ISBN: 978-3-95450-132-8 doi:10.18429/JACoW-IPAC2014-WEOAA02

DEVELOPMENT OF THE VERY SHORT PERIOD UNDULATORS*

Shigeru Yamamoto,
Photon Factory, KEK, Tsukuba, Ibaraki 305-0801, Japan
and
Department of Materials Structure Science, The Graduate University for Advanced Studies,
Tsukuba, Ibaraki 305-0801, Japan

Abstract

We are exploring a novel method to fabricate undulator magnets having a very short period. We have succeeded in producing a 100-mm long magnet plate with 4-mm period length, which gives an undulator field of approximately 4.1kG at a gap of 1.6mm. A spectrum calculation shows that the quality of the radiation emitted from this magnetic field is satisfactory for the fundamental radiation as compared to the ideal field.

INTRODUCTION

In order to obtain higher energy photons with lower harmonics of undulator radiation, we usually utilize in-vacuum undulators with period lengths of several cm installed in electron storage rings with 6-8GeV energies [1, 2]. Construction of newer sources has recently been planned and partly realized in compact 3rd generation light sources with in-vacuum undulators of period lengths around 2cm [3]. This was preceded by the construction of three in-vacuum-type Short Gap Undulators (SGU) at the Photon Factory (PF), High Energy Accelerator Research Organization, KEK. It proved that these SGUs were very useful as hard x-ray sources in the 2.5-GeV storage ring [4, 5].

Along this line, we have been seeking a new method to construct very short period undulators having period lengths one order-of-magnitude shorter than the ordinary period of several cm. We are developing a plate-type undulator magnet some 100mm long in the longitudinal direction by setting 4mm as a current target value of the period length. The 4-mm period length allows us to obtain 12-keV radiation with the first harmonic of this undulator in the 2.5-GeV storage ring, whereas the higher harmonics need to be used in case of the PF's SGUs as shown in Table 1.

A multi-pole magnetizing method was applied to magnetizing this plate: a periodic undulator field (of 4-mm period in this case) was generated by pulsed electro-magnets, and was transcribed into the plate. The magnetization procedure allows the undulator field to be obtained in a very short gap between the pair of opposing plates. Thus, these undulators operate in a gap one order-of-magnitude shorter than that of ordinary undulators, and are very useful when they are combined with very low emittance storage rings and linacs.

In this paper we describe the magnetization method to obtain a very short period and report current achievements with the test results.

*Work partially supported by JSPS KAKENHI Grant Number 24651107.

Table 1: Short Gap Undulators in the Photon Factory, KEK. The 4th column indicates the harmonic to be used to obtain the 12-keV photons.

Name	λ_u	N	12-keV photons	K_{max}
SGU#17	16mm	29	5th	1.374
SGU#03	18mm	26	5th	1.684
SGU#01	12mm	39	3rd	0.781

FABLICATION OF VERY SHORT-PERIOD UNDULAOTR MAGNETS AND FORMATION OF AN UNDULATOR FIELD

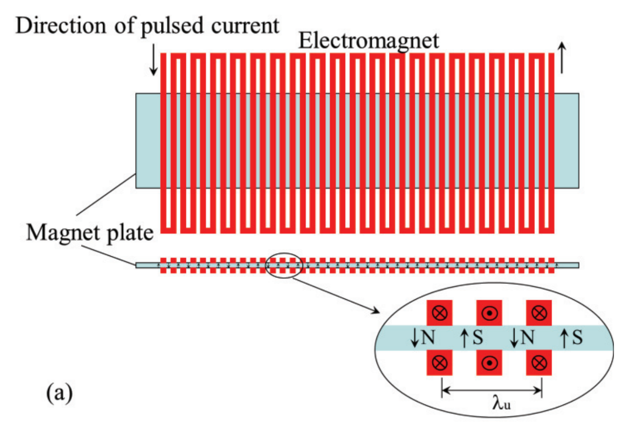

Figure 1a: Schematic of magnetization of the magnet plate in perpendicular geometry.

In the construction of the ordinary undulators, we adopt a method in which accurately shaped magnet blocks (usually mounted on the non-magnetic holders) are aligned longitudinally on a pair of rigid girders. When we try to shorten the period length, λ_u of the undulator in this method, we need to reduce the size of the magnet blocks while keeping an accuracy (*i.e.* a ratio of the error in block size and λ_u, in this case). However, when of λ_u is less than 10mm it is rather difficult to fabricate the accurate magnet blocks to maintain the above accuracy. Further the components for installation of these blocks such as screws, are too small to use.

On the contrary to the ordinary method, we try to develop a completely new one to fabricate very short period undulator magnets. Here a multi-pole magnetizing

Content from this work may be used under the terms of the CC BY 3.0 licence (© 2014). Any distribution of this work must maintain attribution to the author(s), title of the work, publisher, and DOI.

ISBN: 978-3-95450-132-8 doi:10.18429/JACoW-IPAC2014-WEOAA02

method is applied to magnetize thin plate of the magnets. This is shown schematically in Figure 1.

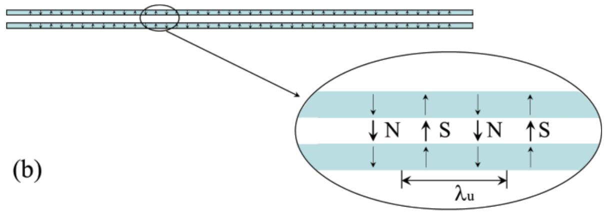

Figure 1b: Formation of an undulator field in perpendicular geometry.

The magnet plate is made of Nd-Fe-B type magnetic material. Here it is embedded between a pair of flat electromagnets having a zigzag wire. By applying a pulsed current to these electromagnets, N- and S-poles are formed simultaneously in the plate with a periodic spacing. After the magnetization, a pair of these plates is combined with faces opposing each other, and the magnetic field is produced in the short gap between the plates. In Figure 1a, the magnetization direction is perpendicular to the plate surface (the perpendicular case). The geometry is similar to a perpendicular magnetic recording method in a recording media. The other geometry (the longitudinal case) is also possible. In this case the magnetization is formed along the plate surface as in longitudinal magnetic recording. The magnetic field in the longitudinal case may be weaker than that in the perpendicular case. However, there is an advantage that the first field integral becomes zero if the magnetization direction is purely longitudinal, even if there are errors in the strength of magnetization.

By adopting the perpendicular geometry a preliminary magnetization test was performed on the magnet plate 100mm long, 20mm wide and 2mm thick, with a period length of 4mm. The plate was made of NEOMAX-48BH with a remnant field of B_r=13.9kG and a coercivity of iH_c=14kOe (Hitachi Metals Co. Ltd.). However, the result was not satisfactory at all for the undulator field. Deviations in both magnetic field strength and period length were as large as ±50% and ±30%, respectively[6]. We found this result is due to the improper fabrication of the electromagnets in the magnetizing head. In order to simplify the procedure to fabricate the magnetizing head and to obtain a successful result with reduced number of ways, we adopted a different method while keeping the perpendicular geometry. This method allowed the same plate to be driven by a linear motor and to be magnetized by a fixed head as shown in Figure 2.

We devised a one-period (or two-pole) magnetizing head in which the wire with a diameter of 1.1mm was fixed tightly with an epoxy resin. An accuracy of the periodic spacing between the magnetic poles is 0.05mm. The wire was wound twice around each pole. The head was excited by applying a pulsed current of 9.6kA during 0.1msec to the magnetizing head. The step width of the moving plate was set to a half (*i.e.* 2mm) of the period length of the magnetic field. At each step of the plate movement the direction of the pulsed current applied to the head was reversed to form the undulator field with the 4mm period length. Here we use the magnet plate with the same dimension made of NMX-39EH also supplied by Hitachi Metals Co. Ltd. (B_r=12kG and iH_c=25kOe).

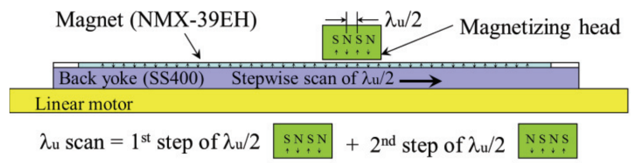

Figure 2: Magnetization employing a linear motor.

This material is more suitable for the undulator due to its high coercivity. The magnetized plates are shown in Figures 3: the surface of the plates A and B is coated by TiN for vacuum sealing, and the magnetic field pattern is seen through a magnetic fluid sheet for the plate B. The plate movement on the linear motor was controlled by a closed loop scheme with an accuracy of 0.003mm. The accuracy of the period length of the plate magnetic field was mainly determined by the accuracy of the spacing of the wires in the head and of the step width of the plate movement driven by the linear motor. Thus, the accuracy of the achieved field strength was essentially affected by the accuracy in the period length and of the quantity of the electric charge applied to the head at each step.

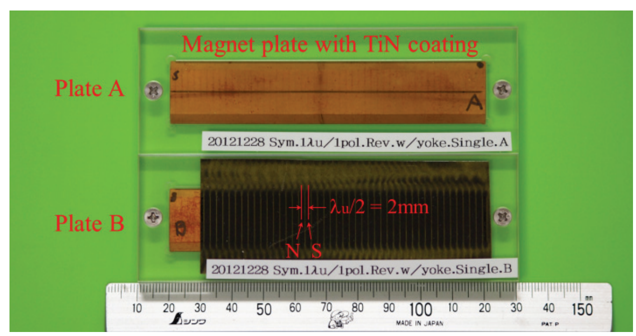

Figure 3: Magnetized plates A and B. A pair of these plates is opposed to form a undulator field.

MAGNETIC FIELD MEASUREMENTS AND CHARACTERIZATION

The quality of the magnet plate for an undulator was examined by measuring the magnetic field. The magnetic field in the vertical direction was measured by a scheme shown in Figure 4. As a magnetic sensor we installed a Hall probe in a holder made of copper with the thickness of 1.3mm. The electric area of the Hall probe is 0.05mm × 0.05mm. The undulator field was formed between the opposing plate magnets which were magnetized by a method shown in Figure 2 to be measured at a fixed gap condition of 1.6mm.

Result of the measurement for this fixed-gap undulator field is shown in Figure 5. Figure 5a shows the undulator field and Figure 5b shows the electron orbit in this field in

Content from this work may be used under the terms of the CC BY 3.0 licence (© 2014). Any distribution of this work must maintain attribution to the author(s), title of the work, publisher, and DOI.

ISBN: 978-3-95450-132-8 doi:10.18429/JACoW-IPAC2014-WEOAA02

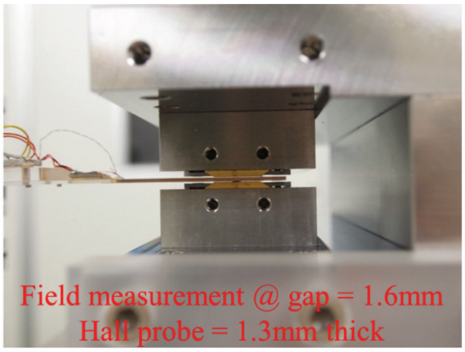

Figure 4: Field measurement at a fixed gap of 1.6mm. The plates A and B in Figure 3 are opposed to form the undulator field.

case of an electron energy of 2.5GeV. The magnetic field of approximately 4.1kG was obtained at the gap of 1.6mm. We did not pay any special attention to the magnetization of the end poles at this stage of the development. The Magnetization for the end poles was made in the same way as for the other inner poles.

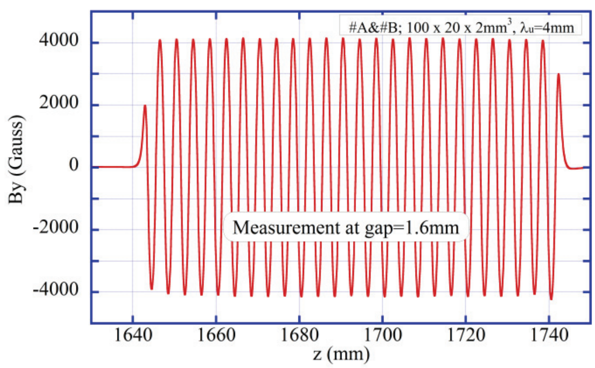

Figure 5a: The measured undulator field with a period length of 4mm: measurement made at a gap of 1.6mm.

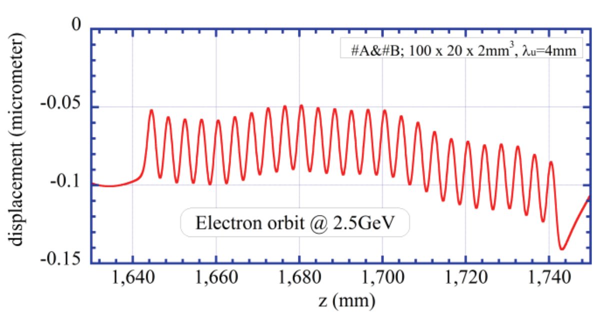

Figure 5b: The electron orbit when the energy is 2.5 GeV.

Although the orbit correction at both ends of the magnetic field was not sufficient with the present method, the orbit in the present undulator field seems satisfactory. To examine the present field, the spectrum of the flux density was calculated on the basis of the measured data of Figure 5a. Figure 6 shows the result in a case of 2.5-GeV electron energy, zero emittance and zero energy spread, compared to that with the ideal field of the same strength.

It should be noted that the radiation (red curve in Figure 6) from the present undulator field compared well with that (green one) from an ideal magnetic field in the region of the fundamental radiation, though discrepancy was large in the third harmonic region. For the condition in Figure 6, the radiation from 10 to 15keV was found to be useful for synchrotron radiation experiments.

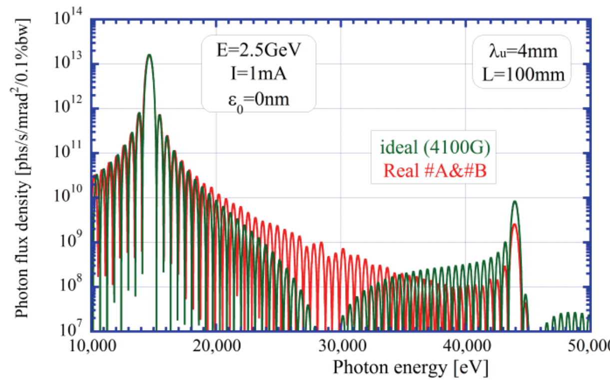

Figure 6: Flux density spectrum calculated on the basis of the measured field, compared to that of the ideal field in a case of 2.5-GeV energy of the electron beam with zero emittance and zero energy spread.

CONCLUSION

The present results indicate that we have been resolving major subjects and taking the right direction to develop the very short period undulaotrs. The construction of undulators for practical use would require further improvements in magnetization method to achieve higher magnetic field intensity and accuracy and to realize adequate magnetic field in the both ends of the undulator. The development of precise magnetic field measurement methods in the very short gap and the proper characterization of the undulator field upon it are also very important to accomplish the above items.

We believe, however, that evaluation experiments of the very short period undulator based on the real electron beams will take place in the near future.

REFERENCES

[1] S. Yamamoto, et al., J. Appl. Phys. 74, 500 (1993).
[2] *e.g.* http://www.esrf.eu/, http://www.aps.anl.gov/ and http://www.spring8.or.jp/
[3] *e.g.* http://www.bnl.gov/ps/nsls2/about-NSLS-II.asp http://www.psi.ch/sls/, and http://www.lunduniversity lu.se/research-and-innovation/max-iv-and-ess
[4] S.Yamamoto, et al., AIP Conf. Proc. 879, 384 (2007).
[5] S. Yamamoto, et al., AIP Conf. Proc. 1234, 599 (2010).
[6] S. Yamamoto, Journal of Phys.: Conf. Ser. 425 032014 (2013).

Content from this work may be used under the terms of the CC BY 3.0 licence (© 2014). Any distribution of this work must maintain attribution to the author(s), title of the work, publisher, and DOI.