Development of a new MgB_2 superconducting open MRI magnet

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The technology challenge. The magnet design defines many of the most important clinical and economical properties of the final MRI system. As a matter of fact the patient comfort, the image quality (IQ), the field of view (FOV), the life, the installation and the final costs of an imager are definitely determined by the magnetic system. In the last decade, to improve the patient comfort and for specialized applications, open magnet systems have been largely diffused; low maintenance costs have been achieved by the use of permanent magnets. The drawback of this technology is the low field strength, which means a lower noise to signal ratio and finally a lower IQ. Typically, MRI systems that use permanent magnets have a central field lower than 0.4 T. To overcome this physical limit it is necessary to use superconducting magnets, although they normally imply larger costs and maintenance. Several producers provide such magnets, often helium liquid cooled, using recondensers to achieve zero boil-off units. Alternatively, as far as whole body imagers are concerned, conduction cooled, cryogen free, open systems have been developed only by few companies [1], using both low-TC (Nb_3Sn) and high-TC (BSSCO-2223) superconductors. But if on one hand we can use LTC superconductors (at low cost) but with high maintenance (or cooling) costs, on the other hand we can consider HTC superconductors to reduce the cooling costs, but largely increasing the conductor and the final magnet costs. In this technology-economic puzzle, the recent diffusion of a new superconductor (MgB_2) could open new possibilities [2].

In fact, since the discovery of the superconductivity in the magnesium diboride in 2001 [3], its great potentially in the applied superconductivity has appeared clear. The simplicity of the binary compound involves lower fabrication costs. The high critical temperature, near to 40 K, which is between the LTC and HTC typical values, implies the possibility of cryogen free systems with no maintenance or cryogen liquid refill. Finally, the high current density at middle and low field strength has appeared promising in specialized MRI applications.

In this context, Ansaldo Superconduttori is developing an open C-shape superconducting MRI magnet based on the new MgB_2 superconductor. In this abstract, we describe the main features of the magnet design, and the progress in the prototype building.

Magnet Design. The magnet design consists of a C-shape ferromagnetic yoke plus a MgB_2 tape winding for each pole. The effective distance between the poles, i.e. the patient accommodation, is 600 mm. The FOV sphere has a diameter of 400 mm, and therefore the magnet is suitable for whole body imagers. The target peak-to-peak uniformity on the FOV sphere is below 35 ppm. The central field strength is 0.5 T, which is the highest value for conduction cooled whole body magnets. The cooling system is made of cryocoolers, with operational temperature 20 K. The coils are made of MgB_2 tape produced by Columbus Superconductor [4]. Each winding is composed of double pancake coils. The double pancake coil length is approximately 1.5 km, which is by far the longest produced with a magnesium diboride conductor. The total winding lengths is about 20 km. At present, resistive junctions are set between double pancakes, and the magnet is powered by a DC supplier that can guarantee a high temporal stability. Substitution of the resistive junctions with superconducting ones, not yet available, is expected in the near future. The stray field could be confined below the 0.5 mT limit, by the use of standard passive shielding.

The MgB_2 coil results. The MgB_2 winding undoubtedly is the most challenging aspect of the new MRI project. Several demo pancake coils were wound and tested by Ansaldo Superconduttori in order to verify the fabrication techniques, the wire homogeneity and the feasibility of the final MRI coils. The coils were built with the wind-and-react technique, using a devoted Columbus Superconductors' tape (fig.1). We performed quench tests for different coils (the last one named #21), and several short sample measurements as references (experimental apparatus details could be found in [6]). All the coils were insulated with a glass tape, which is wound at the same time as the conductor. Lastly, the windings were impregnated with epoxy resin. The inner and outer radius of the pancakes are 120 mm and 200 mm respectively. The coil consists of 48 turns, for a total length of 24 m. Pancake #21 was wound with part of a Columbus Superconductor 1.5-km class tape (named #409) by the use of the same winding machine designed for the final MRI pancake manufacturing. The average critical current of conductor #409 in function of the temperature and the magnetic field is shown (fig.2). These values have to be compared with the #21 pancake quench current (Iq). At 14K we have found Iq=318A (which implies a self-field above 0.7 T on the coil fringe), and Iq=255A at 20K; then Iq(T) follows a quite linear fit up to 30K. No training or low quench current degradation were observed. The obtained results have definitely confirmed the feasibility of the project. Subsequently, since September 2005, Ansaldo Superconduttori has been producing full size MRI devoted double pancake coils, which currently are under testing.

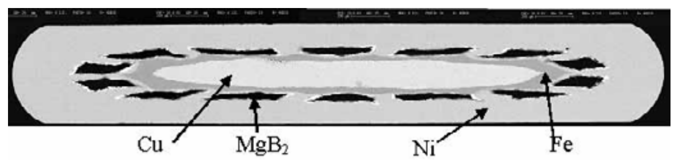

Fig. 1. Cross section of the magnesium diboride conductor (3.65x0.65 mm).

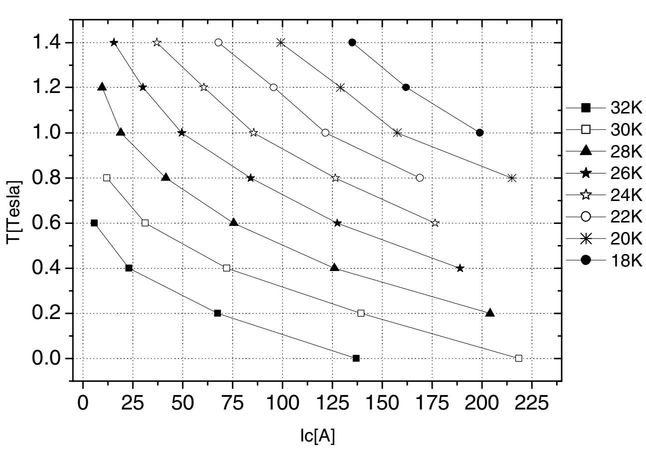

Fig. 2. Average critical currents of #409 tape

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