Fluxgate Sensor with a Special Permalloy Core - Construction and Investigation

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Abstract. *In the paper the operating principle and basic parameters of a special core fluxgate-based transducer to measure a static magnetic field is described. A theoretical analysis has been made and an approximate transduction function has been derived. The presented results of tests carried out on a transducer model testify that the device in question is distinguished by a high and easily adjustable sensitivity and a linear transduction characteristic.*

Keywords: Fluxgate Sensor, Magnetic Field Transducer

1. Introduction

To transduce direct current [1], [2] a special permalloy-made core has been developed, the moulding of which is depicted on Fig. 1. The specific form is conditioned by the requirement that the entire core volume could be magnetized in reverse sense in order to restrict its magnetic memory. Measuring of heavy currents by means of the compensation method requires that an appropriately high compensating passage of current be created, which is not always possible to achieve.

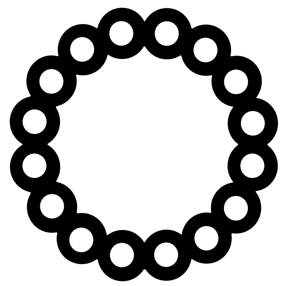

Fig. 1. Core moulding of the DC transducer

Extension of the measurement range may be accomplished in another way. Contactless heavy DC transducers operating on the principle of compensation with an open magnetic circuit (not embracing the wire carrying the current to be measured) make use of fluxgate-based transducers built around a permalloy core either assembled from a number of mouldings or representing a part of the moulding shown in Fig. 1. The attention should be paid that winded and magnetizes core of DC transducer is really the fluxgate sensor.

In classical fluxgate sensor only one ring core is used [3], [4]. Here, in presented proposition, the sensor is built of 16 ring cores that are connected in closed magnetic circuit. Magnetizing and detecting coils (N_m and N_d respectively) are winded in special way.

2. Design and mode operation of the sensors

Presented sensors are based on a core presented in Fig. 1. The core of the DC transducer is assembled from 16 permalloy mouldings. The magnetizing winding N_m has been threaded through the core holes. And then the following windings have been applied throughout the toroid circumference, namely the detecting N_d and the compensating N_c.

Fig. 2 depicts the core winding diagram and Fig.3 the block diagram of the transducer.

The operating principle is the following [2]. The sinusoidal magnetizing current I_m brings into saturation that part of the core, which bears the magnetizing winding N_m.

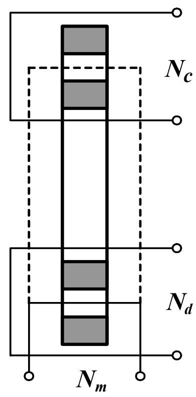

Fig. 2. Core winding diagram of the fluxgate sensor

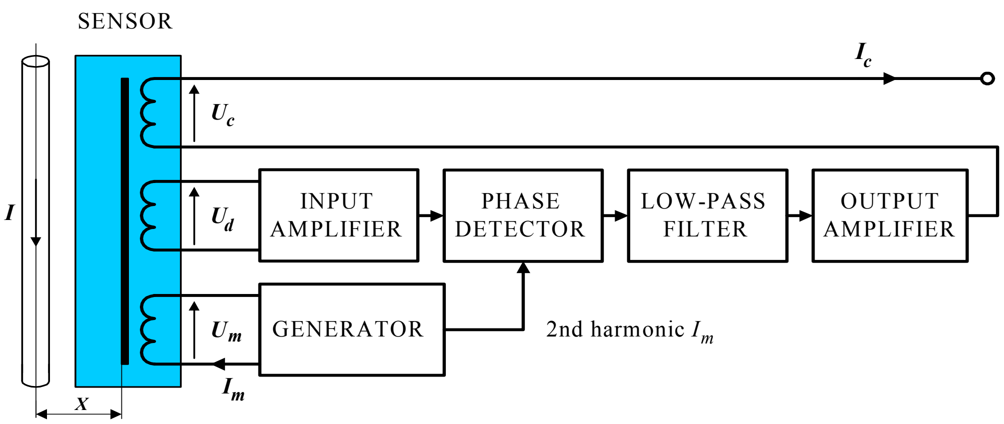

Fig. 3. Block diagram of the transducer

Because of saturation, the external magnetic field threading the core does not change its internal magnetic flux. However, when the core is not saturated, i.e. in the magnetizing current zero-crossing area, the core flux generated by the external field does increase. This results in inducing an U_d voltage, with the 2nd harmonics of the magnetizing current being dominant in the detecting winding N_d. After having been amplified U_d is passed to a phase-sensitive detector driven by the second harmonics of the magnetizing voltage. The detector output voltage, after averaging, drives the output amplifier, which forces in the compensating winding N_c a current flow I_c such that the voltage across the detecting winding N_d be equal zero.

The sensor is placed in X distance from the current-carrying wire axis. The sensor core flat is parallel to the current wire. The relation between measured I and compensating I_c currents is defined like:

$$I_c \approx \frac{k}{N_c X} I \tag{1}$$

where k – is coefficient allowing geometrical core dimensions and geometrical relation between sensor and current-carrying wire.

Fig. 4 presents the relation between measured I and compensating I_c current for different distances X. The experiments confirmed the character of relation (1).

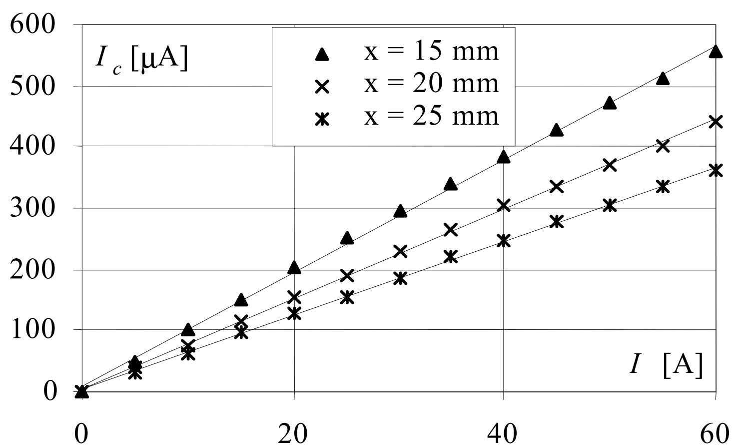

Fig. 4. The relation between measured I and compensating I_c current

The nonlinearity error decreases as the X distance is increasing. Its value is less than 1% for X > 25 mm.

The experiments disclosed that sensor has directional features and that they depend on value of magnetizing current.

To ensure that the transducer parameters be stable and repeatable, the core and method of coil winding are to be modified. In the core assembled from mouldings shown on Fig.1 a gap 1 mm long has been made. The new version of sensor is presented on Fig. 5.

The magnetizing winding N_m has been threaded through two holes situated opposite the air-gap. The detecting winding N_d has been applied on that part of the toroid, which bears the magnetizing winding N_m. The compensating winding N_c has been applied on the remaining part of the core. The following number of turns have been wound here: N_m = 20, N_d = 100, N_c = 100.

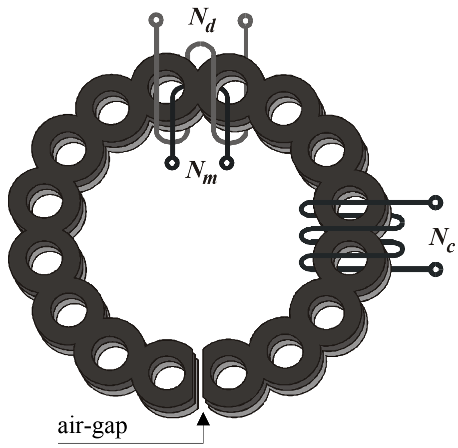

Fig. 5. Fluxgate sensor winding diagram

A transduction function of the fluxgate sensor placed in homogeneous magnetic field with intensity H is defined like [6]

$$I_c = \frac{k\, d\, g\, l_p}{S_p\, N_c} H \tag{2}$$

where

k – a coefficient allowing for the influence the core exerts on the magnetic field;

d – the external diameter of the sensor;

g – the core thickness;

S_p – the air-gap area;

l_p – the air-gap length.

As may be inferred from (2), the output (compensating) current I_c is directly proportional to the field intensity H. The current depends on geometric dimensions of the sensor (core's thickness g and external diameter d) as well as on the number of compensating turns N_c. The value of output voltage also depends on the gap dimensions: it is directly proportional to its length l_p and inversely proportional to its area S_p. The relationship expressed by (2) is an approximate only. This is because it is dependent on k, a coefficient that takes into account the influence the sensor core exerts on the magnetic field to be measured. As follows from (2), the transduction sensitivity depends on the air-gap length l_p, number of turns N_c and core geometry.

3. Transducer model tests

The sensor presented above has been tested by its placing in a homogenous magnetic field produced by Helmholtz coils. It makes possible to adjust the position of the sensor in two planes for its transducer sensitivity, linearity and directionality testing.

Experimentally determined sensor sensitivity came out to around $3\,10^{-4}$ A/A/m. The transducer features high linearity, as the measured linearity error is in the order of some tenths of a percent.

The angle α shown in Fig. 6 identifies an angle between the straight line being normal to the core axis of symmetry and the magnetic field intensity vector H.

The dependence of the sensor sensitivity S on the magnetic field direction in the other plane has also been investigated. The angle β, i.e. the angle between the sensor plane and the

direction of the field permeating the plane, has been varied for α = 0°, hence, for the maximum of the sensor's sensitivity. It means that the coils have been turned in relation to the plane in which the sensor is situated. It has also been assumed that β = 0°, when the field lines are parallel to the sensor plane.
From the test results obtained it may be inferred that the transduction sensitivity S depends on the α and β angles in a cosine-like manner. The discrepancy between the experimental and predicted dependence $S = f(\alpha, \beta)$ is at a level of inaccuracy the α and β angles are given when measurements are made. Taking it into account the approximate transduction function may be written as

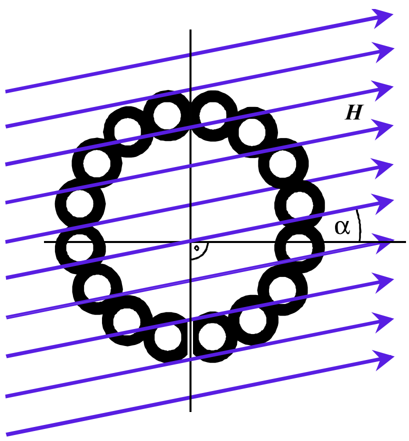

Fig. 6. Sensor arrangement in relation to the magnetic field

$$I_c \approx \frac{k d g l_p}{S_p N_c} H \cos\alpha \cos\beta \qquad (3)$$

As may be seen, the transducer output current I_c is a function of two angles, which determine how the sensor is arranged in relation to the magnetic field to be measured.

4. Conclusions

Results of tests carried out on the sensor model have confirmed the nature of the dependence given by equation (2) and made it possible to supplement it to the form given by equation (3). The way the sensor sensitivity is dependent on the angular position in relation to the magnetic field given by equation (3) could be expected. Tests on directional properties the sensors models exhibit enable one to state that the magnetic field to be measured is influenced by the sensor core to a small extent only.

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