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► To cite this version:

A. Momy, J. Taquin. Design and Realization of Large Dimension Ferrite Rings. Journal de Physique IV Proceedings, 1997, 07 (C1), pp.C1-131-C1-132. 10.1051/jp4:1997143 . jpa-00255090

HAL Id: jpa-00255090

<https://hal.science/jpa-00255090>

Submitted on 1 Jan 1997

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Design and Realization of Large Dimension Ferrite Rings

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Abstract: Low leakage, low field, easy access flat hybrid magnets for MRI applications are being investigated. This configuration associates bobbins and ferrite permanent magnets having a Br field equal to 0.4 T. The complete magnet is designed using the laboratory-conceived CALMAG3D code[1] which allows us to simulate, in three dimensions, the various magnetic field producing elements (resistive bobbins, permanent magnets, ferromagnetic pieces) while taking into account their nonlinearity. A full-scale magnet should produce a sufficiently homogeneous field of a few ppm over a 30 cm sphere for whole body imaging purposes. For this reason we have elaborated a configuration of cylindrical [2] form with a revolution symmetry. The realisation of a 1/3 prototype requires some ferrite disks of big dimensions. We propose here a relatively low cost fabrication method with respect to that proposed by the manufacturers.

1. Introduction :

In the course of study to improve the MRI magnets, we investigate the feasibility of a novel hybrid structure (bobbins and permanent magnets) which allows us to obtain a very low leakage field. Indeed, the magnetic field B_z parallel to the axis of a magnetised disk reverses its polarity at a certain distance from its center at the outside of the cylinder [3]. It is not the case for a resistive magnet. We benefit from this property to compensate the field of one by the other at the outside of the magnet. It is therefore necessary that the supply power to the bobbins be weak to assure a low running cost. The fields from the bobbins and the permanent magnets add at the center, this condition can equally be satisfied. To ensure a low cost construction, the choice of permanent magnet predominates. We have chosen the Strontium ferrite as it possesses better characteristics than those of the Barium ferrite. Realisation of such a prototype requires the fabrication of very big dimension disks.

2. Proposed solutions for the realisation of magnetic disks :

The fact that each ferrite disk exceeds 150 mm in diameter, this excludes the idea of realising it in one whole piece. The reconstitution of a ring from a series of magnetised needles in order to optimise the filling coefficient would have been ideal, but it is impossible to make ferrite needles. The fabrication processes are such that the magnetisation is directed towards the smallest dimension, which is in contradiction with the needle principle. The second possibility to reconstitute a disk is to fabricate and assemble different sectors. The main drawback of this solution is the realisation of several moulds, this leads to excessive manufacturing cost. In order to pass round the difficulty in machining a hard and brittle ceramic material such as the ferrite, it is possible to make use of the composite materials (incorporating NdFeB powder in plastic material), but the fabrication cost remains very high. The most economical solution is to elaborate an assembly of standard ferrites followed by a complementary trimming.

3. Ferrite cutting

Straight cutting is perfectly mastered by the technique of moulding using diamanted tools which can attain very close dimensional tolerances. On the other hand, circular cutting is much more delicate and particularly for big diameters. We decided to use water jet cutting (3000 bar pressure from a 0.8 mm nozzle). This cutting allows us to obtain a precision of one tenth of a millimeter provided only a single layer of ferrite is cut at a time as in the case of multilayer cutting, the water jet has a tendency to disperse at each layer thus leading to subsequent defects. This is a cold cutting technique which solves the thermal problem encountered in laser cutting: rapid temperature increase leads to split of the ferrite.

4. Ferrite choice

The choice of ferrite is based on its relatively lower cost than other magnetic materials. Among the different possible types, we have chosen the one that possesses the highest possible coercive force because in the magnet configuration, an inverse field is applied on the ferrites. Also, the field produced by the ferrite rings must be symmetrical, that is why we used small parallelepiped ferrites ($48 \times 28 \times 12.2 \text{ mm}^3$), in order to obtain an average magnetisation dispersion ($B_r \pm 100\text{G}$). To optimise the filling coefficient, the ferrites were laterally rectified in order to eliminate the rounded angles produced by the mould.

5. Size of ferrite rings

Owing to the revolution symmetry of the configuration, there are two rings for each group (Tab.1).

	Internal diameter (mm)	external diameter (mm)	thickness (mm)	number of layers
magnets 1	292	540	36.6	3
magnets 2	203	236	24.4	2
magnets 3	203	244	24.4	2
magnets 4	203	250	48.8	4

Tab.1 : Ferrite disks dimensions

Thus a total of 6 big ferrite rings used to cancel the leakage field and 16 small ones used to improve the homogeneity.

6. Realisation

These parallelepiped magnet pieces were clamped in a mould and glued together using standard Araldite resine and the assembly is as shown in Photo 1. Photo 2 shows the result obtained after water jet cutting and gluing of three rings. Care must be taken not to superimpose the joints to avoid weakening the assembly. The latter is then progressively magnetised by an electromagnet having a 5 cm air gap and a field of 17 KG, more than four times the B_r of the ferrites, well beyond the saturation point of the latters.

7. Results

Theoretical values were determined based on an average B_r value of 3900 G and a distance of 0.3 mm between each layer (Tab.2). This distance corresponds to the thickness of the glue. Measurements were realised using a Hall effect gaussmeter the precision of which is $\pm 2\%$.

8. Conclusion

The results obtained from these ferrite rings are in good agreement with theory. They constitute now part of the hybrid magnet system which supplies a 0.1 T field at the centre. The intrincique inhomogeneity, without adjustment, is of the order of 500 ppm over a sphere of 80 mm. Work is in progress to further improve the homogeneity by means of shims.

Photo 2 : Final assembly of ferrite rings

	Field measured at centre (G)	Theoretical value (G)	Field error	New average B_r (G)	Br error
magnet 1.1	205	217	5.5%	3675	5.7%
magnet 1.2	211		2.7%	3790	2.8%
magnet 2.1	60		4.7%	3700	5.1%
magnet 2.2	60	63	4.7%	3700	5.1%
magnet 3.1	71		6.9%	3650	6.4%
magnet 3.2	72		5.6%	3680	5.6%
magnet 4.1	152	162.7	6.5%	3650	6.4%
magnet 4.2	154		8.7%	3700	5.1%

Tab.2 : Experimental measurements and theoretical values

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