Journal of ELECTRICAL ENGINEERING, VOL 57. NO 8/S, 2006, 51-53

COLLECTOR AND DIFFUSER EFFECT OF FOREHEAD DISCS ON CYLINDRICAL FERROMAGNETIC CORES

Jozef Blažek* — Ivan Mikita*

This paper investigates the influence of the collector and diffuser effect of forehead discs on cylindrical ferromagnetic cores and the magnetic properties within the models of rod and dumbbell-type sensors and exciters core especially.

Keywords: Rod-type magnetic core, apparent permeability, forehead disc, magnetic sensor and exciter

1 INTRODUCTION

Sensors and exciters of magnetic fields within the ELF and LF ranges very often feature ferromagnetic cores of cylindrical rod-type shape. By design, they are simple and similar are their windings. It is, however, generally known and exactly detailed by an example [1] that magnetic field in cylindrical core is non-homogenous and owing to its winding design, only 50 as much as 60% of the length of the core can be made use of. The contribution is to point out that a simple adaptation of the core geometry can result in a practically homogenous magnetization at a much higher level. Further it is dealing with designing parameters for quantitative assessment of the core efficiency.

2 THEORY

The basic quantity describing use of the ferromagnetic field is the so-called μ_a - apparent permeability which is constant (independent of the geometrical coordinates) only for homogenously magnetized bodies such as rotational ellipsoids. Such shapes, however, are not suitable for manufacturing cores and designing windings and, additionally, it results in magnetization μ_a at the lowest level [1]. An extreme, generally known example is a spherical body with permeability $\mu_a = 3$, even in case of best ferromagnetic materials.

In [2] the single modes have shown that a substantially higher value of μ_a of the core can be achieved not by way of gradually narrowing but by gradually widening the core towards its end. The characteristics of such core may appear quite complex but the method of single modes enables us to define μ_a permeability as constant for the given mode of magnetization. The principal theoretical and practical importance is attached to the first mode of magnetization, i.e. to the one, which is not changing its polarity along the axis of the core. For example the short rod (D:*l*=1:1) has the apparent permeability of first mode equal 2.69 and for inverted two-side cone (D:d:*l*=1:0.1:1) is the same permeability $\mu_a = 9.48$ (if the calculated material permeability μ_r is more then 1000) [3]. But method of single mode has one disadvantage. It provides proper solutions only in cases of rotary symmetric bodies where magnetization is homogenous in each lateral cross-section, a method applicable to bodies with constant or continuously changing diameters. Practice has, however, shown that highly advantageous magnetic properties are also typical of cores with extreme changes in diameter.

The finding that a suitable widening of the core-ends enables increasing the apparent permeability and the flux density within the core has remained still valid in general. From this point of view, a cylindrical core ending in a thin forehead disc, reminding us of a dumbbell appears to be extreme in design. It is the very type of core that, at sensors of existing designs, is known for its higher as much as three times value of μ_a as is the maximum value of such parameter for the original cylindrical cores. Additionally, this dumbbell-type core is, practically, magnetized homogenously, i.e. its effective length is nearing to the free length of the cylinder between the foreheads. For the mentioned dumbbell geometry, i.e. the configuration of the magnetic circuit in rod-plus-forehead-discs core shape, it was, however, necessary to apply other methods of magnetic field solutions.

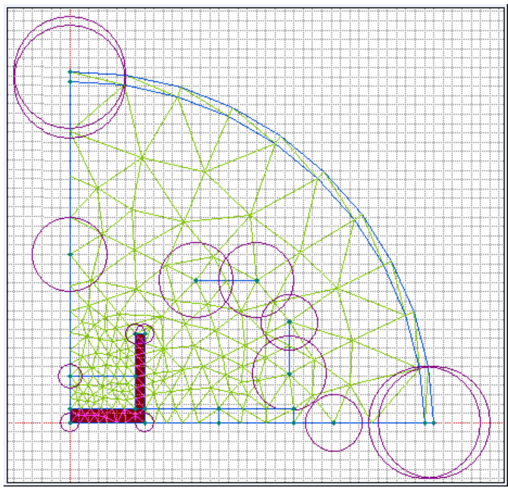

Fig.1. QuickField Geometric model

Modelling using QuickField SW proved to be highly advantageous, purposeful and simple. The model of the

*Technical University in Košice, Faculty of Aeronautics, Department of Technical Studies,
Rampová 7, 041 21 Košice, e-mail: jozef.blazek@tuke.sk

ISSN 1335-3632 © 2006 FEI STU

axially symmetric case in a single quadrant is shown in Figure 1. To determine the exciters fields it was inevitable to solve the fictive dimensions of the area where the modelled field goes to the infinity. For such a widening of an area, an infinite element was successfully applied, which in Figure 1 appears to be a peripheral layer.

3 EXPERIMENTAL PART

The basic facts applicable to magnetization of cylindrical, rod-type core (B_{rod} characteristic) and the core ending in narrow discs ($B_{rod + fh}$ characteristic) is documented in Figure 2 - 5, as a result of modelling the core 320 mm in length, rod diameter 30 mm and in case of dumbbell-type cores featuring disc foreheads 380 mm in diameter and 20 mm thick, all that applying the Quick Field computer program. Equal results can be obtained in cases when all geometric dimensions are multiplied by a coefficient 0.1, or similar ones. The exciting, outer homogenous magnetic field for sensors was defined as B_o = 0,01T and the total number of Ampere-Turns was equal 1500 for exciters.

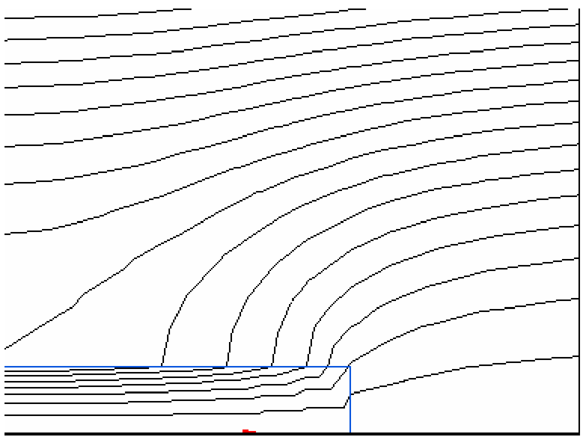

Fig. 2. Magnetic field lines of rod sensor

Illustrations Fig.2 and 3 are showing the collector effect of forehead discs in case of sensor cores.

Both qualitative and quantitative presentations of proportions existing within the rod-type and dumbbell-type cores are shown in Fig.4. Flux density in longitudinal axis x within the rod-type sensor core corresponds to waveforms already known. Flux density for dumbbell sensor core is very different.

It is practically constant along the majority of the core length and the apparent permeability is 3,66 higher than is the one in rod-type core. The interesting mechanism of the collector effect at the forehead discs is explained by characteristics of the B-forehead and $B_{(rod + fh)sur}$, flux density at the forehead and beneath the rod surface. These are mutually linked-up and demonstrate an understandable continuum between the collector effect of the forehead and the increased rod magnetization.

The magnetic properties within the models of rod and dumbbell-type exciters are documented in Fig.5. The shapes of flux density curves are similar to those in the previous case. The difference lies only in the fact that the continuum effects of foreheads and rods are presented by an exponential waveform running opposite to the one shown by sensors.

4 DISCUSSION

In [4], by defining the quantity μ_{efm} (effective permeability), we have designed a general-purpose integral parameter of quality (use) for the magnetic circuit of the core:

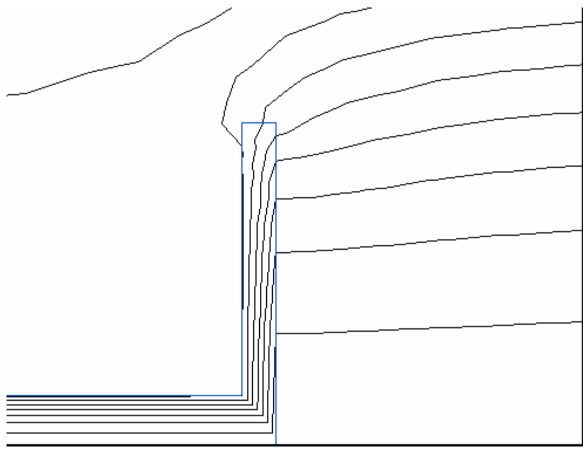

Fig. 3. Magnetic field lines of rod with forehead disc (dumbbell) sensor.

$$\mu_{efm} = \frac{\int_0^l B(x)dx}{B_0 . l} = \frac{1}{l}\int_0^l \frac{B(x)}{B_0}dx$$

In case of the dumbbell-type core of the exciter or sensor, we are now suggesting a more simple and appropriate quantity of Q_m. It is defined as the multiple of the maximum value of apparent permeability μ_{amax} and the effective length of the core, determined as the length $l_{90,}$ at which, the level μ_a is exceeding the value 90% of μ_{amax} to the overall halve core length $l_{o.}$

$$Q_m = \mu_{amax} . l_{ef} = \mu_{amax} . l_{90} / l_o$$

Variables namely μ_{amax} and l_{ef} can be determined also by the detected characteristics of the magnetic flux density in the core – see Figure 4 and by the known exciting value B_o.

$$\mu_{amax} = B_{max}/B_o, \quad \text{similarly as } l_{ef}$$

When applying the figures of merit as defined and suggested above to model cases, it can lead to quantitative comparison of rod- and dumbbell-type cores.

The maximum apparent permeability for the rod-type core of modelled dimensions is 25,8 and that of the dumbbell-type core 94,5.

The effective halve length of the core in the first case is 0,072 m and in the second case 0,147m. Expressed proportionally, the permeability is increased by cca 3,66x and the effective core length two times. The suggested figure of merit of the core quality Qm is 1,857 to 13,89, which gives a proportion as much as 7,5. The collector effect of the forehead discs is extremely efficient.

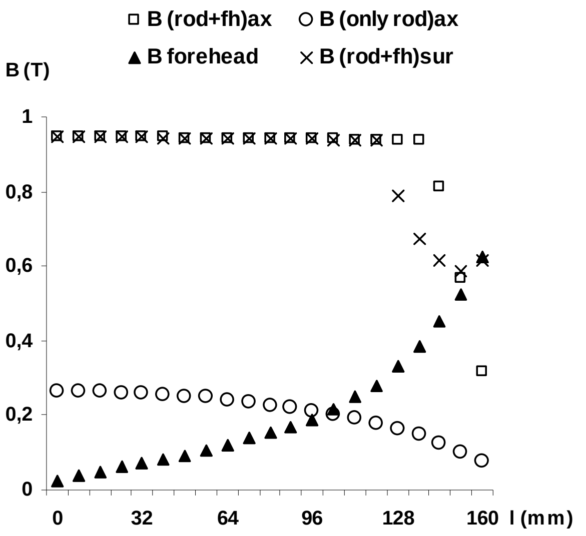

Fig.4. The magnetic properties within the models of rod and dumbbell-type sensors

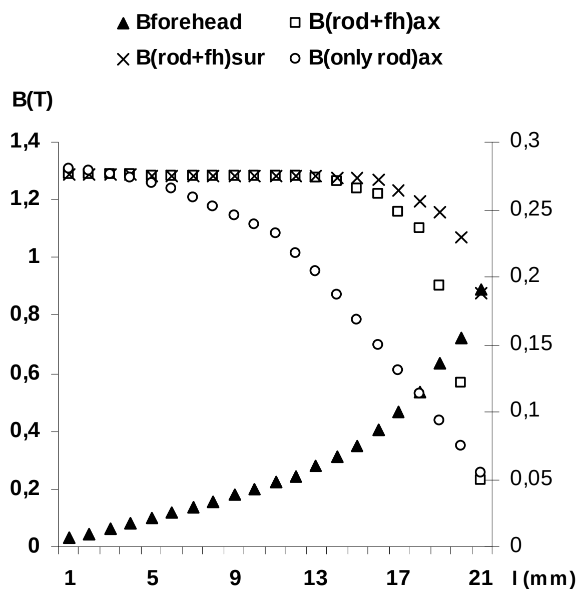

Fig.5. The magnetic properties within the models of rod and dumbbell-type exciters

Comparison of similar type can be conducted based on the radiation of exciters with equal lengths and equal total Ampere-Turns excitation. The magnitude of the flux density radiation on the longitude axis, from a distance larger than the two-multiple of the core length, is larger in case of the dumbbell core approximately by a proportion equal as set by the apparent permeability (3,6:1). In the y axis the radiation proportion is even higher, in the case under solution cca 5,5:1. The first explanation of this fact is offered by the conclusion, i.e. the dumbbell exciter at a larger distance appears to be a magnetic dipole but with higher permeability (magnetization) and greater effective length.

5 CONCLUSION

A cylindrical core ending in a thin forehead disc, reminding us of a dumbbell appears to be extreme in design. It is the very type of core that, at sensors of existing designs, is known for its higher, as much as three times, value of μ_a, as is the maximum value for the original cylindrical cores. Additionally, this dumbbell-type core is almost homogenously magnetized, i.e. its effective length is nearing to the core length of the cylinder between the foreheads.

At our place of work, exciters and sensors created by the principles shown above have been successfully implemented and made use of for several times. Apart from their magnetic effects, the disc foreheads endings have been used as structural parts of the system design.

Acknowledgement

This work was supported by Grant VEGA 1/3216/06.

REFERENCES

[1] RIPKA, P.: Magnetic Sensors and Magnetometers. Artech House, Boston, London, (2000)

[2] BLAŽEK, D. – BLAŽEK, J.: Non-homogeneous magnetization of the body and its single modes. J. Magn. Magn. Mater. 242-245, (2002), pp. 1227-1229

[3] BLAŽEK, J. – BLAŽEK, D. –HUDÁK, J.: Determination of eigenmodes of magnetization for bodies of chosen geometrical shapes. J. Magn. Magn. Mater. 242-245, 2002, pp. 1230-1233

[4] BLAŽEK, J. AND D.-MIKITA, I.- PRASLIČKA, D.: Analýza obvodu s indukčným snímačom, Acta Avionica, No 8/s, (2003), pp. 70-80 (in Slovak)

Received 14 November 2006

Josef Blažek (Prof., Ing., CSc.) and **Ivan Mikita** (Ing., PhD.), biographies not supplied.