ASTATIC MAGNETOMETER AND ITS CALIBRATION

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C E R T I F I C A T E

Certified that the dissertation entitled "Assembly of an Astatic Magnetometer and Its Accessories" being submitted by Rajendra Pal Sharma in partial fulfilment of the Degree of M.Sc. Tech. in Applied Geology of the University of Roorkee, is a record of the student's own work carried out by him under my supervision and guidance. The matter embodied in this dissertation has not been submitted for the Award of any other degree or diploma.

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CONTENT

CHAPTER I

INTRODUCTION

Palaeomagnetism :- A large number of rock's exhibit naturally occurring magnetization which is called natural remanent magnetism (N.R.M.). Palaeomagnetism is a loose term applied to this type of property. N.R.M. is acquired by rocks at the time of their formation and can therefore serve as a fossil compass useful in determining the directions of ambient geomagnetic field. Occasionaly the intensity of the N.R.M. can also lead to useful investigation but most of the work in rock magnetism is confined to the study of directions of magnetization.

Origin of fossil magnetism :- As most of the rock forming minerals are nonmagnetic they do not contribute to the N.R.M. which owes mainly to the presence of sulfides and oxide minerals of Iron and Titanium. The intensity of the N.R.M. is much less than what would be expected if all the magnetically active phase were aligned in the direction of ambient field, but it has been found that only a small portion of these have prefered orientation. By the study and identification of magnetically active phase of the rock constituents the prefered orientation may be determined.

The mechanism where by N.R.M. originates depends upon the mode of formation and the subsequent Geological history of the rocks. Thus it may be acquired by rocks on cooling from a temperature higher than their curie point when it is called the Thermoremanent magnetism (T.R.M.), or by chemical changes during the formation of iron minerals at low temperature, when it is called the chemical remanent magnetism (C.R.M.). Further more magnetization may be acquired by alignment of detrital magnetic particles when it is called detrital remanent magnetism (D.R.M.).

Applications :- Palaeomagnetism has made substantial contribution to the problems of stratigraphic correlation and tectonics. It is also intimately connected with palaeogeography. Thus from the knowledge of N.R.M. it is possible to study the paleolatitude spectrum of a particular type of deposit, the climatic conditions of the past Geologic ages and position of land masses relative to the pole's and to each other in different Geological times. The latter studies provide a test for the hypothesis of Polar wandering and continental Drift by a method which is independent of the Geological methods.

Palaeomagnetic survey's :- Rock units can be compared to an observatory in which the record of the Geomagnetic actigity is preserved. The first step toward a Palaeomagnetic survey is to select a rock unit of known Geological age and to collect oriented samples from it. Such a unit may be comprised of a series of sedimentary beds, lava flow or intrusive bodies. Sampling sites are usually selected to cover a small area.

The second step in palaeomagnetic investigation is to measure the N.R.M. of rocks in terms of their direction and intensity of magnetization. The N.R.M. consist of a primary component acquired at the time of the formation of rocks and a secondary component which is introduced by the subsequent variations in the direction and intensity of Geomagnetic field. The secondary component of N.R.M. is less stable and may be removed from a sample in the laboratory by cleaning of sample either magnetically or thermally.

The last step is to combine the observations on samples of an area and obtaining an estimate of the mean direction of magnetisation.

Reversal of Geomagnetic field :- In any of the palaeomagnetic study the directionsof N.R.M. fall into two distinct groups opposed in direction to one another. In those cases where care has been taken to correct for unstable component the mean directions of groups are found to be 180° apart. This phenomenon is refered as reversal of magnetization being defined as the actual change of polarity from one to another.

Recent development and Motivation behind Palaeomagnetic Investigation :- The earlier studies have been of very confined nature. The studies carried upto 1940 were very scanty, the data available were not adequate for developing any theory for the Geomagnetic field. A realisation of this defect lead to a rapid advance in palaeomagnetic studies, resulting in the development of necessary instrument and of the statistical methods for data reduction. The mechanism by which rock can acquire a remanent magnetization were also studied in detail. Finaly the technique of calculating paleopole provided an analytical tool of immense power, not only for intigrating the data but also to provide a neumerical estimate of the problem related to historical Geology. After an initial slow growth these studies are now expanding rapidly into many fields of Geology and Geophysics.

The ultimate aim of palaeomagnetic work is to build up a picture of variation of earth's field in the Geological past - an endless undertaking as yet barely begun. The palaeomagnetic methods can also offer valuable help in a better understanding and proper elucidation of the problems of structural Geostratigraphy, Palaeogeography, origin of certain special type of deposits, detection of certain changes in earth's radius and problems related to Engineering Geology where the site investigation and determination of depth of bed rock are concerned.

From the foregoing it is clear that all palaeomagnetic studies are based upon the assumption that N.R.M. is acquired in certain way, and the conclusion drawn from these investigation are therefore valid to the extent that these assumption based on our present knowledge of solid state physics are correct. In the words of Prof. Popper

> " ... A theory may be true
> even though nobody believes it,
> and even though we have
> no reasons for accepting it,
> or for believing it is true;
> and an other theory may be false
> Although we have comperatively
> good reasons for accepting it "
>
> K.R.Popper

CHAPTER II

THEORY OF THE INSTRUMENT

Introduction

Various types of instruments have been used for measuring weak magnetic fields associated with natural remanent magnetization of igneous and sedimentary rocks. Of these only two have been developed to a high degree of sensitivity necessary for the study of very weak N.R.M. These are the spinning magnetometer also referred to as rock generators and the astatic magnetometer.

In 1952 Blackett made a detailed study of the study of the design of the Astatic magnetometer and constructed an admirable instrument for the study of N.R.M. of sedimentary rocks. Before this a group of worker in America notably Johnson & Johnson, Murphy and Michelson and in Japan Nagata, Takasi, Rikitake and others had constructed instruments of the rock generator type. The ultimate senstivity of rock generators is limited by the thermal noise of the pick up coils and the amplifier.

Rock Generators

In these instruments a rock sample is rotated about the axis of a pick up coil system. The sample which behaves like a dipole, thus induces an e.m.f. in the coils. The phase of this e.m.f. is compared with respect to a reference e.m.f.

obtained. The latter is obtained from a reference coil which derives the sample. The direction of magnet can be adjusted so that it coincides with that of the magnetization of the sample in the plane perpendicular to the shaft. A potentiometric methods is used to balance these two alternating e.m.fs. for determination of the intensity of magnetization.

Alternatively the phase difference between the e.m.fs. produced by the reference coil and the measuring coils may be measured which will give the direction of the magnetic component perpendicular to the axis of rotation of the sample with respect to that of the magnet. The rotation about this mutually perpendicular directions of the rock sample enables the determination of the directions of the total vector. The intensity of magnetization can be obtained by the amplitude of the signal.

Design factors

The coils generally used are either in solenoidal form with samples rotating inside them or of the shape of a flat disc with samples rotating about their axis.

The flux 'F' through a circular coil of radius r due to a magnetic dipole P situated on and directed along the axis of the coil, at a distance z from it is given by (2-11).

$$F = \frac{2\pi P \ r^2}{(r^2 + z^2)^{3/2}} \qquad (A - 1)$$

consider a coil of a rectangular cross-section with dimension as shown in figure (2-1).

If the wire has a cross-sectional area 'a' and the packing factor is K, then the number of turns linking an elementary area dr dz is given by

$$dN = \frac{K}{a} \quad dr \quad dz \qquad (3)$$

The magnetic flux $d\phi$ due to this element of coil is given by

$$d\phi = 2\pi \frac{PK}{a} \frac{r^2}{(r^2+z^2)^{3/2}} \quad dr.\ dz \qquad (A - II)$$

The total flux for the coil is

$$\phi = 2\pi P \frac{K}{a} \int_{r_1}^{r^2} \int_{l_1}^{l_2} \frac{r^2}{(r^2+z^2)^{3/2}} \quad dr \quad dz \qquad (A-III)$$

If the specimen is rotated with a frecuency of f revolutions per second the r.m.s. voltage induced in the coil is given by (2-ii).

$$e_s = \frac{\pi^3 PK\ f \times 10^{-8}}{a\sqrt{2}} \times \log \frac{[r_2+(r_2^2+l_2^2)^{1/2}]}{[r_1+(r_1^2+l_1^2)^{1/2}]}$$

$$- l_1 \log \frac{[r_2+(r_2^2+l_2^2)^{1/2}]}{[r_1+(r_1^2+l_1^2)^{1/2}]}$$

The resistance R_c of the coil expressed in the same terms is

$$R_c = (\pi^2 \rho K/a^2) \cdot (l_2 - l_1)(r_2^2 - r_1^2) \qquad \text{(A-V)}$$

The root mean square of the noise voltage in arising due to this resistance is given by

$$en = 1.27 \times 10^{-10} \times (R_c \, \Delta f)^{\frac{1}{2}} \qquad \text{(A - VI)}$$

Where Δf is the effective band width of the circuit.

The signal to noise ratio by the combination of equations (A - IV) and (A - VII) for the instrument is given by

$$\frac{es}{en} = A. \frac{P.K^{\frac{1}{2}}}{\rho^{\frac{1}{2}}} \times \frac{1}{(l_2 - l_1)(r_2^2 - r_1^2)^{\frac{1}{2}}}$$

$$\left[l_2 \log \frac{\left[r_2 + (r_2^2 + l_2^2)^{\frac{1}{2}} \right]}{\left[r_1 + (r_1^2 + l_1^2)^{\frac{1}{2}} \right]} - l_1 \log \frac{\left[r_2 + (r_2^2 + l_2^2)^{\frac{1}{2}} \right]}{\left[r_1 + (r_1^2 + l_1^2)^{\frac{1}{2}} \right]} \right] \qquad \text{(A-VIII)}$$

Where A is constant.

For hollow cylindrical coils with specimen rotating at its centre $l_2 = - l_1, = \ell$ then the signal to noise ratio is given by

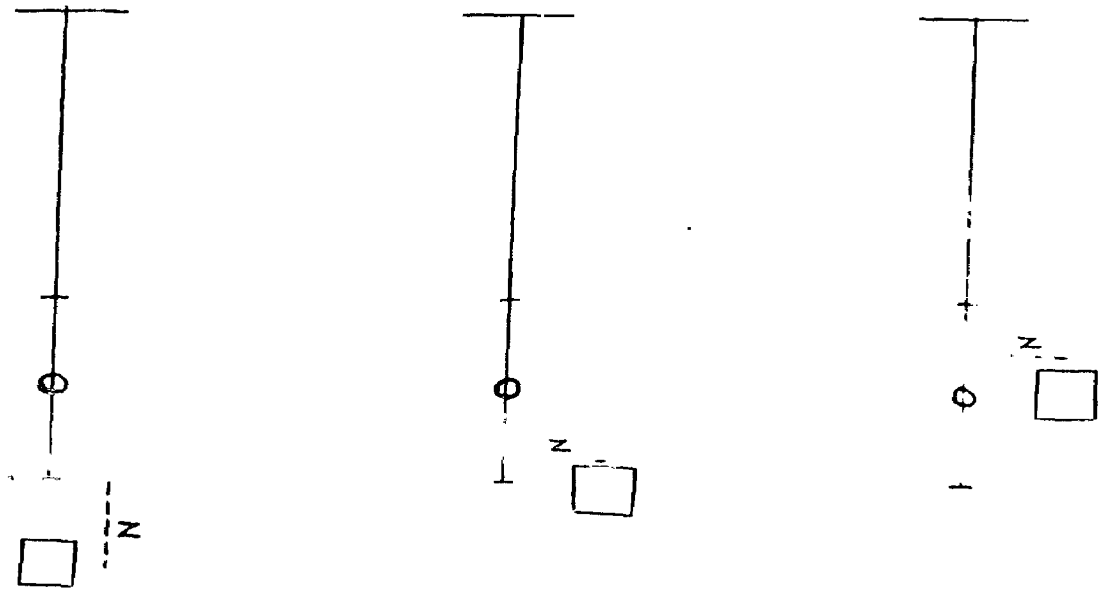
$$\frac{es}{en} = \frac{A \; P \; K^{\frac{1}{2}} \; f}{\rho^{\frac{1}{2}}} \times F(r_1 r_2 l). \qquad \text{(A-IX)}$$

Where

$$F(r_1 r_2 l) = \frac{l^{\frac{1}{2}}}{(r_2^2 - r_1^2)^{\frac{1}{2}}} \cdot \log \frac{\left[r_2 + (r_2^2 + l_2^2)^{\frac{1}{2}} \right]}{\left[r_1 + (r_1^2 + l_1^2)^{\frac{1}{2}} \right]}$$

(a) (b)

FIG. 2.1 SCHEMATIC VIEW OF ASTATIC MAGNETOMETER.
a HAVING TWO MAGNETS
b. HAVING THREE MAGNETS



(A) (B) (C)

FIG 2.3 SPECIMEN POSITIONS

ASTATIC MAGNETOMETER

Both ordinary and astatic magnetometers have been widely used for measuring the magnetization of ferromagnetic substances. Since intensity of magnetization as well as susceptibilities are susally very small for most rocks, an astatic magnetometer offers a relatively more accurate means of measuring them.

The equation of equilibrium of an astatic magnetometer in which two magnets of identical magnetic moments, M_1 and M_2 are held one above the other, in antiparallel arrangement, is given (1-1) (fig 2.2a)

$$(M_1 - M_2)\,H \sin\theta = T\theta \qquad (I)$$

where θ is the angle between the axis of the magnet and the horizontal direction of the geomagnetic field. H is the horizontal component of the earth's field T is the torsion constant of the suspension fibre.

If we assume that the additional force h affects only the lower magnet M_1 set in a direction perpendicular to the geomagnetic field the equation (I) is modified as follows :

$$(M_1 - M_2)H \sin\theta + M_1 h \cos\theta = T\theta \qquad (II)$$

Differentiating equation (II), we get

$$(M_1-M_2)\,H\cos\theta\,d\theta + M_1\cos\theta\,dh - M_1 h\sin\theta\,d\theta = T\,d\theta$$

or, $$\frac{d\theta}{dh} = \frac{M_1\cos\theta}{(M_1-M_2)\,H\cos\theta + M_1 h\sin\theta + T} \qquad \text{(III)}$$

when $M_1 = M_2$, the sensitivity $\left(\frac{d\theta}{dh}\right)_0$ becomes equal to $\frac{M_1}{T}$, which indicates that it is independent of the fluctuations in H.

Generally the main problem in measurement is not one of obtaining a high sensitivity but is one of reducing the noise due to the fluctuations in the external fields. Suppose H' be an erratic field and let it lie in a horizontal plane perpendicular to the earth's field H, then the effect of H' on the sensitivity can be obtained from equation (III), we have therefore,

$$\frac{d\theta}{dH'} = \frac{M_2-M_1}{(M_1-M_2)\,H + T} \qquad \text{(IV)}$$

showing that if the erratic field is uniform the sensitivity remains unchanged.

Nagata has explained that these effects can be removed if we arrange three magnets as shown in figure 2.2 b so that $M_1 = 2\,M$ and $M_2 = M_3 = M$. The magnets M_2 and M_3 are placed in the centre with its polarity opposed to those of M_2 and M_3.

Another condition to be fulfilled for the proper working of the astatic magnetometer is that the force to be measured should affect only the lower magnet. This requirement necessarily limits the number of magnets in the astatic magnetometers.

Practical Problems in the astatic magnetometer.

It is possible to adjust M_1 and M_2 so that $(M_1-M_2)H = 0$ within an accuracy of 99%. However, in order to acheive further accuracy an additional magnetic force h' on M_2 is provided either by means of current carrying coil or by a small Trimmer magnet. The condition will then be,

$M_1H - M_2 (H \pm h') = 0$ For current carrying coil

$M_1H - (M_2 + M_3)H = 0$ For Trimmer magnets

It is presumed that M_1 M_2, a condition which can always be endured.

An alternative technique is to tilt the lower magnet by a small angle δ from the original plane such that

$$M_2 - M_1 \cos \delta = 0.$$

Specimen Position

The specimen to be measured can be put in three different positions relative to the magnetic system,[2,3] These are as follows : 2-1.

(A) Beneath the lower magnet of the astatic pair (this configuration was used by Blackett and Collinson et al).

(B) On one side of the lower magnet along its axis and in the same horizontal plane.

(C) On one side of the magnetic system and midway between the astatic pair.

The sensitivity of the systems is different for each of these conditions. However, it is important to know which of these positions will yeild the best results for a given system. The most practical measure of the sensitivity is given by the intensity of magnetization required to give a minimum readable deflection.

All the three positions mentioned above have some merits and demerits. Thus position A and B provide considerably higher sensitivity as compared to that provided by position C . A given system shows the ratio Hx / Px twice as much for position B as for position A, but owing to the ease in handling the specimen if it is kept in position A this position has been selected for use.

Specimen Position A

Let the specimen be placed as shown in figure 2.3 A

It is situated on the vertical axis of the magnetometer at a depth z below the lower magnet. Let the specimen be represented by a small dipole P, the horizontal component of its dipole-moment being Px, which makes an angle θ with the direction of lower magnet. Let Hx be the effect on the lower magnet of the system.

$$Hx_{lower} = Px \sin\theta \frac{1}{z^3} \qquad (V)$$

Similarly the effect on the upper magnet, which is separated by a height ℓ, will be,

$$Hx \text{ upper} = Px \sin\theta \frac{1}{(z+\ell)^3} \qquad (VI)$$

combining equation (V) and (VI)

$$\frac{Hx \text{ upper}}{Hx \text{ lower}} = \frac{z^3}{(z+\ell)^3} \qquad (VII)$$

The relation (VI) gives the ratio of the effects on the lower and the upper magnets. For higher sensitivities the effect on the upper magnet should be a minimum. In order to ensure this, z is to be reduced to have lesser effect on the upper magnet, which however, is limited by the size of the sample. The bigger the specimen the further it is to be kept where as for smaller specimen z can be much smaller.

The size of the rock smaple can not be reduced in-definitely because of the inhomogenity of distribution of the magnetic materials in it. A convenient size usually chosen for cubic or a cylinderical specimen is about 3 cm. This consideration therefore limits the value of z which has to be a minimum of 3 cm.

When $z \ngtr 3$ and the effect on the upper magnet is desired to be of the order of 1.%0 as compared to that on the lower magnet, the effective separation of magnets in the system should be

$$\frac{z^3}{(z+\ell)^3} = \frac{1}{100}$$

$$z + \ell = 4.65\ z$$

$$\ell = 3.65\ z$$

$$= 11 \text{ cm for } z \text{ to be } 3 \text{ cm}$$

$$= 7 \text{ cm for } z \text{ to be } 2 \text{ cm}$$

$$= 4 \text{ cm for present circumstances}$$

Factors controlling the design of the magnetic system

Consider the effect of a small dipole on the upper and lower magnets of the astatic system when the magnetic dipole is placed at a depth z below the lower magnet on the axis of the magnetic system. The ratio of H and H8 is given by 2-1

$$\frac{H}{H'} = \frac{(L+z)^3}{z^3} .$$

where H is the effect on the lower magnet
H' is the effect on the upper magnet.

when $\frac{H}{H'} >>> 1$

the sensitivity S may be written as

$$S = \frac{\theta}{H} = \frac{T^2 P}{4\pi^2 I} \quad \text{for unit deflection}$$

where

T is the time period of the system,
P magnetic moment of one of the magnet
I the moment of inertia of the system, and
σ is the torsion constant of the suspension fibre.

Design for the maximum sensitivity

The sensitivity depends upon the time period and the factor I/P. However the time period is chosen so that it is of the order of the time required for one measurement i.e. about 15 seconds. The moment of inertia I can be written as

$I \propto I_o$ I_o is the moment of inertia of one of the magnet

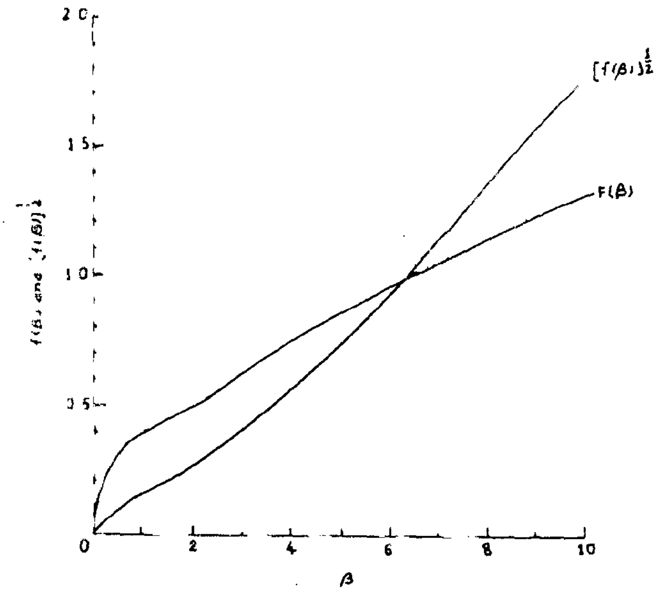


FIG 2·4 VARIATION OF f(β) & [f(β)]$^{1/2}$ WITH FINENESS RATIO

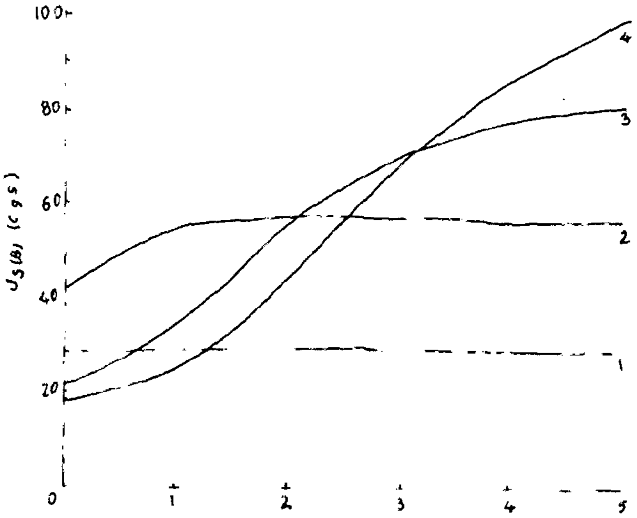


FIG 2·5 INTENSITY OF MAGNETIZATION PER UNIT MASS, $J_s(\beta)$, PLOTTED AGAINST VALUES OF β. CURVE 1: PLATINAX II, 2 MAGNADUR II, 3 TICONAL K, 4 ALCOMAX IV.

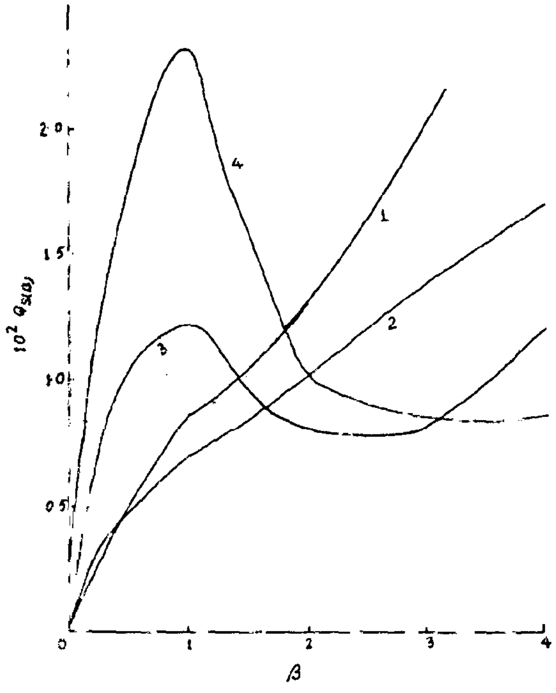


FIG 2·6 VARIATION OF $Q_s(\beta)$ FOR DIFFERENT VALUES OF β FOR THE MATERIALS OF FIG

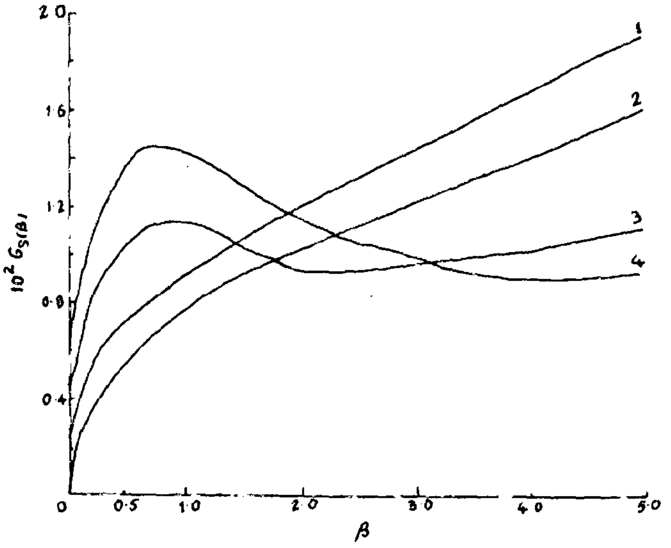


FIG 2·7 VARIATION OF $G_s(\beta)$ WITH FINENESS RATIO β FOR THE MATERIALS OF FIG

$$\frac{H}{H'} = \frac{(L+z)^3}{z^3} .$$

where H is the effect on the lower magnet
H' is the effect on the upper magnet.

when $\frac{H}{H'} >>> 1$

the sensitivity S may be written as

$$S = \frac{\theta}{H} = \frac{T^2 P}{4\pi^2 I} \quad \text{for unit deflection}$$

where

T is the time period of the system,
P magnetic moment of one of the magnet
I the moment of inertia of the system, and
σ is the torsion constant of the suspension fibre.

Design for the maximum sensitivity

The sensitivity depends upon the time period and the factor I/P. However the time period is chosen so that it is of the order of the time required for one measurement i.e. about 15 seconds. The moment of inertia I can be written as

$I \propto I_o$ I_o is the moment of inertia of one of the magnet

$I_0 \propto l^5$ and $P \propto l^3$.

$\frac{I_o}{P} \propto l^2$

This indicates that the sensitivity can be increased by decreasing the length of the magnet. However, there is a limit to the size of the magnets, their supports and the deflecting mirror. A thinner and lighter system will have the tendency to warp, neither is it advisable to use a mirror of size less than 4 mm. diameter.

I_a and P both depend upon the size of the magnet. Let l be the length and a be one of the sides of its square cross-section. For ordinary magnets the length is greater than the breadth. A fineness ratio β defined by l/a is therefore generally greater than one. The moment of inertia about an axis perpendicular to the axis of magnet and passing through the centre of gravity is given by

$$I_o = \frac{Ml^2}{12} \times (1+\beta^{-2}).$$

or $$= M^{5/3} . \rho^{-2/3} . f(\beta)$$

where $$f(\beta) = \beta^{4/3} \frac{(1+\beta^{-2})}{12}$$

Graph 2.4 shows the behaviour of $f(\beta)$ and $[f(\beta)]^{1/2}$ with β the 'fineness ratio'. This shows a change in gradients at = 1 for both $f(\beta)$ and $[f(\beta)]^{1/2}$ indicating that the fineness ratio should be chosen to be greater than one in indicating the shape of the magnet. The intensity of magnetization also varies with the shape and the type of magnetic material. The intensity of magnetization is plotted against β in graph 2.5 for four different materials of identical 'fineness ratio'. The ticonal and alcomax show a gradual increase in the intensity of magnetization with increase in the 'fineness ratio'

We may further write,

$P = m \; J_\delta(\beta)$ m is the mass of the magnet and $J_\delta(\beta)$ is intensity of magnetization.

$$I_{a/p} = P^{2/3} . Q_\delta(\beta)$$

where $$Q_\delta(\beta) = \frac{f(\beta)}{\rho^{2/3} . [J_\delta(\beta)]^{5/3}}$$

Factor $Q_\delta(\beta)$ is purly a function of shape and intensity of magnetization. For an ideal shape this function should be a minimum. This factor is plotted against β in graph 2.6, the alcomax and ticonal show minimum values of $Q_\delta(\beta)$ for the 'Fineness ratio' of 2.25 and 2.5 respectively.

Effects of the thermal noise

Blackett has pointed out that temperature variations may cause the magnetic system to be deflected, if the minimum detectable field is lesser than the field produced by the temperature variations.

He showed that the field produced by thermal noise is a function of $G\delta(\beta)$ where is defined as

$$G\delta(\beta) = \frac{[H(\beta)]^{1/2}}{p^{3}\,[J\delta(\beta)]^{5/6}}$$

this factor depends upon the 'fineness ratio' and the intensity of magnetization as shown in graph 2.7 . The value of fineness ratio is chosen so that $G\delta(\beta)$ is a minimum in order to avoid the fluctuations caused by thermal noise. The graph show minimum values of β for alcomax as being equal to 4 and for Ticonal, 2.2.

For selecting the shape of the magnet in a magnetic system, the 'Fineness ratio' is chosen according to the above considerations.

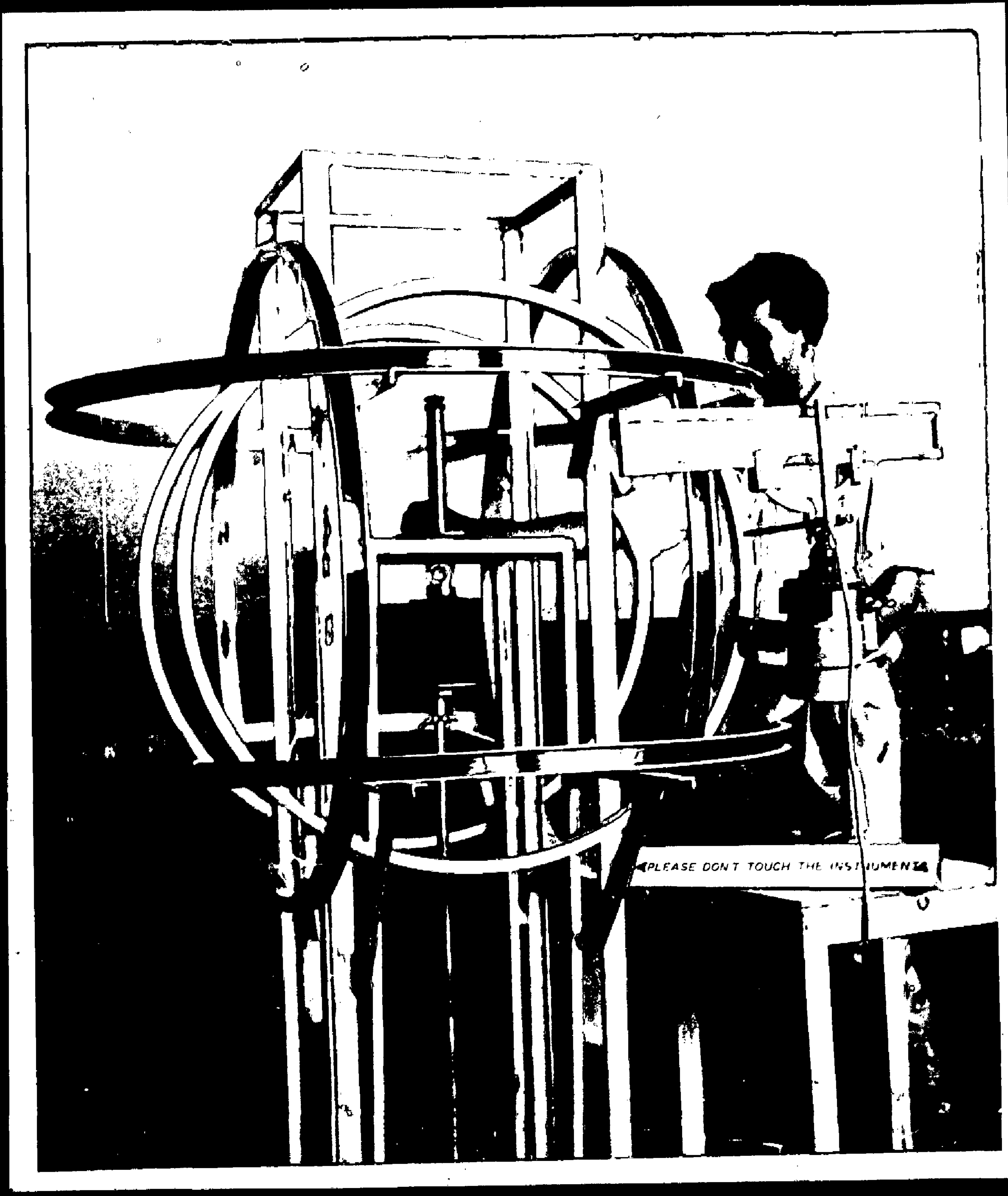


Fig 3.1 GENERAL SET UP OF THE ASTATIC MAGNETOMETER

CHAPTER III

DESCRIPTION OF THE INSTRUMENT

Figure 3·1 shows a general view of the instrument which was constructed in the laboratory. The entire system can be divided into two main groups.

(1) Measuring instrument
(2) Additional accessory for improving the sensitivity.

Measuring instrument

The magnetometer case is made of brass. The upper cylindrical put of the magnetometer case houses the suspension strip. This is joined to a thick circular disc which rests on three point supports. The lower part of the case is made of perspex and is attached to the upper part by means of sockets and screws. It contains a small window through which a beam of light after reflection from the mirror of the magnetic system may be observed. A lens is used to focus the light spot on a linear scale placed at one meter distance from the centre of the magnetic system. A copper plate is suitably placed at the bottom of the case to provide critical damping. The entire system is positioned at the centre of a field free space on a one square foot aluminium stool at a height of 4 foot. In order to remove the effects of extraneous vibration and ensure stability, the stool is loaded by lead bricks to its crumpling strength.

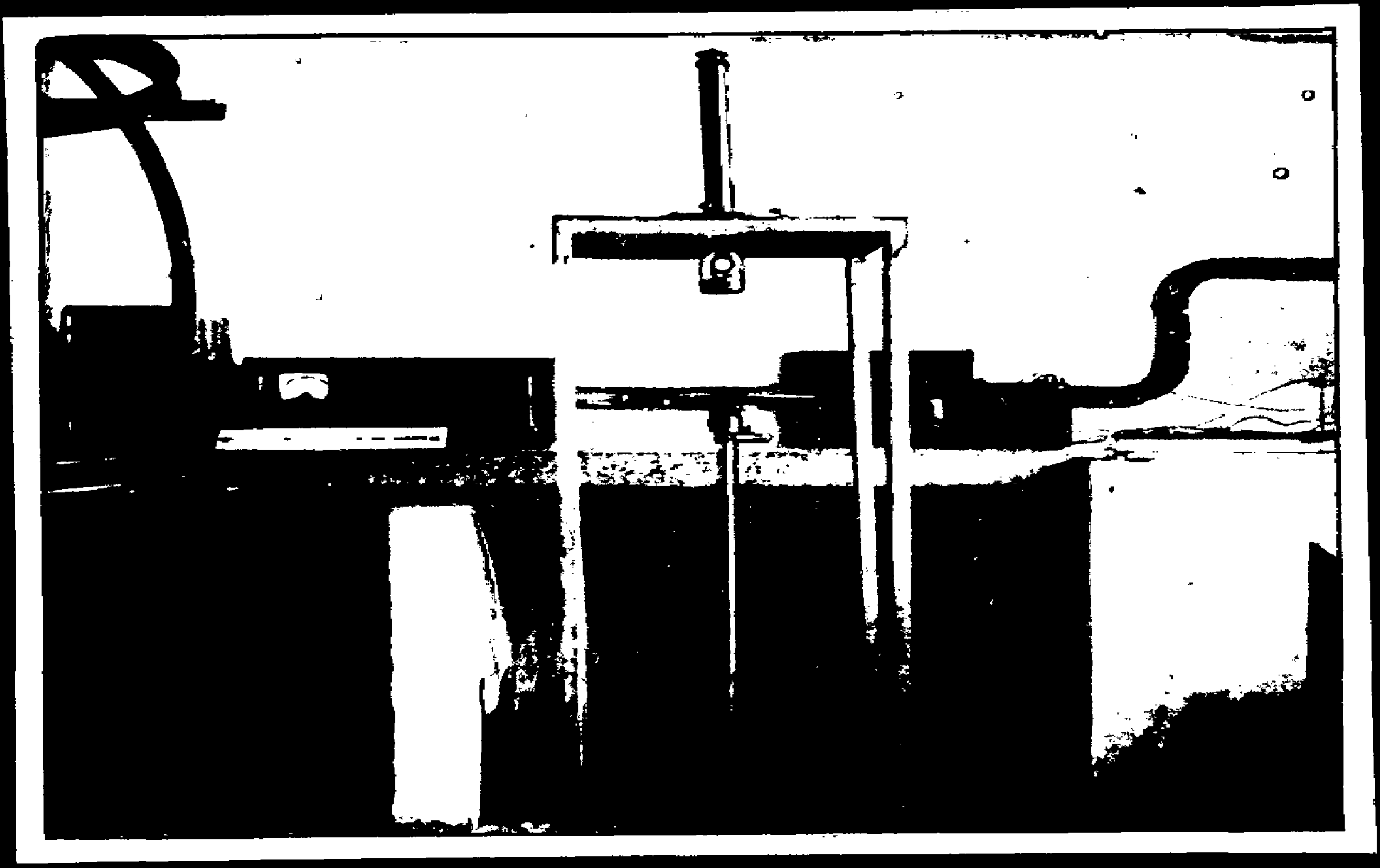


Fig 3·2 MAGNETOMETER WIT

TURNTABLE.

The magnetic system consists of two magnets 3mm. x 1mm x 1mm. These are supported, at a distance of 4 cm. from each other by a thin aluminium strip.

A mirror is attached to the centre of this strip which permits to determine the deflection of the system by means of a lamp and scale arrangement. At the top of this strip a hook is provided to engage the suspension fibre, through a copper loop. Additional trimming magnets are sometime fixed on this strip to attain high astatization. The entire system is suspended by a phosphor-bronze fibre attached to a rigid support at the tops of the magnetometer case. The length of the fibre used was 21.5 cm.

In order to make the measurements it was required to raise and lower the specimen underneath the magnetic system with an accuracy of about 0.5 cm. In addition to this the specimen has also to be rotated in a horizontal plane. To accomplish this a rotating horizontal turn table has been designed (see photograph 3.2). The turn table could be raised and lowered by moving a cylindrical rod to which it is attached by means of a cup and cone arrangement. The turn table which is an aluminium disc of 10" diameter, can be raised to a maximum of four feet from the base level. The turn table can be rotated by an Observer, at a distance of one M from the system, by means of a string wound around pulleys and a groove at the base of the table.

The distance of the scale from the magnetic system can be adjusted to give higher sensitivity because the scale deflection is proportional to the distance of the scale from the magnetometer. Let θ be the small angular deflection and p be the distance of scale from the magnetic system then the scale deflection is given by $p\theta$. For the present set the value of p is one metre.

The sensitivity of the system can be greatly improved by elluminating the earth's field around the magnetometer. This is accomplished by 3 pairs of Helmholtz coils carrying suitably adjusted currents. The field produced by a pair of tHelmholtz coils carrying a current i is given by (4 -1)

$$F = \frac{64\pi ni}{\sqrt{5}\cdot a}$$

where

F is the field produced in oersteds,
n the number of turns each coil,
i the current in amperes, and
a the radius of the coil in centimeters

the details of the present set up of the Helmholtz coils are in fig 3.3.

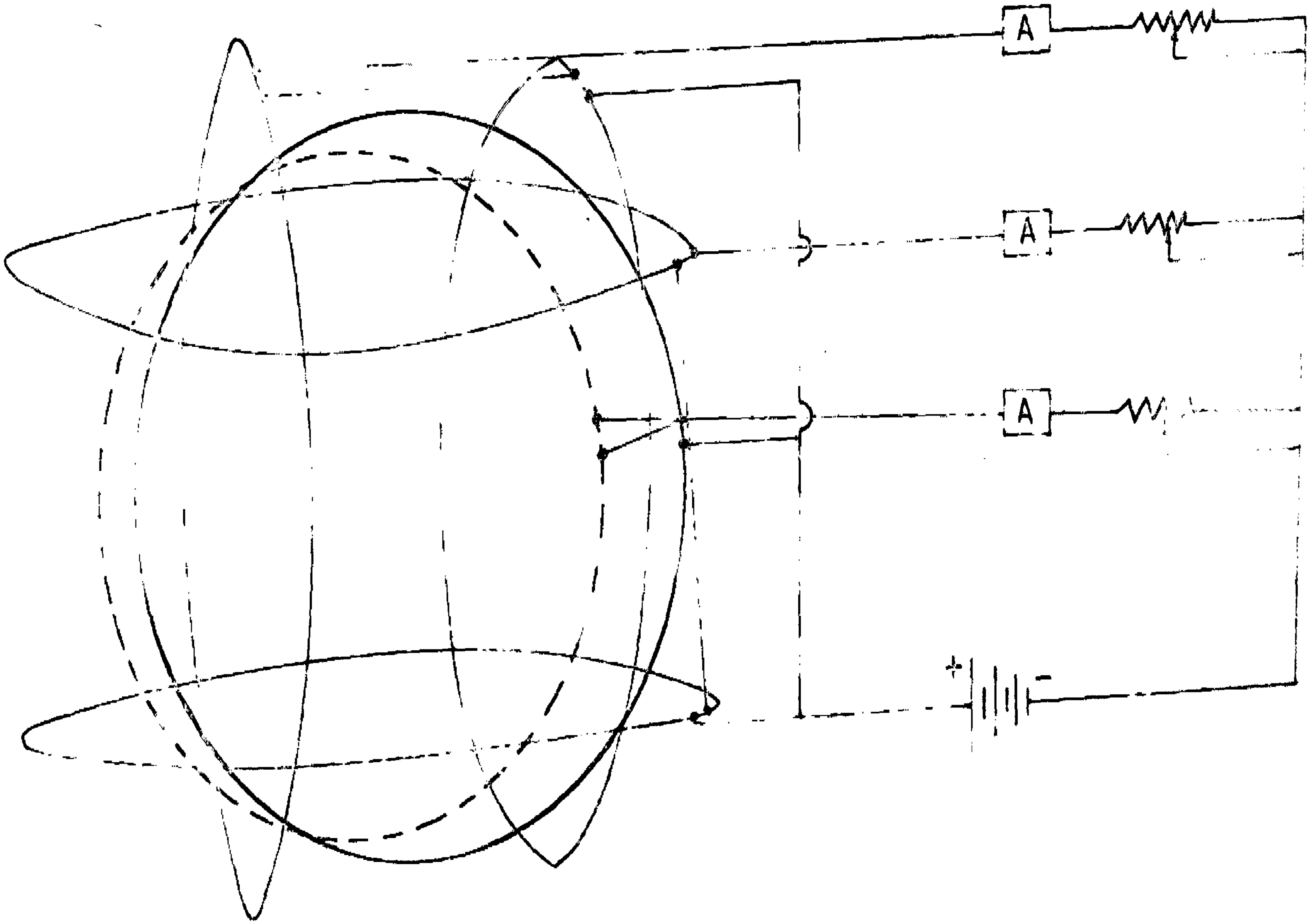


Fig 3.3 SCHEMATIC ELECTRICAL CIRCUIT

The earths field can be considered to be made up of 3 components, one vertical and two horizontal in the NS and EW directions. The horizontal pair of coils produce a field in the vertical direction the currents in which can be adjusted to annul the vertical component of the earths field. The two vertical pairs on the other hand, produce fields in the horizontal direction and the currents in them are adjusted to annul the horizontal component of the earth's field. The two vertical pair are used for the obvious advantage of producing a resultant horizontal field in any desired direction so as to annual the earth's horizontal field completely. The same purpose could however be achieved by a single pair provided that its axis was oriented to lie in the magnetic meridian.

The vertical component of the earth's field at Roorkee is approximately ·34 oersteds, and the horizontal components in the NS and EW directions are approximately ·38 oersteds and ·03 oersteds respectively. The required values of current in the 3 coils would therefore be of the orders of 185 amperes, 190 amperes and 18 amperes.

The details of the present set up of the Helmholtz coil and the field produced by them given in the table below :

	Orientation	Diameter	No. of turns of 27 SWG superenamelled copper wire	field/ per ampere
1	2	3	4	5

1	2	3	4	5
Coil 1	Horizontal	115.9 cm	100	1.543 oersted
Coil 2	Vertical NS	91 cm	"	1.997 "
Coil 3	Veritcal EW	106.7 cm.	"	1.657 "

Calibration

The instrument can be calibrated by the application of an artificially produced field by means of a single loop of wire carrying a known current. Alternatively a magnet of known strength placed at a fixed distance from the magnetic system, can be used to calibrate it.

C_H_A_P_T_E_R IV

ANALYSIS AND REPRESENTATION OF THE DIRECTIONS.

The directionsof N.R.M. are generally studied with a view to obtaining information regarding the ambient field. The directions observed in rock bodies do not coincide exactly. Some times these are closely grouped, sometimes highly dispersed. Because of this variability it is necessary to condense this information in terms of statistical parameters of comparative value. An estimate of the mean direction of magnetisation of rock units provides a measure of dispersion of individual results about the mean direction and as well as of the accuracy with which the mean is estimated. Estimates of the mean direction are the basic information needed for the study of variations of the earth's field.

Sampling Scheme : – In any particular study large number of oriented samples are collected from a formation which is recognised on geological grounds as a single unit such as a set of sedimentary beds, lava flows or intrusives. Oriented samples are collected from all available exposures which are termed as localities or sampling sites. Generally more than one sample is obtained from each site in order to study variations within the site. Several specimen are of-ten prepared from each oriented sample in order to study the variations within a sample.

The sampling schemes are of heirarchical type comprised of two or more levels. In one of the simplest schemes one oriented sample is obtained from each locality and one specimen is obtained out of each sample. Further levels may occur when several members are recognisable within a rock unit. The specimen are obtained from several sites in each member.

Representation of the direction : — Every direction is represented by a vector of unit length drawn in polar coordinates. The results may refer to a horizontal or tilted bed, but it is necessary for purpose of analysis to refer them to a horizontal at the time of formation by applying corrections using trignometrical or graphical methods. The strikes and dips of the formation are estimated at the site.

The directions are plotted on an equal area net. In most cases a polar projection is used. The primitive of the net is chosen to be a horizontal plane either the existing or the estimated horizontal plane at the time of formation. The directions are plotted in such a way that lines through the respective plots and the pole of the net, make angles equal to the Declination of the sample represented. The distance of point from primitive is proportional to the inclination or radial scale. Hypothetical figure 4.1 shows a set of point directions (Dn,In).

Source of Dispersion : — The dispersion may arise due to

(1) Errors inherent in the palaeomagnetic methods.

(2) Due to variations of the ambient fields.

In order to ensure a correct analysis it is necessary to over come the palaeomagnetic errors. Several errors of this type are listed below :

(1) errors may arise due to errors in orientation or those

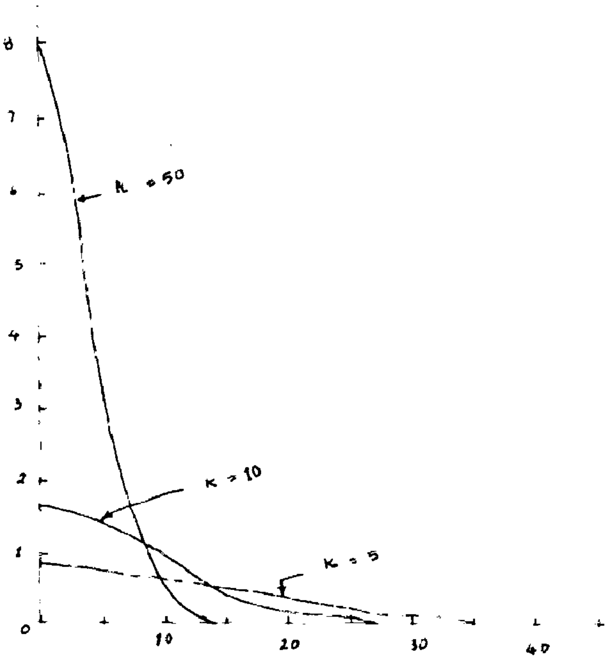


Fig 4.2 VERIATION of θ WITH PA FOR DIFFERENT VALUES OF K

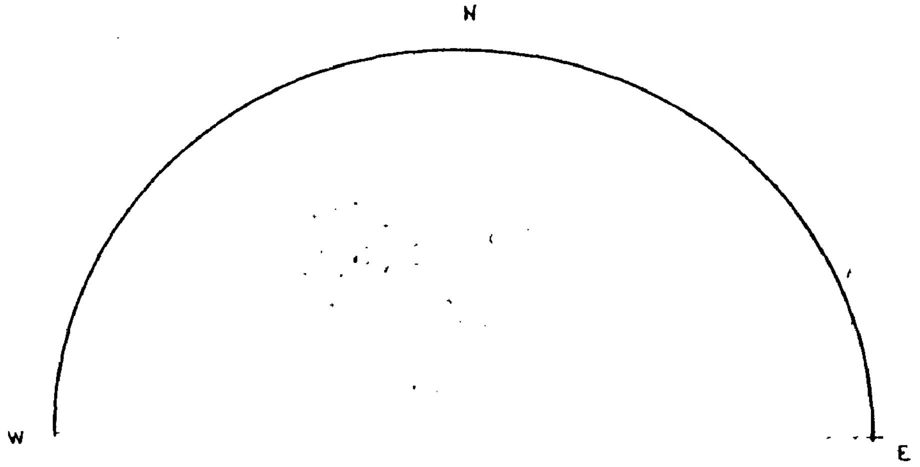


Fig 4.1 DIRECTION OF FOSSIL MAGNETISM SHOWING A CLOSE GROUPING

incurred at the time of measurement. Generally the cumulative errors of this type are between 2' and 5'.

(2) errors may also arise due to failure of rocks to magnetize themselve exactly in the direction the ambient field. Possible cause for this type of error are compaction in sediments and anisotrophy in igneous rocks.

(3) The direction of primary magnetization may be subsequently modified by strong secondary components.

(4) An incorrect estimate of the initial horizontal plane of the rock formation may lead to dispersion.

(5) The alignment may be limited by a fundamental noise level different for different rock types.

(6) If the time span of the collection of sample at the collecting site is great, compared to the rate of Geological or Geomagnetic process, the dispersion may arise.

(7) The variations of the field during the time span, between the magnetisation of different levels of the same formation, may contribute a component of scatter.

If the component of scatter arising from these sources are each denoted by precision parameter K_1, K_2, K_3 ....K_n. The overall precision K_o of the direction in a rock crust is given by

$$\frac{1}{K_o} = \frac{1}{K_1} + \frac{1}{K_2} + \cdots + \frac{1}{K_n} .$$

In order to remove the palaeomagnetic errors various statistical methods are used, which are given below :

Fisher's distribution :- Fisher (1953) gave a method for dealing with the observation of position lying on a sphere. Suppose that N directions are known. The direction cosine (l_1, m_1, n_1) of the ith direction (Di, Ii), regarded as unit vectors are .

$$li = \mathrm{Cos}\,Ii\ \mathrm{Cos}\,Di, \quad m = \mathrm{Cos}\,I'\ \sin Di.$$

$$n_1 = \sin I.$$

Fisher suggested that individual point direction on the sphere will be distributed with probability density

$$P_A \cdot dA = \frac{k}{\pi \sin hk} \cdot e^{K \mathrm{Cos}\,\theta} \sin \theta\, d\Sigma\, d\theta$$

Where (Σ, θ) are the polar coordinates of element of are dA, θ being angular departive from the mean direction and the azimuthel angle.

The density is axially symmetrical about the true mean direction Σ being distributed uniformly through out 360°. The probability of finding a point in the belt between θ and $\theta + d\theta$.

$$P_\theta \cdot d\theta = \frac{K}{2 \sin hk} e^{K \mathrm{Cos}\,\theta} \cdot \sin \theta\, d\theta.$$

The parameter K pepresents the precision of the point. From the study of the above equation. If K = 0, the points are uniformly distributed and the direction are random. For very large values of K they are confined to a very small portion of the sphere in the vicinity of the mean direction. The distribution is illustrated in figure 4.2 for different values of K.

C H A P T E R V

SUGGESTIONS AND CONCLUSIONS

At the time of their formation, rocks acquire a primary permanent magnetization in the direction of the prevailing earths field. Subsequently they may be subjected to local heating and other Geological processes which cause it to acquire a weaker and less stable secondary magnetization. It is now well realised by workers on pālaeomagnetism that except for a few cases, most rocks possess this secondary spurious or viscous magnetization. Thus investigation of rocks which possess secondary magnetization may lead to in consistant results unless accounted for. It is therefore necessary to study the stability of the magnetization of rocks critically. Removal of the spurious magnetization thus becomes a necessary step before computing the mean direction of femanent magnetization.

For a long time no tests were available to assess the magnetic stability of the rocks apart from the indications of consistency of magnetization in a rock formation. For the removal of the weaker secondary components which introduce's a great deal of scattering in the data, two types of techniques are available, both having their merits and demerits. One of these is the alternating field demagnetization, and the other is thermal demagnetization. The process of removal of secondary components is referred to as cleaning of the sample.

A.C. Field Demagnetization

The alternating field demagnetization technique was developed by Creer at New Castle and Shahasrabudhe and Radhakrishnamurti with Clagg and Wilson at Imperial College London in 1957. Both these instruments are similar in principle but differ in design and construction.

The important part of the Alternating field demagnetization apparatus is a specially designed perspex specimen holder which is capable of rotating simultaneously in two perpendicular planes, placed at the centre of a demagnetizing solenoid. The frequency of rotation are respectively one and two cycles per second in the vertical and horizontal planes; this is achieved by a motor. The demagnetizing coil system consists of two separate solenoids which are held convenient distance apart so as to allow free rotation of the specimen holder. In these demagnetizing coils the peak fields at the centre of system are of the order of 150 oersteds per ampere. The D.C. resistance of the coils is of the order of 50 ohms and the coils take up a maximum current of over four amperes when 230 volt A.C. mains is fed to them. In this set up peak fields are of the order of 150 oersted per amperes. In practice, for magnetic cleaning of the rocks, the specimen are demagnetized first at 75 oersted and then at 150 oersted peak fields. Some soft secondary components can be removed in as low as 25 oersted peak fields (S-1). The entire assembly of coils and the specimen holder is mounted at the centre of the three pairs of Helmholtz coils, which provides the field free space.

Thermal demagnetization

Wilson in 1961 developed the technique of thermal demagnetization. The apparatus consists of a nonmagnetic furnace placed underneath an astatic magnetometer. The essential part of the furnace is the heating element which is made of pure platinum wires wound on quartz tubes and is held in position by Mica sheets. A hole is provided at the exterior of the furnace to handle the specimen. The rock specimen to be heated is placed on a porcelain tube which also carries a thermo-couple to register the temperature. The specimen can be rotated round a horizontal axis with an aluminium screw driver which is inserted through the hole provided at the exterior of the furnace (5 - 11).

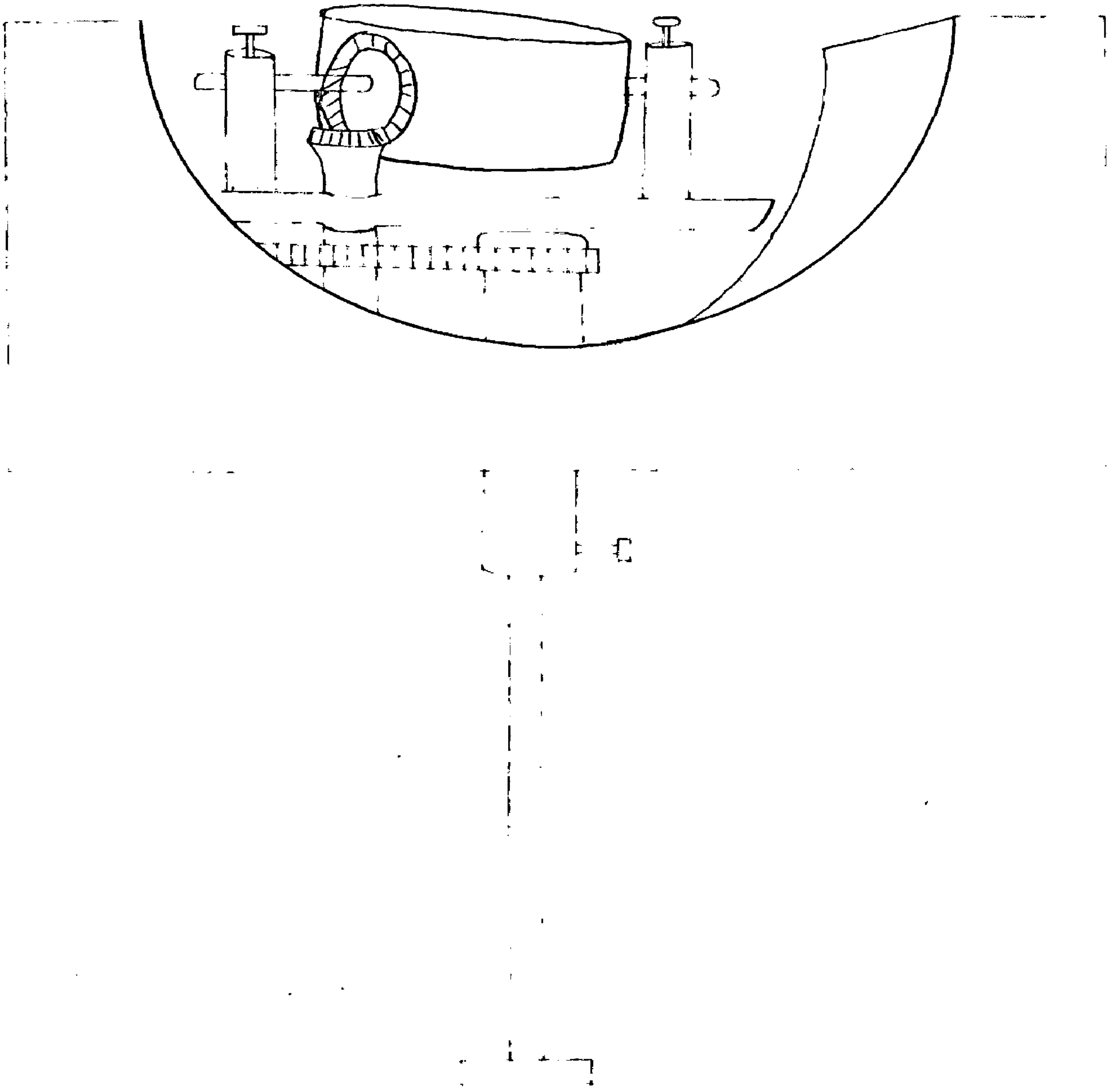
Relati~~ng~~ve merits and demerits

Generally speaking both the techniques are equally effective. However a critical comparison of these is of interest. Wilson found that whilst he could remove secondary magnetization from laterite smaples by thermal cleaning he could not do so by alternating field technique. He therefore concluded that when secondary components are partial thermoremanent magnetization, the secondary magnetisation can not be removed without destroying the primary T.R.M. at least in part. Thermal cleaning of the sample is therefore advantageous in such cases.

The techniques for cleaning, the samples have not yet been developed in the department owing to the time and resources consumed by the main set up. These, however can also be fabricated at Roorkee. A sketch of the A.C. demagnetization system is given in figure 51 .

The measurements of direction and intensity of permanent magnetisation are usually done either by an astatic or by a spinner magnetometer. The only type of instrument which appears capable of challenging the sensitivity and facility offered by the above two types of instrument is the resonance magnetometer which was designed and constructed by Kawai in Tokyo. The improvement of the astatic magnetometer by means of an electronic feed-back system is a further possibility towards sophastication in the future.

The instrument and measurement as described in earlier chapters are concerned with the principal outstanding problem in the subject today, namely the origin of magnetization of sediments, the cause of reversal of magnetization and better methods for eliminating the second-



CLOSE UP OF THE SPECIMEN HOLDER IN AC FIELD DEMAGNETIZATION ary components in order to reveal true nature of the fossil magnetization. For these purposes various techniques have been employed such as oremicroscopy, separation of ferromagnetic grains, X-ray methods, electron microscopy, neutron diffraction etc.

The fundamental information obtained from the palaeomagnetic measurements is the direction and intensity of magnetization. Reduced observations for palaeomagnetic errors are applied for the study of problems related to structural geology, stratigraphy, palaeogeography, continental drift and polar wandering and origin of certain special deposits. The present attemps are directed toward the use of palaeomagnetic observation in problems relating to engineering geology and Himalayan geology as several investigations are engaged in various aspects of these problems in this department.

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