PART - 1

1.1 Experimental set up of Proton Precession Magnetometer at Ahmedabad.

1.2 Comparison of geomagnetic field as recorded by the Proton Precession Magnetometer at Ahmedabad with the field recorded at magnetic observatory at Alibag.

1.1 Experimental set up of Proton Precession Magnetometer at Ahmedabad

INTRODUCTION

The phenomenon of nuclear magnetic induction is the basis of the development of nuclear precession magnetometers. Bloch (1946) observed that the direct observation of nuclear magnetic induction should be possible. Purcell (1952) remarked in his Nobel lecture about his looking on snow with new eyes "There the snow lay around my door-step - great heaps of protons quietly precessing in the earth's magnetic field". However it was left to Packard and Varian (1954) to translate Purcell's remark into an instrument for the measurement of geomagnetic field intensity. Waters (1955, 1958) constructed a Magnetometer based on the phenomenon of precession of protons in the earth's magnetic field.

Principle of operation

About 500 c.c. of water is subjected to a polarizing magnetic field of about 100 oersted for a few seconds. The polarizing field is approximately perpendicular to the geomagnetic field. When the polarizing field is suddenly switched off the protons in the water precess about the earth's magnetic field vector with a frequency proportional to the ambient magnetic field intensity.

$$\therefore \quad 2\pi f = \gamma F \qquad \ldots\ldots\ldots(1)$$

where f is the precession frequency of protons.

γ is the gyromagnetic ratio of protons.

F is the ambient magnetic field.

The value of the gyromagnetic ratio (γ) for the proton has been measured by Driscoll and Bender (1958) to be

$$\gamma_p = 2.67513 \pm 0.00002 \times 10^{-4} \text{ gauss}^{-1} \text{ sec.}^{-1}$$

The expression (1) reduces to

$$\frac{F}{f} = \frac{2\pi}{\gamma} = 23.4874 \qquad \ldots\ldots\ldots(2)$$

An accurate measurement of f the frequency of precession leads to a precise determination of F the ambient magnetic field. The frequency of precession is 4257.60 ± 0.03 cps per gauss.

Theory

The quantum mechanical description postulates the emission of quanta of energy as the protons flip from one quantized state to another. Zeeman splitting of the proton energy state in a uniform magnetic field leads to parallel and antiparallel states of magnetization amongst the proton population. The transition between these two states occurs at the resonance radiation $h\nu_0 = \frac{\mu F}{I}$ where μ is the proton magnetic moment associated with its angular momentum. Ih due to the single spin state $I = \frac{1}{2}$. The angular frequency of the resonance radiation is linearly related to the field by the expression

$$\omega_0 = 2\pi\nu_0 = \gamma F.$$

The above expression is the same as expression (1). Between the two energy states the probability of a transition to a lower energy state from a higher energy state is by far larger compared to the reverse action. The number of protons excess in the lower energy state is proportional to the magnetic field intensity. If the proton population is abruptly transferred to a smaller ambient field from a much higher magnetic field then a redistribution of proton population between the two energy states will take place. The transition frequency and the previously mentioned frequency of the proton precession are identical. A rigorous quantum mechanical treatment of this principle can be found in the works on nuclear resonance. viz. Andrew (1956), Pake (1958).

Hall (1962) has derived the following expression for the induced proton precession signal on the basis of the quantum theory.

$$V = K_1 \vartheta M_o^1 \sin^2\theta \sin \omega_o t \quad \exp(-t/\tau_2) \, ..(3)$$

Expression (3) shows that the induced signal of magnitude V at a Larmor angular frequency ω_o is proportional the coil constant K_1 the volume of fluid ϑ, the net magnetization M_o^1 attained during the time t for which the external magnetic field was operating and to the term $\sin^2\theta$ where θ is the angle between the axis of the coil and the ambient magnetic field F. The induced signal decays exponentially and the rate of decay depends on the relaxation time T2 of the protons in the sample fluid. The relaxation time determines the duration of the nuclear precession signal and is known to be different for different proton sources.

Description of the equipment

The proton precession magnetometer constructed at the Physical Research Laboratory, Ahmedabad is described in the following. Shirke (1964) has given the details of construction for this equipment. The block diagram of the set up is given in Fig. 1 and some of the operational details are given below. Each block has been described later in further detail. The magnetometer unit

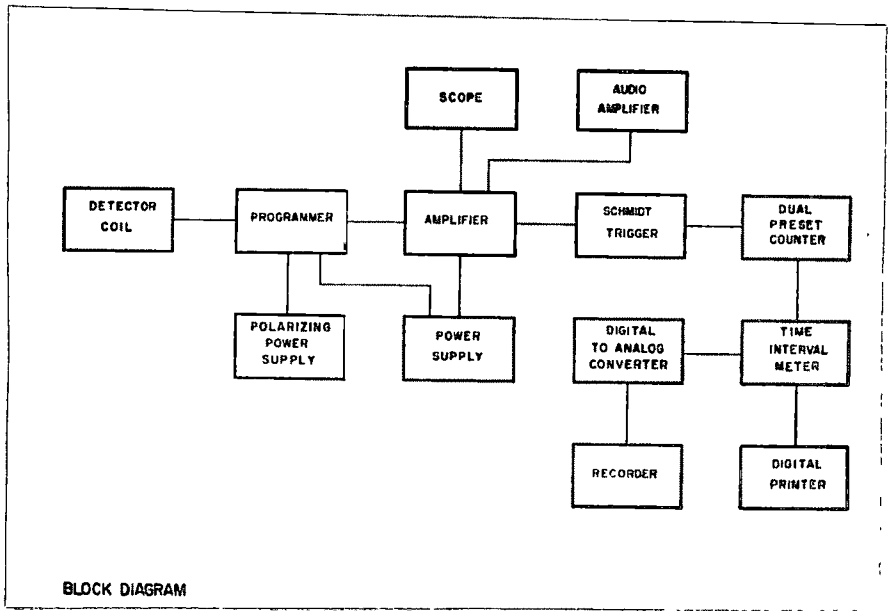

Fig - 1

consists mainly of the following units, a programmer, a detection assembly, a frequency measuring unit and a recording system.

The sensing coil is suspended in a vessel filled with kerosene. The coil is kept fully immersed in kerosene with its axis in the eastward direction. The coil assembly is located about forty to fifty feet away from the building where in the electronic units are housed. Besides separating the coil from the RCC structures it is lifted above the ground level by about one metre using a wooden stool. Firstly current of about five amperes is passed through the coil for about five seconds, a time sufficient to polarize a large number of the protons in the sample. The current is then suddenly switched off and the coil connected to the amplifier. The gradually decaying precession signal induced in the coil is usually of the order of a few microvolts and has to be brought to a convenient magnitude of a few volts for a successful measurement of the frequency of precession. The remaining circuitary is therefore for the precise measurement of the frequency of the precession signal. The error of one cycle in the measurement of the precession frequency corresponds to an error of about 23 γ in that of the magnetic field which is sufficient to obliterate the daily variation in the total geomagnetic field intensity. An elaborate frequency measuring system is therefore employed leading to an accuracy of $\pm 1 \gamma$ in the measurement of the geomagnetic field intensity.

Detector assembly

The detector assembly consists of a coil and a sample fluid rich in proton content. Water is the most suitable sample for ground based magnetometers. It has got a convenient relaxation time with a facility to alter the same by the addition of certain paramagnetic salts. Moreover the gyromagnetic ratio of protons for water is known with a high degree of accuracy. The duration of the precession signal can be lengthened by removal of dissolved oxygen from the water. At the Physical Research Laboratory kerosene is used as the proton source. Kerosene is preferred to water in this system because kerosene does not give electrolytic action even when the coil is immersed in the same. The gyromagnetic ratio for kerosene is believed to be close to that for distilled water. Other than water and kerosene there are fluids which could be used as a source of protons. The values of the relaxation time T_2 are listed for a few known fluids.

Water	- two to three seconds
Kerosene	- about two seconds
n-heptane	- five to six seconds
Benzene	- eighteen seconds.

The coil wound from enammeled copper wire is used for polarizing the protons in the sample fluid as well as for detecting the precession signal. Two forms of the coil design are normally observed.

(1) A simple solenoidal form

(2) Toroidal form in which the wire is wound on a hollow acrylyc ring.

Toroidal winding is normally more difficult however it picks up less noise generated in the vicinity of the coil. Some of the major requirements for the construction of a good coil are stated below.

(1) The coil should have a large number of turns to obtain a large signal.

(2) It should have a high **Q** so as to avoid excessive noise.

(3) It should have a large volume within so as to accommodate large sample.

(4) It should be capable of producing a uniform polarizing field.

In the instrument designed at the Physical Research Laboratory detecting element consists of a pair of copper coils connected in series bucking. This arrangement is found to reduce pick up from noise sources situated outside the coil assembly. Each coil is wound with a twin wire with S.W.G. 18 gauge. Each coil has 500 turns of double wire. The winding length of each coil is five inches and the inner diameter of the coil is also of the same dimension. The series bucking combination of the two coils with a total of 2000 turns offers a resistance of 2.6 ohms and gives an inductance of 40 mH. The coil assembly is rather big in size but generates a polarizing field of a few hundred gauss by passing a current of four to five amperes giving a signal well above the noise level. Initially each of the coils were wound on a former and the former removed carefully thereafter. The coil was indirectly warmed to remove any absorbed water vapour. Before the coil could reabsorb water vapour it was given a thick coating of araldite.

Amplifier and Schmidt trigger

The voltage induced in the coil due to the precession motion of protons is of the order of a few microvolts. This signal voltage suffers some attenuation in the forty to fifty feet long cable connecting the coil to the amplifier. To bring the microvolt signal to a workable level of a few volts a high gain low noise amplifier is necessary. Such an amplifier should be protected against microphonics and should have a stabilized gain.

The circuit diagram of the amplifier used is given in Fig. 2. The circuit is the same as designed by Tepley (1961). It is a three stage RC coupled amplifier, the fourth stage is a cathode follower output. The input circuit of the amplifier consisting of the sensing coil is tuned by means of a condenser to resonant frequency of 1885 cps which is close to the precession frequency normally observed at Ahmedabad. Another tuned circuit is introduced at the input end of the third stage. The band width of the amplifier is considerably reduced by

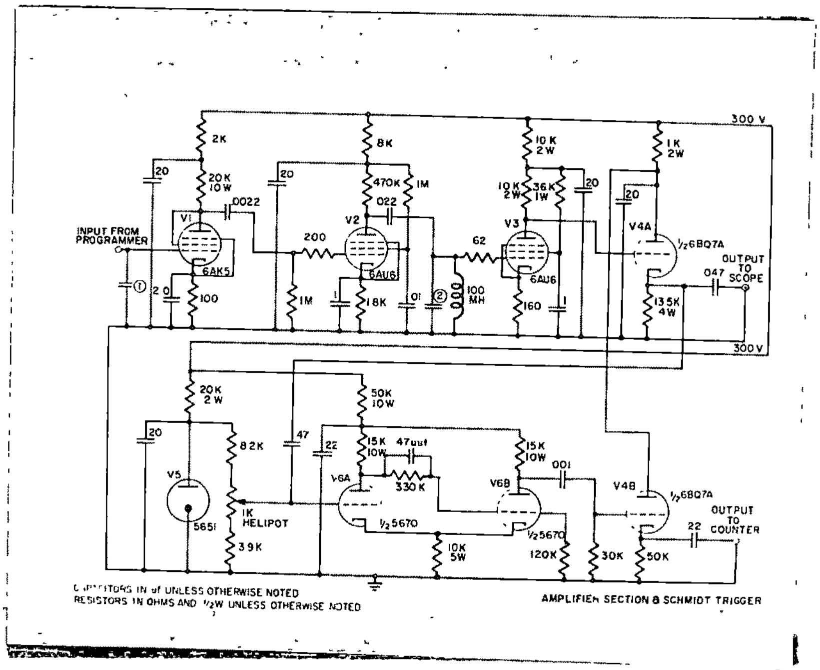

Fig -2

means of the two tuned stages. The first stage tube of the amplifier is mounted on a rubber grommet. This helps reduction in microphonic noise to a great extent. Proper negative feed back incorporated in the amplifier stablizes the amplifier gain. The overall gain of the amplifier is of the order of 120 db. The output voltage falls exponentially and mixes with the noise in a second or two. The signal to noise ratio of the amplifier is fairly high.

Following this a Schmidt trigger circuit is used so as to give pulses with sharp rise time. One such pulse corresponds to each of the sinusoidal wave from the precession signal. The circuit is shown in Fig. 2. The circuit consists of a cathode coupled multivibrator giving a square pulse corresponding to each sine wave fed to it. It could be adjusted to give its leading edge when the sine wave is passing through its mean value. For this setting the effect of a given noise amplitude is minimum in determining the time interval between a fixed number of wavelength of the precession signal. Hence the Schmidt trigger circuit determines the accuracy of the field measurements. Extreme care has to be taken for the stable operation of this circuit.

Dual Preset Counter

The dual preset counter is constructed similar to the design given by Messers Phillips using decatron E1T tubes. It is a fully automatic four decade counter device which will count any predetermined number upto 10000. After the desired cycle of counts has been completed the counter is automatically reset to its starting position and a pulse is produced which operates a relay by means of an additional output stage. The relay breaks the circuit and the preset counter does not receive input pulses. The minimum duration of a complete cycle of counts is 1/3000 cycles. During this operation it issues two pulses first at the beginning of the predetermined count and second at its end.

The output from the Schmidt trigger is fed to the dual preset counter. The counter is adjusted to give two pulses at an interval of 1000 cycles of the (input) precession signal. Further the counter is adjusted to issue the first pulse after rejecting first couple of hundred cycles in the precession signal which might be mixed with spurious pulses due to electrical noise generated by the relays.

Gate generator and gate amplifier

In this circuit a unishot multivibrator is employed to generate a gate pulse. The two pulses provided by the dual preset counter are fed in to the unishot multivibrator. Each pulse will drive the multivibrator from one stable condition to another. This ultimately gives out a square pulse with a duration equal to the total period of 1000 cycles of the precession signal.

The above gate pulse then controls a gated r.f. amplifier. A pentode valve is kept in a cut-off state and gives no output. It gives output only when the gate pulse is fed to the screen grid of the pentode. At the control grid of the pentode a sinusoidal input of 1 Mc/s is fed from a crystal controlled oscillator. The 1 Mc/s signal is now available at the plate electrode of the amplifier only for the duration of the gate pulse which in the present case corresponds to 1000 cycles of the precession signal.

The 1 Mc/s sinusoid output of the gated amplifier is converted into sharp pulses of equal frequency with very small rise time employing another Schmidt trigger circuit.

Frequency Counter

The frequency counter unit consists of six decade counters in succession. Each decade counter consists of four binary stages with a feedback system, simulating sixteen counts for only ten counts at the input of the decade unit. The first counter is specially designed so as to respond to 1 Mc/s input signal. The following decade counters all identical to each other and have an upper limit of counting speed of 120 KC/S. There is a provision in each decade unit to give a stair case output when the circuit is operating. The stair case output is ladder like having ten steps corresponding to counts 0 through 9. The resetting of a decade is done by disconnecting momentarily the grid leak resistance of the right hand sections of the binaries from the earth point. For visual read out ten neon bulbs are appropriately incorporated in the circuit.

Recording Unit

A triplex Evershed Recording Milliammeter is used to record simultaneously the outputs of the three decade units which show the most significant figures in the diurnal variation of geomagnetic field. The stair case output voltages from the decades are fed to the recording meters through proper impedance matching.

A change of one count on a decade representing units in a Mc/s frequency counting system corresponds to a change of 0.08 gamma in the total magnetic field. A change of one count on a decade representation ten, hundred and thousand in a Mc/s frequency counting system correspond to a change of 0.8, 8 and 80 gamma respectively. The channels representing change in a unit step of 0.8, 8 and 80 gamma are recorded on the chart. A sample record chart is reproduced in Fig. 3. The chart speed is 1" per hour.

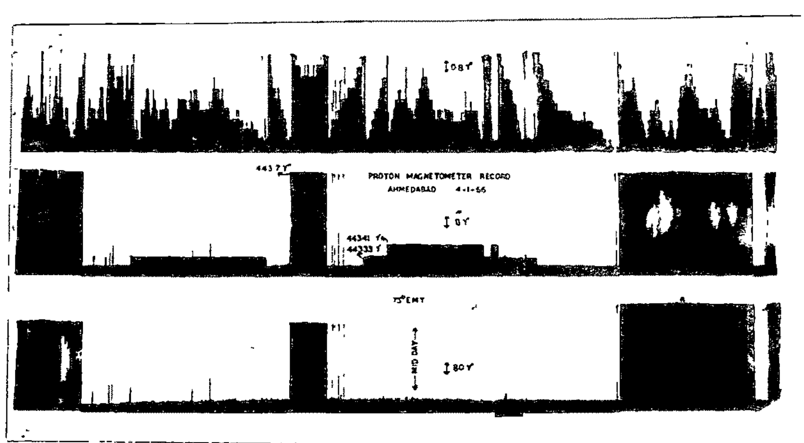

Fig-3

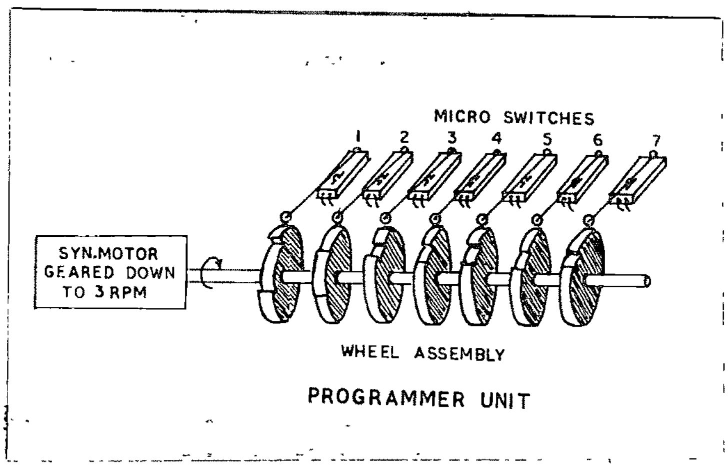

Fig -4

Programmer

The sequence of operation of the various units is achieved through a programmer unit. It consists of a synchronous motor geared down to a speed of one revolution in 20 seconds. This rotates an assembly of Geneva wheels which are given suitable cuts on the periphery so that each wheel makes and breaks a circuit through a micro-switch at appropriate instances in each revolution. The various operations managed by the programmer unit are shown in Fig. 4. The switch No. 2 a relay which keeps the detector coil connected to the polarizer just prior to each sensing for about four to five seconds. As the cam rotates, the polarizer is disconnected from the coil and through another relay operated by switch 1, the amplifier gets connected to the sensing coil. This operates the dual preset counter giving the appropriate gate for passing on the microsecond pulses, derived from the crystal oscillator, to the Mc/s counter. During the period the counting is on switches No. 3, 4, 5 keep three recording meters shorted. Just prior to each sensing switch No. 6 presets the decade counters. Once the counting is over switches 3, 4 and 5 are released and the output of the final three decade counters is recorded on the meters.

1.2 Comparison of Geomagnetic Field as recorded by the Proton Precession Magnetometer at Ahmedabad with the field recorded at magnetic observatory at Alibag

A proton precession magnetometer installed at Ahmedabad has been recording earth's total magnetic field intensity since November 1962. The coordinates of Ahmedabad are given below:

Geographic latitude = 23°01'N

Geographic longitude = 72°36'E

Geomagnetic latitude = 14°01'N

Magnetic dip = 34°N

The total geomagnetic field is recorded at the interval of twenty five seconds. Accuracy of ± 1 γ is claimed in the measurement made by the proton precession magnetometer.

A typical magnetogram record is presented in Fig. 3. of Chapter 1. The record clearly indicates diurnal variation in the total field. The average range of diurnal variation in the total geomagnetic field at Ahmedabad is about 20 γ to 25 γ . During night-time total field intensity practically remain constant, by sunrise it starts increasing, reaches maximum at about midday and later starts falling, reaches night-time value by sunset. In Fig. 1 are shown average Sq variation for

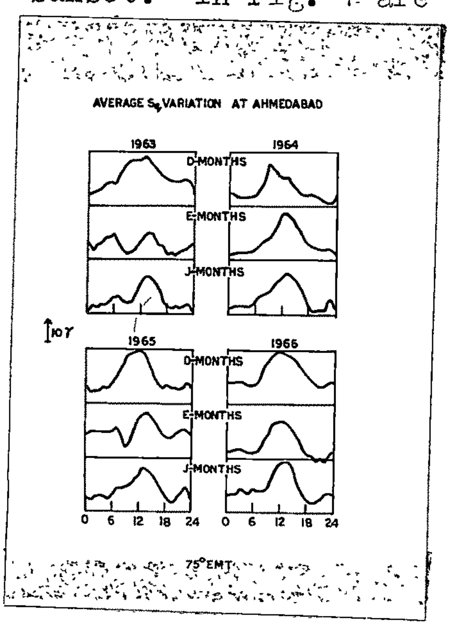

Fig-1

each season for the years 1963, 1964, 1965 and 1966.

The total magnetic field variation observed at Ahmedabad are compared with similar observations made at a standard magnetic observatory of Alibag (18.6°N, 76°E, (Geographic), 24.6° dip). The data used for the comparison are of the year 1964. The magnetic data published for Alibag presents variations in H, D and Z components of the geomagnetic field. For exact comparison with total field observations of Ahmedabad, total field is calculated for Alibag using the relation $F^2 = H^2 + V^2$. For the comparison of the magnetic field variation at the two stations monthly mean Sq variations derived from the five quiet days of each month is considered. In Fig. 2 are shown

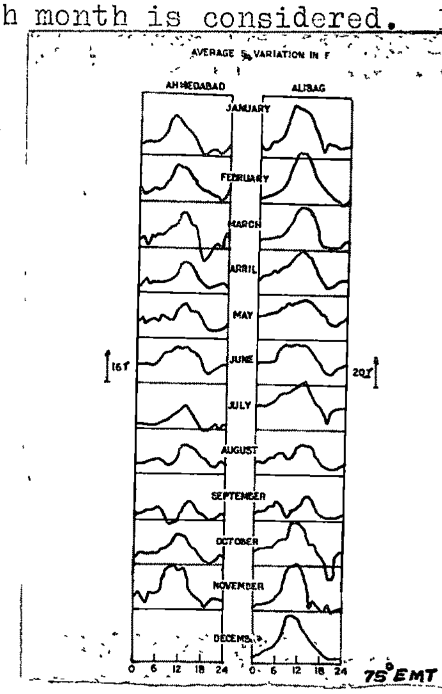

Figure.2.

the Sq variation for each month of the year 1964. At Ahmedabad the data for the December month is lost due to failure of the equipment. It is seen from the diagram that total magnetic field variations at Ahmedabad are similar to Alibag total field variations. The range of daily variation at Alibag is slightly more compared to the range at Ahmedabad. In general the range of diurnal variation in total field is less compared to range in H variation. However the H variation at Alibag and F variation at Ahmedabad are similar in shape. The daily variation curves for a few days with different C_p index are illustrated for both the stations. Refer Fig. 3 and Fig. 4.

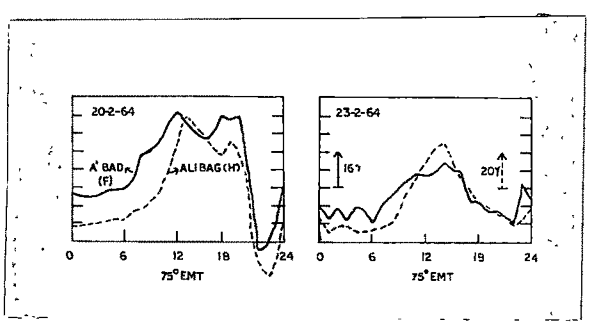

Figure.3.

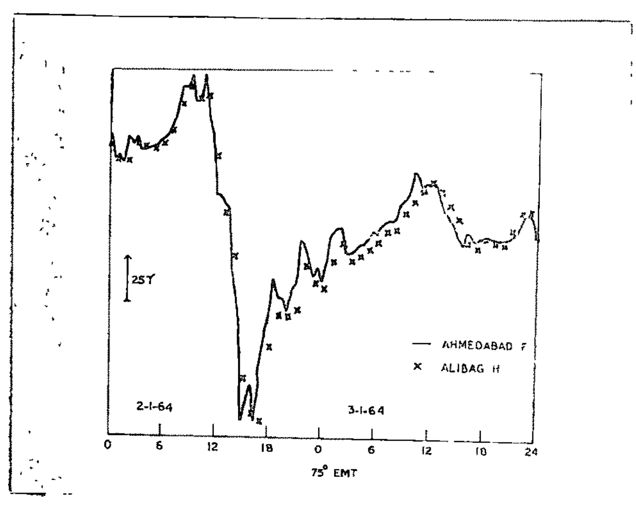

Figure.4.

Besides comparing Sq variation at Alibag and Ahmedabad comparison is necessary for the daily variation on the days having various degrees of disturbances. It is seen above that Ahmedabad F and Alibag H variations possess same character. Here Ahmedabad F and Alibag H data for the year 1964 are grouped according to the following index ranges.

1. C_p value between 0.0 to 0.4
2. C_p value between 0.5 to 0.9
3. C_p value between 1.0 to 1.4
4. C_p value between 1.5 and more.

Magnetic character figures C_p are prepared by the university of Gottingen and published in Journal of Geophysical Research by J. Virginia Lincoln. Average

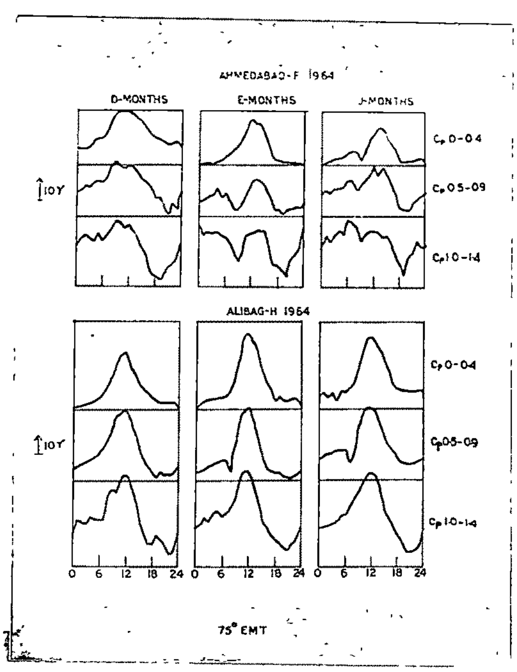

Figure.5.

daily magnetic variation for each group was computed and plotted as shown in the diagram. In the Fig. 5 left hand side it is seen that Ahmedabad F closely follows Alibag H in character and nature.

Several magnetic storms have been recorded at Ahmedabad. In our records sudden commencement does not stand out clearly. The increase in total field is found to be gradual. The storm following SC is determined from the published data of other magnetic observatories. If there is some relationship between the occurrence of magnetic storm and the period of the suns rotation some disturbance will be followed by about 27 days after the initial storm. It is tried to group all magnetic storm with many series of storms following at an interval of about 27 days. We find storms have a tendency to recur at an interval of 27 days. Two disturbances during 1963 were found to persist for seven rotations of the Sun. On most of the other occassions recurrence for three cycles was observed. H.W. Newton (1949, 1950) has pointed out the recurrence feature of the storm of 24-26 January 1949 and also observed a marked resemblance of the repeating storm to the first storm in the same sequence. In certain cases such similarity is observed from Ahmedabad records.

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