A SHIPBORNE NUCLEAR-SPIN MAGNETOMETER

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The Department of Geodesy and Geophysics of Cambridge University began the development of a nuclear-spin magnetometer for use at sea in 1956 and since then extensive magnetic profiles of the total magnetic field have been obtained with its use.

The principles of operation of this type of instrument are described by Waters and Phillips (1956) and Cahill and Van Allen (1956); the development of this type of instrument for airborne use was made by Varian and Packard.

Briefly, the method consists in measuring the precessional frequency of the protons in a liquid (usually a hydrocarbon, or water) whose magnetic spin axes have previously been displaced from the direction of the earth's field by a superposed field. This frequency is independent of the angle of the spin axis relative to the direction of the Earth's field and is directly proportional to the value of the field. The advantage of this method is that the measurement of the field depends only upon the physical properties of the protons, and precise timing. Further, unlike the fluxgate magnetometer, no directional stabilization is required.

The superposed (or polarizing) field is applied to the liquid by a coil surrounding it. On account of the precession of the protons this coil has an alternating voltage induced in it during the period when the polarizing field is off and before the proton magnetic spin axes are realigned with the Earth's field. This alternating voltage has the frequency of the precession.

The voltage induced in the coil is given by the expression :

$$V = k\,H\,H_e \sin^2\theta\,(\gamma\,H_e\,t)\,e^{-t/\tau}$$

where k is a constant depending upon the apparatus, the temperature and and the physical properties of the liquid.

H is the polarizing field;
H_e is the earth's field;
θ is the difference between the directions of the polarizing field and the earth's field;
γ is the gyromagnetic ratio of the protons in the liquid;
t is the time after the polarizing field is switched off;
τ is the thermal-relaxation time.

In water the value of V is such that $\frac{\gamma}{2\pi} = 4257.8$. This results in the precessional frequency being approximately 2 100 c.p.s. in a field of 0.5 G.

The value of γ for water is approximately 3 sec so that the signal decays to e^{-1} times its initial value in approximately 3 sec. Similarly the relaxation time for the polarizing field is such that, for maximum signal, it must be maintained for at least 5 sec.

The maximum value of V is obtained when $\theta = \pi/2$ but the signal level may still be adequate at angles smaller than this. For example, by maintaining the polarizing field in a horizontal direction, the inclination of the earth's field provides, at all azimuths of the polarizing field, an adequate angle over a wide range of latitudes. In equatorial regions between, say, the latitudes 25° N ot 25° S, where the inclination is small, it would be necesary to maintain the direction of the polarizing field more or less vertical if the signal level is to be adequate at all azimuths.

The details of our instrument are as follows :

(1) The *Bottle* containing the water required for the measurement of the proton precessional frequency consists of a coil of ten layers of 23 standard wire gauge copper wire, of external diameter 4 in, and of length 10 in. This coil is impregnated and closed at its ends with Araldite, and the container thus formed is watertight, non-magnetic, and is filled with distilled water.

(2) The coil is housed near the tail end of a " fish " which is made from fibre glass (plexiglass) tube, of length 5 ft, of 1/4-in wall thickness, and of 4-in internal diameter. The fibre glass tube and the *bottle* are coaxial. This *fish* is provided with a hemispherical nose and cylindrical tail fins and is made negatively buoyant by an internal lead keel which stops the *fish* spinning about the axis of the tube. The end plugs of the tube are made from solid brass, and the watertight seals are provided by two *O* rings inset in the brass.

At the nose end of the *fish* there is a two-staged tuned preamplifier and the two relays for switching the coil from the source of the polarizing current to the preamplifier input. These are kept as far from the *bottle* as possible in order to keep the magnetic field associated with them as small as possible in the vicinity of the *bottle*. The distance is approximately 4 ft; this is not quite adequate where measurements of field strengths are required to an accuracy of 1 γ. Because of this inadequate distance there is a heading correction to be applied which varies over a range of 6 γ. At speeds up to 10 knots, the *fish* swims at a depth of approximately 30 ft when towed 500 ft astern of the ship.

(3) The towing cable is 700 ft in length and enters the *fish* through a tube passing through the centre of the hemispherical nose. The cable is slightly greater than 1/2 in over-all diameter and is sheathed with a P.V.C. (*) skin approximately 0.1 in thickness. The electrical conductors consist of 7 P.V.C. covered flexible copper conductors laid around a P.V.C. covered flexible stranded steel stress core of breaking strain approximately 0.5 tons. The steady towing stress in the cable when the *fish* is 500 ft astern of the ship is approximately 70 lb wt at a speed of 9 knots. In order to

(*) P.V.C. = Polyvinylchloride.

avoid the effects of the ship's magnetic field it has been found necessary to tow the magnetometer a distance astern which is greater than the two ship-lengths.

(4) The precessional signal from the *bottle* is connected to a two-stage tuned amplifier in the ship. This amplifier is of approximately 100-c.p.s. band width and with a centre frequency which can be varied in steps; the output from this amplifier is squared in a Schmitt trigger circuit. The sharp pulses from the trigger circuit operate an eleven-stage binary counter unit; the last stage of this unit operates a *gating* circuit which at the first operation allows the signal from a 100-kc.p.s. crystal oscillator to pass to a six-decade counter unit reset to zero. When the last binary is operated for the second time the *gating* circuit closes and the decade counter units stop counting. The readings on these decade units are inversely proportional to the value of the earth's field. The binary units are reset in such a way that 512 cycles of the precessional frequency are required before the final binary operates for the first time. This ensures that the electrical disturbance due to the switching process does not cause false readings on the decade units.

(5) The digital information from the six decades is recorded by a punch tape machine; the machine also automatically punches at hourly intervals (or at any required time) the minute, the hour, the day of the month and the month. With observations at half-minute intervals, the tape is changed once every eight hours. The tapes allow the reduction of the observations to be undertaken by an electronic computer.

(6) The digital output of the last three (units, tens and hundreds decades) is converted into a voltage which is recorded on a visual potentiometer recorder. This recorder has a synchronous motor drive which is provided with a 50-c.p.s. stabilized frequency supply derived from a 100-kc.p.s. crystal unit. The motor also operates cams for the automatic cycling of the magnetometer. The sequence is as follows and is repeated every 30 or 60 sec :

(*a*) The binary and decade units are reset, and the potentiometer recorder pen drive is switched off

(*b*) The polarizing current through the bottle is switched on for 5 sec

(*c*) The precessional counting process follows (*b*) immediately and lasts approximately 1 sec

(*d*) The potentiometer recorder pen drive voltage is switched on

(*e*) The digital punch tape recorder operates.

(7) The polarizing current is approximately 1.0 A and is obtained from a rectified 50-V supply running from the ship's A.C. mains. It is not necessary that this supply should be electrically smoothed. The polarizing field is approximately 100 G.

REFERENCES

CAHILL L. J. and VAN ALLEN J. S. (1956). High altitude measurements of the earth's magnetic field with a proton precession magnetometer. *J. Geophys. Res.* 61, 547-559.

WATERS G. S. and PHILLIPS G. (1956). A new method of measuring the earth's magnetic field. *Geophys. Prospect* 4, 1-9.