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A TRANSDUCTOR-BASED CONTACTLESS DC TRANSDUCER

Stanislaw Moskowicz

Technical University of Szczecin, Institute of Control Engineering,
26 Kwietnia 10, 71-126 Szczecin, Poland, Phone: +48 91 449-5119,
Fax. +48 91 486-2977, E-mail: smoskow@ps.pl

Abstract - A transductor sensor of magnetic field intensity designed for use in a contactless transducer for measuring of heavy direct currents is presented. The sensor is built around a specially shaped and wound permalloy core and operates on the model of compensation arisen from the action of the magnetic field produced by the second harmonic of the magnetizing current.

Keywords: contactless DC transducer, magnetic field sensor

1. INTRODUCTION

In [1] the design and basic parameters of AC and DC transformer transducers have been presented. The AC transducers operate in an automatic AC comparator while the DC transducers run in a magnetic current comparator. Unlike classical Kusters [2, 3] twin-cored transducers used in magnetic DC comparators, a single-cored transducer utilizing a specially designed permalloy core has been applied here.

To transduce direct current [1,] a special permalloy-made core has been developed, the lamination of which is depicted in 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.

Extending 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 transductor-based transducers. They are built around a permalloy core either assembled from a number of laminations or representing a part of the lamination that is shown in Fig. 1.

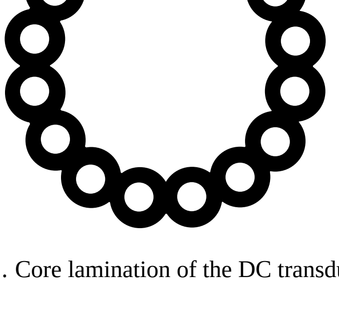

Fig.1. Core lamination of the DC transducer.

2. DESIGN AND MODE OF OPERATION

Technical problems connected with measurements of heavy direct currents (in the order of tens and hundreds of ampers) arise mainly from difficulties associated with producing of an accordingly great compensating flow. They have given rise to developing of a contactless transducer operating according to the above described principle, with the difference that the action of the magnetic field generated by the current to be measured is utilised here. The current flows along a wire that is located outside the core.

To attain a high transducing accuracy in transformer DC transducers with a core built from laminations shown in Fig. 1, a core isotropy is required. The following factors play a decisive role here: quality of the permalloy being used, good workmanship of core laminations and method of coil winding. An ideal isotropy is not possible to attain, hence, the core exhibits a certain directionality in relation to a current-carrying wire.

To ensure that the transducer parameters be stable and repeatable, the core and method of coil winding are to be modified. The core of the transducer is composed of toroidal laminations punched from sheet permalloy being 0.15 mm thick, and stacked together making up an assembly being 0.60 mm thick.

In the core assembled from laminations shown in Fig.1 a gap 1 mm long has been made. Eight magnetizing turns N_m have been threaded through the four holes opposite the gap. Then the detecting winding N_d has been applied on that torus part the magnetizing winding N_m had been threaded through. On the remaining part of the core the compensating winding N_c has been wound. Hence, a distinct asymmetry in the transducer's magnetic circuit has been introduced. Both parts of the sensor have been separated from each other, namely the one that is sensitive to the external magnetic field (with the magnetizing winding) from the compensating one (the remainder of the magnetic circuit). The following number of turns have been wound here: N_m = 20, N_d = 100, N_C = 100. The external diameter of the core d = 42 mm.

Adequately wound and magnitized core is in the end the magnetic field sensor.

Fig.2 presents a schematic winding diagram of the DC contactless transducer.

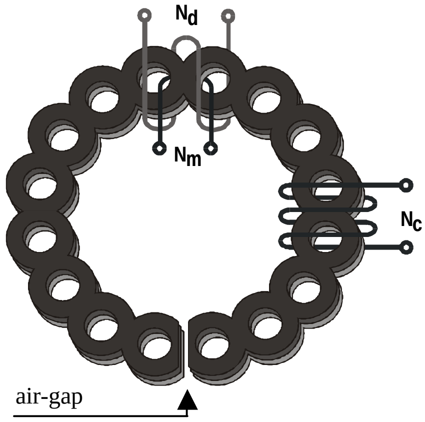

Fig. 2. Sensor winding diagram of the magnetic field transducer.

The sensor and its arrangement in relation to a current-carrying wire that ensures the highest sensitivity are diagramatically illustrated by Fig. 3.

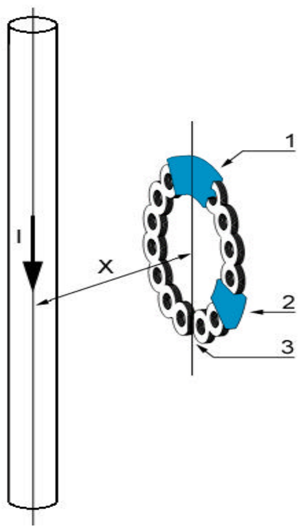

Fig. 3. Arrangement of the sensor in relation to the current-carrying wire. 1 – N_m and N_d windings; 2 – N_c winding; 3 – air-gap.

The transducer co-operates with a typical automatic DC comparator [3], which includes a magnetizing generator, a phase detector driven by the second harmonic of the magnetizing current, and an output amplifier. The block diagram of the transducer is shown in Fig. 4.

The operating principle is as follows below [4]. The sinusoidal magnetizing current I_m brings into saturation that part of the core, which bears the magnetizing winding N_m.

Because of saturation, the external magnetic field threading the core at that time does not change its internal

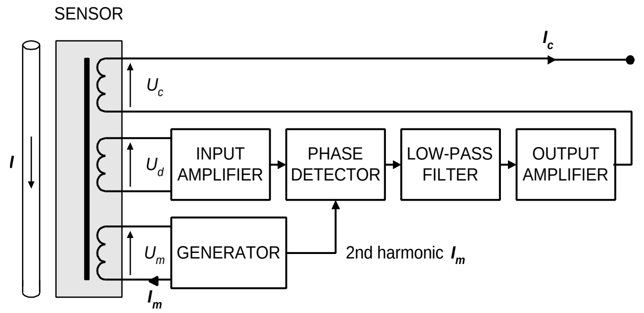

Fig. 4. Block diagram of the contactless DC transducer.

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 I_m 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 is equals zero.

As an illustration of the sensor operation, Fig.5 shows an oscillograph record of the magnetizing current I_m and that of the voltage U_d being induced in the detecting winding.

The sensor operating in the measuring circuit of Fig. 4 is in principle a compensating one. An external

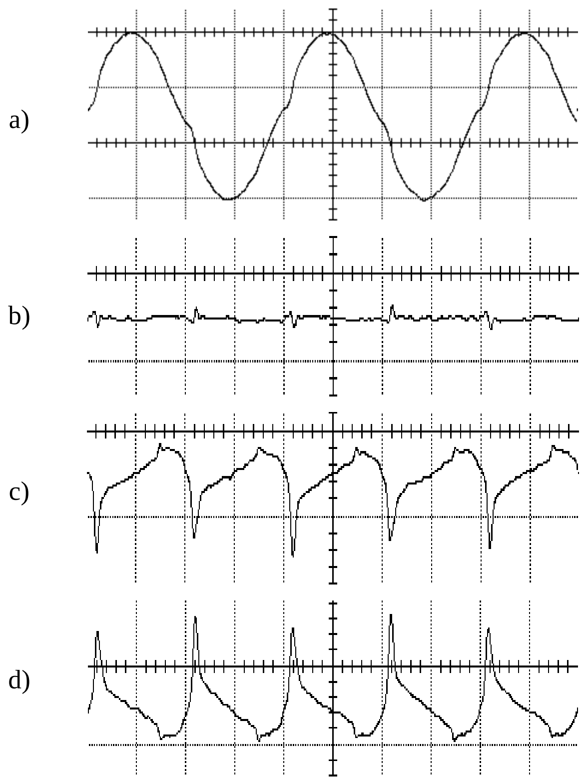

Fig.5.Temporal variation of the magnetizing current I_m and that of voltage U_d induced in the detecting winding N_d (for open-loop feedback, I_C = 0): a) I_m, b) U_m for I = 0, c) U_m for I = 10A, d) U_d for I = -10A.

magnetic field is being compensated in it by the compensating field generated by the I_C current, flowing through the compensating winding N_C. The shape of the magnetic circuit, especially that of the compensating part, may differ. The compensating circuit may also be made up of another magnetic material. The shape of the part that detects the magnetic field is due to desirability of enabling the core to be saturated in full.

3. TRANSDUCTION FUNCTION

In the arrangement shown in Fig. 4 the magnetic flux f (produced by the current I flowing through the wire) threading the cross-sectional plane surface of the sensor may be written as

$$f = m_o\, k\, d\, g\, \frac{I}{2p\, X} \tag{1}$$

where

- k is a factor allowing for the finite length of the current-carrying wire and the influence the core exerts on the magnetic field around the wire,
- d is the external diameter of the sensor,
- g is the sensor core thickness.

The magnetic flux threading the core gap (see Fig. 4) is

$$f_p = m_o\, S_p\, H_p \tag{2}$$

where

- S_p is the gap area,
- H_p is the magnetic field intensity in the gap.

In a state of compensation the flux threading the sensing part of the core equals zero, therefore

$$f_p = f \tag{3}$$

and

$$H_p l_p = N_c I_c \tag{4}$$

where l_p is the gap length.
Substituting (1), (2) and (4) into (3) we get the compensating current meeting the condition of compensation (3)

$$I_c = \frac{k\, d\, g\, l_p}{2p\, S_p\, N_c\, X}\, I \tag{5}$$

As may be inferred from (5), the output (compensating) current I_C is directly proportional to the input current I. 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.

Assuming the magnetic leakage around the air-gap is negligible, then the air gap area S_P, may be taken as

$$S_p = g\, s \tag{6}$$

where s is the air gap width.
Introducing (6) into (5) we get

$$I_c = \frac{k\, d\, l_p}{2p\, s\, N_c\, X}\, I \tag{7}$$

As is evident from (7), the transduction function is independent of the core assembly thickness g. This is an obvious statement, which follows from the operation principle of a compensating transducer, where the core serves only to detect the unbalance, according to (3).

Equation (7) gives an approximate relation for the transduction function. The coefficient k allows for the influence the core exerts on the magnetic field to be measured, and it should be expected that the influence will be the weaker, the less magnetic material will constitute the sensor. Hence, the core of the sensor should have geometrical dimensions as small as possible. In case the typical moulding depicted in Figs. 1 is employed, only one lamination should be used supposedly. However, this is not an obvious matter, since a small core thickness results in a magnetic flux leakage around the airgap [5]. The less is the cross-sectional area of the core at the given airgap length l_P, the greater is the leakage. The relationship given by Eq. (6) would be too rough in such a case. A correction [5] that would magnify the effective airgap area is to be introduced here. However, it should be kept in view that the effective airgap area is also dependent on the magnetic flux value within the airgap.

As follows from Eq. (7), the sensitivity of the proposed sensor may be changed by altering the airgap length l_P, the number of turns of the winding N_C or geometrical dimensions of the core, i.e. its shape and/or diameter.

4. TESTING TRANSDUCER MODELS

Tests carried out [4] have shown that the transducer sensor is characterized by a high sensitivity, which makes it possible to perform contactless measurements of currents being even below 1 A.

The transduction features high linearity, as the measured linearity error is in the order of some tenths of a percent.

The transducing characteristic depends most on the distance X between the sensor and the wire axis, and on the length L of the current-carrying wire. The latter factor is not reflected in (7), since an infinite wire length has been assumed in (1). The effect of the wire length is lesser, the less are geometrical dimensions of the sensor in relation to L.

Figure 6 shows diagrammatically a transductor-based magnetic field sensor with significantly smaller dimensions as compared to that presented in Fig. 2 and its arrangement in relation to the wire traversed by the current I to be measured. The sensor core is composed of two moulding elements assembled (Fig.1). The magnetising winding N_m has been threaded through the core holes, and then the following windings have been applied throughout the core length, namely the detecting N_d and the compensating N_C ones.

Figure 7 shows how the relative transducing factor change dK depends on the current-carrying wire length L for both transducer versions. As may be seen, the less are dimensions of the sensor, the less is the influence exerted by the wire length.

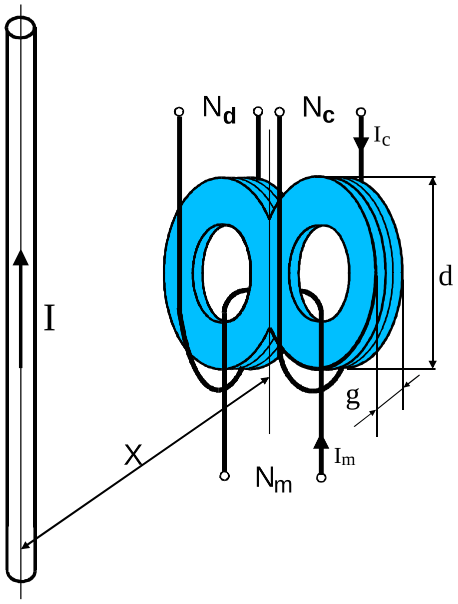

Fig. 6. Diagram of the smaller transducer and its arrangement in relation to the wire flowed through by the current to be measured.

The second factor, which exerts influence upon transduction accuracy, is the distance between the sensor and the current-carrying wire axis. The distance can be taken into account when calibrating the transducer and made fixed by employing appropriate distance elements. However, this can be done accurately only if the wire diameter is known, as the distance is reckoned from the wire axis. In case of wires having a different diameter than that assumed, a substantial measurement error may occur.

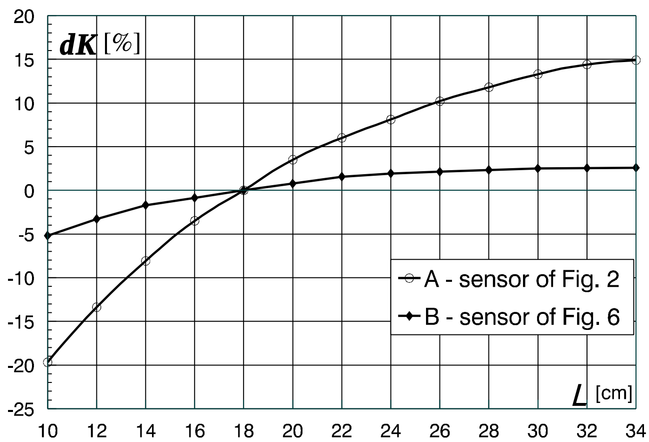

Fig. 7. Relative transducing factor change *dK* vs wire length *L* for both transducer versions taken for the distance *X* = 50 mm.

5. RECAPITULATION AND CONCLUSIONS

The contactless DC transducer presented in this paper employs transductor-based sensors in view of advantages they offer, viz. high sensitivity and suitability for using in compensation-based transducers. This is due to the fact that detection and compensation of the magnetic field is performed in the permalloy-made sensing core, so the transducer does not require any other magnetic field sensor to be employed in order to detect the state of compensation.

The design of the described two versions of contactless transductor-based DC transducers is based on a specially developed permalloy-made core lamination. When comparing the both versions, it may be stated that the sensor with an air-gap in the core shown in Fig. 2 is characterized by better parameters than the sensor shown in Fig. 6. The latter is more sensitive and more resistive to disturbances. Its main disadvantage lies in bigger geometrical dimensions. Reducing the dimensions may be achieved by changing the form of the compensating circuit and/or by developing a new much smaller shape of the core lamination.

Contactless current transducers are susceptible to some extraneous factors, such as geometric arrangement of the sensor in relation to the current-carrying wire, influence of extraneous magnetic fields and ferromagnetic elements situated in the proximity. The influence of the geometric factors can be considerably reduced, as it was shown in the paper. The remaining factors, as much as the cross-sectional area of the current-carrying wire, can be taken into account when calibrating. The influence of extraneous magnetic fields and ferromagnetic materials can be reduced by proper selecting the site of making measurements, and, to some extent, utilizing the directional properties of the transducer. All factors considered, it may be stated that measurement inaccuracy of such transducers is of the order of several percent, which is to be recognized as acceptable in some cases.

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