Temperature Influence on the Magnetic Characteristics of Mn-Zn Ferrite Materials

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Abstract. The subject of this paper was to investigate the temperature influence on the magnetic characteristics B-H of crystalline soft magnetic materials. Four different Mn-Zn ferrite material were investigated. The investigated ferrites were formed into ring-shaped cores with closed magnetic circuit and magnetizing and sensing windings were coiled on them. All cores were placed in the cryostat which was used to set temperature. Magnetic B-H characteristics was measured by computer controlled hysteresis graph. The results of the investigations were presented in the paper and analyzed. On the basis of presented results, the conclusions were formulated, which are also included in the paper.

Keywords: ferrite, temperature influence, magnetic characteristics, ferromagnetic material.

1 Introduction

Researches on magnetic properties and characteristics of magnetic materials are very important from the point of view of modern electronic, where inductive components play very significant role. One of the most important materials for technical applications are ferrites, which are widely used as magnetic cores for inductive components as chokes, filters and transformers [1].

Ferrites are ceramic materials composed of iron oxide (Fe_2O_3) chemically composed with one or more metallic elements [2]. They are ferrimagnetic materials and due to their magnetic properties they can be classified into two groups: soft ferrites, which are used as magnetic cores of transformers and other inductive elements and hard ferrites, which are the materials for permanent magnets. One of the most popular groups of soft ferrites for technical applications are Mn-Zn ferrites, containing magnesium and zinc as additive metallic elements.

The most complete description of magnetic properties of the magnetic material is its B-H characteristic [3]. It presents all changes in the structure of magnetic material and its magnetic properties due to changes of external magnetizing field.

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For the technical applications it is very important to determine the influence of environmental conditions on magnetic characteristics of ferrite. It is commonly known, that environmental conditions, especially temperature, is more or less affecting magnetic properties of magnetic materials [4–7]. This paper presents the methodology and results of investigation of temperature influence on magnetic characteristics of Mn-Zn ferrite materials.

2 Investigated Samples

During the investigation, four Mn-Zn ferrite material samples of different chemical compositin were tested. Chemical composition of all materials can be described by the general formula $Mn_{1-x}Zn_xFe_2O_4$. The difference between the materials was the content ratio of magnesium and zinc (value of the x parameter). Two of them (F-3001, F-807) were fabricated by POLFER (Poland) and the other two (T38, N41) by TDK-EPC Epcos (Germany).

All investigated samples were formed into ring-shaped magnetic cores, as presented in Fig. 1. Based on the geometrical dimensions of the core, basic geometrical parameters: the flow path of the magnetic flux in the magnetic circuit l_e and cross-sectional area of the core S_e, were calculated. They were necessary to correctly designate the values of magnetic field strength H and magnetic flux density B.

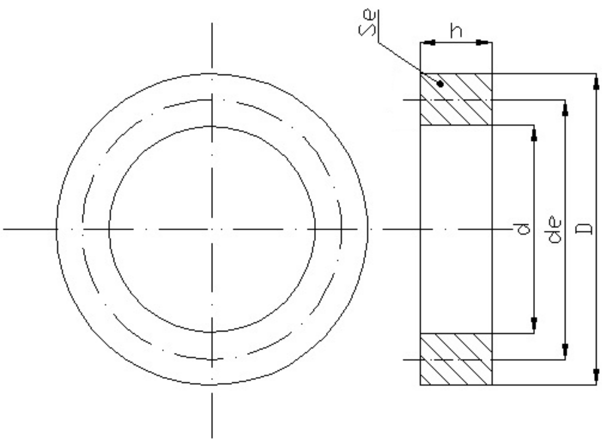

Fig. 1. Shape and geometrical dimensions of investigated Mn-Zn ferrite cores, D – outer diameter, d – inner diameter, d_e – average diameter, h – thickness

On each investigated core magnetizing and sensing windings were made. Sensing winding was located under magnetizing winding in order to decrease influence of demagnetization effects. Geometrical parameters and numbers of coils in each winding for all samples are presented in Table 1.

Table 1. Geometrical parameters and numbers of magnetizing (N_m) and sensing (N_s) coils of investigated Mn-Zn ferrite cores

Sample	F-3001	F-807	N41	T38
l_e (mm)	62.8	82.0	92.3	62.8
S_e (mm^2)	60	60	99	39
N_m	5	5	10	5
N_s	25	25	50	25

3 Measurement System

Temperature influence on the magnetic characteristics of Mn-Zn ferrite materials was tested with the special computer controlled measurement system with cryostat for temperature stabilization. The block diagram of the measurement system is presented in Fig. 2.

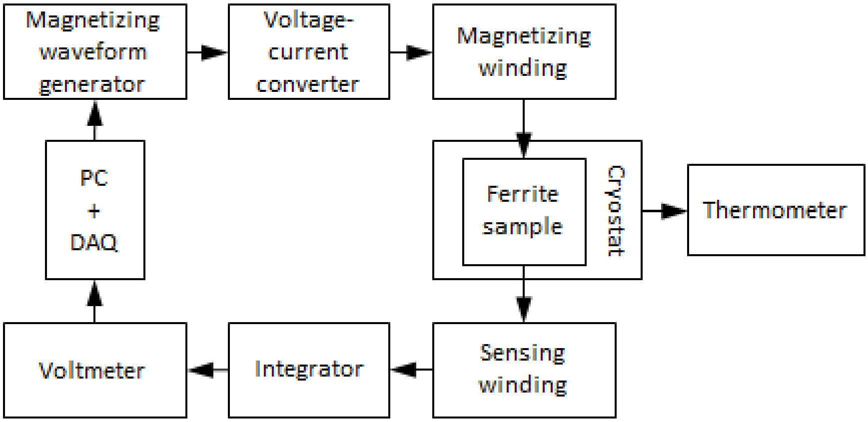

Fig. 2. Schematic block diagram of the measurement system

To control the measurement system, PC with Data Acquisition Card (DAQ) and special control software installed was used. Magnetizing waveform was generated as voltage waveform and then converted into current magnetizing waveform by voltage-current converter. The parameters of the waveform, such as frequency and amplitude, were set in the control program. Magnetizing waveform was sent to magnetizing winding, changing magnetizing field H acting on the investigated sample in time according to the formula:

$$H(t) = \frac{N_m i(t)}{l_e}, \quad (1)$$

where $i(t)$ is function describing changes of magnetizing current in time. Changes of magnetizing field H caused changes of the voltage induced in sensing winding. The induced voltage waveform was integrated over time by integrator to obtain values proportional to the values of magnetic flux density B in the investigated sample. Integrated values of voltage were measured by voltmeter and sent to the PC, where values of the flux density B were calculated in control program. Changes of B in time depending on the induced voltage can be described by the formula:

$$B(t) = \frac{K_c}{N_s S_e} \int u(t)dt, \tag{2}$$

where $u(t)$ is function describing changes of induced voltage in time and K_c is the constant of the integrator. Having the values of both $H(t)$ and $B(t)$, B-H magnetic characteristic could be determined.

The investigated samples were placed in the cryostat chamber filled with thermally conductive fluid. The chamber was built as Dewar flask. The cryostat was able to both cool and warm the objects placed in the chamber. The temperature inside the chamber was measured by digital multimeter with K-type thermocouple connected.

4 Experimental Results

For all four investigated samples B-H magnetic characteristics were measured within the temperature range of −20 °C to 60 °C. For each investigated core maximum value of magnetizing field was equal or close to the saturation value. In Fig. 3-6 hysteresis loops of investigated ferrites are presented. For each sample, three hysteresis loops are shown: in minimum temperature of −20 °C, in normal room temperature of 20 °C and in the maximum temperature of 60 °C.

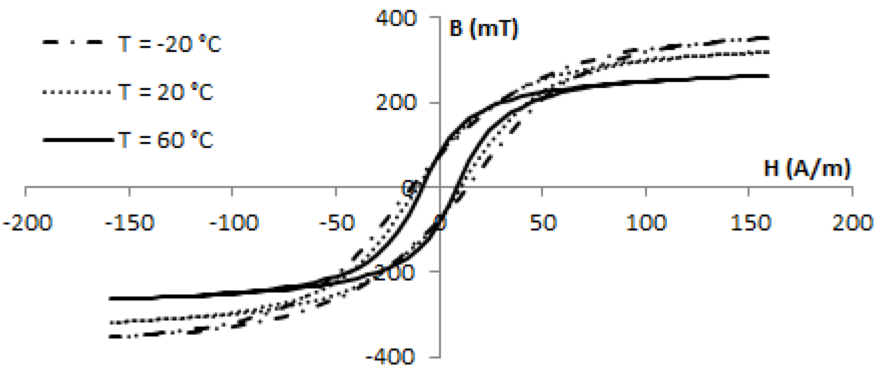

Fig. 3. The temperature dependence of B-H magnetic characteristics of F-3001 Mn-Zn ferrite material, H_m = 160 A/m

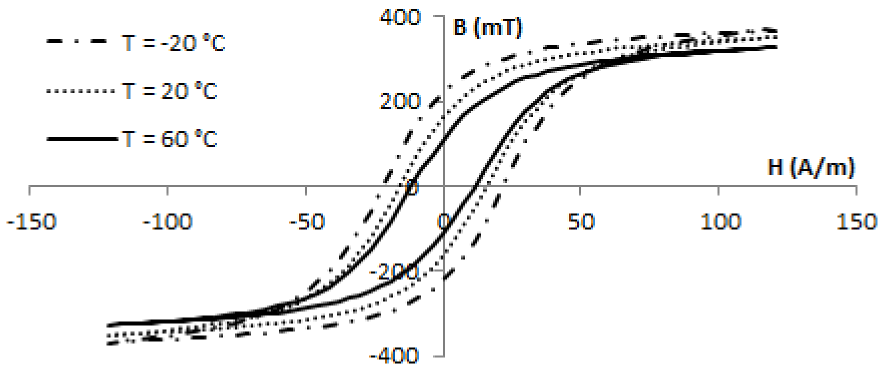

Fig. 4. The temperature dependence of B-H magnetic characteristics of F-807 Mn-Zn ferrite material, $H_m = 120$ A/m

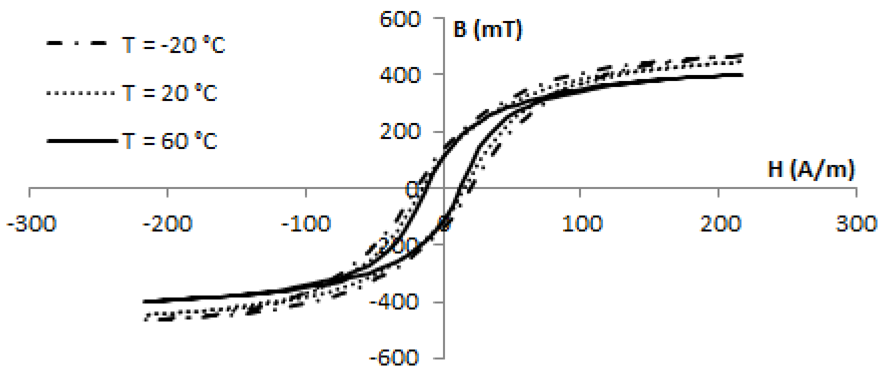

Fig. 5. The temperature dependence of B-H magnetic characteristics of N41 Mn-Zn ferrite material, $H_m = 215$ A/m

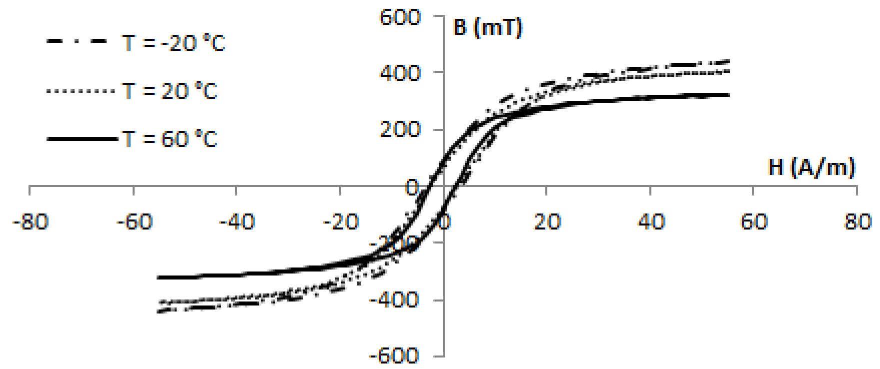

Fig. 6. The temperature dependence of B-H magnetic characteristics of T38 Mn-Zn ferrite material, $H_m = 55$ A/m

As in can be seen in the presented charts, temperature influence on the magnetic B-H characteristics of Mn-Zn ferrite materials is clearly noticeable. With increasing temperature, the area of the hysteresis loop of Mn-Zn ferrite is decreasing. For the maximum temperature the area of hysteresis loop is the smallest. It means, that with increasing temperature, values of all parameters of the hysteresis loop, such as coercive field, remanence and maximum flux density, are decreasing. Changes of remanence are clearly seen especially for F-807 material. Decreasing values of coercive field can be observed in all investigated materials.

The most noticeable effect of temperature influence on the magnetic B-H characteristics of Mn-Zn ferrite materials is a decline in the values of maximum flux density with increasing temperature. It is presented in Fig. 7, which shows temperature characteristics of maximum value of flux density B_m. Presented results were obtained for the amplitude of magnetizing field H_m = 120 A/m for all investigated samples.

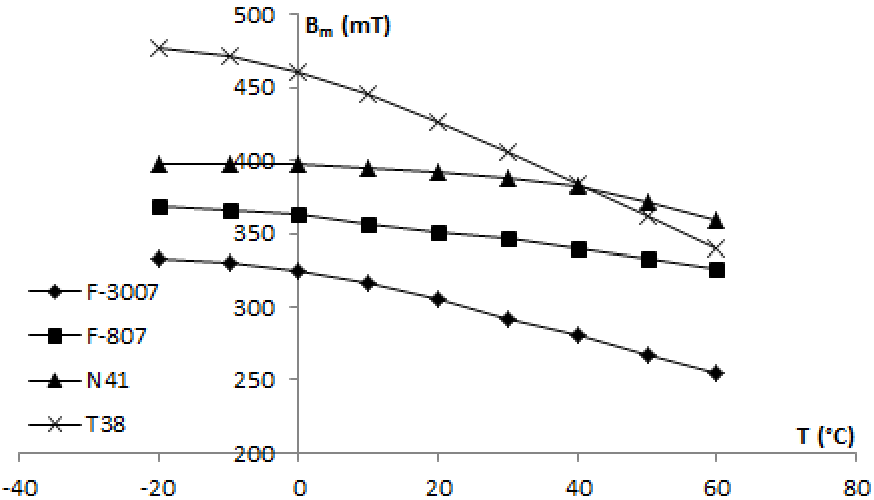

Fig. 7. Temperature dependence of maximum flux density B_m for investigated Mn-Zn ferrite materials, H_m = 120 A/m

The temperature dependence of maximum value of flux density B_m in all investigated cores is monotonic. For low temperatures, under 0 °C, maximum flux density reaches the highest values. With increasing temperature, maximum flux density values are decreasing. For the highest investigated temperature (60 °C), B_m takes a minimum value. The most significant difference between the highest and the lowest value of B_m occurs in T38 material. In other samples temperature dependence of maximum flux density is slightly smaller. This may be due to chemical composition of T38 material, which could be significantly different from the other investigated materials.

5 Conclusion

Presented results are consisted with the Weiss theory of molecular field [8] and show that there is a significant temperature dependence of magnetic properties of Mn-Zn ferrite materials. It is caused by processes occurring in the atomic structure of the material. If ferrite material is placed in the magnetizing field, magnetic moments of the ferrite's atoms are setting according to the direction of the field. When temperature is increasing, the thermal energy of atoms in the crystalline structure is also rising. Thermal vibrations of atoms become stronger, so it is easier for magnetic moments to change their directions in the direction of external field. This causes a decrease in the values of coercive field and remanence of the material in higher temperatures. But strongly vibrating atoms also makes it harder to achieve full arrangement of magnetic moments when external magnetizing field is reaching saturation values, so maximum flux density of material is lower for high temperatures. So in high temperatures it is easier to demagnetize the material but magnetic moments of atoms cannot reach full arrangement in saturation area of the hysteresis loop.

Results of the research shows, that there is a strong correlation between the temperature and magnetic properties of Mn-Zn ferrite materials. This connection is so significant, that it cannot be neglected in technical applications. It is very important matter when designing electronics containing inductive components with Mn-Zn ferrite cores to take into account the operating temperature range of the device and to assess whether the inductive components will work properly in such thermal conditions.

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