Review Article

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Study and characterization of biological samples for rmn with the Halbach prototype

Abstract

The aim of this work is to design and simulate an equipment for the analysis of samples by NMR consisting of Halbach type permanent magnets: rectangular and equidistant, confined and distributed in a non-ferromagnetic circular structure, which generates a high induction and homogeneity of magnetic field, in a specific area (or zone), for the diagnosis of any type of pathology, in a portable, simple, light and economical way that improves the quality of life of the human being and his environment.

Keywords: NMR, Halbach type, Magnets, Magnetic field

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Introduction

In recent years, magnetic, electric and electromagnetic fields have been framed in the following lines of research: development of methods and equipment for the treatment of diseases, methods and equipment for the diagnosis and study of alterations in the organism (imaging methods) and study of the adverse effects produced by these fields in living organisms. Nuclear Magnetic Resonance (NMR) is both a physical phenomenon and a measurement; that is used to obtain structural and dynamic information about the state of magneticatomic nuclei, which can be used to reveal information about molecules, materials andbiological tissues;the measurement is based on the magneticresonance, which occurs when atomic nuclei interact with external magnetic fields and appliedradiofrequency (RF) electromagnetic radiation with appropriate frequency.[1] In medicine, nuclear magnetic resonance is one of the most widely used, innovative, promising and non-invasive diagnostic methods for the treatment of different pathologies, since it provides specific information (image processing) on the structure and molecular kinetics of the opaque bodies of any type of sample) under the action of a high and homogeneous magnetic (or electromagnetic) field in a given area.[2] The application of these magnetic Halbach arrays for NMR sample analysis has become increasingly popular in different socio-economic activities such as: oil extraction, food product characterization, biomedicine, materials analysis, art conservation, and soil and plant research. Blümler et al. 2004, describe the use of Halbach-type arrays with a geometry (linear, circular or spherical) of high magnetic homogeneity fields in a specific inside or outside a non-ferromagnetic structure in a simple and low-cost way; but it has to be: stable, armored, of great weight and dimensions, in a finite volume.[3] Cooley et al. 2018 propose the design of a homogeneous, portable, low-cost, lightweight Halbach magnet that requires no cooling, no electrical power, and no heat dissipation, with a genetic algorithm (GA) low-cost portable MRI scanner for brain imaging that offers the possibility of a rotational spatial encoding field pattern; but it requires major standardised mechanical adjustments to achieve magnetic field homogeneity in a limited area of the patient (arm, leg, head, etc.).[2] Meribout et al. 2019, describe a Halbach matrix-based nuclear magnetic resonance device for multiphase flow measurement. Three-dimensional finite element method (FEM)-based software combined with a particle swarm optimization algorithm was used for device design. The magnetic system consists of 12 permanent cube-shaped Halbach magnets with dimensions of (0.02×0.020×0.046) m, which generates a highly homogeneous magnetic field B= 0.890 T and a homogeneity H= 6.06 x10^{-4} ppm, within a probe cross section of 0.04 m radius. This is adequate for the desired application while it leads to a relatively homogeneous magnetic field inside the target sensing area using a compact and lightweight magnet array.[4] Rubicondo et al. 2025, propose the optimization of a permanent magnetic structure, characterized by magnetic field homogeneity of interest variable field strength between Bz = (0.16 - 0. 19) T, within a spherical region of interest of 20 cm in diameter, through the use of a computer program that progressively modifies the configuration of the structure of the magnetic system to obtain more advanced 3D images that require cryogenic refrigeration and have high acquisition and maintenance costs.[5] Tullio V.D et al. 2024, describe the use of portable unilateral magnetic resonance imaging equipment to investigate the state of conservation and degradation of works of art and various materials. he inconvenience of this technology is the non-uniformity of the magnetic field, which limits theoptimization of the experiment.[6]

In Cuba, in 1993, the Center for Medical Biophysics (CBM) was founded at the University of Oriente, in the province of Santiago de Cuba, and for the first time, an MRI tomograph is designed and built, with a high level of effectiveness and reliability, which allows the diagnosis and treatment of different diseases, introducing a new technology in the public health sector of the country, its observed that it was possible to use this technique in different biomedical applications.[7]

The scientific literature analysed shows that these devices have structural and operational limitations, with high acquisition costs, immobility, weight and maintenance, and require a controlled, armoured work area with manoeuvrability in fixed environments where logistical resources are limited, which limits the type of experiments that can be carried out. It is therefore difficult to generate an efficient and uniform magnetic field induction in a given area.[8] The objective of this work lies in the design of a permanent magnet Halbach type to generate the induction of the magnetic field and the optimal magnetic field homogeneity for the analysis of any type of biological samples by NMR;through a computer program that increases the universality and effectiveness of this therapy in the diagnosis of various pathologies, in a simple, portable, low weight, cost, size geometry and without consumption of electrical energy, except when performing: magnetometer, recalibration and maintenance and installation in a specific work area, thus introducing a new methodology in medicine as it improves the quality of life of patients and their environment.[9]

Materials and methods

Among the equipment used for its application are active magnetic devices (resistive magnets or electromagnets) that generate a magnetic field if a direct electric current circulates through them; however, passive magnetic devices (permanent magnets and ferromagnetic elements) do not require a direct electric current to circulate through them in order to generate a magnetic field. The design of a passive and/or active magnetic device with high magnetic field homogeneity for NMR sample analysis is very complex, as several parameters must be taken into account, such as: the type and dimensions of the material, the magnetic induction and the magnetic gradient of the external field; as well as whether the configuration used is discrete (permanent magnet elements) or continuous (ferromagnetic bars, loops); otherwise, the magnetic device will be overdesigned and an optimal magnetic field will not be obtained for the desired purposes.[10,11] In this device, the magnetic system configuration consists of a non-ferromagnetic circular structure in the form of two rings with a radius (R = 0.2) m and length (L = 0.5) m, containing 12 rectangular permanent magnets, confined and distributed equidistantly; made of Halbach (N42) material, with dimensions (0.05, 0.05, 0.25) m. To calculate the magnetization direction (βi) and the iterations (rotation angle) of the permanent magnets (γi) with respect to the x-axis is realized, according to the calculation expressions.

$$\beta_i = i\alpha \text{ where } i=0,1,\ldots\ldots\ldots\ldots,n-1 \text{ y } \alpha = \frac{2\pi}{n} \quad (1)$$

$$\gamma_i = \left(1+k\right)\beta_i \text{ con } k \in Z \text{ e } i=0,1,\ldots,n-1 \quad (2)$$

where n is the number of permanent magnets, i is the number of iterations, (i =1, 2, 3….8), α, angle between each magnetic sector, which were implemented in Matlab® R2015a software (The MathWorks, Inc. USA).The calculation and simulation of magnetic field induction, magnetic field homogeneity, and magnetic field corrections (shimms) were performed in the volume of interest (sphere with a radius of 0.02 m) occupied by the sample under study, according to;[2,12-14] for this purpose, a computer program was used that has the calculation expressions implemented, allowing for the optimal design of the desired configuration depending on the study.

Results

Table 1 shows the calculation of the magnetization direction and the position of the permanent magnets (N42).

n	B_i	γ_i
1	0	11,25⁰
2	11,25⁰	22,5⁰
3	33,75⁰	67,5⁰
4	45⁰	90⁰
5	56,25⁰	112,5⁰
6	67,5⁰	135⁰
7	78,75⁰	157,5⁰
8	90⁰	180⁰
9	101,25⁰	-11,25⁰
10	112,5⁰	-22,5⁰
11	123,75⁰	67,5⁰
12	135⁰	-90⁰

Where n:is the number of permanent magnets, B_i : is the magnetization direction, γ_i : is theposition of the permanent magnets.

In the figure 1 is shown magnetic induction map.

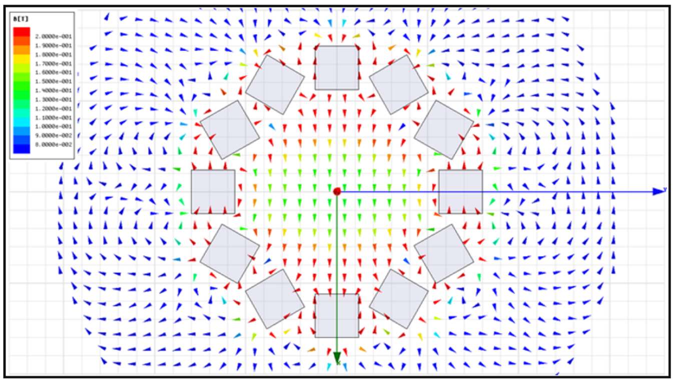

Figure 1 The magnetic field induction is B=(1,20-1,5) mT in a spherical volume with a radius of 0.02 m. Courtesy of PhD.AlejandroBordelois Boizán.

Figure 2 shows the magnetic field homogeneity map.

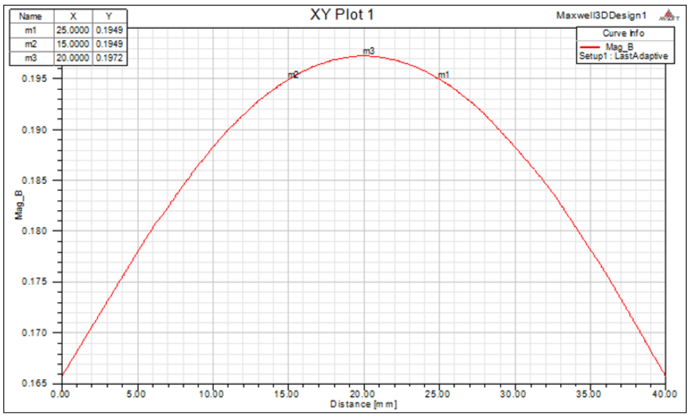

Figure 2 The homogeneity is H = 2.4 x10^{-4} ppm.

Discussion of results

The configuration shown in figures 1 and 2 can be used for the purposes intended in this work, since the magnetic induction generated by the magnetic system is transverse with respect to the z-axis, which is sufficient for the diagnosis and image processing of any type of pathology, except malignant tumors.The magnetic field homogeneity (on the order of 10^{-4}) guarantees the use of Halbach magnets for NMR sample analysis, in a portable manner, with low weight, low operating costs, recalibration, maintenance, and construction. In the figure 3 shows the design of the proposed magnetic device for characterising samples by NMR with an array of 12 permanent magnets (N42).

For its construction and fine-tuning, a B-660 CNC drill was used to manufacture and assemble the set of semi-finished parts (made of PVC) according to the specific parameters and dimensions required for the desired purposes.

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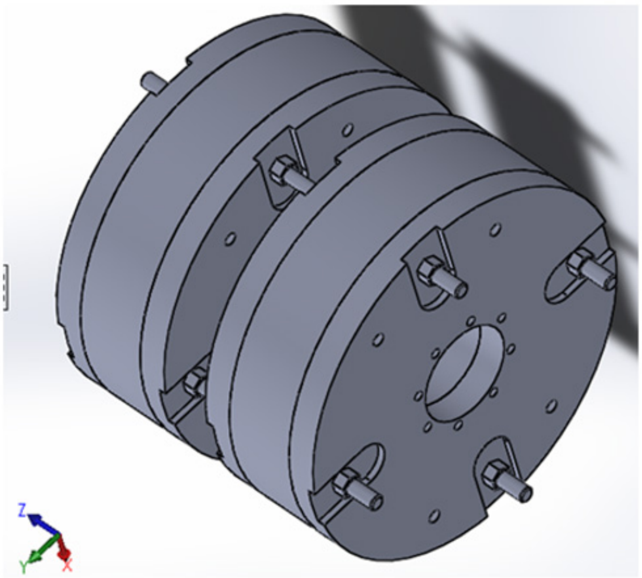

Figura 3 Dispositivo magnético portátil con imanes permanentes tipo Halbach (N42) para el análisis de muestras por RMN.

Conclusion

The prototype Halbach-type permanent magnet device is feasible for NMR sample analysis, as the magnetic induction and field homogeneity generated are effective for sample analysis, in accordance with the experiment determined; in a simple, versatile and portable way, as it enhances the quantification of various molecular structures and the integration of this methodology with other techniques; which broadens its range of applications in the diagnosis of any type of pathology, with the use of artificial intelligence to enable the improvement of the quality of life of humans and their environment in various parts of the world.

Recommendations

Optimise the configuration of the magnetic system in the prototype design proposal for NMR sample analysis.

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Conflict of interest

The authors declare that there are no conflicts of interest.

References

1. Foongkajornkiat S. Portable Nuclear Magnetic Resonance (NMR) for Quantitative Measurement of Biological Tissues. Doctoral dissertation. Queensland University of Technology; 2025.
2. Cooley CZ, Haskell MW, Cauley SF, et al. Design of sparse Halbach magnet arrays for portable MRI using a genetic algorithm. *IEEE Trans Magn.* 2018;54(1):1–12.
3. Soltner H, Blümler P. Dipolar Halbach magnet stacks made from identically shaped permanent magnets for magnetic resonance. *Concepts Magn Reson Part A.* 2010;36(4):211–222.
4. Meribout M, Sonowan S. Optimal Halbach magnet array design for portable NMR targeting multiphase flow metering applications. *IEEE Trans Magn.* 2019;55(1):1–7.
5. Rubicondo F. Design of a Permanent Magnet Array for Head Imaging in a Low–Field Portable MRI System. Doctoral dissertation. Politecnico di Torino; 2025.
6. Di Tullio V, Proietti N. Recent applications of unilateral NMR to objects of cultural heritage. *Heritage.* 2024;7(5):2277–2295.
7. Novo CD, Delis AL. Diseño y fabricación de una mesa para máquina de resonancia magnética de imágenes. 2001.
8. Yunaisis Leon Sardiñas S, García Naranjo JC, Ramírez Aguilera A. Diseño de un imán Halbach para el estudio y caracterización de muestras empleando resonancia magnética nuclear (RMN). Bachelor's thesis in Physics. Universidad de Oriente; 2017.
9. Torres LM, Cayamo AAB, Rodriguez JLG. Magnetic bed for the treatment of different somatic diseases: design and simulation. *Diagnostics and Therapeutics.* 2023:41–46.
10. Cabrales LEB, Reguera FM. Calculation and analysis of magnetic field corrector coils for air core NMRI equipment: I—saddle–shaped coils. *Cuban J Phys.* 1992;12(3):194–205.
11. Cabrales LEB, Reguera FM. Calculation and analysis of magnetic field corrector coils for air core NMRI equipment: II—circular coils. *Cuban J Phys.* 1992;12(3):243–253.
12. García Bello JL, Bordelois Cayamo A, León Montoya J, et al. Diseño de bobinas de excitación–recepción para la detección de señales de RMN 19F provenientes del compuesto politetrafluoroetileno/óxido de grafeno. *An Acad Cienc Cuba.* 2022;12(3).
13. Mesa Torres L, Cayamo AAB, Mesa Mariño Y, Ramirez Salinas Y. Magnetic treatment of microorganisms in the food industry. *Phys Astron Int J.* 2024;8(3):138–141.
14. Phuc DH. Développement d'aimants bas champ pour RMN portable: conception et construction. Thesis. Institut National des Sciences Appliquées de Lyon; 2015.