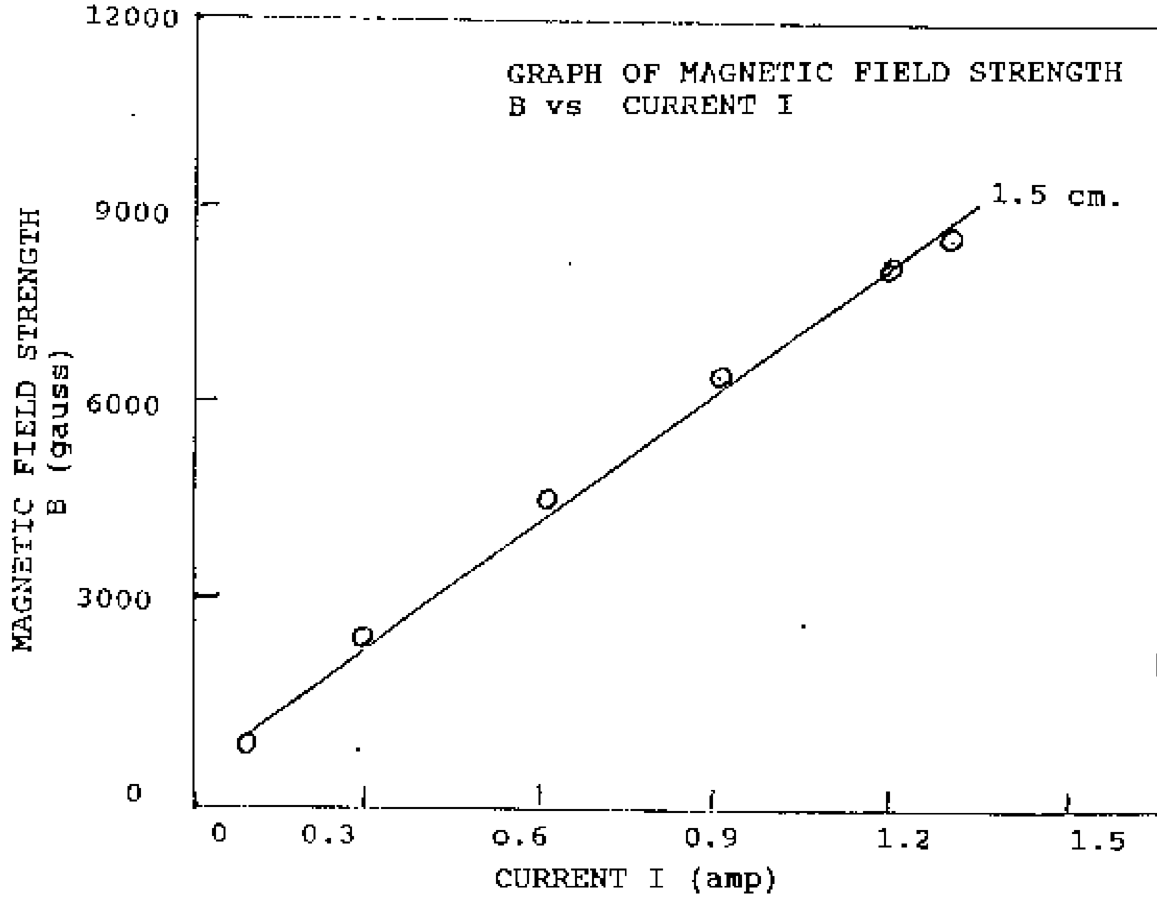


FIG. 5.8 VARIATION OF MAGNETIC FIELD STRENGTH WITH HIGHER CURRENT AT POLE GAP 1.5 cm.

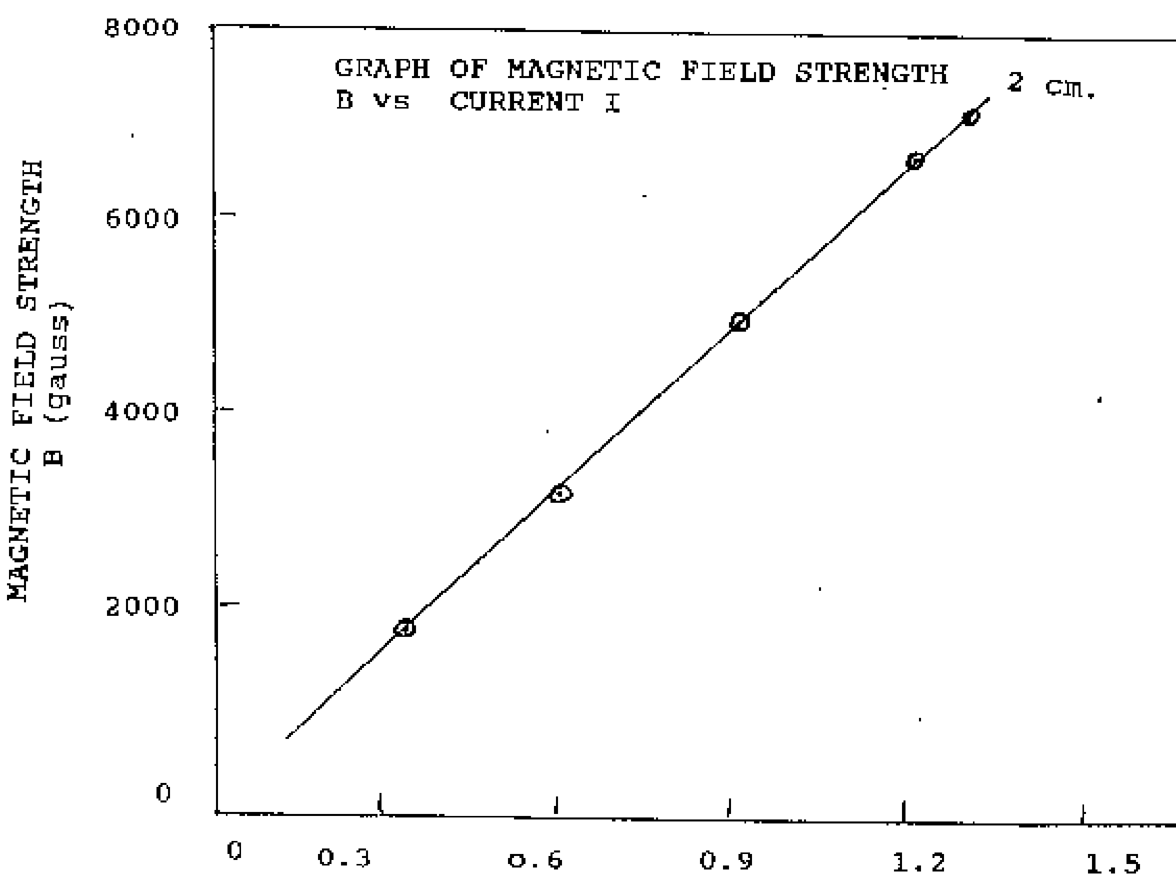


FIG. 5.9 VARIATION OF MAGNETIC FIELD STRENGTH WITH HIGHER CURRENT AT POLE GAP 2 cm.

TABLE - 5.10

VARIATION OF MAGNETIC FIELD STRENGTH WITH CURRENT

Pole Gap = 2.5 cm.

Max. Current = 1.3 amp.

Voltage Range = 0 - 99 volts.

Current (I) (amp.)	Magnetic Field Strength (B) (Gauss)		
	Forward Value	Reverse Value	Average Value
00	49	51	50.00
0.10	622	620	621.00
0.20	1066	1068	1067.00
0.30	1560	1561	1560.50
0.40	2104	2102	2103.50
0.50	2570	2571	2570.50
0.60	3108	3106	3107.00
0.70	3588	3588	3588.00
0.80	4078	4079	4078.50
0.90	4545	4543	4544.00
1.00	5020	5021	5020.50
1.10	5417	5419	5418.00
1.20	5871	5872	5871.50
1.30	6436	6436	6436.00

TABLE - 5.11

VARIATION OF MAGNETIC FIELD STRENGTH WITH CURRENT

Pole Gap = 3 cm.

Max. Current = 1.3 amp.

Voltage Range = 0 - 99 volts.

Current (I) (amp.)	Magnetic Field Strength (B) (Gauss)		
	Forward Value	Reverse Value	Average Value
00	23	21	22
0.10	510	518	514.00
0.20	920	921	920.50
0.30	1364	1372	1368.00
0.40	1524	1525	1524.50
0.50	2200	2208	2206.00
0.60	2600	2609	2604.50
0.70	3032	3038	3035.00
0.80	3503	3503	3503.00
0.90	3952	3948	3950.00
1.00	4350	4351	4350.50
1.10	4722	4723	4722.50
1.20	5148	5153	5150.50
1.30	5601	5601	5601.00

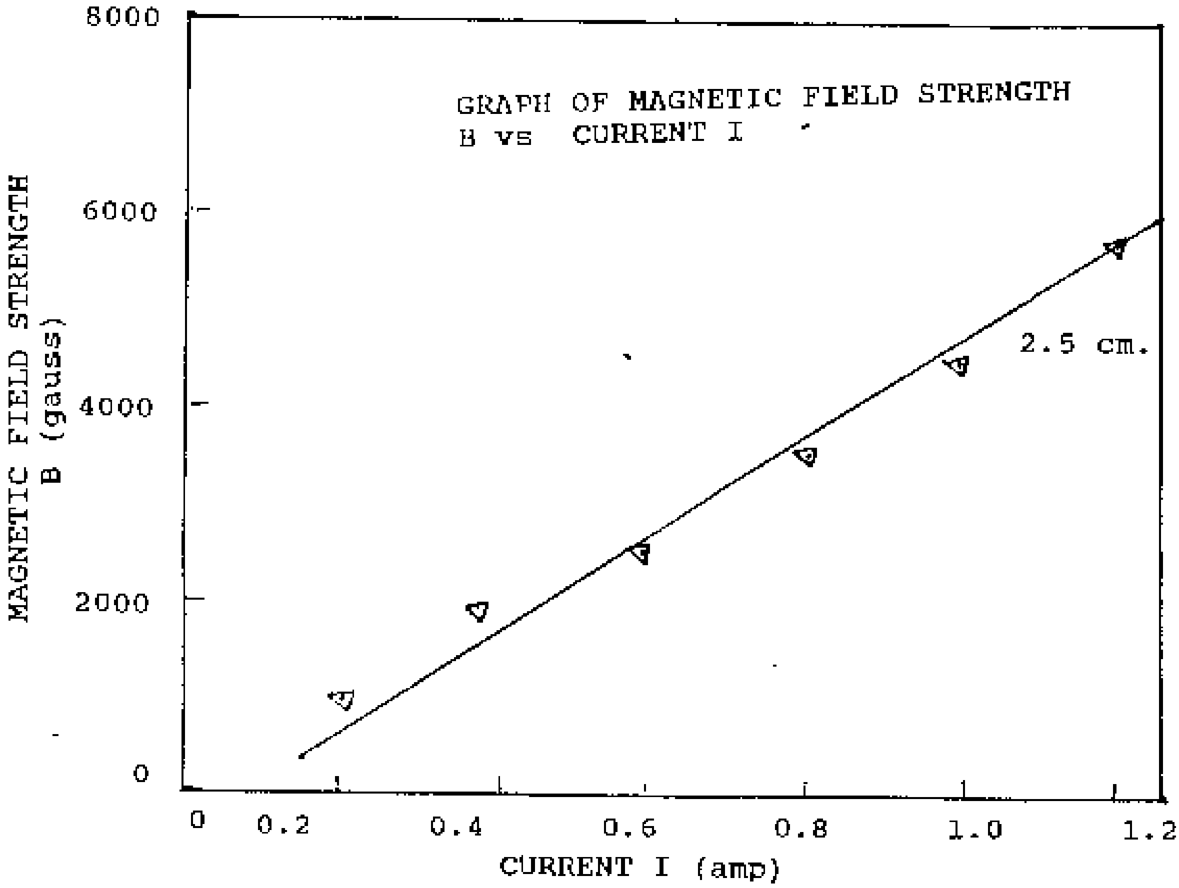


FIG. 5.10 VARIATION OF MAGNETIC FIELD STRENGTH WITH HIGHER CURRENT AT POLE GAP 2.5 cm.

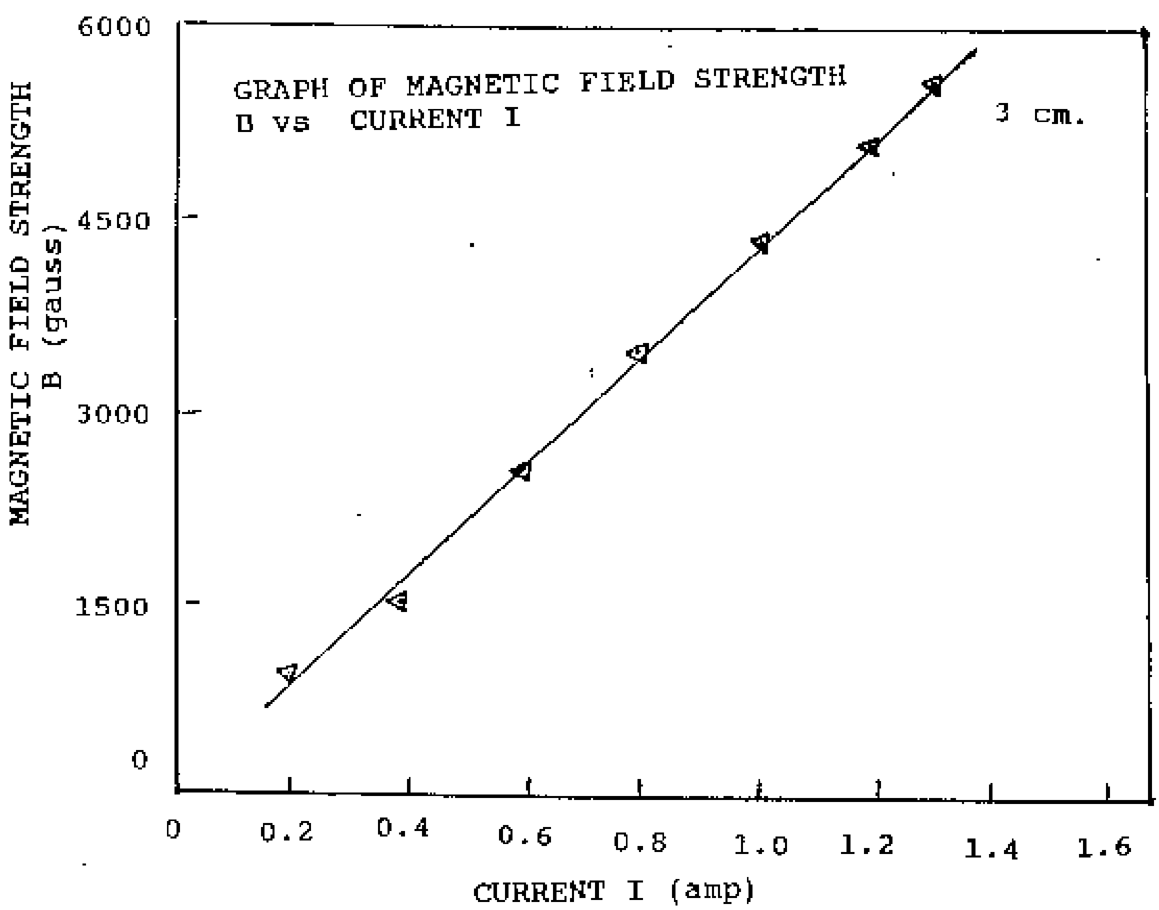


FIG. 5.11 VARIATION OF MAGNETIC FIELD STRENGTH WITH HIGHER CURRENT AT POLE GAP 3 cm.

TABLE - 5.12

VARIATION OF MAGNETIC FIELD STRENGTH WITH CURRENT

Pole Gap = 3.5 cm.

Max. Current = 1.3 amp.

Voltage Range = 0 - 99 volts.

Current (I) (amp.)	Magnetic Field Strength (B) (Gauss)		
	Forward Value	Reverse Value	Average Value
00	21	15	18
0.10	248	240	244.00
0.20	750	751	750.50
0.30	1150	1154	1152.00
0.40	1518	1520	1519.50
0.50	1828	1828	1828.00
0.60	2232	2230	2231.00
0.70	2572	2573	2572.50
0.80	2900	2906	2903.00
0.90	3270	3273	3271.50
1.00	3664	3665	3664.00
1.10	4026	4027	4026.50
1.20	4319	4320	4319.50
1.30	4648	4648	4648.00

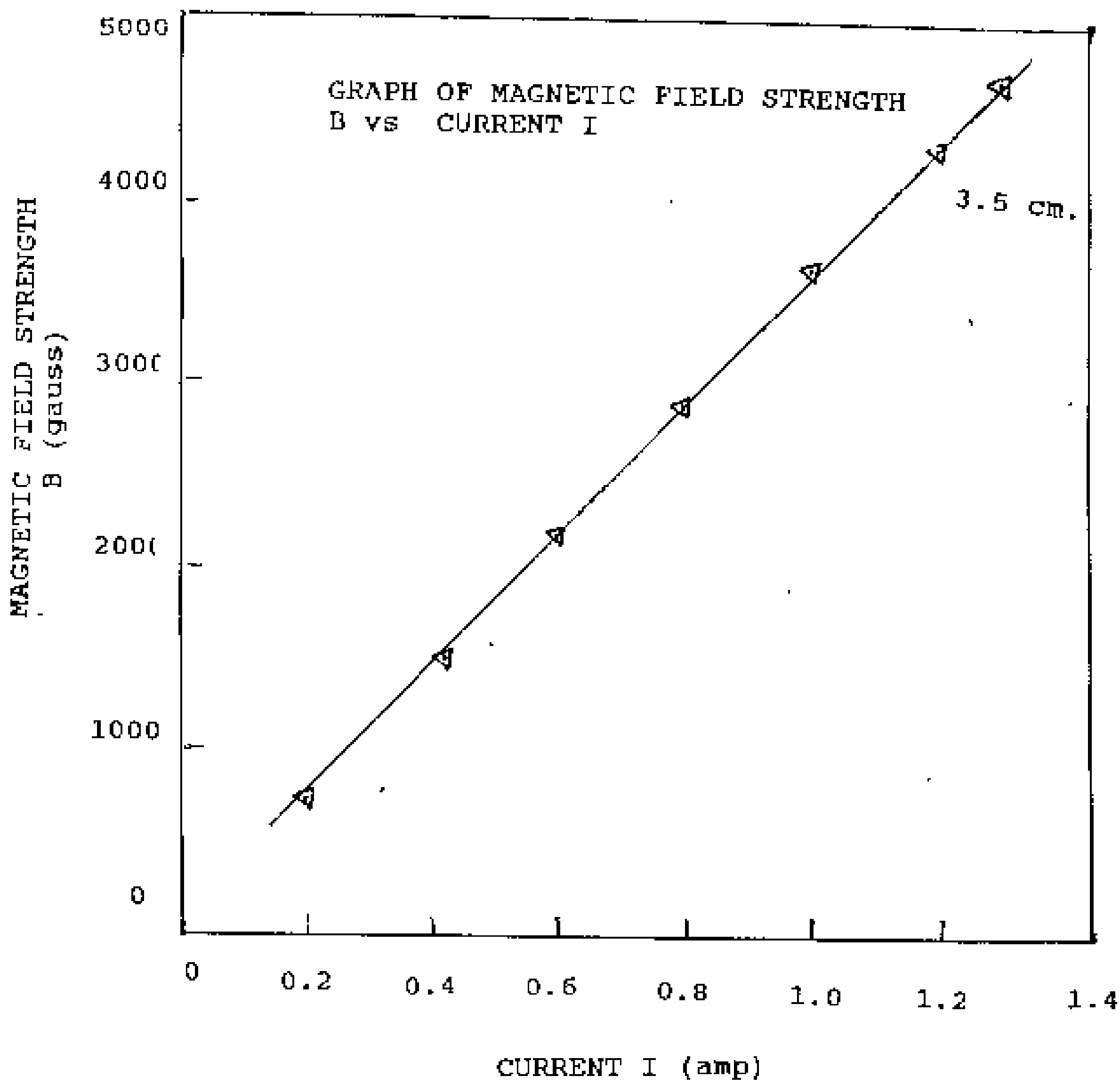


FIG. 5.12 VARIATION OF MAGNETIC FIELD STRENGTH WITH HIGHER CURRENT AT POLE GAP 3.5 cm.

TABLE - 5.13

VARIATION OF THE FIELD (GAUSS) IN THE CENTRE OF GAP WITH EXCITATION AND GAP LENGTH

Max. Current : 1.3 Amp.

Voltage Range : 0 - 99 Volts.

CURRENT (amp.) \ POLE GAP (cm)	1.5	2.0	2.5	3.0	3.5
0.00	61	54	50	22	18
0.10	972	732	621	514	397
0.20	1721	1320	1067	920	750
0.30	2642	2267	1560	1368	1152
0.40	3465	2938	2103	1796	1519
0.50	4266	3513	2570	2206	1828
0.60	5097	4136	3107	2604	2231
0.70	5885	4752	3586	3035	2572
0.80	6593	5339	4078	3503	2903
0.90	7219	5846	4544	3950	3271
1.00	7677	6231	5020	4350	3664
1.10	8070	6519	5418	4722	4026
1.20	8384	6800	5771	5152	4319
1.30	8688	7122	6436	5601	4648

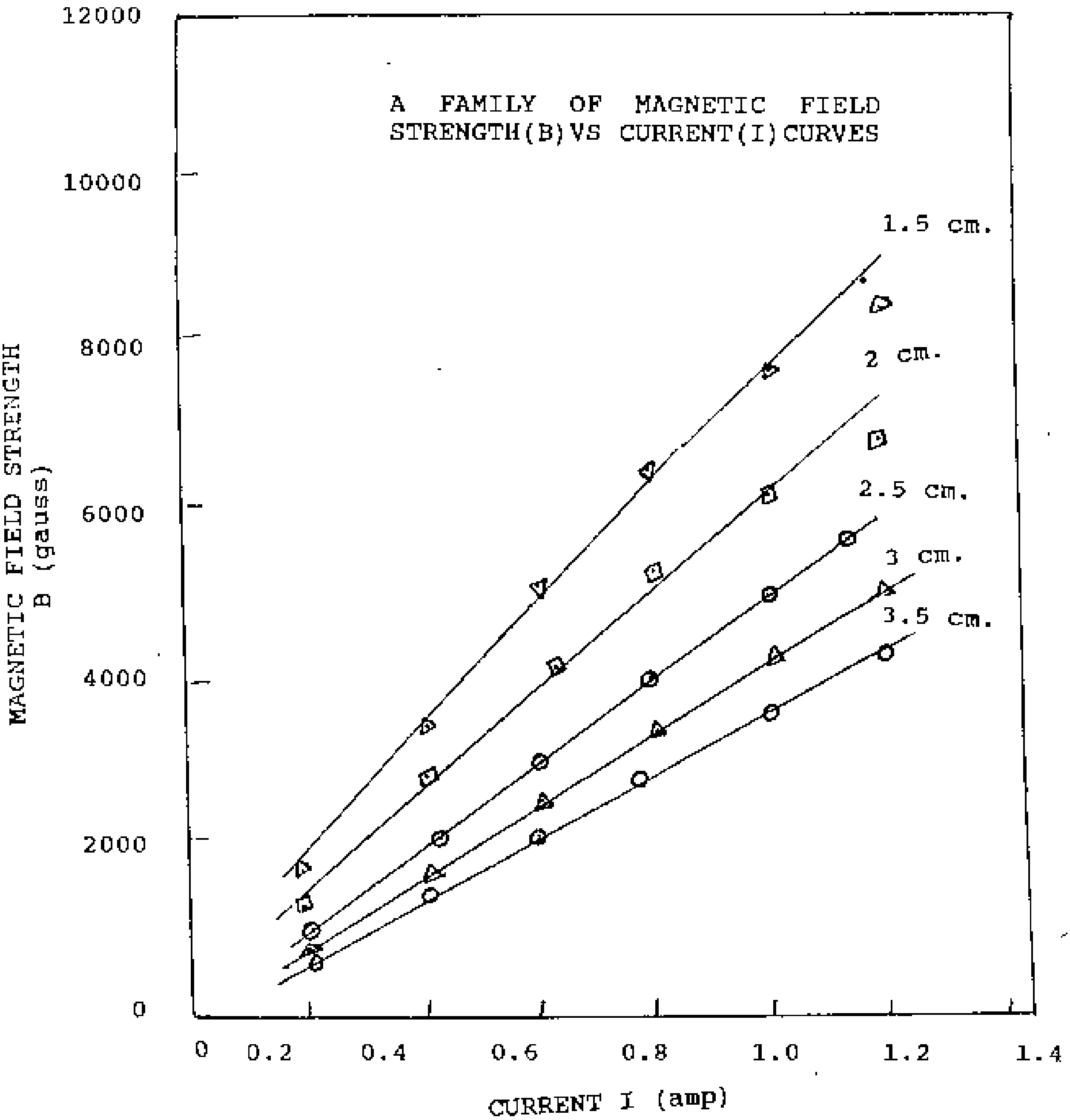


FIG. 5.13 VARIATION OF MAGNETIC FIELD STRENGTH WITH HIGHER CURRENT AT DIFFERENT POLE GAPS.

5.2 POLE-GAP ADJUSTMENT

The purpose of this experiment is to see the field conditions at different pole gaps. The maximum fields at 0.4A corresponding 1cm, 1.5cm, 2cm, 2.5cm, 3cm and 3.5cm pole distnces are 4839 gauss, 3355 gauss, 2578 gauss, 2080 gauss, 1754 gauss and 1549 gauss. When the current was increased to 1.3 A using higher power source the maximum fields are 8688 gauss, 7122 guss, 6536 gauss, 5601 gauss and 4648 gauss for pole-gaps of 1.5cm, 2cm, 2.5cm, 3cm, 3.5cm respectively. It appears that the field decreases with increasing pole gaps. The field can be decreased lowering the current value as well as increasing the pole distance. This pole-gap adjustment provision is an importnt design aspect of this electromagnet. Field strengths at different pole-gaps along with different current values are shown in Tables 5.14 and 5.15 and figures 5.14 and 5.15 show the results in graphical form. Analysis of the curves reveals the fall of fields with increasing pole-gap.

TABLE - 5.14

VARIATION OF MAGNETIC FIELD STRENGTHS WITH POLE GAPS AT DIFFERENT CURRENT VALUES

Pole Gap Range : 1 - 3.5 cm.

Current Range : 0.10 - 0.4 amp.

POLE GAP (cm) / CURRENT (amp.)	1.0	1.5	2.0	2.5	3.0	3.5
0.10	1320.50	880.00	680.50	543.50	455.50	402.00
0.20	2482.50	1708.50	1299.00	1055.50	867.50	776.50
0.30	3633.50	2526.00	1926.00	1557.50	1302.50	1146.00
0.40	4839.00	3355.00	2578.00	2080.00	1754.00	1549.00

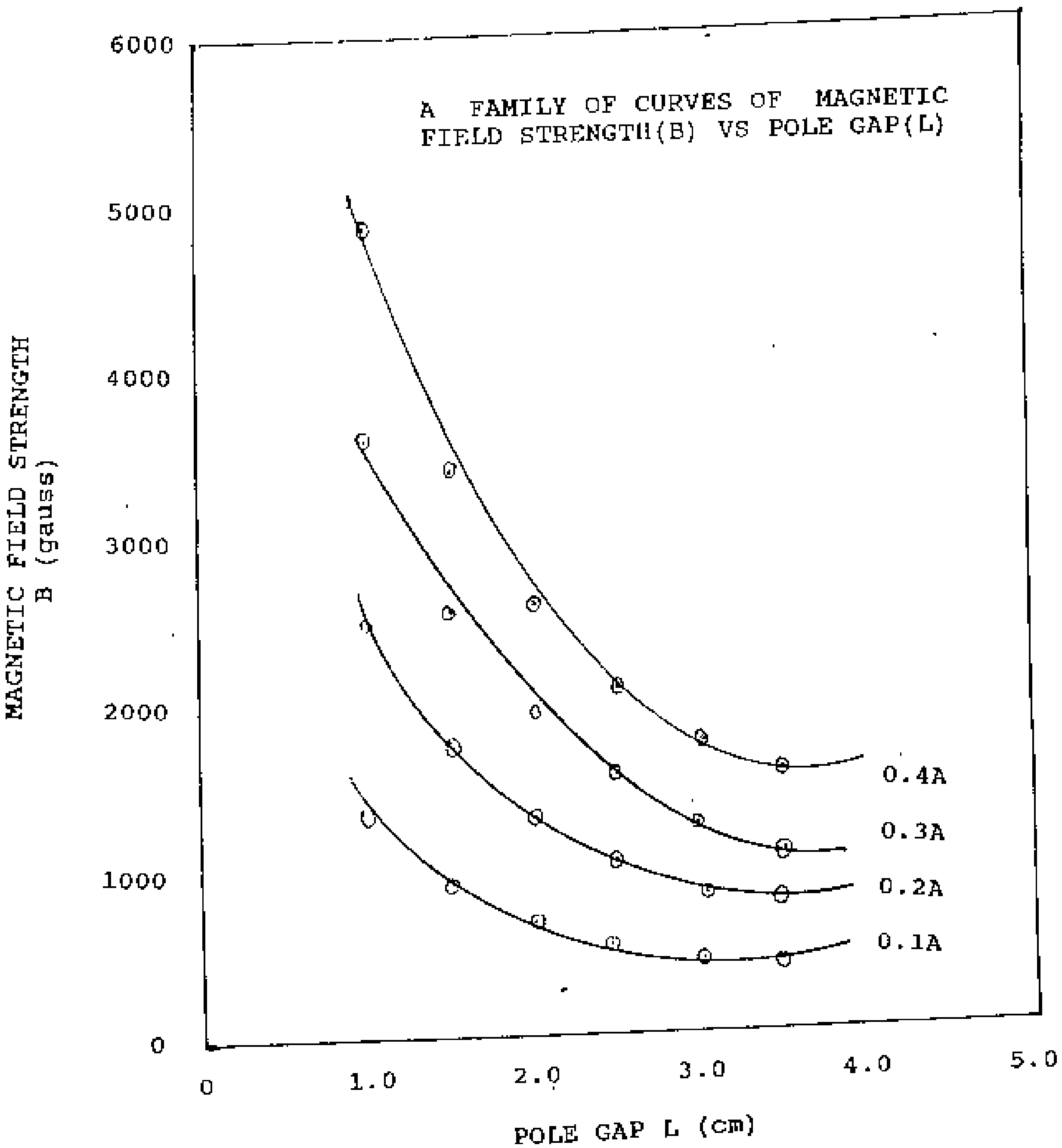


FIG. 5.14 VARIATION OF MAGNETIC FIELD STRENGTH WITH POLE GAPS AT DIFFERENT CURRENT VALUES.

TABLE - 5.15

VARIATION OF MAGNETIC FIELD STRENGTHS WITH POLE GAPS AT DIFFERENT CURRENT VALUES

Pole Gap Range : 1.5 - 3.5 cm.

Current Range : 0.30 - 1.3 amp.

CURRENT (amp.) \ POLE GAP (cm)	1.5	2.0	2.5	3.0	3.5
0.30	2642	2267	1560	1368	1152
0.60	5097	4136	3107	2604	2231
0.90	7219	5846	4544	3950	3271
1.30	8688	7122	6436	5601	4648

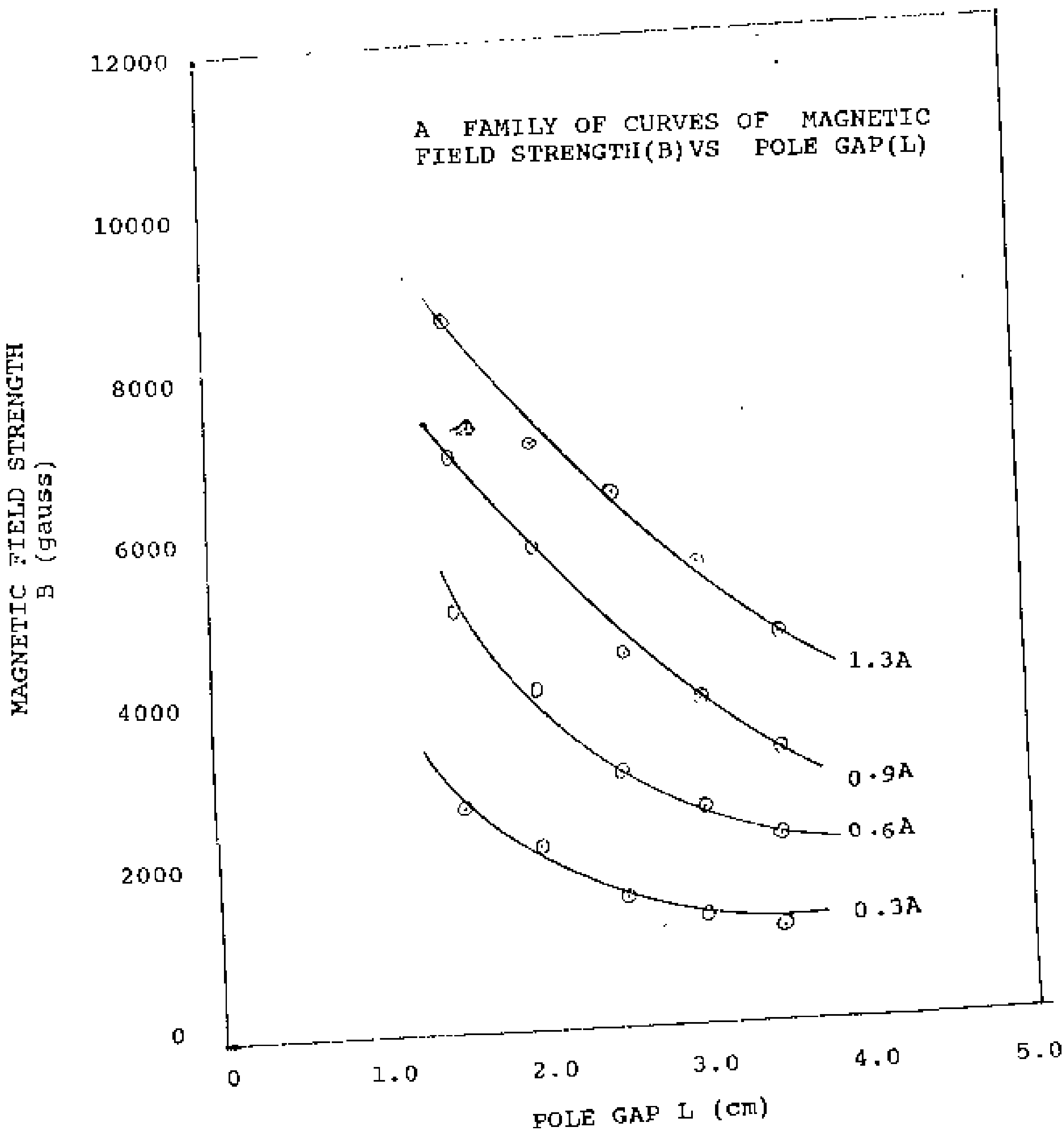


FIG. 5.15 VARIATION OF MAGNETIC FIELD STRENGTH WITH POLE GAPS AT DIFFERENT HIGHER CURRENT VALUES.

5.3 MAGNETIC FIELD DURATION

In order to study the stability of the field generated, the electromagnet was run continuously for about four hours. The field conditions were observed at different pole gaps and different current values.It is noticed that the fields remain very nearly static. A very slight fall observed can be attributed to the higher resistance of the energising coils which they attain for the rise of temperature with current flow in them. Slight adjustment of the D.C power supply with attention can compensate for minimum field loss and the coils along with their higher resistance will ensure static field during the course of any experiment. Tables 5.16-5.23 show the field values at different time-intervals and figures 5.16-5.23 are the graphical representations.

TABLE - 5.16

VARIATION OF MAGNTIC FIELD STRENGTH WITH TIME

Current Value : 1.3 amp.

Pole Gap : 3.5 cm.

HOURS	TIME-INTERVAL(T) IN MINUTES	MAGNETIC FIELD STRENGTH B (GAUSS)
11:00	00	4651.00
11:15	15	4651.00
11:30	30	4651.00
11:45	45	4650.50
12:00	60	4650.00
12:15	75	4650.00
12:30	90	4649.00
12:45	105	4649.00
01:00	120	4648.50
01:15	135	4648.00
01:30	150	4648.00
01:45	165	4647.00
02:00	180	4647.00
02:15	195	4646.00
02:30	210	4646.00
02:45	225	4646.00
03:00	240	4646.00

TABLE - 5.17

VARIATION OF MAGNTIC FIELD STRENGTH WITH TIME

Current Value : 1 amp.

Pole Gap : 3.5 cm.

HOURS	TIME-INTERVAL(T) IN MINUTES	MAGNETIC FIELD STRENGTH B (GAUSS)
11:00	00	3664.00
11:15	15	3664.00
11:30	30	3663.00
11:45	45	3663.00
12:00	60	3662.50
12:15	75	3662.50
12:30	90	3662.00
12:45	105	3662.00
01:00	120	3661.00
01:15	135	3660.00
01:30	150	3659.50
01:45	165	3659.00
02:00	180	3659.00
02:15	195	3659.00
02:30	210	3658.00
02:45	225	3658.00
03:00	240	3658.00

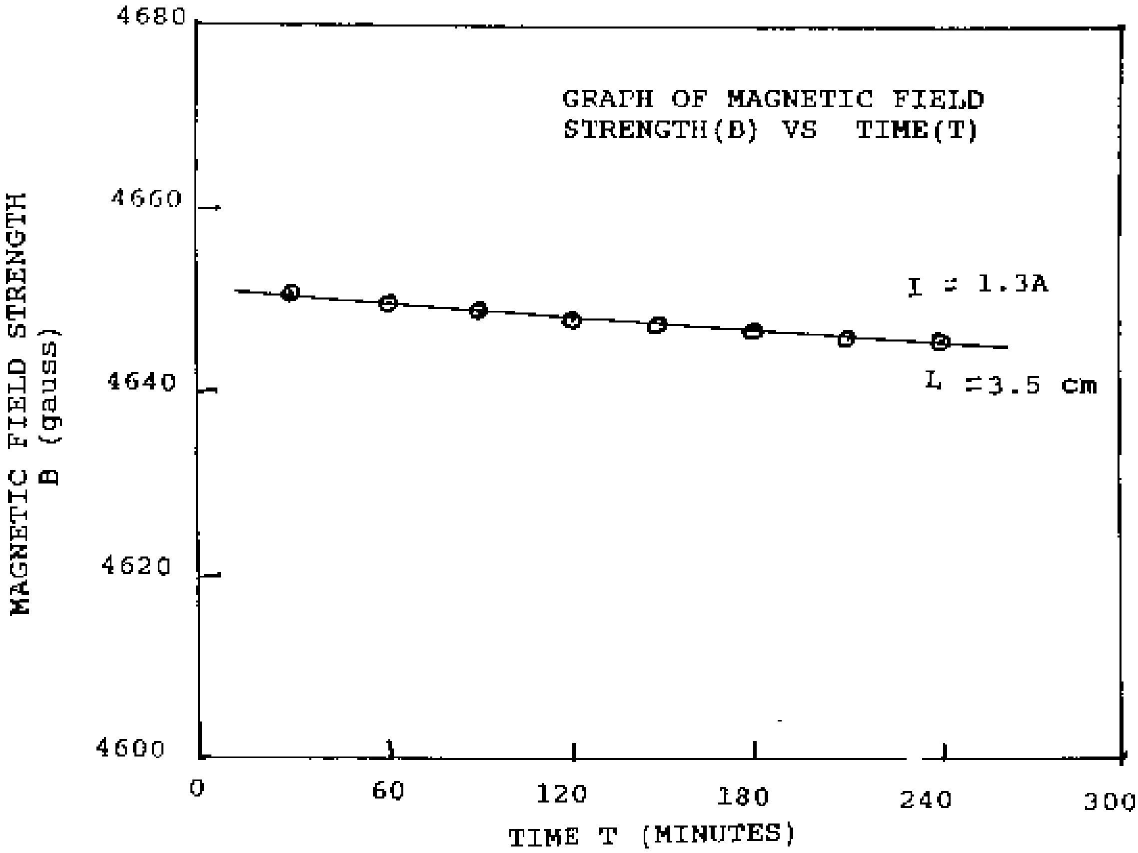


FIG. 5.16 VARIATION OF MAGNETIC FIELD STRENGTH WITH TIME AT POLE GAP 3.5 cm AND CURRENT 1.3 A

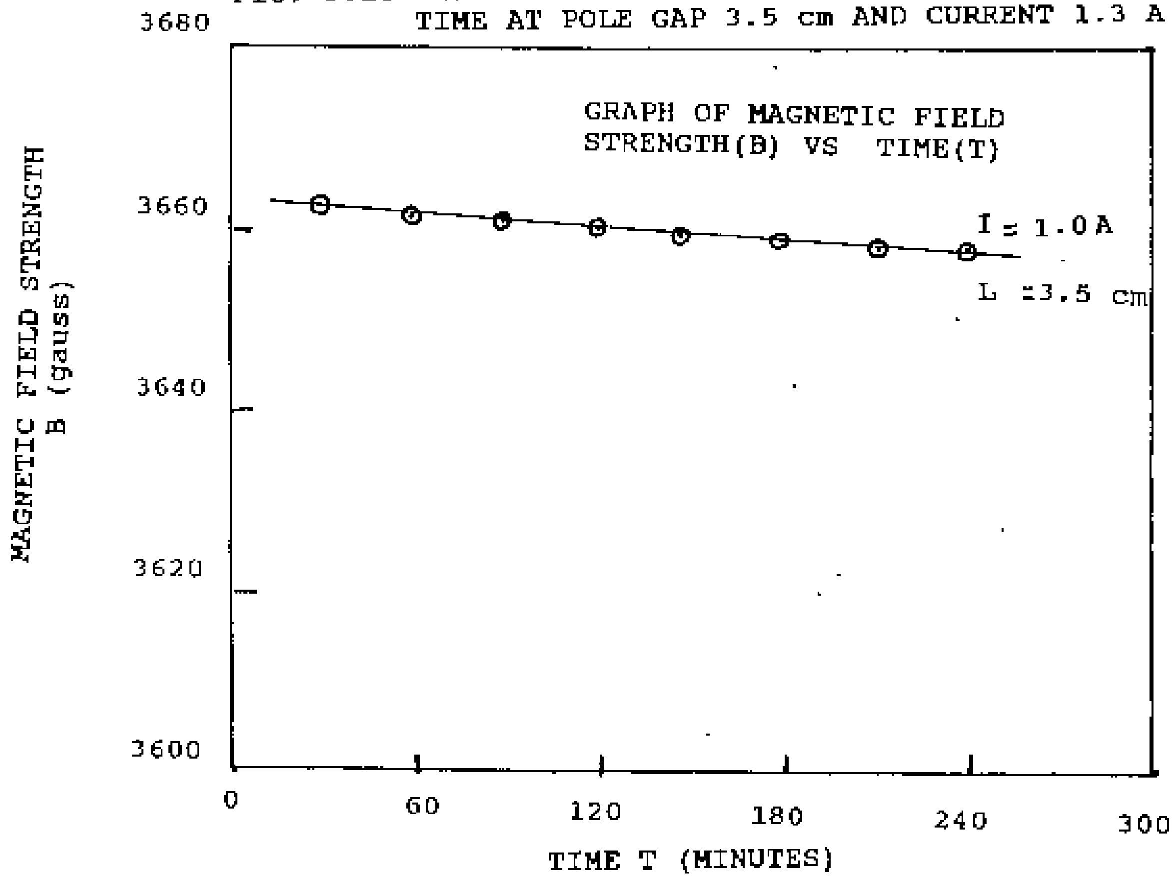


FIG. 5.17 VARIATION OF MAGNETIC FIELD STRENGTH WITH TIME AT POLE GAP 3.5 cm AND CURRENT 1.0 A

TABLE - 5.18

VARIATION OF MAGNTIC FIELD STRENGTH WITH TIME

Current Value : 1.3 amp.

Pole Gap : 3.0 cm.

HOURS	TIME-INTERVAL(T) IN MINUTES	MAGNETIC FIELD STRENGTH B (GAUSS)
12:00	00	5600.00
12:15	15	5600.00
12:30	30	5599.00
12:45	45	5599.50
01:00	60	5598.50
01:15	75	5598.00
01:30	90	5598.00
01:45	105	5597.00
02:00	120	5597.00
02:15	135	5596.50
02:30	150	5596.50
02:45	165	5596.50
03:00	180	5596.00
03:15	195	5596.00
03:30	210	5596.00
03:45	225	5596.00
04:00	240	5596.00

TABLE - 5.19

VARIATION OF MAGNTIC FIELD STRENGTH WITH TIME

Current Value : 1.0 amp.

Pole Gap : 3.0 cm.

HOURS	TIME-INTERVAL(T) IN MINUTES	MAGNETIC FIELD STRENGTH B (GAUSS)
12:00	00	4352.00
12:15	15	4352.00
12:30	30	4352.00
12:45	45	4351.00
01:00	60	4351.00
01:15	75	4350.50
01:30	90	4350.00
01:45	105	4350.00
02:00	120	4349.50
02:15	135	4349.00
02:30	150	4349.00
02:45	165	4348.50
03:00	180	4348.50
03:15	195	4348.00
03:30	210	4348.00
03:45	225	4448.00
04:00	240	4348.00

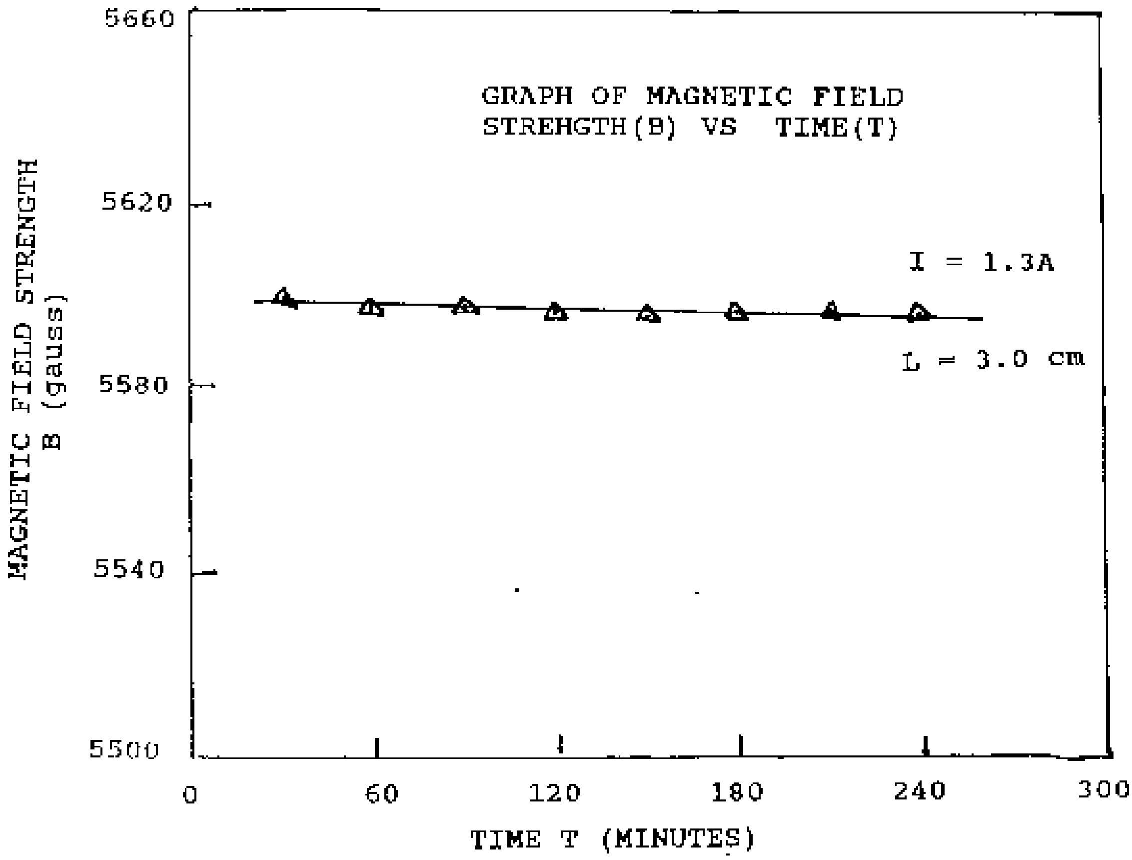


FIG. 5.18 VARIATION OF MAGNETIC FIELD STRENGTH WITH TIME AT POLE GAP 3.0 cm AND CURRENT 1.3 A

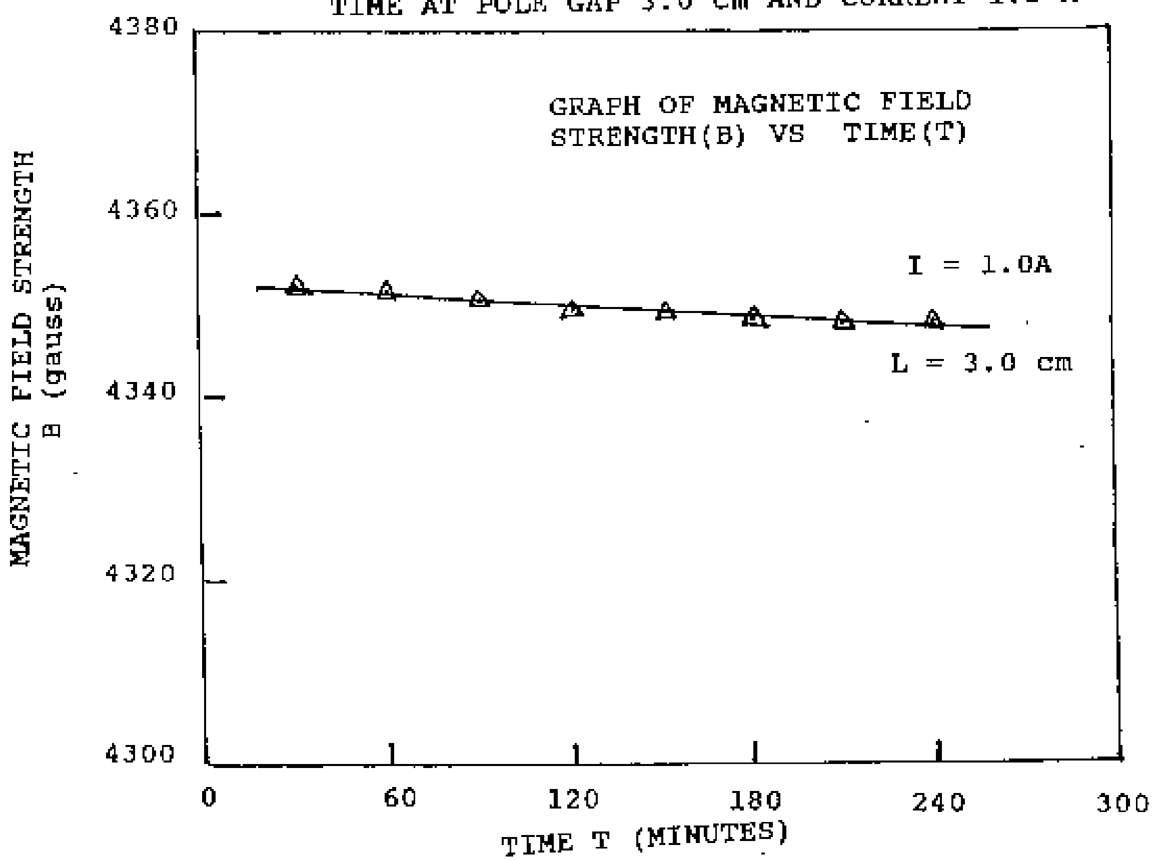


FIG. 5.19 VARIATION OF MAGNETIC FIELD STRENGTH WITH TIME AT POLE GAP 3.0 cm AND CURRENT 1.0 A

TABLE - 5.20

VARIATION OF MAGNTIC FIELD STRENGTH WITH TIME

Current Value : 1.3 amp.

Pole Gap : 2.5 cm.

HOURS	TIME-INTERVAL(T) IN MINUTES	MAGNETIC FIELD STRENGTH B (GAUSS)
10:00	00	6440.00
10:15	15	6440.00
10:30	30	6440.00
10:45	45	6439.00
11:00	60	6439.00
11:15	75	6438.50
11:30	90	6438.00
11:45	105	6438.00
12:00	120	6438.00
12:15	135	6437.00
12:30	150	6437.00
12:45	165	6436.00
01:00	180	6436.00
01:15	195	6436.00
01:30	210	6436.00
01:45	225	6436.00
02:00	240	6436.00

TABLE - 5.21

VARIATION OF MAGNTIC FIELD STRENGTH WITH TIME

Current Value : 1.0 amp.

Pole Gap : 2.5 cm.

HOURS	TIME-INTERVAL(T) IN MINUTES	MAGNETIC FIELD STRENGTH B (GAUSS)
10:00	00	5025.00
10:15	15	5025.00
10:30	30	5025.00
10:45	45	5024.50
11:00	60	5024.00
11:15	75	5023.50
11:30	90	5023.50
11:45	105	5023.00
12:00	120	5022.00
12:15	135	5022.00
12:30	150	5021.50
12:45	165	5021.50
01:00	180	5021.50
01:15	195	5021.00
01:30	210	5021.00
01:45	225	5021.00
02:00	240	5021.00

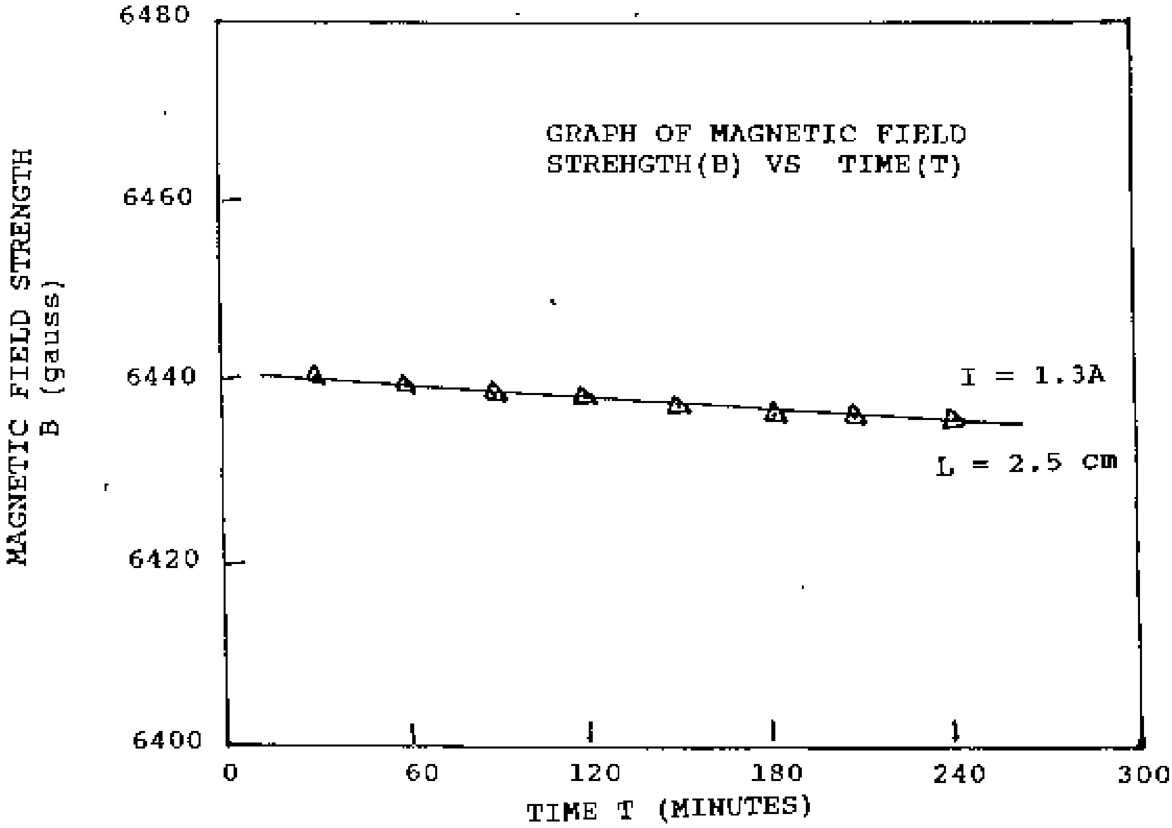


FIG. 5.20 VARIATION OF MAGNETIC FIELD STRENGTH WITH TIME AT POLE GAP 2.5 cm AND CURRENT 1.3 A

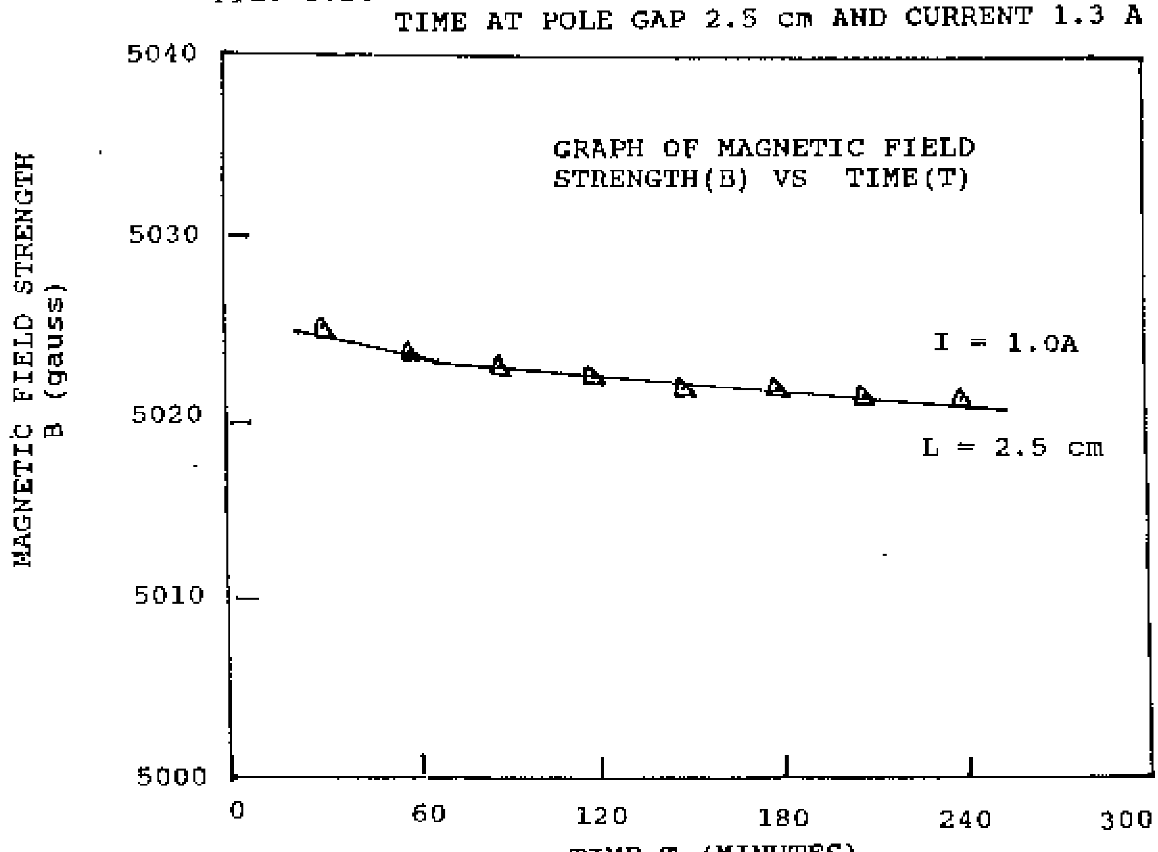


FIG. 5.21 VARIATION OF MAGNETIC FIELD STRENGTH WITH TIME AT POLE GAP 2.5 cm AND CURRENT 1.0 A

TABLE - 5.22

VARIATION OF MAGNTIC FIELD STRENGTH WITH TIME

Current Value : 1.3 amp.

Pole Gap : 2.0 cm.

HOURS	TIME-INTERVAL(T) IN MINUTES	MAGNETIC FIELD STRENGTH B (GAUSS)
09:00	00	7123.00
09:15	15	7123.00
09:30	30	7123.00
09:45	45	7123.00
10:00	60	7122.00
10:15	75	7122.00
10:30	90	7122.00
10:45	105	7122.00
11:00	120	7121.50
11:15	135	7121.50
11:30	150	7120.00
11:45	165	7120.00
12:00	180	7119.00
12:15	195	7118.50
12:30	210	7118.00
12:45	225	7118.50
01:00	240	7118.50

TABLE - 5.23

VARIATION OF MAGNTIC FIELD STRENGTH WITH TIME

Current Value : 1.0 amp.

Pole Gap : 2.0 cm.

HOURS	TIME-INTERVAL(T) IN MINUTES	MAGNETIC FIELD STRENGTH B (GAUSS)
09:00	00	6233.00
09:15	15	6233.00
09:30	30	6233.00
09:45	45	6233.00
10:00	60	6232.50
10:15	75	6232.50
10:30	90	6232.00
10:45	105	6232.00
11:00	120	6232.00
11:15	135	4648.00
11:30	150	6231.50
11:45	165	6231.00
12:00	180	6231.00
12:15	195	6230.50
12:30	210	6230.50
12:45	225	6230.50
01:00	240	6230.50

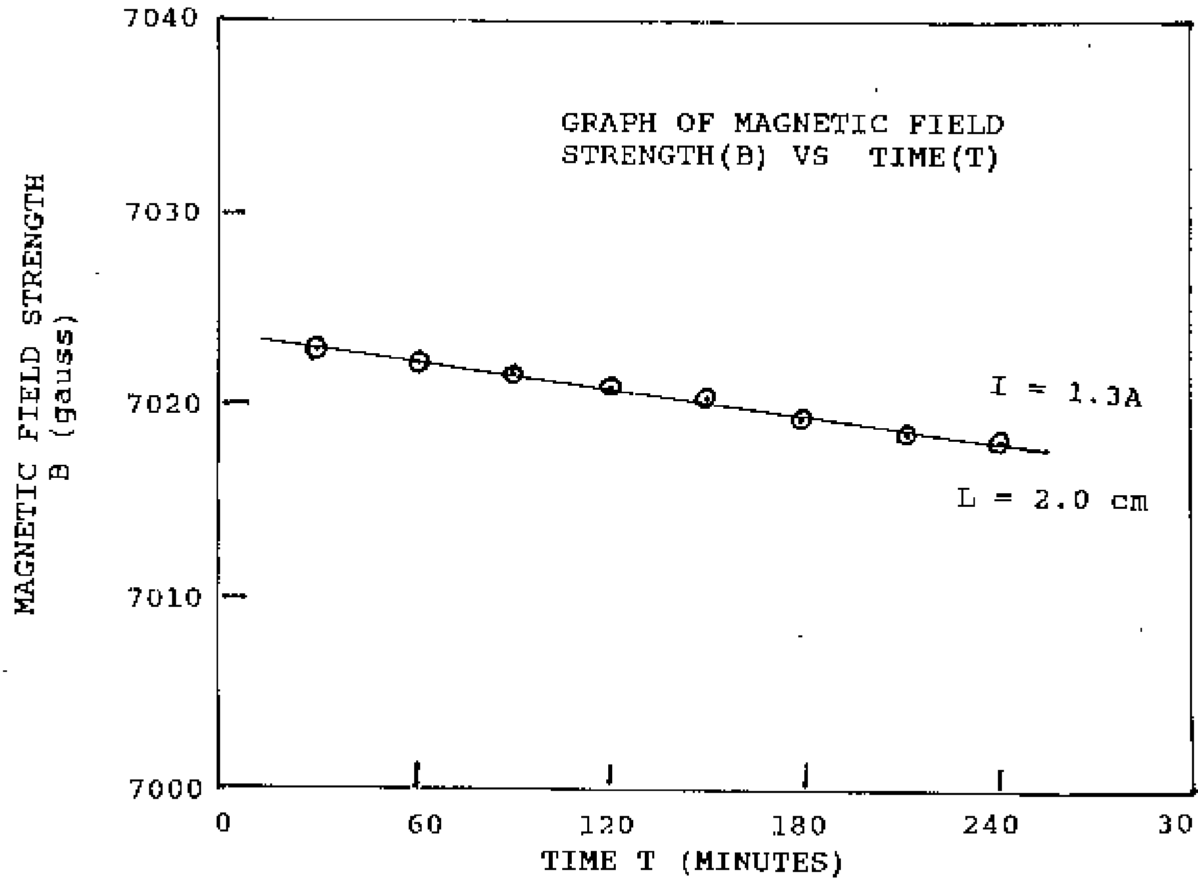


FIG. 5.22 VARIATION OF MAGNETIC FIELD STRENGTH WITH TIME AT POLE GAP 2.0 cm AND CURRENT 1.3 A

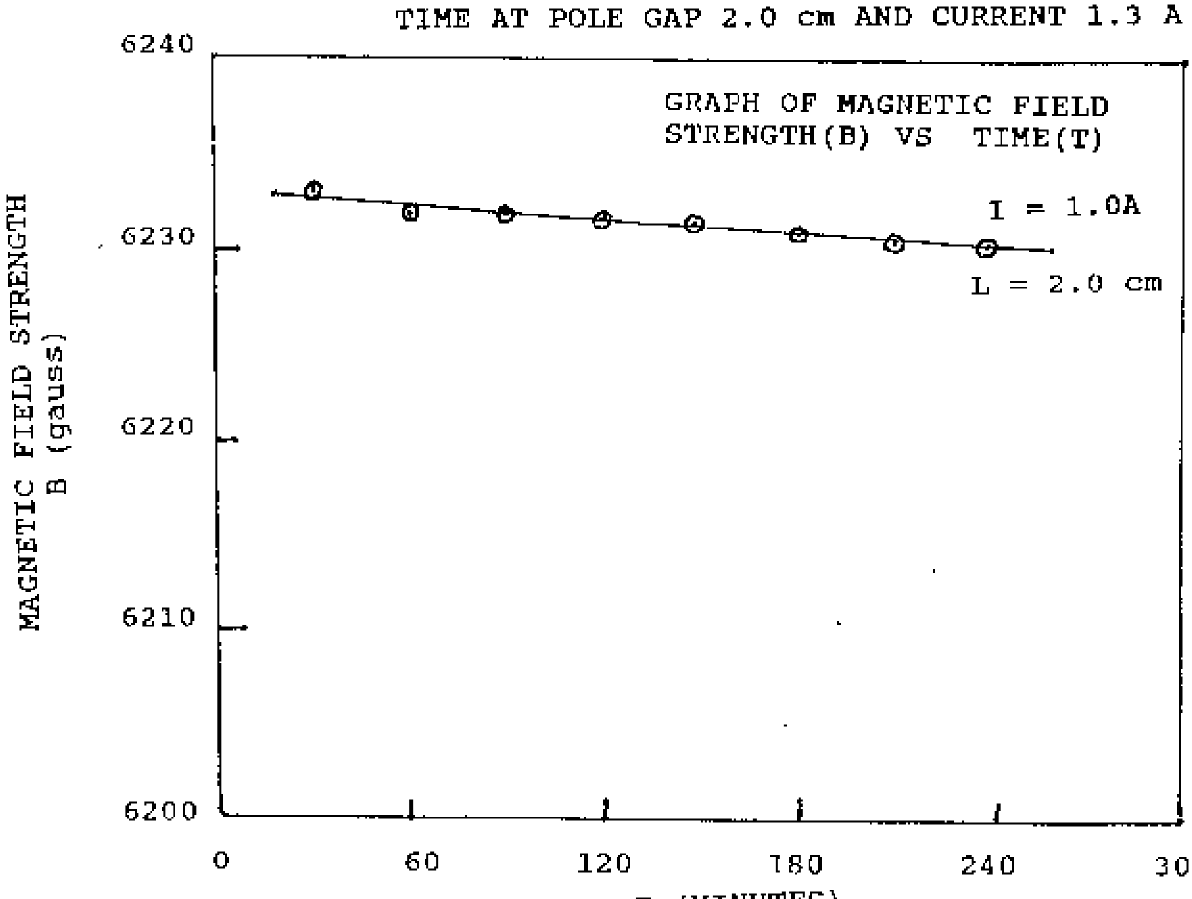


FIG. 5.23 VARIATION OF MAGNETIC FIELD STRENGTH WITH TIME AT POLE GAP 2.0 cm AND CURRENT 1.0 A

5.4 TEMPERATURE MEASUREMENT

The purpose of this experiment is to study the heat generation and heat dissipation at different layers of the energising coils. Three copper-constantan thermo-couples have been inserted in inner, middle and outer layers of one of the coils of the electromagnet. The temperature conditions have been studied for current values of 2A, 1.5A and 1.3A. For 2A current the highest temperature 93.5^{o}c was recorded at the middle layer. Time required to attain this temperature was 190 minutes. For 1.5A current the highest temperature in the middle layer was 48^{o}c. The middle layer took 85 minutes to develop this temperature. For 1.3A the highest temperature was 44.5^{o}c and that was aleo recorded in the middle layer. Time needed in this case was 90 minutes. The difference in temperature between different layers for a particular current flow ie shown. For 2A current flow, the differential temperature has been recorded and the results show that difference is low. Temperatures at different layers at different current values are givben in Tables 5.24-5.32 and figures 5.24-5.32 show the resulte graphically. Tables 5.33-5.35 show the differential charts and figures 5.33-5.35 are the graphical represntations.

TABLE - 5.24

VARIATION OF TEMPERATURE WITH TIME IN THE INNER LAYER OF THE EXCITATION COIL AT CURRENT 2 AMPERES

COPPER-CONSTANTAN THERMO-COUPLE

Room Teperature : 31^oC

Current : 2.0 Amp.

HOURS	TIME-INTERVAL IN MINUTES	THERMO-VOLTAGE mV	TEMPERATURE 0^oC
12:00	00	00	00 + 31 = 31.00
12:15	15	0.65	12.50 + 31 = 43.50
12:30	30	1.25	24.25 + 31 = 55.25
12:45	45	1.70	32.50 + 31 = 63.50
01:00	60	2.06	39.00 + 31 = 70.00
01:15	75	2.38	45.50 + 31 = 76.50
01:30	90	2.62	49.50 + 31 = 80.50
01:45	105	2.84	53.50 + 31 = 84.50
02:00	120	2.96	56.00 + 31 = 87.00
02:15	135	3.08	58.00 + 31 = 89.00
02:30	150	3.20	60.25 + 31 = 91.25
02:45	165	3.22	60.75 + 31 = 91.75
03:00	180	3.24	61.00 + 31 = 92.00
03:05	185	3.25	61.25 + 31 = 92.25
03:10	190	3.26	61.50 + 31 = 92.50
03:15	195	3.26	61.50 + 31 = 92.50
03:20	200	3.26	61.50 + 31 = 92.50

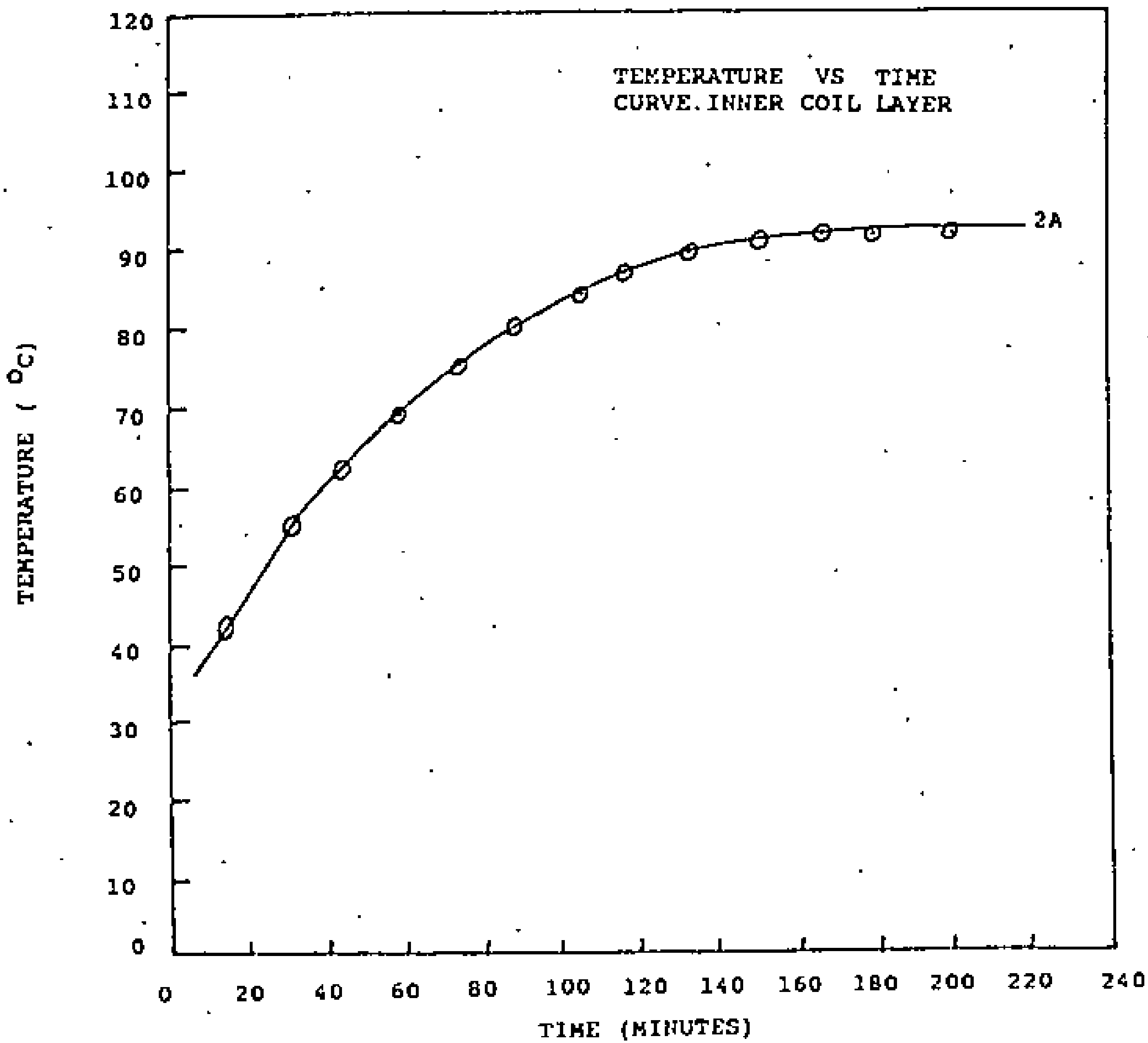


FIG. 5.24 VARIATION OF TEMPERATURE WITH TIME IN THE INNER LAYER OF THE EXCITATION COIL AT CURRENT 2 A.

TABLE - 5.25

VARIATION OF TEMPERATURE WITH TIME IN THE MIDLE LAYER OF THE EXCITATION COIL AT CURRENT 2 AMPERES

COPPER-CONSTANTAN THERMO-COUPLE

Room Teperature : $31^{o}C$

Current : 2.0 Amp.

HOURS	TIME-INTERVAL IN MINUTES	THERMO-VOLTAGE mV	TEMPERATURE $0^{o}C$
11:00	00	00	00 + 31 = 31.00
11:15	15	0.60	13.00 + 31 = 44.00
11:30	30	1.24	24.00 + 31 = 63.00
11:45	45	1.69	32.00 + 31 = 70.50
12:00	60	2.07	39.50 + 31 = 76.50
12:15	75	2.38	45.50 + 31 = 81.00
12:30	90	2.63	50.00 + 31 = 84.50
12:45	105	2.84	53.50 + 31 = 87.00
01:00	120	2.96	56.00 + 31 = 89.50
01:15	135	3.09	58.50 + 31 = 91.00
01:30	150	3.19	60.00 + 31 = 92.00
01:45	165	3.25	61.00 + 31 = 92.50
02:00	180	3.30	61.50 + 31 = 93.50
02:05	185	3.31	62.50 + 31 = 93.50
02:10	190	3.31	62.50 + 31 = 93.50
02:15	195	3.31	62.50 + 31 = 93.50
02:20	200	3.31	62.50 + 31 = 93.50

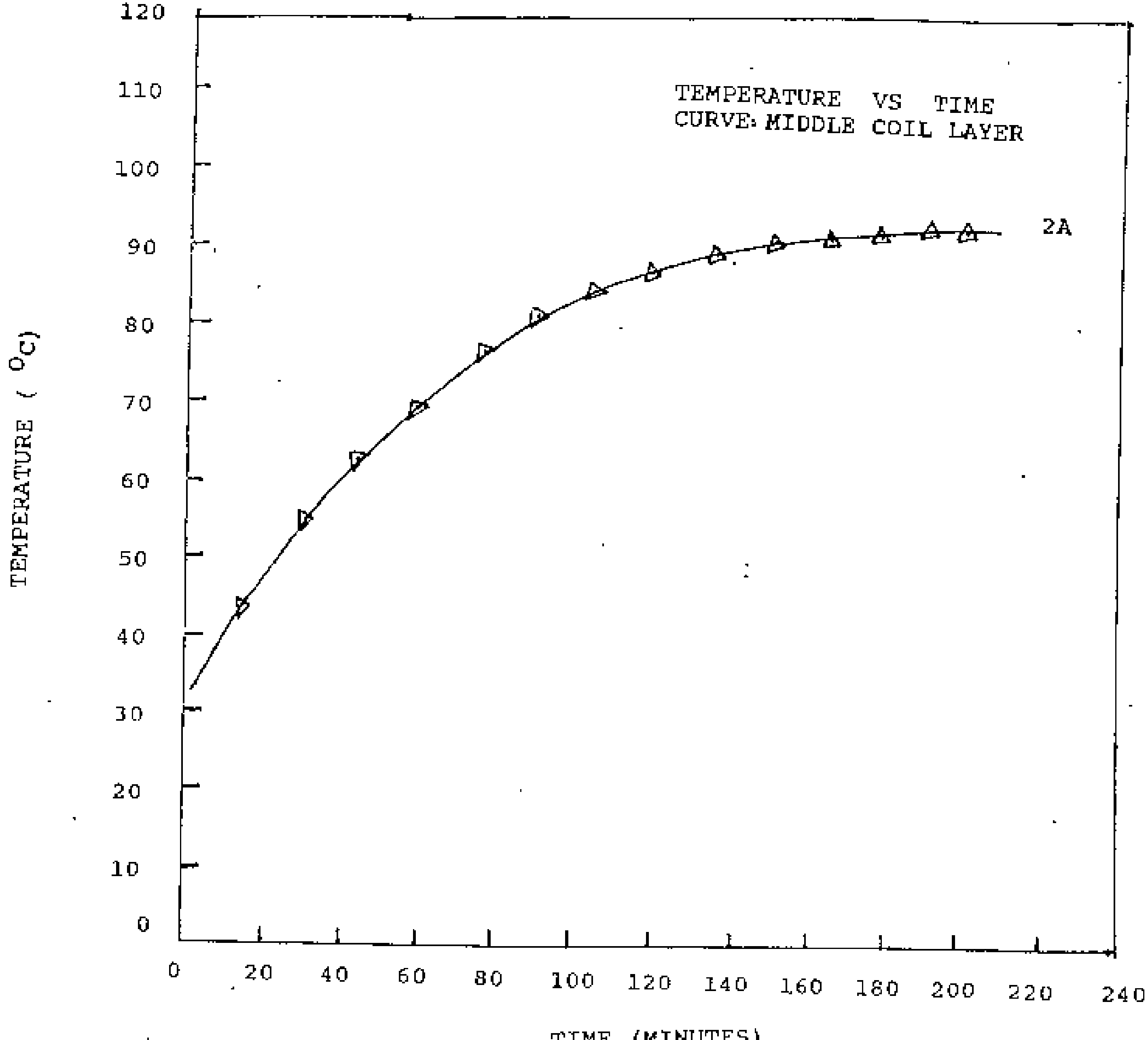


FIG. 5.25 VARIATION OF TEMPERATURE WITH TIME IN THE MIDDLE LAYER OF THE EXCITATION COIL AT CURRENT 2 A.

TABLE - 5.26

VARIATION OF TEMPERATURE WITH TIME IN THE OUTER LAYER OF THE EXCITATION COIL AT CURRENT 2 AMPERES

COPPER-CONSTANTAN THERMO-COUPLE

Room Teperature : $31^{o}C$

Current : 2.0 Amp.

HOURS	TIME-INTERVAL IN MINUTES	THERMO-VOLTAGE mV	TEMPERATURE $0^{o}C$
10:00	00	00	00 + 31 = 31.00
10:20	20	0.56	11.00 + 31 = 42.00
10:40	40	1.12	21.50 + 31 = 52.50
11:00	60	1.44	27.50 + 31 = 58.50
11:20	80	1.80	34.50 + 31 = 64.50
11:40	100	2.16	36.00 + 31 = 67.00
12:00	120	2.32	44.50 + 31 = 75.50
12:20	140	2.42	45.50 + 31 = 76.50
12:40	160	2.56	48.50 + 31 = 78.50
01:00	180	2.66	50.00 + 31 = 81.00
01:10	190	2.76	52.25 + 31 = 83.00
01:20	200	2.80	52.50 + 31 = 83.50
01:25	205	2.80	52.50 + 31 = 83.50

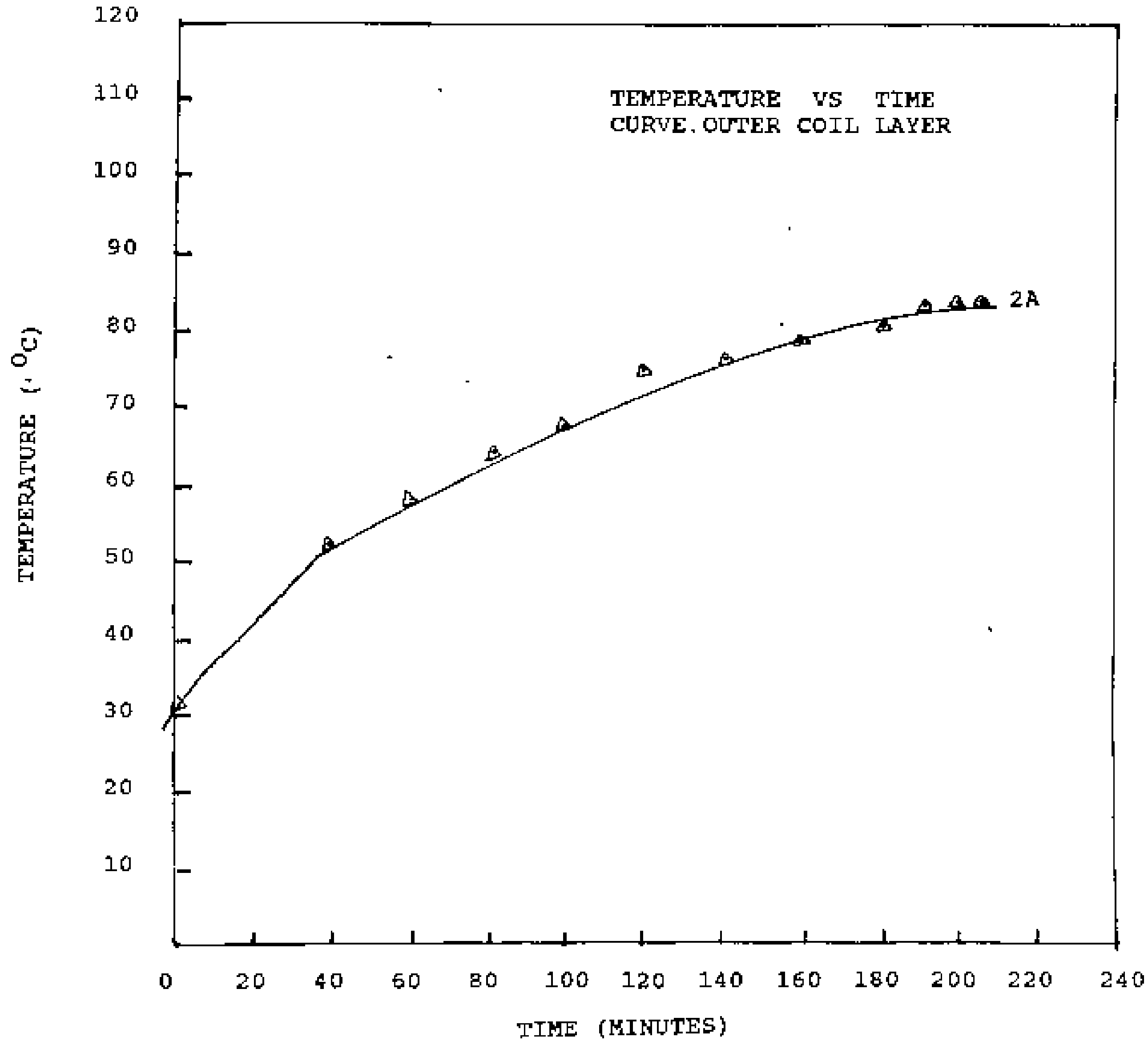


FIG. 5.26 VARIATION OF TEMPERATURE WITH TIME IN THE OUTER LAYER OF THE EXCITATION COIL AT CURRENT 2 A.

TABLE - 5.27

VARIATION OF TEMPERATURE WITH TIME IN THE INNER LAYER OF THE EXCITATION COIL AT CURRENT 1.5 AMPERES

COPPER-CONSTANTAN THERMO-COUPLE
Room Teperature : 26°C
Current : 1.5 Amp.

HOURS	TIME-INTERVAL IN MINUTES	THERMO-VOLTAGE mV	TEMPERATURE 0°C
11:50	00	00	00 + 26 = 26.00
11:55	05	0.06	01.00 + 26 = 27.00
12:00	10	0.15	03.00 + 26 = 29.00
12:05	25	0.24	05.00 + 26 = 31.00
12:10	20	0.31	06.25 + 26 = 32.25
12:15	25	0.39	08.00 + 26 = 34.00
12:20	30	0.46	09.25 + 26 = 35.25
12:25	35	0.53	11.00 + 26 = 37.00
12:30	40	0.60	11.75 + 26 = 37.75
12:35	45	0.65	13.00 + 26 = 39.00
12:40	50	0.71	14.00 + 26 = 40.00
12:45	55	0.76	15.00 + 26 = 41.00
12:50	60	0.82	16.25 + 26 = 42.50
12:55	65	0.87	17.50 + 26 = 43.50
01:00	70	0.92	18.50 + 26 = 44.50
01:05	75	0.97	19.00 + 26 = 45.00
01:10	80	1.06	19.75 + 26 = 45.75
01:15	85	1.06	20.50 + 26 = 46.50
01:20	90	1.06	20.50 + 26 = 46.50
01:25	95	1.06	20.50 + 26 = 46.50

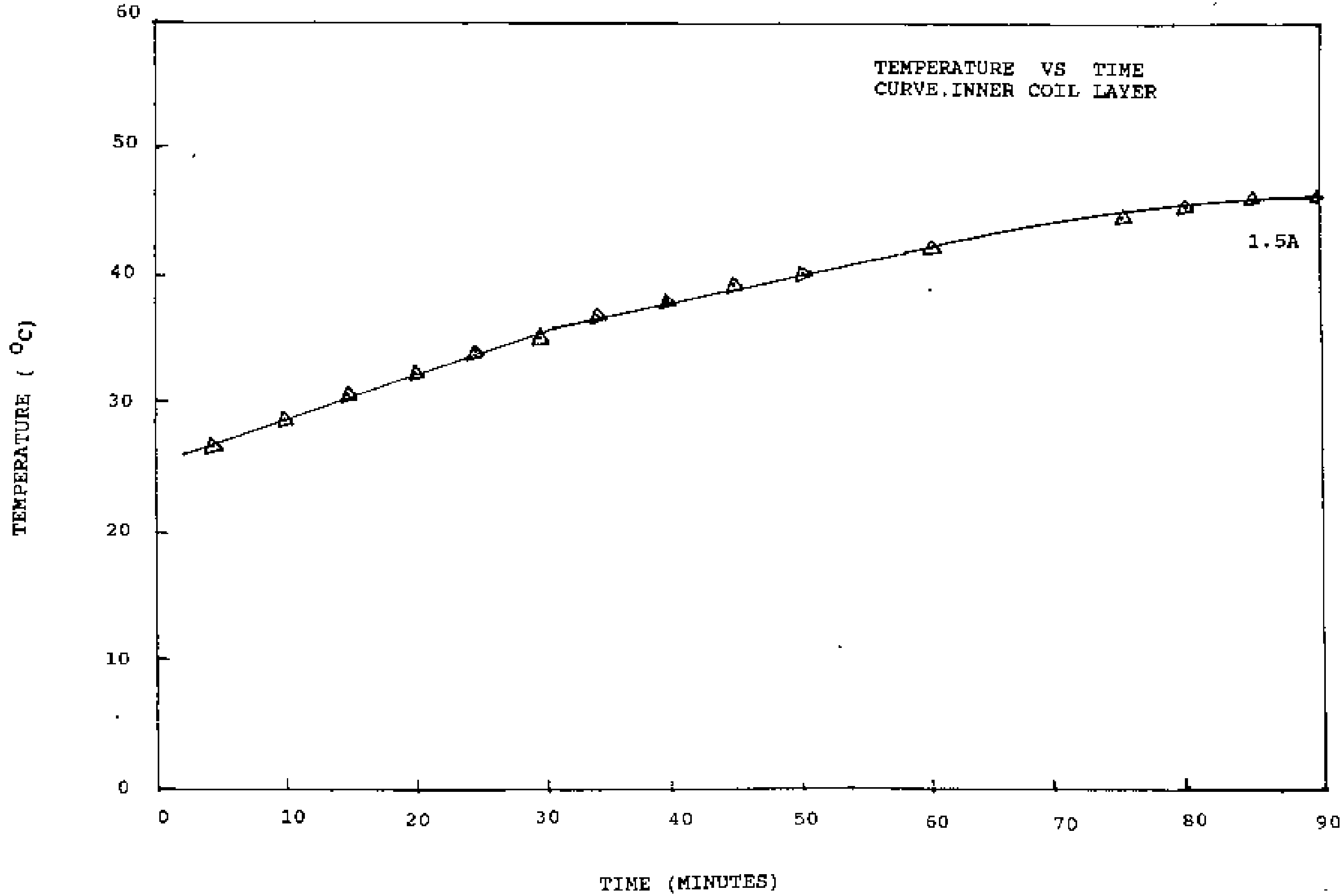


FIG. 5.27 VARIATION OF TEMPERATURE WITH TIME IN THE INNER LAYER OF THE EXCITATION COIL AT CURRENT 1.5 A.

TABLE - 5.28

VARIATION OF TEMPERATURE WITH TIME IN THE MIDDLE LAYER OF THE EXCITATION COIL AT CURRENT 1.5 AMPERES

COPPER-CONSTANTAN THERMO-COUPLE
Room Teperature : 26^{o}C
Current : 1.5 Amp.

HOURS	TIME-INTERVAL IN MINUTES	THERMO-VOLTAGE mV	TEMPERATURE $0^{o}C$
10:00	00	00	00 + 26 = 26.00
10:05	05	0.08	01.50 + 26 = 27.50
10:10	10	0.16	03.50 + 26 = 29.50
10:15	15	0.24	05.00 + 26 = 31.00
10:20	20	0.33	06.75 + 26 = 32.75
10:25	25	0.42	08.25 + 26 = 34.25
10:30	30	0.50	10.00 + 26 = 36.00
10:35	35	0.58	11.50 + 26 = 37.50
10:40	40	0.66	13.00 + 26 = 39.00
10:45	45	0.72	14.00 + 26 = 40.00
10:50	50	0.80	15.50 + 26 = 41.50
10:55	55	0.87	17.50 + 26 = 43.50
11:00	60	0.92	18.25 + 26 = 44.25
11:05	65	0.99	19.25 + 26 = 45.25
11:10	70	1.04	20.00 + 26 = 46.00
11:15	75	1.08	21.00 + 26 = 47.00
11:20	80	1.11	21.75 + 26 = 47.75
11:25	85	1.12	22.00 + 26 = 48.00
11:30	90	1.12	22.00 + 26 = 48.00

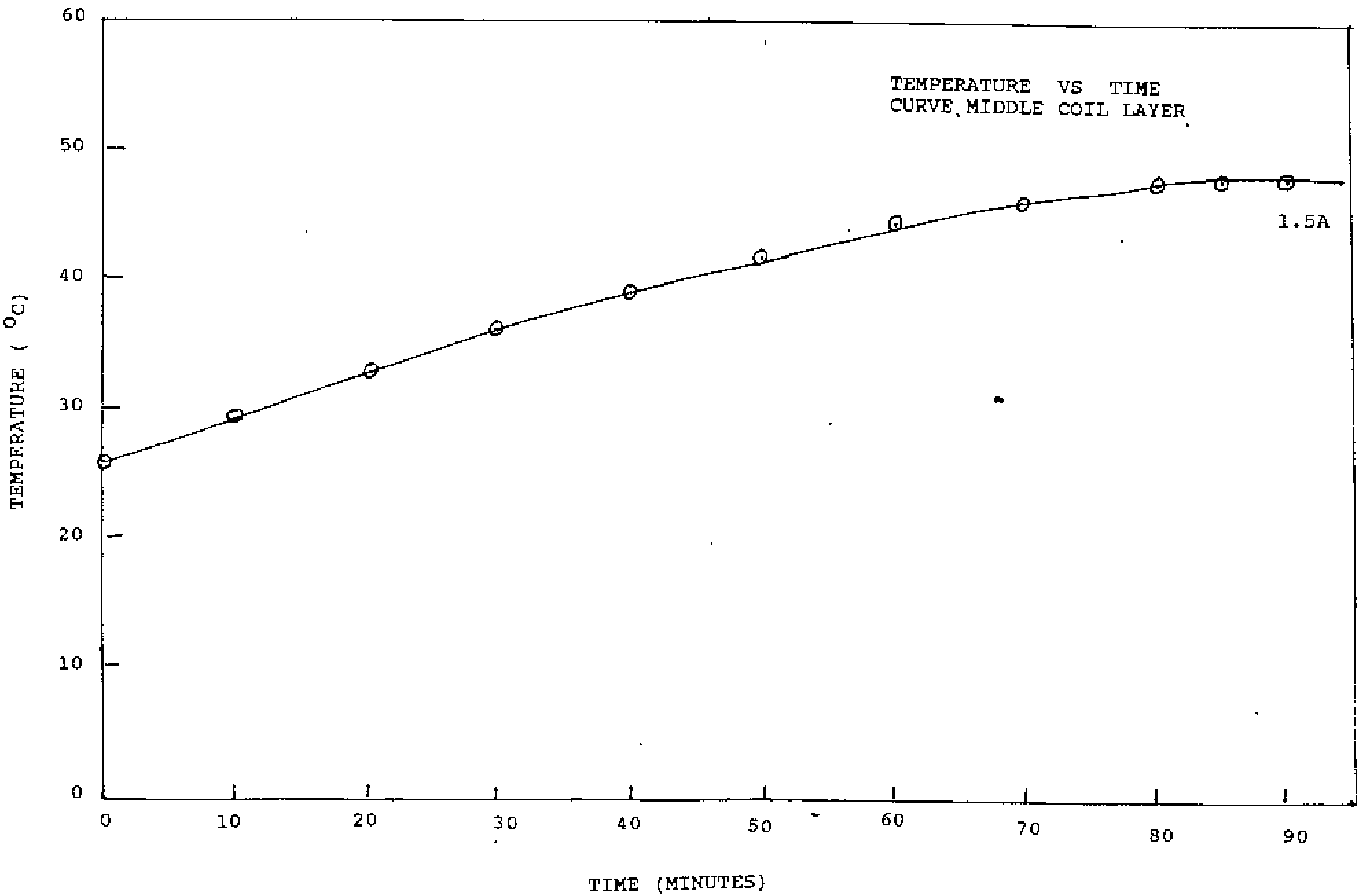


FIG. 5.28 VARIATION OF TEMPERATURE WITH TIME IN THE MIDDLE LAYER OF THE EXCITATION COIL AT CURRENT 1.5 A.

TABLE - 5.29

VARIATION OF TEMPERATURE WITH TIME IN THE OUTER LAYER OF THE EXCTTATION COIL AT CURRENT 1.5 AMPERES

THERMO-COUPLE : COPPER-CONSTANTAN
Room Teperature : 26°C
Current : 1.5 Amp.

HOURS	TIME-INTERVAL IN MINUTES	THERMO-VOLTAGE mV	TEMPERATURE 0°C
10:00	00	00	00 + 26 = 26.00
10:05	05	0.05	01.00 + 26 = 27.00
10:10	10	0.12	02.50 + 26 = 28.50
10:15	15	0.20	04.50 + 26 = 30.50
10:20	20	0.28	05.00 + 26 = 31.00
10:25	25	0.34	07.00 + 26 = 33.00
10:30	30	0.34	08.00 + 26 = 34.00
10:35	35	0.40	08.75 + 26 = 34.75
10:40	40	0.45	09.50 + 26 = 35.50
10:45	45	0.48	11.50 + 26 = 37.50
10:50	50	0.60	14.00 + 26 = 40.00
10:55	55	0.69	15.00 + 26 = 41.00
11:00	60	0.75	16.00 + 26 = 42.00
11:05	65	0.81	16.50 + 26 = 42.50
11:10	70	0.84	17.75 + 26 = 43.50
11:15	75	0.87	18.50 + 26 = 44.50
11:20	80	0.90	19.00 + 26 = 45.00
11:25	85	0.95	19.00 + 26 = 45.00
11:30	90	0.95	19.50 + 26 = 45.00

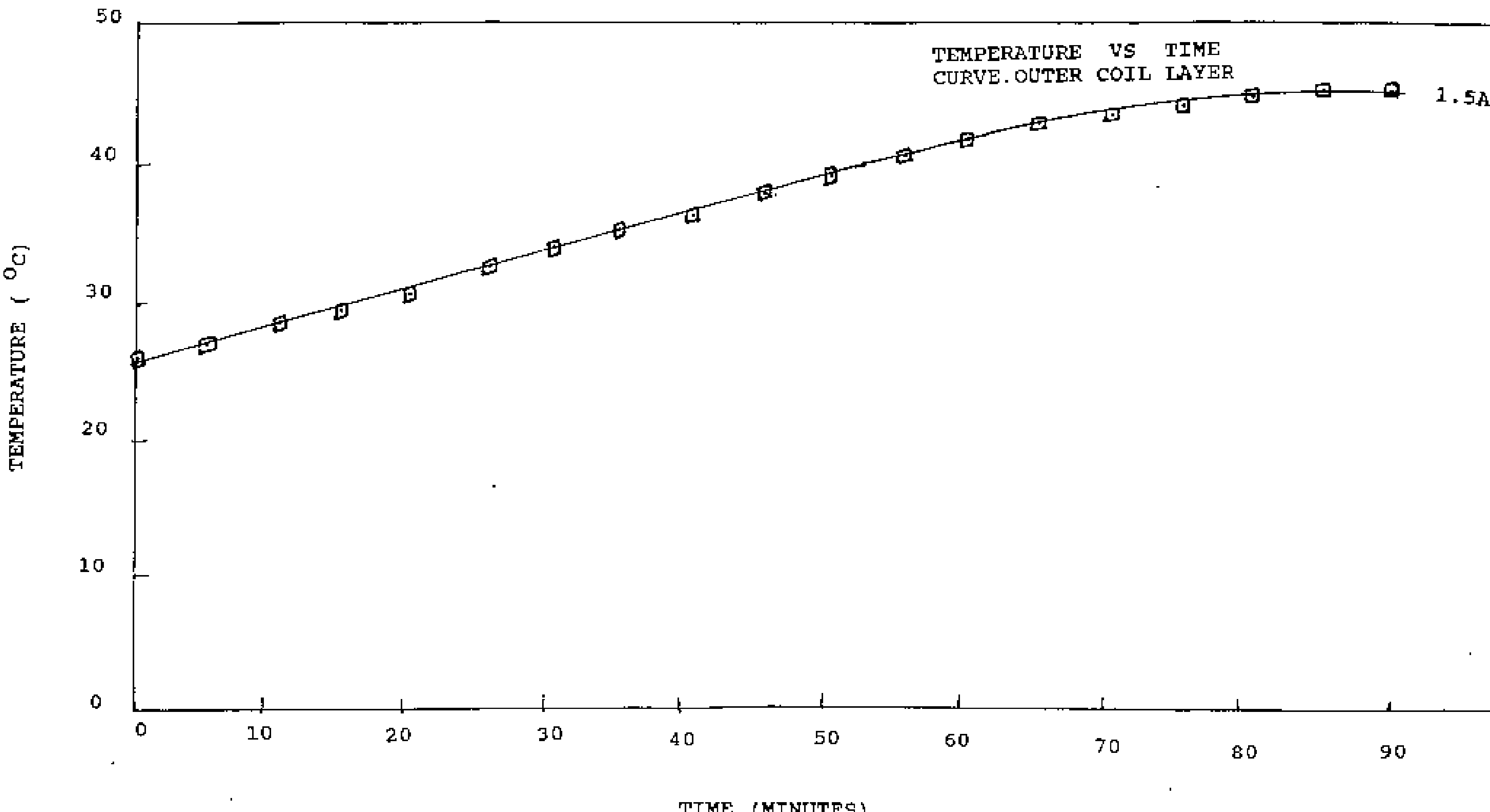


FIG. 5.29 VARIATION OF TEMPERATURE WITH TIME IN THE OUTER LAYER OF THE EXCITATION COIL AT CURRENT 1.5 A.

TABLE - 5.30

VARIATION OF TEMPERATURE WITH TIME IN THE INNER LAYER OF THE EXCITATION COIL AT CURRENT 1.3 AMPERES

THERMO-COUPLE : COPPER-CONSTANTAN
Room Teperature : $25^{o}C$
Current : 1.3 Amp.

HOURS	TIME-INTERVAL IN MINUTES	THERMO-VOLTAGE mV	TEMPERATURE $0^{o}C$
12:45	00	00	00 + 25 = 25.00
12:50	05	0.04	01.00 + 25 = 26.00
12:55	10	0.09	02.00 + 25 = 27.00
01:00	15	0.14	04.00 + 25 = 29.00
01:05	20	0.19	04.50 + 25 = 29.50
01:10	25	0.24	05.00 + 25 = 30.00
01:15	30	0.30	05.50 + 25 = 30.50
01:20	35	0.35	06.50 + 25 = 31.50
01:25	40	0.40	08.00 + 25 = 33.00
01:30	45	0.48	09.50 + 25 = 34.50
01:35	50	0.56	12.00 + 25 = 37.00
01:40	55	0.67	13.25 + 25 = 38.25
01:45	60	0.75	14.50 + 25 = 39.50
01:50	65	0.79	15.00 + 25 = 40.00
01:55	70	0.82	16.00 + 25 = 41.00
02:00	75	0.84	16.50 + 25 = 41.50
02:05	80	0.86	17.00 + 25 = 42.00
02:10	85	0.89	17.50 + 25 = 42.50
02:15	90	0.90	17.50 + 25 = 42.50
02:20	95	0.90	17.50 + 25 = 42.50

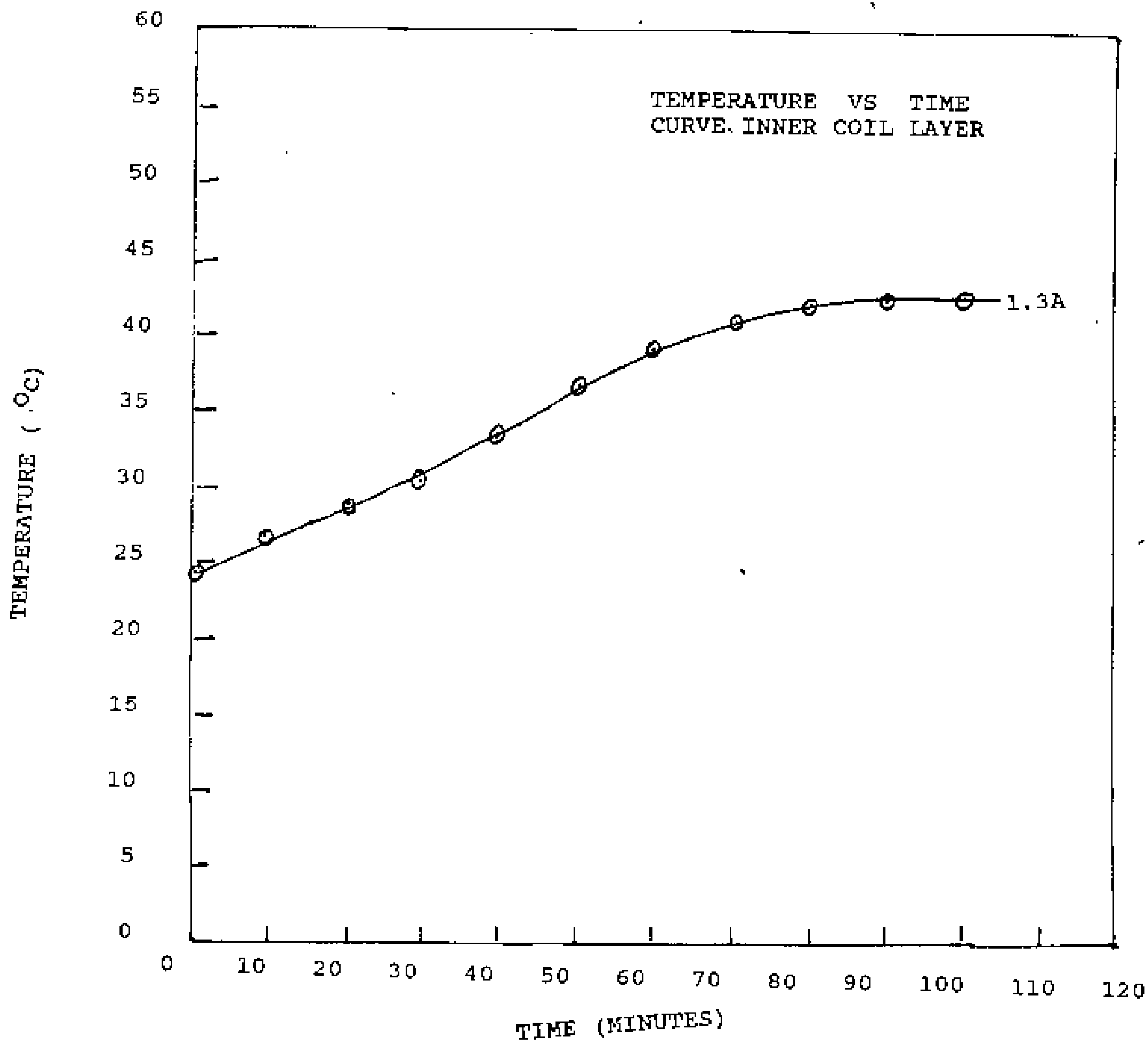


FIG. 5.30 VARIATION OF TEMPERATURE WITH TIME IN THE INNER LAYER OF THE EXCITATION COIL AT CURRENT 1.3 A.

TABLE - 5.31

VARIATION OF TEMPERATURE WITH TIME IN THE MIDDLE LAYER OF THE EXCITATION COIL AT CURRENT 1.3 AMPERES

THERMO-COUPLE : COPPER-CONSTANTAN
Room Teperature : 25°C
Current : 1.3 Amp.

HOURS	TIME-INTERVAL IN MINUTES	THERMO-VOLTAGE mV	TEMPERATURE 0°C
10:00	00	00	00 + 25 = 25.00
10:05	05	0.07	01.50 + 25 = 26.50
10:10	10	0.16	03.50 + 25 = 28.50
10:15	15	0.26	04.75 + 25 = 29.75
10:20	20	0.35	06.50 + 25 = 31.50
10:25	25	0.44	08.50 + 25 = 33.50
10:30	30	0.51	09.75 + 25 = 34.50
10:35	35	0.60	11.50 + 25 = 36.50
10:40	40	0.66	13.00 + 25 = 38.00
10:45	45	0.72	14.00 + 25 = 39.00
10:50	50	0.78	15.00 + 25 = 40.00
10:55	55	0.82	16.00 + 25 = 41.00
11:00	60	0.86	17.00 + 25 = 42.00
11:05	65	0.90	17.50 + 25 = 42.50
11:10	70	0.93	18.25 + 25 = 43.20
11:15	75	0.95	18.50 + 25 = 43.50
11:20	80	0.95	19.00 + 25 = 44.00
11:25	85	0.96	19.50 + 25 = 44.50
11:30	90	0.97	19.50 + 25 = 44.50
11:35	95	0.97	19.50 + 25 = 44.50
11:40	100	0.97	19.50 + 25 = 44.50

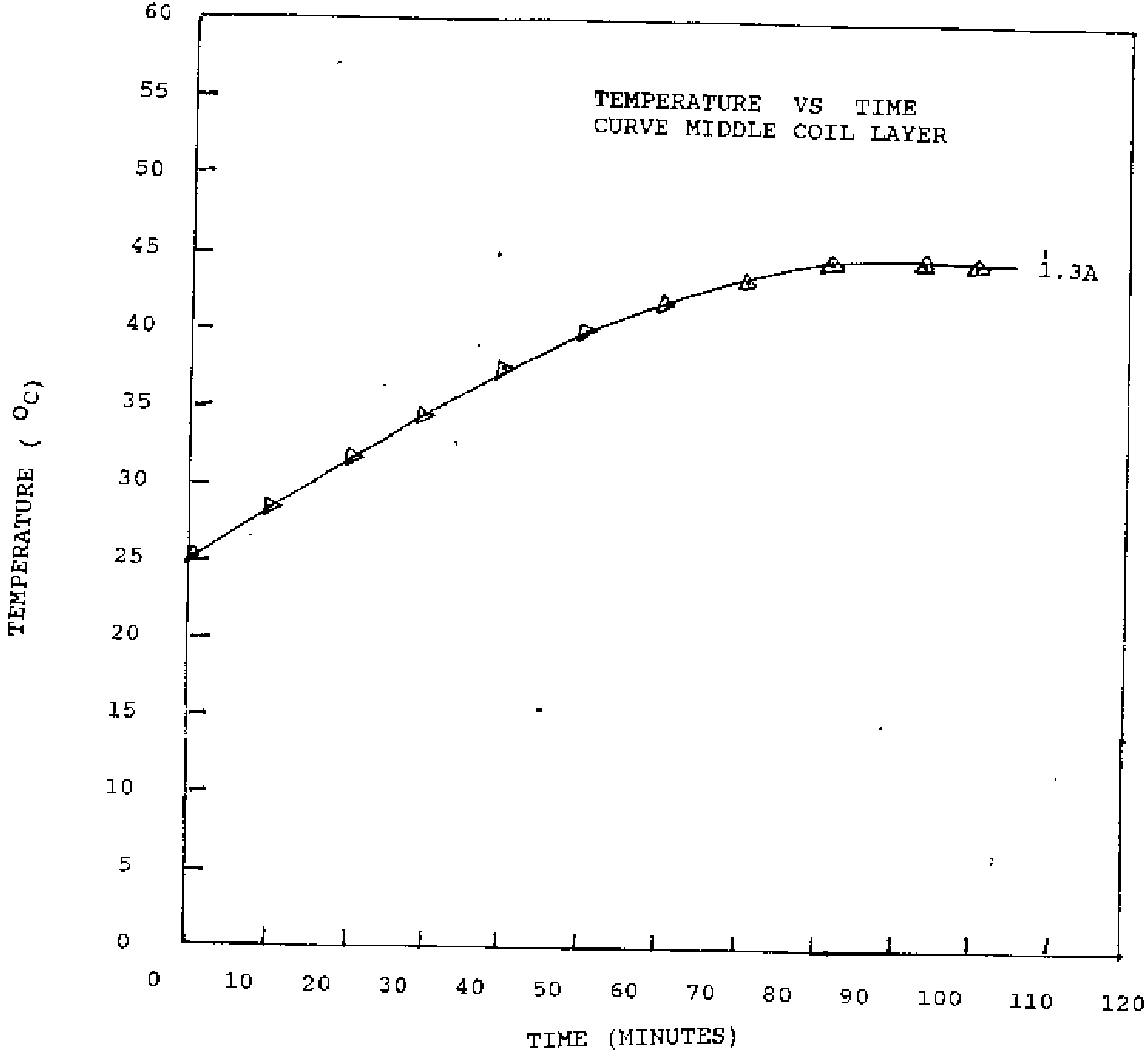


FIG. 5.31 VARIATION OF TEMPERATURE WITH TIME IN THE MIDDLE LAYER OF THE EXCITATION COIL AT CURRENT 1.3 A.

TABLE - 5.32

VARIATION OF TEMPERATURE WITH TIME IN THE OUTER LAYER OF THE EXCITATION COIL AT CURRENT 1.3 AMPERES

THERMO-COUPLE : COPPER-CONSTANTAN
Room Teperature : 25°C
Current : 1.3 Amp.

HOURS	TIME-INTERVAL IN MINUTES	THERMO-VOLTAGE mV	TEMPERATURE 0°C
10:00	00	00	00 + 25 = 25.00
10:05	05	0.05	01.00 + 25 = 26.00
10:10	10	0.10	02.00 + 25 = 27.00
10:15	15	0.20	04.50 + 25 = 29.50
10:20	20	0.30	05.50 + 25 = 30.50
10:25	25	0.40	08.00 + 25 = 33.00
10:30	30	0.48	09.50 + 25 = 34.50
10:35	35	0.56	12.00 + 25 = 37.00
10:40	40	0.60	12.50 + 25 = 37.50
10:45	45	0.63	13.00 + 25 = 38.00
10:50	50	0.67	13.50 + 25 = 38.50
10:55	55	0.71	14.00 + 25 = 39.00
11:00	60	0.75	15.00 + 25 = 40.00
11:05	65	0.78	15.25 + 25 = 40.25
11:10	70	0.80	16.00 + 25 = 41.00
11:15	75	0.81	16.00 + 25 = 41.00
11:20	80	0.83	16.50 + 25 = 41.50
11:25	85	0.85	17.00 + 25 = 42.00
11:30	90	0.86	17.00 + 25 = 42.00
11:35	95	0.86	17.00 + 25 = 42.00
11:40	100	0.86	17.00 + 25 = 42.00

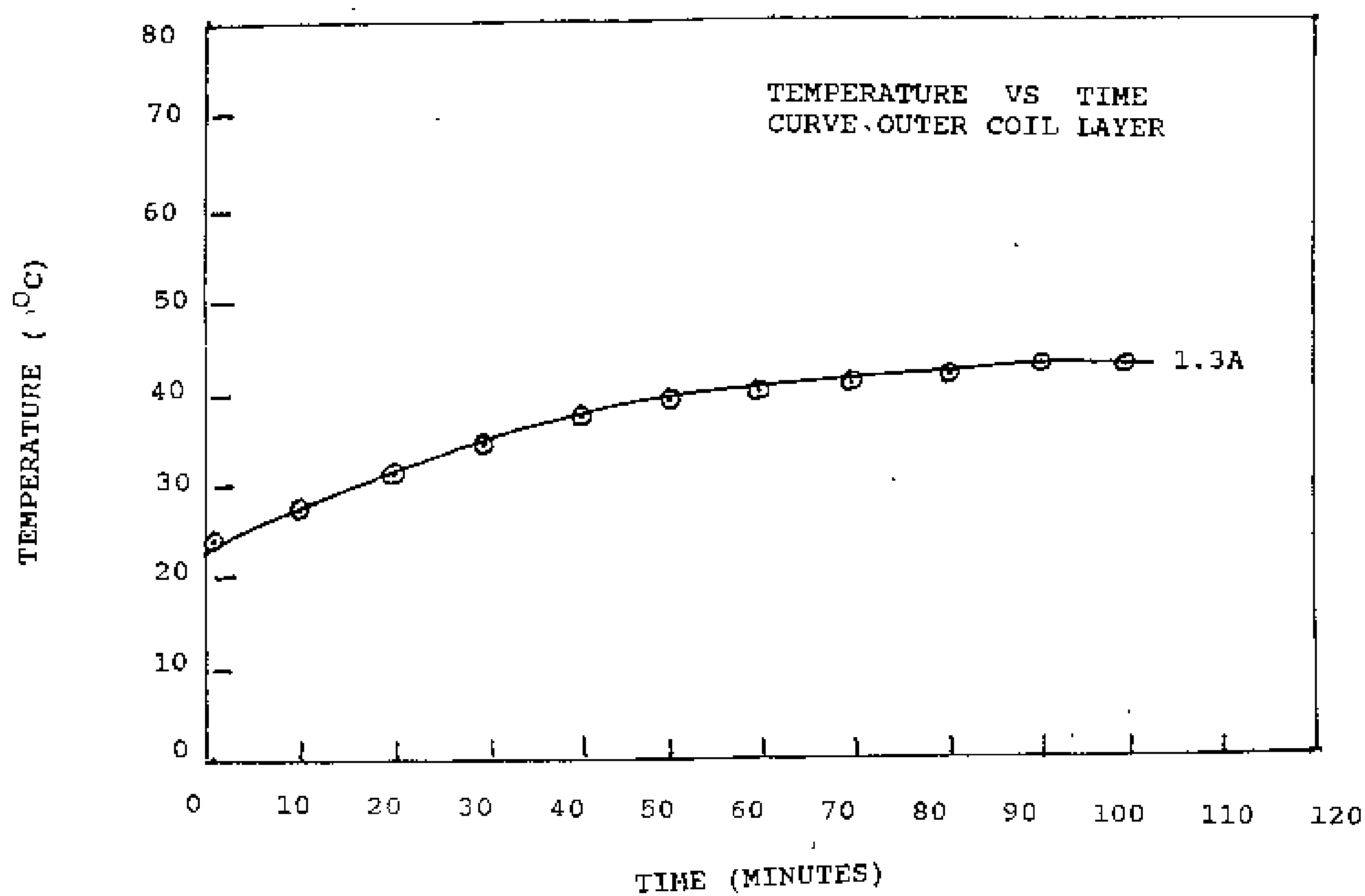


FIG. 5.32 VARIATION OF TEMPERATURE WITH TIME IN THE OUTER LAYER OF THE EXCITATION COIL AT CURRENT 1.3 A.

TABLE - 5.33

DIFFERENTIAL TEMPERATURE BETWEEN INNER AND OUTER LAYERS AT CURRENT 2 AMP. AND ITS VARIATION WITH TIME

THERMO-COUPLE : COPPER-CONSTANTAN

Room Temperature : $31^{o}C$

Current Value : 2.0 Amp.

HOURS	TIME-INTERVAL IN MINUTES(T)	THERMO-VOLTAGE mV	DIFFERENTIAL -TEMPERATURE $0^{o}C$( )
12:00	00	00	00
12:15	15	0.06	01.1
12:30	30	0.12	02.8
12:45	45	0.14	03.5
01:00	60	0.22	04.8
01:15	75	0.31	05.9
01:30	90	0.33	06.5
01:45	105	0.37	07.00
02:00	120	0.39	07.5
02:15	135	0.40	07.7
02:30	150	0.42	08.00
02:45	165	0.43	08.25
03:00	180	0.44	08.5
03:10	190	0.45	08.75
03:15	195	0.46	08.8
03:20	200	0.46	08.8

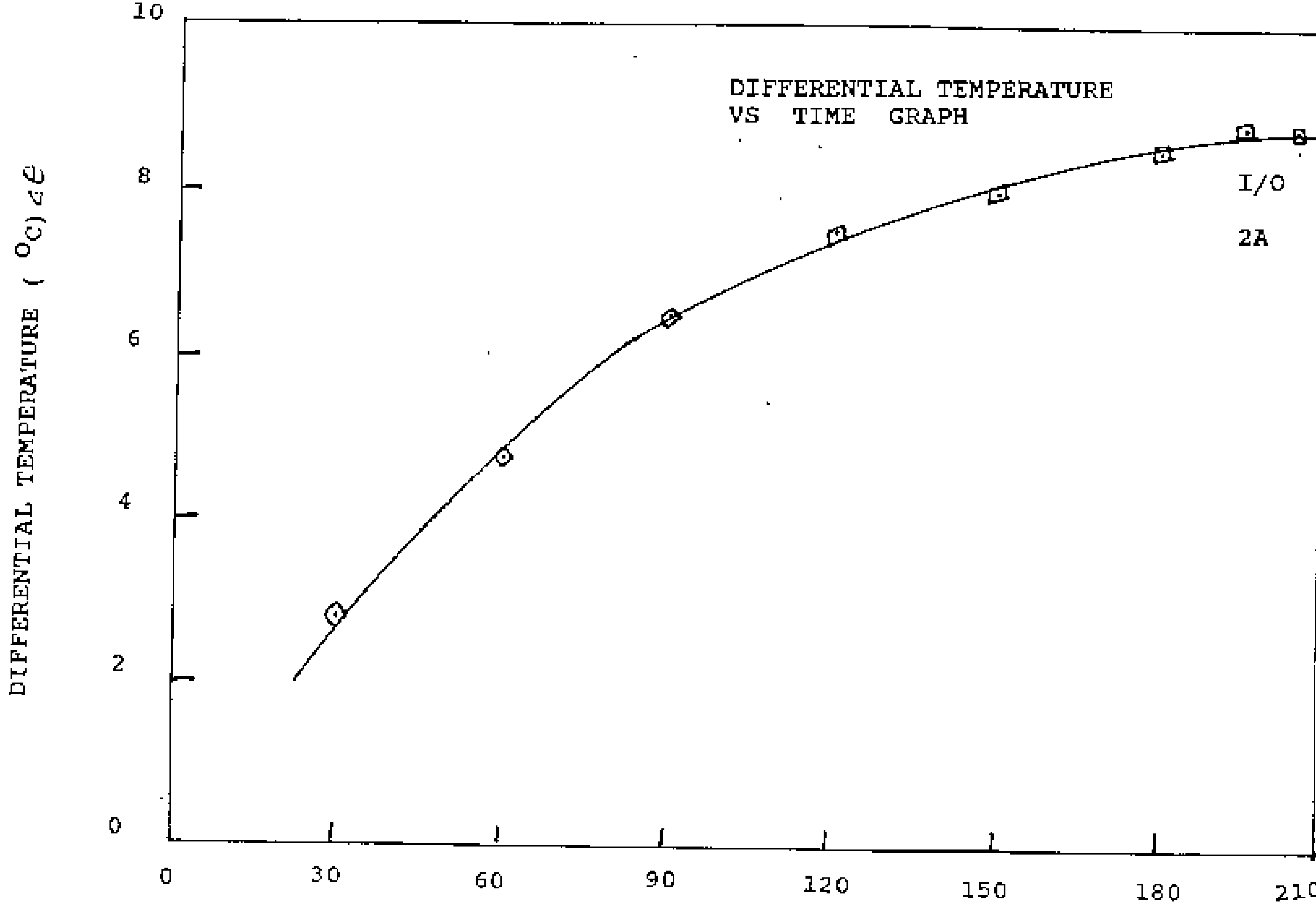


FIG. 5.33 DIFFERENTIAL TEMPERATURE BETWEEN INNER AND OUTER LAYERS AT CURRENT 2 A AND ITS VARIATION WITH TIME.

TABLE - 5.34

DIFFERENTIAL TEMPERATURE BETWEEN INNER AND MIDDLE LAYERS AT CURRENT 2 AMP. AND ITS VARIATION WITH TIME

THERMO-COUPLE : COPPER-CONSTANTAN
Room Temperature : 31°C
Current Value : 2.0 Amp.

HOURS	TIME-INTERVAL IN MINUTES (T)	THERMO-VOLTAGE mV	DIFFERENTIAL -TEMPERATURE 0°C( )
11:00	00	00	00
11:15	15	0.04	0.50
11:30	30	0.04	0.50
11:45	45	0.04	0.50
12:00	60	0.04	0.50
12:15	75	0.04	0.50
12:30	90	0.04	0.50
12:45	105	0.04	0.50
01:00	120	0.05	0.70
01:15	135	0.05	0.70
01:30	150	0.05	0.70
01:45	165	0.055	0.75
02:00	180	0.055	0.75
02:05	185	0.06	1.00
02:10	190	0.06	1.00
02:15	195	0.06	1.00
02:20	200	0.06	1.00
02:25	205	0.06	1.00

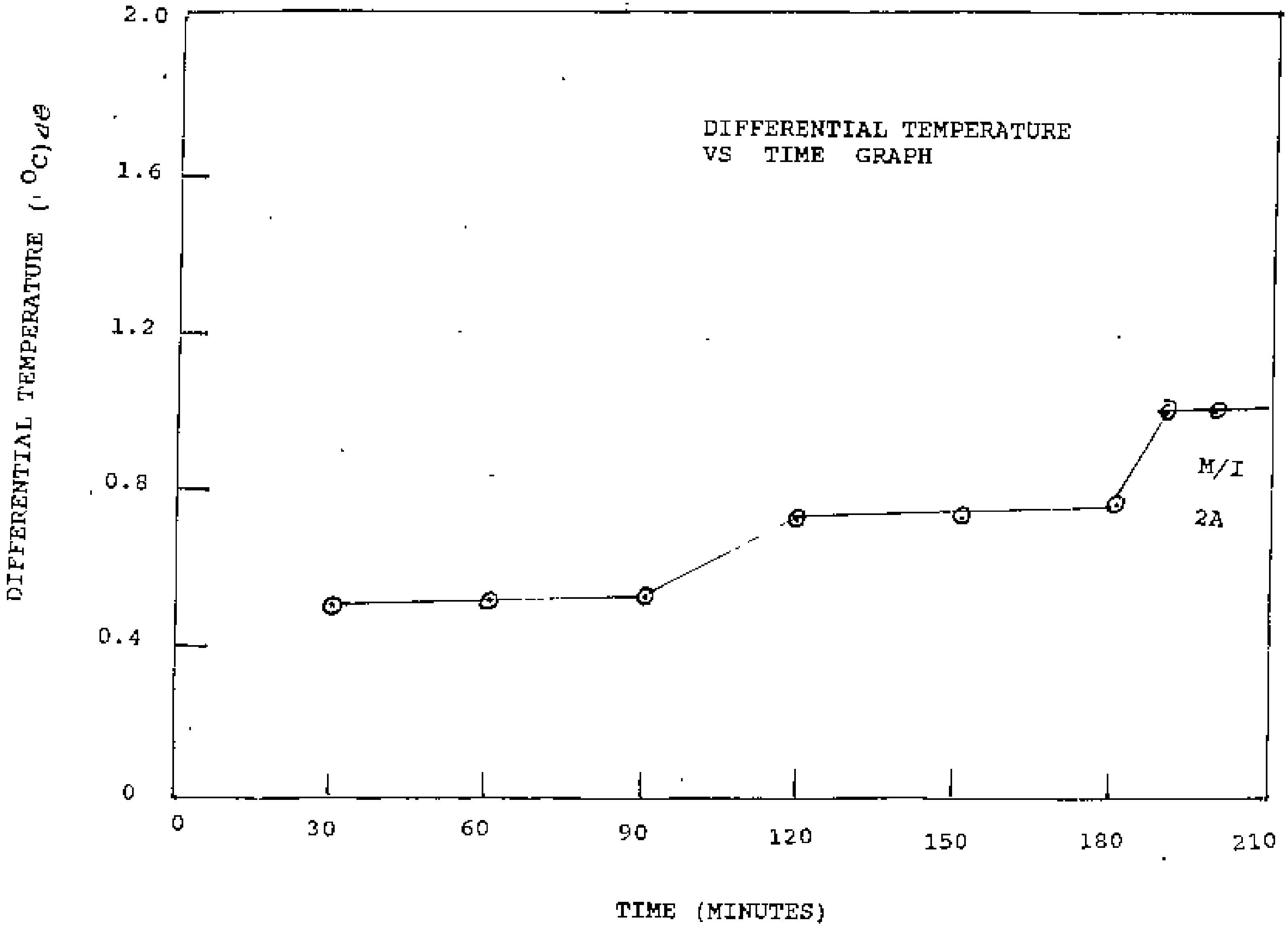


FIG. 5.34 DIFFERENTIAL TEMPERATURE BETWEEN INNER AND MIDDLE LAYERS AT CURRENT 2 A AND ITS VARIATION WITH TIME.

TABLE - 5.35

DIFFERENTIAL TEMPERATURE BETWEEN OUTER AND MIDDLE LAYERS AT CURRENT 2 AMP. AND ITS VARIATION WITH TIME

THERMO-COUPLE : COPPER-CONSTANTAN

Room Temperature : 31°C

Current Value : 2.0 Amp.

HOURS	TIME-INTERVAL IN MINUTES (T)	THERMO-VOLTAGE mV	DIFFERENTIAL -TEMPERATURE 0°C ( )
10:00	00	0.00	00
10:15	15	0.06	01
10:30	30	0.12	02.7
10:45	45	0.14	03.5
11:00	60	0.22	04.8
11:15	75	0.32	06.0
11:30	90	0.34	06.7
11:45	105	0.38	07.2
12:00	120	0.39	07.9
12:15	135	0.43	08.5
12:30	150	0.44	08.9
12:45	165	0.44	08.9
01:00	180	0.45	09.0
01:05	185	0.46	09.2
01:10	190	0.47	09.3
01:15	195	0.47	09.3
01:20	200	0.47	09.3

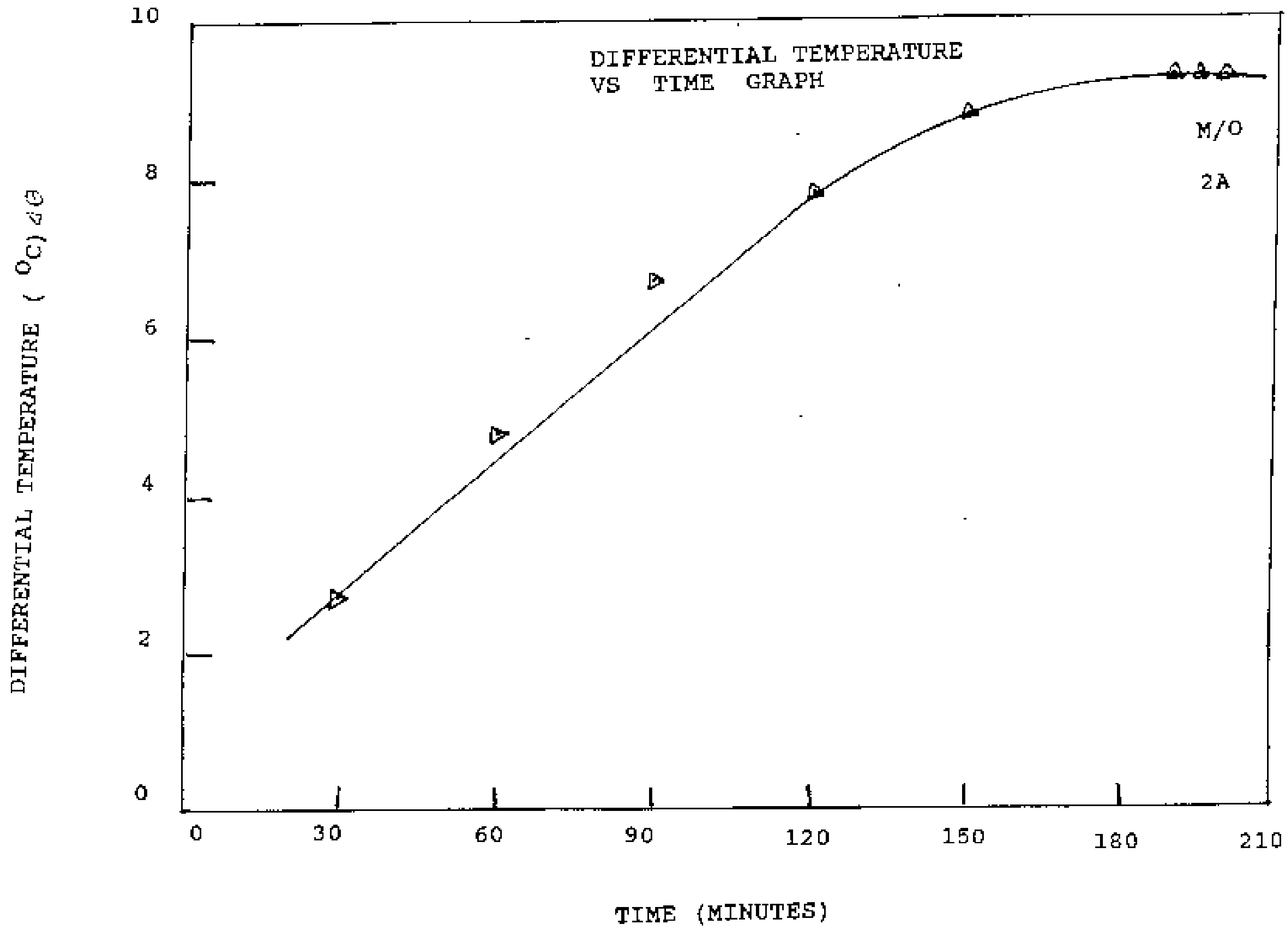


FIG. 5.35 DIFFERENTIAL TEMPERATURE BETWEEN OUTER AND MIDDLE LAYERS AT CURRENT 2 A AND ITS VARIATION WITH TIME.

5.5 RESIDUAL FIELD MEASUREMENT

In order to study the remanence of the electromagnet, the residual field was measured first energising the magnet by a maximum current and then dropping the current to zero. At zero current the residual field was also measured at different pole-gaps. The field varied between 12 gauss to 61 gauss. When for all practical magnetic measurements fields of the order of kilo-gauss are required, residual fields remaining, however, will not affect any measurement. The residual field can even be minimised if more carbob-free iron is available. Tables 5.36 and 5.37 show the residual field chart at 0.4A and 1.3A respectively and figures 5.36 and 5.37 show the results in graphical forms.

TABLE - 5.36

RESIDUAL MAGNETISM PRESENT IN THE ELECTRO-MAGNET AT CURRENT 0.4 AMP. AND ITS VARIATION WITH POLE GAPS

POLE GAP L (cm)	RESIDUAL FIELD B_R (Gauss)
1.0	59.00
1.5	49.50
2.0	33.50
2.5	22.50
3.0	15.50
3.5	11.50

TABLE - 5.37

RESIDUAL MAGNETISM PRESENT IN THE ELECTRO-MAGNET AT CURRENT 1.3 AMP. AND ITS VARIATION WITH POLE GAPS

POLE GAP L (cm)	RESIDUAL FIELD B_R (Gauss)
1.5	61.00
2.0	54.00
2.5	50.00
3.0	22.00
3.5	18.00

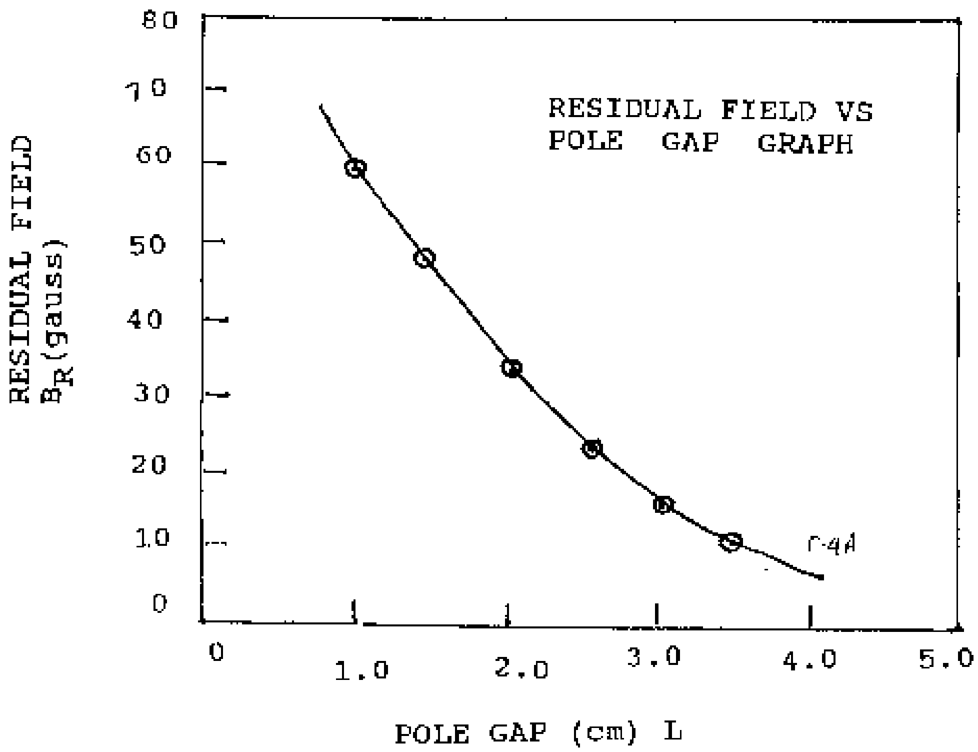


FIG. 5.36 VARIATION OF RESIDUAL MAGNETISM WITH POLE GAP AT 0.4 A.

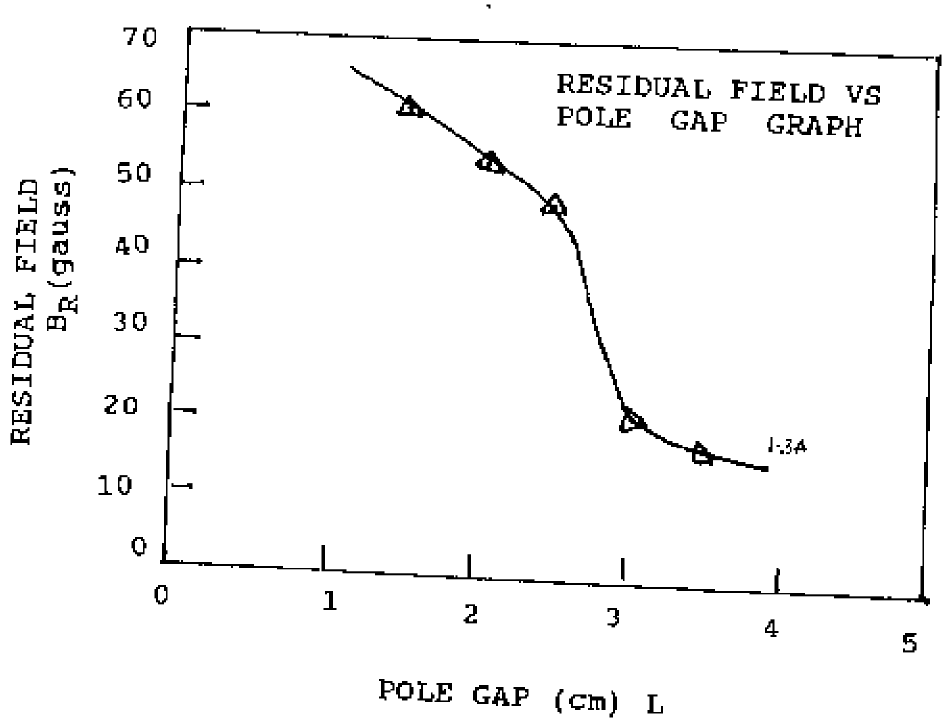


FIG. 5.37 VARIATION OF RESIDUAL MAGNETISM WITH POLE GAP AT 1.3 A.

5.6 COOLING

Air cooling has been used in the electromagnet. The magnet could well be employed to any laboratory measurement purposes involving not too high field. The magnet has capacity to draw currents around 30A without damaging the wires and their insulation. In that case higher fields will be obtined but water-cooling will be necessary against excessive temperature rise.

The electromagnet in its present set up can compete with commercial electromagnets. Over 8.5 kilogauss field have been generated and the percentage loss of the field is insignificant. No faults and inclusions have been noticed in or near the surface of the pole-tip faces during hours long run of the electromagnet. And so experiments involving good accuracy can be carried out using this electromagnet.

CHAPTER - 6

IRON - SILICON ALLOYS

CHAPTER - 6

IRON - SILICON ALLOYS

6.1 INTRODUCTION

Alloys of iron and silicon are of prime importnce in the electrical industry which consumes hundreds of thousands of tons annually. The low-percentage alloys, containing 1.5 - 3.5% silicon, are used primarily for motors, generators and relays. The higher-percentage alloys 3-5%, are used for high-efficiency motors and for power tranformers.

Outside electrical industry, silicon is used as a minor constituent in the manufacture of many steels. Silicon-cast iron, containing about 15% silicon and upto 1% each of carbon and manganese, is used as a corrosion-resistant material in the chemical industry.

6.2 HISTORY OF IRON-SILICON ALLOYS

The usefulness of iron-silicon alloys was made known to the world as a result of researches began by Hadfield. In 1882 he noticed [4] the hardness of an alloy, accidentally produced, containing over 1.5% silicon. The mechanical properties of alloys containing various amounts of silicon were investigated in an attempt to find useful applications of the material. The results were published in 1889[5]. This led to many investigations by others, and especially to the report on magnetic properties by Barrett, Brown and Hadfield in 1900[61, 62, 63].

Although the magnetic properties and resistivity of some alloys had previously been measured by J. Hopkinson[7], the carbon content obscured their good qualities and the paper published in 1900 actually set the stage for commercial use. It stated that the addition of 2-2.5% silicon increased the magnetic softness to such an extent that the coersive force was about one-half that of the standard iron employed at that time in transformer cores. This report stimulated Gumlich[8] and the Physikalisch-Technische Riechsanstalt to foster production in Germany and the material was produced in quantity by German firms in 1903. The first commercial production in the United States was made in the same year[9]. The improvement over the iron previously used was fourfold : (1) the permeability was increased, (2) hysteresis loss decreased, (3) the eddy-current loss was decreased because of the higher resistivity and (4) there was no deterioration with time.

After the original work of Barrett, Brown, and Hadfield improvements in laboratory specimens were due mainly to the work of Gumlich[18G2] in Germany, and Yensen[10], [10] in the United States. Pioneer work on the effect of cold rolling was reported by Goss[11] in 1934. All these researches were followed by improvements in the commercial product.

6.3 RECENT WORK ON Fe-Si ALLOYS

The energy-saving requirements and competitiveness of alternative materials pushed the producers of conventional grain-oriented silicon iron to develop new steels with improved magnetic properties. The quality of the steels, the relative lower cost of the conventional materials and parallel research effort addressed to simplify this production practice appear as the main tools of steel industry in order to satisfy the new generations of electrical transformer requirement.

An important physical factor influencing the core losses and in particular that part which is known as "Anomalous loss" is strictly related to the spacing of the magnetic domains nucleating in the sheet under the application of an external field[2]. A particular technique which can increase artificially the domain wall density in the sheet is currently applied. It consists in producing zones of crystallographic discontinuity by the creation on the surface of the sheet of very strong localised stresses or zones of real physical discontinuity. In these places the magnetic domains incline to nucleate randomly having a smaller size than those present in the pre- existing grain.

Another set of parameters affect mainly the control of the texture in various steps of manufacturing process[3]. Recently laboratory test has been carried out on Si 3% sheets of thickness less than 0.1mm having exceptionally high induction values (>1.96T) and low core losses and they have been found equivallent to best amorphous alloys.

Fe based alloys containing about 6.5 wt% Si have a potential application in magnetic devices but too brittle to be worked conveniently. In recent years long and flexible high silicon alloys ribbons with soft magnetic properties have been obtained by rapid solidification. The details are reported in the literature[14].

The rapidly solidified ribbons were annealed in a dynamic vacuum ($5X10^{-5}$mmhg). Specimens were first recrystallised at $1050^{o}c$ for two hours and then cooled outside the furnace to room temperature.After that they were annealed at $700^{o}c$ for various times and again cooled outside the furnace.

In the asi-quenched state, the coercive force, hysteresis loss, measured at a maximum induction of 1 tesla where H_c = 0.61 oe, W_h = 1.24 w/kg. The average grain size was about 10 micrometre in diameter.Oxide particles mainly on the airside of ribbons could be observed. The recrystallisation at $1050^{o}c$ for two hours leads to the following values :-

H_c = 0.21oe

W_h = 0.43 w/kg.

Grain size = 30 micrometre

It was found by Shimanaku[15] that there is not too sharp minimum in the core-loss as a function of grain size in the 0.05-0.2mm range. It was theoretically shown that the most harmful inclusion size was in the range of domain wall size 0.1 micrometre [16].

Silicon-Iron alloys suffer localised strains due to the presence of domains which naturally occur to minimise the force energy in the material. When external mechanical stresses are applied, the energy distribution of the steel is altered and the magneto elastic energy is reduced for the presence of tension along the direction of applied field. The resulting change in domain direction can cause a large magnetostriction[17], which causes noise or vibration in electrical cores. G.H. Shirkoohr and A.J. Moses of University of Wales college of Cardiff, U.K. made (3M;83(1990)177-78) measurements on non-oriented electrical steels and their investigations showed that under applied uniaxial stress magnetostrictive properties were similar to those observed for grain oriented steels although the stress sensivity was not so great. The higher harmonics of magnetostriction are small and not stress sensitive so they should not produce any problem in electrical machines.

The excellent soft magnetic properties of 6.5% Si-Fe alloys are widely known for its zero magnetostriction coefficient [18]. However, the commercial production of 6.5% Si-Fe sheets by cold rolling had been believed to be impossible because of its brittleness while steel below 3% Si content is ductile and easy to cold roll. Y. Tanaka, et al of Steel Research Centre, NKK Corpn., in a recent paper [3M83(1990)375-376] reports that NKK corporation, Kawasaki, Japan has succeeded the world's first commercial production of 6.5% Si-Fe sheets by two different methods :- The rolling method and CVD (Chemical Vapour Deposition) method[19]. Due to the productivity, the steels of thickness range between 0.5 and 0.35 mm are manufactured by the rolling method and those of thickness range between 0.35 and 0.1 mm are manufactured by the CVD method.

The shapes of the sample for the measurements of dc and ac magnetic properties are rings and single sheets. The dc and ac magnetic properties were measured by computer controlled dc and ac BH- loop tracer. The magnetostriction were measured by strain gauge method in the magnetic field upto 80KA/m.

For a 0.5mm thick sample, the maximum relative permeability is $62X10^3$ and coercive force is 6A/m. There are very low iron loss because of low eddy current loss caused by about twice as much resistivity as 3% Si-Fe.

The magnetostrictions are quite small at any direction which suggests that it would be possible to reduce the core noise even at the corner of a transformer core or the rotational magnetic flux parts.

6.5% Si-Fe alloys are euitable materials for High Speed Motor and Low Noise Transformers. Mochizuki et el[20] fabricated high speed induction motor with 6.5% SiFe sheets, the core loss of this motor was reduced by 35% and the efficiency was improved from 85.3% to 88.4% compared to that of conventional 3% si-Fe sheete.

The noise level of the high frequency transformer using 6.5% Si-Fe sheets is much lower than that of Go's in addition to core loss of the former is also much lower than that of the latter. These drastic improvements of the Noise-level and the core-loss mean that it is possible to operate at higher flux density which suggests that the size of the transformer becomes small. The obtained results suggest that 6.5% Si-Fe sheets have excellent soft magnetic properties and are effective for high frequency use such as a high speed motor and low noise, low loss high frequency tranformers.

6.4 METHODS OF PRODUCTION

Commercial iron-silicon alloys are usually melted in the basic open hearth furnace, although occasionally electric arc or induction furnaces are used.

In all cases a careful selection of scrap and rigid control of furnace conditions, particularly during refining period, are important. Recently the introduction of oxygen during the refining operation has been found to have advantages, as pointed out by Slottman and Lounsberry[24]. In the basic open hearth furnace the alloying is done by adding ferro-silicon in the ladle. When the higher ferro-silicons such as 90% are used, the increased heat caused by the exothermic reaction makes it necessary to hold the material in the ladle for a considerable length of time before pouring. The pouring temperature must not be too high, for iron-silicon alloys have a tendency to develop large shrinkage cavities or pipe in the ingot.

After casting and solidification of the ingots, which are often over 5 tons in weight, they go to soaking pits and then to the blooming or breakdown mills at 1200-1250^{o}c. The rolling speed and the per cent reduction per pass differ only slightly from the processes normally used for low-carbon steel products. Some higher temperatures are permitted and slow cooling of the thick sections is desirable when the silicon content is over 2.5% in order to avoid internal rupturing from cooling stresses.

The final thickness of electrical sheet is attained either by hot rolling or cold rolling.

A recent development in the United States is the use of a final cold rolling or a series of cold reductions with intermediate anneals to final thickness. Cold reduced materials fall into two main groups :- (1) isotropic materials which have almost the same magnetic characteristics as the hot rolled sheets and (2) anisotropic or grain oriented materials.

Materials having the best magnetic properties are produced today by cold rolling and annealing in such a way that the material is recrystallised with favourable crystal orientation and purified at the same time.

6.5 MAGNETIC SATURATION

Magnetisation at saturation at room temperature is well established as the result of many determinations, among which only those of Gumlich[22] and Fallot[23] are very important.

Saturation has been determined by Fallot at $0^{o}K$ by extrapolation from $110^{o}K$ and H=16000 oersted and the curve of Fig.6.1 shows the results. The broken line indicates the effect expected if the silicon behaves simply as a diluent, without effect on the moment of iron atoms; the initial tandency of this line shows that silicon at first acts in this manner and its continuing departure means that with increasing silicon content the average atomic moment of the iron atoms is reduced.

A substantial amount of aging may occur in low-silicon sheet and perceptible aging may occur in any commercial silicon alloy if impurities occur in certain proportions."Aging" here means a

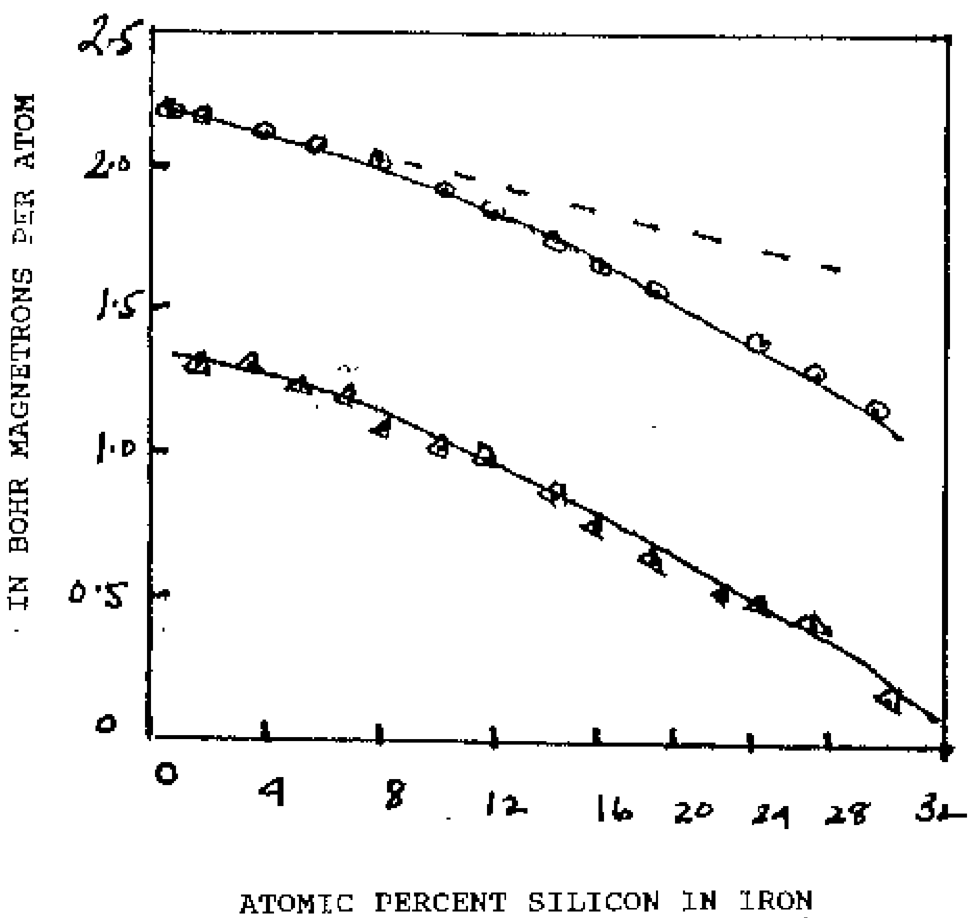


FIG. 6.1 VARIATION OF BOHR MAGNETRONS PER ATOM WITH ATOMIC PERCENT SILICON IN IRON

change of permeability or core loss with time and invariably the change is a deterioration. The standard test for aging is to maintain at 100^{o}C for 600 hours and note the resulting increase in core loss at room temperature. The behavior of alloys with a given silicon content may be quite erratic because of variable amounts of impurities they contain but losses in alloys containing 0.5-1.0% silicon may increase 50 and 20% respectively.

Alloys containing 1.5% silicon are generally considered to be non-aging and are so if they are low in carbon and are slowly cooled, but an increase of loss of 5 or 10% with time is not uncommon in the usual product.

CHAPTER - 7

MAGNETISATION MEASUREMENT

CHAPTER - 7

MAGNETISATION MEASUREMENT

7.1 The magnetisation measurements of Iron-Sample taken from the same material as used for the yokes and poles of the Electromagnet and also of iron-silicon alloys have been done by vibrating Sample Magnetometer. This instrument is installed at Magnetic Material Division, Atomic Energy Centre, Dhaka (AECD).

The magnetisation measurement of Iron-Sample is chosen to find the magnetisation process of the material and also its saturation magnetisation. These magnetic characteristics are important for determining the performance of this material as it has been used in yoke and poles construction.

A commercial sample of iron-silicon alloy is chosen for magnetisation measurement to look at saturation magnetisation and to compare with that of iron-sample.

7.2 A BRIEF DESCRIPTION OF VSM

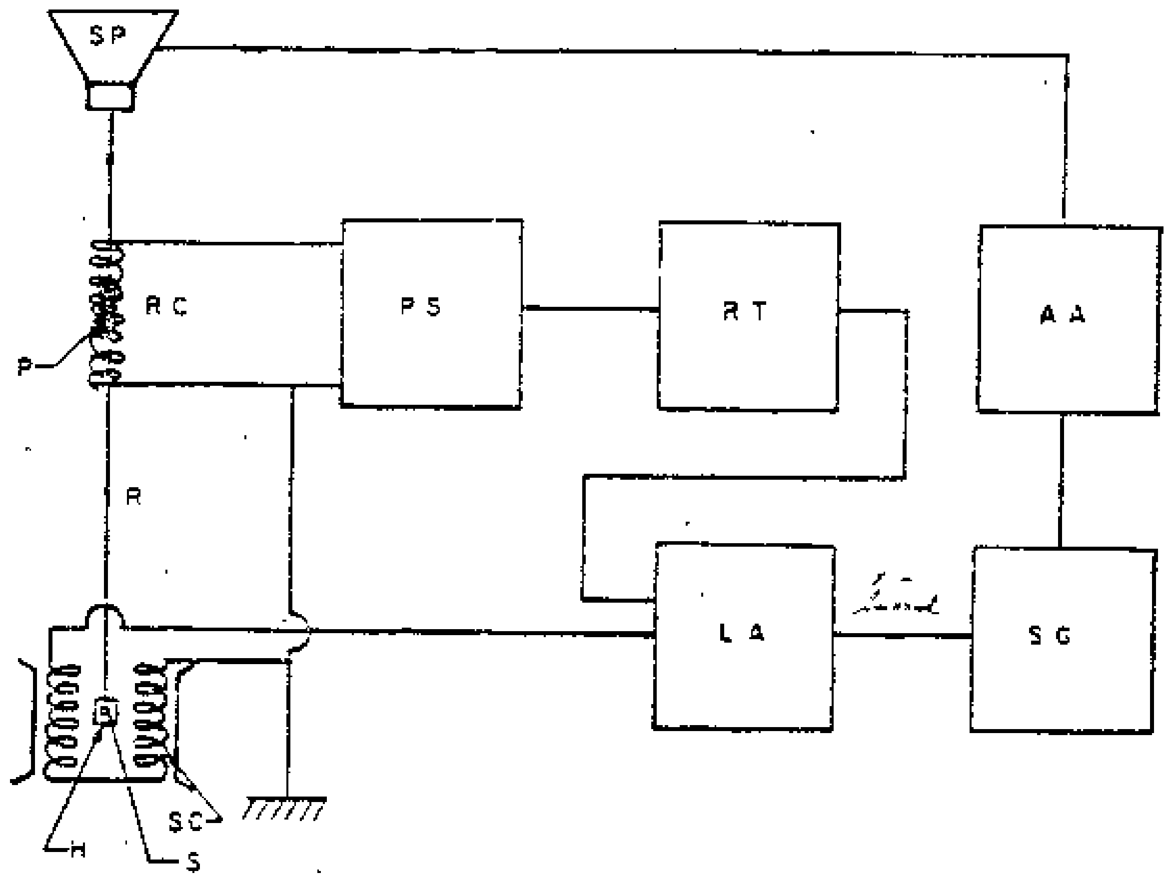
The vibrating sample Magnetometer is a highly sensitive and versatile equipment for measuring magnetisation of small sample very accurately. It was first invented by Van Oster-hout' in 1956. In the same year another VSM was constructed by Simon Foner[24] independently. Because of some new and extra facilities of Foner's insturment, it is largely used in laboratories and known as Foner type Magnetometer. The main aspects of a Foner type VSM are given below.

7.3 THE PRINCIPLE

A schematic diagram of the VSM is given in figure 7.A and in figure 7.B. Photograph of instrument is also shown.

The signal generator SG feeds a sine-wave of 80 Hz frequency to the audio amplifier AA. The audio-amplifier drives the speaker SP. The output of the signal generator is also connected to the reference Channel Input of the lock-in amplifier LA. The drive-rod assembly R tightly coupled to the vibrating paper cone of the epeaker vibrates in a vertical direction along its length. The amplitude of vibration may be varied at will by changing the gain of the audio amplifier. A permenent magnet (BaO, 6Fe_2O_3) of cylindrical shape is fitted to the drive-rod at its lower end with the help of a sample holder H. Two cylindrical sample coils SC with their axes kept vertically placed on oppoeite sides of the sample and along the line joining the centres of the pole-tips (N.S) of the electro-magnet. They are connected in series opposition and the net output signal is connected to the lock-in-amplifier through a shielded cable. This pair of coils is referred as the sample coil system. Another pair of co-axial coils RC also connected to each other in series opposition is placed symmetrically around permanent magnet P. This coil pair is the reference coil system.

As the drive-rod assembly is vibrated with a particular frequency and amplitude the sample S induces a signal of the same frequency in the sample coil system. This signal is proportional to the dipole-moment of the sample. Ae the field in the pole-gap



LEGENDS :

SC — Sample – Coil System
SG — Signal generator
AA — Audio Amplifier
RT — Ratio Transformer
LA — Lock-in-Amplifier
PS — Phase Shifter
RC — Reference coil system
R — Drive-rod assembly
H — Sample Holder
P — Permanent magnet

FIG. 7.A Schematic diagram of the electronic system of the V.S.M.

is gradually increased by increasing the current through the electro-magnet, the sample becomes increasingly magnetised and induces a larger signal in the sample coil system. The process is continued till saturation magnetisation is reached.

This signal directly goes to one of the inputs of the lock-in-amplifier. Similarly another signal of the same frequency is induced in the reference coil system due to vibration of the permanent magnet P. Since the moment of the magnet is fixed, this signal is also of fixed amplitude for a particular frequency and vibration amplitude. This eignal is termed as the reference-signal and it is first fed to a unity gain phase shifter unit. The phase shifter, capable of continuously changing the phase from 0^o to 360^o, is used to bring the reference signal in phase with the sample signal.

From the phase-shifter, the reference signal passes on to the decade ratio transformer RT of constant Input Impedence. The output of thie transformer then goes to the other Input of the lock-in-amplifier. The Output to Input ratio of the decade transformer can be accurately varied from 10^{-8} to 1. By turning various knobs of the decade transformer, the amplitude of its output is made equal to that of the sample signal. The lock-in-amplifier is operated in the differential Input mode and is used as a null detector.

When the eample signal and the output signal of the decade transformer are of equal amplitude and are in the same phase, d.c. meter of the lock-in-amplifier gives a null reading. The whole electronic system then correctly measures the ratio of the sample signal to the reference signal. Since the sample S and the permanent magnet P are vibrated with the drive-rod assembly the sample signal and the reference have a direct phase and amplitude relationship. As a result the ratio of the sample signal to the reference signal is proportional to the magnetic moment of the sample.

7.4 DESCRIPTION OF MECHANICAL PARTS

The various mechanical parts of the VSM are described in detail in figure 7.B.

The base B of the vibrating Sample Magneto-Meter is a cicular brass plate of 8 mm thickness and 250 mm diameter. A brass tube T of 25 mm outer diameter and 0.5 mm thickness runs normally through the base such that the axis of tube and the centre of the plate coincide. The tube extends 60 mm upward and 24 mm downward from the base. There is a vacuum port on the lower part of the tube 1240 mm below the base. The lower end of the tube T is joined to a brass extension tube L by a threaded coupling and O'ring Seal. Another thin tube K made of german silver and of 8 mm inner diameter runs through the extension tube L from the coupling point C to about 50 mm below the same position. Above the base there is a hollow brass cylinder M of 180 mm length and 130 mm inner diameter and having 40 mm wide collors at its both ends. The lower collor sits on a O'ring seal which is situated in a circular groove in the base plate.

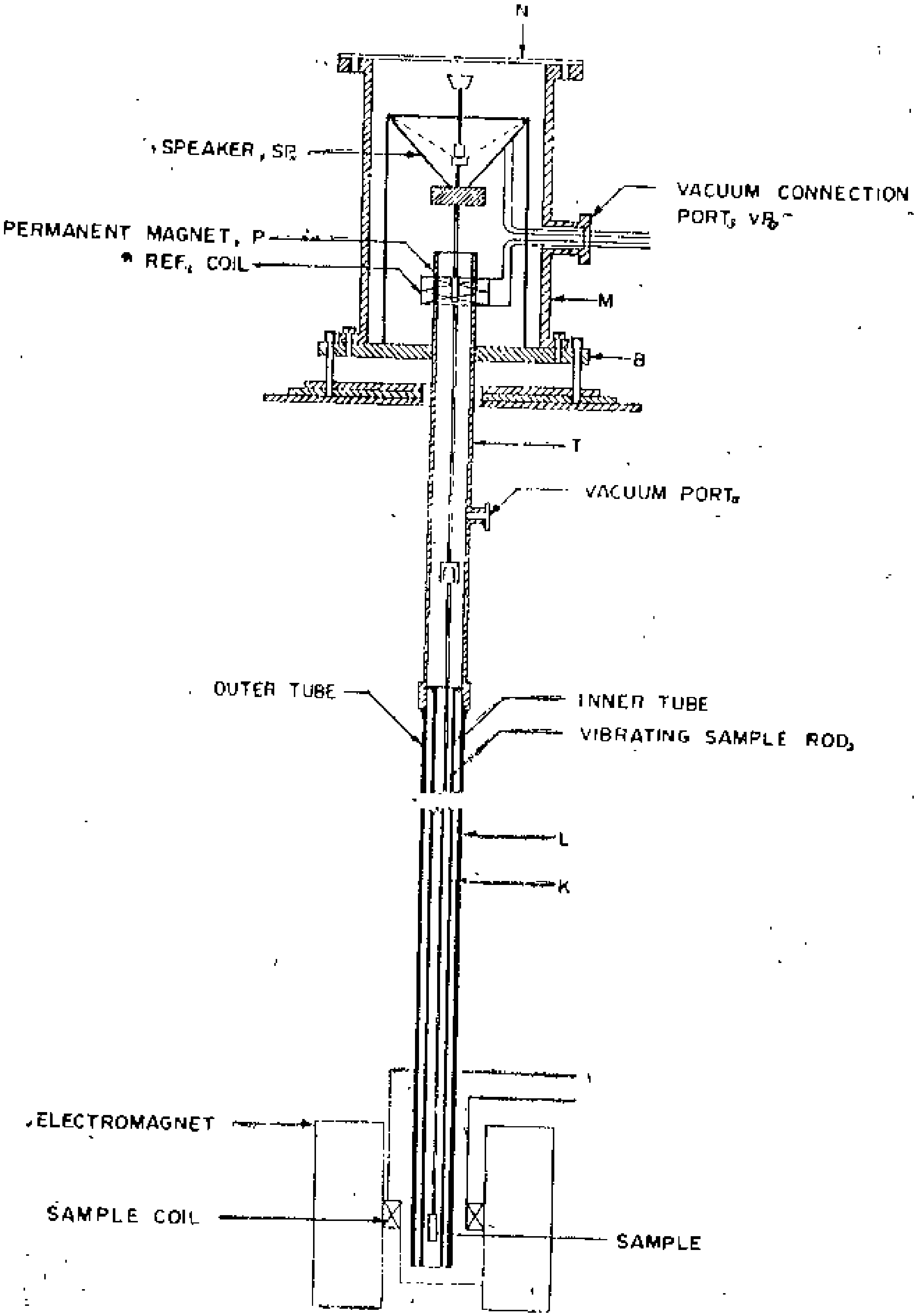


FIG. 7.B MECHANICAL CONSTRUCTION OF THE V. S. M.

On the upper collor there rests an aluminium top N with an O'ring seal. The brass cylinder M has a side port VP. There is again a brass tube of 41 mm diameter and 43 mm length. The port has a collor at the end away from the cylinder. A perspex vacuum feed-through is fitted at its end with O'ring seal. This port is connected to the cylinder by soft-solder.

Electrical connections from the audio amplifier to the speaker and from reference coil system to the phase shifter are taken via the perspexfeed-through.

By connecting the vacuum port of the tube T to a vacuum pump, the sample environment can be changed. The speaker SP is fitted 25 mm above the tube T with the help of four brass stands. The lower ends of the stands are srewed on the tops of the stands. The speaker has a circular hole of 10 mm diameter along the axis of it. An aluminium disc having female threads in it is fitted to the paper-cone with araldite. The aluminium connector having male thread on it and attached to the drive rod assembly fits in the aluminium disc and thus the drive rod assembly is coupled to the speaker. The drive rod aseembly consists of two detachable parts which are joined together by means of aluminium threaded connector. Each part is a thin pyrex glass tubing of 4 mm diameter. The upper part has a small permanent magnet P situated 100 mm below the aluminium connector attached to it. At the lower end of the drive-rod assembly a perspex sample holder quite thin wall is fitted tightly with the sample it it. A few perspex spacers are also attached to the drive-rod throughout its length. The spacers guide the vibration of the sample only in the vertical direction and stops side-wise vibration or motion. The total length of the drive rod assembly is 920 mm.

The base plate of the VSM rests on three levelling screws above a brass frame which in turn rests on a iron angle bridge. The bridge is rigidly fitted to the side wall of the room. The brass frame is provided with arrangements with the help of which it can be moved in two perpendicular directions in the horizontal plane.

The levelling screws are used to make drive rod vertical and to put the sample at the centre of the pole-gap between the sample coils. The sample can be moved up and down by levelling screws.

7.5 SAMPLE AND REFERENCE COILS

Both the sample coil system and the reference coil system are a double coil system. The reference coil system consists of two coils wound oppositely side by side on the two grooves of a former. The former is made of bakelite. Each coil is 4 mm long, 2 mm thick and its inner diameter is 25 mm. The wire is superenamelled BICC copper wire of 0.02 mm diameter. Total number of turns in each coil is 6000. Since the two coils are connected in series opposition the output signal is only due to the vibrating permanent magnet P. Any noise induced in it due to background will be minimum.

The coil system fits over the brass tube T about 25 mm above the base. It is positioned by moving it up and down the tube T while vibrating the magnet so that the output signal is a nice sine-wave. The sample coil SC system is also a two-coils system and each coil is wound on a cylindrical bakelite former. The length of the coil is 6 mm and its diameter is 4 mm. The same super enamelled BICC wire of 0.02 mm diameter has been used in these coils. The number of turns of each coil is 6000 again. The coil stands on a platform of thin bakelite sheet and are equidistant from the nearby pole-tips. The brass tube T passes through the gap in the platform and the sample is at equal distance from the sample coils on opposite sides of it. The sample and sample coils are put on the same horizontal plane visually. The final and optimum position of the sample is obtained by maximising the sample signal.

The signal due to the sample moment induced in the sample coil system is, in principle, given by the relation

$$V_s = K_s \, WA \exp(wit) \, M_s \; . \; . \; . \; . \; . \; . \; . \; . \; . \; . \; . \; . \quad (1)$$

where K_s is a constant dependent on the coil geometry, W is the angular frequency of vibration, A is the amplitude of vibration, M_s the magnetic moment of the sample. The e.m.f. induced in the reference coil is given by

$$V_r = K_r \, WA \exp(wit) \, M_r \; . \; . \; . \; . \; . \; . \; . \; . \; . \; . \; . \; . \; . \quad (2)$$

Taking the r.m.s. values of V_s and V_r it can be seen that the ratio of the two signals is independent of frequency and amplitude. The ratio is

$$V_{ont} = \frac{(V_s)\text{r.m.s.}}{(V_r)\text{r.m.s.}} = \frac{K_s}{K_r} \, \frac{M_s}{M_r}$$

$$\text{or, } M_s = K \, V_0 \; . \; . \; . \; . \; . \; . \; . \; . \; . \; . \; . \; . \; . \; . \quad (3)$$

where K is a constant, since K_s, K_r nd M_r are all constants. Here V_{out} is actually the ratio-Transformer reading.

The coils have been prepared depending mainly on the considerations of (1) maximisation of area-turns, (2) minimisation of size and (3) making the shape compatible to accomodate an one inch diameter tube between them and also to put them as far as possible from the pole-tips.

7.6 CALIBRATION

The calibration of the VSM has been done using a 300 mg spherical sample of 99.9% pure nickel. The sample was made spherical with the help of a sample-shaping device. It was then annealed in helium atmosphere at about 900°C. The ratio-transformer reading is obtained by actual measurements and thus from the relation (3), the value of the calibration constant K is obtained.

7.7 SENSITIVITY OF THE VSM

The sênsitivity of a VSM is usually determined by the signal to Noise ratio. The maximum sensitivity of the lock-in-amplifier is 10 micro volt r.m.s. So the differential method has been used to measure the sensitivity. It is found to be about 10^{-4} e.m.u. It may be mentioned here that the sensitivity of a commercial VSM made by PARC (Princeton Applied Research Corporation), USA is about $5X10^{-5}$ e.m.u.

With the sensitivity so far achieved this VSM can be used for investigation of ferromagnetic, ferrimagnetic and strongly para-magnetic materials at room temperature.

7.8 THE OPERATION OF THE VSM

The sample is fitted to the drive-rod assembly and then positioned at about mid-point of sample coil by eye-estimation. The switches of the electro-magnet power supply unit, the signal generator, the audio-amplifier and phase-shifter are turned on. At least half an hour is needed for the Warm-up of all component units. The frequency of the sine wave from signal generator is set at 80 Hz.

The gain of the audio-amplifier is adjusted to make the output 3 volts peak-to-peak. This drives the speaker. The signal produced in the reference coil-system is found to be 5mV pp. The rod assembly is made vertical by adjusting the levelling screws. About 2A or more current is passed through the electro-magnet depending on the size and material of the specimen. The sample signal alone is first seen on the d-c amplifier of the lock-in-amplifier. The meter reading is maximised by changing the phase of the locking signal in the reference channel. The sample signal is then optimised i.e. maximised by moving the sample in the Z-direction and in the Y-direction and then minimised by moving it in the X-direction.

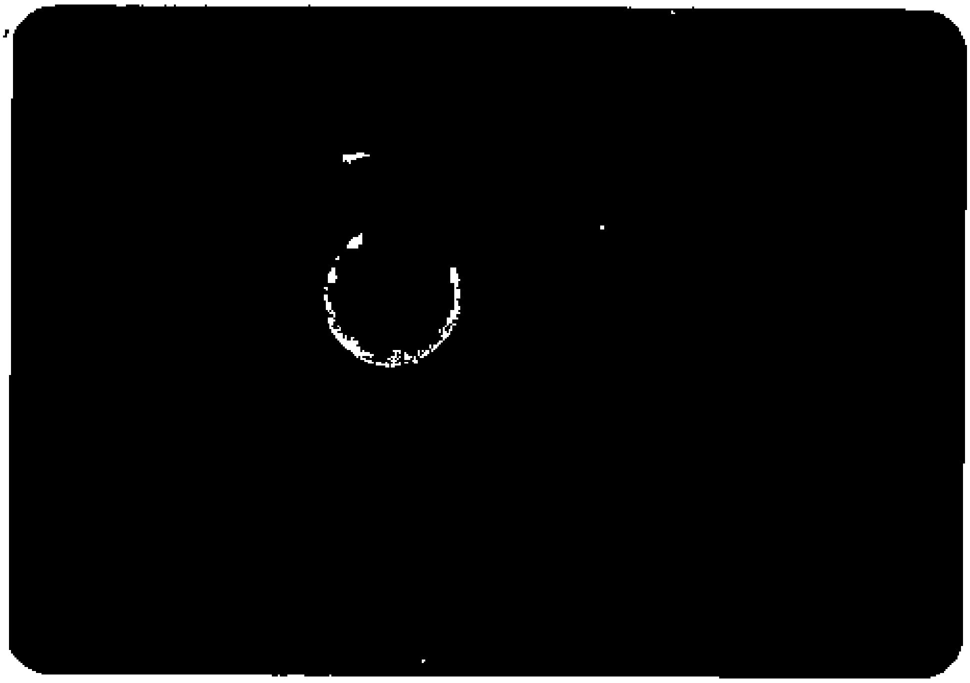
The locking signal in the reference channel is brought in exact quadrature with the sample signal to give a correct null reading on the meter. The two signals are then brought in the same phase to give a maximum reading on the meter to the right. Similarly the reference coil signal is alone seen on the meter. The signal is first brought in quadrature with the locking signal with the help of the external phase shifter in such a manner that it gives a deflection to the left. The lock-in-amplifier is then set in the differential mode. The null reading is obtained by correctly equalising the decade tranformer output with the sample signal. The reading on the decade transformer when multiplied by calibration constant gives the sample moment.

7.9 SAMPLE PREPARATION

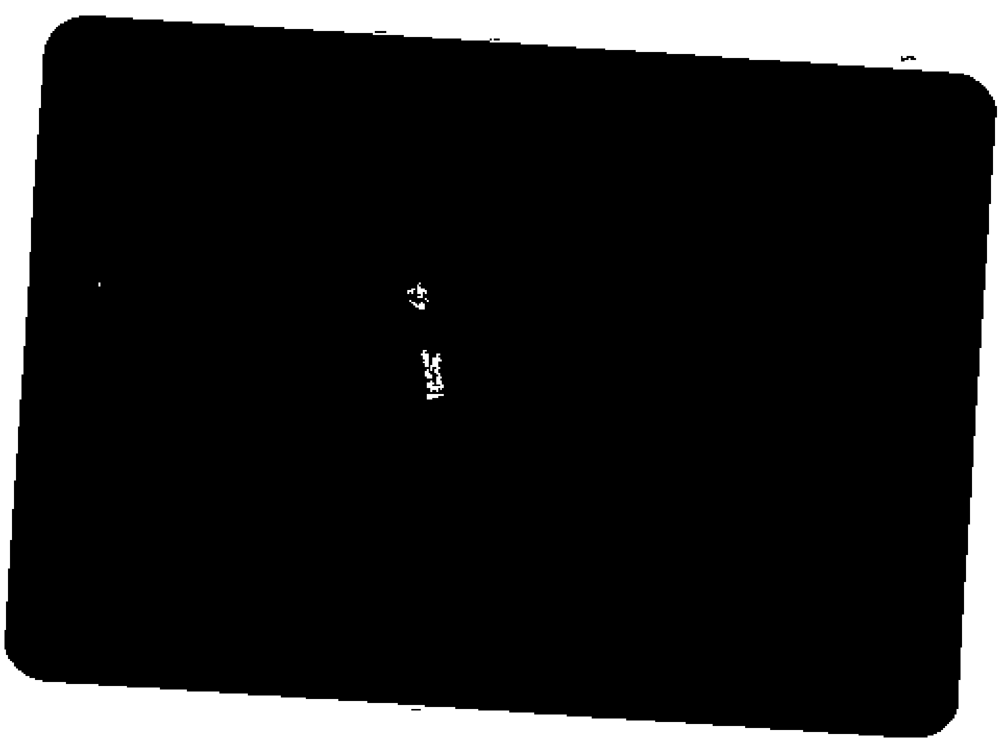
In order to measure the magnetic moment of the material used in the construction of the Electromagnet, a rectangular sheet 20 cm by 15 cm and of roughly 15 mm thickness has been cut apart from the bulk-material. The material is soft-iron having a carbon composition of around 0.08%. It has been prepared in Chittagong Steel Mills according to our specifications. From 20 cm X 15 cm sheet a small square plate of area 25 mm X 25 mm has been prepared using different kinds of metal saws. Since the machine shop of BUET ie not equipped with machines to make thin discs of very small diameter, the sample disc has been made maually. Making discs manually is very time consuming and strenuous. Over ten weeks have been spent to make the discs.

The reduction of thickness of the 25 mm X 25 mm equare sample has been first tried with a polisher, in the Physics Department, BUET. But there is a problem regarding the gripping

DISC SHAPED IRON (0.08%C) SAMPLE



DIA : 3.8 mm



THICKNESS : 0.7 mm

of the sample. A plier is used to hold the sample over the polishing paper. But as the speed of the rotor over which polish-paper is pasted is very high, the sample falls from the plier. Then a pointed nose-plier has been tried. But this technique does not work.

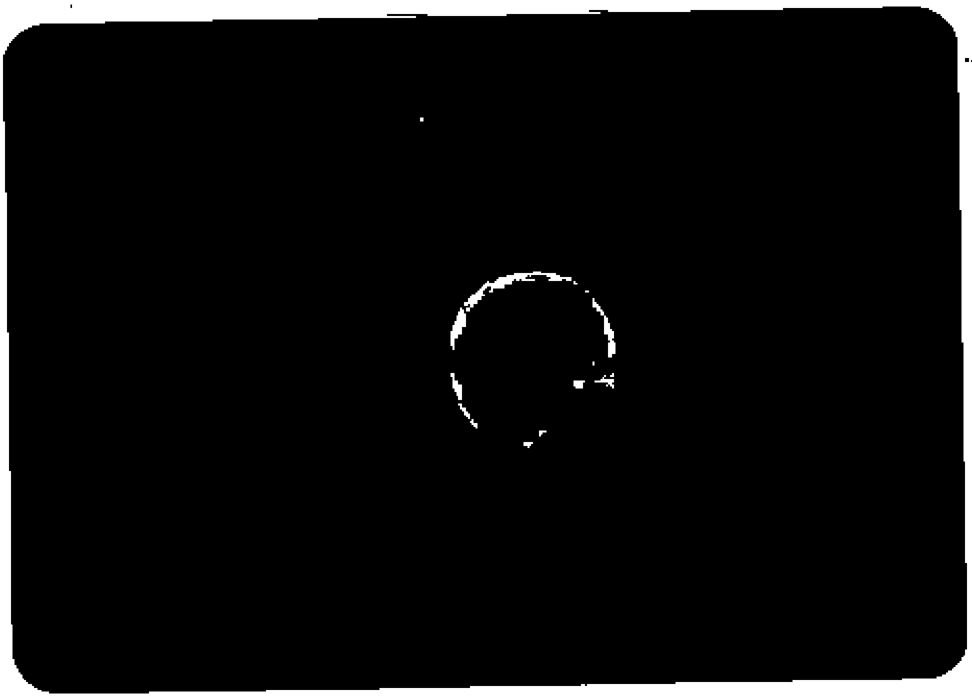
As an alternative method, a sand paper is fixed over a tool. The sample then, is moved over the sand-paper slowly by hand. Every-day over four to five hours the sample has thus been rubbed and the sample is reduced in thickness from 15 mm to 0.75 mm.

Next different cutters have been used to make the sample round. But it has been noticed that the sample gets damaged. So the sample is put between the jaws of a very small vice and to make it circular in shape, the edges are smoothened out by a very fine squared file. This technique worked very well. Finally a disc of mass 65.7 mg., thickness 0.7 mm and diameter 3.8 mm has been prepared.

7.10 IRON-SILICON SAMPLE

In order to measure the magnetisation of the Iron-Silicon alloy, a sheet of the same alloy hae been obtained from a transformer core which is in use at Atomic Energy Centre, Dhaka (AECD). Then a emall square 10 mm X 10 mm has been cut apart. The square-shaped sheet is then polished with sand-paper. After polishing, its edges have been removed with a very sharp cutter. And in this way a circular disc of 6 mm diameter is made.

DISC SHAPED Fe-Si SAMPLE



DISC-SHAPED Fe-Si ALLOY

DIA : 4.85 mm

THICKNESS : 0.30 mm

The circular disc of the Iron-Silicon alloy is again polished to reduce its thickness. When it is found that it has a thickness of around 0.5 mm, polishing is stopped. Then it is gradually made smaller with a very small squared file and vice. Thus two weeks have been spent to reduce its diameter to 4.85 mm. Again the sample is polished. Finally a circular disc of mass 39 mg., diameter 4.85 mm and thickness 0.30 mm has been prepared.

7.11 ACTUAL MAGNETISATION MEASUREMENT

First the magnetisation of Iron (0.08%C) sample is measured with VSM. The sample is put to the drive rod assembly of the vibrating sample magnetometer. It is then positioned at about mid-point of the sample coile by eye-estimation. After proper check, the sample is attached tightly to the sample-holder with adhesives. A few perspex spacers are also attached to the drive-rod throughout its length. After this the electromagnet is fed with power. Simultaneously the signal generator, the audio-amplifier, and the phase shifter are turned on. Next half an hour is spent for the warm-up of the component units. The frequency of the sine wave from signal generator is eet at 80 hertz.

Next the speaker voltage is adjusted to 1.53V. The sensitivity of the lock-in-amplifier is set at 100 micro-volt.

As the field current is passed, the sample signal is seen on the d.c. meter of the lock-in-amplifier. The sample signal ie then optimised-maximised by moving the sample in the Z-direction(vertical) and in the Y-direction and then minimised by moving it in the X-direction(Field direction).

The sample signal and the locking signal in the reference channel are brought in exact quadrature to give a correct null-reading on the meter. The two signals are then brought in the same phase to give a maximum reading to the right. Similarly the reference coil signal is alone seen in the meter. The signal is first brought in quadrature with the locking signal with the help of an external phase shifter in such manner that it gives a deflection to the left on the meter. It is then again brought in phase with the sample signal.

After all these precise adjustments, the lock-in-amplifier has been set in the differential mode. Field current of the magnet is gradually increased. Correctly equalising the decade transformer output with sample signal, the null-readings have been obtained. The Decade Transformer reading is multiplied by calibration constant which is 28.33 and thus sample moment has been obtained. Table 7.1 shows the results and figures 7.1, 7.2 and 7.3 are the graphical represetations.

In the same way, the magnetisation of Fe-Si sample has been measured in the same VSM. Table 7.2 shows the results and figures 7.4 and 7.5 are the graphical representations.

TABLE - 7.1

VARIATION OF MAGNETISATION WITH MAGNETIC FIELD FOR IRON USED IN THE CONSTRUCTION OF THE ELECTROMAGNET

Sample Composition: Fe (0.08%C), Shape: DISC, Dia: 3.80 mm, Thickness: 0.70 mm, Mass: 65.7mg, Temperature: Room Temp.

Instrument: VSM of AECD, SV: 1.53V, Cal.Const.: 28.33, Sensitivity: 100 micro volt.

FIELD CURRENT AMP. (A)	MAGNETIC FIELD KILO-GAUSS (K.G)	D.T.R. (FORWARD)	D.T.R. (REVERSE)	D.T.R. (Av)
1.0	0.5196	913000×10^{-7}	970000×10^{-7}	941500×10^{-7}
2.0	1.0490	1875700×10^{-7}	1923000×10^{-7}	1899950×10^{-7}
3.0	1.5690	2800000×10^{-7}	2868000×10^{-7}	2834000×10^{-7}
4.0	2.0760	3658000×10^{-7}	3720000×10^{-7}	3689000×10^{-7}
5.0	2.6170	4340000×10^{-7}	4386000×10^{-7}	4363000×10^{-7}
6.0	3.1620	4692000×10^{-7}	4730000×10^{-7}	4711000×10^{-7}
7.0	3.6940	4822200×10^{-7}	4840000×10^{-7}	4831100×10^{-7}
8.0	4.1940	4886000×10^{-7}	4890000×10^{-7}	4888000×10^{-7}
9.0	4.7170	4910000×10^{-7}	4925000×10^{-7}	4917500×10^{-7}
10.0	5.2050	4911000×10^{-7}	4925000×10^{-7}	4918000×10^{-7}
11.0	5.6480	4933000×10^{-7}	4933000×10^{-7}	4933000×10^{-7}
12.0	6.0590	4933000×10^{-7}	4933000×10^{-7}	4933000×10^{-7}

TABLE - 7.1 (CONTD.)

VARIATION OF MAGNETISATION WITH MAGNETIC FIELD FOR IRON USED IN THE CONSTRUCTION OF THE ELECTROMAGNET

Sample Composition: Fe (0.08%C), Shape: DISC, Dia: 3.80 mm, Thickness: 0.70 mm, Mass: 65.7mg, Temperature: Room Temp.

Instrument: VSM of AECD, SV: 1.53V, Cal.Const.: 28.33, Sensitivity: 100 micro volt.

MAGNETIC MOMENT (e.m.u) D.T.R (AVERAGE) X CAL.CONST.	MAGNETIC MOMENT/UNIT MASS (e.m.u/gm)
$941500 \times 10^{-7} \times 28.33 = 28.33 \times 0.941500 = 2.670$	$2.67/0.0657 = 40.64$
$1899950 \times 10^{-7} \times 28.33 = 28.33 \times 0.1899950 = 5.382$	$5.382/0.0657 = 81.92$
$2834000 \times 10^{-7} \times 28.33 = 28.33 \times 0.2834000 = 8.028$	$8.028/0.0657 = 122.19$
$3689000 \times 10^{-7} \times 28.33 = 28.33 \times 0.3689000 = 10.450$	$10.450/0.0657 = 159.06$
$4363000 \times 10^{-7} \times 28.33 = 28.33 \times 0.4363000 = 12.360$	$12.360/0.0657 = 188.13$
$4711000 \times 10^{-7} \times 28.33 = 28.33 \times 0.4711000 = 13.346$	$13.346/0.0657 = 203.14$
$4831100 \times 10^{-7} \times 28.33 = 28.33 \times 0.4831100 = 13.686$	$13.686/0.0657 = 208.31$
$4888000 \times 10^{-7} \times 28.33 = 28.33 \times 0.4888000 = 13.847$	$13.847/0.0657 = 210.76$
$4917500 \times 10^{-7} \times 28.33 = 28.33 \times 0.4917500 = 13.931$	$13.931/0.0657 = 212.04$
$4918000 \times 10^{-7} \times 28.33 = 28.33 \times 0.4918000 = 13.932$	$13.932/0.0657 = 212.05$
$4933000 \times 10^{-7} \times 28.33 = 28.33 \times 0.4933000 = 13.975$	$13.975/0.0657 = 212.70$
$4933000 \times 10^{-7} \times 28.33 = 28.33 \times 0.4933000 = 13.975$	$13.975/0.0657 = 212.70$

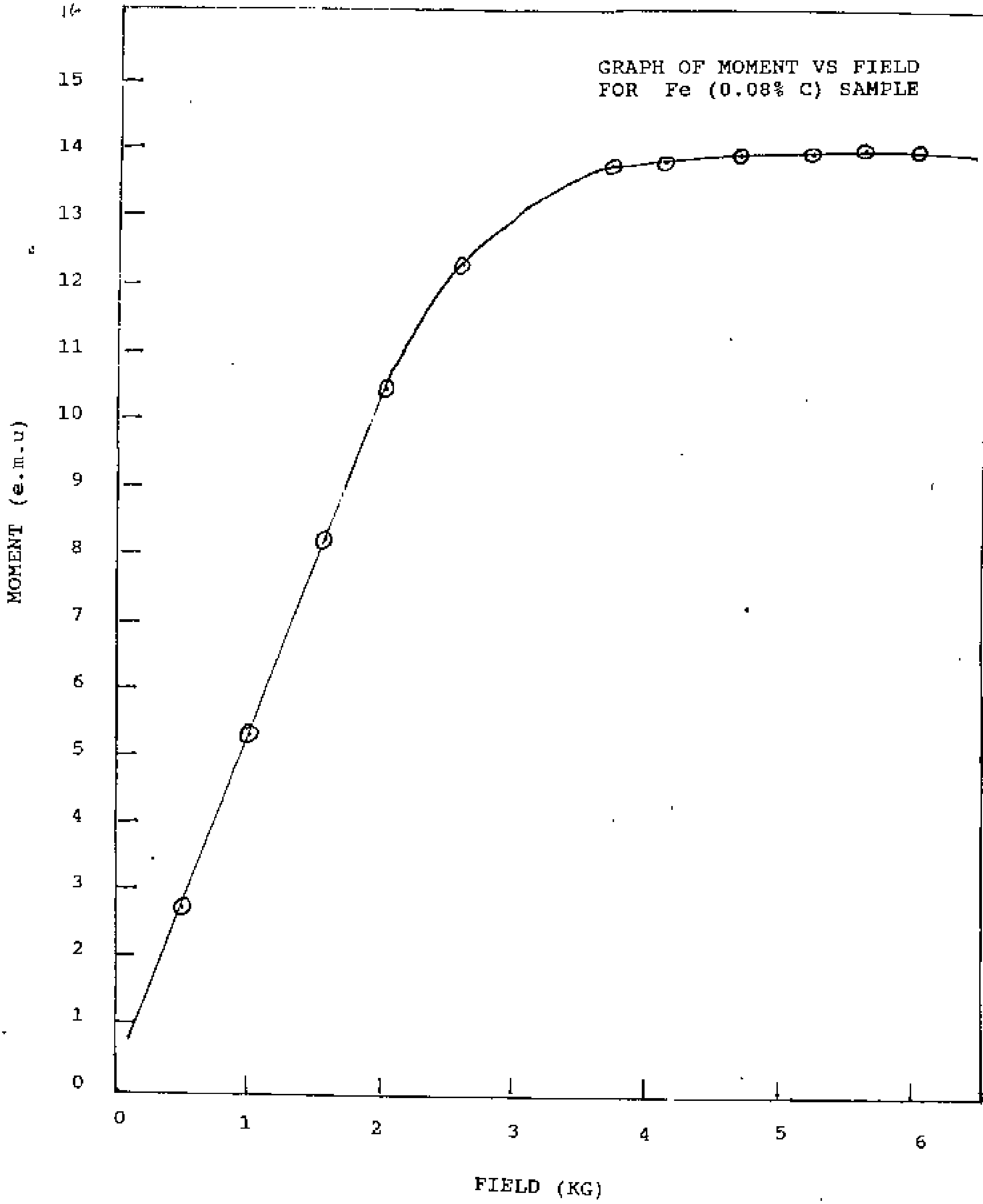


FIG. 7.1 VARIATION OF MAGNETISATION WITH MAGNETIC FIELD FOR IRON USED IN THE CONSTRUCTION OF ELECTROMAGNET.

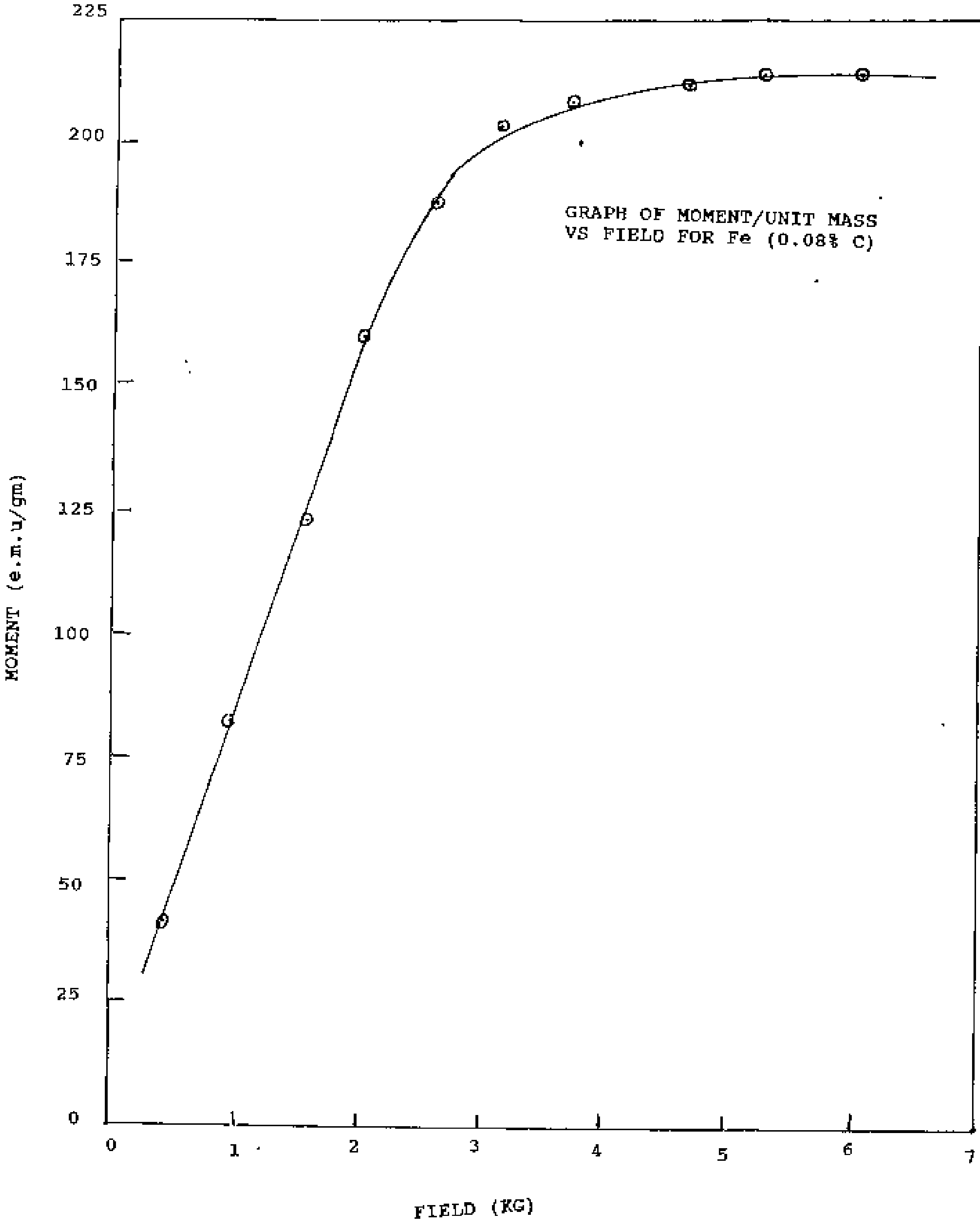


FIG. 7.2 VARIATION OF MAGNETIC MOMENT PER UNIT MASS WITH FIELD.

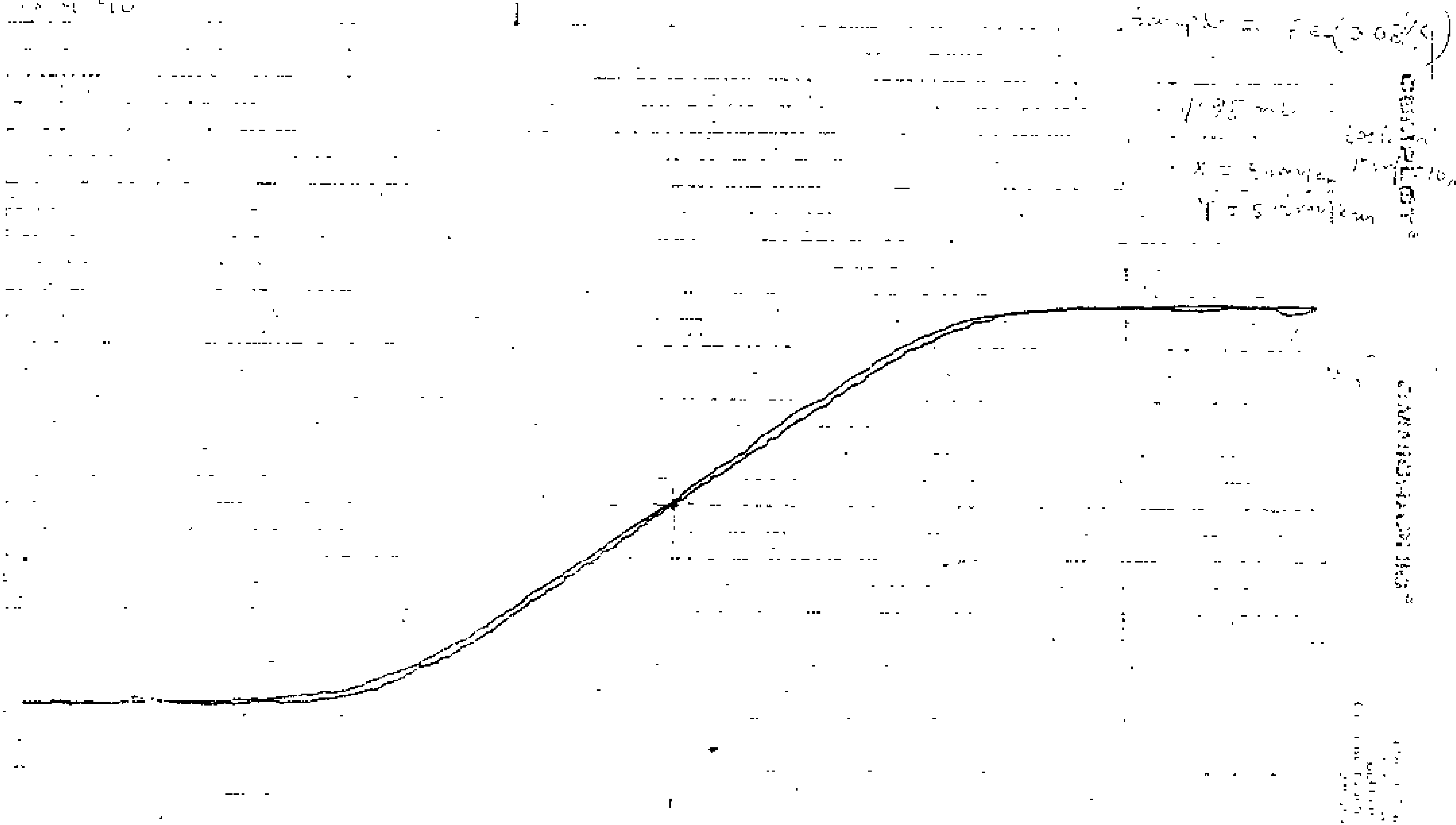


FIG. 7.3 THIS GRAPH IS RECORDED WITH X-Y RECORDER AND SHOWS NIL HYSTERESIS FOR IRON (0.08%C) SAMPLE

TABLE - 7.2

VARIATION OF MAGNETISATION WITH MAGNETIC FIELD FOR IRON-SILICON ALLOY

Sample Composition: Fe - 3% Si, Shape: Disc, Dia: 4.85 mm,
Thickness: 0.30 mm, Mass: 39 mg,
Measuring Instrument: VSM of AECD, Cal. Const.: 28.33, SPV: 1.5 v,
Sensitivity: 100 micro v.

FIELD (GAUSS)	D.T.R.X10^{-7} FORWARD	D.T.R.X10^{-7} REVERSE	D.T.R.X10^{-7} AVERAGE	MOMENT(e.m.u) D.T.R.AVERAGE X CAL. CONST.	MOMENT/ UNIT MASS e.m.u./gm.
100	269000	276000	272500	0.771	19.769
200	519000	535000	527000	1.492	38.256
400	1008000	1030000	1019000	2.886	74.000
600	1480000	1510000	1495000	4.235	108.589
800	1902000	1950000	1926000	5.456	139.897
1000	2250000	2260000	2255000	6.388	163.794
1250	2400000	2440000	2420000	6.855	175.769
1500	2558400	2520000	2539200	7.193	184.435
1750	2559000	2620000	2589500	7.334	188.051
2000	2550000	2640000	2595000	7.351	188.487
2250	2560000	2630000	2595000	7.351	188.487
2500	2560000	2630000	2595000	7.351	188.487

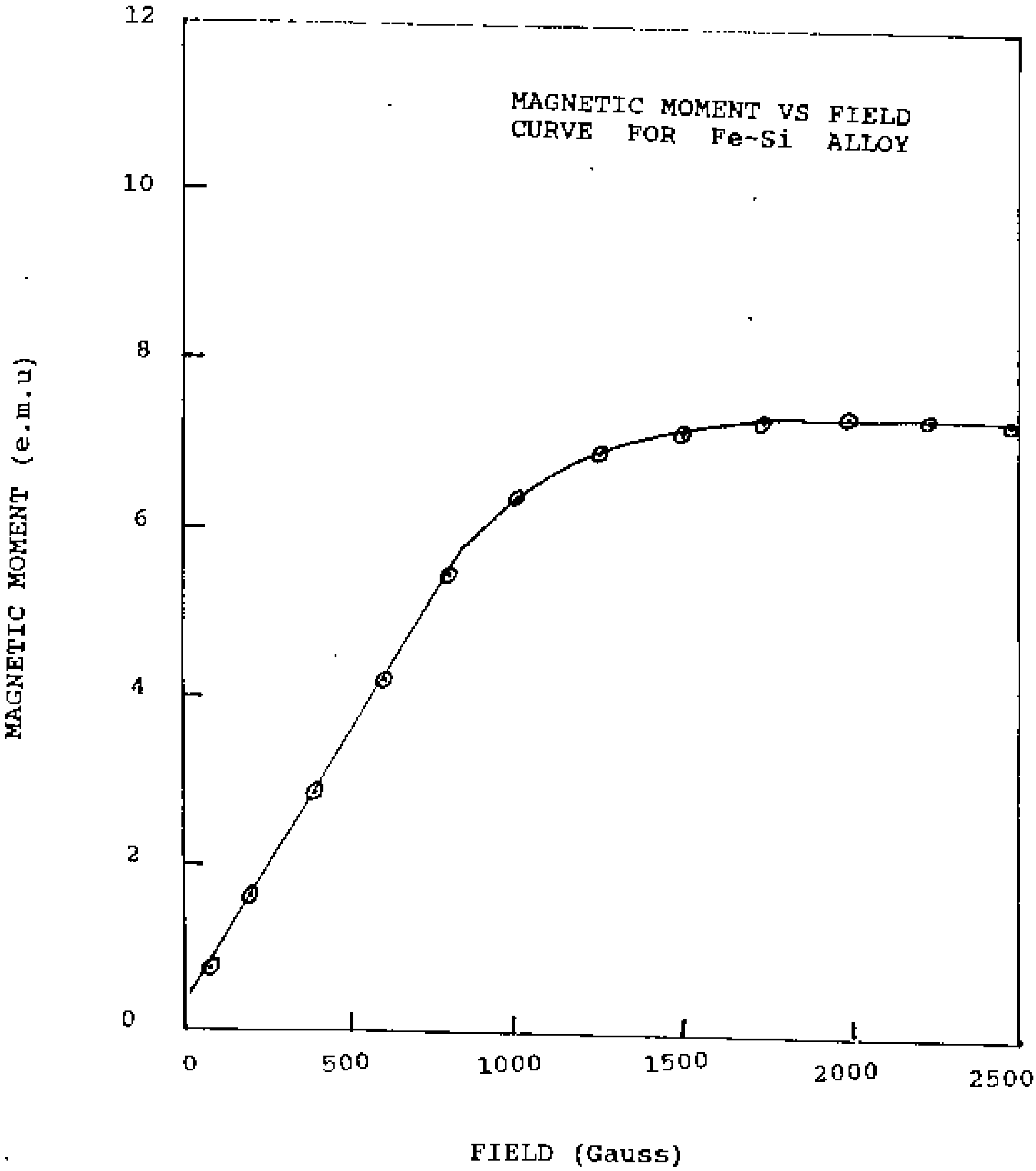


FIG. 7.4 VARIATION OF MAGNETIC MOMENT WITH FIELD FOR Fe-Si ALLOY.

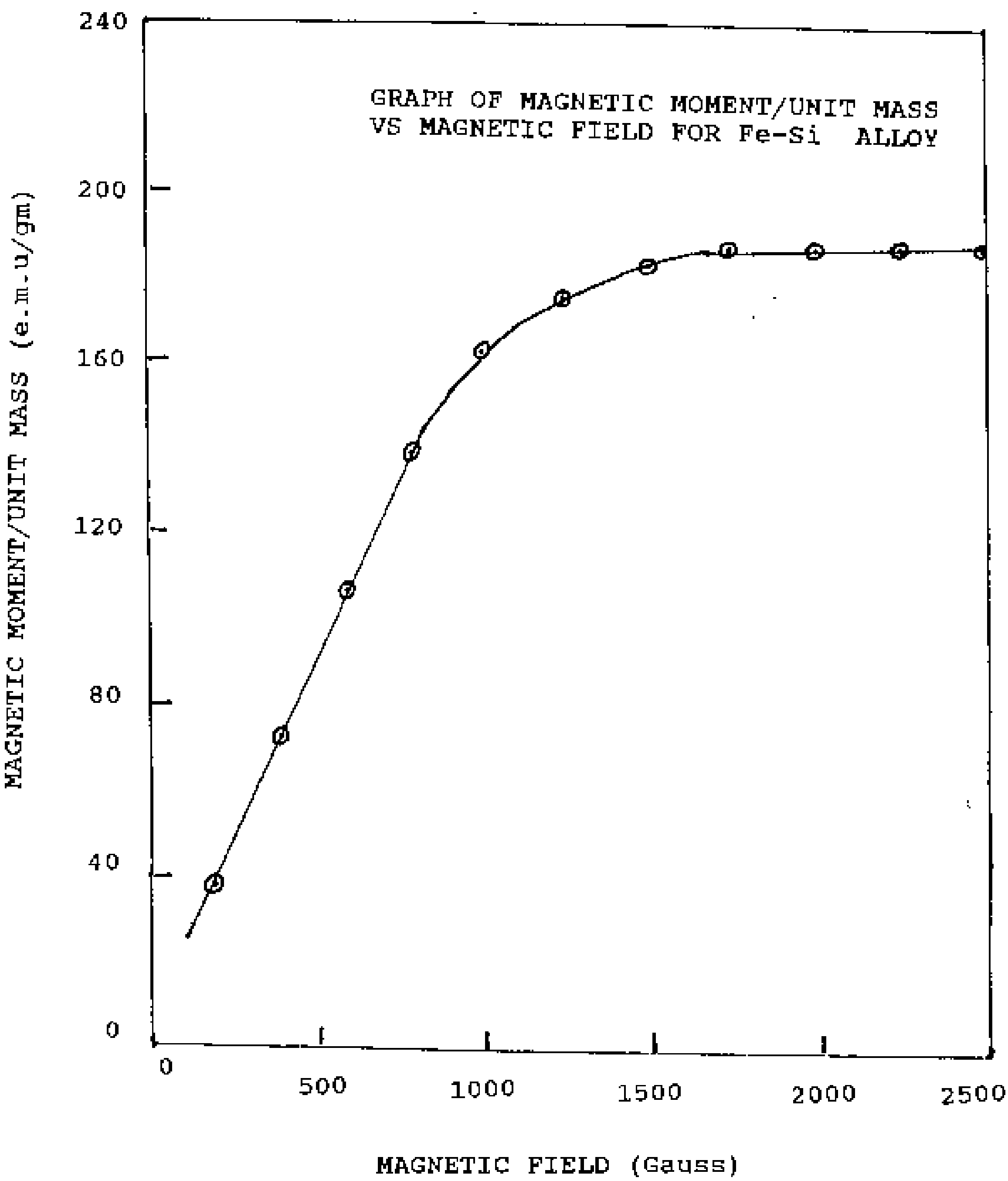
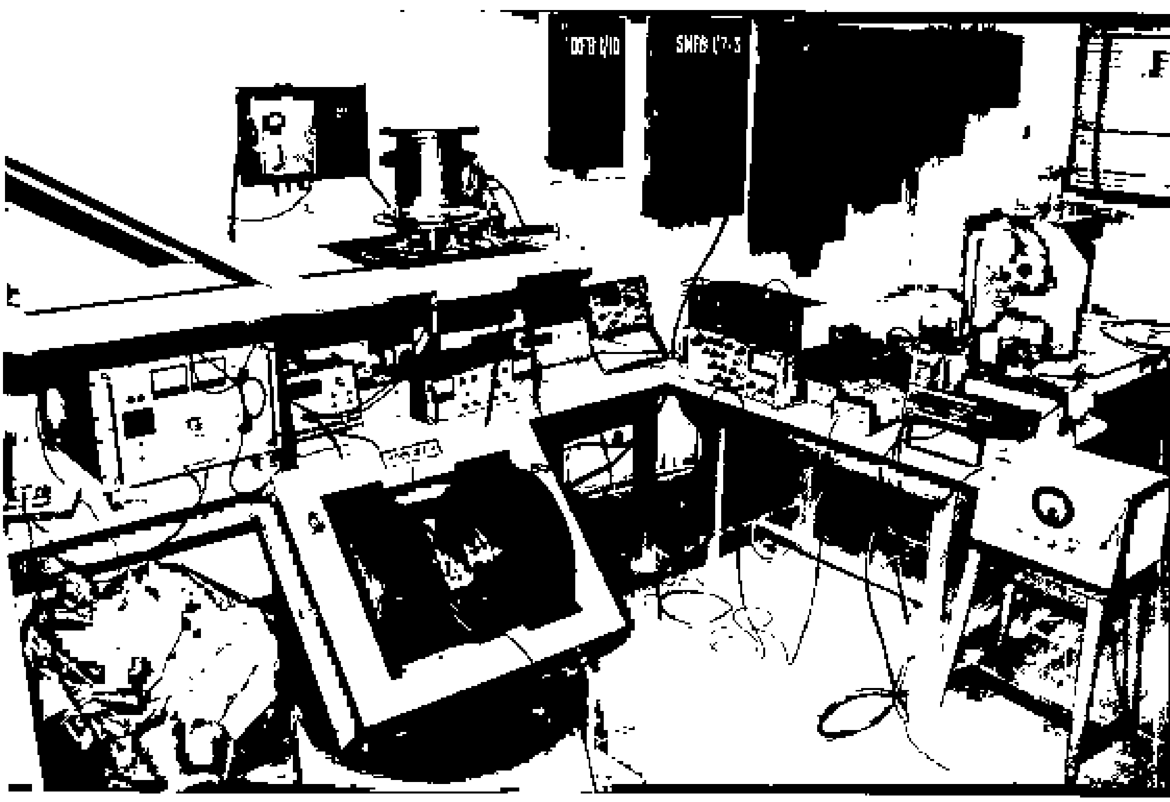


FIG. 7.5 VARIATION OF MAGNETIC MOMENT/UNIT MASS WITH MAGNETIC FIELD FOR Fe-Si ALLOY.



VIBRATING SAMPLE MAGNETOMETER (VSM) ALONG WITH OTHER MEASURING AND RECORDING DEVICES

CHAPTER - 8

FUTURE PROSPECTS

CHAPTER - 8

FUTURE PROSPECTS

The present electromagnet can produce a maximum field of 8688 gauss at a maximum current of 1.3 ampere. This is because the core material has not been saturated due to non-availability of a high rated power supply. The future development of the electromagnet will require powerful d.c. power source so that the electromagnet can be supplied with sufficient current. And it appears that the electromagnet in its present set-up will be able to generate 25 kilogauss field safely and easily.

The volume of the material of the pole-pieces and pole-faces determines the working space of the electromagnet. The poles of the electromagnet have diameter 75 mm and length 250 mm each. If in future both diameter and length are increased, a more spacious working gap is possible and hence more intense field could be maintained in the pole-gap with low loss.

The residual field generated varies from 12 gaues to 61 gauss depending on pole-gap variations. But the importance of residual field depends on the type of measurement envisaged. Thus in saturation measurements of soft ferromagnets, a high residual field is never desirable whereas in susceptibility determinations, the effect of even higher residual field is usually unimportant. An Iron-forging as nearly pure as can be obtained and carefully annealed is essential for an absolute minimum residual field. The electromagnet has been constructed with iron having a carbon composition of 0.08%. Reduction of carbon content in iron will minimise the residual field considerably but that will depend on our local manufacturing capacity.

In the electromagnet, no seperate pole-tips have been used. The same material has been used for both pole-pieces and pole-tips. For general requirements, no problem will arise. But if high degree of uniformity and intense magnetic fields are necessary, a variety of pairs of pole-tips may be needed. And these tappering pole-faces of superior soft magnetic materials and also cobalt-based pole-tips designed according to specific requirements may be inserted in the present electromagnet.

Since the resistance of the energising coils is high, the magnet may develop high temperature if enough current is passed to obtain intense field. And the future improvement of the electromagnet will require developing cooling system for temperature control. Seperate water jackets may be used or hollow conducting tubes may be used for cooling the magnet.

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CHAPTER - VII

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