DEVELOPMENT OF A PrFeB CRYOGENIC UNDULATOR AT NSLS-II

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Abstract

Recent cryogenic undulators use Praseodymium-Iron-Boron (PrFeB) magnets cooled down to 80K. The main drawback of the PrFeB magnet grades developed so far are their relatively low coercive field at ambient temperature, below 2 T which prevents PrFeB based cryogenic undulator from baking. Some precautions are required during the undulator assembling and shimming to ensure Ultra High Vacuum (UHV) compatibility. However Hitachi Metal Industry (HMI) recently developed two different grades of PrFeB magnet with large coercive field but at the expense of the remanent field. The magnetization curves have been measured from 40 K up to 400 K to determine the field increase and to investigate the magnet withstanding to baking. An In Vacuum Undulator (IVU) prototype has also been baked. Magnetic measurements before and after baking are also presented.

INTRODUCTION

The first cryogenic undulators ([1], [2]) installed in the third generation generation light sources are based on the Neodymium-Iron-Boron (NdFeB) magnet technology. Because of the Spin Reorientation Transition (SRT) in NdFeB magnet, the undulator magnetic field is maximum at a temperature higher than 135 K while the most common available cooling systems use liquid Nitrogen or Helium and work below 80 K. As a consequence cooling was the one of the main technological challenges of these devices. In addition, similarly to standard IVU, these devices were baked above 373 K to ensure an UHV compatibility. This limits the selection to NdFeB grades with a high intrinsic coercivity and a low remanent field, typically around 1.2 T, able to withstand such high temperature.

Recent achievements in IVU and magnet technology allowed to overcome these two initial burdens. First the European Synchrotron Radiation Facility (ESRF) successfully installed a non baked IVU, at the expense however of a longer commissioning [1]. This achievement is significant for the cryogenic undulator technology as it broadens the NdFeB grade selection to magnets with a remanence as high as 1.5 T [3]. In parallel Hitachi Metal Industries (HMI) and VacuumSchmelze developed new magnets compatible with cryogenic applications below 80 K. HMI produced Praseodymium-Iron-Boron (PrFeB) magnets which unlike NdFeB don't exhibit SRT. HMI first realized CR53 magnets for BNL and SOLEIL [3] [4] and more recently the CR47 and CR50 which have higher intrinsic coercivity. In the next year, one may even have more high performance PrFeB magnets if the Dysprosium diffusion process successfully applied to NdFeB [6] is also used. VacuumSchmelze produced for BESSY $Nd_{0.2}Pr_{0.8}FeB$ magnets. The Pr lowers below 80 K the temperature threshold below which the SRT occurs [5]. Fig. 1 shows the variation of the remanent field and the intrinsic coercive field with the temperature, for the four different materials.

At NSLS-II it has been decided to bake all the IVUs and to use magnets with very high intrinsic coercive field (32 kOe) to minimize the risk of demagnetization. Therefore CR47 which exhibits a intrinsic coercive field higher than 1 T at 413 K is of primary interest to build cryogenic undulator with bake-able PrFeB magnets. The R&D program on PrFeB cryogenic undulator at NSLS-II is reviewed hereafter.

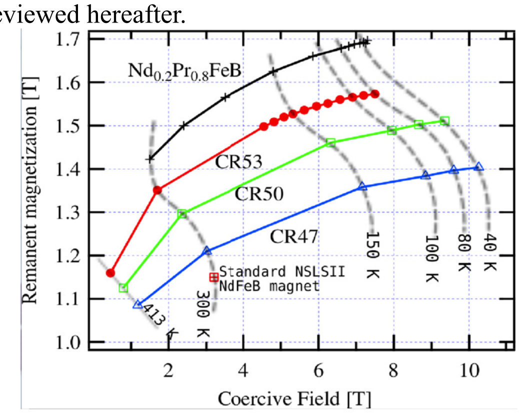

Figure 1: Variation with the temperature of the remanent field and the intrinsic coercive field of the CR47, CR50, CR53 and $Nd_{0.2}Pr_{0.8}FeB$ magnets. Data of the CRXX magnets at 413 K have been graciously provided by HMI. Data of the $Nd_{0.2}Pr_{0.8}FeB$ (resp. CR53) magnets are from [5] (resp. [3]). CR47 and CR50 have been measured with the 10 T magnetometer at the Institut Louis Néel [7].

CR47 PROTOTYPE

In order to investigate the resistance of the CR47 magnets to a baking at 373 K, a short period (16.8 mm) small and fixed gap (5 mm) hybrid undulator arrays composed of CR47 magnets and Vanadium Permendur poles have been fabricated at BNL. No elaborate shimming was done except for trajectory optimization by magnet sorting. The main parameters of the magnets and poles are listed in Table 1.

Table 1: Geometry of the Magnets and Poles in the Prototype

	Magnet	Pole
Width	50 mm	40 mm
Height	29 mm	25.5 mm
Thickness	5.6 mm	2.8 m

Magnetic Performance at Cryogenic Temperature

The 3D magnetostatic software RADIA [9] was used for the calculation of the magnetic field of the prototype. The geometry of the full prototype as used in RADIA is drawn in Fig. 2. We described the magnets as linear anisotropic magnetic materials in the RADIA model. The remanence and the parallel susceptibility of the CR47 and CR50 are derived from the magnetization measurements made at the Institut Louis Néel. A detailed description of similar measurements can be found in [3]. The remanence and the parallel susceptibility of the CR53 were found in [3]. Finally we assumed a null perpendicular susceptibility.

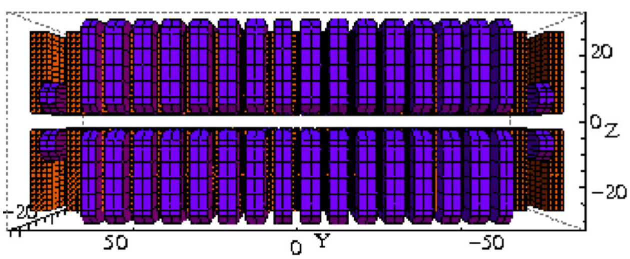

Figure 2: Geometry of the RADIA model.

The dependence of the peak field with respect to the temperature is plotted in Fig. 3. The peak field achieved with standard NdFeB magnets used for room temperature IVU is given for comparison.

Compared to our CR47 prototype At 77 K, a hybrid prototype made of CR53 magnets would only produce a 0.106 T higher peak field while a difference in remanence as high as 0.177 T is observed. The vicinity of the high permeability Vanadium Permendur poles in the hybrid structure levels the difference in remanence.

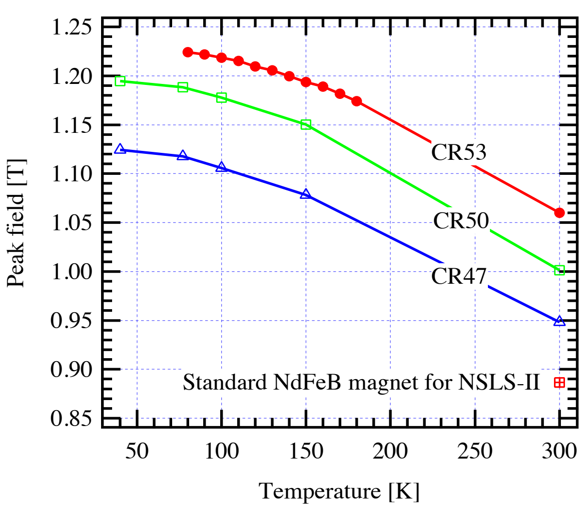

Figure 3: Expected peak field increase of the hybrid prototype with geometrical parameters listed in Table 1 and for a gap of 5 mm. The three different PrFeB magnet grades CR47, CR50 and CR53 are considered.

The increase of the peak field as the temperature decreases from room temperature down to 80 K slightly depends on the magnetic material (0.17 T for the CR47, 0.187 T for the CR50 and 0.164 T for the CR53). Finally as reported in earlier publications [4] [5] cooling the magnet below 77 K would marginally increases the magnetic performance of the prototype and is therefore unnecessary.

Magnetic Field Before and After Baking

The CR47 prototype was placed in an oven and a thermocouple was fixed on the side of the magnet array to trigger the temperature of the oven. The prototype was kept at a temperature as high as 373 K for only two hours and was continuously monitor to avoid any demagnetization before the first cooling. The record of the structure temperature is displayed in Fig. 4.

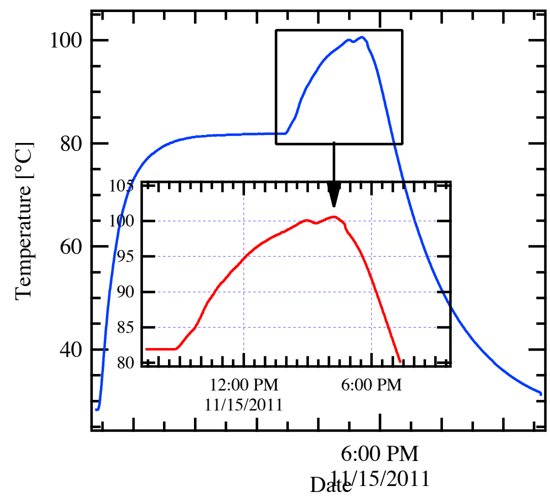

Figure 4: Temperature of CR47 prototype in the oven.

After the baking, the magnetic field prototype has been remeasured with the NSLSL-II Hall probe bench and compared to an initial measurement. No demagnetization was observed, as plotted in Fig. 5.

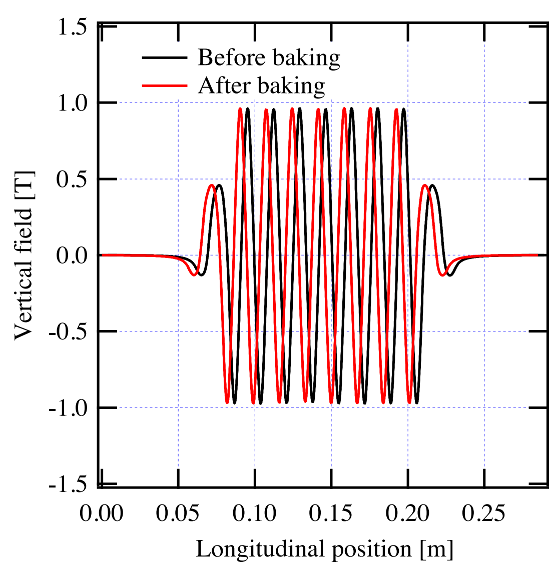

Figure 5: Magnetic field measured with the NSLS-II Hall probe bench before and after baking.

ISBN 978-3-95450-115-1

NEXT STEPS

The CR47 prototype is now mounted on the Vertical Test Facility (VTF) as pictured in Figure 6. The VTF was originally developed at NSLS-I for R&D on super conducting undulators [8]; it has been recently modified to measure the magnetic field of a CR53 prototype at 4 K and 77 K [4]. Magnetic measurements of the CR47 prototype at 77 K will take place in June. The prototype will then be baked again at higher temperature and for a longer time. Further magnetic measurement at room temperature will be done especially off axis where most likely a demagnetization would first occur.

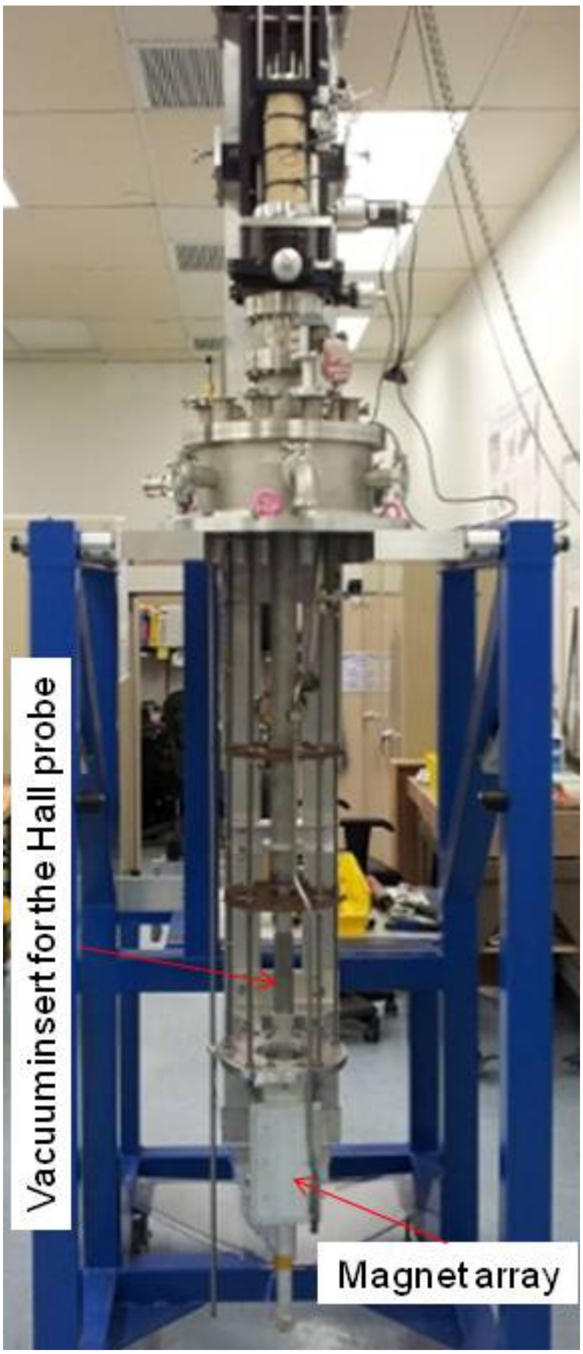

Figure 6: CR47 prototype installed on the VTF.

SUMMARY

Several grades of PrFeB magnets are now available from HMI. Around 80 K the remanence between the different grades differs by 0.177 T. However as used in an hybrid structure with high permeability poles, the peak field difference reduces to 0.106 T. A short hybrid undulator arrays has been built at BNL with CR47 magnets and Vanadium Permendur. The prototype has been been baked and no decrease was measured in the on-axis magnetic field. The magnetic field will be measured at 77 K with the VTF in June.

ACKNOWLEDGMENT

The authors wish to thank Mr. D. Dufeu of the Institut Néel in Grenoble, France for performing the magnetization measurement of the CR47 and CR50, Dr. T. Kohda and Dr. Y. Matsuura of HMI for their support.

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