FLUX DENSITY DISTRIBUTION OF A MAGNET WITH AXIAL SYMMETRY TO BE USED IN FFC-NMR

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ABSTRACT

According to the application, magnets can have different structures or be based on different types of materials [1-2]. In this work, a magnet without moving parts is designed having axial symmetry. With this magnet is intended to achieve a flux density distribution in its air gap in accordance with the requirements of the Fast Field Cycling Nuclear Magnetic Resonance (FFC-NMR) technique [3].

The main structure of the proposed magnet is represented in Fig. 1, being the magnetic core spot facing using standard steel. In order to achieve 0.2T on the air gap, a current density of 4A/mm^2 is defined for the copper coils. In addition, high flux homogeneity ($\Delta B/B_0$) should be attained at the air gap volume. For that, a trapezoidal shape for the pole surface was optimized.

MAGNET STRUCTURE

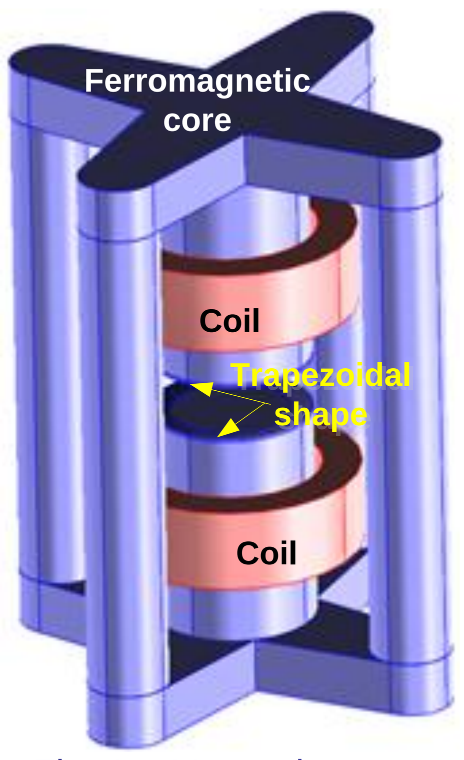

Fig. 1 – Magnetic core structure.

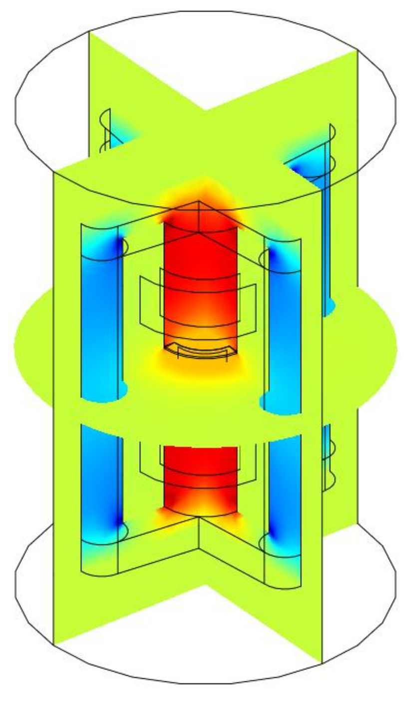

Fig. 2 – Flux distribution along the magnetic core.

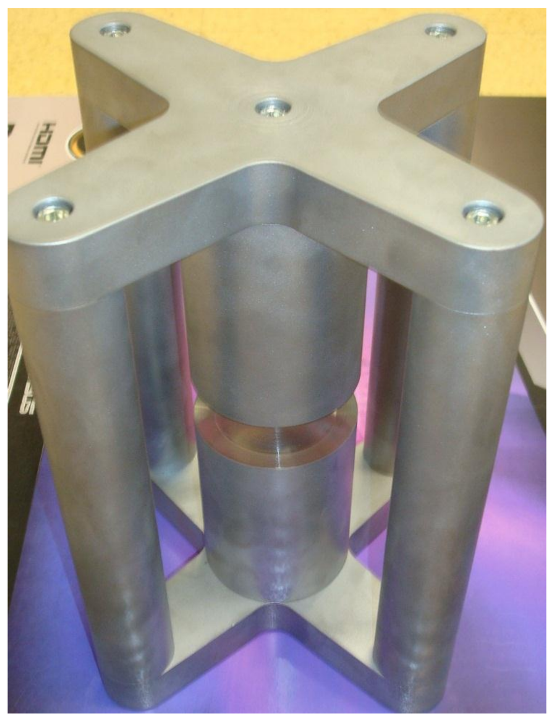

Fig. 3 – Magnetic core skeleton.

CORE WITHOUT RING

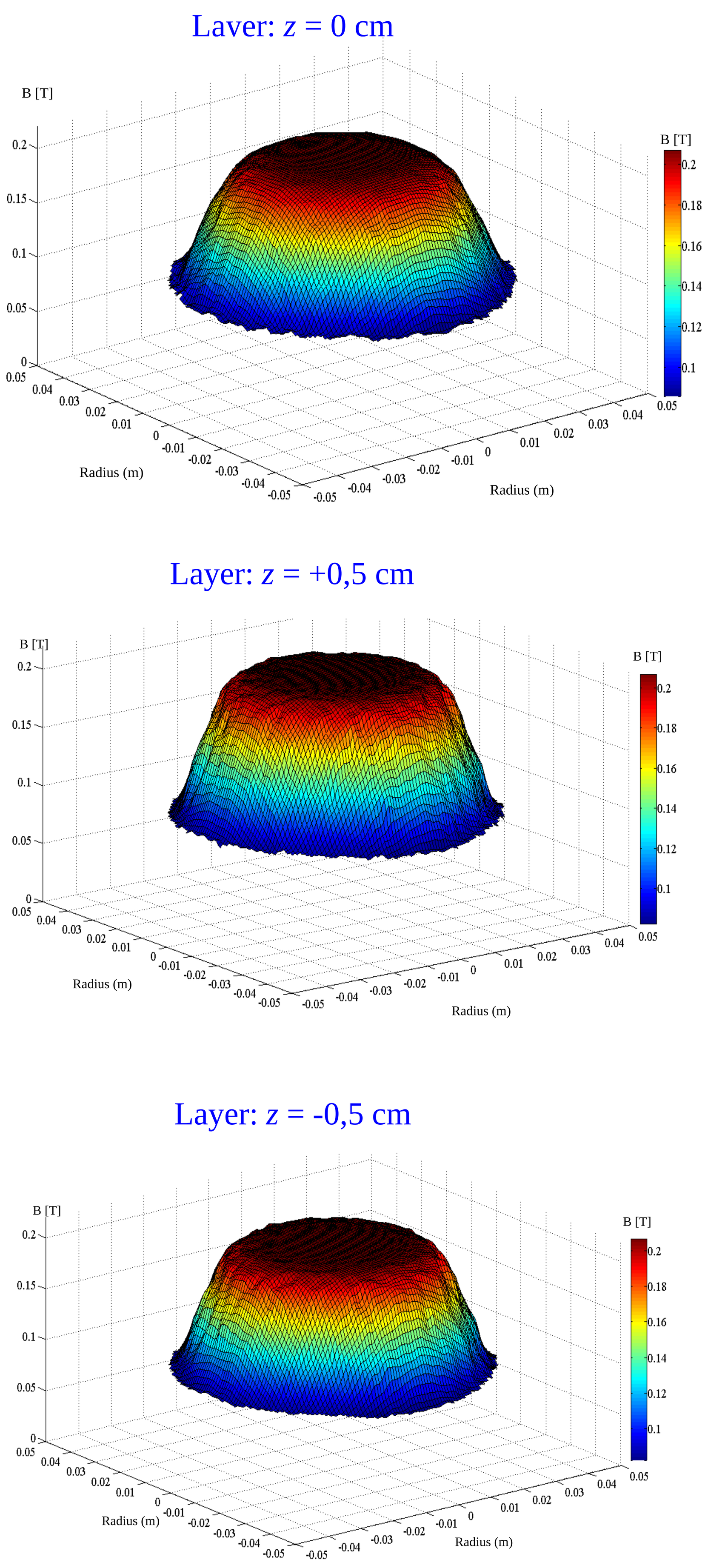

Fig. 4 – Flux density distribution to three layers in the air gap of the magnetic core.

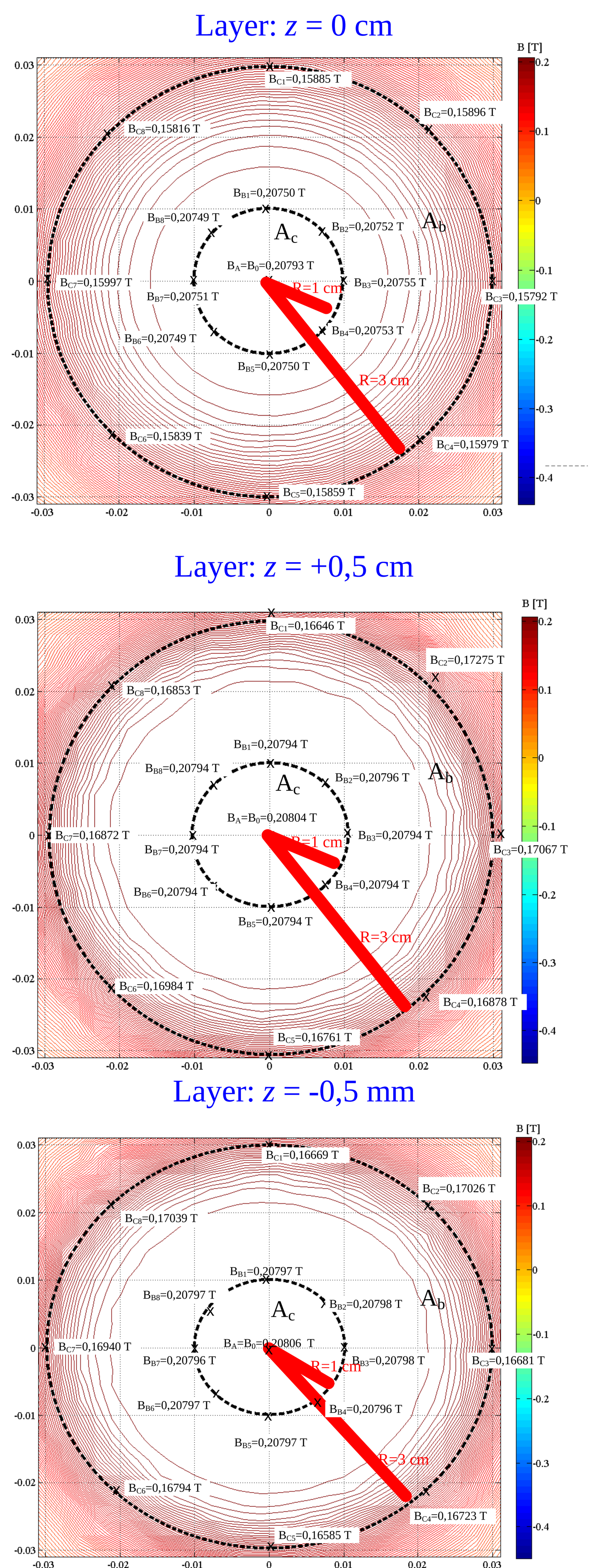

Fig. 5 – Level curves for the flux density distribution of the three layers .

[1] Van den Bossche, A.; Valchev, V.; Filchev, T.: Improved approximation for fringing permeances in gapped inductors. 37th IAS Annual Meeting, 932 - 938 vol.2 (2002).
[2] di Gaeta, A.; Glielmo, L.; Giglio, V.; Police, G.: Modeling of an Electromechanical Engine Valve Actuator Based on a Hybrid Analytical–FEM Approach. IEEE/ASME Transactions on Mechatronics, pp. 625-637, Volume: 13, Issue: 6 (2008).
[3] Noack, F.: NMR Field-Cycling Spectroscopy: Principles and Applications. Progress in NMR Spectroscopy 18, pp. 171-276 (1986).

CORE WITH RING

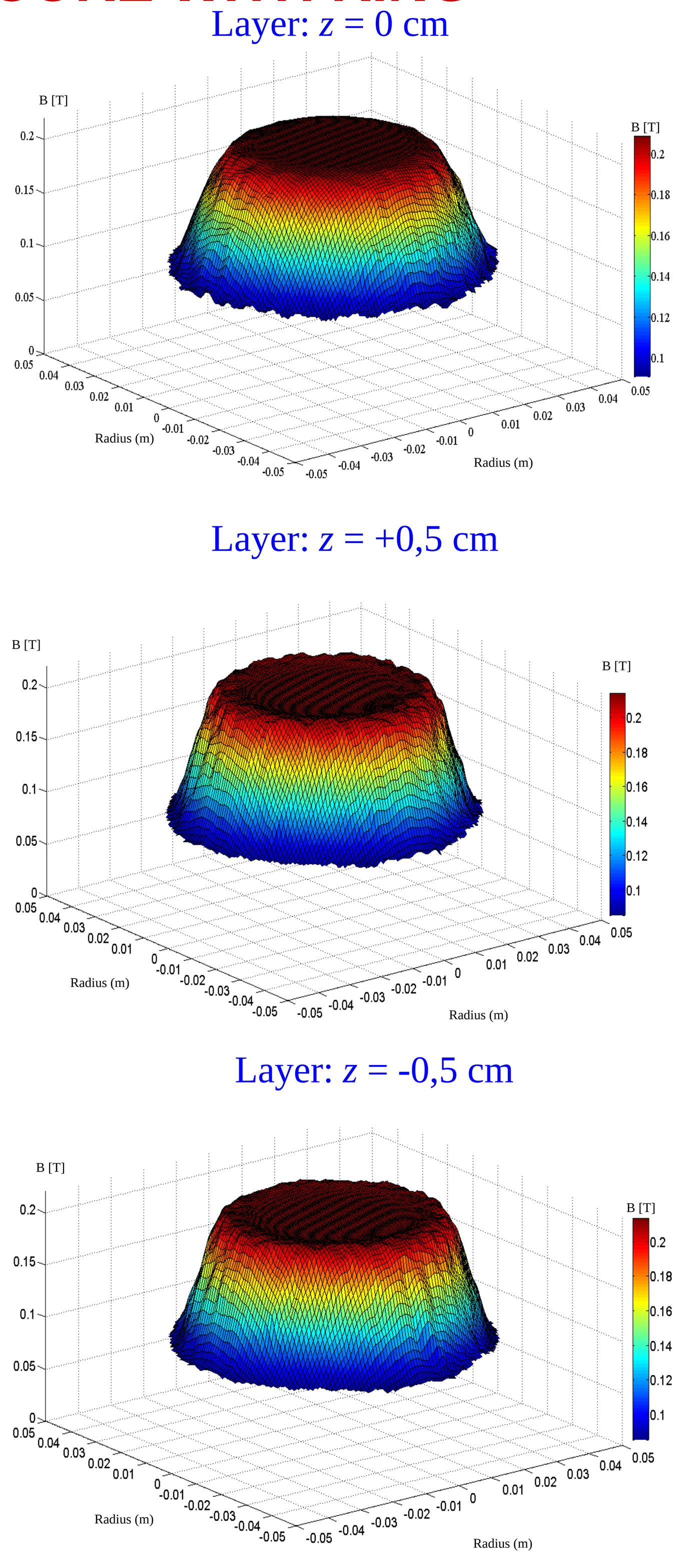

Fig. 6 – Flux density distribution to three layers in the air gap of the magnetic core.

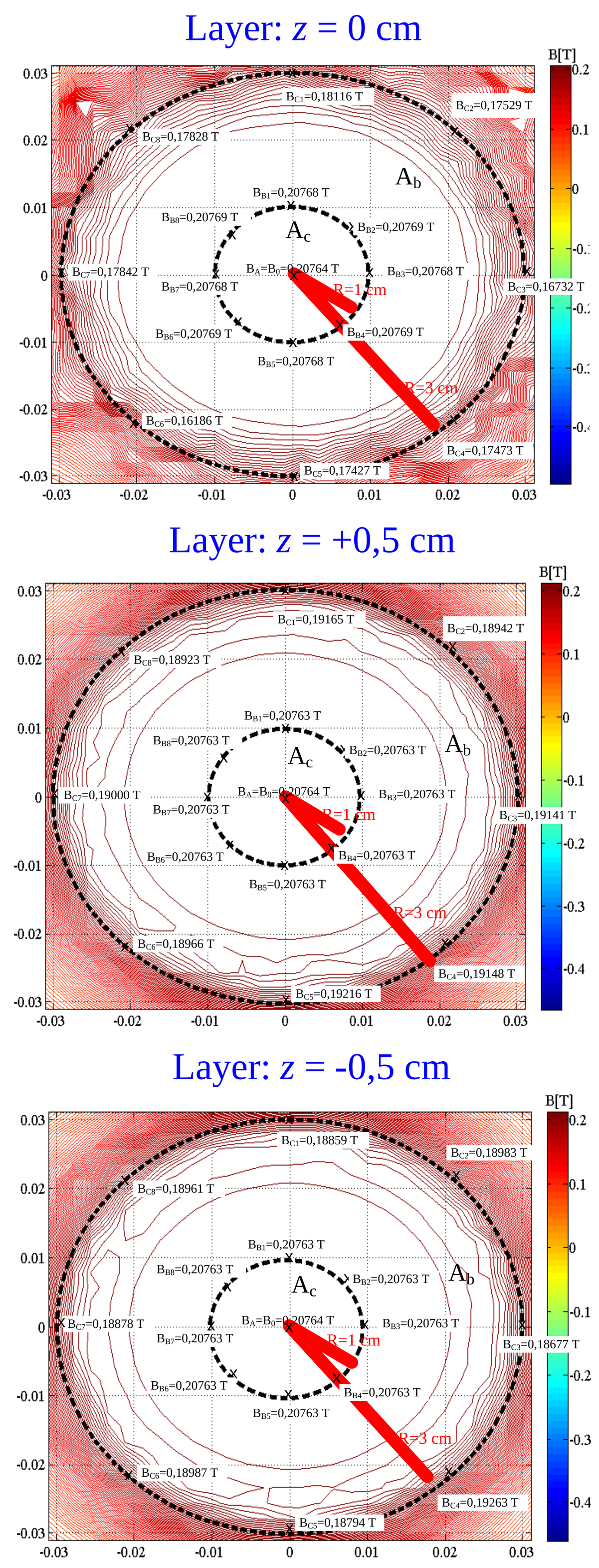

Fig. 7 – Level curves for the flux density distribution of the three layers .

CALCULATION OF THE POTENTIAL

Using the three-dimensional vectorial formulation for the regions without currents (free space) :

$$\nabla \times \frac{1}{\mu_r} \nabla \times \vec{A} = -\mu_0 \vec{J}.$$

The coils total current is: $\vec{I}_{total} = N\vec{I}$.

Being the total magnet motive force 1600 A.turn, the current density (J) is given by:

$$\vec{J} = \frac{\vec{I}_{total}}{S}.$$

To obtain the magnetic induction in the air gap, it is known that:

$$\vec{B} = \nabla \times \vec{A}.$$

Being the potential given by:

$$\vec{A} = \sum_{i=1}^{3} \left(A_{ix}\vec{u}_x + A_{iy}\vec{u}_y + A_{iz}\vec{u}_z\right) \varphi_i(x,y,z)$$

$$\varphi_i(x,y,z) = a_i + b_i x + c_i y + d_i z$$

The magnetic induction is:

$$\vec{B} = \sum_{i=1}^{3} \left[(c_i A_{iz} - d_i A_{iy})\vec{u}_x + (d_i A_{ix} - b_i A_{iz})\vec{u}_y + (b_i A_{iy} - c_i A_{ix})\vec{u}_z \right].$$

Table I – Field homogeneity comparison with and without ring.

Volume	Without ring			With ring				Homogeneity ratio with and without ring
	$B_{max} = B_0$ (B_A) [T]	B_{min} [T]	$\frac{\Delta B}{B_0}$ [%]	B_{max} [T]	B_{min} [T]	B_0 (B_A) [T]	$\frac{\Delta B}{B_0}$ [%]	
V_1	0,20806	B_{B8} 0,20749	0,27	B_{B8} 0,20769	B_{BA} 0,20764	0,20764	0,024	$\frac{0,27}{0,024} \approx 11$
V_2	0,20792	B_{C6} 0,15839	23,82	B_{C6} 0,20764	B_{C6} 0,16186	0,20764	22,04	$\frac{23,82}{22,04} \approx 1$

CONCLUSION

Using computational tools based on the finite element method, the flux density distribution for the proposed structure was studied for different dimensions of the magnetic core. In Fig.2, the flux density distribution along the magnetic core is shown. Since the FFC NMR technique requires high flux homogeneity, it was verified that with flat poles (central leg) it is not possible to fulfil this requirement. In order to overcome this restriction, the poles shape was optimized, resulting on a trapezoidal shape, as can be slightly seen in Fig. 1. With this optimization, the flux density uniformity is better than the minimum target value ($\Delta B/B_0$ > 1×10^{-4}). The flux density distribution at the air gap is shown, being possible to observe that the flux density is almost constant for the pole sections.