OPTIMIZATION OF A MULTIPOLE WIGGLER FOR TPS

†J. C. Jan, C. Y. Kuo, C. H. Chang, T. Y. Chung, J. C. Huang and C. S. Hwang, National Synchrotron Radiation Research Center, Hsinchu, Taiwan, R.O.C

Abstract

Taiwan Photon Source (TPS) is a synchrotron radiation facility with electron energy 3 GeV that was commissioned in 2015. Taiwan Light Source (TLS) with electron energy 1.5 GeV concurrently provides user time. Three beam lines of TLS supply photons of energy 6-18 keV for user experiments; these beam lines are served with an in-achromatic superconducting wiggler (IASW, 3.1 T). This superconducting insertion device has the disadvantages of complicated maintenance and operation. A traditional multipole wiggler (MPW) magnet of hybrid type is hence planned to be installed in TPS to cover the range of photon energy of IASW for user experiments. For the design of the magnetic circuit, the side block and the extreme block are arranged surrounding a Permendur Vanadium cobalt steel pole that enhances the field strength and good field region of a MPW magnet. The dynamic integral field and the demagnetizing field of MPW magnet were estimated. The optimization of the pole dimensions and photon characteristics were simulated and are discussed in this work.

INTRODUCTION

The storage ring of TPS has six long and eighteen short straight sections for insertion devices (ID), superconducting radio-frequency (SRF) and injection sections. The lengths of the long and short straight sections of TPS are 12 m and 7 m, respectively. A short length of multipole wiggler was designed to share the same straight section with a SRF to save space, displayed in Fig. 1. The allowed space of a MPW magnet is about 2000 mm (W) × 1000 mm (L) × 2500 mm (H). The primary design length of the magnet array is limited to near 600 mm. The photon spectra of a MPW magnet were calculated (SPECTRA8) and are displayed in Fig. 2 [1]. The IASW is a superconducting wiggler magnet of field strength 3.1 T, operating in TLS with electron beam current 360 mA [2-3]. The MPW magnet is a traditional permanent wiggler magnet of field strength about 1.8 T and will be installed in TPS with electron beam current 500 mA.

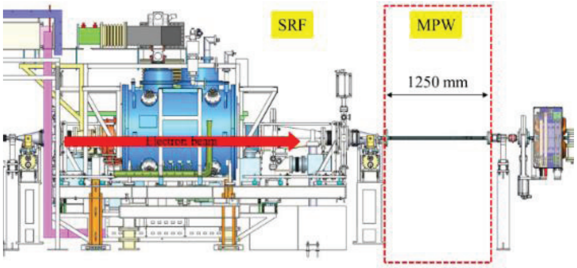

Figure 1: Location of a MPW magnet.

The photon flux density of a MPW magnet is ten times that from an IASW above 11 keV. The photon flux density of a MPW magnet is still greater than 1x10^{14} (photons/s/mr^2/0.1%bw) when the photon energy is extended to 40 keV. The MPW magnet operates without complicated cryogenic supplies and maintenance.

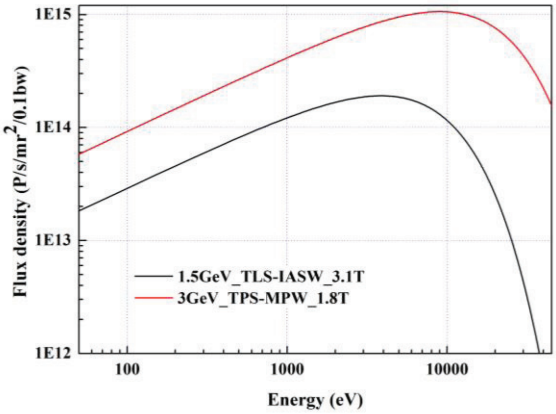

Figure 2: Spectra of a traditional MPW magnet operating at 3 GeV and a superconducting IASW magnet at 1.5 GeV.

GEOMETRY OF THE MAGNET ARRAY

The MPW magnet array was discussed as to how to obtain a field strength and uniform transverse field homogeneity (good field region, GFR). The MPW array is composed of a main permanent-magnet block (PM block, cyan color), side permanent-magnet block (side block, dark blue), extreme-magnet block (extreme block, red) and Permendur Vanadium cobalt steel pole (VP pole, pink), displayed in Fig. 3 (a). Here, the dummy end pole was set at both ends of the array. The VP pole protrudes beyond the PM block or side block by approximately 1 mm. L_m (L_{mx}, L_{my}, L_{mz}), S_m (S_{mx}, S_{my}, S_{mz}), E_m (E_{mx}, E_{my}, E_{mz}) and L_p (L_{px}, L_{py}, L_{pz}) are the dimensions of the PM block, side block, extreme block and VP pole, respectively. The assembly of the upper and lower arrays is called the magnet module. The gap between upper and lower arrays was fixed at 14 mm. The various modules were studied and are displayed in Fig. 3 (b); these modules are named modules H, L, X, O, W and W2. The field strength and transverse field homogeneity of these modules are calculated with RADIA code and listed in Table 1 [4]. The GFR was defined by field homogeneity better than 0.2 %. The B_{max} is the maximum field strength and obtained with L_{pz} scan. Figures 4 and 5 display the GFR and dynamic integral field of these modules. These modules are summarized as follows:

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† janjc@nsrrc.org.tw

- Module O has the broadest GFR because of the side pole contribution and a field strength smaller than that of other modules.
- The field strength is enhanced by the side block approximately 5.6 %, see module H/W2 and module X/W.
- The GFR was broadened 61 % and 46 % after a side-block was added; see module H/W2 and module X/W.
- The field strength is enhanced by the extreme block approximately 3.9 % in L_{my} 59 mm; see module H/X and module W/W2, but the field strength is enhanced 5.9 % in L_{my} 39 mm; see module L/O. Therefore, the field increase of the extreme block added is more notable in the small L_{my}.
- The field strength was increased up to 9.6 % when the side and extreme blocks were added simultaneously; see module H/W.
- The field strength is increased on increasing L_{my}; see module H/L and module X/O.
- Module H is a compromise result between field strength and GFR to meet our requirements. Module H was thus selected and is discussed in a subsequent section.

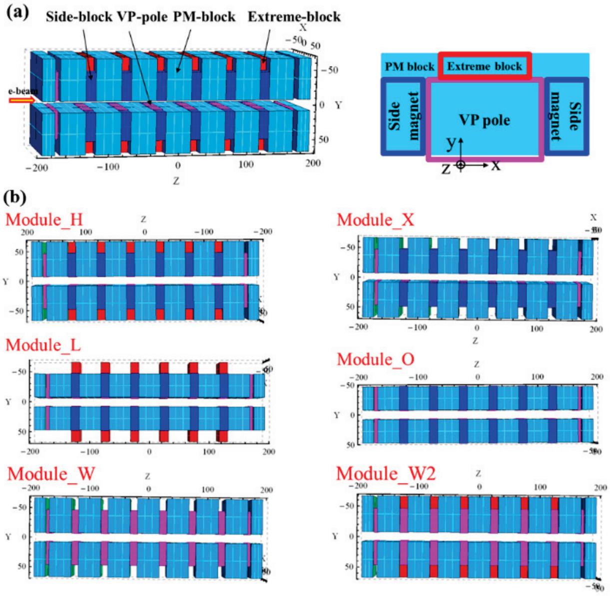

Figure 3: Sketch of (a) module composed of a MPW magnet and (b) various modules of a MPW magnet.

Table 1: Summary of Various Modules

Module	H	L	X	O	W	W2
S_{mx}	20	20	20	20	0	0
E_{mx}	20	20	0	0	0	20
L_{my}	59	39	59	39	59	59
B_{max}	1.819	1.656	1.750	1.563	1.660	1.722
GFR	±13.2	±16	±13.6	±16.9	±9.3	±8.2

Unit: mm, T

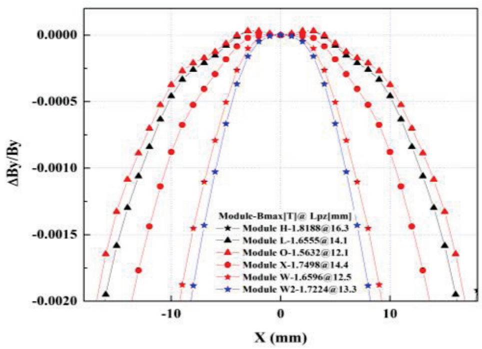

Figure 4: Transverse field homogeneity of a MPW magnet with various modules.

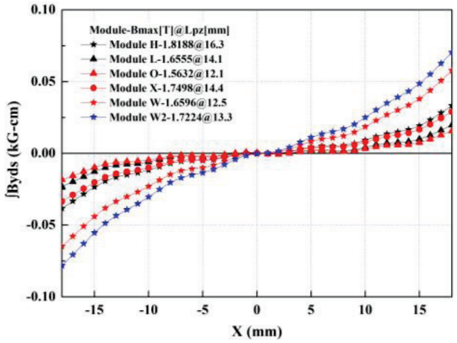

Figure 5: Dynamic integral field of a MPW magnet in the transverse direction.

OPTIMIZATION OF POLE AND PERMANENT BLOCK

Figure 6 displays the relation between field strength, period length and pole thickness (L_{pz}), and lists also the parameter setting. The field strength is proportional to the period length; the increasing field strength seems to become saturated at period length 100 mm.

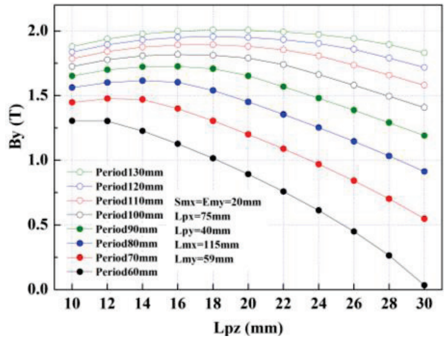

Figure 6: Field strength of module H with period length and VP-pole thickness (L_{pz}) varied.

Figures 7(a) and (b) display the variation of field strength with VP-pole dimension for period length 100 mm. Figure 7(a) displays the variation of field strength with L_{px} (L_{py} fixed at 40 mm). The field strength is similar when L_{px} varies. Figure 7(b) displays the field strength increasing with L_{py} (L_{px} fixed at 75 mm). Figure 8 displays the variation of field strength with side block and extreme block. The increase of field strength seems to become saturated at E_{my} 20 mm. The field strength with E_{my} 20 mm added is increased 10.2 % when S_{mx} widens from 5 mm to 30 mm.

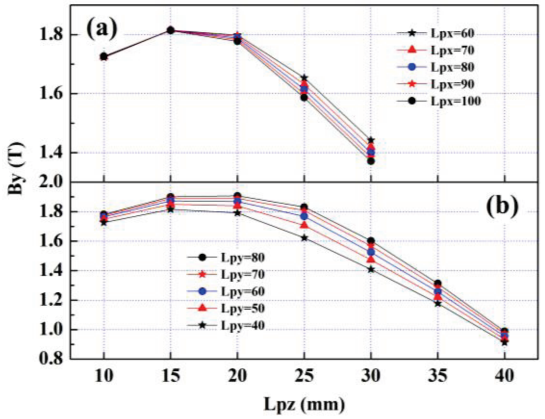

Figure 7: Field strength of module H: (a) VP-pole thickness (L_{pz}) and width (L_{px}) varied. (b) VP-pole thickness (L_{pz}) and height (L_{py}) varied.

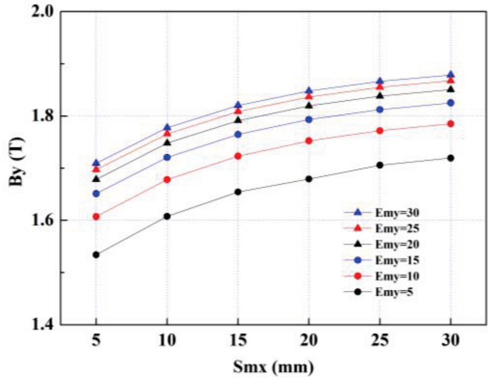

Figure 8: Field strength of module H with side-pole width (S_{mx}) and extreme-block height (E_{my}) varied.

The other method to broaden the GFR is to increase L_{pz} (pole dimension in the direction of the electron beam). Figure 9 displays the GFR broadening of module H with varied thickness of L_{pz}. The GFR is broadened from ±13.2 mm to ±14.6 mm after L_{pz} thickens 2 mm, but the field strength becomes slightly decreased, 0.4%.

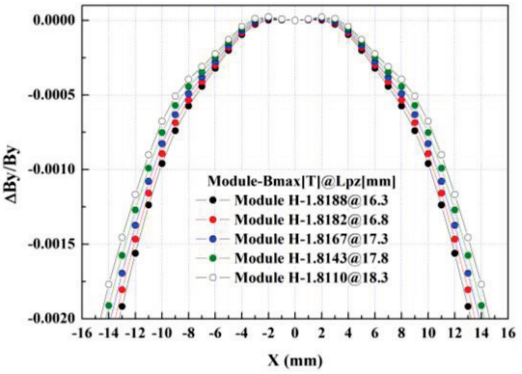

Figure 9: Variation of transverse GFR of module H with pole thickness (L_{pz}).

DEMAGNETIZING FIELD

The demagnetization analysis of a magnet block was undertaken to ensure that the penetrating field of the MPW magnet is less than the coercitivity field of the magnet block. Figure 10 displays the check points inside the PM block and side block. H_{cz1} (lower middle of PM block), H_{cz2} (lower corner of PM block) and H_{cz3} (lower corner of side block) display the various check points inside the magnet block of edge 0.1 mm. The penetrating field components of H_{cz1}, H_{cz2} and H_{cz3} along z-axis scan are plotted in Fig. 10. For example, label H_{cz1x} denotes the x component of the penetrating field at point H_{cz1}. A high penetrating field (B_{max}) was observed at H_{cz1z} (1.5607 T), H_{cz2z} (-1.2186 T) and H_{cz3y} (1.5752 T). Thus, the coercitivity choice of the block should hence be larger than 16 kOe (1 T=10 kOe=795.8 kA/m).

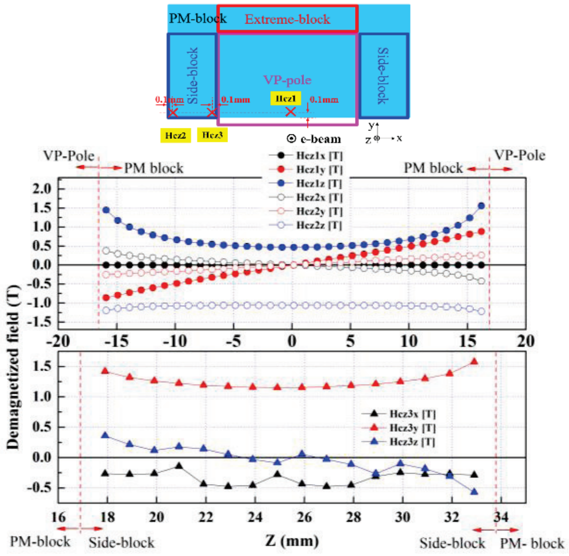

Figure 10: The field test points in the permanent-magnet block that are compared in the plot.

SUMMARY

The maximum field strength of a MPW magnet was optimized at approximately 1.8188 T with period length 100 mm. The flux is greater than 1×10^{14} (photons/s/mr^2/0.1%bw) extending to photon energy 40 keV. In the magnet structure simulation, the side block increases the field strength and broadens the GFR. The extreme block notably increases the field strength only in the small L_{my} module. The GFR of module H is broadened from ±13.2 mm to ±14.7 mm when L_{pz} increases 2 mm. From the demagnetization of module H it was estimated that the coercitivity of the permanent- magnet block should be larger than 16 kOe.

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