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PROGRESS OF FRONT ENDS AT HEPS

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Abstract

High Energy Photon Source (HEPS) is a 6 GeV synchrotron radiation facility building in Huairou, with a storage ring perimeter of 1390.6 m and 41 straight sections. In phase I, 15 front ends will be installed, including 14 insertion device front ends and 1 bending magnet front end. These front ends are divided into three types: the Undulator front end, the Wiggler front end, and the BM front end. The U-type front end will receive 766 W/mrad^2 of peak power density and 25 kW of the total power. The design of the W-type front end is based on compatibility with various insertion devices, including undulators and wigglers. In this paper, the designs and the progress of HEPS front ends are presented.

INTRODUCTION

HEPS is a 6 GeV synchrotron radiation facility building in Huairou, storage ring has 48 straight sections, and 41 of them that are 6 m long can extract user beams, as 7 are required for injection and RF straights. Therefore, there is a capacity for 41 Insertion Device (ID) Front Ends and 41 Bending Magnet Front Ends to be installed. Fifteen beamlines are being built in Phase I of HEPS project. One of them is BM beamline, others use ID as light source. These front ends are divided into three types: the Undulator front end (UFE), the Wiggler front end (WFE), and the BM front end (BFE). The UFE will receive 766 W/mrad^2 of peak power density and 25 kW of the total power. The design of the WFE is based on compatibility with various insertion devices, including undulators and wigglers.

GENERAL LAYOUT

Front ends at HEPS are divided into three types: Undulator Front End (UFE), Wiggler Front End (WFE), and Bending Magnet Front End (BFE). There are 12 UFEs, 2 WFEs, and 1 BFE. Due to the implementation of a unified standardized design, the layout of the three types of front ends is similar. The main components of front ends are: (1) Pre-Mask, (2) Low Power Photon Shutter, (3) All-metal Fast Valve, (4) 1st Fixed Mask, (5) XBPM, (6) Photon Shutter, (7) Slits, (8) Filters, (9) Safety Shutter, (10) Ratchet Wall, (11) 2nd Fixed Mask, (12) Be Window. Figure 1 shows the layout of UFE. Table 1 summarizes the front end parameters.

COMPONENTS

Pre-Mask

The isolation valve on the crotch leg of the storage ring is followed by the Pre-Mask which is to reduce dipole radiation to downstream 1st Fixed Mask. The absorber of the Pre-Mask is made of OFHC and cooled by water. The mechanical module of the Pre-Mask is shown in Fig. 2.

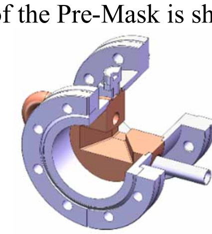

Figure 2: Mechanical module of the Pre-Mask.

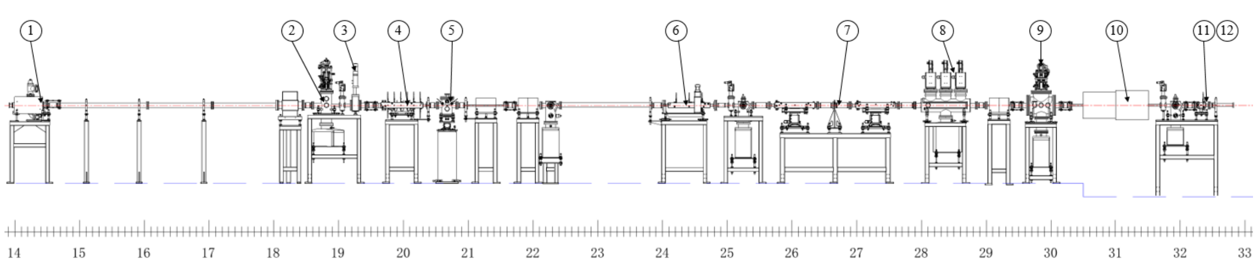

Figure 1: Layout of the UFE.

Table 1: The Parameters of Front Ends at HEPS

	UFE	WFE	BFE
Length [m]	18.9	18.9	22.2
Beam Size at Entrance [mrad]	3.1×1.3	3.1×1.3@ID19, 3.2×1.5@ID42	3.3×1.5
Beam Size at Exit [mrad]	0.2×0.2	1.0×0.9@ID19, 2.0×0.3@ID42	2.0×0.4
Peak Power Density [kW/mrad^2]	766	414	0.18 kW/mrad
Total Power [kW]	25	9	

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Fixed Mask

The Fixed Mask defines the angle of departure of the beam which pass into the front end, and prevents downstream components from irradiated by misteered beam. In the case of normal incidence, the Fixed Mask will be subjected to a power density of 2.0 kW/mm^2. Therefore, the form of aperture presents an hourglass, which provide grazing incidence to the beam in order to reduce the power density on the footprint. The grazing incidence is 0.689˚. The Fixed Mask absorber is made of dispersed copper alloy, which has high thermal conductivity, high yield strength, and high softening temperature, making it very suitable for the manufacturing of absorbers under high heat load. In order to take away the heat load as quickly as possible and reduce the maximum temperature, copper wire-coils are placed in the uniformly distributed water-cooled pipes near the internal surface for enhanced heat transfer [1]. After testing, the convective heat transfer coefficient of the pipe wall can reach 25000 W/m^2·K at 4.4 kgf/cm^2[2]. The Fixed Mask module is shown in Fig. 3.

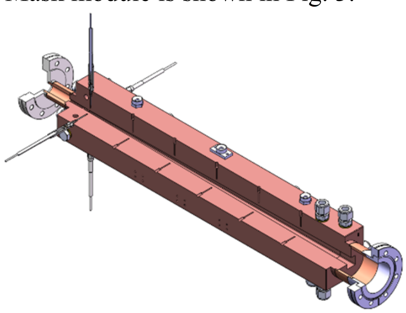

Figure 3: Section view of Fixed Mask.

Photon Shutter

The front ends at HEPS have two types of the Photon Shutter (PS). One of them is a Low Power Photon Shutter (LPPS) (Fig. 4) which is subject to the heat load from upstream and downstream bending magnet of an insertion device. It can be combined with the downstream vacuum isolation valve to ensure that the operation of the storage ring and other beam lines are not affected when the current front end malfunctions. The LPPS absorber is made of OFHC and cooled by water. Another is a white beam Photon Shutter (PS) (Fig. 5), which can close the synchrotron radiation to downstream components. Due to suffering from the peak power density up to 1.3 kW/mm^2, it has a grazing incidence surface with 1.3˚ angle that will intercept the beam. There are four water-cooled channels near the surface, and copper wire-coil inside the channels enhance heat transfer.

Safety Shutter

The function of the Safety Shutter is to block bremsstrahlung radiation. The absorber which is made of Tungsten has two parts, movable block and fixed block, the material thickness is 200 mm. To close the Safety Shutter, the movable block moved down. The size from the edge of the block to the bremsstrahlung radiation spot is larger than three times the Moliere radius. The Safety Shutter is shown in Fig. 6.

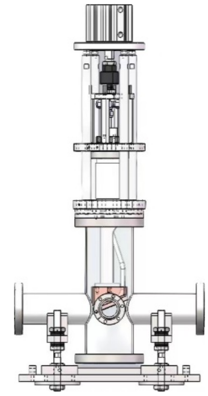

Figure 4: The Low Power Photon Shutter module.

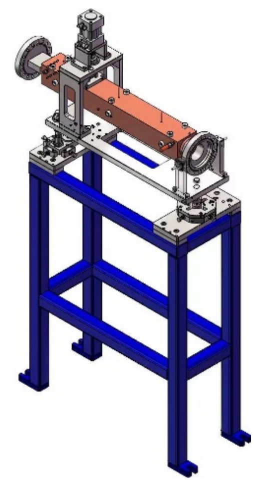

Figure 5: Mechanical module of the Photon Shutter.

Figure 6: Safety Shutter.

Slits

A set of Slits is to define the beam size exiting the front end, the upstream and downstream absorber both are L-shaped components can independently move in the vertical and horizontal directions. The stages below the absorbers have an accuracy of 1 µm with an equivalent angular accuracy of approximately 0.04 µrad. The mechanical module of slits is shown in Fig. 7.

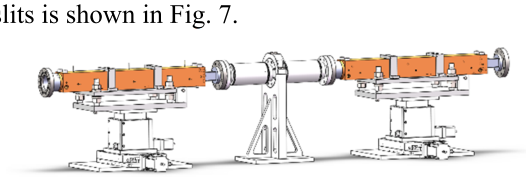

Figure 7: Slits module.

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Filters

A set of Filters is used to reduce the heat load on the downstream components in the First Optical Enclosure. It is composed of three sets of 3-position carbon foils which have different thicknesses installed according to various requirements. A water-cooled copper frame is used to clamp the graphite foils.

Fast Valve

An all metal Fast Valve is installed downstream of LPPS, with a maximum aperture of 60 (H) mm × 20 (V) mm and can be closed within 8 ms. The leakage rate is less than 0.4 Torr·L/s, and the service life is greater than 1000 times. The all metal Fast Valve is shown in Fig. 8.

Figure 8: All Metal Fast Valve.

PROJECT CHALLENGES

Fatigue Life

As a fourth-generation synchrotron radiation facility, HEPS can generate a peak power density of 766 kW/mrad^2 from its insertion devices, which means that the absorbers in the front ends will withstand very high heat loads. In order to reduce the power density on the surface, a grazing incidence design scheme is usually adopted. Previous design and criteria did not allow the maximum stress of the absorber to exceed the yield limit. According to these criteria, if the front end at HEPS is designed with a fixed mask, the total length of the absorber will exceed 2 m. In a storage ring tunnel with limited space, this design is clearly not the optimal choice. According to the research and the practical experience of ESRF [3], APS [4], and SPring-8 [5], the low cycle fatigue life design method within the elastic-plastic range allows for a certain degree of plastic deformation, effectively solving the contradiction between high heat load and absorber length. The design of the HEPS front end absorber is based on a strain based low cycle fatigue life analysis method. The length of the absorber for UFE 1st fixed mask can be restricted within 700mm, and its service life can meet the 30 year usage requirement under twice the safety factor.

Mechanical Manufacturing

The length of the absorber of the UFE components is nearly 700 mm, shown in Fig. 9, and the maximum processing length of the high-precision slow wire-cut machine is only 300 mm. Therefore, the processing technology of the absorber internal surface and optical aperture is a major challenge for the manufacturing of the front ends at HEPS. The current processing technology is to first use a deep hole drill to make a small hole in the centre of the absorber, then use a medium wire-cut machine to process the optical aperture, then cut out the hourglass shape of the grazing incidence surface, and finally manually polish the inner surface through customized tooling. After testing, the internal surfaces and apertures of the 12 UFE 1st Fixed Masks meet the requirements of geometric tolerances, and the surface roughness is less than Ra0.8.

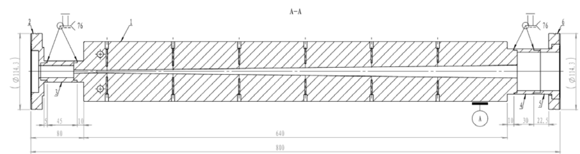

Figure 9: Section view of Fixed Mask.

CONCLUSION AND DISCUSSIONS

The 15 front ends constructed in the phase I of HEPS adopt standardized design, and most of the materials of the absorber are made of dispersed copper alloy. The challenge of High heat loads are well solved by using grazing incidence and enhanced heat transfer, and the design criteria are based on the strain based low cycle fatigue life analysis method. The project has overcome the impact of the COVID-19. At present, 13 of the 15 front ends have completed factory acceptance, and some of the 12 front ends are installed in the tunnel of the storage ring, which is expected to be formally installed in January 2024.

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