A compact counter-flow xenon polarizer for clinical applications

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Abstract

Hyperpolarized xenon offers extraordinary potential as a contrast agent for MRI. The University of New Hampshire's Center for Hyperpolarized Gas Studies is the undisputed leader in xenon polarization technology and methods. Polarized gas is being delivered to Boston's Brigham and Women's Hospital on a regular basis for MRI experiments. Further partnering with outside hospitals is anticipated. In collaboration with UNH, Xemed LLC is developing compact versions of the subsystems that make up the polarizer. The goal is to transform the laboratory setup into a compact polarizer that can be located and maintained elsewhere. This paper describes the permanent magnet subsytem of the compact polarizer.

Introduction

The counter-flow xenon polarization magnet subsystem developed at the University of New Hampshire[1] presently requires thirty square feet of floor space due to the stringent requirements of the magnetic field. In the two-meter-long polarization region, the field must be uniform, in the cryogenic xenon accumulation region the field should exceed several kilogauss, and in the NMR region it should be uniform to a part in ten-thousand and adjustable to compare xenon and water NMR signals. Through the transition regions field changes should be gradual. These requirements have previously been met by placing large separations between the uniform low-field region and all other components, including the high-field freeze-out magnet and the electronics cabinets. Our new approach includes a shielded segmented solenoid, a structured permeability field rotator, an adjustable NMR magnet, a field ramp, and a freeze-out C magnet, each with special characteristics. The new subsystem fits inside a 19" equipment rack.

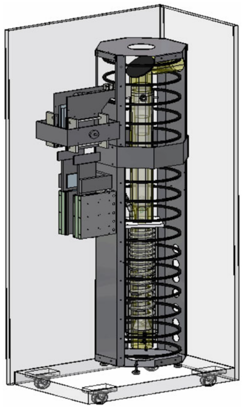

Figure.1. The compact xenon polarizing system.

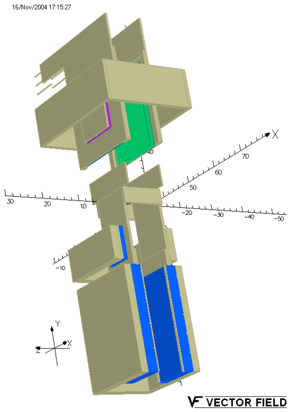

Figure.2. TOSCA simulation of the magnet subsytem

Permanent Magnet Subsystem

Figure 1 shows the outline of the compact polarizer. The two-meter polarization column is visible in the center of the 16 coil solenoid. A 795 nm spectrally narrowed laser beam[2] enters from the side, and is directed down via a 45° dielectric mirror. Xenon gas enters from the bottom of the column, flows opposite to the direction of the laser beam, and exits at the top, into the permanent magnet subsytem. The subsytem consists of a field rotator, a uniform field region for NMR measurements, an exponential field ramp and a high field freezeout region. Figure 2 shows a TOSCA[3] field simulation of the permanent magnet subsystem. Hyperpolarized xenon gas enters the field rotator part of the subsystem, where the field is rotated by 90° while the strength is increased from 20 gauss to 100 gauss. The gas then enters the uniform field NMR region provided by a pair of ceramic-8 magnets with symmetric "H" type low carbon steel flux return. Mu-metal plates separated by Purcell gaps and field clamps provide high field uniformity. After the NMR region, the field rises exponentially due to intermediate Nd-Fe-B C-magnets and a set of field adjusting steel plates. The gas finally arrives in the 3 kilogauss permanent C-magnet and freezes in the LN$_2$ dewar.

Results

One of the criteria of designing the magnet subsystem is to minimize the polarization loss of the hyperpolarized xenon during transfer and freeze out. Field transition in the rotator is critical to meet this goal. The requirement is to maintain constant $d\mathbf{B}_\perp/B$ during field rotation. Simulation results are shown in Figure 3. The ramp area requires an exponential increase in field strength from 100 gauss to 3 kilogauss, as shown in Figure 4. The field uniformity in the NMR region has to be better than one part in 10,000 for NMR calibration at two different fields (water and xenon). Our design shows a uniformity of better than a few parts in 100,000 in a 6 cm long section, as shown in Figure 5.

Outlook

The permanent magnet subsystem and its compact solenoid tower enable us to build a very compact xenon polarizer for the production of hyperpolarized ^{129}Xe in situ for MRI. An automated LN$_2$ dewar freezeout system, also under development at Xemed, will provide high efficiency xenon freezing and thawing. These elements combined with our spectrally narrowed laser and LabView control system comprise a compact commercial xenon polarizer.

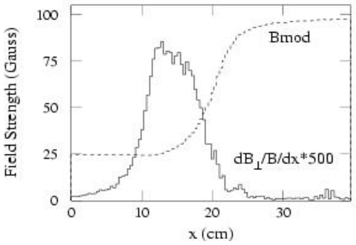

Figure 3. Field transition in the rotator.

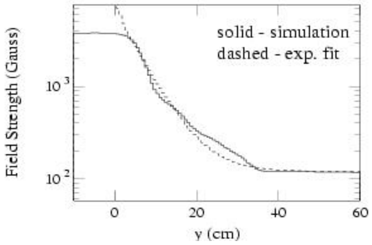

Figure 4. Field transition in the ramp.

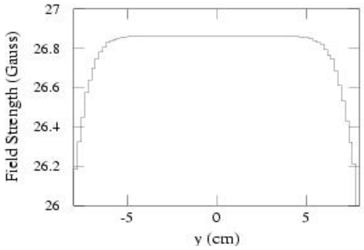

Figure 5. NMR field uniformity.

Acknowledgements

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References

1. F.W. Hersman, *et al.*, *Large Production of Highly Polarized ^{129}Xe and Delivery*, the 2004 International Workshop on Pulmonary Functional Imaging at Penn, Philadelphia, PA, Nov. 12-14, 2004.
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