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IRIS - THE ITALIAN RESEARCH INFRASTRUCTURE ON APPLIED SUPERCONDUCTIVITY FOR PARTICLE ACCELERATORS AND SOCIETAL APPLICATIONS*

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Abstract

The Italian Minister for University and Research has recently funded a large program for an Innovative Research Infrastructure on applied Superconductivity (IRIS) in Italy. Based on the LASA laboratory in Milan, it is a partnership, in the form of a strongly coordinated work, of existing laboratories of various institutes: INFN (leader, participating with 4 labs: Frascati, Genoa, Milan, Salerno); CNR (SPIN institute in Genoa, Naples and Salerno); five Universities: Genoa, Milan, Naples, Salento and Salerno. IRIS will be an upgrade of existing infrastructures, with new state-of-the-art instruments, reinforcing the capability of Italy in the domain of superconductivity aimed to accelerators. IRIS foresees a strong coordination of the activity of the participating laboratories until 2035, at least, thus enhancing the participation of Italian laboratories to future projects requiring advanced superconducting technology, like FCC or the Muon-Collider, and also for developing societal applications of technologies, pursued for high-energy accelerators, especially for the energy domain and the medical sector. In this paper, we present the two novel demonstrators, part of the initial IRIS program: 1) a green superconducting line, 130 m long and designed for 40 kA current capability at 25 kV; 2) a 1 m long HTS dipole magnet with some characteristics similar to LHC dipoles: 10 T, 50 mm × 80 mm bore, but operating at 20 K rather than 1.9 K.

INTRODUCTION

IRIS is the Innovative Research Infrastructure on applied Superconductivity [1] approved by the Italian Ministry for University and Research, whose construction has started in November 2022. The construction is distributed over six poles with the scope of: characterization of new superconducting wires/tapes and cables at high field and large current; implementing the construction of innovative small scale superconducting magnets for accelerator, beam lines, and detectors; developing advanced instrumentation and measurements for magnets and accelerators; testing large superconducting magnets and high power transmission superconducting lines; characterization of new superconducting materials and magnetism in matter. In addition to the infrastructure, in IRIS is foreseen the design and construction of two advanced demonstrators that are very relevant for accelerators and green energy sector: 1) a superconducting line of 1 GW with almost zero dissipation; 2) a HTS dipole of accelerator-like shape and of large aperture, capable of generating 10 T operating at 20 K. This dipole aims at contributing to high field magnets developments by being energy efficient with respect to LHC, HL-LHC and the present FCC-hh baseline (all at 1.9 K). The saving in power for a 20 K cryogenic system is in fact 90% when compared to the superfluid helium cooling [2].

In this paper, we only concentrate on the description of the two IRIS demonstrators, without discussing the infrastructure upgrade in the various poles.

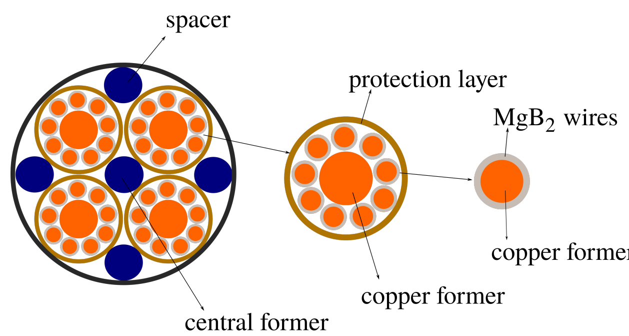

Figure 1: Scheme of the four-conductors cable composition. The figure is intended to be representative only, and not at scale.

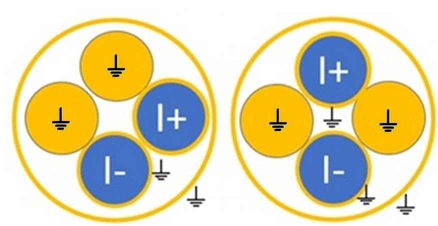

Figure 2: Two out of the four possible configurations for the current in the four-conductor cable for the power transmission (the two condutors are short citcuited in the test stand).

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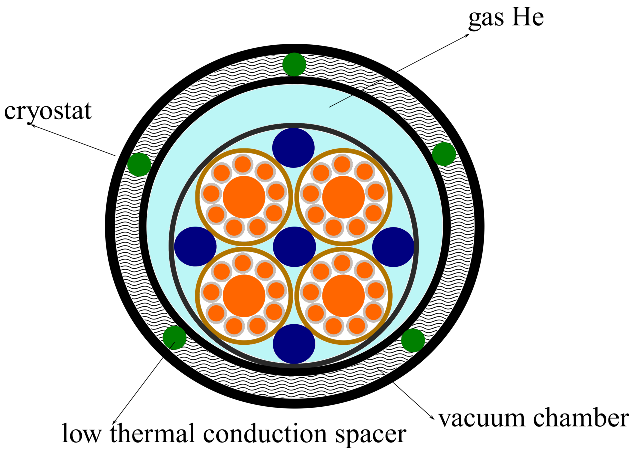

Figure 3: Section of the whole SCL, with the four-conductor cable and the cryostat. The figure is intended to be representative only, and not to scale.

GREEN SUPERCONDUCTING LINE

The Green Superconducting Line (SCL) is a 130 m power transmission line in direct current (DC). It will be designed to transport 1 GW of power working at a medium voltage of 25 kV and a high current of 40 kA. The line will be based on MgB_2 conductor with a critical temperature of 40 K, thus allowing a working temperature well above the temperature of liquid helium, 4.2 K, to reduce energy consumption and footprint. The target working point is of 20 K, with a margin of 5 K, which means that helium gas can be used as a refrigerant. Furthermore, the thermal power required will be below 500 W at 18 K. This concept of a high current MgB_2 based transmission line has been already developed at CERN in the framework of High-Luminosity LHC (Superconducting Links) [3, 4]. However, the use of the IRIS line is different from the one of CERN and so the geometry of the conductors and the cryostats will have different designs. The main differences are the higher voltage used for the IRIS SCL, associated with an higher current of a single cable (18 kA for the CERN Superconducting Links and 40 kA for the IRIS SCL), and the different working environments (LHC tunnel vs. ground). The four conductors of the IRIS SC line will feature a record 160 kA current transport in a single cryostat, though normally only two conductors (80 kA) are activated because the redundancy is required to allow for any interventions on the line once it is installed.

The expected cross-section of the IRIS SCL is characterised by a four-conductor configuration with two of them carrying current and the other two kept as full redundancy. The conductors will be made of a central copper cable former surrounded by ten petals that, in turn, are made by a central copper former surrounded by twenty MgB_2 wires (Fig. 1). The input and output poles will be at the same end of the line, and, at other end, a cold low-dissipation junction between the two main conductors is foreseen. One goal of this project is, indeed, to define an international standard for the cold junctions that are needed to connect two lines of this

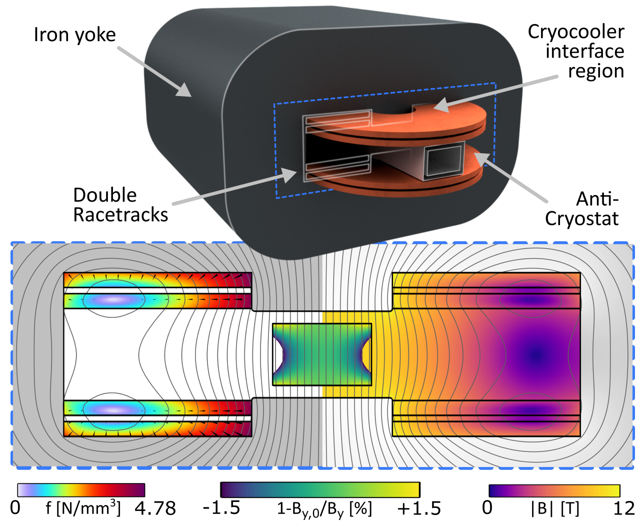

Figure 4: Scheme of the IRIS HTS dipole magnet. A representation of the conceptual design of the magnet is given (top). Lorentz force density, flux density and B_y homogeneity in the aperture are given (bottom). The homogeneity is limited in the picture to ±1.5%, highlighting the need for a proper pole shaping (in progress).

kind, in order to provide a useful method for maintenance or repairs on the whole line once it is operational. In order to do so, two of the four conductors will be shorted at the cold junction, and the presence of the other two conductors will be used to test the insulation between the cables. Four different configurations of the four-conductor design are to be investigated (Fig. 2). The cryostat will have all the interfaces required for the electric, cryogenic, power transmission, protection and monitoring systems and for all the required instrumentation. It will be also suitable for work at 10-20 K with helium gas pressure up to 10 bar (Fig. 3). The cryostat will be designed to be sturdy enough to be buried in the ground. In order to test the line, a new test facility is under preparation by INFN-Salerno and University of Salerno, Italy. Several tests will be performed on single strands, single petals and on the whole line. Some of these tests should

Table 1: Summary of SCL Main Characteristics

Characteristic	
Overall cable diameter	105 mm
Cable length	130 m
Bending radius	2.2 m
Operating temperature	18 K - 20 K
Voltage	25 kV
Current	40 kA
Power	1 GW
Assembling	4 x 40 kA
Expected losses	2.5 W/m at 20 K (187.5 W)
Inner pressure	10 bar

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focus on the trend of the critical current with varying temperature and the response of the insulation to high voltage, especially after many thermal and electric cycles. In order to simulate the final working environment of the line, the test station will be outdoors, even if not directly exposed to the weather. In Table 1 the main characteristics of the line are reported.

ENERGY SAVING HTS DIPOLE MAGNET

The Energy Saving HTS Dipole Magnet is a 1 m long demonstrator for HTS use for accelerator-like magnet in the IRIS project. The realization of the dipole will occur within the next three years and aims at: 1) providing a dipole background field for the facility in Genoa dedicated to the characterization of new materials and high current superconducting cables; 2) contributing to the studies for exploring the use of HTS for high field magnets for next generation high energy collider as FCC[5][6] or the Muon-Collider [7]. This demonstrator thus explores HTS as an alternative to Nb_3Sn magnets, which are currently under investigation [8]. In this respect, one major challenge for this magnet is to demonstrate stability in operation, for both the actual user facility of material testing and as a proof of maturity of HTS technology for accelerators. Given that the magnet is to be operated in nearly DC mode (with field variations of the order of 1 T per hour), a *controlled insulated* coil [9] is regarded as the most promising approach. Both non-insulated and metal-insulated coils are under consideration as viable alternatives to insulation [10]. The IRIS project is foreseeing a HTS dipole magnet able to generate a maximum central field of about 10 T (8 T being the minimum target) and operating at the temperature of 20 ± 2 K, with a reduction in the energy consumption, estimated by Carnot efficiency, of 5 to 10 [2]. Indeed, the magnets will be operated at a temperature of 20 K via cryocoolers in cryogen-free mode. Given its purpose of a testing facility for characterizing materials, the dipole must come with an aperture at room temperature with dimensions of 80 mm × 50 mm.

The magnet is being designed to operate between 2 to 10 T, granting a field quality of 1.5% at most for every field level within the available range. The chosen HTS material to carry out the project is REBCO tape of nominal width 12 mm and critical current of about 500 A at the operating temperature of 20 K and a magnetic field perpendicular to the tape flat surface of 15 T. A preliminary design of the cross section of IRIS HTS dipole magnet is sketched in Fig. 4, and the corresponding Loadline is shown in Fig. 5. Integrated forces on each racetrack reach around 2.2 MN vertically and 1.9 MN on each side horizontally, suggesting the need for a proper mechanical structure which is currently under development. Preliminary thermal calculations by analytical formulas [2] foresee a thermal load of around 100 W for a 60 K thermal shield (80 W of which come from the resistive section of current leads, optimized as [11]), with 2 W for the 20 K bulk (in fully DC condition). Main contributions should be the HTS part of the current leads (0.5 W) and the

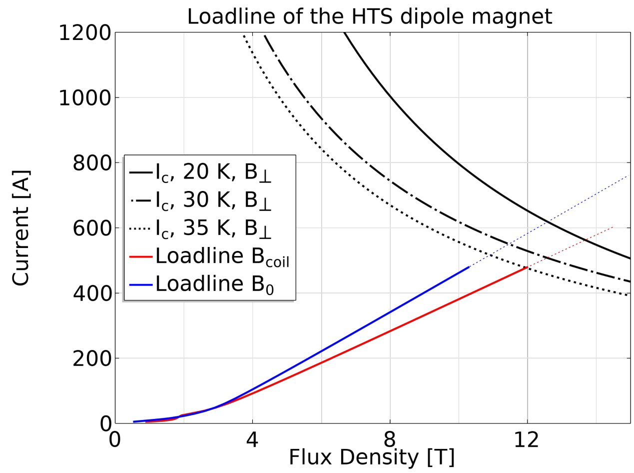

Figure 5: Loadline of the conceptual design of the magnet. Critical currents from reference tapes are given at different temperatures (20 K, 30 K, 35 k) under field perpendicular to the broad face of the tape. The loadline margin is 15%, but it comes with a temperature margin of 15 K.

joints in between tape sections. Assuming a 50 nΩ joint every 150 m, another 0.5 W should be expected. With a 20 K operation and 15 K margin, between 2 and 4 cryocooler are expected to efficiently address the heat load and guarantee a stable operation of the magnet.

CONCLUSIONS

The project IRIS has just started, with the purpose of setting, in three years, a state-of-the-art facility in Italy, distributed over six territorial poles, to advance superconducting technology for accelerators and for green power application. The parameters of the two main demonstrators, which are a key feature of the initial construction of IRIS and the subject of this paper, have been worked out and their construction has been launched.

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