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PHOTON SLITS PROTOTYPE FOR HIGH BEAM POWER USING ROTATIONAL MOTIONS

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Abstract

A new slits prototype utilising a rotatable oxygen-free high thermal conductivity (OFHC) copper block to absorb high heat load is developed for the Diamond-II upgrade. The slits will be used at front end of Diamond I13 X-ray Imaging and Coherence beamline which has two canted beamline branches. Required by the beamline optics, the front end slits function as virtual sources for the 250 meters long beamline. Working for the dual beam geometry, these specialised slits can vary the size of one x-ray beam with rotational motions while allowing the second beam to pass through unaffected. The rotational operations of the slits are achieved by an innovative commercial flex pivot and a unique in-house designed pivoting flexure.

INTRODUCTION

This paper describes the prototype design of a new slits utilising a rotatable OFHC copper block to absorb high heat load. The prototype is part of Diamond-II upgrade pre-development for three front end applications. The design case picked is to prototype for Diamond I13 X-ray Imaging beamline.

The I13 X-ray Imaging and Coherence beamline has two canted beamline branches. The front end slits function as virtual sources which is required by the I13 beamline optics in the long insertion straight of I13. It is essential to place the opposite beam defining blades at close proximity to collimate the x-ray beam. Diamond traditional white beam slits are not suitable for this function. In the traditional layout, the virtual focal point required by the beamline optics cannot be formed because the opposite slit blades are placed at a great distance due to one 'L' shaped blade being fixed onto an upstream copper assembly and another 'L' shaped blade being fixed onto a downstream copper assembly.

The newly developed slits prototype utilises a rotatable copper block assembly with the integration of a pair of 'L' shaped slits blades in one brazed copper block. The pair of 'L' shaped blades are placed at close proximity which is the perfect solution for creating the needed virtual source at the front end. The design concept is inspired by Schmidt's design of "Variable aperture photon mask (slits) for canted undulator beamlines at the Advanced Photon Source" [1]. Working for the dual beam geometry, these specialised slits can vary the size of one x-ray beam with rotational motions while allowing the second beam to pass through unaffected. The rotational operations of the slits are achieved by innovatively designed pivoting flexure and commercial flex pivots. Since the slits are used in the front end, the rotatable slits block is required to handle high beam power from the undulator insertion device of I13 beamline. To consider other Diamond-II applications, we developed the slits to be capable of carrying out raster scanning.

DESIGN

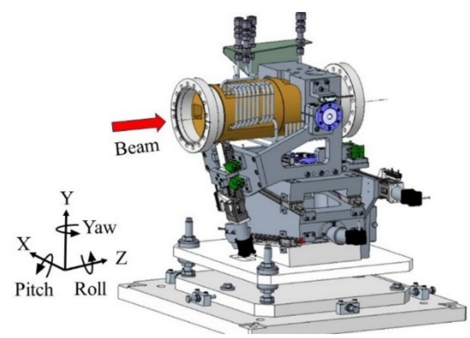

Figure 1: Slit assembly and the coordinate systems.

The overview of the slit assembly is shown in Fig. 1. The slits are installed at 18.4 meters from the source. The dual beam geometry is shown in Fig. 2. At the location, the photon beam size of the I13 Imaging branch is 4.1 × 4.1 mm, and the beam size is 3.7 × 3.7 mm for the Coherence branch. The separation distance of the two canted photon beams is 64.7 mm. The slits vary the size of Imaging beam while allowing the Coherence beam to pass through unaffected. The slit is also required to scan the beam. When carrying out the scanning, the slits are opened a set amount and then driven across the beam in a vertical or horizontal motion.

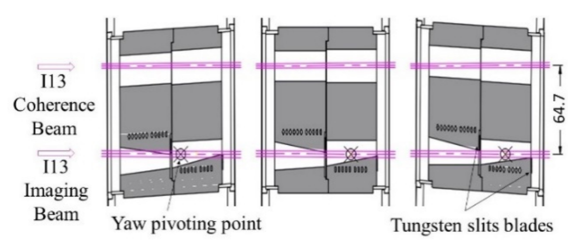

Figure 2: Anamorphic view of sections in X-Z plane showing yaw rotations of the slits. Left: closed position; Middle: neutral position; Right: open position.

Slits Rotary Motions

In normal operation mode, slits are only required for varying opening apertures. Using the concept from Schmidt [1], the variation of slit aperture is achieved by rotating the slit block horizontally (yaw rotation) and vertically (pitch rotation). Two unique pitch and yaw rotary stages (Figs. 3 and 4) are designed to control the slit width in the vertical and horizontal direction. The rotary stages are driven by a linear drive with the rotary motion produced by a flexure link between linear and rotary motion. The

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distance of this drive from the centre of rotation will determine the linear to rotation ratio of the drive.

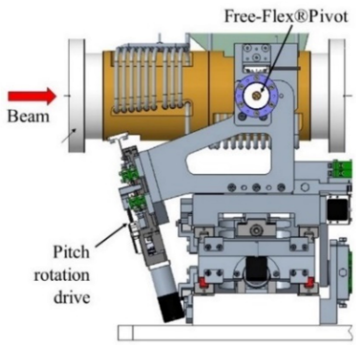

Figure 3: Design of the pitch rotary stage.

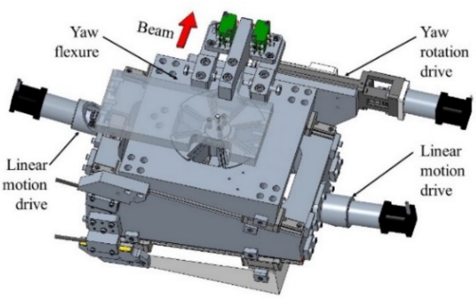

Figure 4: Design of the yaw rotary stage.

In both pitch and yaw rotation, the neutral position of the pivoting axis is set to align the centre of the slit to the beam centre. By rotating ± 1° from the neutral position, the slit is fully closed or fully opened (Fig. 5). Motion limits are set at ± 1° rotation angle. To safely handle the overtravel of the rotary stage, there are additional backup switches and hard stops. Hard stops are set at ± 1.6° rotation from the neutral position.

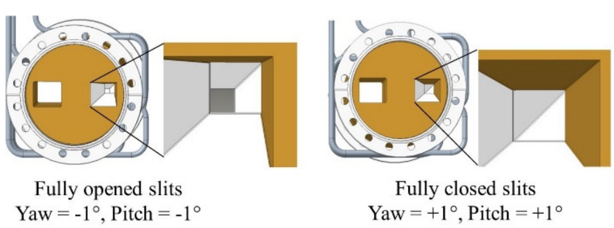

Figure 5: Details of fully opened and closed slits.

We were concerned with the performances of rolling element bearings for small intermittent angle rotations involved in this design application, because frictional hysteresis typically found in rolling element bearings would prevent very accurate control of small rotational positions. For the pitch axis we choose to use a pair of Free-Flex® pivots where we have many successful designs with using them in other Diamond instruments. Stiction-free and lubrication-free Free-Flex® pivots [2] are uniquely suited for the pitch rotary stages that have limited angular travel and use in a radioactive environment such as a front end. For yaw axis, we attempted a unique rotary flexure design as it was not feasible to support the yaw axis from both ends.

The Design of Yaw Rotary Flexure

The rotary flexure uses similar symmetrical leaf flexure design as the concept published by S. Wan and Q. Xu for a rotational micro positioning stage [3]. The design of the yaw flexure is shown in Fig. 6.

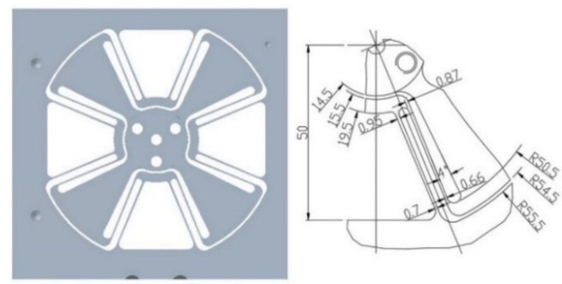

Figure 6: Details of yaw rotary flexure.

We chose to use a martensitic stainless steel BS 970 420S45 heat treated to QT800 condition. This gives a good combination of high strength, tough and corrosion resistant material.

Finite Element Analysis (FEA) was employed to optimise the thickness of the cross sections of the leaf flexure as the thicker the rib section, the higher the stresses on the rib but also the stiffer the rib in the pitch and roll direction. The thickens of the rib varies along its length to give equal stresses along the length of the rib (Fig. 7).

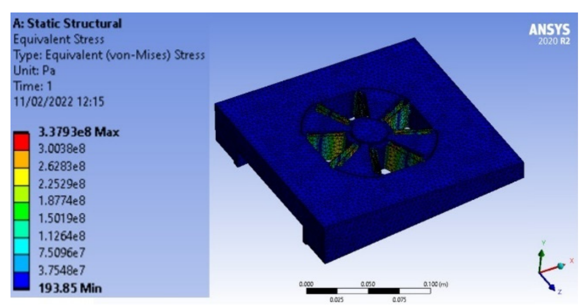

Figure 7: Stress distribution in the flexure.

Based on the FEA analysis, the designed rib configuration gave a maximum stress of 338 MPa at an equivalent deflection of 2° rotational movement. This compares with the material yield stress of 650 MPa at QT800 condition.

Slits Linear Motions

Placed underneath the pitch and yaw rotary stages, the X-Y stages are used to align the slit aperture to the centre of the photon beam, and to allow slits scanning in horizontal and vertical directions (Fig. 4). Due to space restrictions from existing installations, the linear motion components are on a wedge configuration which means that a compound motion is needed to produce a purely horizontal or vertical motion. The scan distance is +/− 2.5 mm horizontal and vertical from the slits neutral position. The scan distance is +/− 4.5 mm at motion hard stops.

Slit Block Design

The Slits block is constructed from an OFHC copper body with cooling channels placed close to the surface

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struck by photon beam. The cooling channels are machined within the body and connected by vacuum brazed stainless steel pipes. The body is constructed in two sections and is brazed to stainless steel flanges. 'L' shaped tungsten blades are fixed to the downstream end of each copper block (Fig. 8).

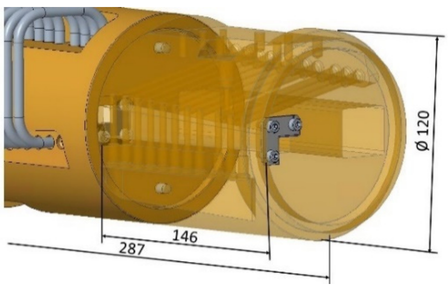

Figure 8: Slit block (downstream cooling pipe hidden).

VIBRATION MEASUREMENT

The initial vibration measurement was caried out with laser vibrometer. The prototype was measured under vacuum and connected to water services with pressure and flow close to operational conditions. Measurements evidenced that was no clear correlation or significant contribution to the power spectral density when adjusting the flow rate or changing the slit position to strain bellows. Cumulative power spectral density (CPSD) for each setup were similar (Fig. 9). We will use accelerometer to measure the slits vibration and further compare the results.

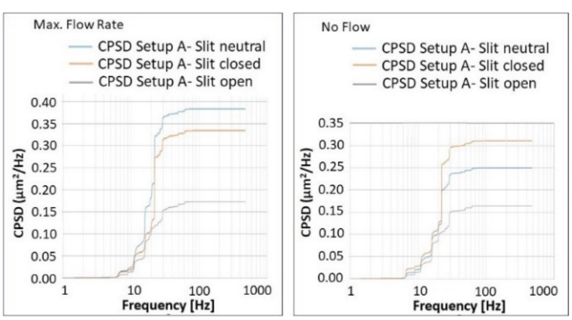

Figure 9: Vibrometer vertical measurement.

THERMAL AND STRESS ANALYSIS

The thermal loading on the copper body is greatly affected by the photon beam grazing angles as the slits rotate and the slits scanning position with a fixed grazing angle. The FEA was carried out for different combinations of grazing angles and liner travels for sensitivity study. The result described here is the worst case condition of the prototyping design case with maximum beam grazing angle of 5.6˚, and the maximum linear travel of X +4.5 mm and Y -4.5 mm. In actual application, the FEA condition is better than the above mentioned worst case. The beam power data is in Table 1. The highest temperature is 125.2 °C (Fig. 10) which is well below Diamond design criteria of 400 °C [4]. However, the peak thermal stress at the corner of the aper-ture is 269 MPa which is slightly higher than the limit (250 MPa) [4] for the elastic analysis. Further elastic-plastic analysis will be carried out.

Table 1: Beam Power Data

Beam energy & current	3.5 GeV, 330 mA
Undulator U22	K: 1.8899
Total power at copper body	2.86 kW
Peak power density at 18.4 m	127.9 W/mm^2

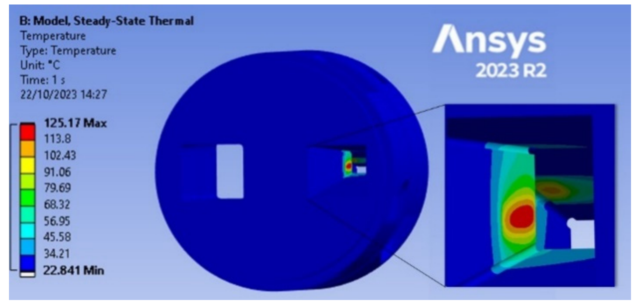

Figure 10: Temperature distribution.

CONCLUSION

This prototype has validated the idea of using rotatable slits as a space saving solution for front ends. The initial vibration measurement confirms that the slits could be used as the beamline virtual source. It is promising that through geometry optimisation, rotatable slits using OFHC copper is feasible for high beam power applications. In our further endeavour, we will measure the slits in close to operational conditions with collimated light to explore the performance of the in-house designed rotary flexure.

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