MAGNETIC FIELD DISTRIBUTION MEASUREMENT BY VIBRATING WIRE STRAIN GAUGE

Arutunian S.G., Dobrovolski N.M., Egiazarian S.L.,
Mailian M.R., Sinenko I.G., Sinjavski A.V., Vasiniuk I.E.

Yerevan Physics Institute 375036, Br. Alikhanian St. 2, Yerevan, Armenia

Abstract

Development of a simple and cheep device for measurement of magnetic field spatial distribution is an urgent problem [1-3]. In this paper we propose the method of magnetic field spatial distribution definition by magnetic interaction measurement of probes from known materials. The developed system for such gravimetric measurement of magnetic field gradients partially solves this problem.

PRELIMINARY NOTES

The force of interaction $\vec{F}$ between a small sample of magnetic moment $\vec{M}$ with an external magnetic field of strength $\vec{H}(\vec{r})$ is defined by expression

$$\vec{F} = grad(\vec{M}\vec{H}). \qquad (1)$$

We are mainly interested in two cases: when the magnetic moment is entirely induced and is determined by the magnetic permeability μ of the sample's material and, the second, when the magnetic moment is independent of the external field.

In the first case one has to take into account the proportionality of magnetic moment to the internal field $\vec{H}_i$ of the sample, which in its turn, is determined by the external magnetic field, magnetic susceptibility and sample's geometric form. For sample located in an axially symmetric magnetic field the interaction force is defined as follows [1]:

$$F_z = \frac{\mu - 1}{8\pi(1 + D(\mu - 1))} V \frac{\partial H_z^2}{\partial z}, \qquad (2)$$

where D is demagnetisation factor determined by the sample's geometry.

The force of interaction of a permanent magnet of magnetic moment M_z with an external field H_z is determined by the expression:

$$F_z = M_z \, \partial H/\partial z. \qquad (3)$$

When studying samarium-cobalt magnets in the fields of the order of Earth's magnetic field one also can ignore the induced magnetisation.

The scanning of a probe along the z axis gives an information about the spatial distribution of the interaction force, which restores the gradient of the magnetic field.

EXPERIMENTAL SETUP

Wire Strain Gauge

A specially developed Wire Strain Gauge (WSG) was used to measure the force of interaction between the sample and magnetic field. String magnetometer [2] with some improvements was taken as a prototype. In particular, by special means the lower end of the string with load was fixed in horizontal plane. As strings were used tungsten or beryl bronze wires of diameter 100 μm.

The magnetic system was made on the basis of samarium-cobalt permanent magnets.

An electromechanical generator excites the string oscillations due to the interaction of alternating current through the string with the magnetic field in the magnet gap. A system of forced automatic regulation keeps a stable current in the string.

Mentioned measures allowed to improve the level of relative sensitivity of WSG down to 10^{-5} at the load $\leq$ 3N. Since the magnetometric measurements are done by slow rate scanning, it was necessary to provide long time stability at the level 10^{-5}. A special method of fixation of the string's lower end practically excludes wire's drawing out of clips. Pickup's thermostabilisation allowed to achieve long-time stability during many hours.

Fig. 1 shows a typical behaviour of pickup readings at permanent load 2.25N during more than 64 hours. The temperature of the base was stabilised. with accuracy 0.1^0C. From Fig. 1 one can see that mean square deviation was $6.65 \cdot 10^{-6}$. This value is

0-7803-5573-3/99/$10.00@1999 IEEE.

more promoted than that of known pickups based on measuring of vibrating wire frequency. E.g. in [5]

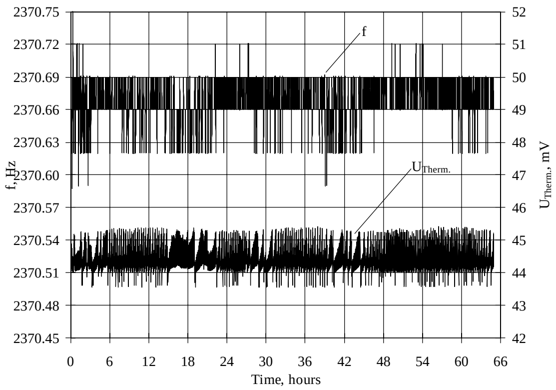

Fig. 1

string pressure pickups of resolution 10^{-4} from measurements interval are presented. String pressure pickups are used in oceanology investigations, and due to some improvement (pickup's thermostabilisation, string's preliminary ageing etc.) the error was lowered to the value $\pm 1 \div 2 \cdot 10^{-4}$ ($\pm 4 \cdot 10^{-5}$ is needed) [6]. The string pickups for measurement of tension in steel and concrete of the firm GeoKon have resolution $\pm 3 \cdot 10^{-5}$ [7].

Probes

Rings from soft magnetic steel, permalloy as well as of samarium-cobalt permanent magnets were used as probes. Usage of ferromagnetic probes in strong magnetic fields entails some difficulties caused by nonhomogenous and non-linear dependence between magnetisation of probes' material and the external field. Since the measurements were done in weak magnetic fields, we had ignored this nonhomogenousity.

EXPERIMENTAL RESULTS

Experiments were done on two types of magnets: composite solenoid with symmetry axis along the z axis and Helmholtz coils system designed to compensate Earth's magnetic field (coils lay in horizontal plane). Each gravimetric measurement was a representation of interaction force between the probe and magnetic field under scanning of z axis. Currents in solenoids and coils were selected to have such a value that the measured values lay in operating range of WSG with optimal range of sensitivity. In case of composite solenoid this current was I=200mA, for Helmholtz coils I=3.1A. Since

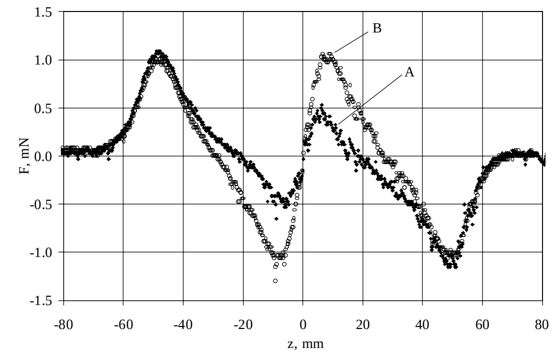

Fig. 2

both systems consist of two separated coils, the measurements were done for parallel and antiparallel currents. Fig. 2 represents the primary experimental results for composite solenoid for parallel (curve A) and antiparallel (B) currents respectively.

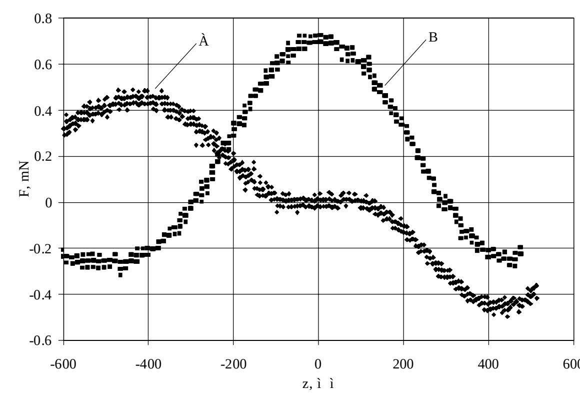

Fig. 3

Vertical axis represents the interaction force in mN. The scanning speed was 0.113mm/sec. A steel-3 ring with inner diameter 3mm, external diameter 13mm and thickness 6.4mm was used as a probe. Signals at going in and out of the solenoid were coincide in satisfactory level (null signals with switched off currents are omitted). The width of experimental track is about 0.1mN and is greater than the resolution of string tension pickup and is mainly caused by swinging of rather big probe in the narrow hole of coils during the scanning. Division of F by the factor $(\mu - 1)V/8\pi(1 + D(\mu - 1))$ gives dependence of the value $\partial H_z^2/\partial z$ on z. In its turn the last function allows to restore the function $H_z(z)$ along the axis of solenoid.

Fig. 3 represents similar gravimetric measurements for Helmholtz coils system (A corresponds to parallel currents, B - to antiparallel ones). Samarium-cobalt magnets were used as probes. Here the track width was about 0.04mN. This is less than that in previous case, since the probes relative sizes were much more less than coils diameter. Presented curves define the Helmholtz coils system magnetic field gradient up to a constant.

PROCESSING OF EXPERIMENTAL RESULTS

Obtained experimental results were processed to define the magnetic field gradients. To find it actually one have to find the factor $(\mu - 1)V/8\pi(1 + D(\mu - 1))$ for probes with magnetic susceptibility μ or magnetic moment M_z for probes from permanent magnet. In principle, one can estimate these parameters using the tabulated values of known materials in use, however, since these factors depend on the samples' shape, finding of these parameters using special calibrating measurements by Hall detectors seemed preferable. Note that measurements done near the experimental points of field's gradient are sufficient.

There are two way to compare the gravimetric measurements with Hall detectors ones: integrate gravimetric curves or differentiate Hall's detectors' ones. Taking into account that during each period of measurement the current trough coils was switched off, the numerical differentiation is preferable, because it uses information of local sections of experimental curves.

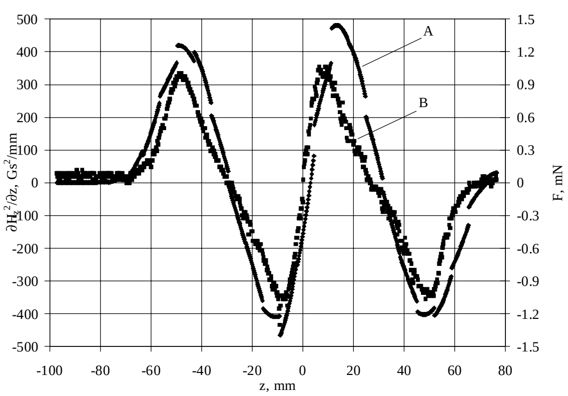

Fig. 4

To calibrate measurements of composite solenoid the experimental results for antiparallel currents were used. Calculation of gradient of magnetic field square using experimental points for composite solenoid was done by numerical approximation of seven groups of currents switching on. Results were compared with gravimetric measurements and are presented in Fig. 4. Such a comparison gives a coefficient of proportionality between gradient of magnetic field square and interaction force equal to 445.48 (Gs^2/cm)/mN with correlation factor 87%.

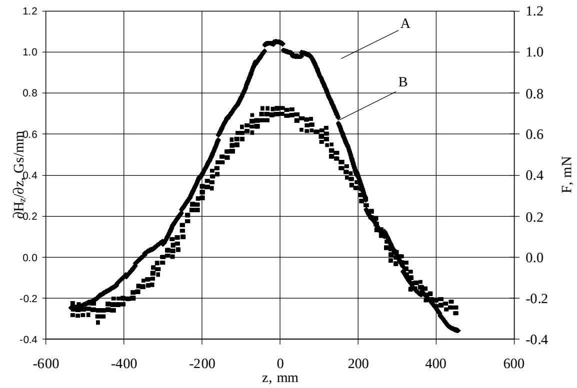

Fig. 5

Similar calculations of the field gradient for the Helmholtz coils system using Hall detector measurements are presented in Fig. 5. In this case comparison with the gravimetric measurements defines the probes magnetic moment of the order of 1.35 (Gs/cm)/mN with correlation factor 95%.

CONCLUSION

This work was aimed to develop and construct a complete system of measurements, although the measurements were done on demonstration samples. Varying of temperature both to the high and low temperatures are possible and will essentially broaden unit's possibilities.

Combination of these method with other measurements of magnetic field characteristics gives a possibility to fulfil sufficiently simple and precise definition of magnetic parameters.

This work was carried out by support of firm HTM Reetz (Berlin), and authors are thankful to Dr. R.Reetz. Authors also thank V.Gavalian and A.Aleksanian for their help.

REFERENCES

1. Methods of Experimental Physics, v.1, Classical Methods, - Ed. by I.Estormann, Acad.Press, 1959, N7, p. 537
2. El'tsev Ju. F., Zakosarenko V.M., Tsebro V.I., String Magnetometer, Trudy FIAN, v. 150, M, 1984.
3. A. Harvey, Proc. Magnet measurement and alignment CERN Accelerator School, Ed. S. Turner (Switzerland, 16-20 March 1992), CERN 92-05, p. 228-239.
4. Tamm I.U. Basics of Theory of Electricity. - M, Nauka, 1976.
5. Asch G. Les Capteurs en Instrumentation Industrielle, v. 1, 2. Dunod, 1991.
6. Kovchin I.S. Autonomous Oceanographic means of Measurement.. - L, Gidrometeoizdat, 1991.
7. Geokon incorporated.- http://www.geokon.com/products.