IN-SITU UNDULATOR FIELD MEASUREMENT WITH THE SAFALI SYSTEM

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Abstract

A new scheme of undulator field measurement has been proposed, which makes it possible to do field mapping inside the vacuum chamber to verify the final magnetic performance of in-vacuum undulators (IVUs) after assembly. Optical laser beams are used in order to measure the positions of the Hall probe during actuation along the longitudinal direction, and dynamic feedback of the position is carried out to ensure a high stability and accuracy of the measurement. A field measurement system based on this concept has been developed at the SPring-8 in order to measure two different types of IVU. Principle of the new measurement scheme and details of the developed system are described together with the results of the field measurement.

INTRODUCTION

Shortening the undulator period is crucial to reducing the electron energy required to get angstrom x-rays in the SR and XFEL facilities and thus the total cost of construction. The in-vacuum undulators (IVUs) have many advantages over out-vacuum devices toward shorter magnetic period and thus have been adopted in a great number of SR facilities all over the world. It should be noted, however, that magnetic measurement after final assembly including the vacuum chamber, i.e., final verification of magnetic performance, is not an easy task. In addition, remeasurement after installation in the accelerator beamline is not trivial. The situation is more severe for cryogenic permanent magnet undulators (CPMUs)[1], an extension of IVUs.

We have recently developed a magnetic measurement system to measure the field inside the vacuum chamber. With optical laser beams introduced into the vacuum chamber, the alignment of the Hall probe positions is dynamically carried out, which ensures a high stability and accuracy of the measurement. This system is called SAFALI for Self-Aligned Field Analyzer with Laser Instrumentation. The SAFALI system has been applied to field measurement of two different undulators. One is an IVU installed in Swiss Light Source in 2001 and had been operated for about 3 years. The other is a CPMU prototype to demonstrate the principle of CPMU. The purpose of the former measurement is to investigate the radiation damage during operation, while that of the latter is to check the variation of the magnetic properties according to the temperature change of magnets. In this paper, details of the SAFALI system are given together with the results of the field measurements.

PRINCIPLE

In the conventional magnetic measurement system, a magnetic sensor such as a Hall probe is placed on a cantilever supported by a 2-axis (x,y) stage mounted on a long actuation table with a high mechanical accuracy, which is usually made of granite. Due to pitching, rolling and yawing of the actuation table, the Hall probe position during actuation can fluctuate. To perform a magnetic measurement with a high accuracy, the positional fluctuation should be kept as low as possible. The positional error of a typical measurement bench is around 30 μm, which corresponds to a field error of 0.02% for an undulator with a magnetic period of 10 mm, and thus enough for magnetic measurement of most undulators. In addition, the measurement result is quite well reproducible: typical deviation of the magnetic measurement in terms of the r.m.s. phase error is usually lower than 0.3 degree. It should be noted, however, that such a Hall-probe scanning method cannot be applied to the field measurement of IVUs as is. We have to modify the actuation method to be adapted to the field measurement of IVUs after assembly.

The most straightforward way is to install a huge vacuum chamber that can accommodate a rigid and robust linear guide with a mechanical accuracy comparable to that of the granite bench, which is not only impractical but also inefficient. Another way is to monitor the position of the Hall probe during actuation along the longitudinal axis and perform a dynamic feedback to ensure that the Hall probe is always in position. In this case, the linear guide does not have to be necessarily rigid or robust: any method of actuation is acceptable unless the positional variation during actuation is too large to be compensated by feedback.

We can consider several methods to measure the Hall probe position. Among them, we decided to use optical laser beams combined with position sensitive detector (PSD) and irises attached to the Hall probe, because they are cost effective compared to other methods. In order to measure the longitudinal position, we can use a commercially available laser scale with a resolution better than $0.1 mu$m. Hereinafter, let us call the field measurement method based on this concept "SAFALI", for Self-Aligned Field Analyzer with Laser Instrumentation. We have so far developed two SAFALI systems for measurement of two different IVUs, the details of which will be discussed in the following sections.

SAFALI FOR IVU24

In 2001, an IVU with a magnetic period of 24 mm and magnetic length of 1.5 m (IVU24) has been constructed at the SPring-8 and installed in the storage ring of Swiss

Light Source (SLS) as a collaboration to aim at utilization of angstrom x rays in the medium-sized SR facility. After 3-year operation, IVU24 has been replaced with another IVU and returned to SPring-8. It is important to measure the magnetic field of IVU24 and compare with the initial state, and to check the variation of magnetic performances from the point of view of demagnetization due to electron irradiation during operation.

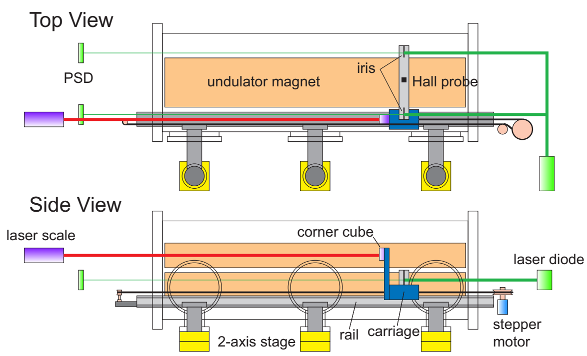

Figure 1: Schematic illustration of the SAFALI system for the CPMU prototype.

Figure 1 shows a schematic illustration of the SAFALI system for IVU24. We have installed a rail and carriage to actuate the Hall probe by means of a tensioned loop wire driven by a stepper motor. The Hall probe cantilever was attached to the carriage together with the cubic mirror to reflect the laser beam of the laser scale to measure the longitudinal position of the Hall probe. In addition, two irises are attached at the both ends of the Hall probe cantilever with a diameter of 2 mm. In order to measure the transverse Hall probe position during actuation, two laser beams were introduced to irradiate the irises and create laser spots at the opposite side. The positions of the laser spot were measured with position sensitive detectors (PSDs), the average of which defines the position of the Hall probe.

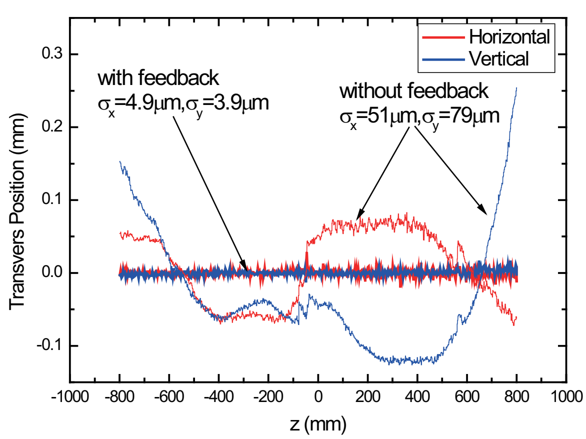

Figure 2: Variation of the Hall probe position with and without feedback.

The feedback of the Hall probe position is done by moving the rail with the three sets of 2-axis stages supporting the rail. Figure 2 shows the variation of the Hall probe position measured with and without the feedback procedure. We can clearly find the effects due to the feedback. The magnetic error due to the positional deviation of 5 μ is just 5×10^{-6} for an undulator with a magnetic period of 10 mm, and smaller for a longer period.

As a field measurement system for undulators, the reproducibility is the most important. We measured the magnetic field distribution of IVU24 four times under the same condition to examine the reproducibility. The results are shown in Fig. 3 in terms of the phase error as a function of the pole number, where we find quite a good agreement between the measurement results.

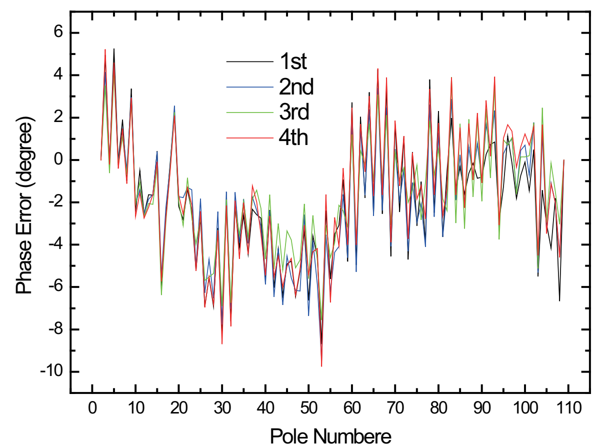

Figure 3: Reproducibility of the field measurement in terms of the phase error distribution.

As described above, the developed SAFALI system has been found to have a performance good and reliable enough to measure the magnetic field of IVU24.

SAFALI FOR CPMU PROTOTYPE

The CPMU is a novel undulator proposed at SPring-8 in 2004 [1]. The permanent magnets in the IVU is cooled down to improve the magnetic property in terms of the remanence and coercivity. The operation temperature will be around 100$\sim$150K where the remanence becomes maximum, and much higher than liquid helium, so the operation will be much more feasible than superconducting undulators composed of NbTi wires. We have constructed a prototype of CPMU with a magnetic length of 600 mm and a magnetic period of 15 mm and made experiments to investigate the feasibility of CPMUs such as the cooling capability, variation of the magnetic gap and tapering during the cooling process [2]. Although promising results have been obtained in these experiments, we have to establish a field measurement technique to be adapted to the CPMUs. So, we have developed a system based on the SAFALI method to measure accurately the magnetic performance at a cryogenic temperature [3].

Figure 4 shows a schematic illustration of the SAFALI system for the CPMU prototype. A pair of O-ring recipro-

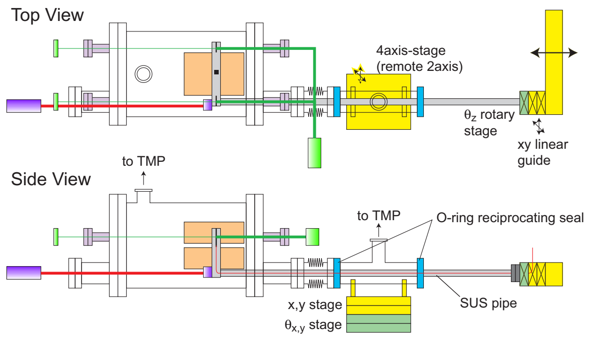

Figure 4: Schematic illustration of the SAFALI system for the CPMU prototype.

cating seals have been installed to insert the SUS tube to fix the cantilever of the Hall probe, which is actuated by means of pushing or pulling the end of the tube. The Hall probe position feedback is performed by the multi-axis stage supporting the vacuum duct including the O-ring seal. The variation of the Hall probe position during actuation was slightly worse than the system for IVU24 described in the preceding section, however, the reproducibility was similar. For details, refer to [3].

RESULTS OF MEASUREMENT

IVU24

We measured the magnetic distribution at the gap values of 6, 8, 10, 14, and 20 mm and compared the magnetic performances with those measured by a conventional method in July 2000, just after the field correction and before installation in the SLS ring. The results are shown in Fig. 5 in terms of the electron trajectory (2nd field integral) and phase error distribution.

We find negligible difference between the two measurements in terms of the electron trajectory, while a small discrepancy in the phase error distribution suggests that the magnetic field distribution has changed slightly. It should be emphasized, however, that the variation is very small and less than 0.5 degree in r.m.s. So we can conclude that no significant demagnetization took place in the IVU24 during operation.

CPMU Prototype

We measured the field distribution of CPMU prototype at different temperatures and found that the peak field became maximum at a temperature of 130 K. During the measurement, the gap was fixed at 5 mm by measuring directly the distance between the top and bottom magnet arrays by means of a laser scan micrometer. From the point of view of field correction, what is important is the phase error variation due to temperature change. Figure 6 shows the magnetic performances measured at room temperature and 130 K in terms of the electron trajectory and phase error. We find negligible difference between the performances at two

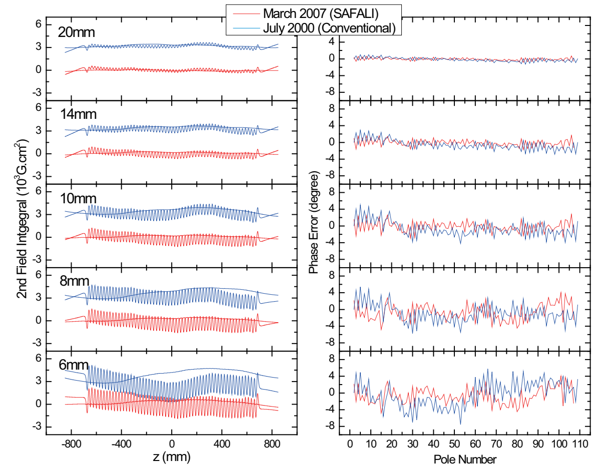

Figure 5: Comparison of magnetic performances of IVU24 between July 2000 and March 2007. Note that measurement in July 2000 was done by a conventional method.

different temperatures, suggesting that cooling the permanent magnets did not induce a large change in the error magnetic components that could affect the undulator performance. This is a very encouraging result toward realization of CPMUs.

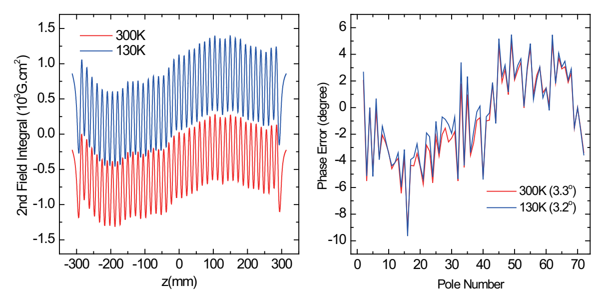

Figure 6: Variation of magnetic performances of CPMU prototype at room temperature and 130 K.

SUMMARY

We have described the SAFALI system as a new scheme of undulator field characterization and its practical application. It should be also stressed that the SAFALI system is portable: the magnetic performance of IVUs can be checked at any time without moving to the laboratory or facility for the field measurement. Such a portability is very important especially in X-ray FEL facilities where a number of undulators will be installed. The SAFALI system can be used not only for the final check after assembly but also to monitor the magnetic performance as the FEL driver. We also note that most undulators nowadays have a C-shaped frame, but not a O-shaped frame, in order to ensure openings for field mapping with Hall probe scanning, whether they are in-vacuum or out-vacuum. This imposes a severe restriction on the undulator design, because C-shape frame is much less rigid than the O-shape frame. By means of the SAFALI method, the mechanical frame does not have to be C shape from the point of view of field measurement and new undulator designs would be be possible.

REFERENCES

[1] T. Hara, T. Tanaka, H. Kitamura, T. Bizen, T. Seike, T. Kohda, and Y. Matsuura, Phys. Rev. ST-AB 7, 050702 (2004).

[2] T. Tanaka, T. Hara, T. Bizen, T. Seike, R. Tsuru, X. Marechal, H. Hirano, M. Morita, H. Teshima, S. Nariki, N. Sakai, I. Hirabayashi, M. Murakami and H. Kitamura, New J. Phys. 8 287 (2006).

[3] T. Tanaka, R. Tsuru, T. Nakajima and H. Kitamura, J. Synchrotron Rad., 14 416 (2007).