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Research of magnetic properties of permanent magnets in the magnetic circuit with air gap

Abstract. *This work presents results of measurements magnetic properties for permanent magnets in magnetic circuit with different value of air gap. Measurements were conducted at room temperature. Results of the measurements were compared with template data defined according to the inductive method using the histeresisgraph produced by the Italian company Laboratorio Elettrofisico.*

Streszczenie*. W artykule przedstawiono wyniki pomiarów właściwości magnetycznych magnesów trwałych. Pomiary zostały przeprowadzone w temperaturze pokojowej z wykorzystaniem hallotronowych czujników indukcji magnetycznej. Zmieniano wartość szczeliny powietrznej obwodu magnetycznego: 1,62; 2,35; 3,08; 25,6 mm. Wyniki pomiarów porównano z wartościami wzorcowymi otrzymanymi w wyniku pomiarów metodą indukcyjną za pomocą histerezografu włoskiej firmy Laboratorio Elettrofisico. (****Badania właściwości magnetycznych magnesów w obwodach ze szczeliną****)*

Słowa kluczowe: magnesy trwałe, dielektromagnesy, właściwości magnetyczne, histerezograf.
Keywords: permanent magnets, dielectromagnets, magnetic properties, histeresisgraph.

Introduction

Magnetic properties of the permanent magnets are determined by measuring the magnetic field intensity and magnetic induction inside the sample placed in the external region of the homogeneous demagnetization field.

One of the methods allowing to designate the magnetic properties of the permanent magnets is the inductive method. This method relies on the measurement of magnetic flux in a sample placed between the poles of an electromagnet. The fact that there is no air gap in the magnetic circuit makes the magnetic field distribution in the sample homogeneous; the magnetic flux intensity inside the sample is the same as the intensity of the external magnetic field. In the inductive method, the measurement of the magnetic flux inside the sample is made with the use of a coil covering the measured sample. Due to the changes of the value of the magnetic flux in the course of time, the induced voltage in the coil is measured with the use of the measuring device with the ultra low zero-drift. Measurement of magnetic properties in closed magnetic circuit is difficult to conduct in low or high temperatures. During cooling permanent magnet is also cooled electromagnet, it has disadvantageous influence on stability of the temperature.

Other method allowing to measure magnetic properties of permanent magnets is method in which the sample is places in the partially opened magnetic circuit. Between the face surfaces of the sample and the electromagnet's poles there is an air gap. It may be filled with the thermally insulating material. In case of the temperature measurements, it is necessity to cool only magnetic material sample. There is no need to change the temperature of the entire magnetic circuit. The air gap allows to measure normal component of magnetic induction B_o as well as the external magnetic field H_o using the static method. To conduct the magnetic measurements using the static method, Hall sensors are commonly used. However, the presence of the air gap in the magnetic circuit causes the formation of the inhomogeneous demagnetization field. It is necessary to know the correlations between the values characterizing the magnetic samples and the values that are actually measured. Demagnetization ratios allows to determine this correlation. They are determined to the given magnetic circuit. This method relies on the homogeneous distribution of the external magnetizing field strength and low slenderness of the sample [1-2]. The external values, H_o and B_o, were measured while the internal values defining the magnetic properties of the measured magnetic samples are calculated on the basis of the equations considering the demagnetization ratios. The measurements was conducted for two electromagnets. In first one, the air gap was changed and its value was equal to 1.62, 2.35 and 3.08 [mm]. In second electromagnet the value of air gap was constant and equal to 25.6 [mm]. Designed software allows to obtain characteristic of magnetic properties such as Br, H_{cJ} and H_{cB}. The abovementioned program can also calculate the demagnetization ratios on the basis of the previously measured B_o and H_o values and the references data. Knowledge of the physical properties of permanent magnets at extreme temperatures is, therefore, an essential factor to be considered when designing electric motors [3-5].

Method of measurement and determination the demagnetization ratios

Basing on the measured external values B_o , H_o (fig.1) and by use two demagnetization ratios, it is possible to designate the internal magnetic properties for hard magnetic sample. The internal properties are as follows : magnetic polarization J, magnetic pole strength H and the induction B. The equations binding the internal and external values are presented below:

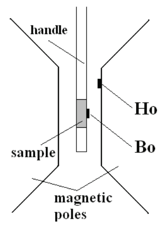

Fig.1. Location of hall sensors in air gap of electromagnet

$$J = \frac{B_o - \mu_o H_o}{D_2} \quad (1)$$

$$H = H_o - \frac{J D_1}{\mu_o} \quad (2)$$

$$B = \mu_o H + J \quad (3)$$

where: D_1 - demagnetization ratio of the magnetic sample placed between the electromagnet poles, D_2 - demagnetization ratio of the air gap between the face surface of the magnetic sample and the electromagnet poles.

D_1 and D_2 demagnetization ratios depend on the size of the sample (that is diameter d and height h), the length of the air gap and, in a lesser degree, the position of the Hall sensor in the air gap.

Actually demagnetization ratios was calculated basing on specific analysis of the magnetic circuit. In conducted research demagnetization ratios was calculated without knowing parameter magnetic circuit but based on the template curves.

The demagnetization ratios was designated by numerically method for each magnetic circuit. Designed computer program compares template to calculated curve for various configuration of demagnetization ratios. For some configuration of this demagnetization ratios the curves will be the most similar to each other.

Determination of characteristics of hall sensors

Hall sensors THS-119 [6] were used to measure the value of Bo and Ho. Their voltage characteristics were determined in room temperature. Figure 2 presents the characteristics of the measured output voltage of Hall sensor, depending on the real value of induction measured at room temperature, by teslameter F. W. Bell model 5070. Calibration equation was determined by use of Excel. The dependence of the output voltage from Hall sensor on the supply current is shown in fig 3.

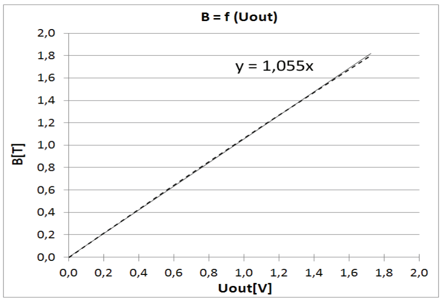

Fig.2. Characteristics B = f (Uout) of hall sensor THS-19 measured at room temperature

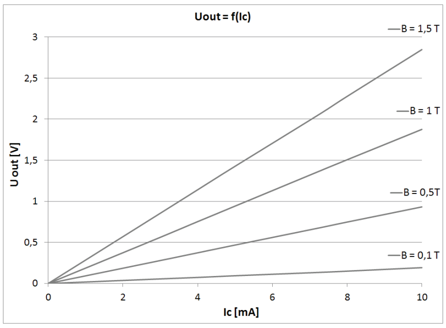

Fig.3. Characteristics Uout = f (Ic) of hall sensor THS-119 measured at room temperature

Based on the determined voltage characteristics, the calibration equation was described as fallows:

(4) $B=1,055 * U_{wyj}$

Results of research

To conduct research, the following samples of Nd-Fe-B dielectromagnets were selected (table 1). Samples of permanent magnets were manufactured in ITR from two commercially available powders. This permanent magnets were of cylindrical shapes: diameter 10 mm and 4 mm length.

Table 1. Nd-Fe-B dielectromagnets selected for research

sample	material	Producer of powder
A	MQP-B	Maqnequench
B	NQP-B	Xuxiang

Preliminary studies were conducted in electromagnet with adjustable air gap length. The maximum value of magnetic induction for the 5.62 mm air gap is 1.6 T. Numerically calculated demagnetization coefficients allows to obtain curves, corresponding to reference curves B,J=f(H) measured by inductive method. Figure 4 presents example characteristics B,J=f(H) for reference and calculated curves measured in electromagnet with 1.62 mm air gap. Numerically calculated demagnetization ratios for different values are presented in table 2.

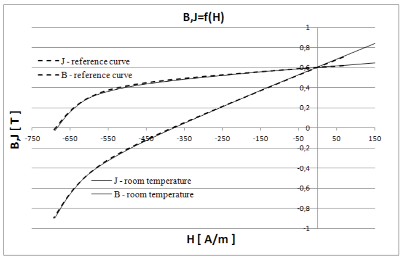

Fig.4. Characteristics of B, J = f (H) for dielectromagnet made from NQP-B powder. Length of air gap is 1.62 mm

Table 2. Numerically designated demagnetization ratios for different values of air gap

Air gap length		D_1	$1/D_2$
h=1.62	mm	0.35	1.53
h=2.35		0.41	1.72
h=3.08		0.45	1.91

By increasing the air gap length is easier to carry out measurement in different temperature. However, this reduce of the maximum value of magnetic induction in air gap.

Further studies were carried out using an electromagnet with air gap of length 29.6 mm (without measuring sample). Maximum value of the magnetic induction in the air gap is 1.88 T. In order to check the homogeneity of the distribution of magnetic field intensity in the air gap of the electromagnet, measurements were taken of the magnetic induction in the various points placed on the air gap's length using the various values of the currents supplying the electromagnet. The curves showing the correlation between the magnetic induction and the measurement points placed on the air gap's length, are presented in the figure 5.

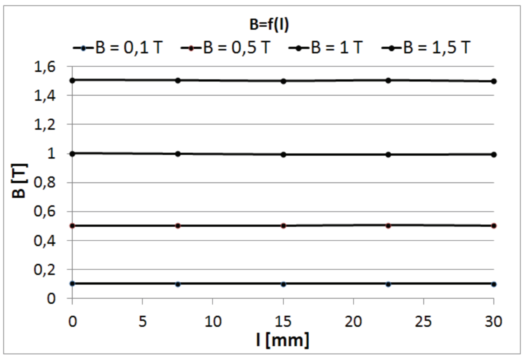

Fig.5. Distribution of the magnetic induction in the air gap located between the electromagnet poles

The large value of the air gap allows the use of insulating material of thickness 10 mm. Characteristics of B,J=f(H) for the dielectromagnet from NQP-B and MQP-B powder are shown in figure 6 and 7.

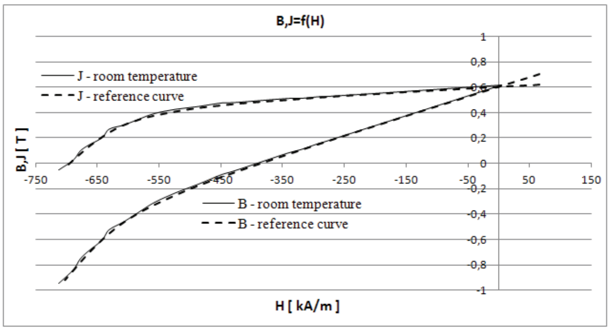

Fig.6. Characteristics of B, J = f (H) for the dielectromagnet from NQP-B powder

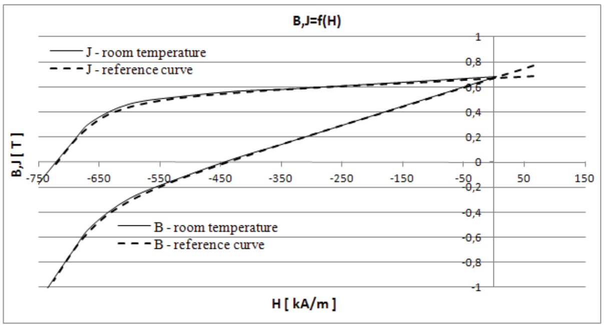

Fig.7. Characteristics of B, J = f (H) for the dielectromagnet from MQP-B powder

Demagnetization ratios obtained by numerical method are presented in table 3. On the basis of these measurements software allowed to calculate the characteristic magnetic parameters, characterizing the magnetic properties of investigated permanent magnets. The values of the parameters B_r, H_{cJ}, H_{cB}, for reference and calculated curves are shown in the table 4.

Table 3. Numerically designated demagnetization ratios for air gap length 25.6mm

Air gap		D1	1/D2
h = 25.6	mm	0.65	3.7

Table 4. The values of parameters B_r, H_{cJ}, H_{cB} for the reference and calculated curves, including calculated demagnetization coefficients

Type of sample		Br	HcJ	HcB
		[T]	kA/m	kA/m
A	References curve	0.670	719	437
	Measured	0.672	721	442
B	References curve	0.604	694	386
	Measured	0.610	697	392

Conclusions

Magnetic properties of permanent magnets were measured in induction histeresisgraph and in electromagnets with air gap by use of described method. Results of measurements are similar which indicates that, despite the presence of the air gap in the magnetic circuit of electromagnet, it is possible to determine correctly magnetic parameters for investigated permanent magnets. Research showed that by using described method it can be determined the magnetic properties of permanent magnets in magnetic circuit with an air gap with length 25.6 mm. Such a large dimensions of air gap allows to conduct measurements in very low temperatures by use special thermally insulated container. Inside it a test sample of magnetic material can be placed and flooded with cooling liquid. Thermally insulated container would cause isolate poles of an electromagnet from the influence of coolant temperature. The developed algorithm can determine the demagnetization coefficients based on measured external values H_o and B_o, and on the known reference curve. A computer program automatically adjusts the demagnetization coefficients so that the reference curve coincides with the calculated curve. Presented results of research were conducted in room temperature. They constitute the first stage for build measurement stand, which allows the measurement of magnetic properties of permanent magnets at very low temperatures. At the present stage of research laboratory stand is not automated, and the developed software does not supervise the work of the stand. Automating the measurement cycle will allow examination of a large series of samples in quicker time.

Knowledge of the magnetic parameters of permanent magnets in very low temperature is important information for designers of electrical machines destined to operate at extremely low temperatures.

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