Journal of Magnetic Resonance 259 (2015) 216–224

Contents lists available at ScienceDirect

Journal of Magnetic Resonance

journal homepage: www.elsevier.com/locate/jmr

Air core notch-coil magnet with variable geometry for fast-field-cycling NMR

S. Kruber, G.D. Farrher, E. Anoardo *

Laboratorio de Relaxometría y Técnicas Especiales, Grupo de Resonancia Magnética Nuclear, Facultad de Matemática, Astronomía y Física, Universidad Nacional de Córdoba and IFEG – CONICET, Córdoba, Argentina

ARTICLE INFO

Article history:
Received 27 June 2015
Revised 24 August 2015
Available online 5 September 2015

Keywords:
Fast-field-cycling
Magnet system
Optimization
Notch-coil

ABSTRACT

In this manuscript we present details on the optimization, construction and performance of a wide-bore (71 mm) α-helical-cut notch-coil magnet with variable geometry for fast-field-cycling NMR. In addition to the usual requirements for this kind of magnets (high field-to-power ratio, good magnetic field homogeneity, low inductance and resistance values) a tunable homogeneity and a more uniform heat dissipation along the magnet body are considered. The presented magnet consists of only one machined metallic cylinder combined with two external movable pieces. The optimal configuration is calculated through an evaluation of the magnetic flux density within the entire volume of interest. The magnet has a field-to-current constant of 0.728 mT/A, allowing to switch from zero to 0.125 T in less than 3 ms without energy storage assistance. For a cylindrical sample volume of 35 cm^3 the effective magnet homogeneity is lower than 130 ppm.

1. Introduction

Fast-field-cycling (FFC) nuclear magnetic resonance (NMR) is a well-established experimental method for determining certain physical properties in a wide-range of materials [1–5]. The method is particularly useful to perform NMR experiments at low magnetic fields, where conventional methods exhibit severe limitations due to the signal-to-noise (S/N) ratio degradation of the free induction decay (FID) or NMR signal. While the magnetic field is cycled between different values according to the selected experiment, the signal detection field is fixed. In consequence, the probe as well as the receiver electronics are usually optimized for a fixed working frequency, which is independent of the Larmor frequency at which the nuclear spin system evolves.

A critical part of any electronic field-cycling apparatus is the electromagnet. It defines the general performance of the instrument, in close dependence with the electric power management and control electronics. Desired features for this sort of machines are: (i) The achievement of high magnetic flux densities, thus favouring the S/N ratio of the FID while increasing the dynamic range of the instrument. (ii) A fast switching of the magnetic flux density, thus allowing the observation of nuclear magnetic events associated with short relaxation times and eventually, the access to zero-field NMR spectroscopy. (iii) The spatial field homogeneity of the magnetic flux density within the sample volume should be conveniently compatible with, at least, low-resolution NMR. It is then possible to summarize the three main requirements for a FFC electromagnet:

- The generation of a maximal possible magnetic flux density for a given power ($B_{max}(P)$).
- The switching between the different magnetic flux densities performed in minimal time (dB/dt).
- The achievement of an adequate homogeneity inside a given volume of interest, where the sample will be located ($\Delta B/B$).

Due to the mutual interrelation between these requirements, the optimization process is a challenging task. Different air-core electromagnet designs can be found in the literature [6–8]. Schweikert's [7] and Lip's [8] magnets are based on non-uniform current-carrying paths performed on metallic cylinders. Concentric cylinders are assembled together in order to reach the desired magnetic flux density. This approach allowed to produce magnets with excellent electric performance for the fast switching (a few ms) of magnetic fields over 1 T. In both cases, the machining process requires the cutting of complicated helix profiles along the metallic cylinders. As a consequence of the non-uniform current distribution, the power dissipation along the coil is localized.

In a recent paper we described the optimization method for variable notch-coil magnets that, in addition to the typical

* Corresponding author.
E-mail address: anoardo@famaf.unc.edu.ar (E. Anoardo).

http://dx.doi.org/10.1016/j.jmr.2015.08.015
1090-7807/