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THE MAGNETIC FIELD MEASUREMENT SYSTEMS FOR A CRYOGENIC UNDULATOR AND A SUPERCONDUCTING UNDULATOR AT SSRF

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Abstract

Two cryogenic permanent magnet undulators (CPMU) have been developed and assembled into storage ring at Shanghai Synchrotron Radiation Facility (SSRF) in order to produce higher brilliance in the hard X rays domain. At low temperatures, permanent magnet materials can provide both higher magnetic field and higher resistance to radiation-induced demagnetization of the magnet compared to room temperature operation. Test results indicate that lowering the temperature of permanent magnets (Nd2Fe14B) increases the magnetic field strength about by 11%. The magnetic field distribution of the CPMU must be measured after the magnetic arrays are installed into the vacuum chamber and cooled to cryogenic temperature. We have finished a magnetic measurement bench based on a Hall probe to perform cryogenic temperature measurement. In this papers, the details of the magnetic field measurement system and some test results of a CPMU20 with 20mm period and Nd2Fe14B type are described. In addition, two superconducting planar undulator (SCU) prototypes with period 16mm are also under development at SSRF to research some key technologies

INTRODUCTION

So far, many facilities built CPMUs of various types. ESRF built two Nd2Fe14B CPMUs in 2008[1]. SOLEIL, UCLA and NSRRC built and tested Pr2Fe14B CPMU prototypes [2–4]. In order to meet the rapidly increasing user's demand, the SSRF Phase-II aims to substantially improve experimental research capabilities, particularly for energy science, environmental science, material science, life science, and so on. Three CPMUs will be used in Phase-II at SSRF. Two CPMU prototypes have been finished at SSRF in last three years [5]. The period lengths and the period numbers of two undulators are 20mm/80 and 18mm/144 respectively. Different types of permanent magnets Nd2Fe14B (N48H) and Pr2Fe14B (P46H) are used for the two undulators because of their higher remanences at cryogenic temperature and higher intrinsic coercivity (close to 1600kA/m) at room temperature [6]. The effective peak fields at the minimum gap of 6mm are 1.03T and 0.91T respectively. Magnetic field measurements at cryogenic temperature for the two CPMUs have been finished successfully.

MEASUREMENT BENCH FOR CPMU

A cryogenic temperature magnetic measurement bench has been developed at SSRF, as Fig. 1 shows. It is used to perform magnetic measurement at cryogenic temperature to check if any deviation on the magnetic field happens. The cryogenic temperature magnetic measurement bench is integrated inside the vacuum chamber with a 390 mm diameter and it will be removed after the measurements. A guide rail is set on the aluminum beam. Then, the aluminum beam is assembled into the vacuum chamber. It is supported by seven rods which are connected with outside mechanical supporter. A hall probe is fixed on the sliding block of the guide rail. Two wheels are used to drive the hall prove moving by a steel rope. The wheels are connected with two step motors by two magnetic fluid devices. In order to adjust the height of the hall probe at closed space, we assemble the hall probe on a special linear stage which can be remotely controlled and meet with vacuum requirement, shown in Fig. 1. The screw pitch of the stage is 0.5mm and its precision is 5 μm. The vacuum linear stage has plus and minus 5 mm adjustable range.

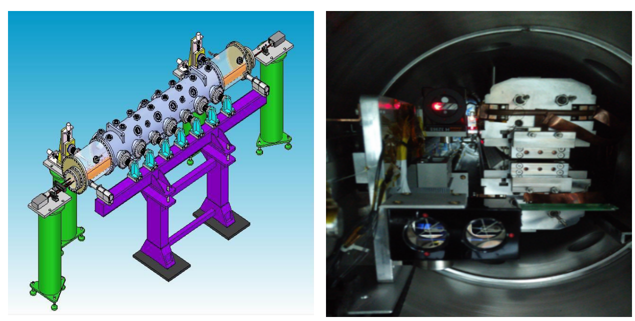

Figure 1: Diagram (left) and a photo (right) of the measurement system.

All components assembled into chamber have been cleaned to avoid contaminating the vacuum chamber.

Figure 2 shows the schematic layout of the system control and data acquisition (DAQ) architecture. Three keithley2701 model multimeters are used to take the voltages from the hall sensors. A four-axis controller, two drivers and two step motors constitute the motion system. Two XL80 laser systems from RENISHAW Company are used to get the deformation of the guide rail. A HS20 model laser ruler can measure the longitudinal position of the hall probe. The linear reflector, straightness beam splitter and the angle reflector are put inside the chamber. The TB10 box from RENISHAW Company is used to accept encoder signals from HS20 and to generate external triggers for data acquisition of keithely2701 multimeters. This probe uses three FW Bell GH-700 hall sensors with the addition of an on board RTD for temperature measurement and was calibrated

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against NMR probes in a standard magnet. The Hall probe is positioned only a few mm away from the surface of the magnets at cryogenic temperature, so its temperature decreases during a measurement. Each time we perform a measurement, the Hall probe temperature will be recorded when it enters and leaves the undulator gap. A linear correction is used on the measured Hall voltages.

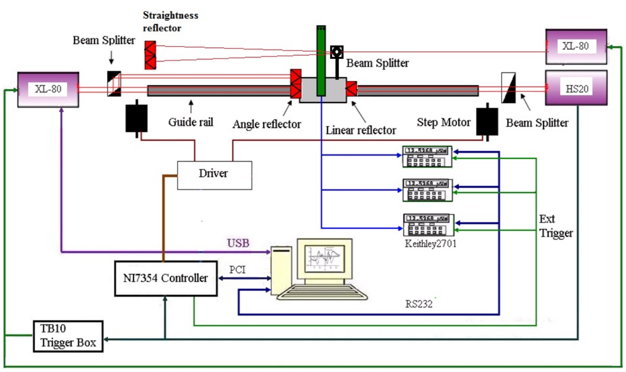

Figure 2: Schematic layout of motion control and DAQ.

The National Instruments LabVIEW software is used to program the human machine interface and control logic for the magnetic field measurement system. Its functions include motion control, data acquisition and data processing and analysis. The programming interface is also able to display warning and error message, record detailed real-time parameters of total system.

MEASUREMENT RESULT OF CPMU20

Firstly, the magnetic fields of CPMU20 were measured and shimmed at the room temperature with normal hall probe measurement system. Then, magnetic field measurements are retested after magnetic arrays and the cryogenic temperature hall probe bench are assembled into vacuum chamber and cooled down to cryogenic temperature. The measurement range is from 0 to 2400 mm at cryogenic temperature. The measurement step is 0.5 mm. At a maximum measuring speed of 30 mm/sec, forty samples every period are taken.

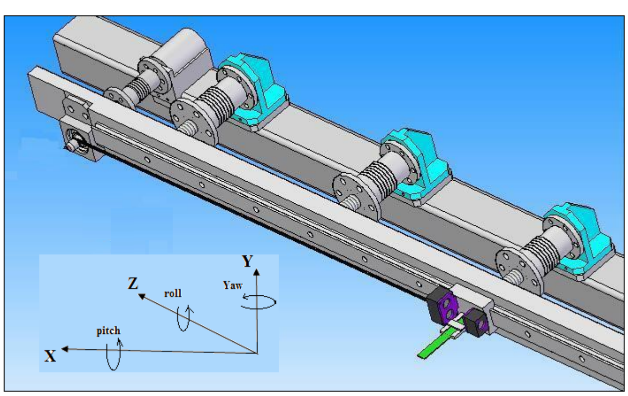

Figure 3: Yaw, pitch and roll of the guide rail.

Because of thermal expansion and contraction, the deformation of the guide rail for the cryogenic temperature measurement bench occurs. The yaw, pitch and roll characterize deformation of the guide rail, shown in Fig. 3. For planar undulator, the yaw is an issue because it results in longitudinal delay which will cause stronger magnetic field errors compare to pitch and roll. As Figs. 4 and 5 show, the vertical straightness and yaw of the guide rail show differences at room temperature and cryogenic temperature. Magnetic field measurement data indicates the vertical straightness results in more than 1.5° RMS phase error increase, and the yaw of the guide rail results in more than 1° RMS phase error increase before magnetic field data are calibrated

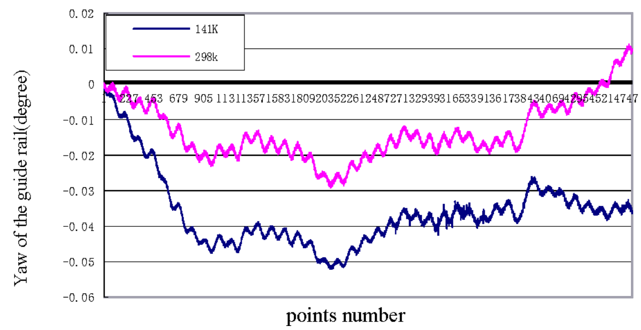

Figure 4: The yaw of guide rail at 141K and 298 K temperature.

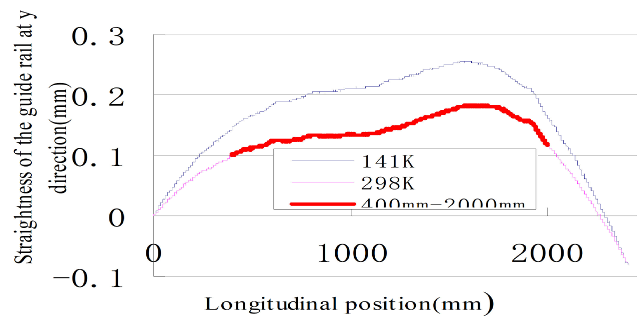

Figure 5: The straightness of guide rail at 141 K and 298 K temperature.

For getting the accurate magnetic field distribution of CPMU20, all measurement points should be calibrated to the centerline at y direction. For arriving to this target, magnetic measurements are done at three different heights. As Fig. 6 shows, three red points are used to do polynomial fitting to calculate the green point (the magnetic field strength at center height).

The reproducibility is a very important issue for a measurement system. The experimental results indicate RMS phase error reproducibility is less than 0.1 degree by four continuous measurements at 10mm gap, as Fig. 7 shows. It is enough to characterize an undulator.

The connection rods between inside girders and outside girders are adjustable again and again according to measurement results at cryogenic temperature until magnetic field performances meet with designed requirements as Table 1 lists. The magnetic field of the CPMU20 is measured at ten different temperature points. The maximum peak field occurs at 141k, and the RMS phase error is 4.38 degree at

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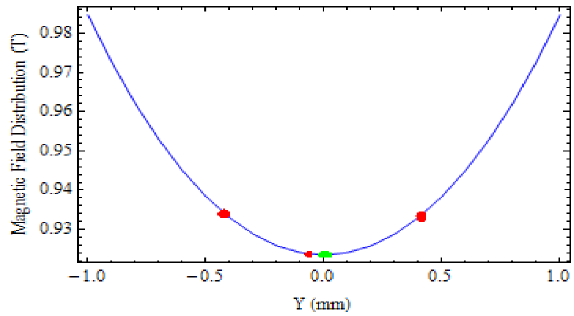

Figure 6: Find the centerline of y direction.

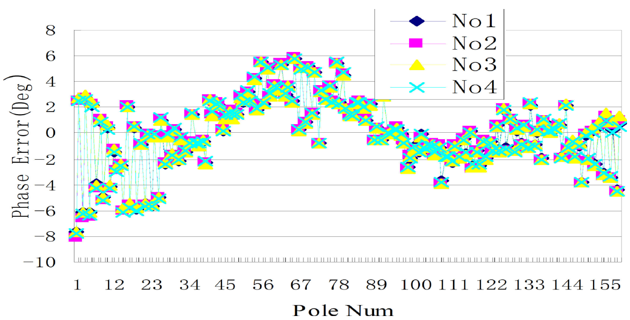

Figure 7: Four continuous measurements at 10 mm gap.

this temperature. The result basically arrives to the designed requirements. From Table 2, we can also see RMS phase error at 141k increases 1.5 degree compare to room temperature. The field errors are mainly resulted from deformation of inside girders and the deviation of the magnetic assembly arrays at cryogenic temperature. Table 2 summarises the magnetic field data of CPMU20.

Table 1: Design Specifications of CPMU20

Parameters	**Values**	
Period length (mm)	20	
Periodic quantity	80	
Operational Physics gap (mm)	6–15	
RMS Phase error	<6°@120–150 K	
Permanent magnet	Nd2Fe14B(N48H)	
Temperature (K)	300	140
Peak field (T)	—	1.07

MEASUREMENT SYSTEM AND RESULTS FOR A 5-PERIOD SCU

A 5-period superconducting undulator prototype with 16mm period length has been designed and fabricated at SSRF. A Cold test and magnetic field measurement were performed in a cryostat. Three Hall sensors are placed a brass board. The distance between sensors is 10mm. The model of hall sensors is HHP-VU from AREPOC Company, and they are calibrated at 4k temperature in standard magnet. A maximum current of 433.2 A was achieved. The peak field of 0.93 T was achieve at stable operating current of 400 A, as Fig. 8 shows. Test results indicate that superconducting

Table 2: Test data of CPMU20 at Different Temperature at 6 mm Gap

Temp (K)	**RMS Phase Error** (Deg)	**Peak Field** (T)	**Period Length** (mm)
301.5	2.93	0.964	20.004
258.2	3.34	0.997	19.979
226.8	3.58	1.024	19.965
176.1	3.75	1.052	19.945
166.0	3.97	1.057	19.942
151.2	4.43	1.060	19.937
146.2	4.40	1.062	19.935
141.0	4.38	1.063	19.934
136.7	4.54	1.063	19.932
130.9	4.49	1.062	19.931

magnet techniques in the SSRF are feasible for the 50-period undulator prototype.

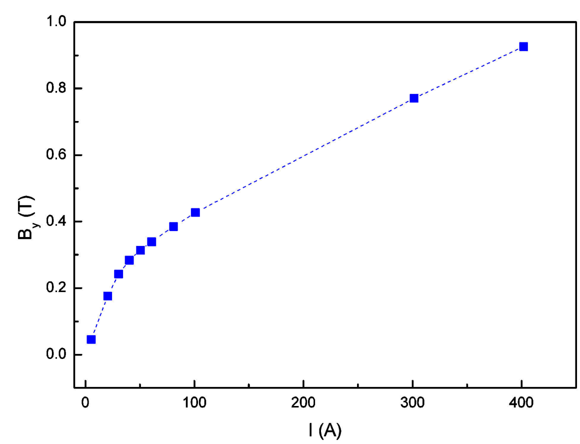

Figure 8: Peak field values versus excitation current.

CONCLUSION

Magnetic field measurements on two cryogenic undulator prototypes have been completed at SSRF. We developed a set of hall probe system to measure the performance of the magnetic field at cryogenic temperature. The hall probe system with 0.1 degree RMS phase error reproducibility indicates it is reliable to satisfy measurement requirements for the CPMU. The test results indicate that the RMS phase error of CPMU20 increases 1.5 degree compare to room temperature after cooling it down to 141K, but still meets with designed requirements. A 5-period SCU prototype has been built and tested successfully, and a 50-period SCU prototype has also been fabricated at SSRF. We plan to carry out a cold test to the 50-period SCU in three months to come.

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