MEASUREMENT AND RESEARCH ON CRYOGENIC REMANENCE OF CHUNKS PM FOR CRYOGENIC UNDULATOR*

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Abstract

Cryogenic remanence measurment system of SSRF cryogenic permanent magnet undulator was built in china (10-300K). Magnetic measurement tooling and magnetic field calculation and measurement method of cryogenic remanence measurment system will be optimized. Hall probe would be pasted on surface of permanent magnet and table magnetic field of permanent magnet would be measured, after being converted, cryogenic remanence of permanent magnet would be obtained and cryogenic remanence variation of permanent magnet would be researched, measurement data will be checked by physical properties measurement system. May 2, 2013, by measuring cryogenic remanence of N50M (NdFeB), the system repeatability was inspection. By this experiment, foundation was established for development of SSRF cryogenic permanent magnet undulator .

INTRODUCTION

In international Synchrotron Radiation Facility field, cryogenic permanent magnet undulator (CPMU) [1, 2, 3, 4] is becoming one of key technologies. In recent years, many countries did research on cryogenic magnetic properties of CPMU permanent magnet (PM) such as NdFeB、PrFeB. For cryogenic remanence of chunks PM, some countries have developed some cryogenic testing device, see table 1:

Table 1: Cryogenic Remanence Test Methods for PM of CPMU

Project	Spring8	NSLS-II	HZB	SOLEIL
Magnet	Nd(Pr)FeB	PrFeB	PrFeB	NdFeB
Temperature	77K-300K	4.2-300K	10-300K	80-300K
Parameter	remanence	magnetic field phase error	magnetic field phase error	remanence and coercivity
Magnet or structure	44mm×8mm ×12mm. 46mm×8mm ×12mm.	8 period (14.5mm) Prototype	20 period (9.0mm) Prototype	4mm×4mm ×4mm
Cooling method	conduction-cooled	gas-nitrogen flow cooling	conductio n-cooled	liquid–nitrogen flow cooling

Commercial PPMS or SQUID only test cryogenic remanence of small size PM (generally size is less than 5.0mm), for CPMU, directly testing cryogenic remanence of actual applied chunks PM is very important.

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In 2012, Shanghai Synchrotron Radiation Facility (SSRF) using PPMS test cryogenic magnetic properties of domestic NdFeB (N50M) PM [5]. In 2013, SSRF self-developed a set of Cryogenic Remanence Measurment System (CRMS) of chunks PM, cryogenic remanence of domestic PM for SSRF CPMU prototype will be test (10-300K). This article describes progress of this work.

EXPERIMENT METHOD

CRMS

In 2012, SSRF selfed-designed a set of Hall Probe cryogenic calibration system, commissioning Nanjing Quixote Super-cryogenic Technology Co., Ltd developed it, by improvements, CRMS of chunks PM was built.

The main method is that temperature control, vacuum components, cooling components etc of Hall Probe cryogenic calibration system does not change, only transformed the second cold head assembly, and enable it can install large size PM and magnetic structure components after transformation, the magnetic structure components can leads to Hall probe and cool PM (10-300K), shown in figure 1:

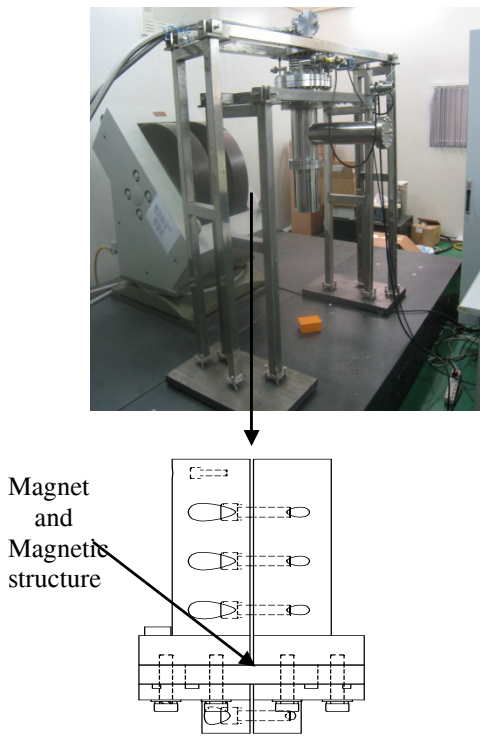

Figure 1: SSRF CRMS for chunks PM.

PM cryogenic remanence

Rectangular PM with size is a、b、h(magnetization direction is h), by Amps molecular circulation assumed, we known: magnetic field of external space at any point is stimulated by all molecules current of PM. Assume magnetization is uniformed, inside magnet, molecular current effects cancel each other out, PM has only macro surface currents without body currents. So we can seen that magnetic field at any point of external space of PM is only stimulated by the surface closed current loop of PM. For PM of SSRF CPMU, it's main shape are square and rectangular, cryogenic remanence of PM can be calculated by principles of molecular current:

For square PM, the relation between cryogenic remanence and surface magnetic field is:

$$B_{dr} = K_0 \frac{B_{dz}\pi}{2\arctan\dfrac{h}{\sqrt{a^2/2+h^2}}} \quad (1)$$

For rectangle PM, the relation between cryogenic remanence and surface magnetic field is:

$$B_{dr} = K_0 \frac{B_{dz}\pi}{\arctan\dfrac{a}{b}\dfrac{h}{\sqrt{a^2/4+b^2/4+h^2}}+\arctan\dfrac{b}{a}\dfrac{h}{\sqrt{a^2/4+b^2/4+h^2}}} \quad (2)$$

In formula, B_{dr}、B_{dz} means cryogenic remanence and surface center magnetic field along magnetization direction of PM respectively, a、b、h means length、width、and magnetization direction height of PM (square PM: length and width is the same) respectively, K_o is calibration factor(it is relationed to magnetic permeability and Hall probe position).

Magnetic properties of PM

PM grand for SSRF CPMU prototype may be: NdFeB(N50M 、 N50H) 、 PrFeB (P42H 、 P45M), PM sample is square: 40mm×40mm×10mm, their room temperature magnetic parameters see table 2:

Table 2: Magnetic Properties of Domestic PM for CPMU

Magnet	Grand	*Br*(T)	*Hcb*(kA/m)	*Hci*(kA/m)	*Hk*(kA/m)
NdFeB	N50M	1.42	1078	1137	1105
	N50H	1.35	1046	1359	1321
PrFeB	P42H#	1.31	1008	1419	1272
	P45M*	1.33	994	1114	1002

Note: 1 with # PrFeB is laboratory level.
2 with * PrFeB is least design indicators

Preliminary results

According to equation (1), using Labview prepared cryogenic remanence measurement program. May 1. 2013, CRMS for PM of SSRF CPMU has been commissioning. Firstly, cryogenic remanence of domestic NdFeB (N50M) has been tested. With cryogenic glue fixed Hall probe close to surface center point of PM along orientation direction, cryogenic remanence of PM will be scanned under the control of CRMS program, measurement temperature step:1.0K/min, temperature acquisition sequence is: 293K→10K and 265K→10K respectively, data results shown in figure 2 (c), and compare to Physical Properties Measurement System(PPMS) test results, shown in figure 2 (a) and (b):

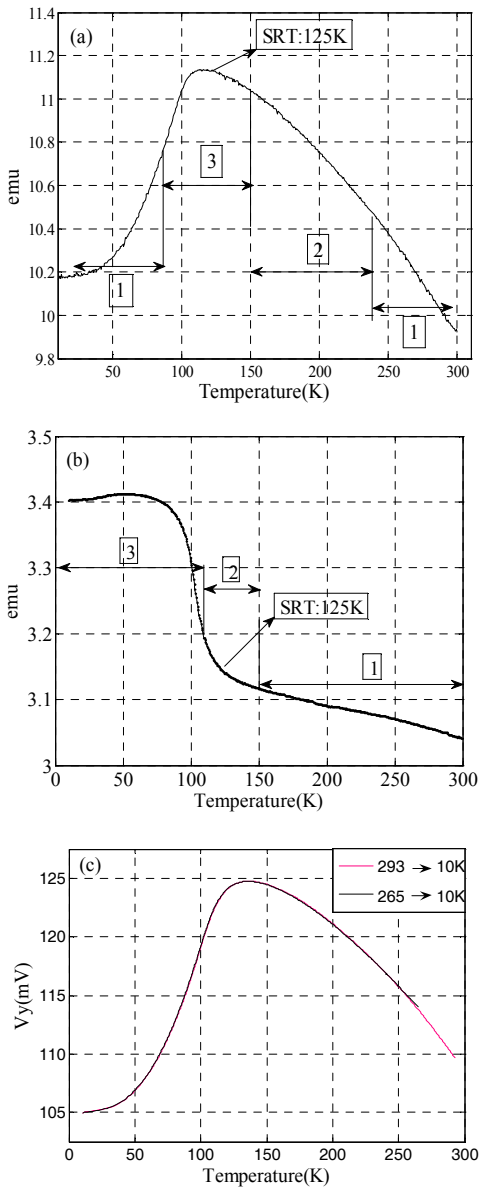

Figure 2: Cryogenic remanence of N50M test results:
(a) PPMS: magnet be magnetized and H of PPMS is 0 Gs, magnet size is 2.0mm×2. 0mm×2. 5mm(orientation is 2.5mm)
(b)PPMS: magnet not be magnetized and H of PPMS is 1000 Gs, magnet size is 2.0mm×2. 0mm×2. 5mm(orientation is 2.5mm)
(c) CRMS: magnet be magnetized and H of CRMS is 0 Gs, magnet size is 40.0mm×40. 0mm×10. 0mm(orientation is 10.0mm)
Note: ① emu: total magnetization means *Bdr* of PM
② Vy: Hall probe voltage means *Bdr* of PM

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If test method is same (293K→10K and 265K→10K), figure 2 (c) show that CRMS of SSRF has good repeatability: 0.096%. For Hall probe without cryogenic calibration, remanence-temperature curve feature of N50M is different to result of PPMS.

CONCLUSIONS

SSRF developed CRMS for bulk PM of CPMU. At present, SSRF have not analysis Hall probe cryogenic calibration data, figure 2 (c) data required being conversion to get cryogenic remanence exact change law of PM (N50M). Affect cryogenic remanence of PM repeatability factors is: vibration, temperature step, temperature control precision, affect cryogenic remanence of PM accuracy factors is: Hall probe positioning, cryogenic calibration reliability, temperature control reliability. SSRF will give CRMS reliability assessment, analysis error factors that affect measurement repeatability and accuracy, optimize measurement method. Next step, SSRF will also test cryogenic remanence of the other brands domestic PM and then make some research on cryogenic remanence and discrete variation of PM. These will lay the foundation for development of SSRF CPMU prototype.

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