THE RESEARCH ON MAGNETIC PROPERTIES OF MAGNET FOR SSRF CRYOGENIC PERMANENT MAGNET UNDULATOR

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Abstract

The temperature coefficient of Br and Hci of $Nd_2Fe_{14}B$ and $Pr_2Fe_{14}B$ magnet are about $-0.1K^{-1}$ and $-0.6K^{-1}$ respectively, the higher Br and Hci can be obtained at cryogenic. By this theory, cryogenic permanent magnet undulator (CPMU) may be designed, The Br and Hci of magnet increased 10-20% and 200-500% respectively, compared with conventional undulator, the higher brightness X-rays and the more resistance to radiation of undulators can be obtained. $Pr_2Fe_{14}B$ magnet has better potential magnetic properties than $Nd_2Fe_{14}B$ magnet at cryogenic for having no spin reorientation phenomenon. Permanent magnets are "heart" magnetic components for cryogenic permanent magnet undulator, since January 2012, the research plan on magnetic properties of domestic permanent magnet for SSRF cryogenic permanent magnet undulator at cryogenic by the support of Shanghai and Nation Nature science funds be started, the paper introduced research status of the item.

INTRODUCTION

We can get higher magnetic field by design In-vacuum undulator(IVU)[1],however, crucial limitation is magnetic properties of magnet. $Nd_2Fe_{14}B$ and Sm_2Co_{17} magnet are widely used at IVUs, remanence (Br) of Sm_2Co_{17} generally is less than 1.12T. $Nd_2Fe_{14}B$ with higher Hci can be adapted to higher temperature baking. $Nd_2Fe_{14}B$ cannot get higher Br and higher Hci at room temperature, Br of $Nd_2Fe_{14}B$ is generally not more than 1.3T to ensure that it has higher coercivity (Hci), which limits magnetic field performance of IVU. We can design cryogenic permanent magnet undulator (CPMU) for obtaining higher magnetic field[2], this undulator use $Nd_2Fe_{14}B$ or $Pr_2Fe_{14}B$ magnet as magnetic field source, its operating temperature range is 50-150K[3]. For $Nd_2Fe_{14}B$ and $Pr_2Fe_{14}B$, temperature coefficient of Br and Hci are about $-0.1K^{-1}$ and $-0.6K^{-1}$[4], which make they can get higher Br and higher Hci at cryogenic temperatures.

Kort given $Nd_2Fe_{14}B$ theory Br is 1.6T [5], by nearly 30 years improvement, Br at room temperature of $Nd_2Fe_{14}B$ has reached 1.5T, close to theory value 94.0%. But $Nd_2Fe_{14}B$ showing spin reorientation (SRT) between 130-150K[6], when temperature is further decreased, Br will also decline. $Pr_2Fe_{14}B$ has the same structure and magnetic properties as $Nd_2Fe_{14}B$ at room temperature basicly, it's theory Br reach 1.56T, Br of $Pr_2Fe_{14}B$ at cryogenic(up to 4.2K) has been increased linearly, has better potential magnetic properties than $Nd_2Fe_{14}B$ magnets, due to low market demand, development technology of $Pr_2Fe_{14}B$ is not mature. By improvement, $Pr_2Fe_{14}B$ may gradually reach current magnetic properties of $Nd_2Fe_{14}B$, $Pr_2Fe_{14}B$ will show excellent magnetic properties at cryogenic, such as between 20-30K, Br can reach 1.8T, Hci has substantial increase at cryogenic.The research on magnetic properties of $Nd_2Fe_{14}B$ and $Pr_2Fe_{14}B$ magnets at cryogenic(10-300K) and obtain basic data, this is very important for CPMU development.

Shanghai Synchrotron Radiation Facility(SSRF) was built in April, 2009, it has ability to accommodate more than 60 beamlines, it will installed 22-24 undulators in next 10-15 years, including number of CPMUs. For X-ray free-electron laser device which will be built in Shanghai, CPMU are also key equipments. In order to master key technology of SSRF CPMU, in January, 2012, by support of Shanghai and National Natural Science Foundation, SSRF start program about the research on magnetic properties of domestic $Nd_2Fe_{14}B$ or $Pr_2Fe_{14}B$ magnet at cryogenics (10-300K) , this article describes research progress of the two subjects currently.

DOMESTIC MAGNENTS

Domestic $Nd_2Fe_{14}B$ (N52 and N50M) experimental magnets for SSRF CPMU have been developed by Zhejiang Innuovo Magnetic Industry Co., Ltd of China, experimental magnets see Fig. 1, magnetic properties of magnets see Table 1.

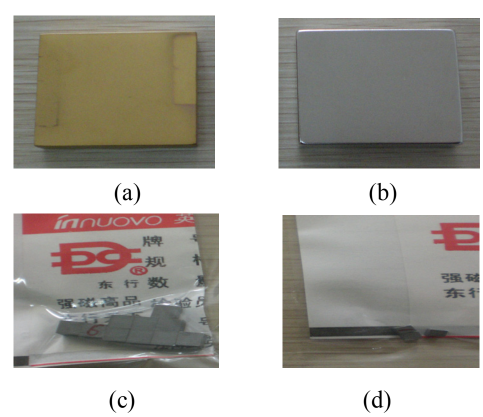

Figure 1: $Nd_2Fe_{14}B$ experimental magnets(N50M).

Table 1: Magnetic properties of $Nd_2Fe_{14}B$ (20℃)

Grade	Br(T)	Hcb(kOe)	Hci(kOe)	Hk(kOe)
N52	1.47	12.06	12.31	11.96
N50M	1.43	13.55	14.29	13.89

From Table 1, although Br of N50M is less than N52, but Hcb、μ_r=Br/Hcb、Hci, Hk are excellent to N52, these specifications are conducive to development of CPMU.

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For domestic $Pr_2Fe_{14}B$ experimental magnet, at present, Its ingredients and process design has been completed by SSRF, will be developed in September 2012 by Zhejiang Innuovo Magnetic Industry Co., Ltd of China.

MEASURING OF MAGNET

Cryogenic Calibration of Hall Probe

Before Br measuring of magnets for SSRF CPMU, standard electromagnet and NMR are use for cryogenic calibration of Hall probe, Cryogenic calibration device of Hall probe shown in Figure 2:

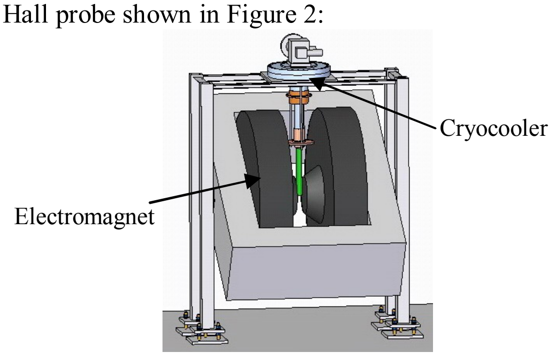


Figure 2: Cryogenic calibration device of Hall Probe.

Design of cryogenic calibration device for Hall probe has been completed by SSRF, it will being developed by Nanjing Cooltech Cryogenic Technology Co.,Ltd of China, System debugging of cryogenic calibration device of Hall probe is expected to be completed by June 2012.

Br Measuring at Cryogenic

Improving cryogenic calibration device of Hall probe, namely removing electromagnet, add fixture in two very cold head (Fig. 3), experiment magnet is placed in the fixture, calibration Hall probe is attached to center point of magnet surface with cryogenic glue (GE Vanish 7301), then the device can be used for Br measurement of experiment magnet at cryogenic. The size of magnet for Br measurement is 40mm×40mm×10mm (magnetization direction is 10mm), see Fig. 1(a).

June 2012, the experimental magnets for SSRF CPMU will be measured at cryogenic for Br by this device.

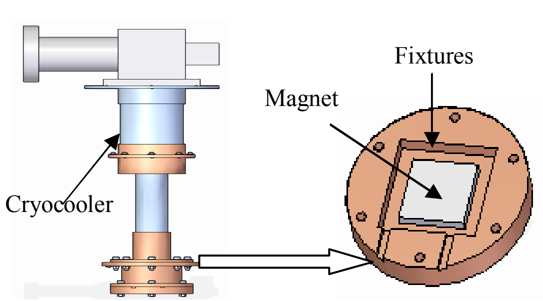
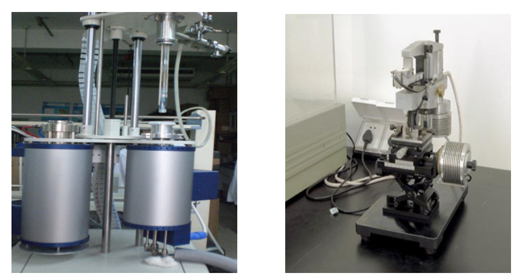


Figure 3: Br measurement device at cryogenic.

Contraction Coefficient Measuring at Cryogenic

Mechanical dimension of magnet at cryogenic has a certain change. Contraction along three directions of magnet is different, that is, parallel to easy axis direction of magnet: $\Delta lx/lx$(c//), perpendicular to easy axis direction and orientation direction of magnet: $\Delta ly/ly$ (c⊥), perpendicular to easy axis direction of magnet and parallel to orientation direction of magnet: $\Delta lz/lz$(c⊥). June 2012, SSRF will use materials thermal expansion measurement device measure contraction coefficient of magnets at cryogenic (10-300K).The device is developed by Technical Institute of Physics and Chemistry of CAS, see Figure 4(a). The size of magnets for contraction measuring is 4.0mm×4.0mm×4.0mm, see Fig. 1(c).

For coating binding of magnets at cryogenic, magnets with Ni and NiT coating respectively were soaked in liquid nitrogen (77K) for 6 hours, then coating binding of magnets were tested by national standard method, and compared to room temperature coating binding of magnets. The experiment will be held in August 2012 by scratch instrument (type WS-1505) of Ningbo Institute of Materials Technology and Engineering of CAS, see Figure 4(b). The size of magnet for coating binding testing is 40mm×40mm×10mm (no-magnetization), see Fig. 1.



(a) (b)

Figure 4: (a) Materials thermal expansion measuring. (b) Scratch instrument (WS-1505).

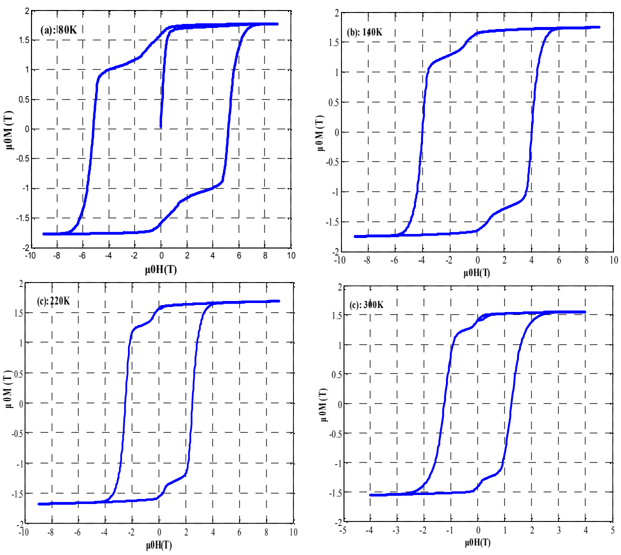
Magnetic Properties Measuring at Cryogenic

The M-H at cryogenic of experiment magnets will be measured by Physical Property Measurement System (PPMS ± 9T: EC-II) of Shanghai Jiaotong University, Supplier of this device is Quantum Design of USA. The size of magnet for M-H measurement at cryogenic is 2mm×2mm×2.5mm (magnetization direction is 2.5mm), see Fig. 1(d).

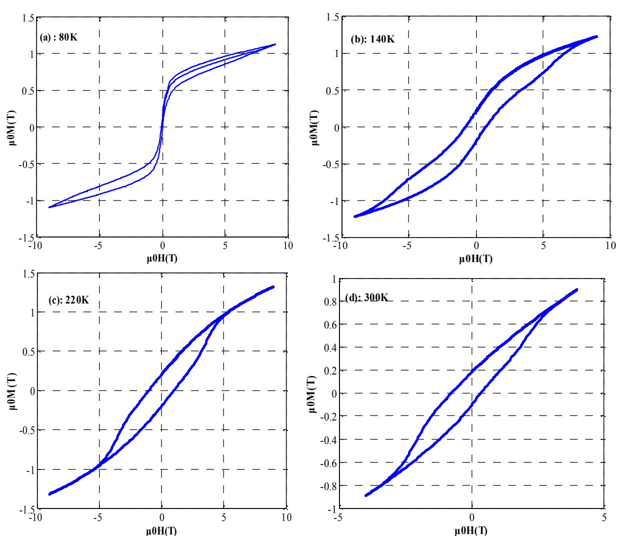
Magnetic field direction of PPMS perpendicular and parallel to easy axis of magnet; measuring temperature point are 300K, 220K, 150K, 130K, 80K.

Figs. 5(a) and (b) are M-H curve parallel and perpendicular to easy axis of N50M magnet, the nonlinear from 80K to150K of M-H curve may be related to SRT of magnet, yet nonlinear at 300K and 220K of M-H curve may be related to measurement methods or magnet or the other reason. By conversion of M-H measuring raw data, we get Br (T) and μ_0H (T) Figure of domestic $Nd_2Fe_{14}B$ magnet (N50M) (parallel to easy axis of magnet), see

Fig. 6(a) and (b). From Fig. 6 we can see, N50M magnet showing SRT phenomenon between 130-140K, it's Br reach 1.65T at 130-140K, it is nearly 16% higher than Br at room temperature (300K). The μ_0H of N50M magnet has linear increase with temperature drop, between 130-140K, it is nearly 220% higher than μ_0H of magnet at room temperature (300K).



(a) Parallel to easy axis.



(b) Perpendicular to easy axis.

Figure 5: M-H curve of N50M magnet at cryogenic.

CONCLUSION

This article only describes current research results and progress of domestic magnets for SSRF CPMU. In next two years, characteristic of domestic magnets ($Nd_2Fe_{14}B$ and $Pr_2Fe_{14}B$) at cryogenic, such as magnetic properties, thermal expansion effect, working point, magnetic circuit structure, stability and so on. By these research results, a 10-perion hybrid CPMU prototype with domestic magnets $Nd_2Fe_{14}B$ or $Pr_2Fe_{14}B$ will be developed in SSRF.

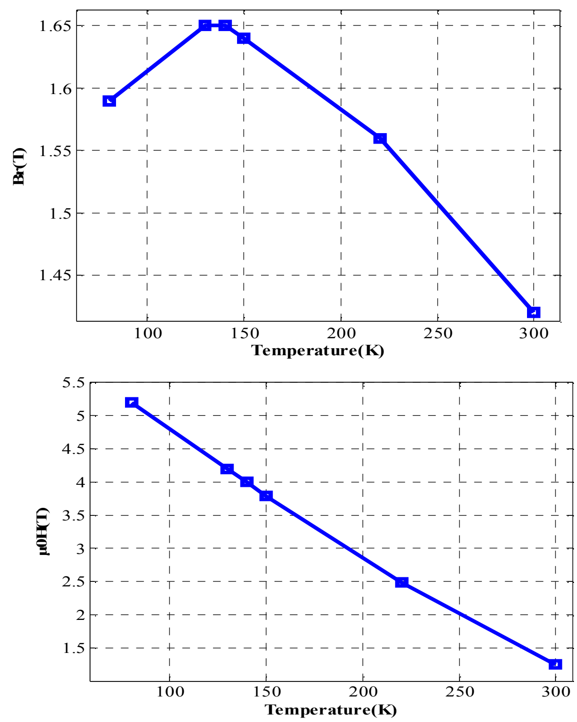


Figure 6: Br–T(up) and μ_0H–T(down) of N50M magnet.

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