Def Sci J, Vol 36, No 3, July 1986, pp 265-271

Peak Height Fluxgate Magnetometer for Measurement of Small Magnetic Fields

B. V. G. K. V. B. V. P. RAO, D. A. V. KRISHNA RAO & G. V. R. S. KUMAR

Naval Science and Technological Laboratory, Visakhapatnam-530006

Received 19 February 1985; revised 25 November 1985

Abstract. In this paper details of peak height fluxgate magnetometer are presented. The instrument can record magnetic fields of the order of one milligauss.

1. Introduction

Magnetometers are of two types those measuring the total field intensity and those measuring a particular component of the field. The former type utilises the magnetic properties of atomic nuclei like the Porton-Precession magnetometer, Alkali Vapour magnetometer etc. Direction-sensitive magnetometers are rotating coil magnetometer, Hall effect magnetometer and fluxgate magnetometer, find wide use in the aspect sensing applications in rockets, satellites and in the measurement of magnetic fields of ships.

The fluxgate magnetometer due to its low power consumption, ruggedness, reliability and simplicity finds wide applications, for example in space applications[1], outer planet exploration like the pioneer mission[2,3] and in Bhaskara satellite[4] and for measurement of magnetic field signature of ships'. The peak height fluxgate magnetometer described here is designed to measure the magnetic field of ships.

2. Principle of PHF Magnetometer

The fluxgate unit (Figs. 1 & 2)' consists of a core of high permeability material like mu-metal or permalloy surrounded by a-drive winding. If an alternate current of sufficient magnitude to drive the core well beyond the magnetic saturation point in

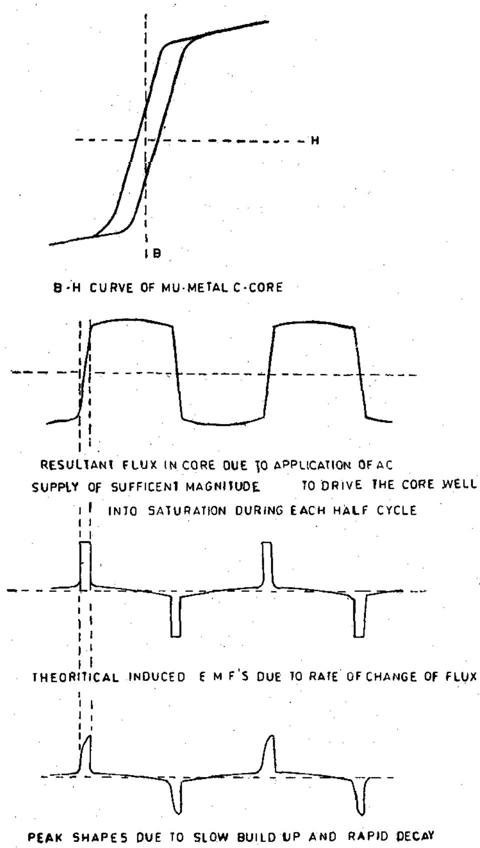

Figure 1. Formation of peaks.

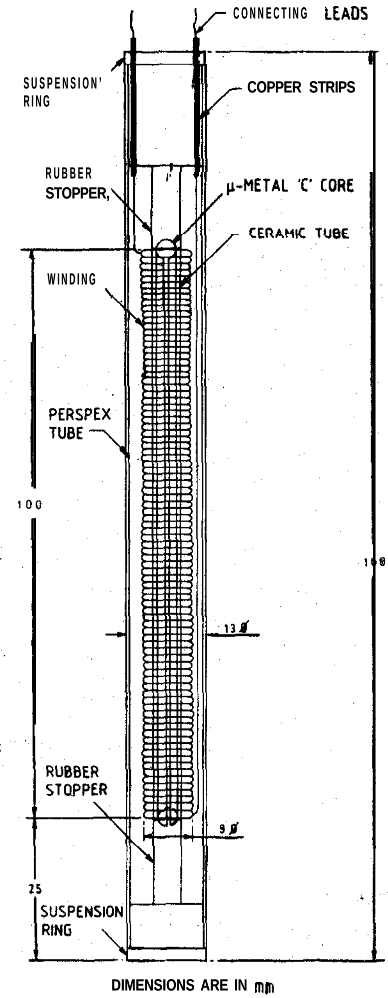

Figure 2. Sensor unit.

both directions is applied to the fluxgate winding, the field in the fluxgate core will be fairly constant during the saturated period and will rapidly reverse when the magnetisation current passes through a non-linear portion. At the instant when the flux reverses from positive to negative and vice-versa an emf is induced in the winding of the fluxgate and resulting emf across the coil will appear as peaks on the applied alternate voltage. However, the emf pulse rises slowly due to the high value inductance of the core at the reversal period and falls rapidly due to the low value of the inductance subsequently.

In a specific application where the small magnetic fields around a ship are to be measured against the background of earth's magnetic field the earth's field needs to be eliminated. For this purpose, two identical fluxgates are connected and driven in antiphase. As a result of this a train of positive and negative pulses of the same size and shape appear at the output of each fluxgate windings. The pulses due to the two fluxgates cancel each other at the output of the bridge. If the phase of excitation of one of the fluxgate is altered by introduction of a shunt resistance the positive and negative pulses due to one fluxgate will be slightly shifted relative to those in the other fluxgate and the resultant will consists of positive and negative pulses of equal amplitude, if the two fluxgates are subjected to the same magnetic field. If the magnetic field acting on one of the fluxgate changes, then the positive and negative peaks will move in opposite direction, since the additional magnetic field cause saturation to be achieved with a lower current in one direction and vice versa.

3. Description of the Equipment

The PHF magnetometer consists of two units (a) the sensor unit and (b) the electronic unit.

3.1. Sensor Unit

The fluxgate sensor unit (Fig. 2) consists of a mu-metal tube of 10cm. long, 0.14cm. external diameter and 0.07cm. thick split along its length to reduce eddy currents. To make split cylinders mu-metal sheets are procured. The mu-metal tubes are fabricated out of the sheets at National Metallurgical Laboratory, Jamshedpur. The mu-metal tube is inserted in the ceramic tube and both ends of the latter are closed by a rubber stopper. On the ceramic tube 500 turns of enameled copper wire are wound and suspended in a perspex tube by means of a suspension ring which press fits into the open end of the perspex tube of 16cm. long and 1.3cm outer diameter. ‘The terminals of the winding on the ceramic tube are brought through the suspension ring and are soldered to thin copper studs for connecting to the cable leads to the electronic console. Sensor units are fabricated for reference on the land and the other for underwater.

3.2. Electronic Unit

The basic block diagram, circuit diagram of PHF magnetometer and electronic system of magnetometer are shown in Fig. 3, 4 & 5 respectively. The various sub-units of the circuit are out lined below :

(1) Oscillator and power amplifier
(2) Bridge circuit, differential and buffer amplifier
(3) Transformer, detector and filter stage
(4) Differential amplifier and variable gain amplifier
(5) Voltage to current convertor
(6) Recorder

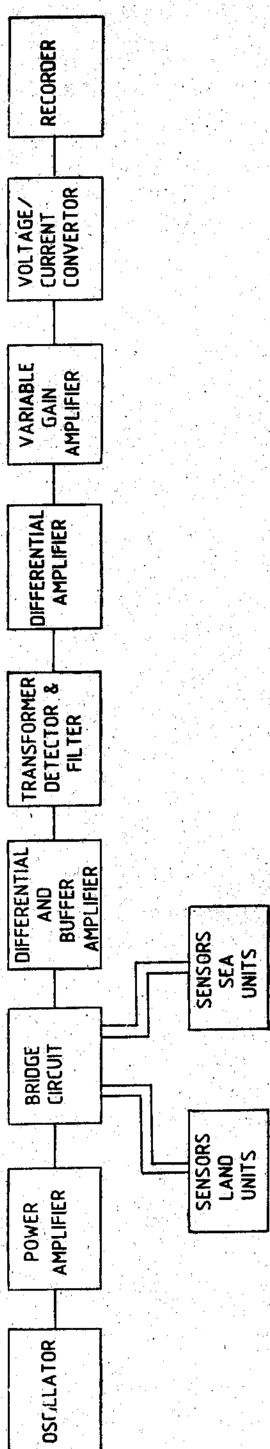

Figure 3. Block diagram of PHF magnetometer.

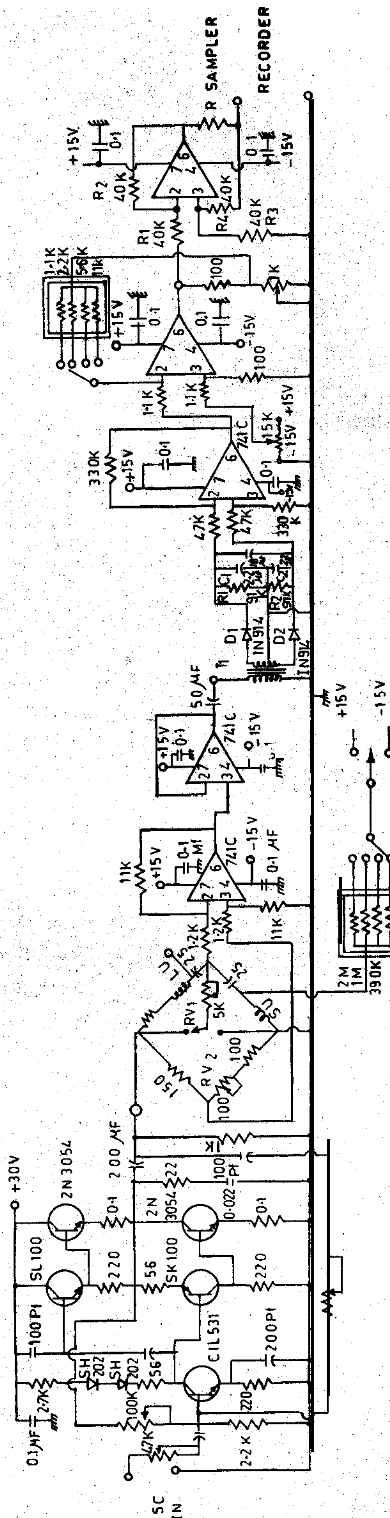

Figure 4. Circuit diagram of PHF magnetometer.

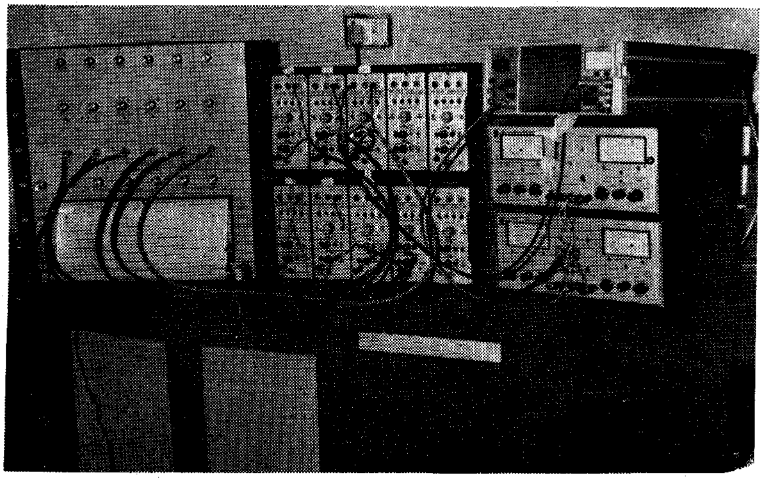

Figure 5. Electronic system of magnetometer.

3.2.1. ***Oscillator and Power Amplifier-A*** 1 KHz signal of 1 volt from a standard signal generator is amplified to about 12 volts which is sufficient to drive the core well into saturation. The power amplifier is transistorized version (Fig. 4).

3.2.2. Bridge Circuit, Differential and Buffer Amplifiers-The bridge circuit consists of two fluxgate sensors forming two arms of the bridge, and one fixed resistance of 150 ohms and one variable resistance of 100 ohms to form the other two arms of the bridge. A 5K ohms potentiometer is connected in parallel with either of the sensors through a change over switch for adjusting the phase difference between the two sensors. The bridge is excited by oscillator and power amplifier (referred above) and the output from the bridge is fed to a differential amplifier.

3.2.3. Transformer, Detector and Filter Stage—The transformer has a centre tapped secondary to provide two antiphase signals for detection and filtering. One monitoring point is provided to monitor the waveform at the primary of the transformer. The correct waveform will be obtained by adjusting the potentiometer (RV1) and (RV2) and is shown in Fig. 4. There are two separate detector stages one for each path, each consisting of one diode IN914 and R & C parallel combination. Two antiphase voltages received from the transformer are separately detected by the diodes D1 & D2 and filtered by R 1 & C I and R2 & C2 respectively. The detector outputs are proportional to the peak heights. The difference between these two voltages is proportional to the field gradients.

3.2.4. Differential Amplifier and Variable Gain Amplifier-The output from the detectors are applied to the input of the differential amplifier where the difference between the two voltages (proportional to the peak heights) is amplified with a gain of 25dB. The output of the differential amplifier is further amplified by a D.C. amplifier.

This amplifier is provided with offset voltage adjustment to make the pen of the recorder at the central position or zero position before measurement of fields. This amplifier is also provided with variable gains 1,2,5 and 10 to amplify the signal applied to its inputs. These gain positions are provided to cover the ranges of 1,2,5 and 10mG. of field gradients applied between land and sea units. These amplifiers are also operated by making use of IC 741T.

3.2.5. Voltage to Current Convertor—The output of the D.C. amplifier is fed directly to the recorder where it records voltages. A voltage to current convertor circuit has to be incorporated between the DC amplifier and pen recorder if it is current recorder. The value of R current sampler can be calculated by making use of the following relationship (Fig. 4).

$$I_L = V_{in}/R \tag{1}$$

where V_{in} = Input Voltage & I_L = Maximum current that the recorder can record and with the condition.

$$R3 + R4 \gg Z_L \tag{2}$$

3.2.6. ***Recorder-The*** output from the variable DC amplifier/voltage to current convertor is fed to the recorder which records the voltage/current which is further interpreted to magnetic fields upto 10mG in steps of 1,2,5 and 10mG depending upon the gain of the DC aplifier. The sensitivities obtained on the recorder are 0.4mG/cm., 0.8mG/cm., 2mG/cm. and 4mG/cm. depending on the gain position of DC amplifier.

3.3 Calibration

For calibrating the instrument a known current is passed through the sea unit to produce different magnetic fields of 1mG, 2mG, 5mG and 10mG. The value of the currents required are calculated by the following relation.

$$H = 4\pi \, nI/10L \tag{3}$$

where H = magnetic field

n = number of turns on the sensor

I = current required

and

L = length of the sensor

Thus different currents are calculated for different field positions.

In practice these currents are derived from the + 15V power supply by using the resistance values obtained by the relation.

$$Z = 15/R \tag{4}$$

Figure 6. A sample record.

Thus these different currents for different magnetic fields are obtained by changing the R values. Similarly by reversing power supply, the field obtained will be in the negative direction.

3.3.1. Magnetic Field Measurement-As mentioned in section 3.2.2 the two **fluxgate** sensors forming the two arms of the bridge are utilised in the PHF magnetometer system for measuring the magnetic field of a ship. For this purpose the sensor is kept in water (These are known as sea units) and other (known as land units) far away in a magnetically clean place. The sea units are incorporated in an underwater tight units. These units are mounted on a framework and the whole framework with the units is laid on the sea bed. The two sensors must be oriented in the same direction for measurement of magnetic field. The system is initially adjusted for zero output on recorder. The ship will make runs over the framework and the magnetic field signature of the ship and will recorded in the recorder. A sample record obtained from the system is given in Fig. 6.

4. Conclusions

The system can record magnetic field of the order of one milligauss. It is found to be stable and free of drift. The system was used to measure the magnetic field signatures of ships for Navy.

Acknowledgements

The authors are thankful to Dr. H.N. Swamy and Sri P. Subbaramiah for their guidance and cooperation.

References

1. **Primdahl, F.,** *J. of Phy. E, Scientific Instruments, 12* **(1979).**
2. **Acuna, M. A., &** *Ness, N.* **F.,** *Space Scie. Instrumentation, 1* **(1975), 2.**
3. **Hedge Cock, P. C.,** *Space Scie. Instrumentation,* **1 (1975), 1.**
4. **Ramanujam, S., Alex, T. K. & Narayana Swamy, V. R.,** *J. Znstn. Electronic and Telecom Engrs.* 25 **(1979)**, 475-478.
5. Sudhakar Menon, M., & Swamy, H. *N., Proc. of the Indian division of IRE, 4* **(1964),** 97-101.