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PERMANENT MAGNET IN SOLEIL II

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Abstract

Twenty years after SOLEIL Synchrotron was established, the facility needs to adapt to follow new scientific fields that have emerged since. The proposed new lattice for upgrading SOLEIL storage ring will reduce the horizontal emittance by a factor 50 to reach less than 100 pm·rad.

This new lattice presents significant challenges and requires compact magnets that provide strong gradients. As a result, PM (permanent magnet) technology is preferred over electromagnet (EM) technology whenever possible. All sextupoles and octupoles will be EM to ensure efficient optic correction. However, all dipoles, reverse bends and quadrupoles will be PM.

The replacement of aging infrastructure and the use of permanent magnets (PM) will lead to a noticeable reduction in SOLEIL's electric power consumption and environmental footprint.

SOLEIL II lattice consists of 116 dipoles with gradient and 354 PM quadrupoles which can also be used as reverse bends. All PM multipoles have been designed by SOLEIL's Mechanical Engineering Group in close collaboration with the Magnetic and Insertion Devices Group.

INTRODUCTION

Since its inception in 2008, SOLEIL has proudly represented the cutting-edge of French third-generation light sources. This facility harnesses an electron beam emittance of 4 nm·rad, fueled by an energy of 2.75 GeV, delivering intensity at 500 mA in a multibunch configuration [1].

Having achieved years of successful operation, SOLEIL embarked upon an ambitious project dedicated to advancing its capabilities. The project, known as SOLEIL II, aspires to reduce the horizontal emittance of the electron beam less down to 100 pm·rad at 2.75 GeV. Our mission is to design and construct a fourth-generation synchrotron light source while preserving the existing infrastructure, including 29 beamlines spanning from far-infrared to hard X-rays.

The lattice of the new storage ring consists of alternating 7BA and 4BA High Order Achromat type cells, including more than twelve hundred magnets. To achieve such challenge, magnet design compactness is a key parameter. Permanent Magnets (PM) technology offers us a great balance between space and magnetic strength. Dipoles, reverse-bends and quadrupoles have been designed with such technology. Table 1 list the main materials used.

Table 1: Main Materials

Class	Designation
Magnets	Sm_2Co_{17}
Iron	XC06 (or ARMCO)
	Permendur (Fe-Co)
	34CrMo4
Stainless Steel	316L (μ<1.01)
Aluminium	2017A T4
Mu-metal	$NiFe_{15}Mo_5$

DIPOLES

Within the SOLEIL II storage ring lattice, there are eight distinct categories of dipoles, including four normal short dipoles (DNC) and four normal long dipoles (DNL). Table 2 is listing their main characteristics [2].

Table 2: Main Dipoles Parameters

Dipole	Diamater (mm)	Deviation (mrad)	Mag. Length (mm)	On axis field (T)	Gradient (T/m)	Quantity
DNC1	23	42.22	460	0.921	-18.7	22
DNC2	23	40.09	460	0.874	-18.7	16
DNC3	23	41.85	460	0.912	-18.7	1
DNC4	23	48.43	460	1.061	-18.7	1
DNL1	19	68.86	940	0.593 1.2 0.593	-21.57 0 -21.57	58
DNL2	19	65.39	940	0.563 1.2 0.563	-21.57 0 -21.57	16
DNL3	19	69.02	940	0.593 1.2 0.593	-21.57 0 -21.57	1
DNL4	19	68.51	940	0.593 1.2 0.593	-21.57 0 -21.57	1

Short Dipoles

DNC are used at the upstream and the downstream of 7BA and 4BA cells [3]. Their poles are curved with a hyperbolic profile, adding a transverse gradient. Low carbon steel is used for all magnetics parts and an aluminium bloc enable the transmission of forces. Mu-metal plates are used as a magnetic shield. They are fixed on both sides of the dipole to prevent crosstalk with the very close magnets next to it. Figure 1 shows the actual 3D model of the DNC.

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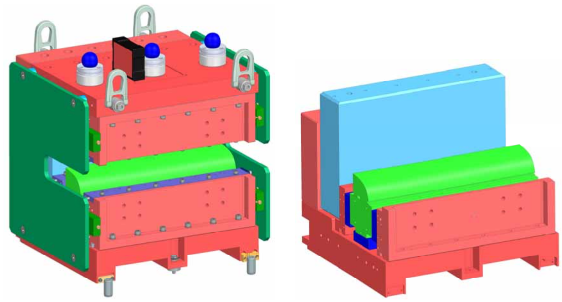
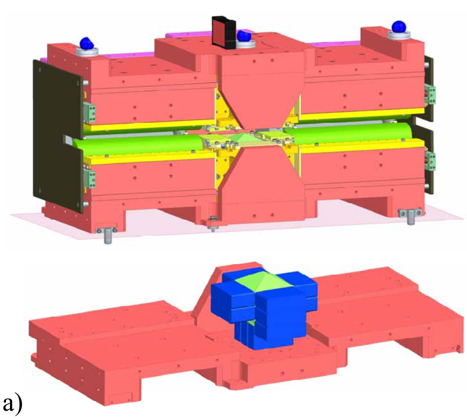


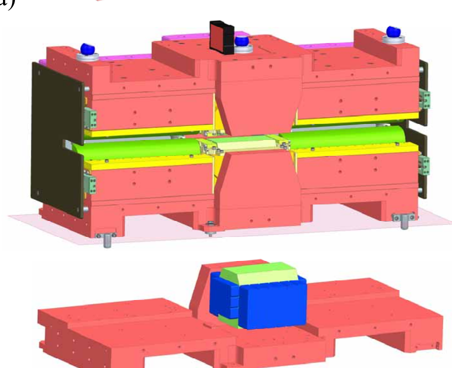
Figure 1: Short dipole 3D model.

Long Dipoles

Every DNL consists of three distinct sections: two identical end regions and a central segment. The end region poles have a straight design featuring a hyperbolic profile. In regular DNLs, the central segment generates a magnetic field of 1.2 T peak without any transverse gradient. Eight DNLs from this group will be used as superbends, with each one capable of producing a central magnetic field of either 1.7 T or 3 T peak. The overall gradient is adjusted mechanically, using floating poles. Low carbon steel is used for all magnetics parts. For 3T superbends dipoles, the central pole is made of permendur to support the magnetic field. Two aluminium blocs enable the transmission of forces. Mu-metal plates are also used as magnetic shield. Figure 2 shows the difference between 1.2 T and 3 T long dipoles.



a)



b)

Figure 2: a) 3 T superbend dipole b) 1.2 T standard dipole.

QUADRUPOLES AND REVERSE BENDS

We have opted for the geometry recommended by the ESRF [4] in the design of SOLEIL II quadrupoles and reverse-bends. This choice is based on its inherent simplicity, which still allows achieving a high gradient within a compact envelope. Moreover, it provides adequate off-axis space for the photon vacuum chamber.

SOLEIL II lattice include a total of 23 families of quadrupoles and reverse-bends, their primary parameters are detailed in Table 3 [3].

Table 3: Main Parameters of the Quadrupoles and Reverse Bends

Magnet type	Reverse Bend		Quadrupole	
Aperture	21	18	16	21
Angle (mrad)	-3.44 to -3.27	-0.81 to -0.77	0	
Length (mm)	136	119	54 to 94	146 to 216
Dipole field (T)	-0.232 to -0.22	-0.059 to -0.088	0	
Gradient (T/m)	82.97	103.69	112 to 127	87 to 90
quantity	152	40	150	12

In practice, our proposal entails the initial creation of a cluster of magnet families, ideally between 7 to 10 in number. This could be achieved by adjusting the thickness of the magnetic shunts located at the ends of the magnets. The precise distribution within the initial cluster will be decided at a later stage, following the finalization of the lattice configuration.

A first quadrupole prototype, showed in Fig. 3, was delivered in early 2021 with a profile intentionally remained unoptimized to highlight a specific signature during magnetic measurements. These measurements aimed to evaluate the precision of the manufacturing process and the results are rather encouraging.

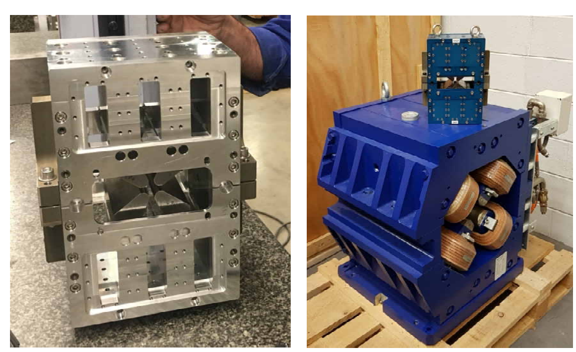


Figure 3: Empty prototype N01 (left) and on SOLEIL quadrupole (right).

A second prototype with a simplified mechanical design and an optimized profile will be delivered before the end of the year. Magnetic shunts are also implemented to control the gradient in orange in Fig. 4.

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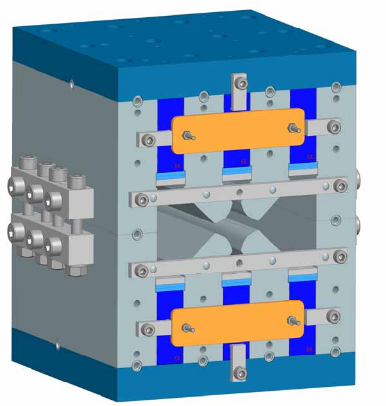

Figure 4: Quadrupole prototype N02 3D model.

TOOLING

Mechanical tooling has been developed internally, with the cooperation of the Magnetic and Insertion Devices Group, to facilitate the precise insertion of magnets inside the empty yoke. This equipment ensures a good integration, enhancing the efficiency and safety placement of the magnets.

For quadrupoles, two tooling are facing each other on the yoke, one pushing the magnets inside, the other one smoothly holding it with the help of springs. Figure 5 shows the inserting tooling on first quadrupole prototype.

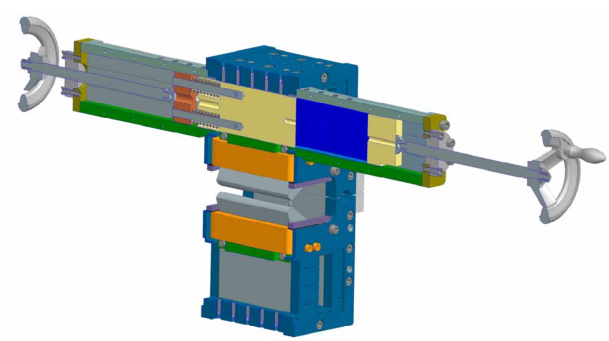

Figure 5: Inserting quadrupole N01 magnets tool.

For dipoles, the tooling is even more important because there are more steps to assemble all parts. The dipoles are in three parts, so we need to assemble all three parts apart before grouping them together. The procedure is as following:

1. Insert the magnets in low-field module and high-field yoke.
2. Insert low-field module on high-field yoke.
3. Adjust the position of floating poles and hyperbolic poles as the reference.
4. Group up upper yoke and lower yoke.

Figure 6 regroups all the steps of the previous procedure.

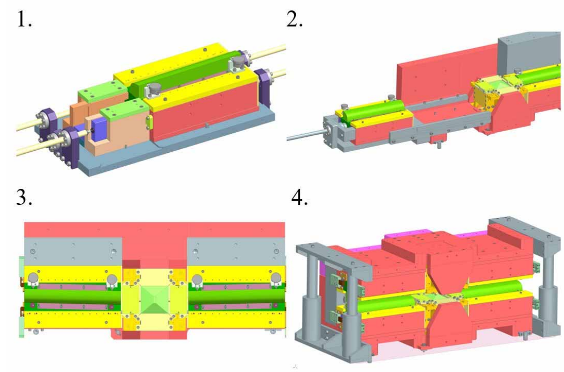

Figure 6: Assembling procedure for long dipoles.

Finally, to be able to lift and bake all the vacuum chambers ex situ, dipoles need to be extracted. A special tooling has been developed for long and short dipoles. The dimensions are not the same between those two dipoles, but the principle is the same. The goal is to raise the dipole without touching the vacuum chamber. The distance available is around 0.5 mm. Figure 7 shows the following sequences:

1. Dipole on the girder,
2. Assembly of the tool on the girder,
3. Lifting the dipole with the help of laser tracker,
4. Sliding the dipole following the flying height with the laser tacker.

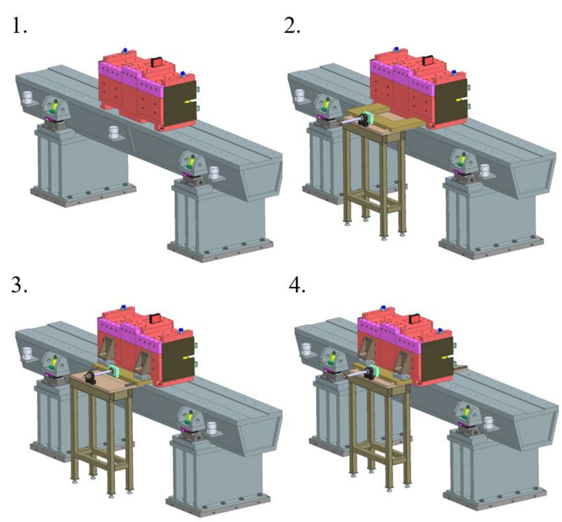

Figure 7: Extracting procedure for dipoles.

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