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REINFORCED DIELECTROMAGNETIC CORES BEHAVIOUR UNDER ROTATIONAL MAGNETIC FIELD*)

ABSTRACT *For last ten years there has been growing tendency for application of dielectromagnetics (DM) for magnetic cores of electrical machines. The paper presents results of research of the influence of various shapes of reinforcements – soft magnetic insertions, on the dielectromagnetic cores magnetic properties. The cores were examined under rotational magnetic field which usually occurs in electrical machines. Magnetic characteristics and parameters of the reinforced magnetic cores are presented and compared with the homogeneous ones, made of DM. Samples of reinforced cores were executed and tested with various configurations of the reinforcements.*

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The examined configurations of the reinforcements can be useful for the improvement of magnetic parameters of dielectromagnetic cores in desired directions. This enables control of magnetic flux's flow, the control of which can be useful for applications in electrical micro-motors, especially in reluctance motors.

1. INTRODUCTION

Dielectromagnetic cores are the products, the structure of which can be strengthened by placing solid materials of specific shapes as its reinforcements. The reinforcement can be applied for the purpose of magnetic properties improving in required directions or control of magnetic flux's flow within the magnetic core. This also allows for mechanical strengthening of the magnetic core. Reinforcements, which can be applied in diversified forms, are characterized by very good magnetic properties, which influence the properties of a magnetic core [3]. Reinforced dielectromagnetic cores, comprising compressed composite powder and magnetically soft reinforcements, are called hybrid magnetic cores. Changing the structure of magnetic cores by their reinforcing would allow the control of magnetic cores' properties without changing the main component – dielectromagnetic (DM) or its properties, which proves to be much more difficult than reinforcing of a core itself. Reinforced dielectromagnetics can be applied in many electrical machines and the rotational magnetic field is one of the most frequently occurring magnetic field types in these machines. Therefore, the magnetic cores for electrical machines should be tested under that kind of magnetic field.

2. COMPONENTS OF REINFORCED DIELECTROMAGNETIC CORES

2.1. Dielectromagnetic

The basic component used in the reinforced cores, is the dielectromagnetic (DM). That material consists of particles of magnetically soft metal – most frequently the iron, coated by a dielectric. The dielectric binds the particles

together, and additionally provides their electrical insulation. The insulation reduces eddy currents induced in the magnetic core. The dielectromagnetic is obtained from the dielectromagnetic powder by its compacting in a die, and afterwards thermally treating it with the aim of curing the material. During curing, the possible reduction of stress in particles of the manufactured element is also desired. Parameters of DM are influenced first of all, by the properties of the applied dielectromagnetic powder, but also by technological parameters, such as compacting pressure and the time and temperature of the thermal treatment [1].

The values of selected magnetic properties of the DM with mass density = 7,2 g·cm^{-3} under rotational magnetic field of frequency 50 Hz, are as follows [1]:

- maximum magnetic permeability μ_{max} = 235
- total power losses Δp = 14,1 W·kg^{-1} (for B = 1 T)

2.2. Reinforcing

Solid soft magnetic materials, as reinforcing components for the dielectromagnetic cores, can be applied in the form of beams, wires and sheets among others. These shapes allow for the change of isotropic dielectromagnetic cores into anisotropic ones. Very good magnetic properties of these materials allow for noticeable changes in directional properties of the dielectromagnetic cores to appear, even with small number of the reinforcement used.

In the manufactured reinforced cores, the ARMCO wires were used in various configurations.

3. CONFIGURATIONS OF REINFORCED CORES

Assumed theoretical configurations of the reinforced cylindrical dielectromagnetic cores for the tests under rotational magnetic field are shown in Fig.1 and Tab.1.

Samples of types B and C are the sample made by the same technology but situated in different directions referring to the measurement detector's axes. For purpose of clear presentation of tests' results, samples with the wire bundles placed parallel to the measurement detector's axis were denoted as B-type cores. Samples with wires placed crosswise to the measurement detector's axis were denoted as C-type ones (Fig.1). The measurement detector's axes are situated along X and Y axes which are shown in Fig.1.

TABLE 1
Description of reinforcements in the specimen's arrangement, according to Fig.1.

Description	Denotation of samples		
	A	***B***	***C***
ARMCO wires number [pieces]	4	8	8
Reinforcement volume [%]	1,3	2,6	2,6
Reinforcement configuration	Parallel to the measurement detector's axis, in the middle of specimen height	Parallel to the measurement detector's axis, in the middle of specimen height	Crosswise to the measurement detector's axis, in the middle of specimen height

The boundary wires of the reinforcing bundles (cores A, B and C), were assumed in the form of an arch for better drawing of the magnetic flux in one specified direction in the core.

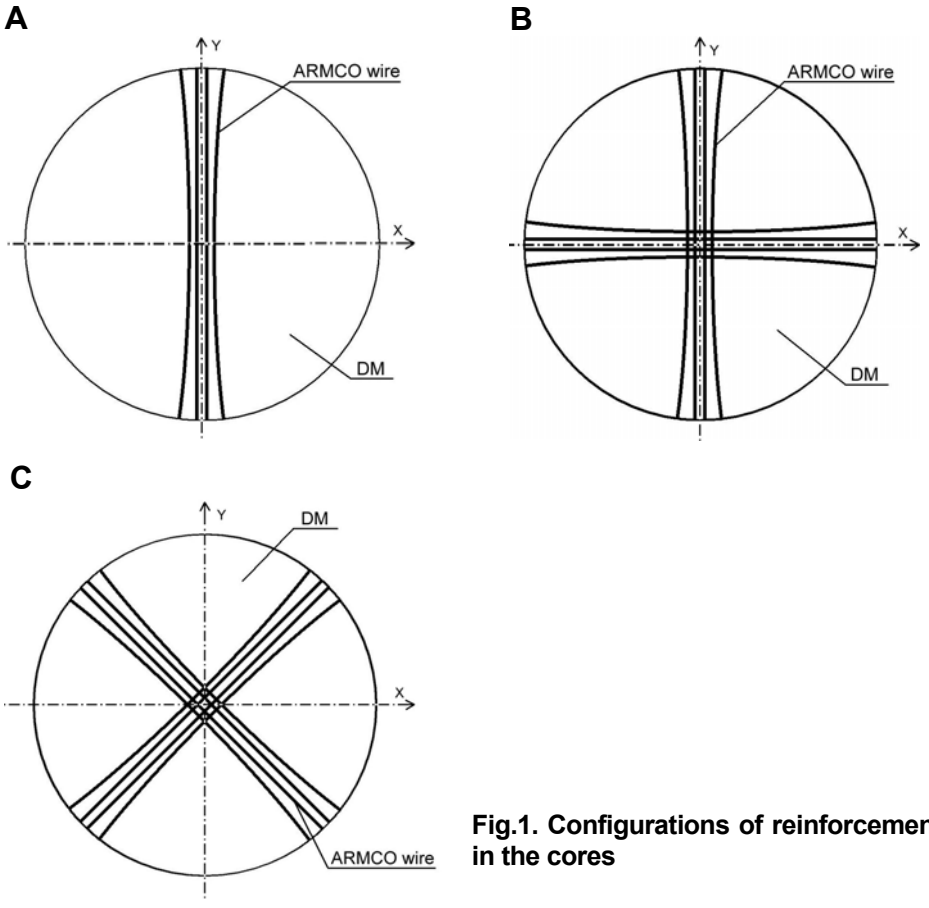


Fig.1. Configurations of reinforcements in the cores

4. TECHNOLOGY OF THE REINFORCED DIELECTROMAGNETIC CORES

The theoretical configurations described in Tab.1 and Fig.1, were treated as the basis for the manufacture of the tested reinforced dielectromagnetic cores. The dimensions of these cores were adjusted to the yoke of the measurement system, and were following: diameter – 60 mm, height – 5 mm. Applied compacting pressure was equal 800 MPa, thermal treatment was carried during 1 hour at 160 ºC in air atmosphere. The reinforcing components were placed in the dielectromagnetic powder during the die filling (Fig.2). The wires' inserting was carried out when half of the dielectromagnetic powder was poured into the die.

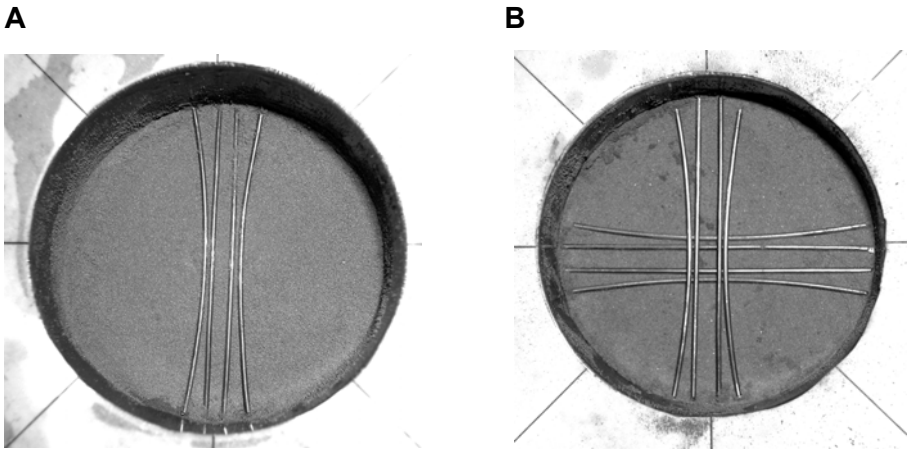


Fig.2. View of wires' arrangement inside the die. Configuration for sample: A and B (the C-type composition corresponds to picture B)

For the sake of comparison, a monolithic cylindrical dielectromagnetic core with no reinforcement, denoted as DMS, was manufactured. For tests, the reinforced dielectromagnetic cores were manufactured, according to descriptions in Tab.1 and Fig.1.

5. RESEARCH OF REINFORCED DIELECTROMAGNETIC CORES

The manufactured reinforced dielectromagnetic cores were tested in MAG-TD200 the computerized measurement system [2], at circular magnetization at frequency 50 Hz. The circular magnetization is a particular kind of rotational

magnetization in which magnetic induction vector changes its direction in time, without a change of its value. Magnetic properties in the circular magnetic field were determined with respect to direct measurement of tangential component magnetic field intensity and average magnetic induction value in specimen's cross-section [1]. Frequency 50 Hz is the most commonly used frequency in electrical machines, and that's why this one was chosen for the samples' tests.

Figure 3 presents visualisation of magnetic induction and magnetic field intensity values during the tests at the circular magnetic field. Presented visualisations are called $BxBy$ and $HxHy$ loci. These loci were obtained by such kind of circular magnetization where modulus of the rotating magnetic induction vector, was constant and equal 1 T. This effect was obtained by proper modulation of the value of the rotational magnetic field. The Tab.2 shows calculated according to equation 1, relative differences between the values of magnetic field intensity in X and Y direction.

$$\delta H = \frac{\Delta H(x) - \Delta H(y)}{\Delta H(x)} \cdot 100\% \tag{1}$$

where:

$\Delta H(\mathrm{x})$ – value of magnetic field intensity in the direction of channel X

$\Delta H(y)$ – value of magnetic field intensity in the direction of channel Y.

The calculations' results allow for estimation of asymmetry's degree of the sample in the X and Y direction.

Measurement of total power losses level in the samples allows for calculating (according to equation 2) the relative difference in energy loss values of reinforced dielectromagnetic cores in reference to DMS cores (Tab.3).

$$\delta p = \frac{\Delta p(A,B,C) - \Delta p(DMS)}{\Delta p(DMS)} \cdot 100\% \tag{2}$$

where:

$\Delta p(A, B, C)$ – value of total power loss of the core A, B or C

$\Delta p(DMS)$ – value of total power loss of the DMS core

TABLE 2
Relative difference in magnetic field intensity between the intensity values in the X and Y axis. Comparison realized by magnetic induction B = 1 T.

Description	Denotation of samples			
	A	***B***	***C***	***DMS***
δH [%]	20	8	11	13

TABLE 3
Relative difference in energy loss values of reinforced dielectromagnetic cores in reference to DM cores.

Description	Denotation of samples					
	A		***B***		***C***	
B [T]	0,5	1,0	0,5	1,0	0,5	1,0
δp [%]	**43**	**73**	**37**	**73**	**35**	**40**

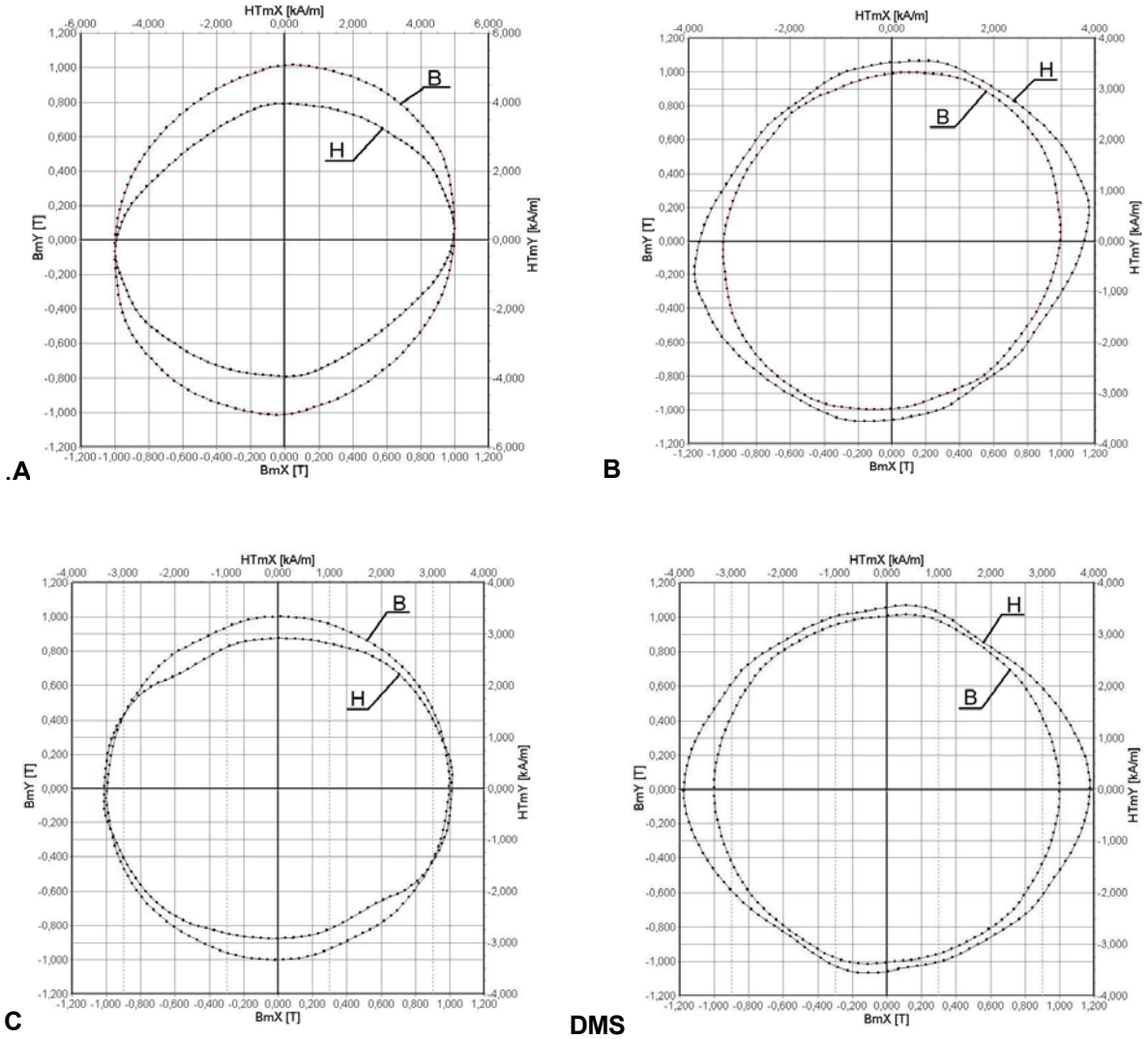


Fig.3. The BxBy and HxHy loci of the tested dielectromagnetic reinforced samples.

The highest increase of the power loss (δp), in reference to the non-reinforced dielectromagnetic core (DMS), can be noticed in the case of cores A and B (Tab.3). The lowest value of this parameter is observed for the cores C, containing the same number of the reinforcement as the B-type cores. By the higher level of magnetic induction, these differences become more noticeable (Fig.4).

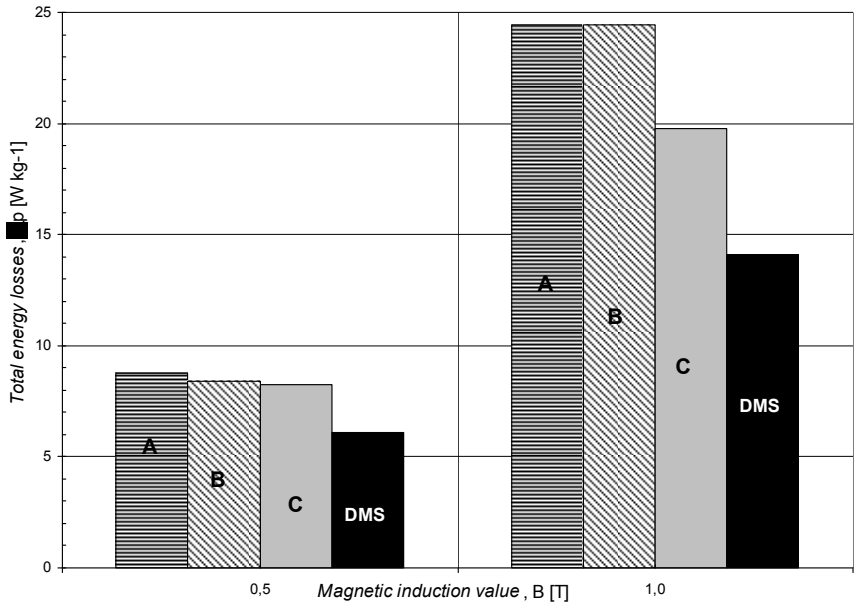


Fig.4. Total energy loss values of the samples tested under rotational magnetic field at frequency 50 Hz

The comparison of magnetic field distribution irregularity is possible through the $BxBy$ and $HxHy$ loci analysis (Fig.3). The biggest difference is noticeable in case of the core A, what was to be expected, because insertion of a single bundle of the ARMCO wire causes the formation of specified axis of better permeance.

The symmetric arrangement of the wire bundles in the DM core (B and C ones), decreases the difference between magnetic field intensity in axis X and Y, what indicates the decrease of the asymmetry of the sample. The magnetic field intensity values for the same induction level, in case of samples B and C, are lower then in samples A (Fig.3). This leads to the conclusion that the increase of symmetry in the magnetic core in rotational magnetic field causes the increase of the DM core's permeance.

The comparison of loci $HxHy$ of the cores B and C, allows for the conclusion that crosswise placing of the wires (C) increases the symmetry of

DM core more than the one parallel to the measurement's detector's axis. The parallel configuration of the wires (B) seems to intensify the asymmetry which is noticeable at the loci of the DMS. Formation of the axis of improved permeance in the tested core as it is in the C-type cores causes the compensation of magnetization possibilities in all the directions in the plain of the tested dielectromagnetic reinforced core.

6. CONCLUSIONS

Executed experiments showed that it is possible to manufacture dielectromagnetic cores reinforced by soft magnetic wires.

The tests of the manufactured reinforced dielectromagnetic cores show the possibility of control of their directional permeance. That control can be realized by proper composition of the reinforcing of the cores which is made of magnetic soft materials of good magnetic properties. Further research of the reinforced dielectromagnetic cores should, therefore, be directed towards precise defining of the influence of the reinforcements' placing in the dielectromagnetic core on distribution of the magnetic flux in the core. The tests of influence of the reinforcement's shape on the magnetic parameters of the dielectromagnetic core may also be advisable.

Research of cores containing larger number of reinforcing elements can also prove necessary. The noticed influence of the reinforcements on directional properties of the core should expectedly increase with the number of reinforcements and allow for manufacturing the cores of strongly diversified directional properties.

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ZACHOWANIE ZBROJONYCH RDZENI DIELEKTROMAGNETYCZNYCH POD DZIAŁANIEM WIRUJĄCEGO POLA MAGNETYCZNEGO

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STRESZCZENIE *W ciągu ostatnich dziesięciu lat zaznaczyły się narastające tendencje stosowania dielektromagnetyków* (*DM*) *na magnetyczne rdzenie maszyn elektrycznych. Artykuł przedstawia wyniki badań wpływu zbrojenia o różnym kształcie – wkładek z magnetycznie miękkiego materiału na magnetyczne właściwości rdzeni dielektromagnetycznych. Rdzenie badano w wirującym polu magnetycznym, jakie zwykle występuje w maszynach elektrycznych. Przedstawiono magnetyczne charakterystyki i parametry zbrojonych rdzeni magnetycznych i porównano je z rdzeniami jednorodnymi wykonanymi z DM. Wykonano i przebadano próbki zbrojonych rdzeni o różnych konfiguracjach zbrojenia.*

Testowane konfiguracje zbrojeń mogą być użyteczne dla poprawienia magnetycznych parametrów rdzeni dielektromagnetycznych w pożądanych kierunkach. Pozwala to na sterowanie przepływem strumienia magnetycznego co może być użyteczne dla zastosowań w mikromaszynach elektrycznych, zwłaszcza w silnikach reluktancyjnych.