900 MHz Reaches Full Field . . .

Sets New Dimensions!

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On July 21, 2004, the Ultra-Wide Bore 900 MHz NMR Magnet reached its full field of 21.1 T. Bringing the world's largest NMR magnet with its 105 mm warm bore operational marks a significant achievement in magnet technology and brings closer a powerful scientific instrument to the NHMFL. This milestone was achieved without incurring any training quenches.

The magnet, shown in Fig. 1, is a concentric assembly of ten superconducting coils, connected in series. Each coil is wound with a monolithic superconductor, composed of either niobium-tin (Nb_3Sn) or niobium-titanium (NbTi) filaments in a copper jacket. Many coils are overbanded with stainless steel wire and all are vacuum impregnated with cryogenically tough epoxy for structural support. The high current density coils produce a highly uniform field of 21.1 T in an extremely large region. Small adjustments to field homogeneity are achieved with a set of superconducting shim coils that fine tune the magnetic field. Fabrication of the NbTi and shim coils occurred in cooperation with an industrial partner, Intermagnetics General Corporation.

This past spring, fabrication of the cryostat around the magnet was completed, schematically shown in Fig. 2. The magnet resides within a vessel of the cryostat containing 2,400 liters of liquid helium at atmospheric pressure. This "magnet vessel" is conductively cooled to a temperature of 1.7 K by use of a closed loop heat exchanger. The pressure of the saturated helium in the heat exchanger is reduced to achieve the superfluid temperature. The level of helium in the heat exchanger is controlled by a Joule-Thompson (JT) valve that draws liquid in from the 1100 liter Helium-I reservoir. This liquid, prior to going through the JT-valve, is precooled to near the lambda point T_λ by the vapor that is being pumped off. The cryostat also contains a number of thermal shields and multi-layer insulation to suppress the radiative heat loads.

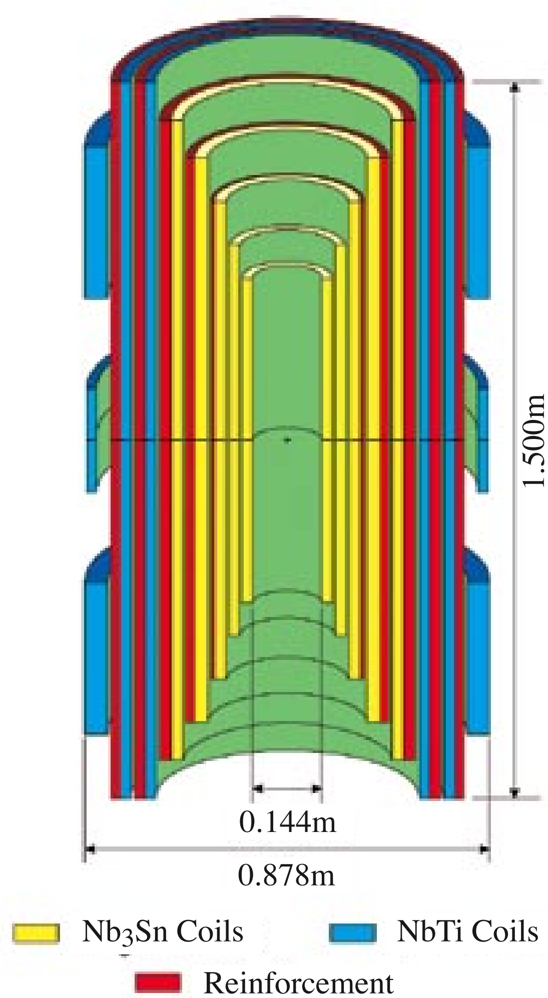

Figure 1. Sectional view of the 900 MHz NMR Magnet primary coils.

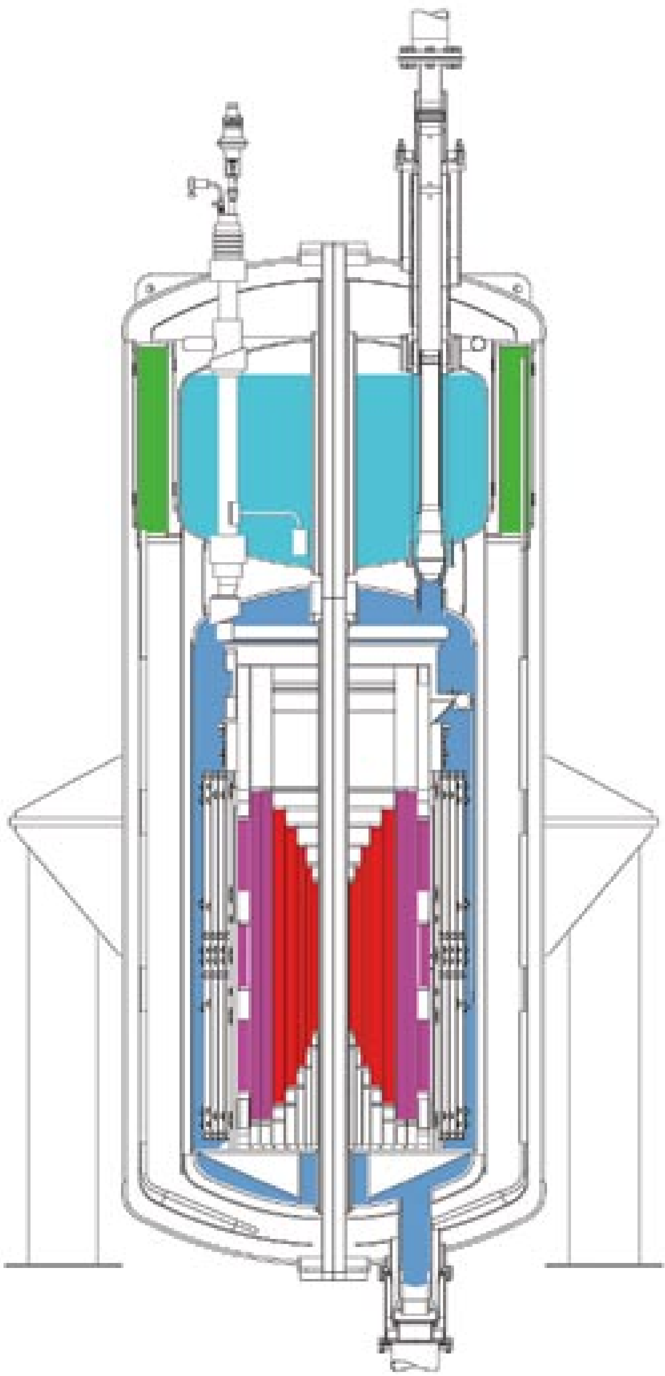

Figure 2. Schematic of the Ultra-Wide Bore 900 MHz Magnet within its cryostat.

The 900 MHz magnet has such a large bore (105 mm) in comparison to typical wide bores (89 mm) and standard bores (54 mm) because this magnet was originally conceived as a prototype to a standard bore 1.1 GHz (25 T) NMR magnet. The field produced by a 1.1 GHz magnet exceeds the operational limits of conventional low temperature superconductors (LTS), requiring the innermost coil to be constructed of high temperature superconductor (HTS). The HTS coil of a 1.1 GHz magnet would produce 5 T with the remaining LTS coils producing 20 T. The 900 MHz magnet is of the same scale as a 1.1 GHz magnet with the same outer LTS coils, but its innermost coil is constructed of LTS, adding an additional 1.1 T for a total central field of 21.1 T and a larger inner diameter. Thus the 900 MHz magnet has been an instrument for the development of skills, tools, and technology necessary to engineer and build state-of-the-art, higher field superconducting magnets.

The ultra-wide bore of the 900 MHz magnet, with its large uniformity zone, relieves many of the spatial constraints placed on scientific users. A number of probes are being developed and set up to optimize the useable space. The room temperature shim set reduces the clear bore to 89 mm, that of a typical wide bore magnet without shims. Some scientific applications, such as imaging, may not need the room temperature shims and may be able to utilize the entire volume.

Since reaching 21.1 T, an initial adjustment of the superconducting shims was performed to achieve a magnet homogeneity of approximately ±2 ppm over a 4 cm sphere. The room temperature (RT) shims, with an inner diameter of 89 mm, developed by Resonance Research Inc., will further improve the uniformity to ppb levels over this volume. A second standard bore RT shim set provided by Bruker Biospin will be used for high resolution solution and solid state NMR. Additional adjustment to the superconducting shims will be performed if necessary.

The magnet has a field decay of 525 Hz/hr. This is being compensated through a novel approach of injecting current through low loss leads into one of the main superconducting coils. The preliminary results of this field stabilization technique are very encouraging and it is expected that the drift will be reduced to less than 5 Hz/hr without significantly influencing the field homogeneity. This is a significant advance for high field NMR magnet technology.

Bruker Biospin is presently installing a four channel Avance 900 MHz console with capabilities for solution and solid state NMR as well as imaging. The console is equipped with ^{1}H/^{19}F solid state amplifiers (100 Watt output for solution NMR and 800 Watt output for solid state NMR), and one 1,000 Watt and two 500 Watt amplifiers for X nucleus irradiation. The console also has 60 Amp X, Y, and Z gradient amplifiers for imaging and diffusion NMR experiments.

For solution NMR, a 5 mm inverse triple resonance probe to observe ^{1}H while irradiating ^{13}C and ^{15}N with a ^{2}H lock is being installed by Bruker. This probe includes actively shielded X, Y, and Z gradient coils with variable temperature control.

For magic angle spinning spectroscopy, Bruker has provided an HCN probe utilizing 3.2 mm rotors with a maximum rotational rate of 23 kHz. Variable temperature capability extends between –100°C and +150°C. A second HX MAS probe with a considerable variable temperature range is under development. For uniformly aligned samples, a square coil HN probe has been designed and assembled in-house with high performance specifications and variable temperature capability.

For imaging and diffusion measurements, a Dodderell microimaging probe system has been obtained from Bruker Biospin. The NHMFL at the University of Florida Advanced Magnetic Resonance Imaging and Spectroscopy (AMRIS) is working on developing a variety of additional imaging probes.

The science program (See *NHMFL Reports*, Fall, 2002) is designed to take advantage of both the high fields and ultra-wide bore of this magnet, for instance:

- Microimaging for ultrastructural characterization and for monitoring diffusional anisotropy.
- High resolution spectroscopy of quadrupolar nuclei for materials characterization and imaging of quadrupolar nuclei for ultrastructural characterization.
- ^{1}H and ^{19}F magic angle spinning solid state NMR of biological and inorganic materials.
- Structural and dynamic characterization of membrane proteins and other macromolecular structures through solid state and solution NMR.
- Characterization of nascent structure in weakly structured macromolecular systems.

Figure 3. Ultra-Wide Bore 900 MHz NMR Magnet System.

Once high performance capabilities are demonstrated in this Ultra-Wide Bore 900 MHz magnet, the NMR Spectroscopy and Imaging Program will be open for users. This program is focused on the development of technology, methodology, and protocols to enhance NMR spectroscopy and imaging at high fields AND to expand the range of scientific applications for NMR spectroscopy and imaging through the use of high magnetic fields. Additional information is available on the NMR Program Web site at *http://nmr.magnet.fsu.edu/*. Researchers interested in requesting time should e-mail Tim Cross (*cross@magnet.fsu.edu*) with a one to two page description of proposed experiments. Priority will be given to proposals that take the best advantage of the high field and wide bore aspects of this system.