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SUPERCONDUCTING DIPOLE FOR ELETTRA 2.0

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Abstract

Elettra 2.0 is the 4th generation synchrotron light source that is going to replace Elettra, the 3rd generation light source operating for 30 years in Trieste Italy. Elettra 2.0 will open to the users in January 2027 after completion of the commissioning of the ring and beamlines that will take place in the last quarter of 2026. Two beam lines require very hard-x-rays i.e. photon energies at 50 keV or more with a flux of 10^13 ph/sec and this can be achieved with a superconducting magnet at 6 T peak field. A new superconducting magnet is developed with an innovative compact design integrated with quadrupole side magnets. A new cryogenic solution will combine the benefits of a liquid-helium cooled inner magnet with a liquid-helium-free upper cooling stage. A C-shaped design will allow to slip in and slip out the magnet from its position on the storage ring vacuum chamber. A prototype of a new 6T superconducting magnet will be constructed and installed in the storage ring to replace a normal 1.4 T magnet allowing a full characterization of its performance. The NbTi superconducting magnet will work at 3.5K conduction cooled, using a system of heat exchanger connected to a subcooled Helium bath.

INTRODUCTION

Our objective is to create an advanced superbending magnet [1,2,3,4] featuring an innovative compact design incorporating quadrupole side magnets. This new cryogenic approach will leverage both the efficiency of a liquid-helium-cooled magnet and a helium-free upper cooling system [2], enabled by two cryocoolers subcooling a liquid helium tank. Using a novel C-shaped configuration, we aim to facilitate easy insertion and removal of the magnet from its position within the storage ring beam line vacuum chamber see Fig. 1. Our plan involves developing a prototype of a 6 T superbending magnet [5] to replace a standard 1.4 T magnet in our storage ring, where we will thoroughly evaluate its performance as a hard X-ray source [6,7]. Additionally, this paper presents a preliminary magnetic and cryogenic design.

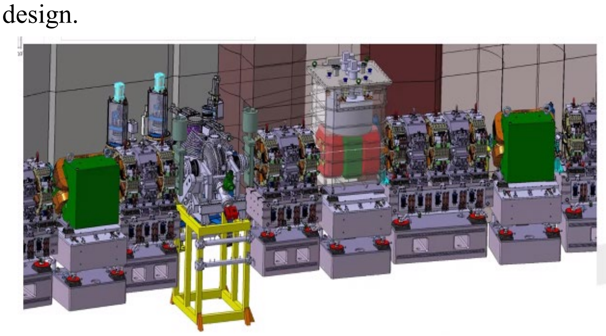

Figure 1: Superbend magnet in the Elettra2.0 storage ring.

MAGNETIC DESIGN

The design of the superbend must meet specific requirements dictated by beam dynamics and the geometry of the ring, including a total bending angle of 6.5° and a magnetic length of 800 mm. Figure 2 illustrates the required field profile for the Elettra light source. This profile consists of a high-field section spanning 80 mm with a non-gradient angle of 3.44°. Lateral to this, there are two sections, each 360 mm long with an angle of 1.53°, achieving 0.594 T with a nominal gradient (k) of -2.02 that can vary by up to 20%. It's critical that the peak field reaches 6 T, and the gradient segment spans at least 720 mm without exceeding 0.8 T at any point. To closely approximate the desired field profile shown in Fig. 2 (blue line), a combination of a dipole and two quadrupoles is necessary (the red curve shows the calucletd magnetic field generated by the whole magnetic system). The quadrupole's field is generated by an imbalance in current between its left and right windings. The four windings of the quadrupoles are not connected in series; rather, the left and right windings are driven by different currents. This proposed solution aims to streamline mechanical design and magnetic tuning, allowing for adjustments to be made remotely by simply modifying the power supply settings.

The simulation showed that the superbend with the longer total magnetic length of 88 cm produces small optical distortion on the linear optic.

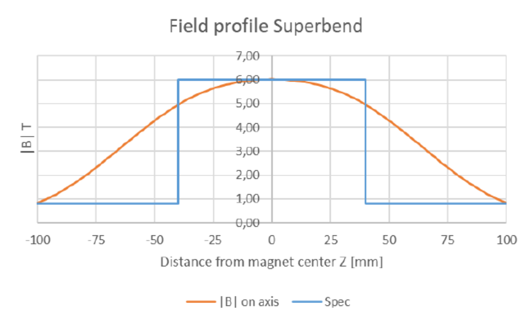

Figure 2: Superbend magnetic field.

SUPERCONDUCTING AND CRYOGENICS

To achieve the necessary magnetic field profile, we require a superconducting dipole along with two superconducting quadrupoles, each featuring asymmetry along the X-axis (with the Z-axis aligned with the beam line direction). The key characteristics of these components are outlined in the following Tables 1 and 2.

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Table 1: Main Dipole Characteristics

Item	value
Superconducting type	NiTi
Operating current at 6.0 T	126 A
Wire diameter	0.85 mm
Max field on the conductor	7.3 T
Engineering current density	161 A/mm2
CU/SC	1.3
Load line fraction	82%

Table 2: Side Dipoles Characteristics

Item	+X side	-X side
Operating current	208 A	94 A
Wire diameter(bare)	0.7 mm	0.7 mm
Max field on the conductor	3.2 T	1.5 T
Load line fraction	54%	25%

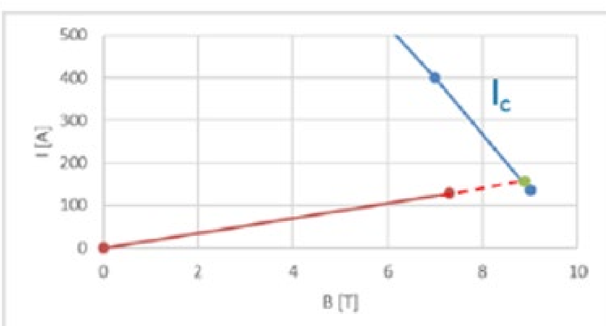

Figure 3: Load line fraction.

The operating margin is reported in the graph below (Fig.3) at 4.2 K.

Inside the C-shaped vacuum chamber (made of SS 316L) as shown in Figure 5, which must maintain a vacuum level of 1 × 10^-7 mbar with a leak rate of 1 × 10^-8 mbar*l/sec, several components are housed. These include the cold mass, six current leads, and a helium tank protected from 300 K radiation by a thermal shield.

To maintain the required temperatures, two cold heads will be installed. Their primary functions are to keep the thermal shield and current leads cold (the tagert temperature is 50 K) and to reduce the vapor pressure of the liquid helium (LHe) bath. A system of heat exchangers will further cool the yoke to below 4.2 K.

The cold mass is conduction-cooled through direct contact between the lower side of the LHe tank and the heat exchanger. The LHe tank is designed to accelerate cooldown times, shorten recovery times after a quench, and keep the system sufficiently cold in case of cryohead failure. The vapor pressure of helium in the tank will be approximately 470 mbar at a temperature of 3.5 K.

The magnet can be cooled even without liquid helium, thanks to its connection to the second stage of the cold heads. Mechanical connections with screws and epoxy resin interfaces will ensure efficient heat transfer.

Thermal loads of the cryostat system are detailed in Tables 3 and 4. These loads provide crucial information for designing and optimizing the cooling system.

Table 3: First Stage Thermal Load

Item	Load(W)
Main dipole current leads	11.9
Quadrupole Plus current leads	25.5
Quadrupole Minus current leads	11.4
Suspension rod-magnet	1.6
Suspension rod-helium vessel	2
Helium inlet pipe	0.6
Helium outlet pipe	0.6
Safety valve	0.6
Burst disc	2.6
Termaprure sensors and voltage taps	NA
Thermal shield – helium vessel	14.5
Total	71.9

Table 4: Second Stage Thermal Load

Item	Load(mW)
Two pairs 250A HTS current leads	300
One pair of 500A HTS current leads	155
Heaters	6
Liquid helium level sensor	61
Suspension rod-magnet	320
Suspension rod-helium vessel	115
Helium inlet pipe	26
Helium outlet pipe	26
Safety valve	26
Burst disc	126
Termaprure sensors and voltage taps	NA
Thermal shield – helium vessel	40
Thermal shield-magnet	40
Total	1241

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The current leads are divided into two sections: a normal conductive part and a part in HTS (High Temperature Superconductor) as shown in Fig 4. The normal conductive part will be made of brass and designed to ensure maximum flexibility to absorb thermal contraction between ambient temperature and the assumed temperature of the first stage of the cold head, which is 50K. The sizing of the normal-conducting part follows the classical treatment of the Wiedemann-Franz Law[8]. The superconductive part will be a commercial HTS current leads to minimize thermal input and ensure maximum reliability. Below is a conceptual design of the current leads.in parallel to the HTs current leads a shunt will be placed in order to protect the magnet in case of major failure of the current leads.

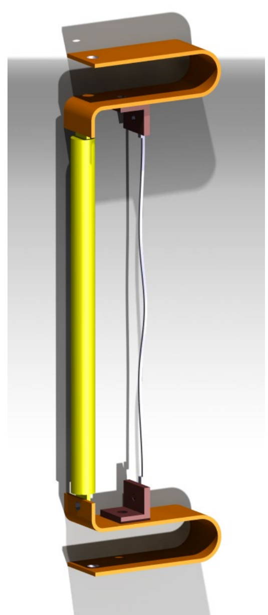

Figure 4: Current leads conceptual design.

A thermal analysis was conducted using two GM Sumitomo cold heads to determine the thermal balance, with the first stage operating at 40 K and the second stage at 3.5 K, as reported in the load map. This configuration provides a greater operating margin compared to working directly at 4.2 K (see Fig.5).

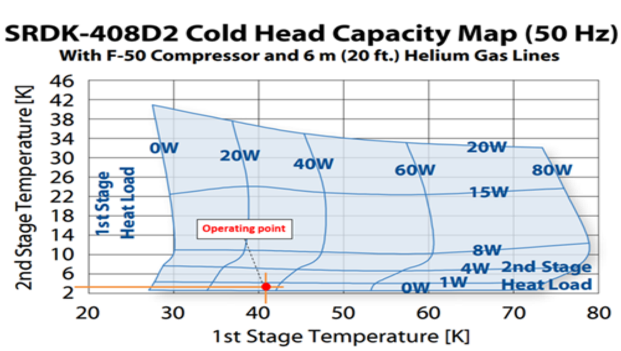

Figure 5: Operating point of cold mass at nominal field.

Pressure and temperature inside LHe vessel should be regulated by a heater in conjunction with a pressure transducer.

A conceptual drawing of the cryostat with a preliminary design is shown in Fig. 6.

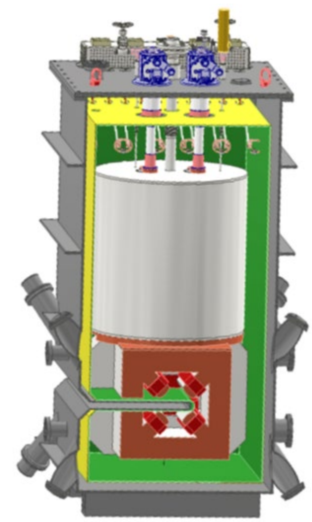

Figure 6: Cryostat with cold mass and LHe tank.

CONCLUSION

In this paper the magnetic design with one dipole e 2 quadrupoles with an asymmetry +-X, for the superbend magnet for Elettra 2.0 storage ring has been shown.

An innovative cryogenic solution has been presented, it has been demonstrated that working at temperatures lower than 4K it is not only feasible but also necessary to have a more reliable system with a simple cryogenic design. A possible superconducting design, which allows to have the desired magnetic performances, taking in account the NbTi wire is reported.

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