Measuring Low Magnetic Field in Electromagnetic Flow Meter

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Abstract. *Space distribution of low magnetic field amounting to 1 mT can be measured in detail using a commercial 3D probe with a modified control circuit. The probe was calibrated carefully using a known field from Helmholtz coils. The 3D positioning system enables the measurement of the field distribution. The apparatus was used for measuring the magnetic field of the electromagnetic flow meter. Additional experiments confirmed high reproducibility of results for repeated probe movement. The magnetic field was calculated numerically by the application of Biot-Savart Law for simplified model of magnetic excitation. The agreement between experiment and theory is good, provided that production inaccuracies and limitations of the model geometry are taken into account.*

Keywords: 3D Hall Probe, Probe Calibration, Low Magnetic Field, Flow Meter.

1. Introduction

Magnetic field interactions are used in many technical areas, for instance strong field in small area are necessary for contactless force action and spatially extended field performs forces on charged moving particles in electromagnetic flow meter [1]. In the design and analysis of such devices the magnetic field should be known. As the structure of the devices is complicated, approximated models are used and calculations are made numerically. Therefore, the experimental verification of the models is necessary.

Commercial 3D Hall probes are available, but they are designed for strong magnetic fields [2]. Their use for the correct low field measuring needs reconstruction of the circuit, careful calibration, special data processing and several other precautions. The solution of these questions is a subject of this paper.

2. Subject and Methods

The main problem is to increase the commercial probe sensitivity while its relative accuracy remains unchanged. If the magnetic field is absent, the output voltage is about half of the supply voltage, i.e. 2.5 V. The change of magnetic flux density by 1 mT results in about 0.15 mV output voltage. The quantization error of a standard 16 bit ADC is 25 % in this case. Therefore, high accuracy of the output meter is necessary for accurate low field measurements.

The solution is to use a stable voltage standard for reference voltage, which can be derived from power supply, and measure the voltage difference between probe output and voltage standard. An additional amplifier further increases the probe sensitivity.

In order to ensure accuracy, the new probe control circuit should be calibrated for several values of low magnetic flux density. Linear calibration formula contains sensitivity and offset. The sensitivity can be simply determined by the use of Helmholtz coils, the offset needs an area of zero magnetic field, which can be achieved by a massive ferromagnetic shielding. Another method is to eliminate all other disturbing fields. Earth magnetic field can even significantly distort the results.

Since the space measurement is proposed, it must be fully automated, because of big number of points. Basic block scheme and photographs of apparatus are in Fig. 1. Computer-controlled space positioning system is used for moving the probe. The probe data are digitalized, noise and unwanted signals are rejected (or reduced) digitally and then all the important data are stored in the computer memory for further processing.
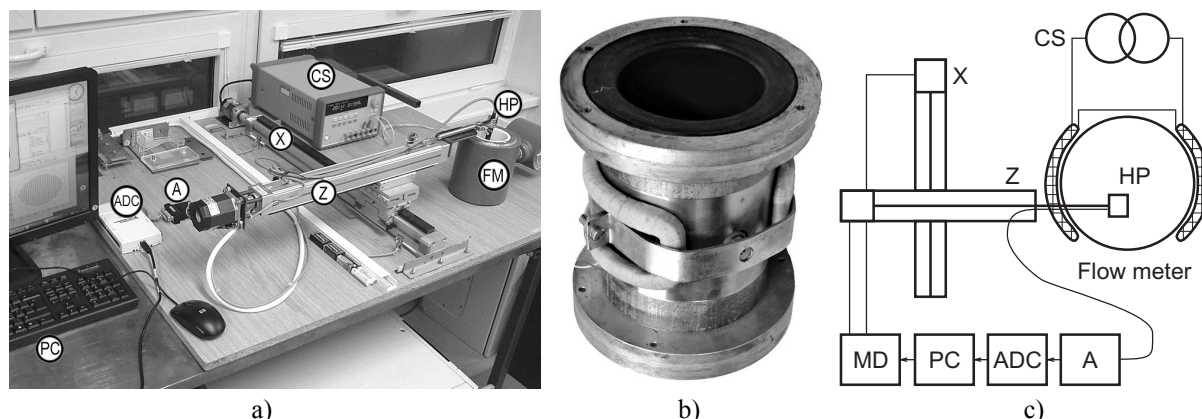

Fig. 1.   a) Realized apparatus, b) Flow meter coil detail, c) Block scheme. Legend: FM follow meter, CS current source, Z and X feed axes, HP Hall probe, A signal conditioning, ADC analogue to digital converter, PC personal computer, MD motor driver.

For the magnetic field calculation, the numeric integration derived from the Biot Savart Law is used. The main problem is to design a good model of exciting currents, since the flow meter exciting coil has a 3D shape that is difficult for exact description. Approximate model uses straight lines and circle arcs for individual conductors. The resulting magnetic field is their superposition. Surface as well as volume currents may be used in principle. A similar approach is presented in the literature [3].

3. Results

For the probe calibration, simple Helmholtz coils were used. Their field uniformity in the central part that was obtained by the numeric integration can be seen in Fig. 2, which shows main and parasitic components. The parameter is the distance from coil axis. The rectangle shows area where the deviation is less than 1 %. The probe sensitivity, obtained by the use of several exciting currents and calculated by the least square method, is 142 µT/mV.
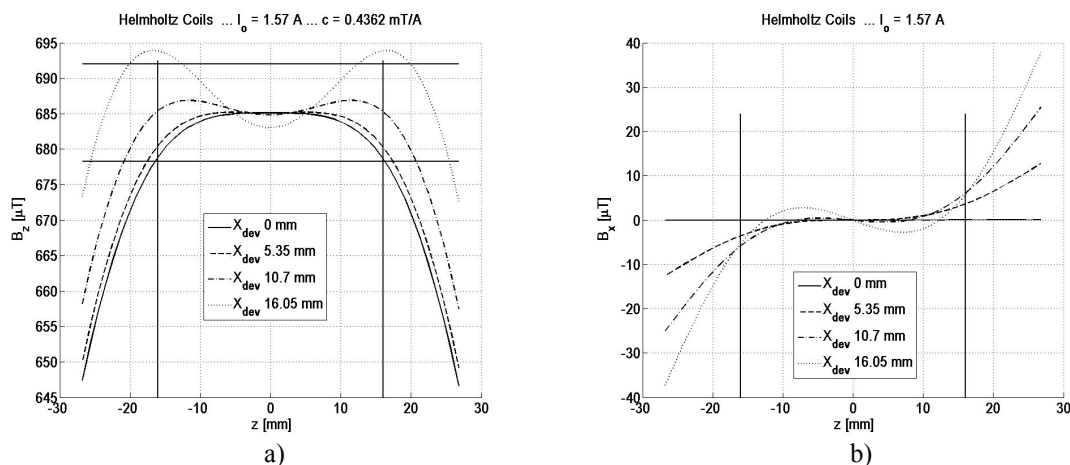

Fig. 2.   Magnetic field in the central part of Helmholtz coils. a) Main component Bz, b) Parasitic component Bx. Area of 1% flux density uniformity is shown in picture a).

The apparatus was tested on a commercial flow meter. DC regime was used, although AC excitation is typical. The probe accuracy was estimated through repeated measurements. The relative error depends on the measured flux density. Typical relative errors are in Table 1. Flux density higher than about 0.1 mT can be measured with good accuracy, which is better by one order as compared to standard probes.

Table 1.   3D Hall probe relative error from repeated measurements of low values of magnetic flux density

B_{mean} [µT]	2000	500	200	100	30
δ B [%]	0.2	1.5	3	5	15

Theoretical calculations were carried out by MATLAB. The coil was modeled either by one centre conductor or spatially distributed conductors using parallel computing to increase the speed. Since the differences were small, only the results obtained from the simpler model will be presented in this study. Correlations with the model improved if the magnetization of ferromagnetic parts of the flow meter was taken into account through modeling them by line bounded currents. A comparison with theory is shown in Fig. 3. The flux density along the flow meter Y axis, i.e. the axis of coils, is shown in Fig. 4. Data in Fig. 4 are taken along a circle with diameter 32 mm close to the winding in plane perpendicular to the axial axis. The agreement is good. Experimental points exhibit small, but visible, asymmetry.
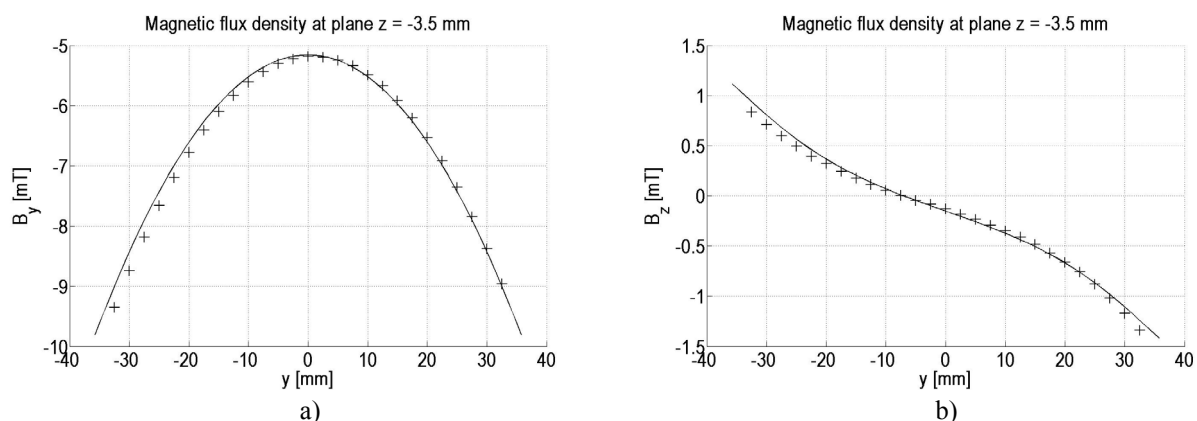

Fig. 3.   Comparison between experiment and theory on Y axis (symmetry axis of exciting coils). a) Main component B_y, b) Parasitic component B_z.
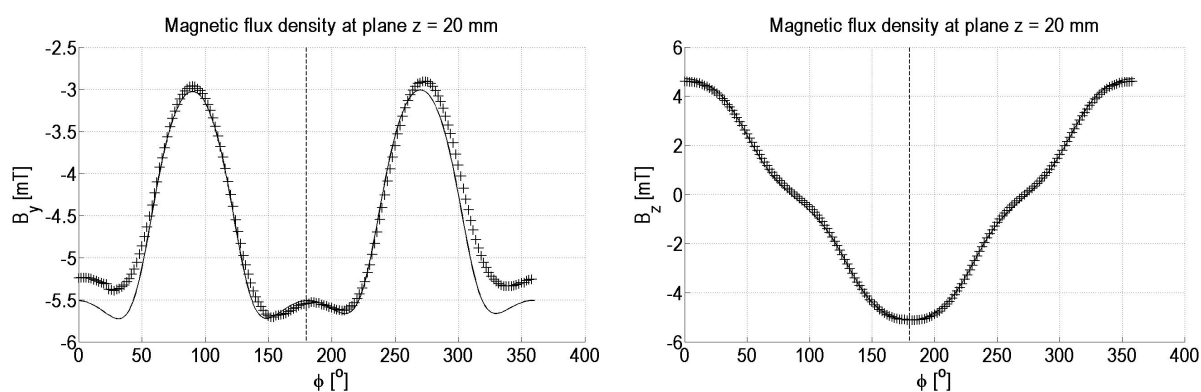

Fig. 4.   Comparison between experiment and theory on a circle in general plane normal to axial axis. a) Main component B_y, b) Parasitic component B_z.

Good technical agreement between theory and experiment makes the flow meter numerical analysis possible. Flux density is almost uniform in the flow meter tube (Fig. 5a), but not outside the tube. However, Hall force in the tube area (Fig. 5b) is well-defined.

4. Discussion

We have shown that the commercial Hall probe designed for applications in the range of 2 T, can be efficiently used for measuring low magnetic field amounting to 1 mT with new control circuit. The relative error is usually less than 3 %. Fully-automated measurement needs a space probe positioning apparatus, error in the coordinates is about 0.5 mm. Therefore, the measurement of space distribution of magnetic field is relative precise.
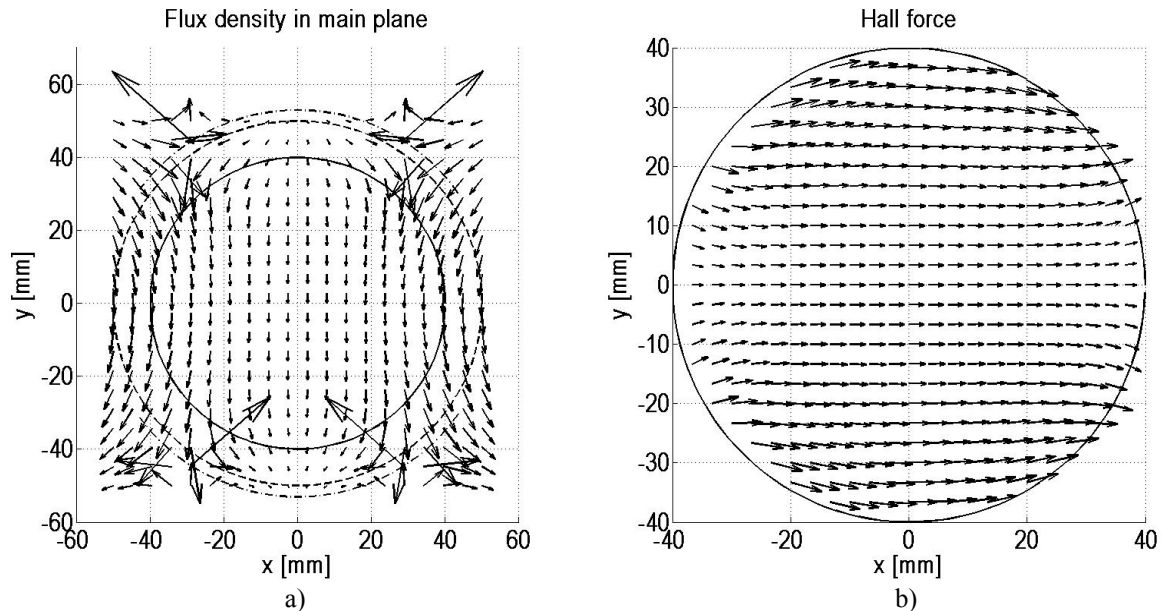

Fig. 5. Flow meter analysis in central plane. a) Flux density vectors. The coil equivalent turn is shown as dot-and-dash arcs outside the external circle. b) Hall force in the inner tube.

The preliminary comparison with theory, using a very simple model, is in a good agreement from the technical point of view. It can be further improved both in theory and experiment. In theory, more precise 3D geometry should be used in flow meter model. In experiment, the coordinates must be corrected for positions of individual sensors of the 3D probe. Then the symmetry of measured points is improved. The remaining experimental asymmetry is then only caused by production errors. Since magnetic field distribution is a key part of flow meter, calculations have shown that the flow meter is well designed; Hall force is almost uniform in is central plane.

Acknowledgement

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