DEVELOPMENT OF A PRFEB CRYOGENIC UNDULATOR AT SOLEIL

C. Benabderrahmane*, N. Béchu, P. Berteaud, M.E. Couprie, J.M. Filhol, C. Herbeaux, C. Kitegi, J.L. Marlats, K. Tavakoli, M. Valléau, D. Zerbib
Synchrotron SOLEIL, St Aubin, France

Abstract

A cryogenic permanent magnet undulator (CPMU) is under development at SOLEIL in order to reach larger magnetic field and to produce higher brilliance in the hard X rays domain. Lowering the temperature of permanent magnets increases the magnetic produced field by 25%. Different grades of permanent magnets (NdFeB [1] and PrFeB) have been characterised. Magnetic measurements on a four period Cryogenic Test Bench (CTB) are compared to the characterisation of single magnet. Thermal characterisation has also been carried out. The design of the CPMU is under progress, the choice of PrFeB magnets simplifies the cooling system of the in vacuum girders. The design of a magnetic measurement bench based on a Hall probe and a stretched wire to perform low temperature measurement is almost finished.

INTRODUCTION

SOLEIL is a 2.75 GeV energy storage ring, on which hard X rays production is achieved by short period and small gap in-vacuum hybrid permanent magnet undulators (U20 with 20 mm period and 5.5 mm gap provides ~1 T magnetic field). In order to shift further the radiation toward higher energies, the peak magnetic field of the undulators can be further increased while operating at cryogenic temperature (around 140 K for NdFeB magnet and 77 K for PrFeB magnet [2]).

When cooling down the NdFeB permanent magnets, the remanence B_r increases down to a certain temperature at which the process is limited by the appearance of the Spin Reorientation Transition (SRT) phenomenon [3, 4]. However, when cooling down PrFeB permanent magnet, the remanence B_r increases without being affected by the SRT phenomenon. In both cases, the coercivity being also enhanced at cryogenic temperature, the resistance to radiation is significantly improved, without being affected by the SRT.

However, this type of magnet grade can not be heated at high temperature without degrading the magnetic properties, so alternative strategies should be found for reaching the proper vacuum level without bakeout. Besides, keeping under control the temperature gradient and the mechanical deformation are additional technical issues.

CRYOGENIC TEST BENCH (CTB)

The cryogenic test bench is dedicated to the characterisation at low temperature of permanent magnets and comparison between the model and the magnetic properties of one single magnet. Studies were performed so far with $Nd_2Fe_{14}B$ magnets (BH50 grade from Hitachi) with a remanence of 1.41 T and with poles in Vanadium Permandur with a saturation induction of 2.35 T. The bench is a four period magnetic system with a period of 20 mm and a gap of 10 mm. It comports a vacuum chamber with several flanges for pumping and vacuum instrumentation (figure 1). The magnets and the poles are mounted on modules, which are assembled on aluminium girders maintained with a frame (fig. 2). The bench is cooled down by liquid nitrogen that circulates in a copper tube fixed on the frame. The magnetic field is measured by a Hall probe. A stepper motor moves the Hall probe from outside the vacuum chamber. A bellow transmits the movement inside the chamber.

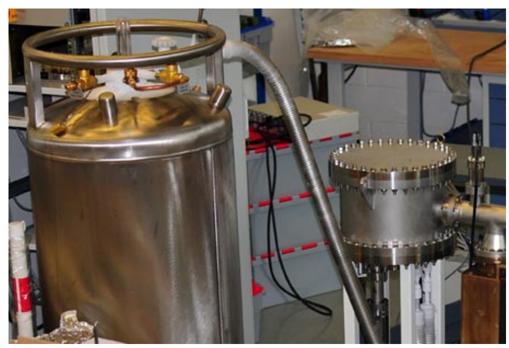

Figure 1: Cryogenic test bench

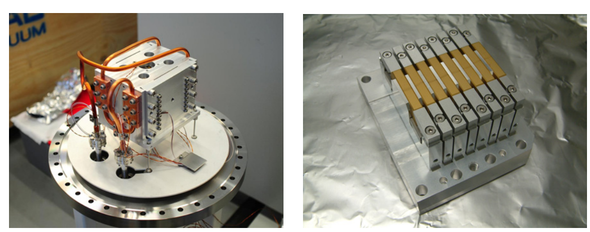

Figure 2: CTB assembly and magnetic system

MAGNETIC MEASUREMENTS ON CTB

The magnetic system of the CTB was modelled using Radia [5] (fig 2). The evolution of the susceptibility χ versus temperature is deduced from the characterisation of the magnet sample with the magnetometer, presented in figure 3. At room temperature, the susceptibility is of 0.05. It then decreases to 0.04 when the temperature reaches 160 K, and increases to reach the room temperature value for 140 K. below 140 K, the susceptibility value continues to increase and reach 0.09 at a temperature of 80 K. The model calculates the magnetic field of the CTB for different values of the remanence B_r at various temperatures.

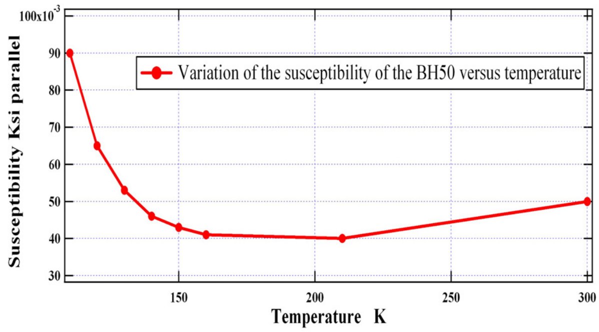

Figure 3: Variation of measured susceptibility versus temperature.

Simulation and magnetic measurements of the CTB are presented in figure 4. The magnetic field measured (resp. calculated) of the CTB is 0.49 T (resp. 0.5001). It increases when the temperature is lowered to reach the maximum value of 0.559 T (0.5686 T) at 140 K, which represents an increase of 13.3 % (13.6%) compared with the value at room temperature.

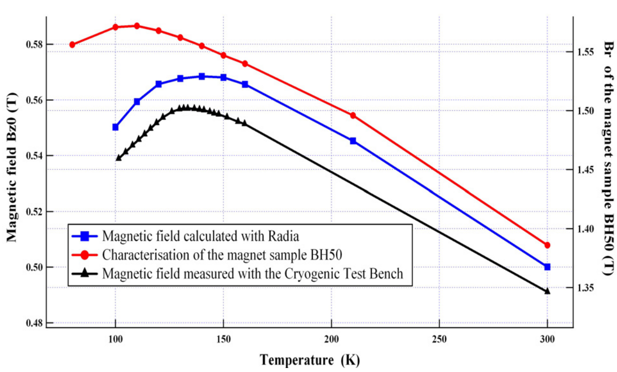

Figure 4: Variation of magnetic field of the CTB and B_r of a single magnet versus temperature.

The measured magnetic field is 1.7% lower than the one calculated field with Radia. This variation is due to the calibration of the Hall probe. The maximum value of the remanence B_r of the magnet sample was reached at 110 K (figure 4), however the maximum of the magnetic field of the CTB is reached at 140 K. This shift is due to the increase of the susceptibility of the permanent magnet below 140 K and the appearance of the SRT at lower temperature, which stops the increase of the magnetic field. The homogeneity of the magnetic field between 130 K and 160 K is 0.05% (0.09%)., it reduces the constraints of the cryogenic undulator cooling system.

THERMAL MEASUREMENTS OF CTB

The different parts of the CTB have been assembled in the magnetic measurement hall of SOLEIL. The main parts of the CTB (magnets, mechanical supports…) are equipped with ThermoCouples TCs (10) and Platinum sensors PT100 (7). In particular, one TC and one PT100 at the entrance and at the exit of the cooling circuit are installed so that their behaviour at low temperature can be compared. All the TCs and PT100 have been tested with liquid nitrogen. The PT100 reach the temperature of the liquid nitrogen, however the TCs present a drift of 5 K.
After the assembly of the vacuum chamber, after five hours pumping, the pressure at room temperature reaches 2 10^{-7} mbar and then after cooling down, it drops down to 1.2 10^{-8} mbar due to the cryo-pumping.

The CTB is cooled with an open loop cryogenic system for 20 hours to get a thermal stable state, and then, the cryogenic system is stopped. The CTB warms naturally up and reaches the room temperature after 7 days. A control system records the different temperatures every 30 mm (figure 5). The temperature of the cooling circuit is 78 K and is the same at the entrance and at the exit. The average temperature of the equipped four magnets (three magnets with a TC and one magnet with PT100) is 88 K.

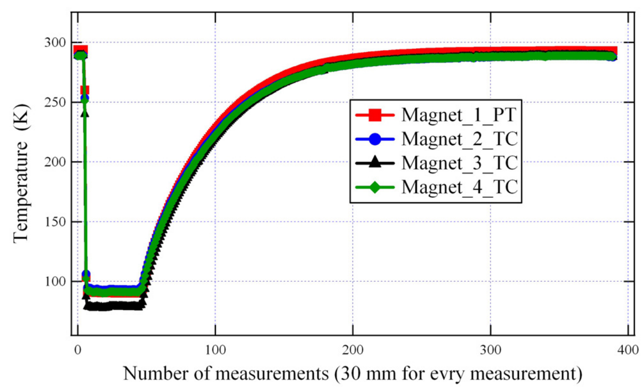

Figure 5: Variation of the temperature of the CTB magnets equipped with thermal sensors.

DESIGN OF THE 2 M CPMU

The cryogenic undulator design is derived from the present design of the SOLEIL in-vacuum undulator. A second motor for the gap movement is added to the carriage to be able to correct a systematic taper on the gap, and the out vacuum girders are equipped with copper plates to avoid temperature gradient and consequent mechanical distortion of the girders (figure 6) which could increase the phase error of the undulator. The choice of the PrFeB permanent magnets simplifies a lot the cooling system, as it enable to operate directly at the liquid nitrogen temperature 77 K instead of the 140 K in case of NdFeB.

The shape of the girder is manufactured out of extruding row aluminium material. The cryogenic undulator will be cooled down by a CRYOTHERM close loop cryogenic system, with a single circuit for both girders.

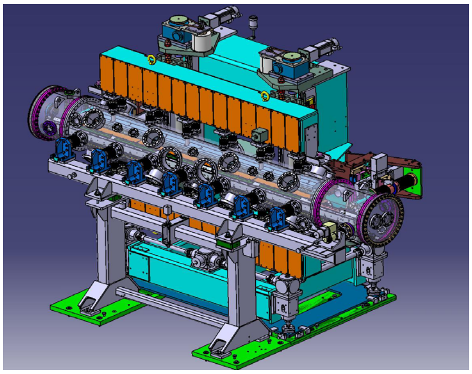

Figure 6: CATIA design of the cryogenic undulator

MAGNETIC MEASUREMENT BENCH AT LOW TEMPERATURE

A standard magnetic measurement bench combining Hall probe and flipping coil measurements will be used to assemble and to shim the cryogenic undulator. A low temperature magnetic measurements bench is under design at SOLEIL. It will be used to check the measurements of the undulator at room temperature and to perform the same measurements at low temperature. This bench enables two types of measurements: Hall probe for the local magnetic field and stretched wire for the field integrals. The low temperature magnetic measurement bench will be integrated inside the undulator vacuum chamber (figure 7). The Hall probe will be fixed on a chariot which is moved by a stepper motor on a rail. The rail is independent from the undulator vacuum chamber and it is fixed from outside the vacuum chamber by seven rods.

The deformation of the rail will be measured with an optical system constituted of a Renishaw Laser, a retro reflector and a beam splitter. The longitudinal position of the Hall probe will be measured with an optical rule.

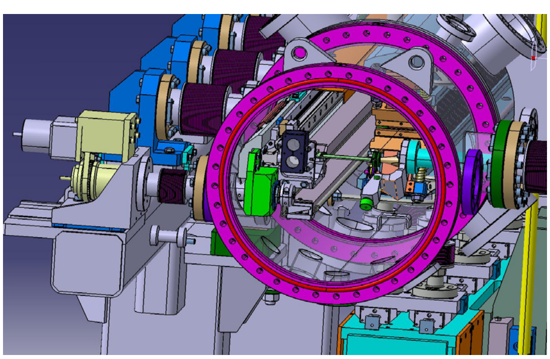

Figure 7: CATIA design of the low temperature magnetic measurement bench.

The stretch wire bench is fixed on the carriage. The vertical and horizontal movements of the wire will be insured by micro-control plates at the two extremities of the undulator. A spring keeps the wire stretched during the measurements.

CONSTRUCTION OF THE 2 M CPMU

PrFeB magnets and Vanadium Permendur poles have been mounted on mechanical supports with two types of modules: PAP modules constituted by one magnet and two poles and A modules constituted by one magnet. All the modules have been characterised on our standard magnetic measurement bench with two poles to reproduce the undulator assembly conditions. The results of the Hall probe measurements are presented in figure 8. The dispersion of all the modules peak magnetic field is less than 1%.

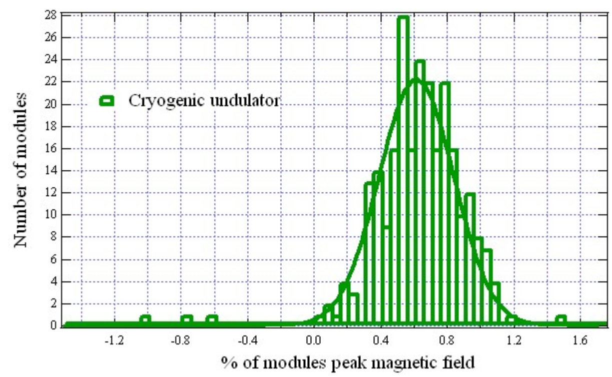

Figure 8: Dispersion of modules peak magnetic field

CONCLUSION

Single NdFeB and PrFeB magnets have been characterised with a magnetometer, enabling the determination of the magnetisation characteristics versus temperature, with insight to the susceptibility. A model constituted of a four period magnetic assembly with the same magnet grade has been assembled. Results of the model and the magnetic measurements are found to be in good agreement. The construction of a 2 m long CPMU with PrFeB together with an associated low temperature magnetic measurement bench is underway and should be completed by spring 2011.

ACKNOWLEGMENTS

The authors thanks Joel Chavanne from ESRF for his kind support during the magnetic characterisation analysis, Didier Dufeu and Denis Maillard from Néel Institute for the magnetometer [6] and the permanent magnet companies (Hitachi, Vacuumschmelze and Atlas magnetics-Yunshen) for providing magnet samples.

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