CHARACTERIZATION OF PrFeB PERMANENT MAGNET BLOCKS WITH HELMHOLTZ COILS AT NSLS-II*

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Abstract

As an investigation into building a cryogenic undulator using bake-able Praseodymium-Iron-Boron (PrFeB) magnet blocks, a short period (16.8mm) and fixed gap (5mm) hybrid undulator prototype[1] has been fabricated at BNL. For this undulator, 36 PrFeB magnet blocks (28 type A, 4 type B, 4 type C) are used. The strength and direction of magnetization of the PrFeB magnet blocks are measured by using a Helmholtz coil system. The data include the three vector components of the total magnetic dipole moment of the blocks and this data also compared with vendor measurement results.

INTRODUCTION

Recent developments in the manufacture of PrFeB magnets with improved intrinsic coercivity (Hci) allows them to be used at liquid nitrogen temperature (77K) without loss of Br due to Spin Transition Reorientation (SRT), and they can also be baked at over 373K[1,2]. In order to investigate the magnetic performance of PrFeB magnets over this wide temperature range, a short period, small gap hybrid test undulator has been fabricated at BNL, using Hitachi type CR47 magnets and Vanadium Permendur poles. (Fig.1).
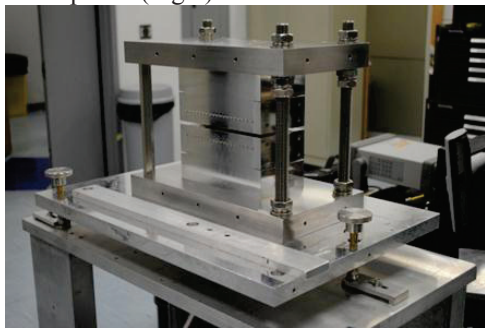

Figure 1: CR47 Prototype Arrays.

The prototype arrays contain 36 magnet blocks (Fig.2) (28 type A, 4 type B and 4 type C) with the dimension of blocks which are shown in Table 1.

Table 1: Geometry of the Magnets and Poles in the Short CR47 Prototype

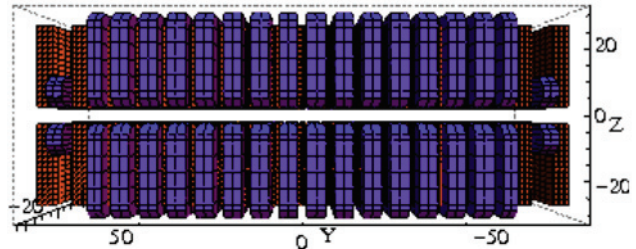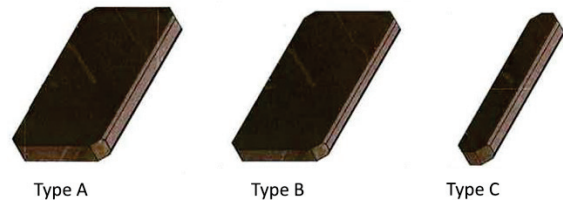|	Magnet(A,B,C)	Pole
Width	50(A,B,C) mm	40 mm
Height	29(A,B), 9.57(C) mm	25.5 mm
Thickness	5.6(A), 4.2(B), 4.76(C) mm	2.8 mm

Figure 2: Geometry of the prototype arrays.

Figure 3: Magnetic blocks (Type A, B, C) of the prototype

The magnetic properties of these magnet blocks required are as below:
(1) The dispersion of the total dipole moment must not exceed ±1.0%.
(2) The angle deviation of the magnetization direction with respect to the easy axis of the block must be less than 1.0°.

EXPERIMENTATION TOOLS

The equipment (Kyma Helmholtz Coil Bench, model KHCB-860/3000) applied here is intended for the magnetic characterization of permanent magnet blocks. The coil pair consists of two identical circular coils, mounted coaxially. Each coil has 3700 turns #38 AWG insulated wire. The coil resistance at 24°C is 19,560 ohms. The mean radius of coil, as well as the axial separation between the coils, are each 430mm [3].

The rotating block holder has a small cube-shaped pocket to constrain a magnet block at its center. The measurement cube is made from Acrylonitrile Butadiene Styrene (ABS) by a 3D printing technique. This holder assembly was designed and machined precisely so that the center of the magnetic block is mechanically aligned with the center of the Helmholtz coil pair while rotating, and maintains the fiducial surface of the block parallel to

the cube face. A cube is made for each specific magnet and should be used only on that magnet size and shape. Each cube face is marked with the appropriate axis label and sign mark. There are six measurement positions, (X, Y Z, X' Y' Z'), three for measuring the magnet in normal orientation and three for reverse orientation.

A block diagram of the HCS for measuring the magnetic moments of PrFeB blocks from Hitachi Metals, Inc. (HMI) is shown in Fig.5. The PC controls the motor to set in motion the block by means of a Nanotec driver (SMCI47-S). A rotational encoder (WEDL/WEDS-5541) is attached to the motor shaft giving the angular position of the block. The induced signal in the coil is detected by the MAGNET-PHYSIK fluxmeter (EF 5) and the data are transferred to the PC which process the data and calculates the magnetic moments.
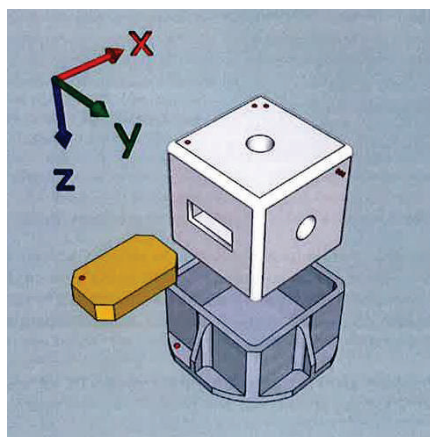

Figure 4: Basic configuration of cube, measurement holder and measured magnet. This is the measurement position one for Mx measurement.
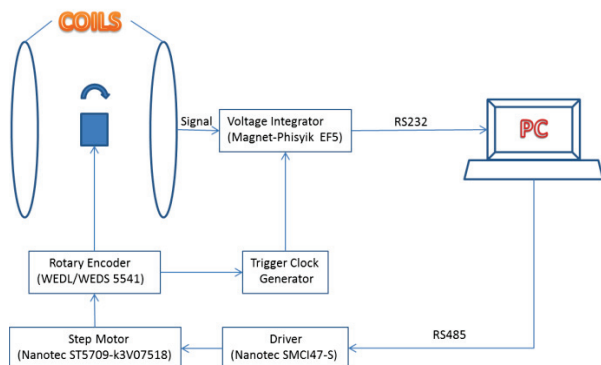

Figure 5: Schematic representation of the magnetic blocks characterization system.

Magnet-Physik EF5 electronic fluxmeter has automatic drift correction and self-adjusts to built-in voltage-time reference. It has two input power ratings 100-120VAC, 60Hz and 200-240VAC, 50Hz. But when we first received and tested it in our lab, it didn't trigger by line with 60Hz, and then we have to build an external trigger box(Fig.6) and provided it with the correct trigger signal.

The specification of Kyma HCS are shown below:
Flux measurement (moments) resolution = 1×10^{-6} Vs
Flux measurement (moments) repeatability = 2×10^{-5} Vs
Angle measurement resolution = 0.01 deg
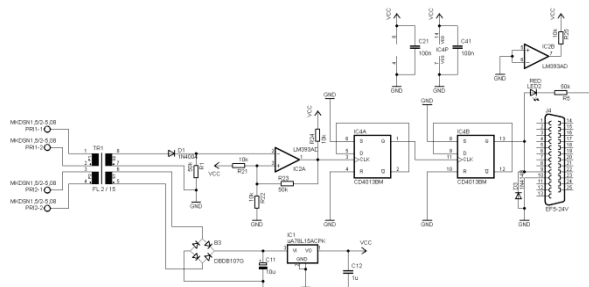
Angle measurement repeatability = 0.05 deg

Figure 6: External trigger box(60Hz) for EF 5 fluxmeter.

The measured repeatability of the HCS for a randomly selected block of magnet type A#28. The total 10 measurements were recorded for the magnetic moments and angles, the measurement errors are the standard deviations (STD) of 10 such measurements. The STD of flux measurement is 4.9×10^{-7}Vs and 0.038 deg for the angle measurements. This result shows that the measurement repeatability of the HCS is better than that required by the specification.

MEASUREMENT RESULTS

Because the temperature coefficient of Br and Hci of the PrFeB block are about -0.1%/°C and -0.6%/°C respectively, the block measurement was conducted in the temperature-controlled clean room where the ambient temperature was controlled at 25°C±0.1°C. All the blocks were stored in the measurement room at least 48 hours for the temperature stabilization before HCS measurement.

To check long-term measurement reliability, we measured a reference block (block# A28) twice a day at the beginning and the end of measurement. For the entire measurement period, the day-by-day magnetization differences of the reference block were within the specification.

The statistic analysis of magnetic measures of Type A magnet block are shown in the graphs Figure 7-8. The reference magnet A#28 data give us the measurement uncertainty. The formula for the total angle deviation of magnet block is:

$$\theta = arctan\frac{\sqrt{Mx^2+My^2}}{Mz}$$

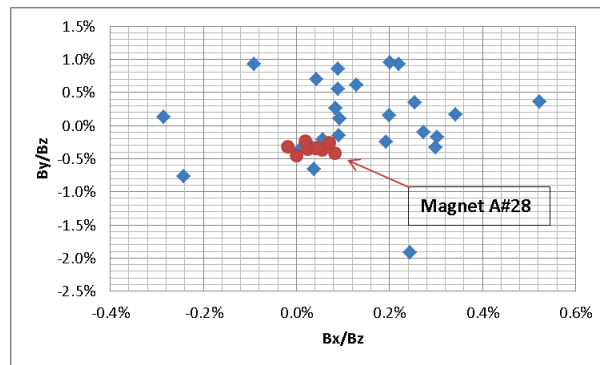Figure 7: Magnetization angle errors (By/Bz vs. Bx/Bz) for all Type A magnetic blocks.

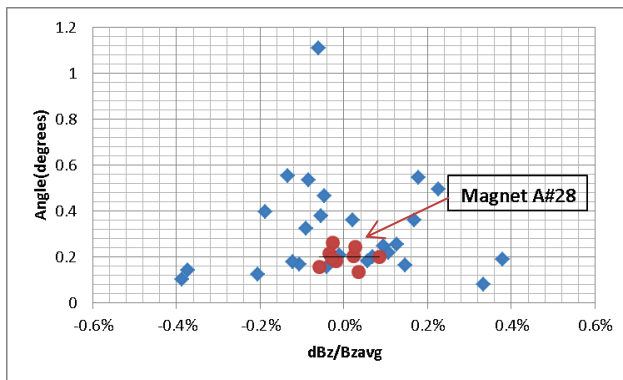Figure 8: Magnetization angle vs. strength error. (angle Θ vs. dBz/Bzavg)

In order to assess the quality of the measurement data, a correlation is made between the measurements provided by the magnet manufacturer (HMI) and those carried out using the Kyma_HCB at BNL. The graph in Figure 9 compares the % deviation from the mean of magnet strength measured by the Kyma_HCB and by HMI. The correlation appears quite poor, but on average the HMI deviations are about a factor of 3 larger. It would appear the magnets are much more uniform in strength than stated by HMI and easily meet our ±1% specification.

Similarly, Fig.10 compares total magnetization angles Θ measured by the Kyma_HCB vs. measurements by HMI. Again, the correlation with HMI data is quite poor, with HMI angles being on average a factor of 4 smaller than those measured by the Kyma_HCB. We also measured Θ using a 3-axis Fluxgate Magnetometer[4]. The results, plotted in Fig.10, agree with Kyma_HCB data within 20%.
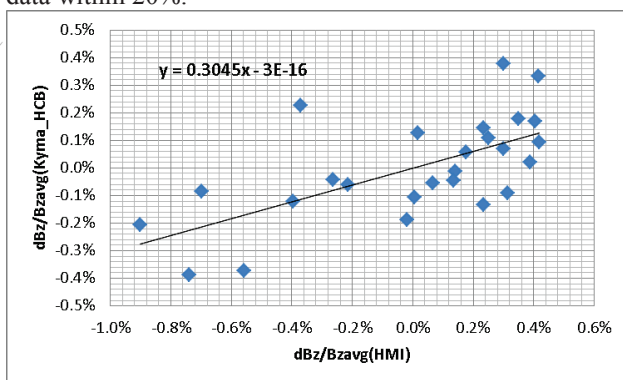

Figure 9: The magnitude of the total magnetic moment of the blocks (Type A) is compared with magnet manufacturer (HMI).
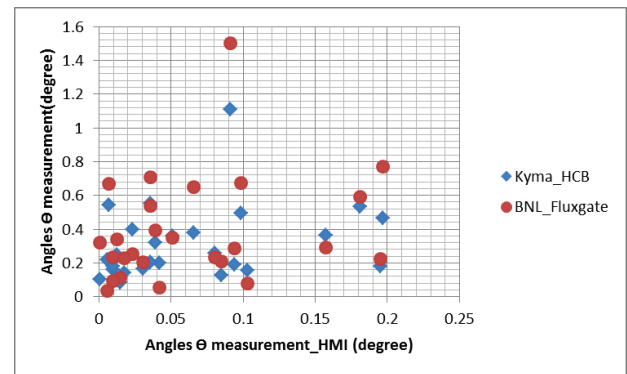

Figure 10: Magnetization angle measurement data comparision (Kyma_HCB and Fluxgate vs.HMI)

SUMMARY

The Helmholtz coils system is fully capable of measuring the moment and angle of magnet blocks. Measurements on the PrFeB block differ significantly from data supplied by the magnet manufacturer, possibly due to differences in measurement technique. A block sorting procedure can be established to reduce trajectory wander and phase error of the insertion device structures. In order to further improve measurement repeatability and reliability, the system need to increase mechanical precision of rotary stage scan, reduce the electromagnetic interference generated by motor, and also may replace the integrator with one which offer better resolution and stability.

REFERENCES

[1] C. A. Kitegi et al. "Development of a PrFeB Cryo-genic Undulator at NSLS-II" IPAC'12, New Orleans, 2012, MOPPP089, p.762

[2] T. Tanabe et al "Cryogenic field measurement of $Pr_2Fe_{14}B$ Undulator and Performance Enhancement Options at the NSLS-II" SRI'09, Melbourne, 2009, AIP Conf. Proc 1234, p. 29

[3] Helmholtz Coil Bench KHCB-860/300, Kyma Srl

[4] MEDA, Inc., 43676 Trade Center Pl., Ste. 145, Dulles, VA20166, USA