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INFLUENCE OF STRESSES ON THE PROPERTIES OF FLUXGATE SENSOR WITH PERMALLOY RING CORE

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Abstract – This paper presents results of investigation on influence of stress from the external forces on the sensitivity of the fluxgate sensor with 80% Ni-Permalloy P-80M ring core. Stress was applied in two directions: in the direction of diameter of the ring or in perpendicular direction to the magnetising field in the ring core. The influence of mechanical stress from the external forces on the magnetic properties of this ring core was measured. Then results of this testing were used in computer simulation of the influence of stress on the output signal of the fluxgate. The results confirmed, that stress sensitivity of the fluxgate sensor's core material must be taken into consideration during the development of such device.

Keywords: fluxgate sensor, magnetoelastic effect.

1. INTRODUCTION

Fluxgate sensors are widely used in various applications such as airborne and aerospace devices, for measurement of the constant weak magnetic field up to 100 μT. In such applications fluxgate sensors can be subjected on different kinds of the external, mechanical stresses caused by vibrations or by the thermal extensions of material. It was presented in previous publications that such external stresses could change sensitivity of the fluxgate sensor [1]. However methodology and quantitative results of testing a stress sensitivity of the fluxgate sensors seems to be still not presented.

This paper presents possibilities of measuring influence of the external stress on the sensitivity of the fluxgate sensor with a ring core. The core of the sensor was made of 80% Ni-Permalloy (P-80M produced by Institute of Non-Ferrous Metals, Gliwice, Poland). Similar alloys were reported as used in construction of fluxgate sensors [2].

2. METHOD OF INVESTIGATION

Applying determined external stresses to a core of operating fluxgate sensor is technically difficult, so the method of investigation contains two steps. The first one was the experimental investigation of the influence of the mechanical stresses caused by the external forces on magnetic characteristics of the ring core used in the fluxgate sensor. The investigation was carried out on the ring-shaped sample. The outside diameter of the sample was equal 40.3 mm, the inside diameter was equal 19.7 mm and the height was 15.4 mm. The second step was the computer simulation of output characteristic of the fluxgate sensor. In this simulation the experimental results from first step were used.

There are two methods of applying the compressive force to a ring core made of amorphous alloy:

- applying the compressive force in the direction of a diameter of a core [3].
- when compressive force is applied perpendicularly to the flux direction; uniform compressive stress are obtained in the ring core [4]

When the compressive force is applied to the ring core in the direction of diameter (as it is presented in figure 1) the distribution of stress is very sophisticated. Moreover both tensile and compressive stresses are present in the sample [5]. Due to the presence of the highly stresses areas in the ring core such way of applying compressive force may lead to the permanent changes of its functional properties. As a result even relatively small values of compressive force may lead to the permanent changes of characteristics of the fluxgate sensor.

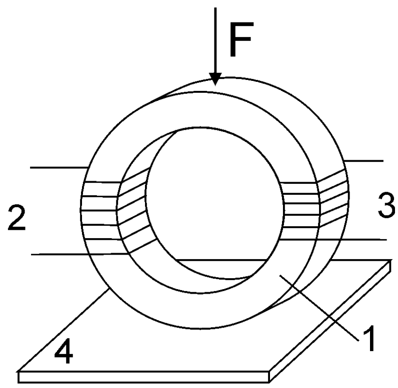

Fig. 1. General idea of applying the compressive force in the direction of diameter of the ring core. 1- core under investigation, 2 – driving winding, 3 – sensing winding, 4 – base plane

In the ring-shaped core uniform distribution of the stresses can be achieved when compressive force is applied perpendicularly to the direction of the magnetizing field. The general idea of this method of applying stresses is presented in Fig. 2. In presented investigation a special nonmagnetic backing were used for applying compressive stress to the core and enable it to be winded [8].

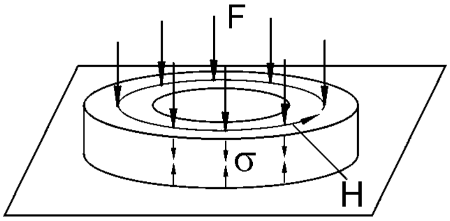

Fig. 2. General idea of applying the compressive stress to the ribbon ring core.

Computer simulation of the influence of the stress on the properties of the ring core fluxgate sensor was performed for constant value of the measured magnetic field H_{meas} equal to 25 A/m (B_{meas} = 31.42 µT). To simplify calculations it was assumed that a presence of the sensor does not affect on the measured magnetic field. The simplified construction of a ring core fluxgate sensor is presented in figure 3 [6].

In this simplified simulation the ring core was driven by sine wave current. The value of the total magnetizing field $H(\phi,t)$, in the cross section of the ring core is given as a sum of measured field H_{meas} and the field from driving current $I_{in}(t)$:

$$H(\phi,t)=\frac{I_{in}(t)\cdot z}{l_e}+H_{meas}\cdot\sin(\phi) \tag{1}$$

where: $I_{in}(t)$ – the value of current in the driving winding, z – number of the turns of the driving winding, l_e – length of the magnetic path of the ring core, ϕ - angle between the direction of the measured field H_{meas} and the direction of the radius of the ring for considered cross section of the core.

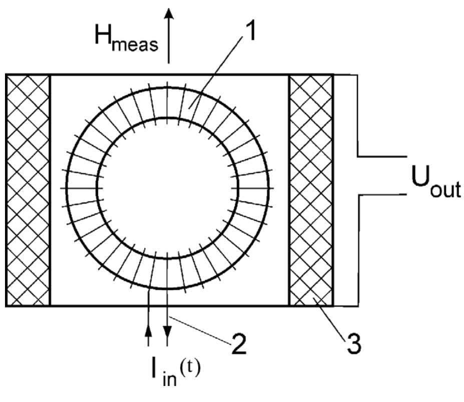

Fig. 3. The simplified construction of a ring core fluxgate sensor: 1 – a ring core made of soft magnetic material (for example Permalloy), 2 – driving winding, 3 – detecting coil [6]

Hysteresis loops $B(H)_{F=const.}$ obtained from experimental measurements of the influence of the compressive force on the magnetic characteristics of the core were used in simulation. Value of the flux density B_c in the ring core was calculated from hysteresis loops $B(H)_{F=const.}$ measured under stresses:

$$B_c=B[H(t)]_{F=const.} \tag{2}$$

The value of the output voltage U_{out} on the detecting coil of the fluxgate sensor can be calculated due to the Faraday law [7]:

$$U_{out}(t)=\frac{d\Phi}{dt}=n\frac{d(\int_A B_p\cdot dA)}{dt} \tag{3}$$

where: Φ - total magnetic flux in detecting winding, n – number of turns in detecting winding, B_p – component of the flux density parallel to the detecting winding on the core, A – total cross section of the core parallel to the detecting coil.

Finally value of the amplitude of second harmonic in voltage U_{2f} on secondary coil was determined from $U(t)$ by Fourier transform.

Described procedure was performed for the hysteresis loops obtained for different values of the compressive forces applied to the ring core of fluxgate sensor. So the changes of the amplitude of the voltage of the second harmonic signal on the detection coil were calculated.

3. RESULTS

The influence of the compressive force F (applied in the direction of the diameter of the core) on hysteresis loop of 80% Ni-Permalloy is given in figure 4. Under compressive force applied in the direction of the diameter of the ring core (Fig. 1) the permeability of the core decreases significantly.

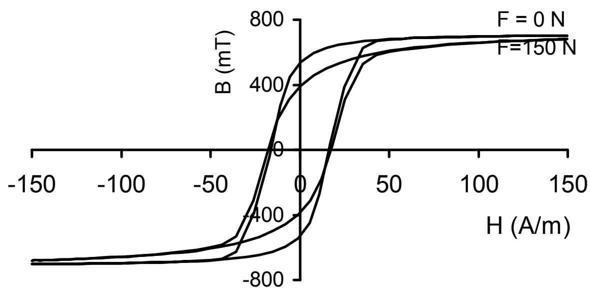

Fig. 4. The influence of compressive force F (applied in the direction of the diameter of the core) on hysteresis loop of 80%-Ni Permalloy

The results of simulation of the normalized changes of the value of second harmonic in signal U_{out} at the sense winding are presented in figure 5. Due to decreasing of permeability of the ring core under compressive force F, the decreasing of measuring signal can be observed. For compressive force F up to 150 N the value of output signal decreases about 5 %.

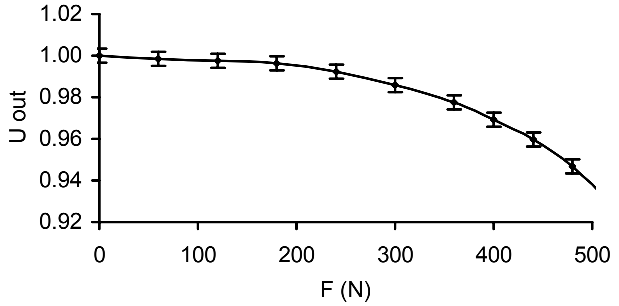

Fig. 5. The influence of compressive force F on normalized value of the amplitude of second harmonic in voltage at the sensing coil

When the stress was applied to the core perpendicularly to the direction of magnetizing field (Fig. 2), the changes of the shape of hysteresis loop were also observed. These changes are presented in figure 6.

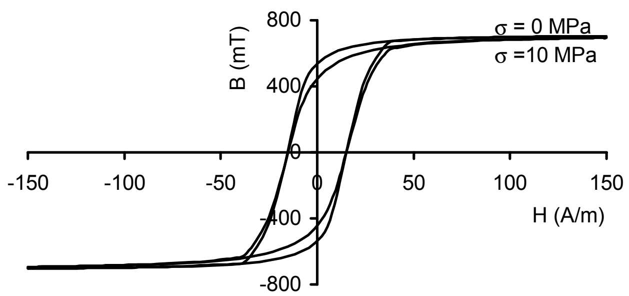

Fig. 6. The influence of compressive stresses σ (applied perpendicularly to the magnetizing field in the ring-shaped core) on hysteresis loop of 80%-Ni Permalloy

The results of simulation of the normalized changes of the value of second harmonic in signal U_{out} at the sense winding for such method of applying stresses to the core are presented in figure 5. Also in this case, due to decreasing of permeability of the ring core under compressive stresses σ, the decreasing of measuring signal can be observed. For compressive stresses up to 10 MPa the value of output signal decreases about 2.5 %.

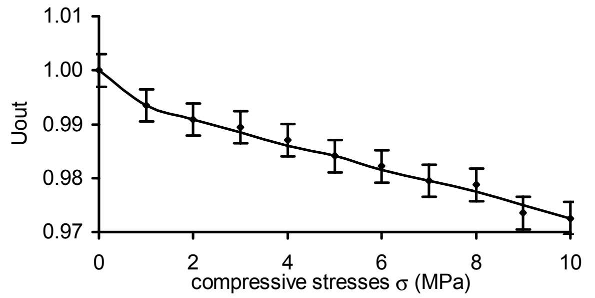

Fig. 7. The influence of compressive stresses σ on normalized value of the amplitude of second harmonic in voltage at the sensing coil

In both ways of applying the compressive force to the 80 Ni-Permalloy ring core the significant decreasing of the permeability was observed. This phenomenon caused decreasing of the value of the amplitude of the voltage of output signal. However the shape of the stress dependence of output signal is different for each way of applying compressive force.

In the case of applying compressive force in direction of the diameter of the ring core, for initial values of compressive force the value of output signal changes slightly. But for larger values of compressive force the output signal decreases more significantly (Fig. 5). Therefore the influence of stresses for larger values of compressive force should be taken into consideration as important factor of functional properties of fluxgate sensors.

In the case of applying compressive force perpendicularly to the direction of magnetizing field in the ring-shape sample, for even small values of compressive force the output signal changes distinctly. For larger values of compressive force the changes of output signal are approximately linear (Fig. 7). As a result in such way of applying compressive force even small forces should be taken in consideration in development of fluxgate sensor.

4. CONCLUSION

In paper the approach to the problem of determining quantitatively the influence of the external compressive force on the functional properties of the fluxgate sensor was presented. Results confirmed practical experience that such stresses changes significantly the sensitivity of a fluxgate sensor. For this reason this influence, as having the great importance, should be taken into consideration by constructors and users of such sensor.

Character of influence of external stresses depends not only of the value of the force, but also of the way of it is applied. In both ways of applying the compressive force to the 80% Ni-Permalloy ring core the significant decreasing of the output signal from the sensor was observed. However for compressive force applied in direction of the diameter of the ring core significant changes are observed for larger values of the external force. Whereas for compressive force applied perpendicularly to the direction of the magnetizing field the largest changes was observed for the initial values of compressive force.

Presented results confirmed necessity of magnetoelastic testing of magnetic materials utilized as the cores of the fluxgate sensors. Selection of the material only on the respect to its good magnetic properties may lead to decreasing of the functional properties of the fluxgate sensors. Such decreasing of important parameters (such as accuracy) may be caused by the influence of external stresses. As a result magnetoelastic properties of the core's material should be taken into consideration in construction of the fluxgate sensors.

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