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A DESIGN OF AN X-RAY PINK BEAM INTEGRATED SHUTTER FOR HEPS*

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Abstract

The main function of the shutter is to accurately control the exposure time of the sample so that the sample as well as the detector can be protected. In order to cover the high thermal load and high energy working environment, we designed an integrated shutter device. The device includes a thermal absorber shutter, a piezoelectric ceramic fast shutter, a vacuum chamber and an adjustable height base. Firstly, SPECTRA and ANSYS were used to verify the device's institutional temperature reliability at a thermal power density of 64 W/mm^2. In addition, the device is suitable for both monochromatic and pink light operation with a horizontal pitch of 15 mm. The device is also compatible with both vacuum and atmospheric working environments, and the recollimation of the device is not necessary when switching modes. Finally, the thermal absorber shutter is also able to function as a beam profile monitor, and the position of the spot can be monitored through a viewing window on the cavity.

INTRODUCTION

The high energy photon source (HEPS) is a fourth-generation synchrotron radiation facility and has characteristics of high brightness, high flux, and high coherence [1].

The integrated shutter is designed for the small angle X-ray scattering station, which is under construction at HEPS and characterized by a pink beam with enormous high photon flux. In order to solve the problem of the vacuum heat dissipation and at the same time ensure a fast response, we proposed the following schematic design. Firstly, as shown in Fig. 1, the integrated shutter is comprised of a thermal absorber shutter in series with a piezoelectric ceramic fast shutter. It works as follows: in the off-work state, the thermal absorber shutter is responsible for taking away the heat from the pink beam to protect the piezoelectric ceramics. When working, the thermal shutter is opened first, and then the piezoelectric ceramic shutter turns on, at the same time the detector starts sampling. After the exposure time, the detector and the piezo shutter turn off first, after that the thermal shutter is closed and continues to absorb the heat. By coordinating their different opening and closing times, the exposure time of the sample can be controlled.

The monochromatic beam and pink beam in SAXS can be switched through moving in and out of the monochromator and there is 15 mm in the horizontal direction between the two beams. In order to ensure that the position of the integrated shutter does not need to be adjusted after switching modes, we designed two pass-through holes in the piezo shutter, which can meet the passing of pink beam as well as monochrome beam.

In addition, after being coated with fluorescent powder, the thermal absorber shutter is also able to function as a beam profile monitor and the position of the spot can be monitored through a viewing window on the cavity.

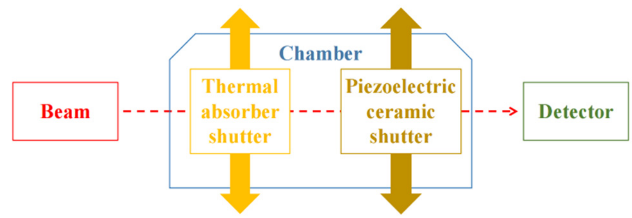

Figure 1: Schematic diagram of integrated shutter.

DESIGN

Overall Description

The integrated shutter consists of three parts: a thermal absorber shutter, a piezoelectric ceramic fast shutter and a stainless-steel vacuum chamber. The assembly drawing is sketched in Fig. 2.

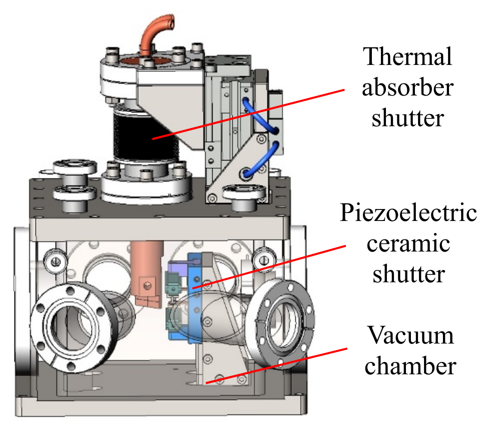

Figure 2: Schematic diagram of integrated shutter.

Thermal Absorber Shutter

At this position the spot size of pink beam is 500 µm and the thermal power density is 64 W/mm^2. It will be a burden for the thermostat system if the heat is emitted directly into the experimental hutch. For this reason, we decided to use water cooling instead of natural cooling. The thermal absorber shutter is driven by an LCG cylinder slide with a stroke of 5 mm, as shown in Fig. 3 and the response time of the cylinder slide is less than 0.1 seconds. The material of water-cooled absorber is OFHC, and the light-receiving surface of the absorber is angled at 45° to the optical axis.

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This can reduce the power density and also facilitate the observation of the spot position. According to these boundary conditions, we performed simulation of the absorber using ANSYS, and the results are shown in Fig. 4. The steady-state temperature of the absorber is about 67 °C, which is much lower than the safe temperature of OFHC [2], indicating that the structural design is reasonable.

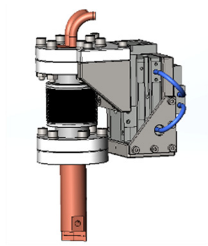

Figure 3: Thermal absorber shutter.

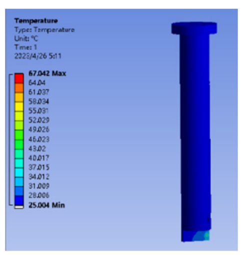

Figure 4: Simulation results.

Piezoelectric Ceramic Shutter

Due to the water-cooled absorber, the response time of the thermal shutter is hardly to the millisecond level, so we need a faster shutter to block x-rays. Piezoelectric ceramic actuators have very fast response, compact structure and small stroke, so they are very suitable as a driving part of the fast shutter.

The fast shutter structure is shown in Fig. 5, which is composed of two piezoelectric ceramic actuators. The stroke of each actuator is 0.6 mm, so an opening range of 1 mm can be achieved through two matching and the response time is less than 1 millisecond. The material for blocking photons of the piezoelectric ceramic shutter is tungsten alloy. There is a horizontally distance of 15 mm between the monochromatic beam and the pink beam in the SAXS station. Considering this, two through-holes with the same distance are designed on the fast shutter, which ensure that both kinds of beams can pass through.

Although most of the heat can be taken away by the upstream absorber shutter, there will still be heat accumulation after a long period of operation in a vacuum environment. This will seriously affect the working life of piezoelectric ceramics. For this reason, a copper braid connected to the tungsten alloy is added, which can transfer the heat to the environment through the cavity. Under the condition that the pink beam continuously irradiated the tungsten alloy for 60 seconds, both structure designs are simulated

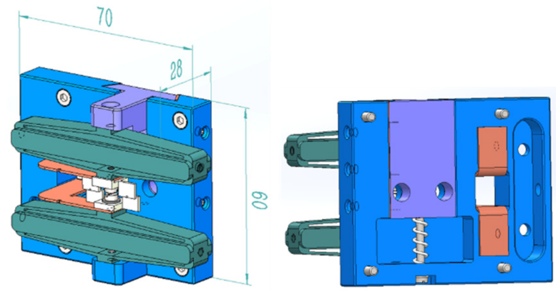

Figure 5: Design of piezoelectric ceramic fast shutter.

and the results are shown in Fig. 6. The maximum temperature of the structure with copper braid is 388 °C, which is much lower than the maximum temperature of 850 °C for the structure without copper braid. After that, natural cooling is carried out and the simulation results are shown in Fig. 7. Obviously, the structure with copper braid has a faster cooling rate and is also closer to the ambient temperature with time.

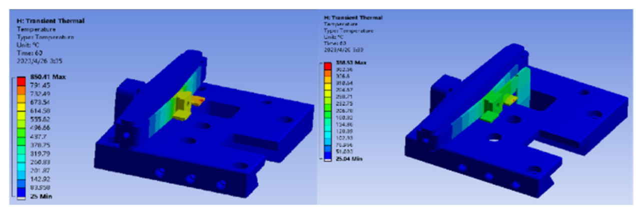

Figure 6: Simulation results of shutter with and without copper braid after heating for 60 s.

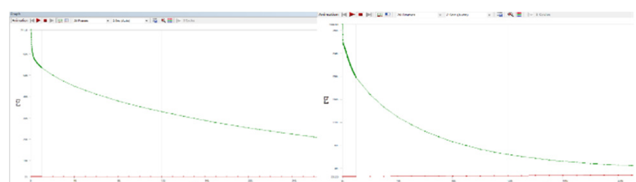

Figure 7: Simulation results of naturally cooling.

Vacuum Chamber

The working environment of the integrated shutter is mainly low vacuum. The design of the vacuum chamber is shown in Fig. 8. The cavity is not only for integration of the thermal absorber shutter and the piezoelectric ceramic shutter, but also can be compatible with the working environment of the atmosphere. When working in atmosphere, an Uniblitz shutter can be used as shown in the Fig. 9. The upstream of the integrated shutter is a beryllium window, while the downstream can be isolated from vacuum by installing a mylar window in the cavity with a quick release flange.

Two observation windows are designed on the cavity. One of them is used to observe the position of the spot on the absorber as well as the functioning state of the piezoelectric ceramic shutter. The other is primarily for observing the functioning state of the shutter UNIBLITZ. After being coated with fluorescent powder, the absorber can be used as a beam monitor. The field of view through both windows is shown in Fig. 10.

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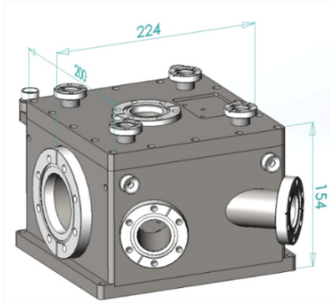

Figure 8: Vacuum chamber.

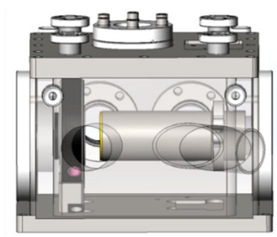
Figure 9: Uniblitz and mylar window.

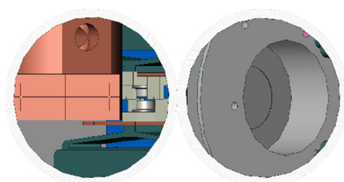
Figure 10: Field of view through the windows.

Main Specifications

The main specifications of integrated shutter are shown in Table 1.

Table 1: Main Specifications

Integrated shutter	
Beam size	500*500 μm^2
Thermal power	16 W
Response time	Less than 2 ms
Function module integration	Thermal absorber shutter, Piezoelectric ceramic fast shutter, Beam profile monitor

CONCLUSION

The integrated shutter incorporates many functional modules, which means that the corresponding control system and collimation calibration work will be challenging. At present, the machining of shutter parts is in progress, and we will carry out further work on the collimation calibration, motion control and accurate response time test of equipment in the future.

REFERENCES

[1] IHEP, `http://english.ihep.cas.cn/doc/2639.html`

[2] Bernard Kosciuk, "Final Design Review of X-Ray Flag", Rep. BNL NSLS-II Final Design Review, August 5th, 2014.

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