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Temperature distribution of a Fast-Field Cycling Nuclear Magnetic Resonance relaxometer's electromagnet with reduced volume

Poster Session
P5

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ABSTRACT

The temperature distribution of a Fast Field Cycling (FFC) Nuclear Magnetic Resonance (NMR) electromagnet plays an important role in the operation of this type of apparatus. The designed electromagnet presents a reduced volume and is iron and copper based, fulfilling the technical requirements for the magnetic field. With this solution, it is possible to increase the overall performance in comparison with former similar FFC relaxometers. Electromagnet's simulation results evaluating the temperature distribution, heating effects and cooling requirements are presented

BACKGROUND

Nuclear magnetic resonance is a physical phenomenon which occurs when the nuclei of certain atoms are immersed in a static magnetic field and exposed to a second oscillating magnetic field. Some nuclei experience this phenomenon, and others do not, dependent upon whether they possess a property called spin. All isotopes that contain an odd number of protons and/or neutrons have a nonzero spin, making them susceptible to magnetic stimulus and therefore suitable for NMR studies.

In nuclear magnetic resonance, nuclear spins interact with the applied external static magnetic field by aligning with it. The average alignment reflects a precession around the external magnetic field due to their nuclear magnetic moment, $\vec{\mu}_i$. This precession has a specific frequency, the so called Larmor frequency, which depends on the applied field and nuclear species:

$$\vartheta_L = \frac{\gamma}{2\pi} B_0$$

γ stands for the gyromagnetic ratio of the nucleus.

The alignment of the net magnetization with the external magnetic field can be disturbed by radio frequency pulses. After a perturbation the spins realign again with the external magnetic in a process called relaxation.

The set of the Bloch equations describes this phenomenon assuming a static magnetic field $\vec{B} = B_0 \vec{e}_z$ and magnetization $\vec{M} = M_0 \vec{e}_z$

$$\begin{cases} \dfrac{dM_x(t)}{dt} = \left[\vec{M} \times \gamma \vec{B}\right]_x - \dfrac{M_z(t) - M_0}{T_1} \\ \dfrac{dM_y(t)}{dt} = \left[\vec{M} \times \gamma \vec{B}\right]_y - \dfrac{M_x(t)}{T_2} \\ \dfrac{dM_z}{dt} = \left[\vec{M} \times \gamma \vec{B}\right]_z - \dfrac{M_y(t)}{T_2} \end{cases}$$

MAGNET STRUCTURE WITH COOLING SYSTEM

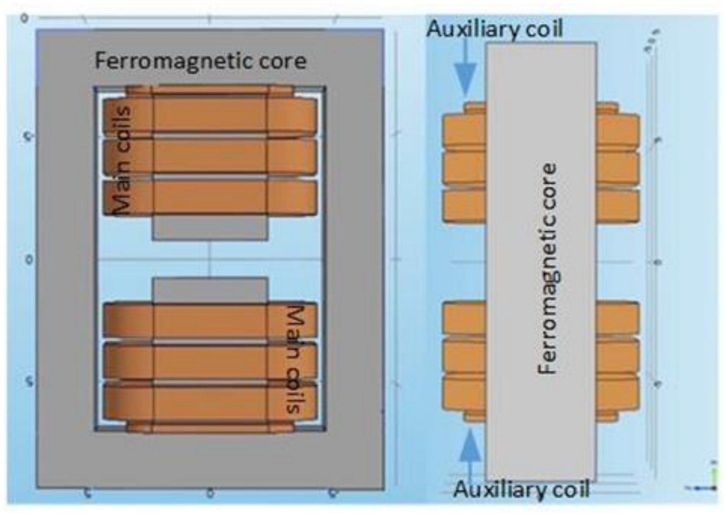

Fig. 1. Electromagnet structure.

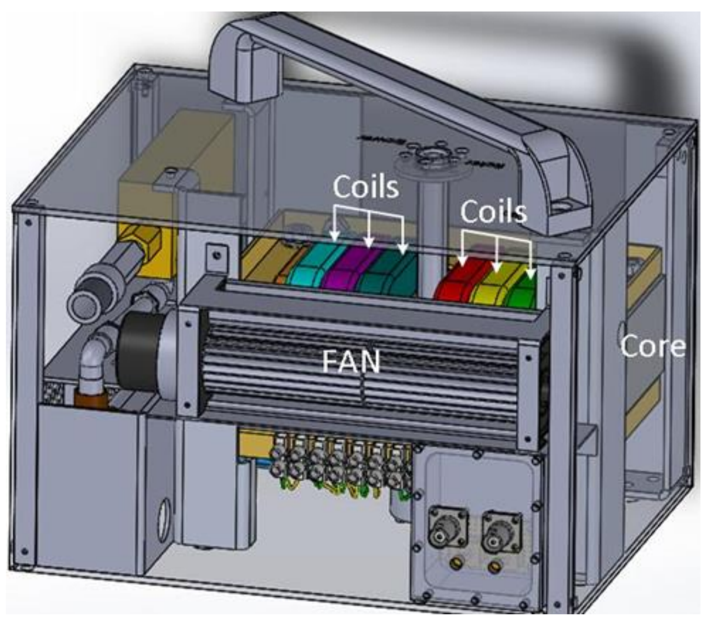

Fig. 2. Magnet enclosure with all parts

TEMPERATURE DISTRIBUTION

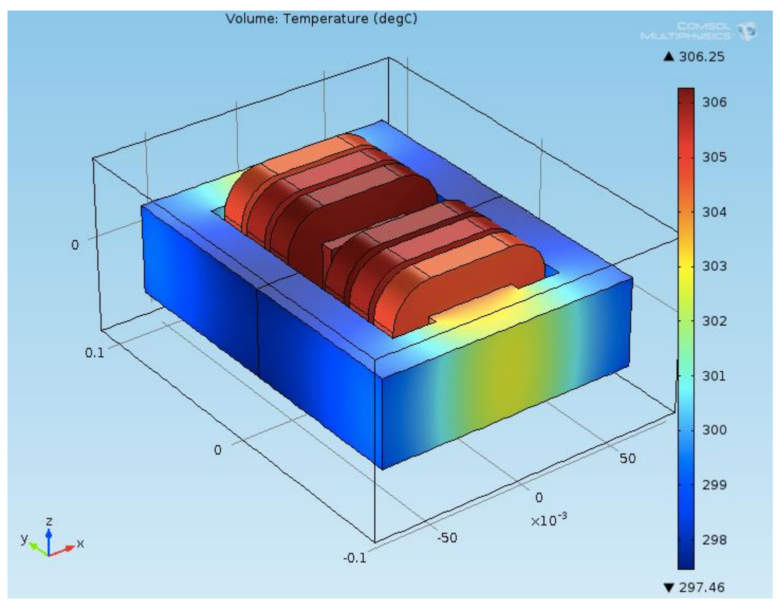

Fig. 3. Temperature Volume plot, 3D view.

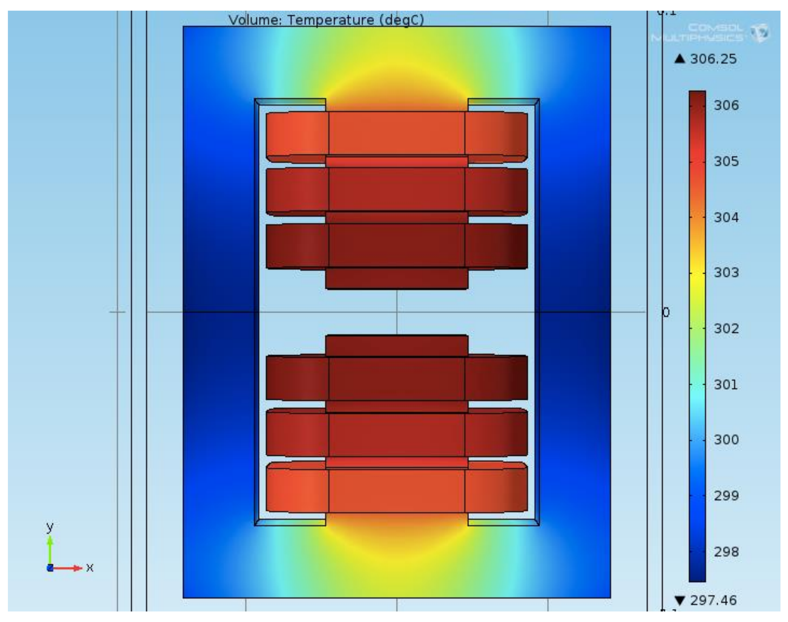

Fig. 4. Temperature Volume plot, top view.

COOLING

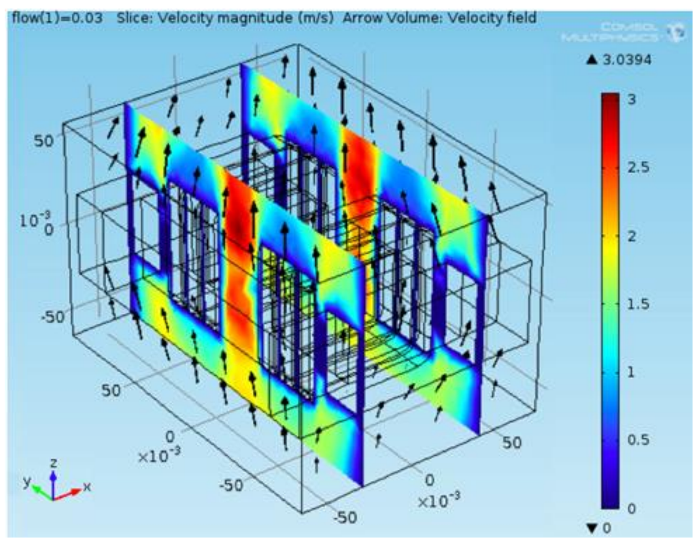

Fig. 5. "Arrow Volume" plot and two "Slice" plots.

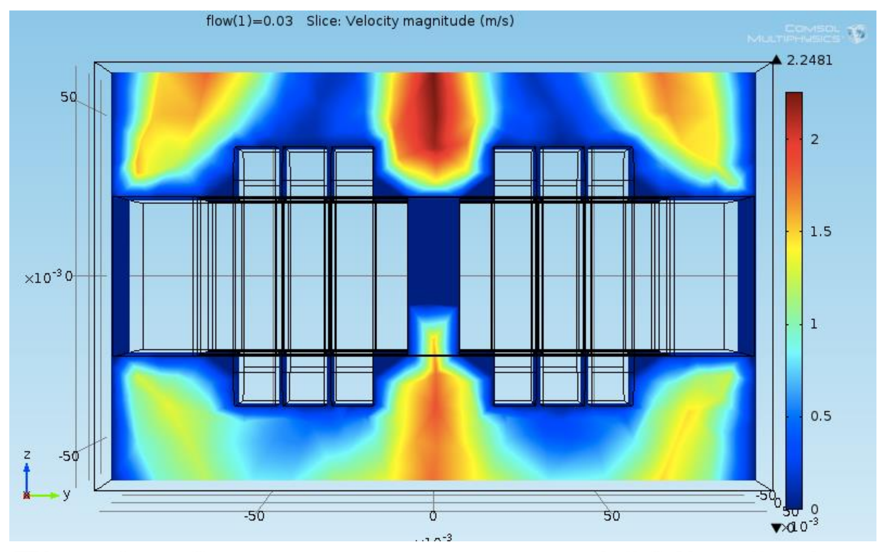

Fig. 6. Geometry centered "Slice" plot, side view.

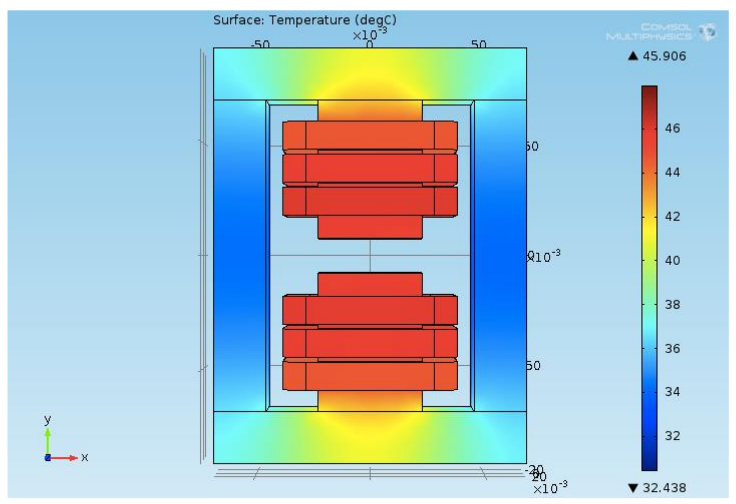

Fig. 7. Temperature "Surface" plot.

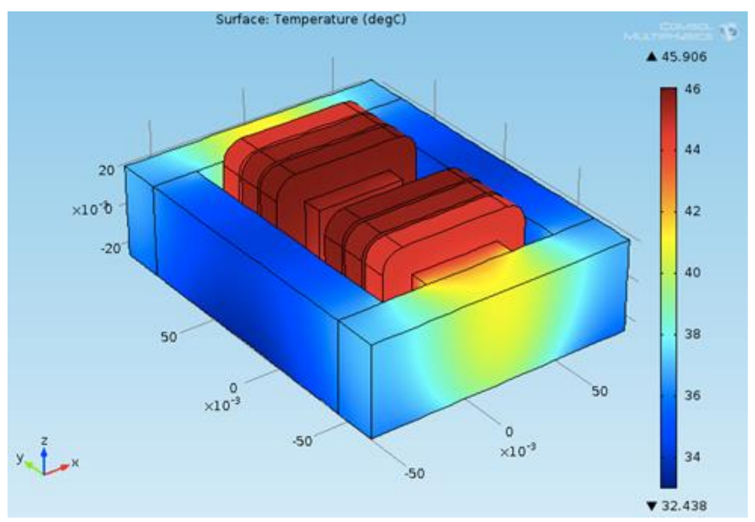

Fig. 8. Temperature "Surface" plot, bottom view.

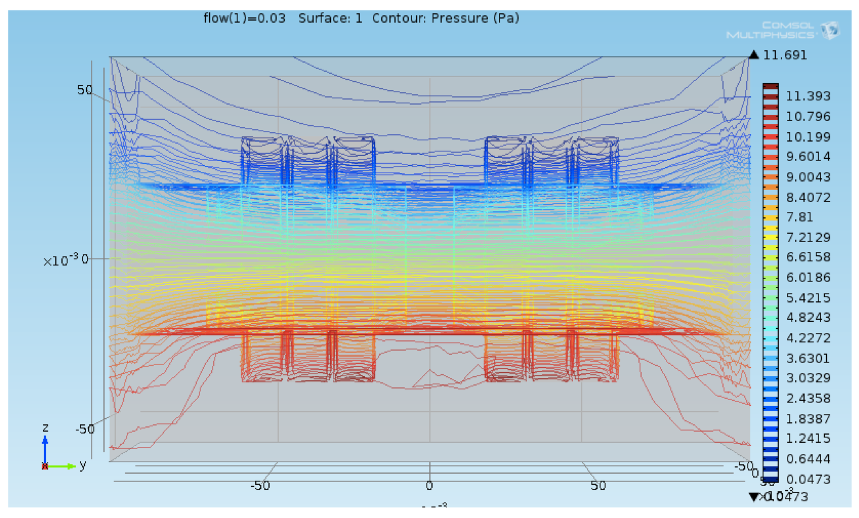

Fig. 9: Pressure "Contour line" plot, side view.

Table I. Maximum (Max. T.) and minimum (Min. T.) equilibrium temperature in the electromagnet for a given flow rate.

Flow [m³/s]	Flow [m³/h]	Max. T. [ºC]	Min. T. [ºC]
0.016	57.6	64.2	49.9
0.022	80	53.4	39.4
0.026	92	49.3	35.6
0.03	108	45.9	32.4
0.044	158	38.9	26.6
0.047	170	37.9	25.9

CONCLUSION: For a FFC NMR magnet operating within the magnetic field range of 0 and 0.33 T, the thermal effects and cooling requirements were evaluated allowing for the projection of feasible systems. The computational simulation allowed to estimate air flow rates for safe measurements over extended periods of time. The sample heating system was projected and some components acquired and defined, which guarantees NMR resonance conditions.

The advantages of the developed FFC magnet relatively to the generality of magnets are: reduced electromagnet's volume and weight, low power consumption, high homogeneity prole, feasible and low power cooling system.