New Measuring System for Testing of the Magnetostrictive Properties of the Soft Magnetic Materials

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Abstract- This paper presents the newly developed measuring system for testing of the magnetostrictive properties of the soft magnetic materials. The semiconductor strain-gauge measurement technique is utilized in this system. As a result the high resolution of measurements was achieved. Moreover, due to utilization of the both strain-gauge bridge and fluxmeter the simultaneous measurements of the flux density B and the magnetostriction λ as the function of magnetizing field H is possible. For this reason developed measuring system creates a new possibility of determination of the B(H), λ(H) and λ(B) characteristics. These characteristics were never tested simultaneously before.

I. Introduction

Magnetostrictive Joule effect is connected with changes of the dimensions of the soft magnetic material during its magnetization. Relative changes $\lambda = \Delta L/L$ of the length L of the magnetized sample is called magnetostriction [1] and is presented in Figure 1a. The value of the magnetostriction for magnetizing of the sample from demagnetized state to saturation one is called saturation magnetostriction λ_s. Saturation magnetostriction λ_s can vary from nearly zero (for high permeability Mn-Zn ferrites [2]) up to 1600 μm/m (for rare-earth based materials, such as Terfenol-D [3]). Typical Magnetostrictive hysteresis loop of soft magnetic material is presented in Figure 1b.

a) b)

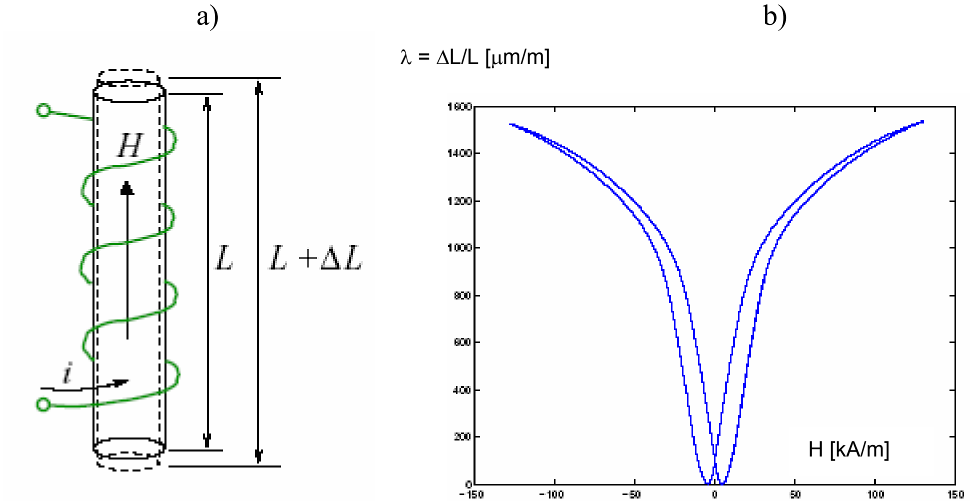

Figure 1. Magnetostrictive Joule effect under the magnetic field H [5]
a) H is proportional to magnetic current i in the winding,
b) magnetostrictive butterfly curve for soft magnetic material

Magnetostrictive properties of the soft magnetic materials are important from both physical and practical point of view. From physical point of view, the results of the investigation of the magnetostrictive properties can be helpful in analyzing some fundamental questions concerning magnetic phenomena in soft magnetic materials alloys [4]. Moreover magnetostrictive effect can be utilized in construction of the different sensors and actuators [5, 6], especially for micro-scale applications.

II. Magnetostriction measurements utilizing semiconductor strain gauges

Different methodologies of the measurement of the magnetostriction were described in previous paper [7]. Among know methods of the magnetostriction measurements, utilization the strain-gauges is the most promising from technical point of view. This methodology creates both possibility of determination of the complete characteristics of tested material (initial curve as well as magnetostrictive hysteresis loop) as well as gives possibility of testing of the properties of magnetic materials subjected to mechanical stresses [8].

For measurement of magnetostriction in the presented system, very sensitive semiconducting strain-gauges were utilized. These strain-gauges have a 120 gauge factor at the resistance about 120 Ω [8]. The strain gauges were connected with an ac Wheatstone bridge. If the greater measuring accuracy is required from the semiconductor gauges, the some corrections must be taken into consideration. The great sensitivity of the semiconductor gauges to temperature can give considerable measuring errors. Measuring errors can also to occur because of a zero shift of a sensitivity curve of semiconductor gauge. This shift is caused by glue shrinking when it is drying during adhesive process. However, when the nature of these errors is understood, suitable calibration techniques can be applied and thus accurate measurements are possible.

For measurements of magnetostriction special frame-shaped samples were utilized. Utilization of this shape of the sample create a possibility of a both measurements of magnetostriction on the samples with closed magnetic circuit as well as measurements of magnetostriction under the influence of external stresses (applied in the direction of longer side of the frame). For measurements of both magnetostriction λ in direction of the magnetizing field and perpendicularly to this direction two strain-gauges were glued ($T_{\perp z}$ and $T_{\| z}$) as it is presented in Figure 2. Moreover, two completes of strain-gauges were glued at external and internal side of the sample.

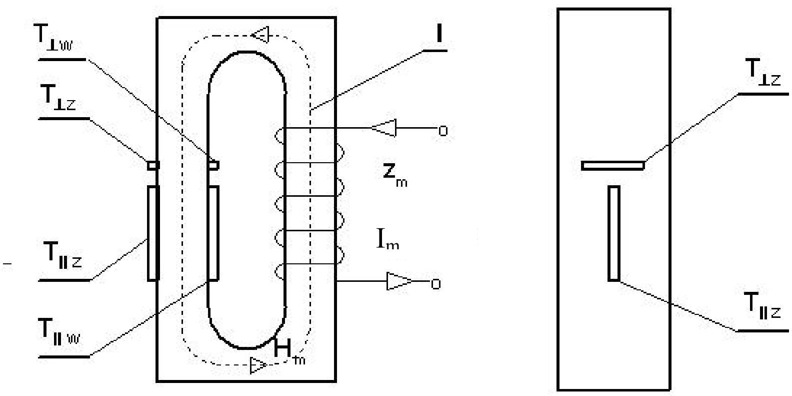

Figure 2. Location of the strain-gauges on the frame-shaped core

III. Idea of the measuring system

Newly developed measuring installation utilizes a semiconductor strain-gauge measuring techniques. The schematic block diagram of the installation is given in Figure 3. This solution creates possibility of simultaneous measurement of the magnetistriction λ as well as the flux density B in the function of magnetizing field H. Moreover developed measuring installation gives possibility of testing of the initial curve and the reversal hysteresis $\lambda(H)$ loops. As a result it gives more complete information about magnetostrictive properties of tested materials, than the known methods of measurement the saturation magnetostriction λ_s [8]. In addition simultaneous measurements of B, λ and H gives more complete information on the process of the magnetization of the soft magnetic materials. This information is important from the fundamental point of view, because creates possibilities of

development of coupled magnetoelastic models of magnetization [1]. Moreover results of this tests of the properties of the soft magnetic alloys is important for the constructors of the mechatronic inductive components with the soft magnetic materials cores [3, 5].
One of the most important element, of utilized measuring methodology, is a digital method of the compensation of the influence of the heat generated by current I_m in magnetizing winding Z_{P1} and Z_{P2} (Figure 2). This heat is the reason of increasing of the offset error of the strain-gauges T_{P1} and T_{P2}. This problem is especially important during the measurements of the properties of nearly zero magnetostrictive materials, such as cobalt ferrites. In this case the compensation of the influence of a heat generation is absolutely necessary to achieve acceptable resolution of the measuring system.

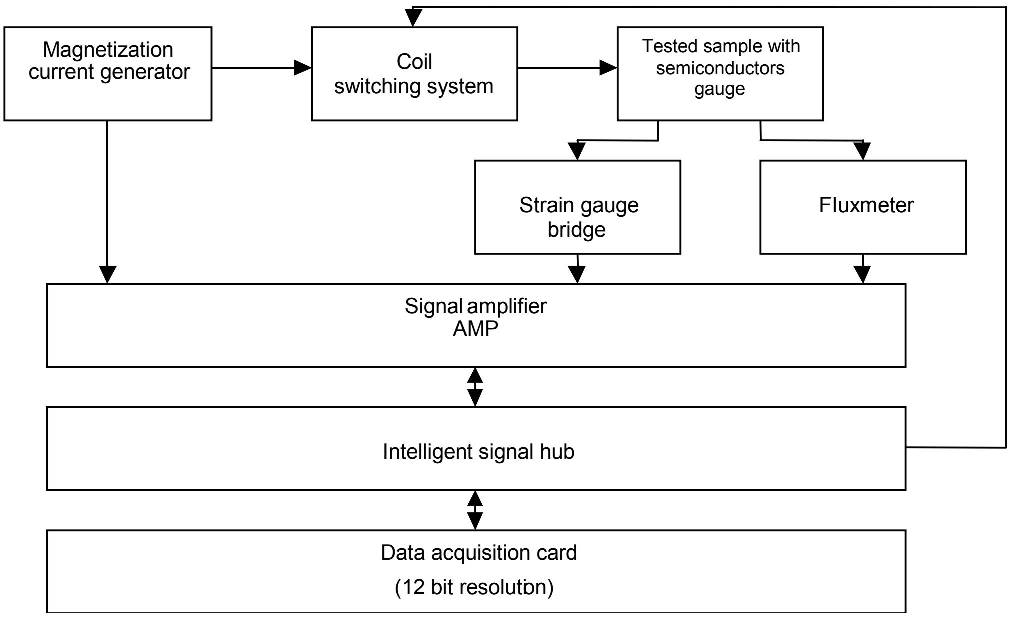

Figure 3. Schematic block diagram of developed measuring system

In developed measuring installation digital method of compensation of temperature-drift caused by a heat generation from magnetizing winding is utilized. For this method two section Z_{P1} and Z_{P2} of magnetizing winding are necessary, as it is presented in Figure 4. In the first step of measurements the sections of magnetizing winding are connected in opposite direction. As a result this winding does not generate magnetizing field, but generate a heat. Influence of this heat generation is measured in system, as a drift with is use to compensation in next step. In second step the magnetizing sections are connected in the same direction. But after measurement of the magnetostriction, the influence of a heat generated by magnetizing winding, can be compensated by using the data acquired in step one. The typical characteristic of a heat influence during the magnetization process is given in Figure 5.

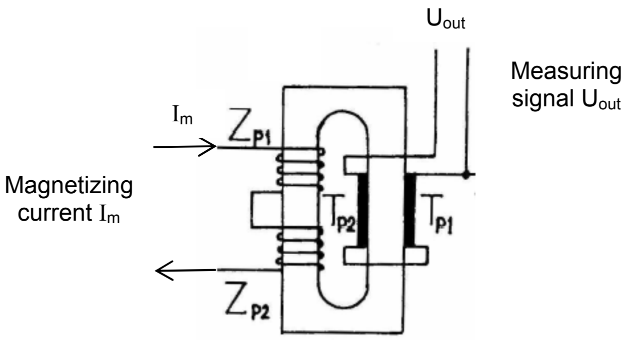

Figure 4. Schematic diagram of the sample for digital based heat influence compensation methodology

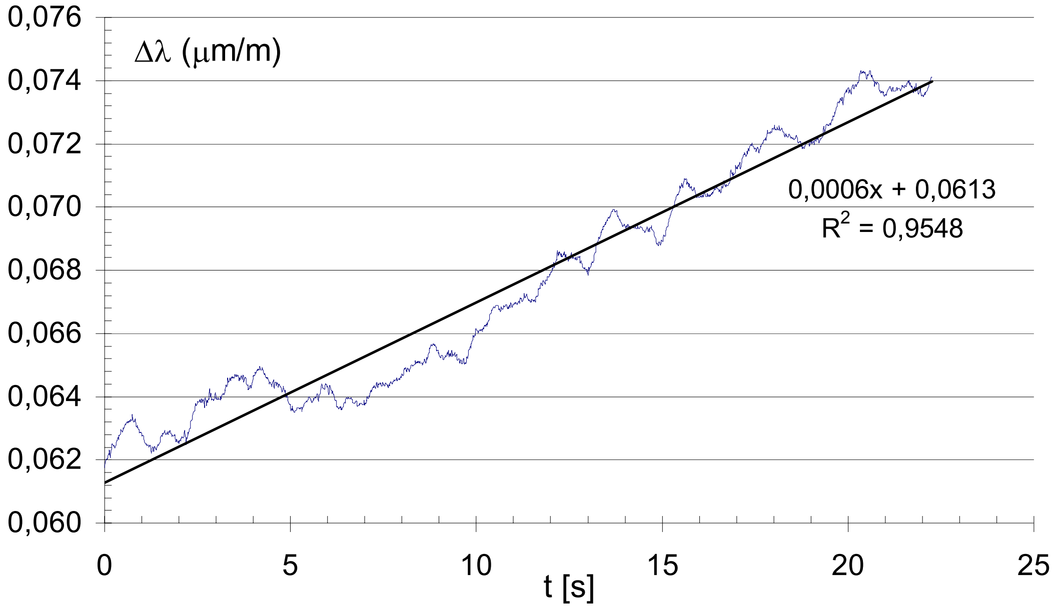

Figure 5. The characteristic of the influence a heat during the magnetization process

IV. Results of investigation

For practical verification of the functional parameters of developed measuring system the magnetostrictive properties of the soft ceramic magnetic materials (ferrites) were tested. Figures 6 and 7 present the magnetostrictive and magnetic hysteresis loops of $(Fe_2O_3)_{50}$ $(NiO)_{17,5}$ $(ZnO)_{32}$ $(CoO)_{0,5}$ ferrite in temperature 25°C. Figure 8 present characteristic's magnetostriction as a function of flux density of the $(Fe_2O_3)_{50}$ $(NiO)_{17,5}$ $(ZnO)_{32}$ $(CoO)_{0,5}$ ferrite in temperature 25°C. It should be indicated that in spite of the low magnetostriction of tested ferrite, the influence if a heat from magnetizing winding was successfully compensated.

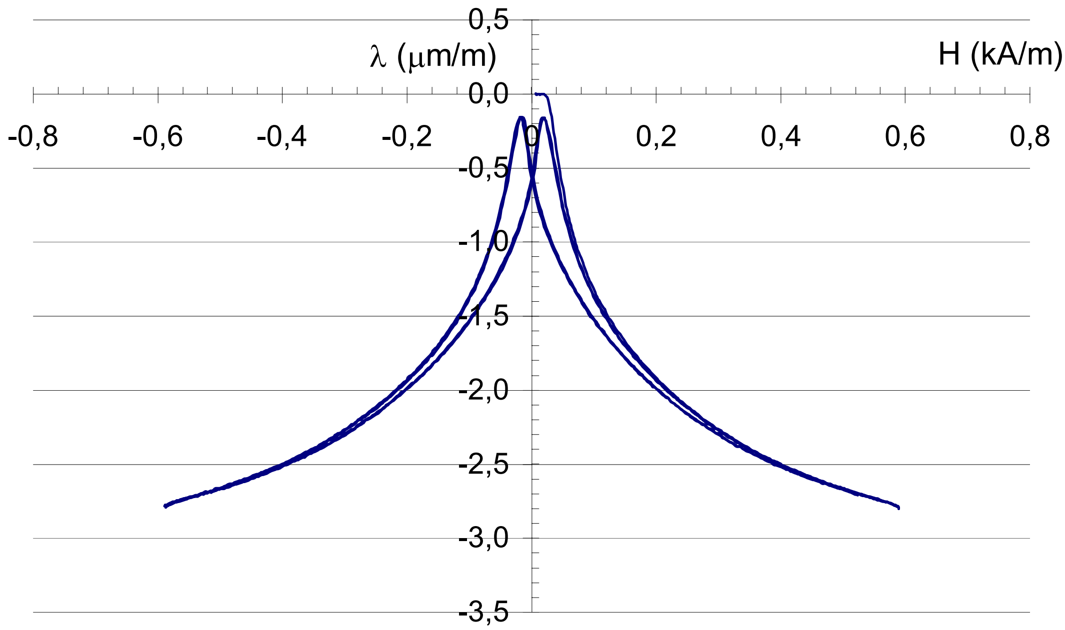

Figure 6. The initial curve and the magnetostrictive hysteresis loop of the $(Fe_2O_3)_{50}$ $(NiO)_{17,5}$ $(ZnO)_{32}$ $(CoO)_{0,5}$ ferrite in the temperature 25°C

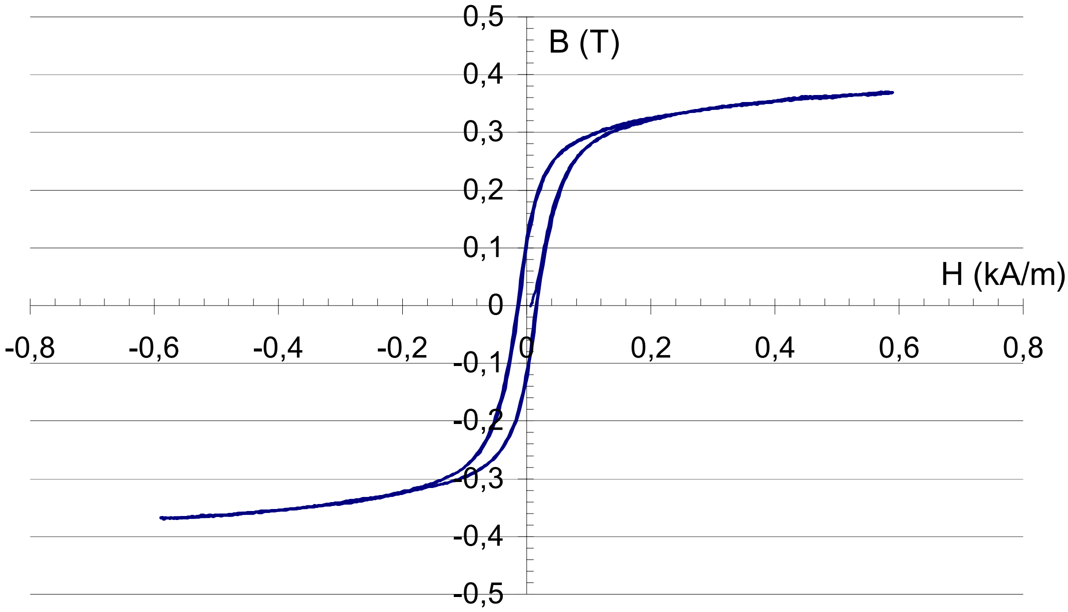

Figure 7. Magnetic hysteresis loop of the $(Fe_2O_3)_{50}$ $(NiO)_{17,5}$ $(ZnO)_{32}$ $(CoO)_{0,5}$ ferrite in the temperature 25°C

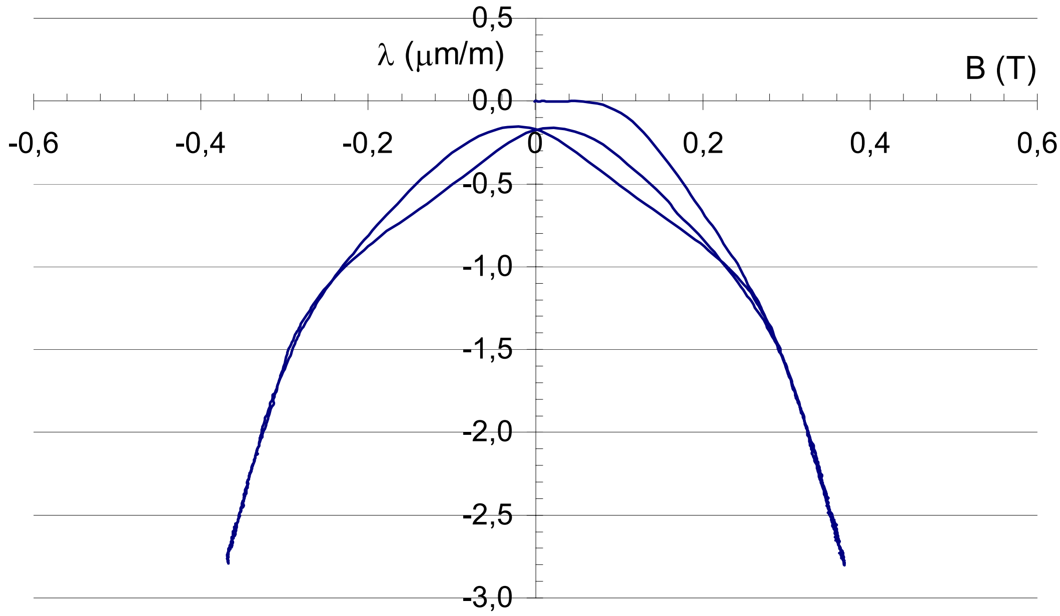

Figure 8. Characteristic's magnetostriction in function of flux density of the $(Fe_2O_3)_{50}$ $(NiO)_{17,5}$ $(ZnO)_{32}$ $(CoO)_{0,5}$ ferrite in the temperature 25°C

V. Conclusions

Developed measuring installation creates new possibility of testing of the magnetostrictive properties of the soft magnetic materials for inductive components. Due to the simultaneous measurement of the flux density B and the magnetostriction λ as a function of the magnetizing field H, the new possibilities of the experimental verification of the theoretical models of the magnetomechanical effects are obtained.

The presented methodology of compensation of the influence of the heat generated by current magnetizing I_m winding gives very good results and creates the possibility of testing of the characteristic of the materials with low value of saturation magnetostriction λ_s.

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