DEVELOPMENT OF COMPACT MAGNETIC FIELD MEASUREMENT SYSTEM AVAILABLE FOR IN-VACUUM UNDULATORS

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Abstract

A low-emittance 3-GeV "KEK-LS" [1,2] ring has been designed at KEK. KEK-LS's undulators can produce extremely high brightness light ranging from VUV to X-ray. Brightness of undulator light strongly depends on the phase error of its periodic magnetic field [3]. Then a precise magnetic field adjustment is required in order to prevent the reduction of the light source performance.

Generally, the adjustment is performed by the conventional field measurement system equipped with hole-probes on a huge stone table. But, for the in-vacuum undulator, the measurement must be performed without the vacuum chamber. Then the additional phase error caused by reattaching the chamber is not negligible for the low emittance rings. Therefore, some groups have developed measurement systems available for the direct field measurement inside the chamber [4,5]. We have started R&D on such compact measurement system. Our system is compacted and stabilized by utilizing the rigid metal beam of the undulator frame instead of the stone table. In this paper, we report the present status of the measurement system development.

INTRODUCTION

Today's electron synchrotron rings generate high brightness light using undulators and deliver the light to the users. The high brightness light is utilized as the excellent probes investigating the novel functions of new materials [6].

The brightness $\mathfrak{B}$ is given by [7]:

$$\mathfrak{B} = \frac{\mathfrak{D}}{2\pi\Sigma_x\Sigma_y} = \frac{\mathfrak{F}}{4\pi^2\Sigma_x\Sigma_y\Sigma_{x'}\Sigma_{y'}}, \quad (1)$$

where $\mathfrak{F}$ is flux. The beam spatial sizes $\Sigma_{x,y}$ and angular sizes $\Sigma_{x',y'}$ are given by:

$$\Sigma_{x,y} = \sqrt{\sigma_{x,y}^2 + \sigma_r^2},$$

$$\Sigma_{x',y'} = \sqrt{\sigma_{x',y'}^2 + \sigma_{r'}^2},$$

$$\sigma_{x,y} = \sqrt{\beta_{x,y}\varepsilon_{x,y} + \left(\eta_{x,y}\frac{\sigma_E}{E}\right)^2},$$

$$\sigma_{x',y'} = \sqrt{\left(1+\alpha_{x,y}^2\right)\varepsilon_{x,y}/\beta_{x,y} + \left(\eta'_{x,y}\frac{\sigma_E}{E}\right)^2}, \quad (2)$$

where $\alpha_{x,y}$ and $\beta_{x,y}$ are twiss parameters, $\eta_{x,y}$ are energy dispersion functions, $\eta'_{x,y}$ are derivatives of $\eta_{x,y}$ and σ_E/E is a energy spread of the ring, respectively. Then, the brightness strongly depends on the beam emittances $\varepsilon_{x,y}$. Therefore, the rings are designed aiming at the lower emittance.

At KEK, Photon Factory has started since 1982 as the first joint-use light source facility in Japan. Photon Factory operates 2.5-GeV PF ring with emittance of 35 nm rad and current of 450 mA, and 6.5-GeV PF-AR with 283 nm rad and 60 mA. Now the next light source "KEK-LS" project is on going at KEK. The first version of KEK-LS have been designed with 20-cell Hybrid Multi-Bend Achromatic lattice with the electron energy of 3 GeV and the natural emittance of 132.5 pm rad [1,2]. The number of straight sections available for insertion devices (IDs) are eighteen with 5.6 m long and twenty with 1.2 m. In addition, there are 20 bending magnets that can extract the synchrotron light. Such large number of light sources will take over the PF and PF-AR users and their science activities.

Then, we start several R&D on undulator development for realizing high brightness light not to lose low emittance feature of KEK-LS. The emittance, expected at a design beam current of 500 mA, is increased to 314.7 pm rad in horizontal and 8 pm rad in vertical by IBS effect [1,2]. This increment causes a degradation of brightness. So we are discussing about the suppression of the degradation by introducing a harmonic cavity [1,2]. As will later be shown, such brightness degradation is also caused by the phase error in undulator magnet array tuning. Especially, the degradation becomes a problem for in-vacuum undulator [8] because the number of the magnet is quite large for KEK-LS. Then, the R&D on a magnetic measurement system with hall probe sensors is in progress.

CONVENTIONAL TUNING

We have developed and used the conventional hall probe system [9] as shown in Fig. 1 for undulators operated at the PF ring and PF-AR.

The conventional system is equipped with hole-probes holder stage on a huge stone table, therefore it cannot access inside of the vacuum chamber and cannot measure the field inside it. Then, we must measure the field and tune magnet arrays without the ID chamber. It causes a problem to the in-vacuum undulator tuning. Because the magnet arrays are attached inside the chamber, the arrays must be removed once after finishing the tuning. And, after that, chamber is reinstalled and the arrays are reattached inside the chamber again.

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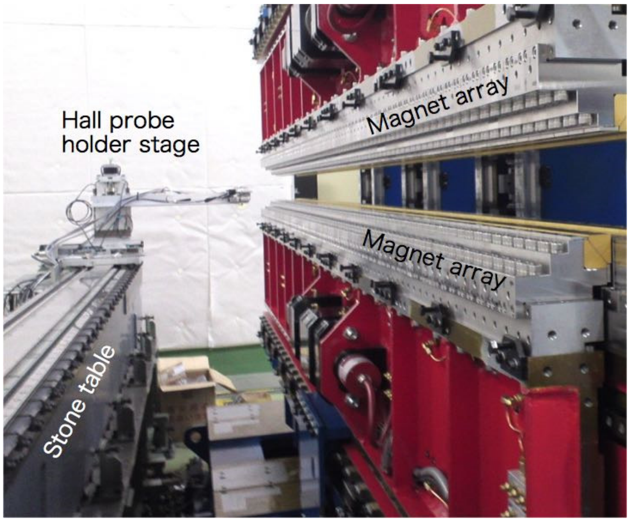

Figure 1: Conventional hall probe system.

Some groups have developed the in-situ measurement system [4,5] and points out reattachment of arrays causes the additional increment of phase error by reattachment of the arrays [10]. This is a motivation to develop the new measurement system that can measure the additional phase error with ID chamber.

KEK-LS IN-VACUUM UNDULATORS

One of the base-line high-brightness light sources for KEK-LS is the in-vacuum undulator with period length of 20 mm and period number of 250 [1,2]. Such long arrays require high stability for the measurement system.

It should be noted that such long arrays takes quite longer time to achieve small phase error, because, in general tuning method, magnet blocks of arrays are exchanged by hand. We have already developed numerical determination method of an excellent initial arrangement of undulator magnet arrays and have constructed some in-air type undulators by using this method [9]. The numerical method drastically shortens the tuning time.

The reduction factor of brightness towards zero phase error is given by [3]

$$R = \exp\left(-n^2 \sigma_\varphi^2\right), \tag{3}$$

where n is a harmonic number of undulator light and σ_φ is rms phase error between magnet array field and photon.

Figure 2 shows some curves with various R in n and σ_φ plane. It clearly shows that the reduction factor is drastically enhanced in higher harmonics number and larger phase error. If the tuning with phase error of 3 degree is achieved, the reduction is suppressed under 10% at 5^{th} harmonics and 20% at 9^{th} harmonics.

And, this brightness degradation is suppressed only by the decrement of phase error at a tuning.

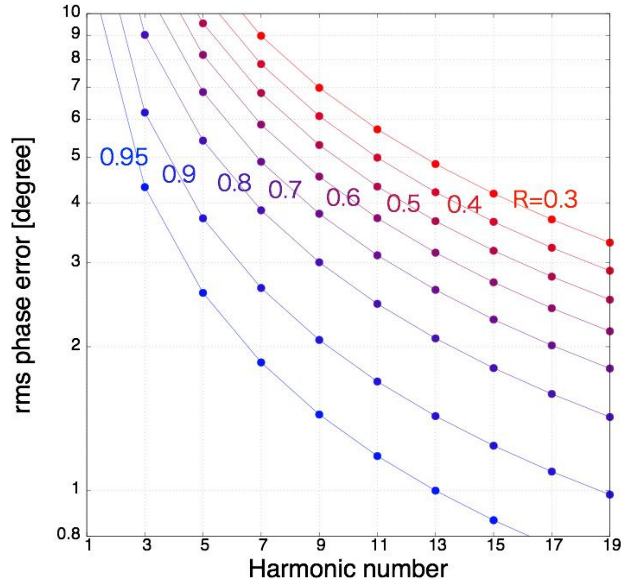

Figure 2: Reduction factor contour lines in the plane of harmonic number and rms phase error.

NEW MEASUREMENT SYSTEM

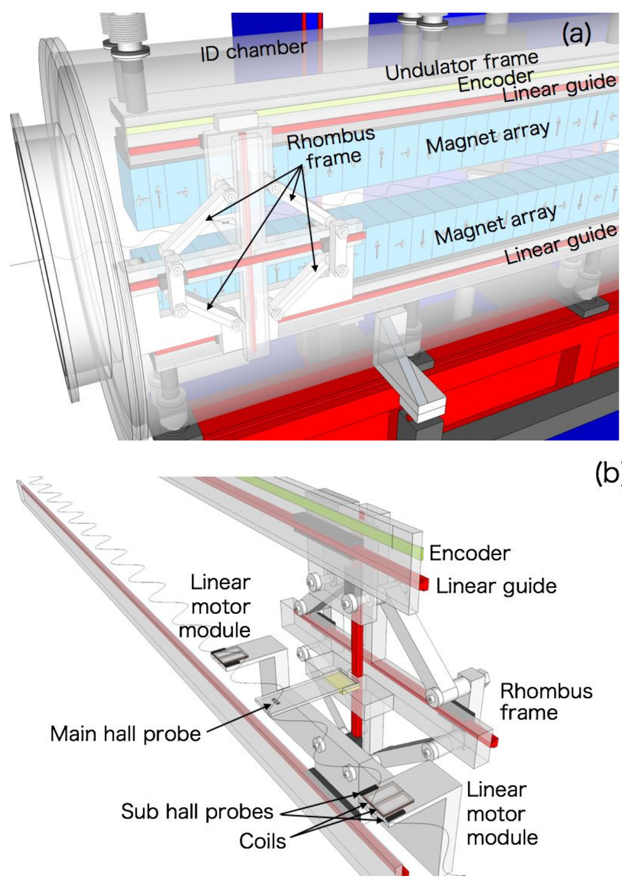

Figure 3: Schematics of developing measurement system: (a) an overview (perspective drawing) and (b) a detail.

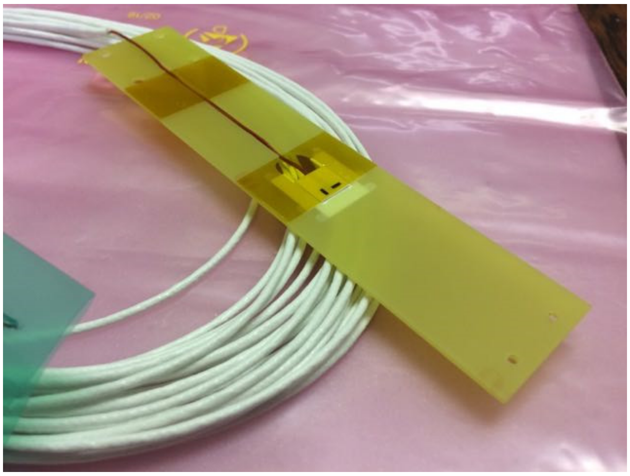

Figure 4: SENIS thin Hall Probe.

Figures 3 (a) and (b) show schematics of our developing system. New measurement system consists of two linear guides fixed on the undulator frame, a main hall probe attached on the rhombus-shape frame, and two linear motor modules as driving force. There are some characteristics:

- Two linear guides are directly fixed on the undulator frames in order to obtain high stability in long distance.
- The high rigidity rhombus-shape moving unit mechanically fixes the main hall probe position to a center between the magnet arrays when the gap changes.
- Separated two linear motors move the main hall probe from one end to another of the array.
- The linear motor module consists of two coils, two sub hole probes, which switches the coil current directions, and undulator magnets. There is no additional magnet array for driving the module.

Minimum gaps are expected to be 4 mm for both straight sections. For the main probe, we have got a three-axis thin hall probe S attached on a holder PHS-H (probe and holder are from the company SENIS) as shown in Fig. 4. Total thickness is around 1.5 mm, which is sufficiently thin comparing with the gap of the KEK-LS undulators.

PRESENT STATUS

We have test-manufactured a measurement system attached on a test-bench mini-undulator as shown in Fig. 5. The mini-undulator is in-air type with two magnet arrays and can change the gap. This mini-undulator makes it easy to see the whole system and find out improvements. As a test, we attached one trial linear-motor module on the rhombus-shape frame unit as shown in the inset of the Fig. 5, and have succeeded to move the unit by using undulator magnet arrays. Now we are trying to measure the parallelism and the flatness on the measurement

FUTURE PLAN

Next, we plan to attach the main hall probe on the unit and try actually measuring the magnetic field with the linear motor drive.

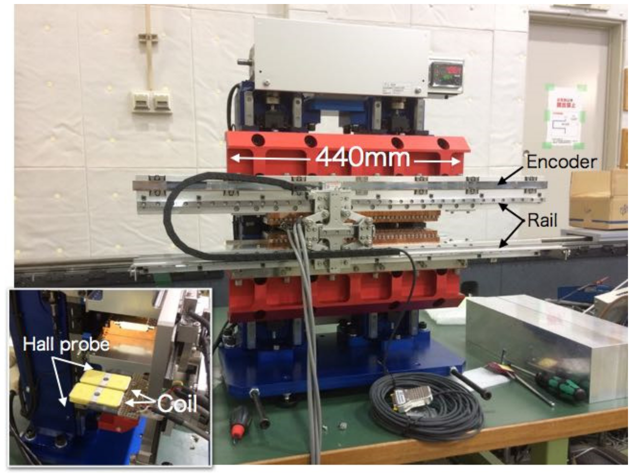

Figure 5: Test machine.

Present measurement system is designed available for both in-air and in-vacuum undulators. This measurement system enables us to tune magnet arrays in air but with the ID chamber. Then the measurement system consists of in-air type parts. In the future, we plan to modify the measurement system to in-vacuum type, then the modified system enables us to measure the field of the cryogenic permanent magnet undulator [11].

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