DEVELOPMENT OF CRYOGENIC UNDULATOR CPMU AT SOLEIL

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Abstract

A cryogenic undulator 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 field they produce by 30%. We present the magnetic characterisation of different permanent magnet grades at cryogenic temperatures. Studies are also carried out on a small assembly of four periods. The comparison of the residual pressures obtained with and without baking the vacuum system of a standard U20 in-vacuum undulators is also described.

INTRODUCTION

SOLEIL is a 2.75 GeV intermediate energy storage ring, therefore producing hard X rays requires 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) [1]. 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).

When cooling down the 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 [2]. The coercivity being also increased at cryogenic temperature, the resistance to radiation is significantly improved. The coercivity is not affected by the SRT.

In the frame of R&D studies, we are investigating the possibility of using NdFeB permanent magnets (instead of SmCo with a B_r of 1.05 T) because of their larger B_r (1.4 T) at room temperature, could enable to reach a 1.3 T peak magnetic field at cryogenic temperature [3] (i.e. larger by at least 30 %). Achieving low pressure in such in-vacuum devices usually requires in situ bake out. Unfortunately this type of magnet grade cannot be heated to high temperature without degrading the magnetic properties, which limits the residual pressure that can be achieved. Besides, keeping under control the temperature gradient and the mechanical deformation are additional technical issues.

CHARACTERISATION OF PERMANENT MAGNET SAMPLES

A characterisation of permanent magnet samples was performed with the magnetometer of Néel Institute (CNRS Grenoble) [4]. It is a fully automatic system for studying magnetic properties, operating in a magnetic field range of ± 10 T and at temperatures between 2 and 300 K. The magnetometer is based on flux extraction method. The sample is fixed on a rod allowing a vertical movement. The magnetization is measured with three sets of pick up coils placed around the sample. The magnetic field H is produced by a superconducting magnet located in a liquid Helium cryostat and the temperature is regulated within 0.01K by a He flow-through arrangement.

We have characterised three samples from three different companies (see table 1). We have chosen NdFeBr permanent magnet material with a very high remanence. Such material can not be used for the construction of room temperature in-vacuum undulator because of its weak coercivity at this temperature. However, when cooled down at cryogenic temperatures, not only its remanence increases but also its coercivity increases and consequently this grade features as high resistance to demagnetisation (up to 5T external field) as the material usually used at room temperature. Hence, it appears very attractive for the construction of cryogenic undulator.

The samples were not coated to avoid wrong measurement. As this material is very sensitive to oxidation, the oxide surface was removed and the weight of the sample was measured precisely to deduce the exact volume.

Table 1: Characteristics of the magnet samples at 20 °C: Br remanence, Hcj coercivity, Tcoef temperature coefficients. Vac stands for Vacuumschmeltze.

Characteristics	**BH 50**	**VAC764**	**N50**
Company	Hitachi	Vac	Yunshen
B_r (T)	1.40	1.37	1.41
H_{cj} (T)	1.39	1.63	1.38
Tcoef B_r (%/°C)	-0.11	-0.10	-0.12
Tcoef H_{cj} (%/°C)	-0.58	-0.58	-0.60
Weight (g)	0.4784	0.4892	0.4570
Dimensions (mm^3)	4	4	4

The magnetic properties of the three samples BH50, VAC764 and N50 have been measured at different temperatures between 300 and 80 K and compared to the ESRF sample 495T provided by Neorem [6].

At every temperature we measure the hysteresis cycle and we deduce the remanence B_r and the coercivity H_{cj} (see figure 1).

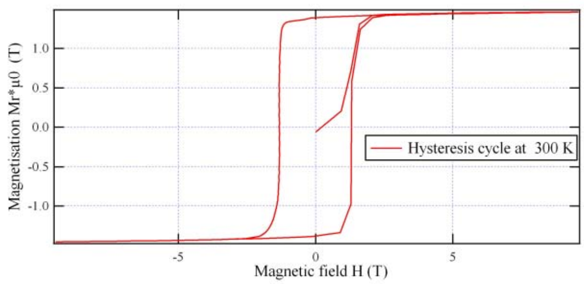

Figure 1: Characterisation of the BH50 at 300 K.

First the sample is placed in the homogeneous volume of the magnetic external field H. When the field is applied, the magnetic moments of the sample are oriented in the same direction of the field (magnetometer). In the first magnetisation curve, the magnetisation M increases with the field and reaches the saturation value M_{sat}. A further increase of the magnetic field does no have any effect on the magnetisation. Then, the external magnetic field is reduced from 10 T to -10 T. The magnetisation decreases slowly with the field, but when the field reaches 0 the magnetisation stays at a positive value called the remanence magnetisation M_r which characterises the strength of the permanent magnet. The magnetisation continues to decrease with the field and it rapidly reaches zero at a certain negative value of the field called the coercivity H_{cj} which characterises the resistance of the permanent magnet to demagnetised field. In this case the permanent magnet sample is completely demagnetised. The magnetisation continues to decrease with the external field until its reaches saturation with a negative sign. The last step is to vary the external field from -10 T to 10 T to close the hysteresis cycle.

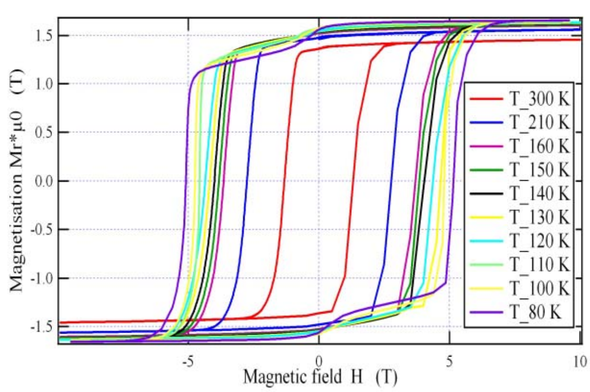

Figure 2: Hysteresis cycle of BH 50 versus temperature.

The surface of the hysteresis cycle gets larger when the temperature is reduced because of the increase of the remanence and the coercivity (see figure 2).

When a negative field is applied the coercivity drops quickly, because the magnetic domains on the surface of the sample have very weak coercivity due to machining and oxidation. This phenomenon does not depend on the temperature as shown in figure 2, but on the volume of the sample. The data are corrected from the surface effect for using the hysteresis curve in a modelling code such as RADIA [5].

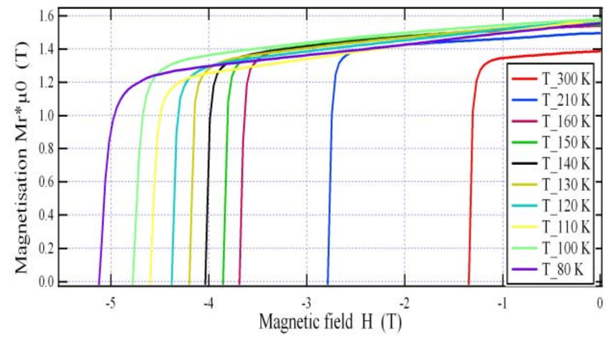

Figure 3: The second quadrant of the hysteresis cycle without the surface effect.

The remanence and coercivity are deduced from the measured hysteresis cycles. They define the magnetic properties of the materiel (figure 3).

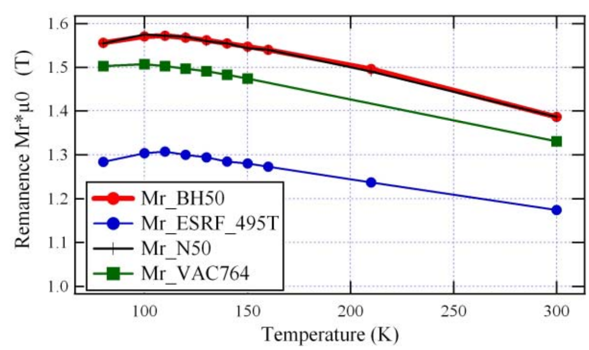

Figure 4: variation of the remanence versus the temperature.

The remanence increases when the temperature is reduced between 300 and 110 K (figure 4). It is almost stable between 110 and 100 K and decreases between 100 and 80 K because of the appearance of the SRT phenomenon. At this temperature the easy magnetisation axis of the material is deviated from the vertical one with an angle φ which reaches 30° at 4.2 K [2].

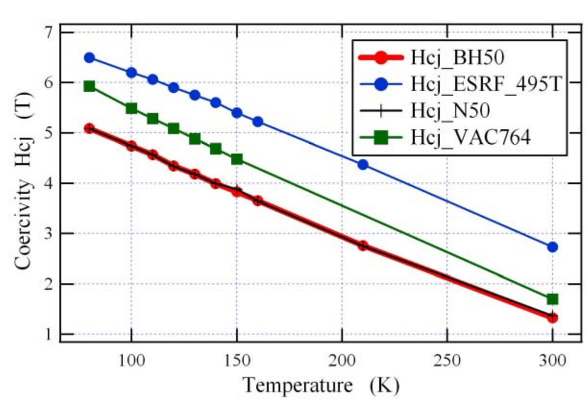

Figure 5: Variation of the coercivity versus the temperature.

The coercivity is not affected by the SRT; it increases continually when we decrease the temperature to reach at 80 K four times the value at room temperature (figure 5).

PERMANENT MAGNET TEST BENCH

The permanent magnet test bench will be dedicated to the characterisation at low temperature of permanent magnets assembled together in a four period hybrid undulator. The measurements will be compared with the results of the individual characterisation.

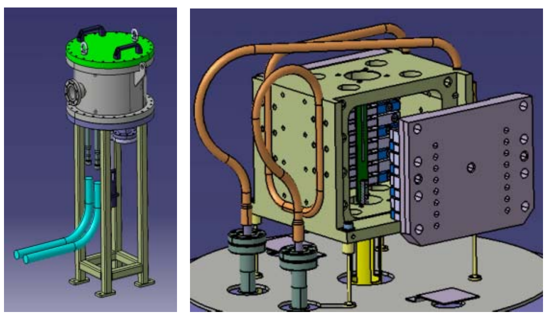

Figure 6: Permanent magnet test bench.

The bench is constituted by a vacuum chamber with several flanges for pumping and vacuum instrumentation (figure 6). The magnets are mounted with poles on modules which are fixed on aluminium girders maintained with a frame. It is cooled down by liquid nitrogen which circulates in a copper tube fixed on it. 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.

MECHANICS

The cryogenic undulator design will be derived from the actual design of the SOLEIL in-vacuum undulator. The heat load was estimated at about 595 W: 247 W coming from conduction through the rods supporting the girders, 138 W due to thermal radiation of the vacuum chamber, 200 W from the warm RF fingers and 10 W deposited by the electron beam. This heat load will be lowered by reducing the dimensions and modifying the material of the rods, by providing water cooling to the RF fingers and by installing a thermal shield on the inner side of the vacuum chamber to reduce the thermal radiation. The girders will be cooled with liquid nitrogen circulating in a copper pipe surrounding them.

VACUUM TESTS

The employment of high remanence permanent magnets does not allow the complete vacuum system to be baked out at high temperature because of the weak coercivity of this type of magnets. Vacuum tests on one of our in-vacuum undulator have been carried. It was found that the vacuum pressure limit without baking the vacuum system (figure 7) reaches 3.45 10^{-9} mbar after 28 days of passive pumping. The pressure we get after baking and 10 days of pumping is 4 10^{-10} mbar.

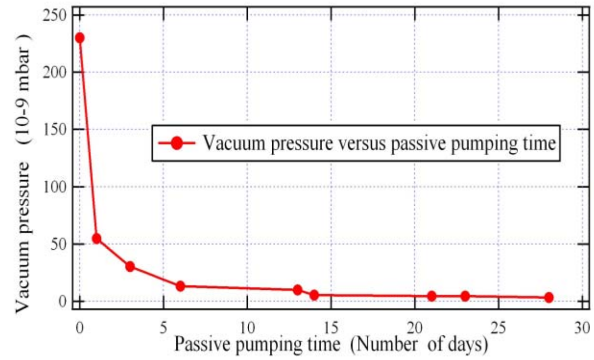

Figure 7: Vacuum pressure versus passive pumping time.

CONCLUSION

Different samples of NdFeB have been characterised leading to the knowledge of the magnetic performances at different temperature. The SRT phenomenon appears around 110 K. The VAC764 sample presents a good compromise between an increase of the remanence and coercivity at cryogenic temperature and an acceptable coercivity at room temperature which will avoid any risk of demagnetisation during the magnetic assembly of the undulator. Thermal and mechanical studies are progressing to adapt the actual in-vacuum undulator to a cryogenic one.

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