New Apparatus, Upgrades & Methodology

In situ field measurement and correction for in-vacuum undulators

Shortening the magnetic period has been one of the most important targets in the development of insertion devices, in particular, undulators. It significantly enhances the brilliance in the hard X-ray region not only by increasing the number of periods but also hardening the spectral range. This is the reason why the in-vacuum undulator (IVU), in which the magnet arrays are installed inside the vacuum chamber and thus the gap can be much narrower than the conventional undulators, has been widely used in many synchrotron radiation facilities. Although the technologies for IVUs have become mature enough, there is still one concern on how to guarantee the magnetic performance, in other words, how to check the magnetic field error before installation and how to correct it if necessary. In this paper, we present the new technologies for answering these questions, which have been recently developed in SPring-8.

In situ Magnetic Measurement and Correction. Because the permanent magnets have some magnetic errors, the undulator field distribution cannot be completely sinusoidal, resulting in the degradation of the available flux. It is therefore important to measure the field distribution to check the undulator performance. If it does not satisfy the required specification, the field errors should be corrected. To measure the field distribution, the Hall-effect sensor is moved along the undulator axis using a rigid and accurate linear guide usually mounted on massive granite. This method, however, cannot be applied directly to IVUs because the magnetic arrays are installed inside the vacuum chamber. Therefore, the field measurement and the following field correction are always carried out without the vacuum chamber. After that, the magnetic arrays should be disassembled once from the mechanical frame to install the vacuum chamber, and then assembled again. If the mechanical reproducibility of the magnet arrays is poor, the field distribution may be varied during the assembling process and the undulator quality is not guaranteed. Thanks to the careful management of the assembling process, no serious problems have been reported so far in SPring-8. It should be noted, however, that the requirement of mechanical reproducibility would be more stringent for shorter-period IVUs. Thus, new technologies toward shortening the undulator period are required, which make it possible to measure the field distribution generated by the magnet array installed inside the vacuum chamber, and to correct its field error if necessary. Hereinafter, they are referred to as the *in situ* field measurement and correction techniques.

New Field Measurement System SAFALI. In order to realize the *in situ* field measurement, the most straightforward way is to install a simple and compact linear guide inside the vacuum chamber and move the Hall sensor along the undulator axis. It should be noted, however, that the straightness of the linear guide, which is so small as to be able to be inserted into the chamber, could not be sufficient good. The long linear guide can be bent owing to the weight itself or other load, which should be compensated dynamically. We have recently developed a new field measurement system that enables the *in situ* field measurement, which is schematically shown in Fig. 1.

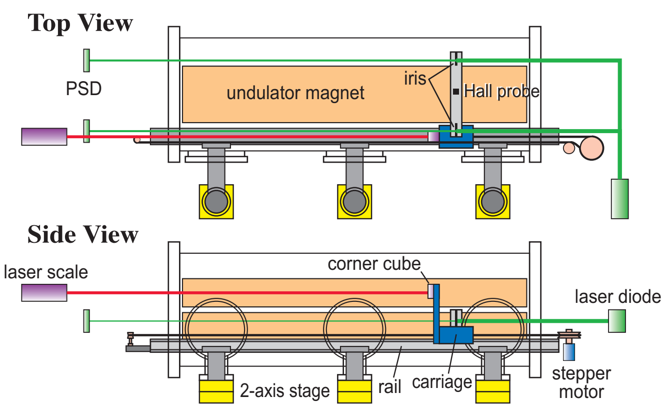

Fig. 1. SAFALI system for the *in situ* field measurement of IVUs.

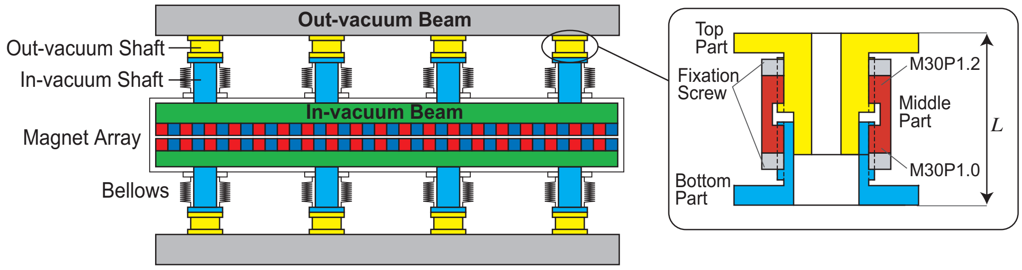

Fig. 2. Schematic illustrations of the IVU structure and differential adjuster as the out-vacuum shaft with the adjustable length.

Two laser beams are introduced to the vacuum chamber to illuminate the pinholes attached to the Hall sensor. The transverse positional variation of the Hall sensor is detected by monitoring the positions of the laser spots created by intercepting the laser beams, by means of position sensitive detectors (PSDs). The linear guide to move the Hall sensor is supported by 2-axis linear stages, with which the positional error of the Hall sensor can be corrected dynamically, once they are detected using the above scheme. This system is called "SAFALI" for Self-Aligned Field Analyzer with Laser Instrumentation.

Differential Adjuster for In situ Correction. Let us consider the possible error sources during the assembling process of IVUs using Fig. 2, which schematically shows the IVU structure. At the time of field measurement, all the components except the vacuum chamber are installed. Then, all the components excluding the out-vacuum beams and shafts are detached in order to install the vacuum chamber. If the positional reproducibility of the in-vacuum shaft is not perfect, then localized gap errors arise, resulting in the significant degradation of the undulator quality. This in turn indicates that if the length of the out-vacuum shaft is adjustable, then the gap variation can be compensated, i.e., the *in situ* field correction is possible. For this purpose, a new out-vacuum shaft has been developed as shown in Fig. 2, the length of which can be adjusted using the mechanism based on the differential screw. Thanks to the difference in the pitch of the threads in both ends, the length of the shaft can be adjusted with the resolution of 0.2 mm per revolution. We have found that the typical sensitivity of the gap error correction is better than 5 μm.

As an example, using the technologies described above, we have tested the *in situ* field measurement and correction using an IVU with the length of 1.4 m and period of 14 mm. The results are shown in Fig. 3 in terms of the phase errors as functions of the magnet pole number calculated with the field distribution data measured with the SAFALI system. Three results are indicated: before and after assembling the chamber, and after the *in situ* field correction using the differential adjusters. It is found that the phase error has increased from 2.9° to 6.1° owing to the assembling process, and reduced to 3.0° by the *in situ* correction, almost comparable to the original value.

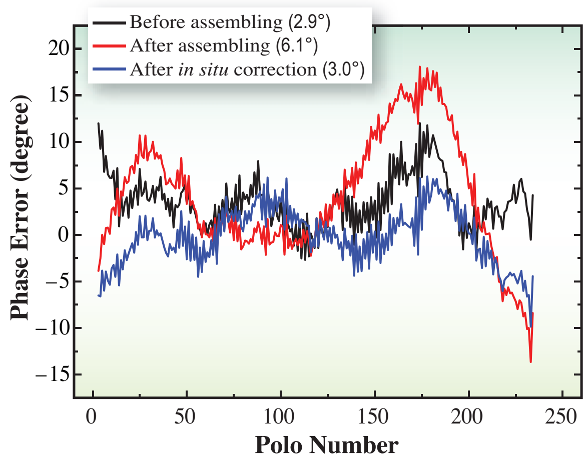

Fig. 3. Results of the *in situ* field measurement and correction for the IVU with the length of 1.4 m and period of 14 mm. The numbers in the brackets indicate the r.m.s. phase errors.

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