Influence of Temperature and Magnetizing Field on the Magnetic Permeability of Soft Ferrite Materials

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Abstract. Soft ferrite materials are commonly used as magnetic cores of inductive components utilized in electronic industry. Magnetic B-H characteristics of ferrites exhibit strong temperature dependence. It is connected with changes of magnetic permeability of ferrite material subjected to different temperatures. In ferromagnetic materials, also ferrites, magnetic permeability depends on the value of magnetizing field. In this paper, results of investigation on the influence of temperature and magnetizing field on the magnetic permeability of soft ferrite materials are presented. Several ring shaped cores made of different manganese-zinc ferrites were investigated on developed test stand utilizing cryostat to set the temperature in the range form −20 °C to 60 °C. Obtained results indicate that there is a strong correlation between temperature of ferrite material and its magnetic permeability, which cannot be neglected in technical applications of ferrite magnetic cores.

Keywords: Magnetism · Soft magnetic material · Ferrite · Magnetic permeability · Magnetic characteristics · Temperature

1 Introduction

Magnetic materials are very important for modern electronic industry. They are widely utilized as magnetic cores in inductive components like coils, filters, chokes, transformers, etc., which are present in all modern electronic devices. Magnetic properties of the material used for manufacturing the core are strongly influencing the characteristics of inductive component and, therefore, it is very important to select proper material for a particular application. Among many existing ferromagnetic materials, ferrites are very interesting group. They are often utilized in inductive components for the purposes of electronic industry, especially in EMC (Electro-Magnetic Compatibility) applications [1].

Ferrites are ceramic magnetic materials. They are composed of iron oxide Fe_2O_3 and one or more metallic elements [2, 4]. This results in double crystal lattice in the structure of material created of atoms of opposite magnetic moments. This opposite moments are not equal, so they do not compensate each other, which is the source of spontaneous magnetization of the material. Such materials are known as ferrimagnetics [3].

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Among many parameters used to characterize magnetic properties of the materials, magnetic permeability is one of the most significant. Magnetic permeability is a physical quantity determining the ability of material to produce magnetic field within itself as a response to the external magnetizing field. Magnetic properties of the material are usually characterized by relative magnetic permeability, which is magnetic permeability of the material in relation to magnetic permeability of free space μ_0 [5]. In ferromagnetic materials, also ferrites, magnetic permeability depends on the value of magnetizing field. Magnetic properties of the material, also its magnetic permeability, are dependent on environmental conditions, especially temperature [6–10]. From technical point of view it is very important to determine the influence of magnetizing field and temperature on the magnetic permeability of ferrite materials due to their possible applications. The following paper presents results of investigation on the influence of temperature and magnetizing field on the magnetic permeability of soft ferrite materials utilized in technical applications.

2 Investigated Materials

Among many ferrite materials developed so far, one of the most important group are Mn-Zn ferrites, containing magnesium and zinc as metallic elements. Their chemical composition is characterized by general formula $Mn_{x-1}Zn_xFe_2O_4$. For performed investigation, four samples of Mn-Zn ferrite materials were prepared. Each of them had different content ratio of magnesium and zinc (*x* parameter in the general formula). Materials F-3001 and F-807 were fabricated by POLFER (Poland), while T38 and N41 by TDK-EPC Epcos (Germany). Investigated materials were formed into ring-shaped magnetic cores, which is presented in Fig. 1.

The flow path of magnetic flux density in the magnetic circuit and cross-sectional area of the core were calculated for each sample, which was necessary to determine

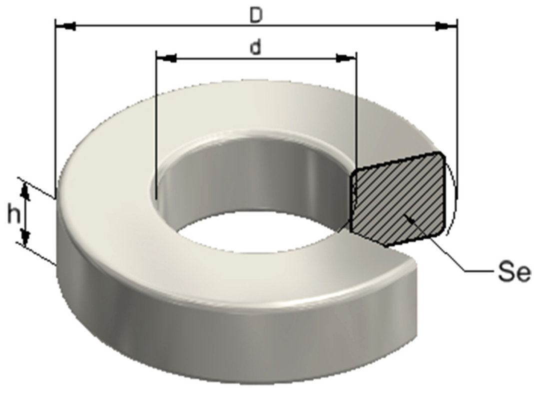

Fig. 1. Investigated Mn-Zn ferrite core, *D* – outer diameter, *d* – inner diameter, *h* – thickness, S_e – cross-sectional area

values of magnetizing filed and magnetic flux density during measurements. Magnetizing and sensing windings were made on each investigated core.

3 Measurement Methodology

For performed experiment, special measurement system was developed with cryostat for stabilization of the temperature. Schematic block diagram of the system is presented in Fig. 2. System was digitally controlled by the Personal Computer with Data Acquisition Card (DAQ) installed.

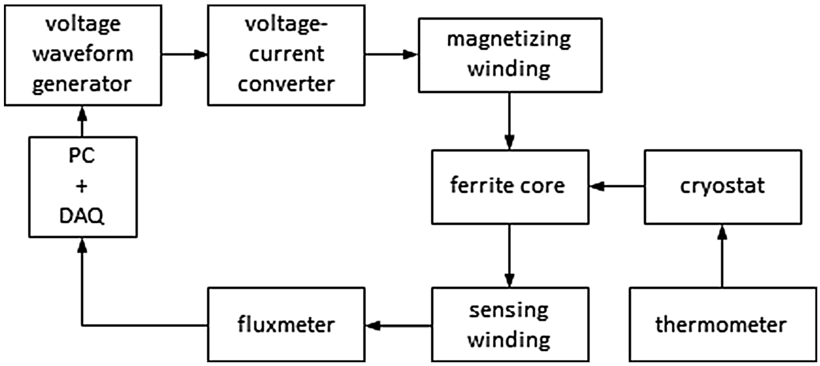

Fig. 2. Schematic block diagram of the developed measurement system

Main part of the developed system were devices allowing investigation of magnetic *B-H* characteristics of the material (*B* – magnetic flux density, *H* – magnetizing field, *B-H* characteristic is initial magnetization curve and magnetic hysteresis loop). To produce magnetizing field, voltage waveform generator was utilized. Voltage waveform from generator was transformed by voltage-current converter into current waveform driving magnetizing winding of the investigated sample. As a result, magnetizing filed acting on the sample was generated, which is dependent on the current according to the Eq. (1):

$$H = \frac{n_m I}{l_e} \tag{1}$$

where n_m is number of magnetizing coils, I is current driving magnetizing winding and l_e is the flow path of magnetic flux density in the sample. Changes of magnetic flux density B in the material resulting from magnetizing field acting on the sample were measured with fluxmeter and transferred to the PC. Developed system allowed to investigate *B-H* characteristics for given value of magnetizing field amplitude and frequency.

Investigated samples were placed in cryostat chamber filled with thermally conductive fluid, which allowed to obtain stable values of temperature within the range from −20 °C to 60 °C. APPA 207 multimeter with K-type thermocouple was used to measure the temperature inside main chamber of the cryostat.

For all investigated samples family of 16 *B-H* characteristics was measured in given temperature. For each obtained *B-H* characteristic relative magnetic permeability was calculated according to the Eq. (2):

$$\mu = \frac{1}{\mu_0} \frac{dB}{dH} \tag{2}$$

where $\mu_0 = 4\pi \cdot 10^{-7}$ H/m is vacuum magnetic permeability (physical constant). As a result, 16 points on each μ-H characteristic (μ – relative magnetic permeability, H – magnetizing field) were obtained for given temperature. The μ-H characteristics were investigated within temperature range from −20 °C to 60 °C with step of 10 °C.

4 Experimental Results

As a result of performed investigation, family of 9 μ-H characteristics was obtained for each sample, each characteristic composed of 16 points. Results are presented in Figs. 3, 4, 5 and 6. For clear presentation only three μ-H characteristics obtained for temperatures −20 °C, 20 °C and 60 °C are shown in each figure.

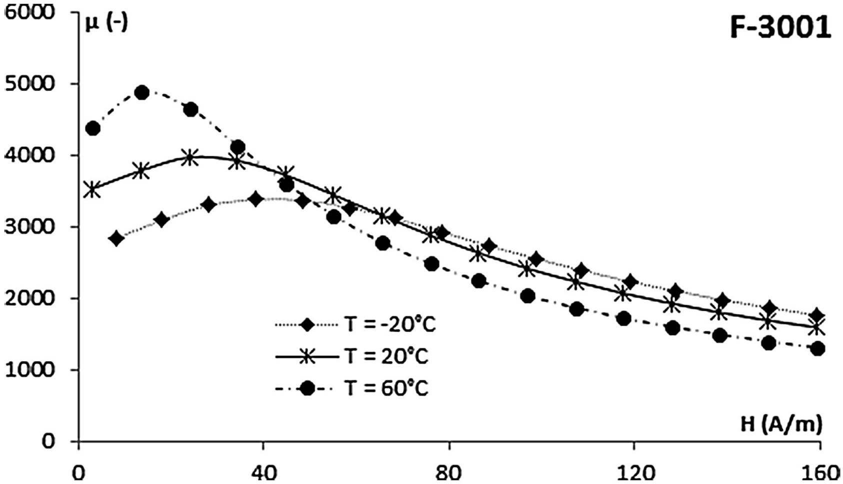

Fig. 3. Magnetizing filed dependence of relative magnetic permeability under the influence of temperature for F-3001 ferrite material

As it can be seen in the figures, all obtained μ-H characteristics have similar shape. Each one starts with initial value for low magnetizing field and then relative permeability is increasing with the magnetizing field to reach its maximum value. Then permeability value starts to decrease with further increase of magnetizing field and is

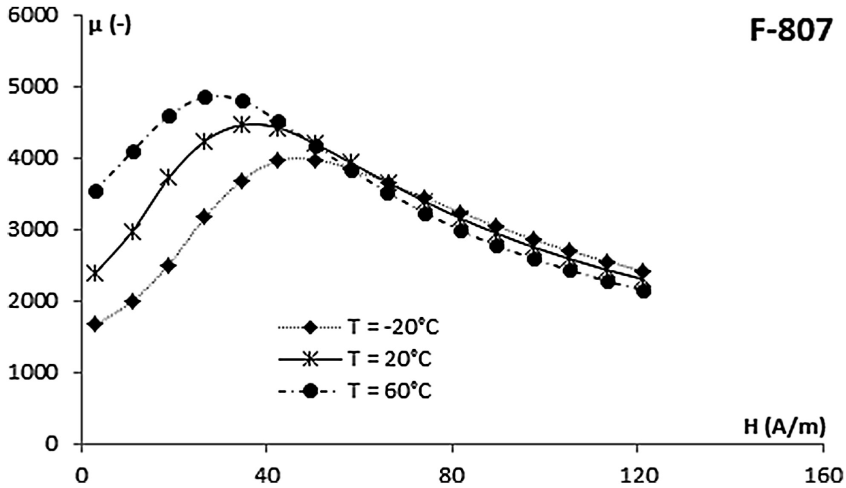

Fig. 4. Magnetizing filed dependence of relative magnetic permeability under the influence of temperature for F-807 ferrite material

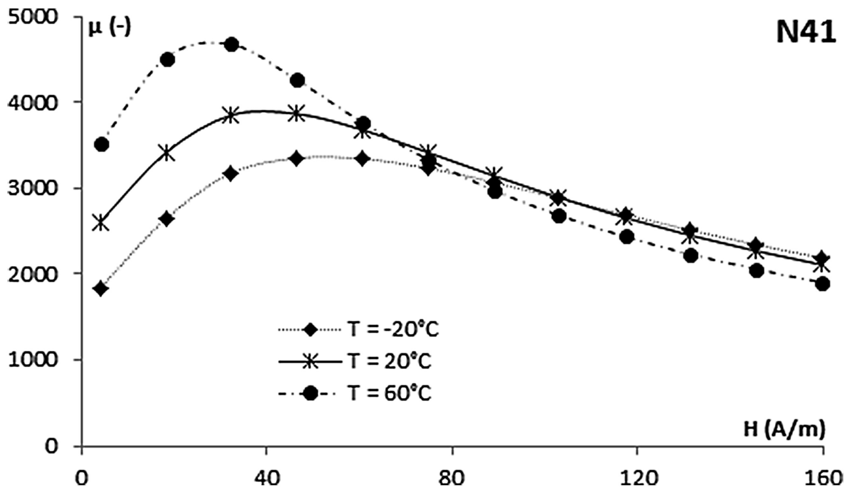

Fig. 5. Magnetizing filed dependence of relative magnetic permeability under the influence of temperature for N41 ferrite material

asymptotically tending to 1. In room temperature, about 20 °C, three of investigated materials have maximum relative permeability value within the range 4000–5000. Only T38 ferrite exhibit significantly higher maximum permeability with the value almost 16 000. This difference is the result of different chemical composition of T38 material (different content ratio of magnesium and zinc).

Temperature influence on the values of relative magnetic permeability is similar for all investigated cores. With the temperature growth value of maximum permeability is

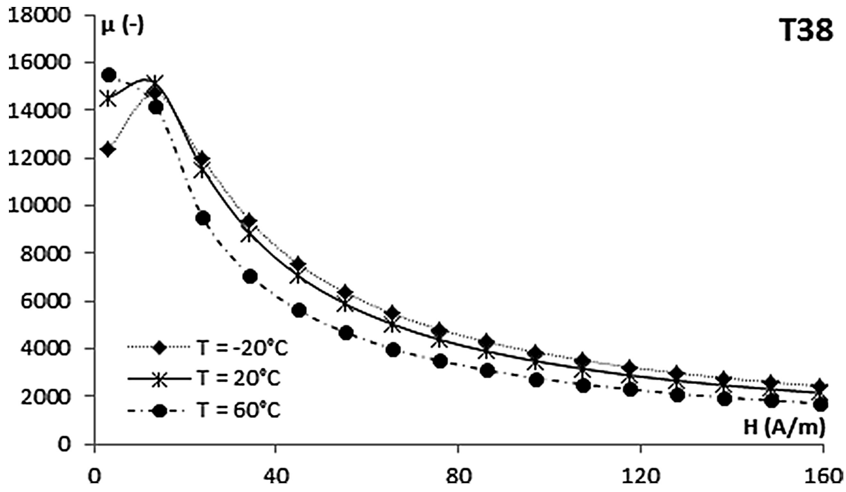

Fig. 6. Magnetizing filed dependence of relative magnetic permeability under the influence of temperature for T38 ferrite material

increasing. For 60 °C maximum permeability is substantially higher than for −20 °C for all investigated materials. Moreover, with temperature increase, maximum value of permeability is reached for lower magnetizing field. For T38 material at 60 °C maximum permeability is reached for magnetizing field so low, that it was not registered during the experiment, which explains, why the initial permeability is invisible in the chart. The decreasing part of the μ-H characteristic is also affected by the temperature. The decrease is greater for higher temperature for all investigated ferrite materials, so the values of relative permeability in the saturation region (high magnetizing filed) are lower for high temperatures. N41 material seems to be the most susceptible for the temperature influence. For this one the differences between the values of maximum permeability are the greatest. F-3001 and F-807 materials also exhibit significant temperature susceptibility. T38 ferrite is definitely the most temperature resistive among investigated materials.

5 Conclusion

For all investigated materials temperature dependence of magnetic permeability is similar. Higher temperature value results in higher maximum relative permeability and lower magnetizing filed necessary to obtain this maximum. It is caused by the increase of thermal energy of atoms in the crystal structure of material resulting from higher temperature. Thermal vibrations of atoms in the crystal lattice are becoming stronger and it is easier for their magnetic moments to redirect their vector to the direction of magnetizing field, which can be observed as increase of the magnetic permeability of the material. At the same time in saturation region, where all atomic magnetic moments should be directed according to the magnetizing field vector, thermal vibrations interfere their arrangement, so permeability of the material in saturation region is lower in higher temperatures.

Results presented in the paper show significant correlation between temperature and magnetic permeability of Mn-Zn soft ferrite materials. This correlation is strong enough to be taken into account in technical applications of ferrite materials. The operating temperature range of ferrite core should be specified and taken into account during designing electronics with inductive components based on ferrite materials to ensure proper operation of the device.

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