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SUPERBEND MAGNET FOR ELETTRA 2.0

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Abstract

The Elettra 2.0 upgrade project is a new storage ring that will replace the existing Elettra. Among the project's flagships are those of three beamlines with a photon flux generated by dedicated bending magnets of up to 10^{13} ph/sec at 50 keV. Since a magnetic field of around 6 T is needed to do this, the magnet designed for those beam lines will employ superconducting technologies, for what it's called superbends. The installation of those three superbends is scheduled in the 2027 while the test of the first prototype is at the beginning of 2025. This paper reports the main magnetic characteristics of the superbend model as well as the mechanical and cryogenic preliminary design. Also, the linear and non-linear effect in the presence of the superbends in the optic of storage ring lattice is investigated.

INTRODUCTION

We plan to develop a new superbending magnet[1,3,4] 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 due [2] to 2 cryocoolers that subcooled a liquid helium tank. A novel C-shaped design will allow to slip in and slip out the magnet from its position on the storage ring vacuum chamber. We will develop a prototype of a new 6 T superbending magnet[5] and install it on our storage ring to replace a normal 1.3 T magnet and fully characterize its performance as a hard-x-ray source[6,7]. In this paper, a preliminary magnetic and cryogenic design and an analysis of the linear and non-linear optic correction in the storage ring lattice have been reported.

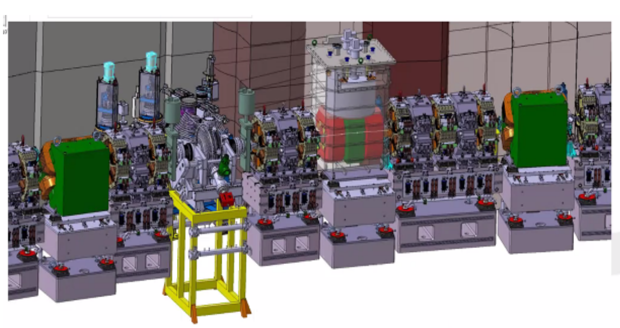

Figure 1: Superbend magnet in the Elettra2.0 storage ring.

The three superbends are replaced instead of the normal dipole in the 4th, 8th, and 12th cells. The Elettra 2.0 storage ring has a circumference of 259.2(m). It comprises 12 symmetric cells with a symmetric six-bend achromat-enhanced (S6BA-E) structure with reverse bending quadrupoles. The superbends are placed symmetrically after the short straight sections in the mentioned cell, replacing the 4th dipole. The position of the superbends is pictured in Fig.2.

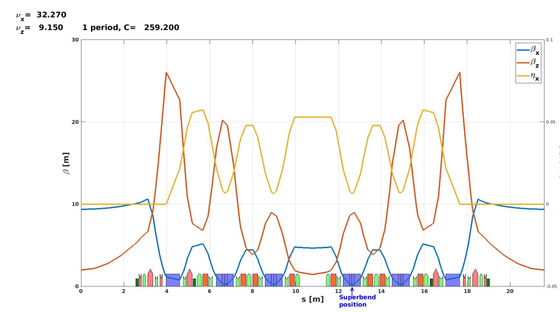

Figure 2: Superbend position in the Elettra 2.0 lattice in the storage ring.

MAGNETIC REQUIRMENT

The design of the superbend could must satisfy the requirement given form the beam dynamic and the geometry of the ring being a total bending angle of 6.5° and a total magnetic length 800 mm. In Fig. 1 the required field profile for Elettra light source is shown. The high field part is 80 mm long with an angle of 3.44° without gradient. The lateral parts have a 360 mm length each, with an angle of 1.53° each, i.e., 0.594 T and a nominal gradient k each of -2.02 variable at 20%. Certainly, the real field distribution will not be as shown in Fig. 2, but it is important that the peak field is 6 T while the gradient portion must have a total length no less than 720 mm, with a field distribution that does not exceed at any position 0.8 T. To approximate as best as possible the required field profile Fig.3, a dipole and two quadrupoles are needed.(the quadrupole field is obteined by a left right imbalance in current. The 4 windings of the quadrupoles are not connetct in series and the left ones are driven by diferent current respect to the right ones.). This solution should simplify the mechanical design and the magnetic tuning even in remote mode just by adjusting the power supplies' settings.

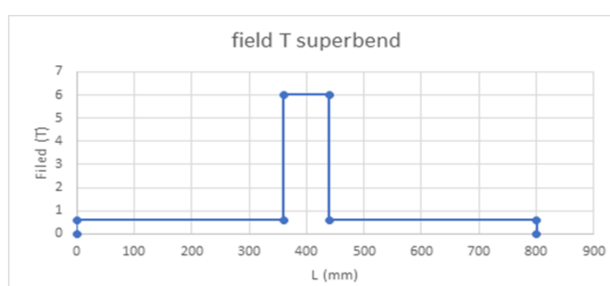

Figure 3: Superbend magnetic field required profile.

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From the optics point of view and the effect of the superbends on the lattice, three schemes were considered, by modifying the length of the lateral quadrupoles while adjusting the length of the drifts.

The simulation showed that the superbend with the longer total magnetic length of 88 cm produces small optical distortion on the linear optic while the shorter one of 72 cm produces the most distortion however in all cases corrections were possible.

SUPERCONDUCTING AND CRYOGENICS

In order to obtain the magnetic field profile required a superconducting dipole and two superconducting quadrupoles (with an asymetry in the X axis, where the Z axis is the beam line direction) are needed with the main characteristics the are summarized in the tables below.

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%

The winding are inserted in a ferromagnetic yoke as reported in the conceptual following figure.

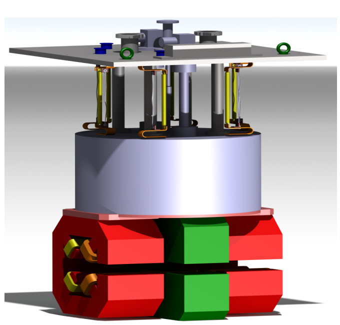

Figure 4: cold mass and iron yoke of superbend magnet.

Inside the C-shaped vacuum chamber(SS 316L) fig.5 , that must guarantee a vacuum of 1*10-8 mabr with a leak rate 1E-8 mbar*l/sec there is the cold mass, 6 current leads, the helium tank protected from the 300 K radiation by a thermal shield.

Two cold heads will be installed with the role to keep the thermal shield and the current leads cold(below 60 K) as well as to reduce the vapor pressure of the LHe bath and thanks to a system of heat exchanger to cool the yoke below 4.2 K.

The cold mass is conduction cooled tanks to a thermal contact between the lower side of the LHe tank and to the heater exchanger in direct contact with the cold heads.

The role of the LHe tank is to speed up the cooldown time, to reduce the recovery time after a quench and keep the system as cold as possible in case of out of service of the cryoheads. The vapour pressure of He in the tank the will be 470 mBar(a) T=3,5 K (WT). The magnet must be cooled even without LHe thanks to connection wuth the second stage of the cold heads. The heat exchanger will be mechanically connected with screws and at the two interfaces an epoxy resign will be used

Here below is reported the thermal loads of the cryostat.the thermal load of the system is the one reported in table 3 & 4

Table 3: Thermal loads on first stage

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

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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**

A calculation using two GM Sumitomo cold head has been done, finding a thermal balance for the first stage at 40 K and for the second one at 3.5 K as reported in the following load map. That allow us to have a higher operating margin respect to work at 4.2 K

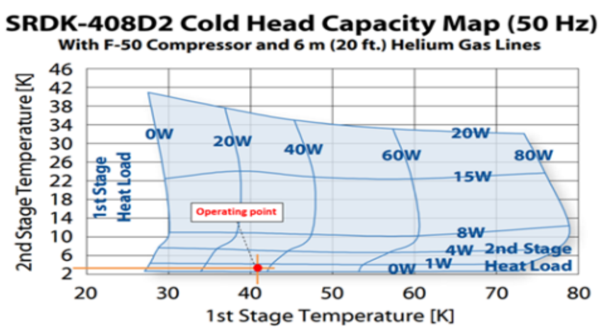

Figure 5: operating point of cold mass at nominal field.

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

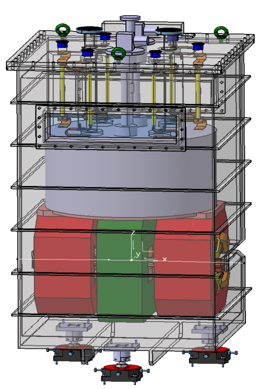

Figure 6: cryostat with cold mass and LHe tank.

THE OPTIC OF MACHINE WITH SUPERBENDS

The optics correction can be done locally and by using the quadrupoles in the cells where we placed the superbends using the Elegant code [9]. The results show that in the worst case of optic perturbation, i.e. shorter than 80 cm magnetic length of the superbends, the twiss and dispersion correction can be done by changing the strength of local quads in that cell by less than 2%.

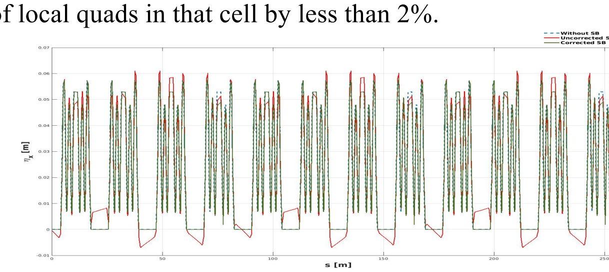

Figure 7: Dispersion correction in the lattice by using the local quadrupoles in the lattice

The lattice including the three superbends after the optical correction is tracked showing that the DA reduction in the linear optics is small and can be ignored.

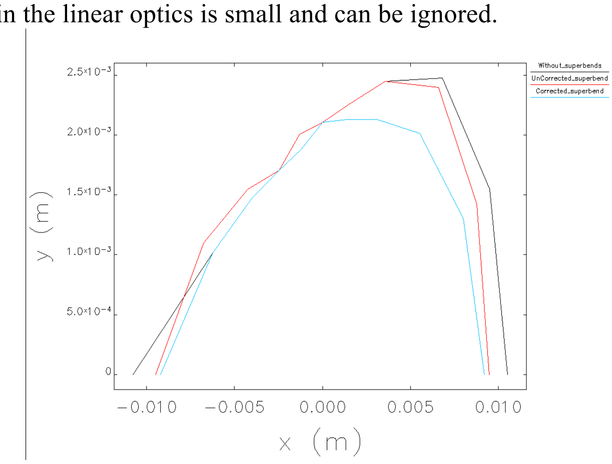

Figure 8: The Dynamic aperture of the lattice including three superbends .

In addition, the simulation for different number of superbends in the lattice in a symmetric and asymmetric situation shows that for all the situations the corrections are minimal, can be done locally and by using the quadrupoles.

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. The linear optic correction by using the local quadrupoles has shown that in any situation of the number and position of the superbends, the linear correction is possible by using the local quadrupoles by less than 2% changes from the initial value.

REFERENCES

[1] M. Wilson, "Superconducitng magnets" Oxford University Press, USA; Reprint ed. (26 march 1987)

[2] R. Conte, "Éléments de Cryogénie", published by Masson & Cie, 1970

ISBN: 978-3-95450-231-8 ISSN: 2673-5490 doi: 10.18429/JACoW-IPAC2023-WEPM056

[3] C. E. Taylor and S. Caspi, “A 6.3 T Bend Magnet for the Advanced Light Source,” IEEE Trans. Magnetics 32, No. 4, 1996, pp. 2175-2178.

[4] J. Zbasnik, et al., “ALS Superbend Magnet System,” IEEE Trans. On Applied Superconductivity, Vol. 11, No. 1, March, 2001, pp. 2531-2534.

[5] Advanced Light Source Division, “Superbend Magnet System Conceptual Design Report,” Lawrence Berkeley National Laboratory Publication, PUB-5457, Apr. 2000.

[6] D. Robin, et al., “Superbend Project at The Advanced Light Source”, Proceedings of the 2001 Particle Accelerator Conference, (2001).

[7] E. Karantzoulis *et al.*, “Elettra 2.0 Technical Design Report”, ST/M-21/01, Elettra – Sincrotrone Trieste, internal document (2021)