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VECTOR PPM SETUP USING FOUR COIL BARKER SYSTEM AND 0.1 nT PPM

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ABSTRACT

The design of four coil (identical air cored) Barker circular coils for producing an extended uniform magnetic field is described. The paper explains in detail how the coil system is interfaced with 0.1nT PPM to make it a complete Digital Vector PPM unit working under computer control. The paper concludes with the comparison of Vector PPM data with that of digital fluxgate magnetometer installed in our Alibag Magnetic observatory.

1. INTRODUCTION

Combinations of circular coils, coaxially arranged are used to generate regions of uniform magnetic field. By installing the proton magnetometer sensor inside such a coil system it is possible to measure the magnitude of the vertical and horizontal components Z and H of the magnetic field vector(Serson[3] 1974). The coil must produce a sufficiently uniform field in the volume of the sensor bottle, otherwise the proton precession signal decays too rapidly for an accurate measurement. After the well known Helmholtz coil, the most commonly used coil systems for vector measurement are those of Braunbeck and Barker[1](1949) ,each an arrangement of four coils. Braunbeck's system has the advantage of requiring the same current in each of its coils, enabling them to be connected in series. But it has a constructional weakness in that outer coils are smaller in diameter than the inner coils.

With all four coils of the same diameter, Barker's coil system is a stable and rigid structure. But the current in the outer coils to be 2.26044 times that in the inner coils. A more stable system is realized if the coils are connected in series and the required ratio is obtained by giving more turns in the outer coils than in the inner coils. The number 2.26044 can be approximated by the ratio 52/23 or 113/50.

Barker coil system described here uses a turns ratio of 52/23 and the wire gauge used is SWG 26.

Proton Magnetometer is basically used for measuring the total field. There are two methods widely used to measure the components of earth's field. These are Nelson's and Serson's methods. In Nelson's method one of the field component is cancelled by applying an equal and opposite field and the remaining component is then measured with the proton magnetometer.

The present system uses Nelson's method for vector field measurement by canceling Z component and measuring H component.

2. WORKING PRINCIPLE OF THE SETUP USING BARKER COIL SYSTEM

The principle of Nelson's method is depicted in fig. 1 (Jerzy Jankowski[4] 1996)

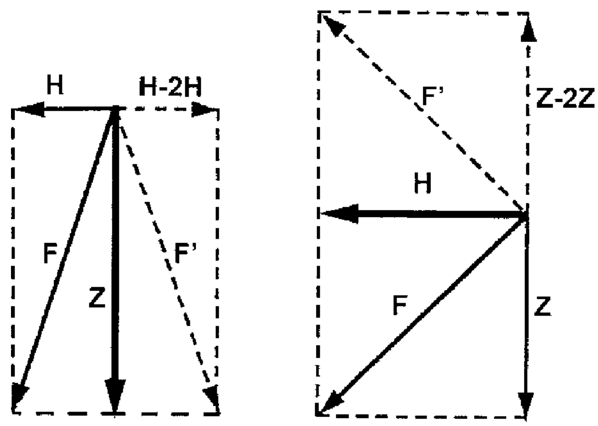

Fig. 1 : The principle of measuring the vertical intensity Z (left) and the horizontal intensity H (right) with a proton Magnetometer, applying Nelson's method where one of the components is cancelled by the coil field. The current to the Compensation coil is found by first making F = F' and then using half of the current for compensation.

Initially field F is measured without passing current. Then current is switched on and increased in such a way that field is decreased to a minimum, then onwards as the current is increased field also is increased. Measure the current when field value F becomes equal to F^1. At this instant of time field equal to -2Z is generated in the vertical direction.. Then the current is halved exactly to cancel the Z component. Now the PPM sees only the 'H' component and measures the same. In Indian Latitudes (H= 40,000 nT min) the change in Z component is of the order of 50 nT on an ordinary day. If the cancellation of Z component is within 90 nT the error in H values calculated is less than 0.1 nT. The system uses a Constant Current Source to generate the current required to cancel Z field. The required accuracy of 0.1nT for PPM is achieved by applying the technique of least square fitting to the data. (A.G. Patil,[5] 2002)

3. FOUR COIL DESIGN SOLUTION

Four identical coils carrying currents in the same sense are symmetrically placed on a common axis. The mechanical design of the coil system was done based on these equations given below. Barker[1] (1949)

$$\frac{\text{Distance of either inner coil from centre of system}}{\text{Radius of any coil}} = 0.243186$$

$$\frac{\text{Distance of either outer coil from centre of system}}{\text{Radius of any coil}} = 0.940731$$

$$\frac{\text{Current through inner coils in series}}{\text{Current through outer coils in series}} = 0.442391$$

Magnetic field at any point along the axis of the coil $B = \frac{\mu_0 I a^2}{2(a^2 + R^2)^{3/2}}$

Where a is the radius of coil, R is the distance of the point from center of the coil and I is the current through the coil in Amperes. The field due to single turn is calculated using the above equation and then the field at the center of the system due to multiple turns of inner and outer coils are calculated. From this the coil constant is calculated and found to be 195nT/mA . To cancel the Z field of 18000 nT, approximately 90 mA of current has to be passed.

4. MECHANICAL FABRICATION

Mechanical fabrication of this coil system was done using the following parameters and the design equations of Barker[1] (1974)

Radius of the coil = 265 mm.

Distance of inner coil from center of the system = 265 * 0.243186 = 64.444 mm

Distance of outer coil from center of the system = 265 * 0.940731 = 249.293 mm

Outer coils have 52 turns and inner coils have 23 turns each. Channels milled on the cylinder are used for winding the coils.

This system is fabricated by casting a cylinder of Special grade Aluminum (non magnetic and with low temperature coefficient of expansion) and machining it to form a cylinder. The construction is exacting and has been done at department of CDM (Centre for Design and Manufacture, Bhabha Atomic Research Centre) where accurate machining was available. In this context it may be mentioned that we are interested in measuring the magnetic field of the

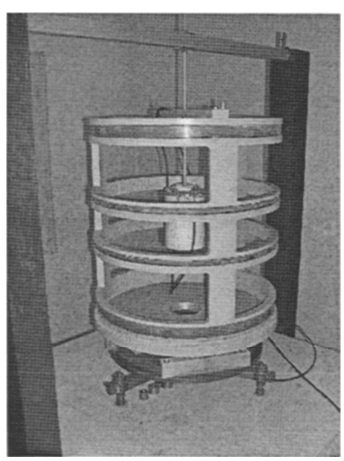

Fig. 2. Picture of Barker coil system installed at Alibag Magnetic Observatory

earth with a sensitivity of 10 ppm.

5. ADVANTAGES OF BARKER COIL SYSTEM

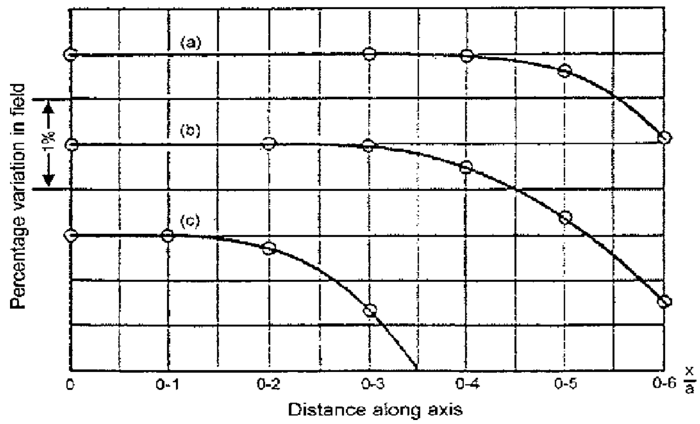

Fig. 3 : Percentage change of field along the axis of coils. a. Four coil system. b. Three coil system c. Helmholtz pair

Though the size of the coil is much smaller. it generates a much larger volume of uniform field. when compared to the Helmholtz coil of same dimension.

6. ERRORS INCURRED IN THE MEASUREMENT OF H

Any maladjustment in bias field in magnitude (Z-Z') causes the measured value H' to be larger than true H. The relation between the two quantities is given by

$(Z'-Z) = [2H (H' - H)]^{1/2}$

If H = 40.000 nT and H'- H = 0.1 nT

then Z' - Z = 90 nT. i.e. 90nT change in calculation of Z corresponds to 0.1 nT change in H.

Error caused in H by mal adjustment of vertical axis of base is given by

dH = Zsina

For Z = 18000 nT and if dH = 1 nT.

Accuracy in vertical axis is to be 12" of the arc. ie error of 12" of the arc in the vertical axis causes change of 1 nT in H.

7. RESULTS

The magnetometer system is installed at ALIBAG observatory and its performance has been tested. The primary objective of the system was to upgrade our VPPM set- up. Data is compared with Digital Fluxgate Magnetometer(DFM) of Danish make with 0.1nT accuracy.

Fig.4 shows the comparison of H of DFM and vector PPM. As can be seen from the plots, the readings are matching well. The scatter is mainly due to the fact that the DFM readings

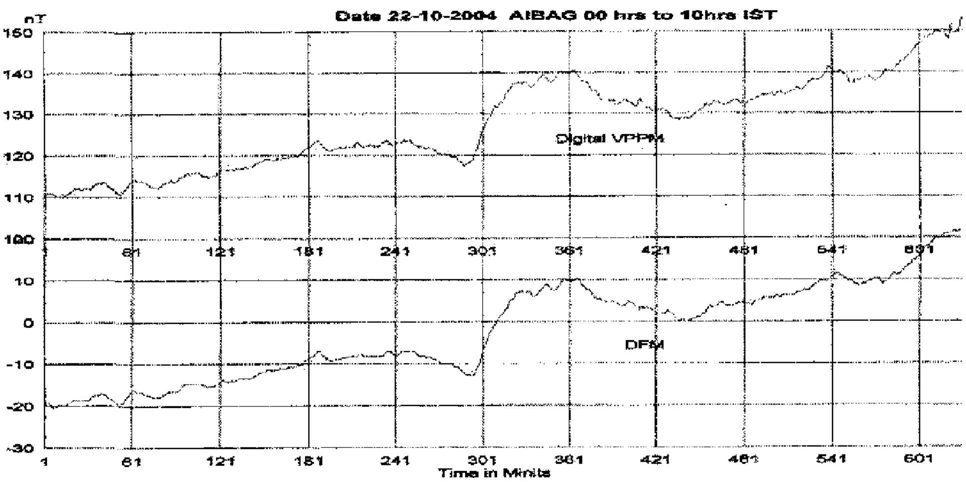

Fig. 4 : A comparison of H values recorded by Digital Fluxgate Magnetometer and the vector PPM setup using Barker coil system.

are basically average of 60 one second readings in a minute, while our system yields only 3 readings to a minute. The graph shows that scatter is well within 1 nT. Standard deviation calculated from the graph is 0.243 nT.

8. CONCLUSION

It can be stated that the newly constructed VPPM set-up performs quite well and yields expected results. The limitation is only of sampling rate. Increasing the Sampling rate would require either cutting down on the Polarization time or change the Magnetometer to a faster sampling variety. Proton Magnetometer can be polarized at a faster rate-say 1 second. However faster rate necessarily shortens the duration of polarization and consequent decline in Signal to Noise ratio. This results in loss of sensitivity and hence is not tenable. The other option is to use Overhauser Magnetometer in place of PPM.

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