STUDY OF HIGH-FIELD MULTIPOLE WIGGLER

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Abstract

We designed a high-field multipole wiggler which can produce a high flux of hard X-rays even with a synchrotron radiation source of a relatively low energy. In this design, the pole pieces are made of high saturation material and the permanent magnet arrangement is devised to enhance the field strength. A half-scale model was manufactured, and it was confirmed by field measurements to generate a magnetic field up to 3 T in agreement with field calculations. The full scale wiggler can achieve the same field strength at the double gap width.

1 INTRODUCTION

Multipole wigglers are expected to provide hard X-ray radiation in the VSX light source[1], a VUV and soft X-ray high-brilliance synchrotron radiation source being planned by the University of Tokyo. Since the critical photon energy of a multipole wiggler is proportional to the magnetic field and the square of the electron beam energy, a high-field multipole wiggler can radiate high-energy photons in an electron storage ring of a relatively low energy such as the VSX light source. It can also reduce the total wiggler length for a required photon flux with the resultant production economy.

Design study of a high-field multipole wiggler was performed with the help of a 3D field calculation program [2] and a hybrid structure[3] was adopted. This wiggler has the ability to generate a magnetic field more than 3 T on calculation and it differs from the ordinary hybrid wiggler in that, in order to strengthen the magnetic field, each pole piece is surrounded by four permanent magnets optimized in size. A half-scale model (1/2 in dimensions and 1/8 in volume for one period unit) with three poles was manufactured and its field measurements were made to verify the magnetic performance. In this paper, we report the structure and field measurements of the model wiggler.

2 STRUCTURE OF MODEL WIGGLER

2.1 Magnet Array

The magnet array has a hybrid configuration where Nd-Fe-B permanent magnets (a remanent field B_r=1.28 T) and permendur pole pieces (a saturation field B_s=2.3 T) are arranged, as shown in Figure 1. Unlike the conventional hybrid multipole wiggler, each pole piece has side magnets on both sides to strengthen the magnetic field between the upper and lower magnet arrays. The sizes of the magnets and pole pieces were decided so as to optimize the field strength and cost effectiveness for a 110 mm width of the magnet array and a 10 cm wiggler period length. The parameters of the model wiggler are summarized in Table 1. Each main magnet of the model was fabricated with ten magnet blocks to have the same condition as the full scale, though the number of blocks was too large for the model main magnet. For the same reason, each side magnet is made of two magnet blocks glued to each other. The main and side magnets are supported by corresponding magnet holders made of stainless steel and the magnet holders are bolted to a stainless-steel base plate. The pole piece is dovetailed and glued to a pole piece holder and its vertical position can be tuned within a range of about 1 mm by a bolt joining the pole piece holder to the magnet holder. All of the side and main magnets and pole pieces are also supported by a stainless-steel protective bar which pass in the x-direction through shallow grooves made in their front and back surfaces.

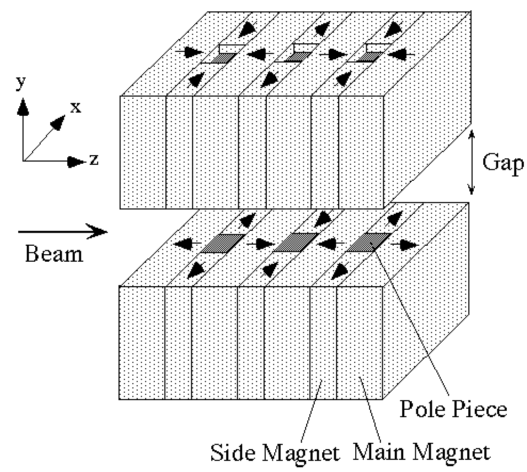

Figure 1: Schematic view of the magnet array of the model multipole wiggler. The arrows on the magnets indicate the directions of the magnetization.

Table 1. Parameters of the model multipole wiggler

Period*	10 cm
Main Magnet Size*	110 x 75 x 36 mm
Side Magnet Size*	42.5 x 75 x 18 mm
Pole Piece Size*	25 x 66 x 18 mm
Magnet Array Size**	110 x 75 x 182 mm
Number of Poles	3
Gap	2 - 100 mm
Magnet Material	Nd-Fe-B (B_r=1.28 T)
Pole Piece Material	Permendur (B_s=2.3 T)

* The values of these parameters are doubled for the full scale wiggler.

** End plates and magnet holders are not included.

2.2 Mechanical Support

The stand of the model multipole wiggler mechanically supports the magnet arrays and adjusts their gap. The stand is 600 mm x 400 mm x 987 mm and consists of four linear guides and a ball screw jack which drives the upper magnet array of approximately 50 kg. The handle of the ball screw jack gives a 1 mm gap change per three turns and the clamp lever can fix the handle for safety. The driving range of gap is 2-100 mm and limited by the stopper on the linear guide. In addition, the projections of 1 mm are established on two stainless-steel end plates of each magnet array in order that the upper magnet does not stick to the lower magnet. This stand resists the absorptivity of 1700 kg at the magnetic field of 3.5 T, and it does not tumble by a great earthquake. Figure 2 shows a whole view of the model multipole wiggler.

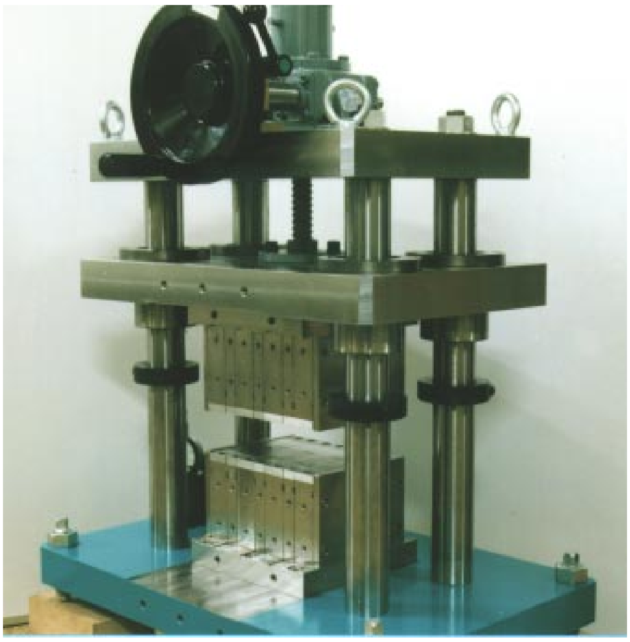

Figure 2: Photograph of the model wiggler

3 FIELD MEASUREMENTS

Detailed field measurements were performed by a field measurement system which consists of an automated three-axis positioning bench with a Hall probe. In the measurements, the surfaces of the pole piece tips were fixed on the same plane as those of the magnets.

Figure 3 shows the measured field distribution along the z-axis at seven magnetic gaps. The magnetic field at three peaks corresponding to the three poles, one central peak (Peak1) and two side peaks (Peak2), in the distribution exceeds 3 T at the gap of 3.5 mm or less and Peak1 has a slightly lower field than Peak2. The average peak field will approach to the Peak1 field more closely than the Peak2 field if the number of poles increases. The field distribution becomes a sine curve with increase of the magnetic gap.

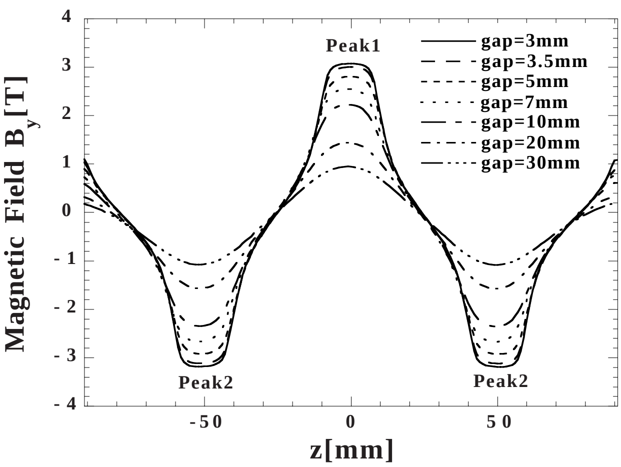

Figure 3: Field distribution along the z-axis at seven different gaps.

The field distribution of the x-direction in the central pole at two different gaps is shown in Figure 4. The magnetic field at the gap of 3 mm drastically changes around the x-position of 12.5 mm which corresponds to the half width of the pole piece, while the distribution curve at the gap of 30 mm is relatively smooth. The full-scale wiggler will also have a sudden decrease of the magnetic field at the x-position of about 25 mm. However such a field decrease is expected not to affect the beam seriously, because the dynamic aperture limited by sextupole magnet fields and magnet alignment errors in a low-emittance ring such as the VSX light source is comparable with the pole piece width of the full scale wiggler[4]. Figure 5 shows the magnetic field of the y-direction in the central pole at the gap of 30 mm. The field around the gap center (y=0) is well fitted with a hyperbolic cosine curve.

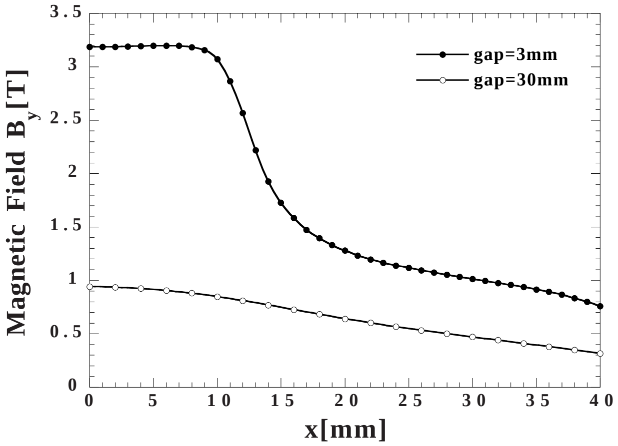

Figure 4: Field distribution of the x-direction in the central pole at two different gaps.

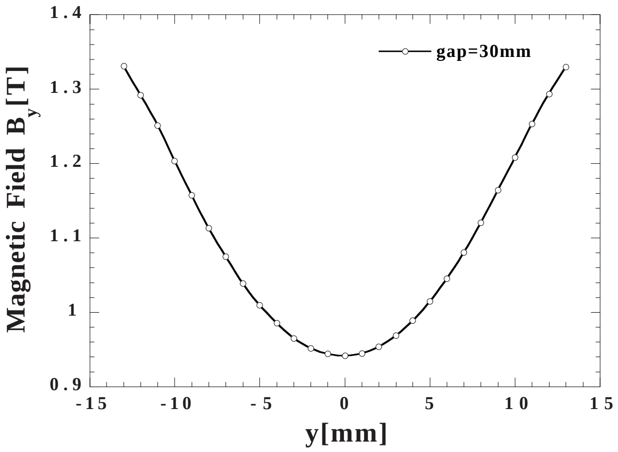

Figure 5: Field distribution of the y-direction in the central pole at the gap of 30 mm.

Figure 6 shows the gap dependence of the peak (Peak1) field obtained by the field measurements. The calculated peak fields of the model and full scale are also shown in the same figure for comparison. As shown in Figure 6, the measured magnetic peak field increases without any sign of saturation as the gap decreases. The difference between the measurement and calculation data of the model varies from 3.3 to 6.5 % in the gap range of 3-30 mm. This can be attributed to two causes, imperfect assembly of the magnet arrays and field calculation errors. From the measurement results and the geometrical similarity between the model and full scale, the full scale wiggler is predicted to generate a 3 T magnetic field at the gap of about 7 mm.

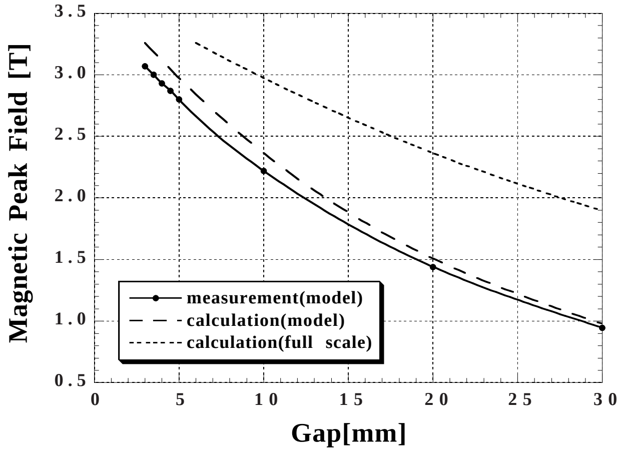

Figure 6: Measured (solid line) and calculated (long- and short-dashed lines) gap dependence of the magnetic peak (Peak1) field.

4 CONCLUDING REMARKS

The model wiggler succeeded in generation of a magnetic field more than 3 T, as predicted by the field calculations. The full scale wiggler will attain the same field at a gap twice as wide as the model. Such a high-field multipole wiggler is expected to contribute to developments of scientific researches requiring hard X-rays, because it can produce hard X-ray radiation even in a low-energy ring. Furthermore, if the magnetic structure adopted in the multipole wiggler is applied to undulators, it will guarantee a high magnetic field even for a short undulator period ($\lambda_u <$ 4 cm) and provide a highly brilliant VUV to soft X-ray radiation, keeping a magnetic gap sufficiently wide for a satisfactory beam lifetime.

5 REFERENCES

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[4] See, for instance, Takaki et al., ‘A Lattice for the Future Project of VUV and Soft X-ray High-Brilliant Light Source in Japan’, Proc. of the 1997 PAC, Vancouver, 1997. See also 1-2 GeV Synchrotron Radiation Source, Conceptual Design Report, July 1986, LBL PUB-5172. ESRF Foundation Phase Report, February 1987. ELETTRA Conceptual Design Report, April 1989.