DESIGN OF A HIGH FIELD STRENGTH 3.4 TESLA WIGGLER FOR THE SRRC STORAGE RING

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Abstract

For expanding higher photon energy, a hybrid magnet structure wiggler with a period length of 25 cm is designed to achieve the field strength exceeding 3.0 Tesla at a minimum gap of 12 mm. The geometrical configuration of a pole and permanent magnet block is optimized using an Opera-3d magnetostatic code. A one-pole magnet model is fabricated and measured to verify that the field strength up to 3 Tesla corresponds to field calculation. Also presented herein is the end pole design to easily compensate for the first integral field. The mechanical considerations are also presented for maintaining a high precision magnet array under the strong magnetic force.

1 INTRODUCTION

The storage ring of Synchrotron Radiation Research Center (SRRC) is operated at 1.5 GeV energy to produce the VUV and soft X-ray photon energy. In general, the critical photon energy of storage ring is proportional to the magnetic field strength and the square of the electron beam energy. Therefore, a higher magnetic field wiggler or bending magnet is desired to significantly extend the synchrotron radiation spectrum to the hard X-ray region. A particular requirement in the lower energy ring is a magnet or insertion device with a higher effective field strength in a useable gap width.

A prior 1.8 Tesla wiggler has been used to provide high intensity X-rays up to 15 keV in the storage ring. [1] To enhance the higher photon energy, our previous study has investigated the effects of a 7.5 Tesla superconducting wavelength shifter or a superconducting bending magnet [2]. However, one more potential magnet is a permanent magnet wiggler which generates a high magnetic strength surpassing 3 Tesla. A merit of the 3 Tesla permanent magnet wiggler is its ability to increase the photon flux and economize production and operation. To our knowledge, the permanent magnet wiggler has not yet been carried out on the storage ring more than 3 Tesla field strength.

A wider photon spectrum is calculated from the wiggler(Fig. 1). The useful photon energy extends to 40 keV and the photon flux reaches the several 10^{11} photons/sec/0.2A/0.1%BW. In this work, we present the magnetic field design and mechanical considerations to perform the stringent requirements. Table 1 lists the main parameters of the 3 T wiggler.

Table 1 : The Main Parameters of 3 T Wiggler

Period length	250	mm
Number of periods	3	
Minimum gap	12	mm
Overall length	0.80	m
Vertical peak field	3.4	T
Transverse roll-off (ΔB/B) < 0.1%	± 2	cm
Integrated dipole field	< 1	Gm
Pole size	10 x 16 x 3.4 cm^3	
Main magnet block size	18 x 20 x 9.1 cm^3	
Side magnet block size	4 x 16 x 3.4	cm^3
Photon energy range	1 - 40000	eV

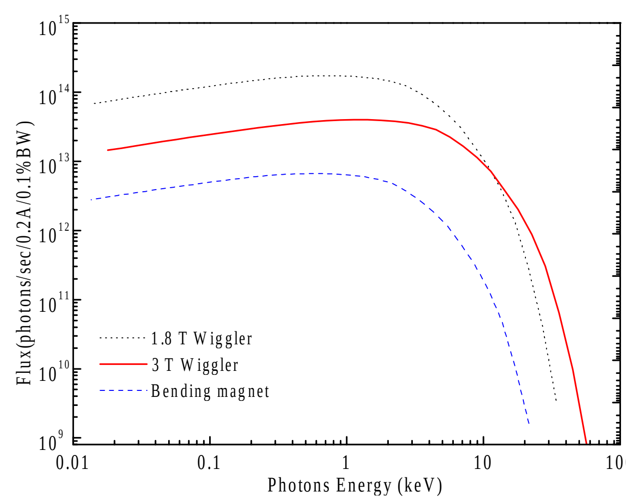

Figure 1: Comparison of photon energy and flux between the wiggler and the bending magnet.

2 MAGNET STRUCTURE DESIGN

2.1 magnetic structure configuration

Under the constraint of available space in the SRRC storage ring, a 0.8-meter long wiggler is proposed for installation, thereby for enhancing the photon flux and extending the photon energy into hard x-ray range. While considering the lifetime and the injection time of electron beams, the wiggler is operated at a reasonable minimum gap width of 12 mm. The achievable peak field is a function of period length (λ_w) in the conventional hybrid structure. However, this field is also limited from the saturation of the steel and a remanent flux density (Br) of magnet block. A typical material for pole is the Vanadium-Permendur steel, which has a saturation field (Bs) at 2.3 T. Herein, we selected good quality Neodymim-Iron-Boron (Nd-Fe-B) permanent magnet with a high remanent field (Br) 1.28 T.

The magnetic field was calculated using the OPERA-2d and OPERA -3d computed code. The preliminary peak field strengths were initially computed to achieve the higher value by varying the ratio of pole thickness / period length. Pole heights and vertical magnet overhangs were also employed to adjust the field strength. The pole was used to confirm saturation levels. The strongly saturated pole edges were slightly narrower to yield higher field strength in the mid-plane. Next, changing the chamfering area at the pole edges and vertical recess between the magnet and pole allowed the magnet to achieve the largest flux density. The edge of pole was chamfered with 10 mm. The peak magnetic field could be significantly increased by the edge pole configuration. 1 mm vertical recess between the magnet and pole was deemed acceptable to allow placement of tuning shims. Furthermore, the pole was surrounded by two side magnets on both sides and small triangular magnet occupying the chamfering area to strengthen the magnetic field.

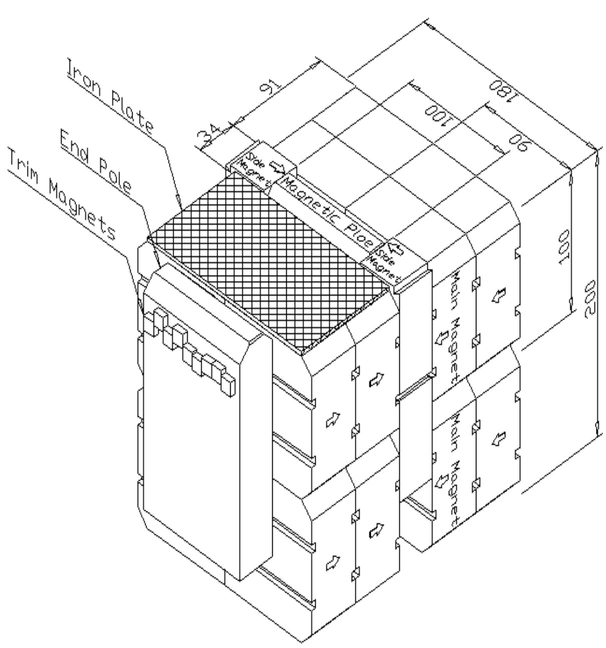

Figure 2: Th geometrical configuration of magnet structure and end pole.

The pole width was set on transverse homogeneity and saturation considerations. Finally, the transverse width of pole and permanent magnet were determined to satisfy the roll-off within 0.1 % at 40 mm range. According to field calculations, the side magnets increased the on axis peak field strength up to 3.4 Tesla and also enhanced the field uniformity within 0.1% from 15 mm extended to 40 mm (Fig. 3). The side magnets could also be used to tune the peak field strength by varying the vertical and transverse positions. Figure 3 depicts the geometrical configuration of magnetic structure and end pole.

2.2 End Pole Configuration

The 3-period magnet array was assembled with a vertical field symmetric configuration. The variation of dipole field in each pole is naturally more sensitive in the shorter length wiggler and the saturated pole. The end pole configuration was intended to compensate for the deviation of the first dipole field integral and zero offset displacement of the electron trajectory at all operating gap widths. To fulfill the stringent field integral within 100 G-cm requirement, the end pole design must moderately easy steer the field strength and fine tune the end field to compensate the field strength.

The field configuration was predicted by the OPERA-3d computed code. The method to roughly steer the strength of end pole is to recess the second end pole and main magnets, as well as adjust the side magnets in vertical or transverse direction. Herein, the fine tuning method was applied to put the iron plates between the first and second pole. [3] The end corrector must provide at least 1000 G-cm at different gap widths. Figure 2 illustrates the end pole compensation scheme. The multiple trim magnets were utilized to trim the field integral in the transverse direction.

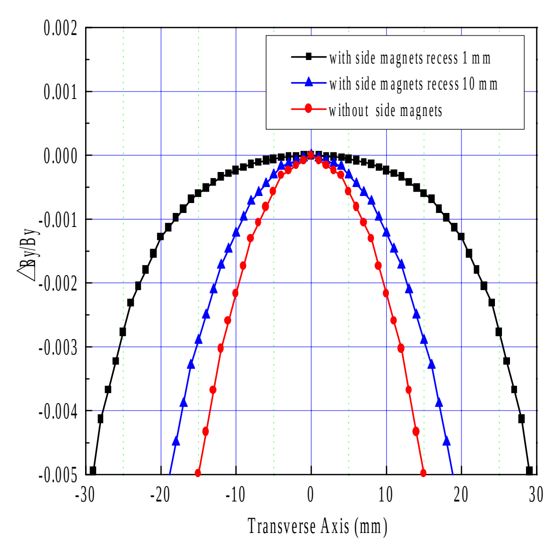

Figure 3: The field uniformity along the transverse axis with side magnets.

3 FIELD MAPPING OF A MODEL

The calculated field strength and the field performance were examined by assembling a one-pole magnet model by using the conventional NdFeB magnet blocks and pole material. The conventional hybrid magnetic structure without side magnets with a period length of 236 mm was used in a one-pole magnet model. The geometrical configuration of magnet blocks was 114 mm wide x 78 mm deep x 51 mm thick and for the pole dimensions with 84 mm wide x 62 mm deep x 16 mm thick. The peak field was calculated to achieve up to 3 Tesla at 4 mm gap width. Figure 4 compares the measured and calculated field profiles along the transverse direction at different gap widths. The vanadium permendure B-H database is sufficiently accurate for the high field wiggler. Also compared herein is the field strength with open and close loop at a minimum gap width. Our results obviously indicate that the field strength didn't incur the field errors due to a spatially non-uniform irreversible demagnetization within the magnets.

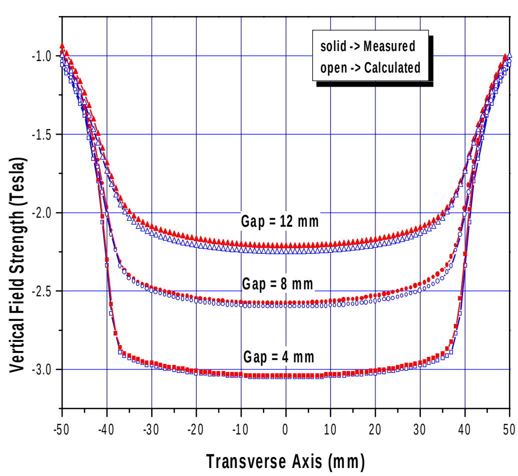

Figure 4: The measured and calculated field profiles along the transverse direction at different gap widths.

4 MECHANICAL DESIGN

The magnetic structure is a high precision magnet array comprised of many parts subject to large forces associated with the 3 Tesla fields. The magnet assemblies utilized the mechanical clamps to avoid reliance on adhesives for positioning of magnet blocks. The magnet structure assembly was intended to maintain the mechanical errors of the pole and magnet blocks within fifty microns. Owing to that the repulsive and attractive magnetic forces of 500 kg interact strongly among the magnet blocks, the magnet holder and the assembly fixture must securely clamp and handle the magnet blocks. The pole was rigidly fixed by using the bolts from the underside of holder. The half magnets are clamped in place on the frame by using the bottom and top clamps and 4 stainless-steel protective bars passing through the magnet block in transverse direction. The side magnet is dovetailed and glued to holder and its vertical and transverse position can be tuned within a range of about 5 mm by a bolt for the field tuning.

5 CONCLUDING REMARKS

This work designed a 3.4 Tesla wiggler to extend the photon spectrum energy into a hard x-ray range in 1.5 GeV ring. However, the Vanadium-Permendur steel for a pole has a saturation field at 2.3 T. The geometrical configuration of the magnetic structure was optimized to achieve a 3.4 Tesla peak field strength. For examining the calculated field strength, a one-pole magnet model successfully demonstrated that the measured field strength was exceeded 3 Tesla, as predicted by the field calculation. Moreover, the easy steering and fine tuning methods for the first integrated field were used in the end pole configuration. Furthermore, the positioning technique of magnet blocks under the strong magnet force was also employed to maintain a high precision magnet array.

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REFERENCES

[1]. H. P. Chang, C. C. Kuo, and J. Safranek, "Correction of Lattice Optics in the Presence of Strong Wiggler Magnet at SRRC", The First Asian Particle Accelerator Conference, APAC98 Proc. 1998.

[2]. M. H. Wang, C.C. Kuo, J.C. Lee, "Study the Effects of Superconducting Magnet on the Beam Dynamics in SRRC/TLS Storage Ring" EPAC98, Stockholm,1998.

[3]. Ch. Wang, et al., "End Compensation Scheme for an Undulator Configured with Strong On-axis Magnetic Field Strength" 15th International Conference on Magnet Technology, Beijing, 1997.