GENERAL DESIGN OF ID FRONT ENDS IN THE TPS

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Abstract

The Taiwan Photon Source is a 3 GeV, 3rd generation synchrotron radiation source at the NSRRC. Phase-I commissioning includes seven Insertion Device (ID) Front Ends which are built to transmit intense synchrotron radiation generated by In-vacuum Undulators and Elliptically Polarizing Undulators in the storage ring to the Photon Beamline. The total power and power distribution on Front End components is calculated and analysed and Finite Element Analysis is used to verify the thermal performance under high heat loads while Monte-Carlo methods are utilized to simulate the vacuum pressure distribution. All apertures of the components are the same to simplify and standardize the design of the Front Ends. This paper describes main design considerations, especially the high heat load and vacuum pressure distribution.

INTRODUCTION

The six-fold symmetric TPS storage ring is 518.4 meters in circumference and uses a 24-cell DBA lattice with 24 straight sections for insertion devices, of which six are 12 m and 18 are 7 m long. In phase-I, seven ID beamlines have been installed in the TPS. The light source and its experimental facilities were opened to the academic and scientific communities for basic and applied research in 2016.

The general design of an ID Front End in the TPS is to reach the following goals: (1) to allow useful synchrotron light generated in the storage ring to pass through the beamline, (2) to scrap unneeded high heat power from the synchrotron light, (3) to allow safe access into the optics hutch when required, (4) to monitor the position of the synchrotron light, (5) to protect the storage ring vacuum if there is a leakage in the beamline, and finally (6) to standardize the FE components.

The designed goal of TPS is 3 GeV electron beam at 500 mA. The intense synchrotron radiation to the FEs is generated by In-vacuum Undulators (IU) or Elliptically Polarizing Undulators (EPU). There are four types of IDs listed in Table 1, with a maximum power density of 63.4 kW/mrad^2 and a maximum total power of 9.7 kW. In three straight sections there are two IDs, generating a maximum total power of 16.3 kW to the FEs, which makes the FE design even more complex. The intercepted power and power density on all FE components are simulated by Finite Element Analysis (FEA) to verify the thermal performance under maximum power and power density.

Table 1: Phase-I 7 ID Parameters

Beamline	ID type	K_x	K_y	$dP/d\Omega$ (kW/mrad^2)	P (kW)
05, 21, 23	IU22(3m)		2.15	63.4	9.7
09, 25	IU22(3m)+		2.15	63.4	9.7
	IU22(2m)		2.15	43	6.6
41	EPU48+	2.51	3.78	26.5	7.1
	EPU48	2.51	3.78	26.5	7.1
45	EPU46	2.23	3.35	27.9	6.5

To reduce the design efforts, manufacture, assembly, maintenance and need for spare parts, all FE components are standardized and the dimensions of all FE components are the same, except for the lengths of one straight tube and one support due to different lengths of FEs.

After completing the configuration of the FE, the vacuum pressure distribution is calculated by a Monte–Carlo method and to keep the simulation easy, a simplified model and a photon flux distribution is used in these calculations.

This paper describes the main design considerations for the ID Front Ends, including high heat load, radiation safety, beam monitoring and vacuum pressure distribution.

FRONT END LAYOUT

The standard ID Front End is illustrated in Fig. 1: (1) Pre-Mask, (2) Screen Monitor, (3) Collimator, (4) 1st X-ray Beam Position Monitor, (5) 1st Fixed Mask, (6) 2nd Fixed Mask, (7) Photon Absorber, (8) All Metal Valve, (9) Fast Closing Valve, (10) 2nd X-ray Beam Position Monitor, (11) 1st Slit, (12) 2nd Slit, (13) Heavy Metal Shutter, (14) Radiation Shielding Blocks, (15) All Metal Valve at the end of the FE.

In phase-I, all seven Front Ends use the same layout. All components and supports have alignment ready receptacles for Laser Tracker survey and alignment. The supports also define a base line for the horizontal and vertical plane [1] to quickly allow a local check of component positions.

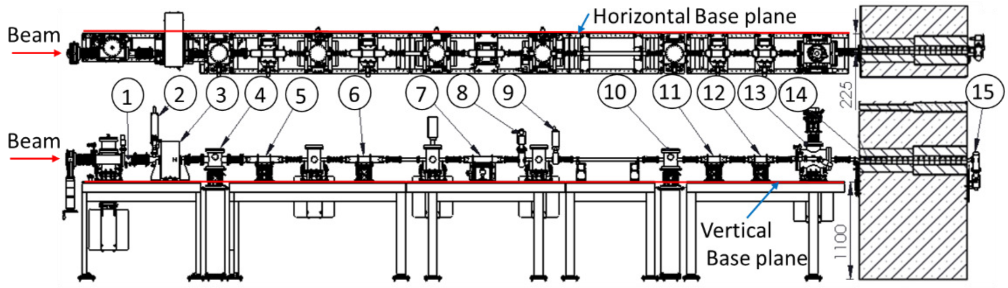

Figure 1: Standard layout of ID Front Ends in the TPS.

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HIGH HEAT LOAD COMPONENTS

Designing an ID Front End, we first consider the required apertures for high heat load components. The users need the photon fan of first harmonic ID radiation. Figure 2 shows the photon flux distribution in the horizontal (X) and vertical (Y) plane. The slit apertures are chosen for HxV=4x4 mm and about 0.16-0.2 mrad in both planes.

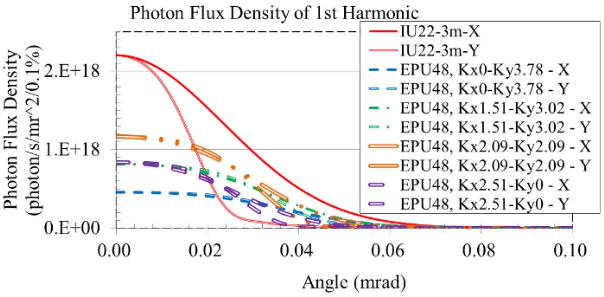

Figure 2: Photon flux distribution of the IDs.

The second step is to calculate the power density distribution for the IDs, and to decide on the reasonable miss-steering range of the electron beam in the storage ring given by eq. (1) for both the horizontal and vertical directions. Note that the equation (1) is only for the use of mechanical design.

$$\frac{|Z'|}{0.2\,mrad} \leq 1\,, \quad \frac{|Z|}{2\,mm} \leq 1, \qquad (1)$$

where Z′ is the angle of the electron beam with respect to the beam axis, and Z is the position of the electric beam. Figure 3 shows the power density distribution in the horizontal and vertical direction. The definition for a Normal Photon Fan (NPF) is defined by the area where the photon power density is more than 5 W/mm^2 at the position of Pre-Mask. Figure 4 shows an example of ray tracing by drawing a photon fan (+/- 2mm) + (+/- NPF mrad) + (+/- 0.2 mrad), and a safety margin of at least 2 mm on the FE components for mechanical tolerances. Completing the ray tracing, the apertures of all components can be selected.

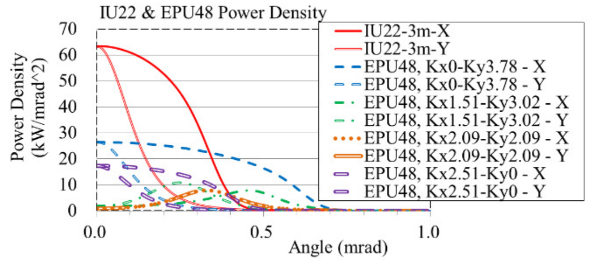

Figure 3: Power density distribution of the IDs.

The goal of the range of electron beam miss-steering for the feedback interlock system is given by eq. (2)[2].

$$\frac{|X|}{0.5\,mm} \leq 1, \quad \frac{|Y|}{0.2\,mm} \leq 1, \qquad (2)$$

After the apertures of all FE components are defined, the maximum power density and total power on intercepting high heat load surfaces can be calculated as shown in Figs. 5, 6 and 7. The limiting power criteria on these surfaces are a power density not exceeding 10 W/mm^2 and a total intercepted power of less than 10 kW on each component.

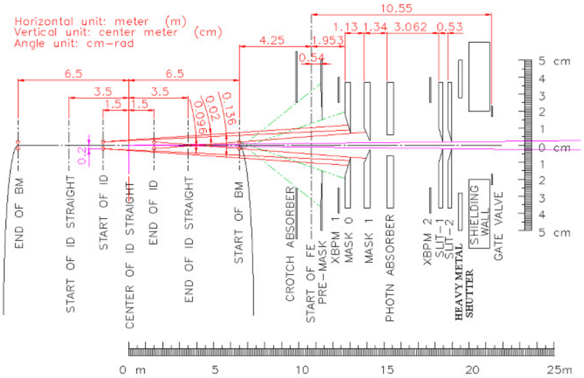

Figure 4: Ray Tracing in a single ID FE.

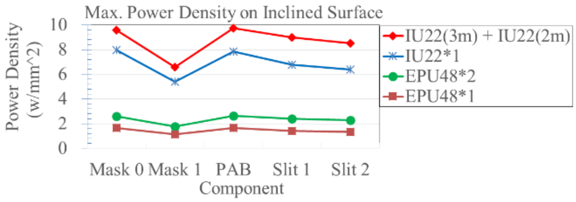

Figure 5: Maximum power density on intercepting surfaces of high heat load components in all ID FEs.

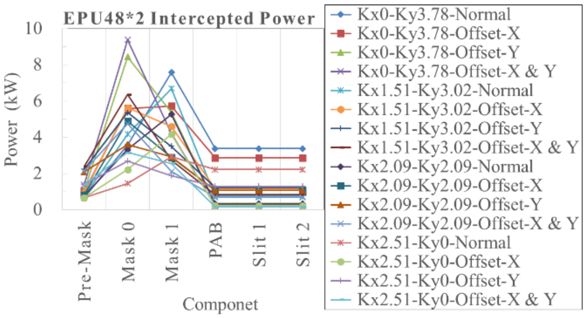

Figure 6: Total power on intercepting surfaces of high heat load components for the tandem EPU48 FE.

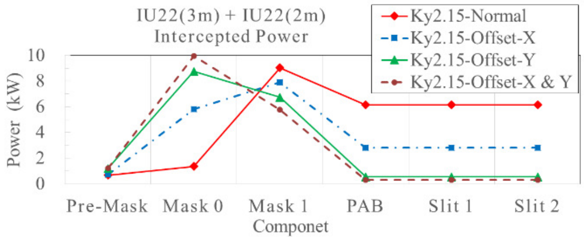

Figure 7: Total power on intercepting surfaces of high heat load components for the tandem IU22 FE.

FINITE ELEMENT ANALYSIS

The design and validation of all high head load components have been carried out by means of Finite Element Analysis using "SOLIDWORKS Simulation" program for the example of Fig. 8 [3].

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A simple temperature based criterion is followed limiting the maximum temperature to less than 150 ℃ on the walls of water cooling channel, a maximum temperature of less than 150 ℃ for Oxygen Free High Conductivity Copper (OFHC) material surfaces, and a maximum temperature of less than 300 ℃ for Glidcop material [4].

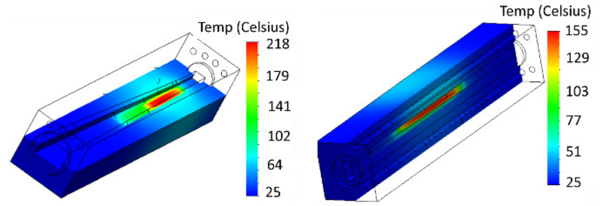

Figure 8: FEA analysis of the 1st Fixed Mask (left, Glidcop) and Photon Absorber (right, OFHC).

PRESSURE DISTRIBUTION

The vacuum pressure distribution can be calculated by a numerical algorithm [5] or a Monte–Carlo method. For both methods, the photon-stimulated desorption (PSD) induced by synchrotron radiation must first be calculated. To calculate the PSD in the ID FEs is straight forward but complicated, and the numerical algorithm is also complex. Therefore, in this paper, the vacuum pressure distribution is calculated only by the Monte–Carlo method in the CERN developed Molflow+ program.

A simple evacuating method is applied, with a simplified model and a generic photon flux distribution to calculate the PSD used in the Monte–Carlo Simulator.

The worst case pressure distribution is caused by the tandem IU22 FE shown in Fig. 9. The criteria of vacuum pressure: (a) at the source z=0 m, the pressure need to be at least in the 10^{-8} Pa range, (b) at the end of the FE, the pressure need to be at least in the 10^{-7} Pa range, and (c) the average pressure in the FEs is in the 10^{-6} Pa range. The maximum pressure is located between the two slits, due to the small apertures of only 4x4 mm.

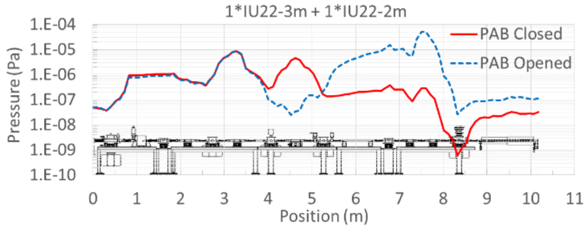

Figure 9: Pressure profile in the 2*IU22 FE.

OTHER DESIGN CONSIDERATIONS

The water flow rate is kept to below 3 m/sec to reduce vibrations. All high heat load components are cooled by two independent water flow channels to obtain more reaction time before damage occurred if one channel failed.

For radiation safety, the Heavy Metal Shutters and Radiation Shielding Blocks must be overlapping to prevent radiation. Radiation Shielding Blocks are embedded in the 1200 mm thick concrete wall. Instead of piling huge piles of lead blocks, a compact design is adopted as Fig. 10.

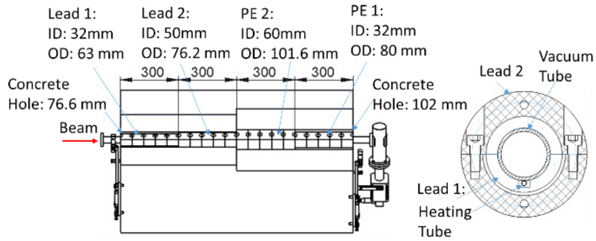

Figure 10: Radiation Shielding Blocks composed of 40 half circle shaped blocks and installed in the concrete wall.

The X-ray Beam Position Monitor (XBPM) is to monitor the position and angle of photon beam. The 1st and 2nd XBPM is separated over 5 m to enhance the resolution of measurement of photon beam angle. The XBPM uses the design of Dr. D. Shu from APS.

Figure 11 shows the photon beam image on a Screen Monitor. The Screen Monitor is to make sure that the photon distribution of an ID and a BM source is on the same level. When using the Screen Monitor, the maximum beam current is limited to below 0.1 mA.

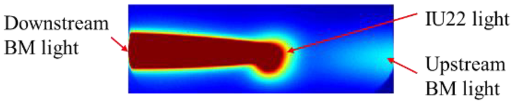

Figure 11: Image of ID and BM photon beams.

CONCLUSION

The general design of ID Front Ends in the TPS matches the initial purposes. Now the ID FEs are operating successfully. The standardized design of ID FE components reduces much work and the quantity of spare parts. Only 1st Mask and 2nd Mask in the long straight section of a Front End are made from GlidCop material, the others are all made from OFHC material. A simplified evacuation method was used in Molflow+ simulations to define an effective and reasonable vacuum pressure distribution.

ACKNOWLEDGEMENT

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