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U15 DESIGN AND CONSTRUCTION PROGRESS

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Abstract

A 15 mm period PrFeB Cryogenic Permanent Magnet Undulator (CPMU) is under construction at SOLEIL, relying on the experience gained from the two PrFeB CPMU already installed at SOLEIL [1, 2]. The improved design includes a magnetic length of 3 m and a minimum gap of 3 mm, leading to a polyvalent device of interest for both synchrotron radiation sources and free electron lasers. A dedicated magnetic measurement bench is also under development to perform measurements at cryogenic temperature, based on the SAFALI system. The designs of both undulator and measurement bench will be explained, the construction progress will be detailed and first results will be given.

INTRODUCTION

The SOLEIL synchrotron light source has been in operation since 2006. 27 insertion devices are installed, including 4 electromagnetic undulators [3, 4], 12 APPLE-II ones [5], 8 in-vacuum ones [6], 2 wigglers [7, 8] and one EMPHU-type device [9]. Two of the in-vacuum devices are cryogenic U18 undulators and a third device of the same type was built and installed at the COXINEL experiment [10, 11], which is part of the LUNEX5 project [12]. A fourth CPMU is under construction in the frame of a collaboration agreement with the MAX-IV laboratory. This U15 undulator is called a cryo-ready one since it can be used at both cryogenic and room temperatures, thanks to the high coercivity material used for the permanent magnets. This particularity leads to a polyvalent device of interest for both synchrotron light sources and Free Electron Lasers. A view of the whole device design is shown in Figure 1.

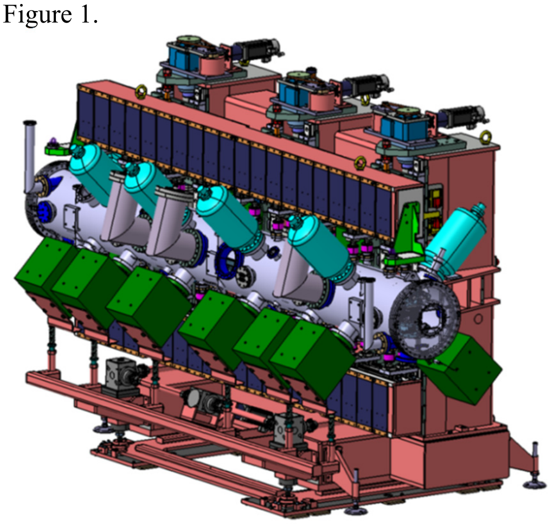

Figure 1: Design of the fully equipped U15 undulator.

MAIN PARAMETERS

The U15 design can be seen as an improvement of the SOLEIL U18 CPMU one since it is longer, has a reduced period, and can reach a smaller gap. The main parameters of both CPMU are compared in Table 1. With these characteristics, U15 has twice periods as compared to U18, leading to a higher radiated flux. By decreasing the period and increasing the peak field, one enlarges the wavelength range of the light emitted by the device.

Table 1: U15 Main Parameters Compared To U18 Ones

Parameter	U15	U18
Length (m)	3	2
Period (mm)	15	18
Min. gap (mm)	3	5.5
Max. field @77 K (T)	1.35	1.15
Nb. Periods	200	100

MAGNETIC DESIGN

The magnetic structure is a hybrid one with poles made of Vanadium Permendur and permanent magnets made of $Pr_2Fe_{14}B$ (CR53 grade). As this material does not experiment Spin Reorientation Transition phenomenon [2], it is thus possible to cool down the magnets directly at liquid nitrogen temperature with no remanent field reduction, leading to a quite simple thermal scheme [13]. The magnetic system characteristics are given in Table 2.

Table 2: U15 Permanent Magnet Properties

Parameter	Value
Remanent field @293 K (T)	1.32
Remanent field @77 K (T)	1.55
Hc_B @293 K (kA/m)	1016
H_{cJ} @293 K (kA/m)	1906
Pole dimensions (mm)	33x26x1
Magnet dimensions (mm)	50x30x5.5

UNDULATOR MECHANICAL DESIGN

The general design is based on the usual SOLEIL CPMU concept: the jaws are made of extruded aluminium parts which are drilled all along, enabling the liquid nitrogen to flow directly in the material and obtain an efficient magnet cooling. The main element designs are very similar between the two undulators, once taken into account the higher length of the device and the stronger magnetic force between the jaws, which is expected to reach 10 t. In order to support this strength, the carriage includes 3 motorized axes rather than 2. Moreover, the design also offers the possibility to generate a 1.5 mm taper, which can be very useful, especially for FEL operation.

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Figure 2: View of the tooling used to install the girders inside the vacuum chamber.

The main difficulty of the 3 m length consists in managing the 12 mm jaw contraction at 77 K, which results in a 6 mm displacement of the extremity rod linking the in-vacuum jaw and out-vacuum carriage girder. This displacement effect on the bellow is minimized by positioning the rod always off-axis, in the range +/- 3 mm according to the temperature. In addition, very tight mechanical tolerances are needed on both jaw and vacuum chamber machining operations to guarantee the correct positioning of the rods through the chamber apertures.

Another consequence of the increased force and length lies in the difficulty of every handling operation, especially the one which consists in inserting the equipped jaws inside the vacuum chamber. A dedicated tooling was constructed to operate such an operation, which needs a 8 m available length when the chamber is aligned with the jaws, as shown in Figure 2.

The holding system of the magnetic elements consists of a simple module type with one magnet inserted between two half-poles, in order to facilitate the magnetic assembly operation. The design of the holders, shown in Figure 3, was improved to minimize deformation and to make it possible to insert thermal sensors after the device assembly, without disassembling the module.

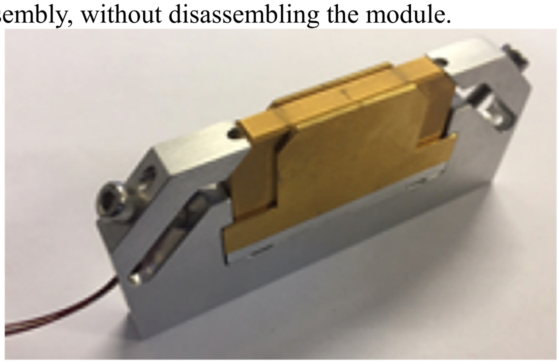

Figure 3: Photo of one module equipped with a thermal sensor.

BENCH MECHANICAL DESIGN

In order to characterize the magnetic field generated by the undulator at low temperature, a dedicated measurement bench is under construction, consisting of a Hall effect probe and a stretched wire system.

Whereas the wire system is very close to the U18 one [1], the Hall effect probe system takes advantage of our experience gained with the U18 bench, especially in the improvement of the holding structure, the guiding mechanical design and the choice of ultra-vacuum compatible elements. Figure 4 illustrates the probe guiding system improvement performed by utilizing twice rails and bearings compared to the previous design.

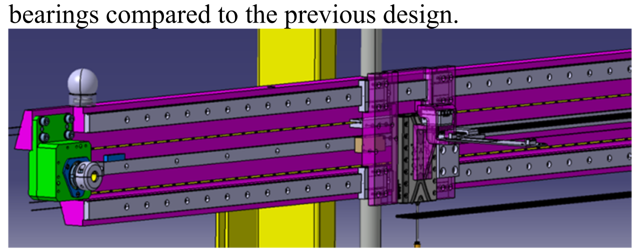

Figure 4: Design of the Hall effect probe bench: girder, sliding carriage, piezo motors and probe holder.

Moreover, it will be possible to operate measurements off-axis in order to get the contribution of each jaw on the on-axis field, and to reconstruct the longitudinal distribution of the skew quadrupole.

Because it is difficult to position precisely the probe in a 3 mm gap along 3 m, a transverse position feedback will be implemented in a comparable way as the SAFALI system [14], thanks to a laser pointing through a pinhole fixed on the probe holder, and received by a PSD placed at the other extremity of the undulator. The scheme of this system is shown in Figure 5.

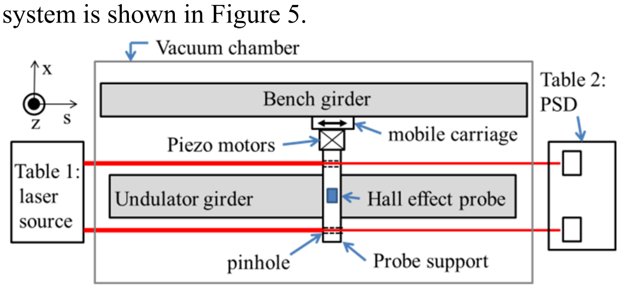

Figure 5: Scheme of the probe transverse position feedback system.

Finally the probe holder is also considerably improved: it will be made of ceramic to assure good tolerances and will operate a temperature regulation.

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CONSTRUCTION PROGRESS

Difficulties were encountered to provide the vacuum chamber and the jaws, mainly explained by the increased length and the tight tolerances**.** All the undulator elements were constructed and most of them assembled. In order to minimize the magnet height variation along the device, every magnet and holder was mechanically measured and these elements were matched by sorting when assembling the modules. The poles were also shimmed, leading to standard deviation on module height of 19 µm, as shown in Figure 6.

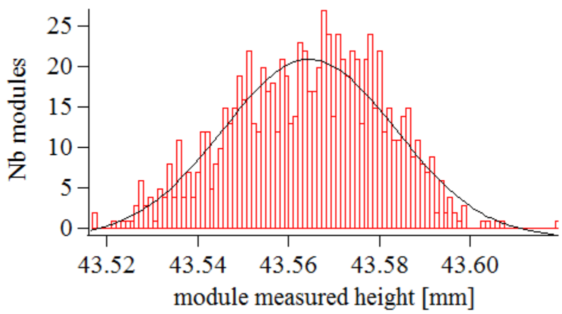

Figure 6: Height distribution of the modules.

The magnetic characterization of every module shows that there is no systematic magnetic effect on the magnets, which means no huge difficulty should be encountered during the undulator magnetic assembly.

A fake assembly of the jaws on the carriage was performed to test their positioning reproducibility, which was measured of 200 µm. A photo of this positioning test is given in Figure 7.

Figure 7: Jaw assembly reproducibility test.

A fake assembly of the carriage, jaws and vacuum chamber is under progress in order to anticipate any mismatch due to wrong machining or any vacuum leakage, since it is easier to solve such a problem now, rather than when the device is magnetically assembled. Figure 8 shows a view of the fake assembly before cooling down.

Figure 8: Undulator after fake assembly at room temperature.

Once this checking step is completed, the undulator magnetic assembly will start.

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REFERENCES

[1] C. Benabderrahmane *et al.*, "Development and operation of a $Pr_2Fe_{14}B$ based cryogenic permanent magnet undulator for a high spatial resolution x-ray beam line", in *Phys. Rev. Spec. Top. Accel. Beams*, vol. 20, pp. 033201, 2017.

[2] C. Benabderrahmane *et al.*, "$Nd_2Fe_{14}B$ and $Pr_2Fe_{14}B$ magnets characterisation and modelling for cryogenic permanent magnet undulator applications", in *Nucl. Instr. Meth. Phys. Res. A,* vol. 669, pp. 1-6, 2012.

[3] O. Marcouillé *et al.,* "Design, construction and magnetic measurements of the HU640 (OPHELIE2) undulator dedicated to the DESIRS VUV beamline at SOLEIL", in *AIP Conf. Proc,*.vol. 879, pp. 311, 2007.

[4] I. Churkin *et al.*, "Elliptical Undulator HU256 for Synchrotron Soleil: Magnetic Design, Computations and Measurements", in *IEEE Trans. Appl. Supercond.*, vol. 16, no. 2, pp. 1852-1854, 2006.

[5] C. Kitégi *et al.*, "Development of a short period high field APPLE-II undulator at SOLEIL", in *Proc. 1st Int. Particle Accelerator Conf. (IPAC'10)*, Kyoto, Japan, May 2010, paper WEPD008, pp. 3099-3101.

ISBN: 978-3-95450-207-3 doi:10.18429/JACoW-MEDSI2018-TUPH03

[6] F. Marteau *et al.*, “Development and installation of insertion devices at SOLEIL”, in *Proc. PAC’09*, Vancouver, Canada, May 2009, paper WE5RFP080, pp. 2453-2455.

[7] O. Marcouillé *et al.*, “In vacuum permanent magnet wiggler optimized for the production of hard x rays”, in *Phys. Rev. Spec. Top. Accel. Beams,* vol. 16, pp. 050702, 2013.

[8] O. Marcouillé *et al.*, “W164: a wiggler dedicated to the PUMA beamline and the femtoslicing project at SOLEIL”, in *Proc. IPAC 2014*, Dresden, Germany, Jun. 2014, paper WEPRO027, pp. 1998-2000.

[9] F. Marteau *et al.*, “The 65 mm period electromagnetic/permanent magnets helical undulator at SOLEIL”, in *Proc. IPAC2011*, San Sebastián, Spain, Sept. 2011, paper THPC151, pp. 3239-3241.

[10] T. André *et al.*, “Control of laser plasma accelerated electrons for light sources”, in *Nature Commun.*, vol. 9, 1334, 2018.

[11] M. E. Couprie *et al,* “An application of laser plasma acceleration: towards a free-electron laser amplification”, in *Plasma Phys. Control. Fusion*, vol. 58, pp. 034020, 2016.

[12] M.-E. Couprie *et al.*, “The LUNEX5 project in France”, in *J. Phys:. Conf. Ser.*, vol. 425, no. 7, pp. 072001, 2013.

[13] T. Hara *et al.*, “Cryogenic permanent magnet undulators”, in *Phys. Rev. Spec. Top. Accel. Beam*s, vol. 7, no. 5, pp. 050702, 2004.

[14] T. Tanaka *et al.*, “In situ correction of field errors induced by temperature gradient in cryogenic undulators”, in *Phys. Rev. Spec. Top. Accel. Beams*, vol. 12, pp. 120702, 2009.