High magnetic field facility in Grenoble

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Abstract: The Grenoble High Magnetic Field Facility (GHMFL) is open to the international scientific community. It can produce steady magnetic fields on 3 magnet sites with a 24 MW power supply and on 6 sites with 12 MW. One of the 24 MW sites is designed to reach 40 T in a future hybrid arrangement. The two other sites give either 33 T in a 34 mm bore diameter or 29 T in 50 mm. The GHMFL has developed the use of helix inserts made of copper alloy tubes cut by spark erosion. This technique allows making high field magnets with more stable mechanical and electrical behaviors than by the “Bitter” technique. Based on this technique a 14 helix insert powered by 11 MW was developed. It was first tested in 2002 and is now in operation on one of our three 24 MW site giving access to 33 T. In parallel a 8 helix insert with enhanced homogeneity was developed taking advantage of the possibility offered by the helix technique to make a variable pitch along the main axis. It gives access to a field of 20 T in a 160 mm bore. In 2006, a new high field version of the 14 helix is under construction and expected to reach 34 T. This technology will also be used for the design of a magnet with homogeneity of the order of 10 ppm on a sphere of 1 cm³ (with extra shimming). This magnet will be dedicated to high resolution NMR studies.

1. Introduction

The three objectives of the GHMFL are:
- to design and construct high field magnets for the generation of steady magnetic fields, with the highest intensity. Efforts are made to obtain both a good stability in long time of the field and the best homogeneity when necessary, for instance in the case of NMR experiments.
- to develop specific instrumentation for its own research on the science in high magnetic fields. Very low temperatures (dilution fridge) or high pressures are often associated with experimental techniques such as: magnetization, transport, infra-red and visible optics, NMR and EPR. Although solid state physics is our main research, we are open to other disciplines (chemistry, biophysics ...).
- to be a "high field facility" open to an international community of scientific users. It works on the basis of semi-annual calls for projects. These projects are then evaluated by an "international program committee" which attribute to the best of them the necessary time of magnetic field. Every year we have around 150 submitted projects, which include about 35% French projects, 50% of European ones, and 15% of projects from other countries. The projects can be independent from the GHMFL researches, or made in collaboration.

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2. Magnet development

The GHMFL has developed the use of helix inserts made of copper alloy tubes cut by spark erosion to design its more advanced high field magnets [1,2]. Based on this technique a 14 helix insert powered by 11 MW was developed. It was first tested in 2002 and is now in operation on one of our three 24 MW site giving access to 33 T. In parallel a 8 helix insert with enhanced homogeneity was developed taking advantage of the possibility offered by the helix technique to make a variable pitch along the main axis. It gives access to a field of 20 T in a 160 mm bore. In 2007, a new high field version of the 14 helix will be available and expected to reach 34 T. This technology will also be used for the design of a magnet with homogeneity of the order of 10 ppm on a sphere of 1cm3 (with extra shimming). This magnet will be dedicated to high field high resolution NMR studies.

2.1 Helix Technique

The principle of the helix technique is shown figure 1. Each helix consists of a copper alloy tube cut by sparking erosion. A mixture of 300 µm diameter glass spheres and epoxy glue is introduced into the slit to ensure the electrical insulation between turns. The helices are held together by a ring as shown in 'figure 1'. This ring ensures the electrical connection between two successive helix connected in series.

![Figure 1. Principle of the helix technique: each helix consists of a copper alloy tube cut by spark erosion. A mixture of glass spheres and epoxy glue is introduced into the remaining gap to ensure the electrical insulation between turns.](image-url)
Figure 2. Picture of the 14 helix insert used as the innermost coil of the 20 MW coil. The outer diameter is 372 mm and the height 420 mm. The 14 helices are concentric and the annular ring between two helices serves for the water cooling of the magnet. The helices are electrically connected in series by mean of silver plated rings. This insert provided 23 teslas in a 34 mm diameter bore for 11 MW and 33 teslas when working with the surrounding 10 MW Bitter stacks.

The cooling is made by forced convection within the annular space between two helices 'figure 2'. The typical hydraulic diameter is of the order of 1 mm. Slits are machined on the mean diameter of the ring in order to control the water flow.

The first 5 MW helix insert we have developed using copper alloy tubes has experienced more than 7500 hours of service from 1994 to 1998 in the center of our 12 MW hybrid and then from 1998 to 2004 in the center of our 24 MW magnets.

2.2. Magnets and magnet homogeneity
As mentioned in the "magnet development", the use of the helix technique permits to develop high field magnets with enhanced homogeneity, it helps to diminish the space needed for the final shimming of the magnet for example for NMR application. But in the frame of this conference it is also important to stress that the high field magnets are placed inside background field magnets of large sizes. These magnets are also available for searchers : typical homogeneity and space available are given Table 1. We also have a hybrid magnet project of 40T, started in 1997!
Table 1. Magnetic fields available at the GHMFL: all magnets above 20 T use the helix technique for the inner magnets.

| Coil number | Bore diameter | Magnetic field | Typical homogeneity |
|-------------|---------------|----------------|---------------------|
| M2 (12 MW)  | 50 mm         | 17T            |                     |
| radial optical access |           |                |                     |
| M3 (12 MW)  | 34 mm         | 26T            | 24T                 |
|             | 50 mm         |                |                     |
| M5 (12 MW)  | 130 mm        | 13 T           | 6 T                 |
|             | 284 mm        | 5% in a cylinder of D = 130mm, H = 150 mm |
| M6 (12 MW)  | 50 mm         | 24 T           |                     |
| M7 (12 MW)  | 50 mm         | 20 T           |                     |
| M8 (24 MW)  | 160 mm        | 20 T           | 0.1 % in a d = 2 cm sphere |
| M9 (24 MW)  | 34 mm         | 33 T           |                     |
|             | 50 mm         | 28 T           |                     |
| M10 (24 MW) | 50 mm         | 30 T           | Toward 0.001 %      |
|             | 376 mm        | 10 T           | for HR NMR          |

3. Conclusion
The development of the high field magnets in Grenoble is user oriented. The use of the helix technique allows new possibilities for the development of specific magnets. Besides obtaining the highest fields, the top priority for our high field magnet development is to enhance both homogeneity and stability to reach specifications imposed by the high resolution NMR for the solid state chemistry community. Others demands are now coming for the construction of high field splitted magnets for (neutrons or X rays) diffraction studies. Researchers are welcome to the laboratory to perform experiments under high fields and define their future need in terms of magnetic fields.

4. Acknowledgement
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5. References
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