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FRONTEND SLITS FOR CLOSELY-SPACED WIGGLER BEAMS

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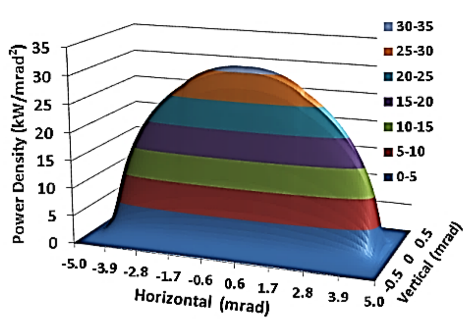
Abstract

A high energy x-ray (HEX) beamline facility will be constructed at NSLS-II for R&D in energy storage technologies using different x-ray imaging techniques. A 4.3 Tesla superconducting wiggler will be used to produced x-rays of total power of approximately 56 kW in 8 keV – 200 keV range. The nominal horizontal fan of ~ 10 mrad will be split into three closely spaced beams of 0.2 mrad, 1.0 mrad and 0.2 mrad fans. Each beam is required to have a frontend slit with four distinct apertures. The conventional L-shape design of the slit is not feasible for these closely spaced beams because of constraints on side cooling and horizontal travel of the slits. In this paper we propose two solutions for these slits using a beam pass-through design, vertical-only travel and optimized cooling configurations.

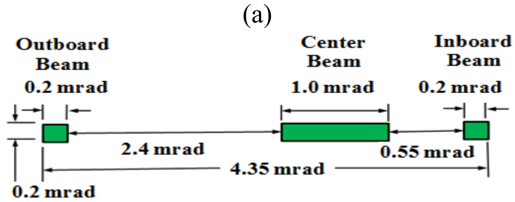
INTRODUCTION

NSLS-II is presently designing a state-of-the-art HEX beamline facility for fundamental research in energy storage technology and associated materials [1]. The facility will support three beamlines integrating multiple high energy x-ray imaging techniques. The beamlines will enable in-situ experiments on real materials and systems under real operating conditions.

The x-ray source will be a 4.3 Tesla superconducting (SC) wiggler that will produce highly intense x-rays of total power of 56 kW in 8 keV – 200 keV range. As shown in Fig. 1(a) this source has a large horizontal fan of 9.87 mrad as compared to the narrow vertical fan of 0.88 mrad. The peak power density is 28.4 kW/mrad^2.



(a)

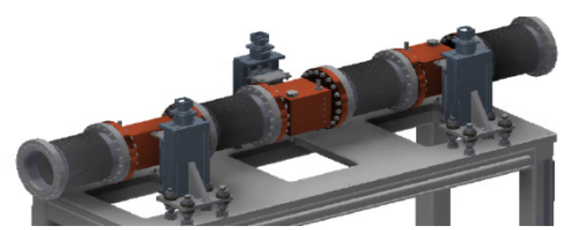


(b)

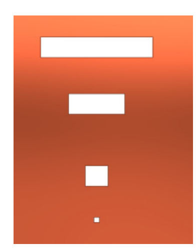
Figure 1: HEX wiggler x-ray source and beams, (a) power distribution of 4.3 Tesla SC wiggler, (b) 3 beams, fan sizes and spacings.

A fixed mask in the frontend, placed at 18 m from the source, divides the horizontal fan into three beams of 0.2 mrad (outboard), 1.0 mrad (center) and 0.2 mrad (inboard) as shown in Fig. 1(b). The separation between the outboard and center beams is 2.4 mrad, whereas it is only 0.55 mrad between the center and inboard beams.

Three slits are provided downstream of the fixed mask to reduce the beam size for each beamline independently (Fig. 2(a)). The conventional design of a pair of L-shaped slits is not possible for these closely spaced beams because there is no room for any significant horizontal travel. The HEX slits will, therefore, have four discreet apertures [2] ranging from a full beam size exiting the mask to a smallest size of (0.05 mrad H x0.05 mrad V). The apertures for the center-beam slit, separated vertically by ~ 10 mm, are shown in Fig. 2(b). Each slit will also act as a beam stop. Single axis high-precision linear stages will be used to provide vertical motion to the slits for remotely selecting one of the apertures.



(a)



(b)

Figure 2: Slits in the HEX frontend, (a) 3-slits assembly on a table, (b) 4 apertures of the center-beam slit with vertical separation of ~ 10 mm.

Two slit designs are described in this paper, one for the case when the narrow spacing between the beams is not sufficient to include cooling channels of reasonable size (> ϕ 6 mm). This design will be applicable to the center and inboard beams. The second design, applicable to outboard beam, is for the case where it is possible to include cooling channels between the beams, even if slightly smaller than ϕ 6 mm. For comparison both designs are discussed with respect to the center-beam slit.

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SLIT DESIGNS

Slit Design 1

The first slit design for the center beam is illustrated in the CAD model shown in Fig. 3. The model is oriented looking into the beam direction. For clarity the upstream flange (ϕ 200 mm) is removed. Overall length of the slit in the beam direction is 280 mm. Beam apertures are created on a surface (A) inclined at 10.8º from the vertical plane. Each aperture also has top and bottom tapered surfaces in order to further reduce the incident beam power density.

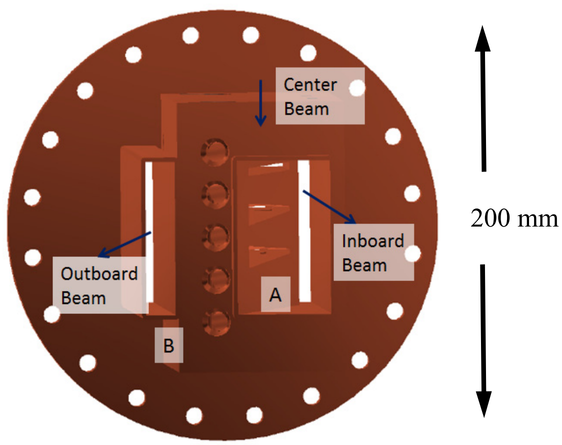

Figure 3: Slit design 1 for the center-beam slit. Apertures are created on the inclined surface (A).

Apertures for the inboard and outboard beams are made to be pass-through apertures taking into account the vertical travel of the slit. The center and inboard beams share the same vacuum space machined in a single part from CuCrZr. A separate rectangular chamber is machined for the outboard beam mainly to avoid water-to-vacuum joints on surface (B). This part is also made from CuCrZr. The two parts are then edge welded to the upstream and downstream CuCrZr flanges.

Because of high power density of the wiggler beam the cooling channels must be within a 3 – 8 mm range from the beam footprint. This is achieved by a cooling channels configuration shown in Fig. 4. Cooling channels C (see sectional view, Fig. 4(a)) of ϕ 9.5 mm are blind-drilled parallel to the inclined surface A (Fig. 3). Another set of channels D of the same diameter are blind-drilled perpendicular to surface B to connect with channels C. Both sets of channels are plugged at the entrances. Channels E and F are then drilled parallel to surface B to interconnect channels C and D, respectively. These channels are of ϕ 16 mm except at the entrances where the standard geometry for a 16 mm tapered plug is used. Custom tapered plugs are used for these channels as shown in (Fig. 4(b)). The stems of these plugs have two diameters, 6 mm in the middle to connect 2 water channels of ϕ 9.5 mm in series, and 16 mm at the end to plug the channels of ϕ 16 mm.

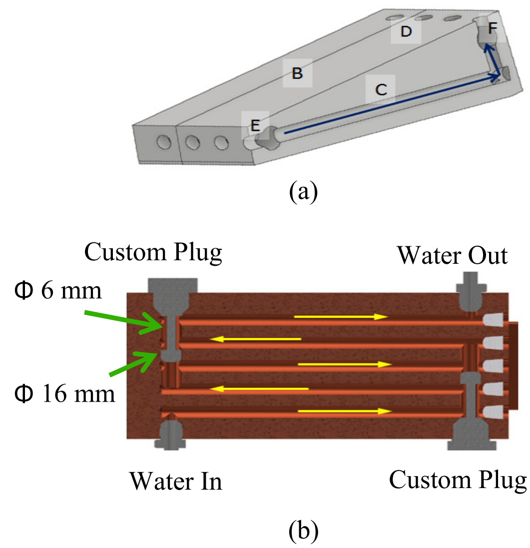

Figure 4: Cooling channels configuration, (a) C and D channels of ϕ 9.5 mm interconnected by channels E and F of ϕ 16 mm, (b) custom plugs for connecting the channels in series.

Slit Design 2

In slit design 2, water channels of smaller diameter (ϕ 5.5 mm) are provided in the narrow spacings between the beams. This slit design, shown in Fig. 5 without the flanges, is simpler due to symmetric cooling on the two sides of the apertures. Beam-intercepting surfaces A and B are inclined at 8.8º from the vertical plane. Overall length of this design is 150 mm including the 2 flanges (ϕ 200 mm). Inboard and outboard beams have pass-through apertures. These beams share the vacuum space with the center beam. The four apertures are EDM wire cut into the inclined surfaces with wire parallel to beam direction. No additional beam intercepting surfaces are created with these wire cuts as they were in the first design.

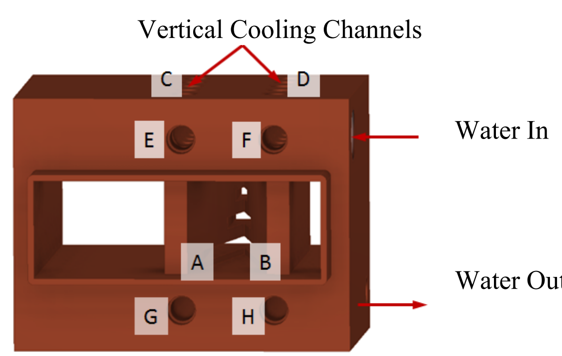

Figure 5: Slit design 2 with beam-intercepting inclined surfaces A and B. Vertical cooling channels C and D are interconnected by horizontal channel E, F, G and H.

Six vertical cooling channels of ϕ 5.5 mm (C and D) are blind-drilled on each side of the apertures. These are connected by 4 horizontal channels, E, F, G and H, of ϕ 9.5 mm. Series connections between the vertical channels are made by 4 custom plug-stems similar in design as in

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Fig. 4. All channel entrances are plugged by Lee© plugs. Water inlet and outlet are provided on the side surface as shown in the figure.

FINITE ELEMENT ANALYSIS

ANSYS finite element (FE) analyses were performed for both the designs. The wiggler beam was positioned at different parts of the slits to ensure that the worst condition was not missed. Heat transfer film coefficient for the cooling channels was assumed to be 0.01 W/mm^2.K. A conservative maximum temperature-rise criterion of 300º C under normal operation was used for CuCrZr. A higher limit, 400º C, was used for rare upset conditions.

Temperature contours for slit design 1 are shown in Fig. 6 for three different cases. Case 1 is for normal operation when the central part of the wiggler beam passes through one of the apertures, 0.2 mrad H x 0.2 mrad V aperture for instance. In this case a maximum temperature rise, ΔT_{max}, of 99.5º C is obtained (see Fig. 6(a)).

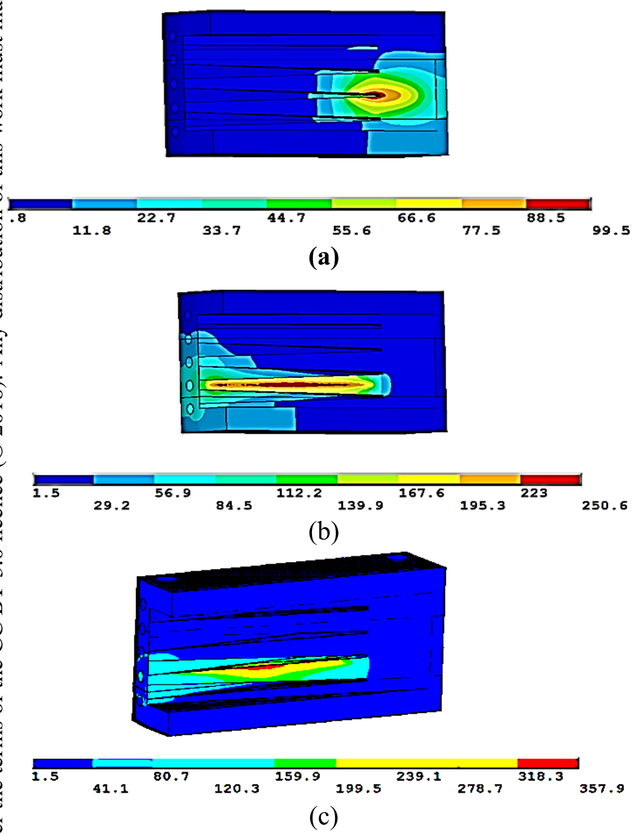

Figure 6: Temperature contours for slit design 1, (a) beam at the center of an aperture, (b) beam on a beam-stop position, (c) beam on an inclined edge (upset condition).

In case 2 the slit is used as a beam stop. The wiggler beam is parked on the inclined surface between any two apertures. For this case a ΔT_{max} of 250.6º C is calculated (Fig. 6(b)) which is sufficiently lower than the acceptable value of 300º C. The third case is for upset conditions such as a failure of the vertical motion stage or controller. In this case the beam can be incident on an inclined edge resulting in a ΔT_{max} of 357.9º C. This is also lower than the acceptable value of 400º C.

Figure 7 shows temperature contours for slit design 2. When the beam is centered on one of the apertures a ΔT_{max} of 194.5º C is obtained (Fig. 7(a)). When this slit is used as a beam stop, ΔT_{max} is 269.1º C. Because of cooling channels of smaller diameter, there is a significant bulk water temperature rise of 21.6º C and 57.3º C, respectively. This design has no inclined edge which means that upset conditions do not result in a higher temperature.

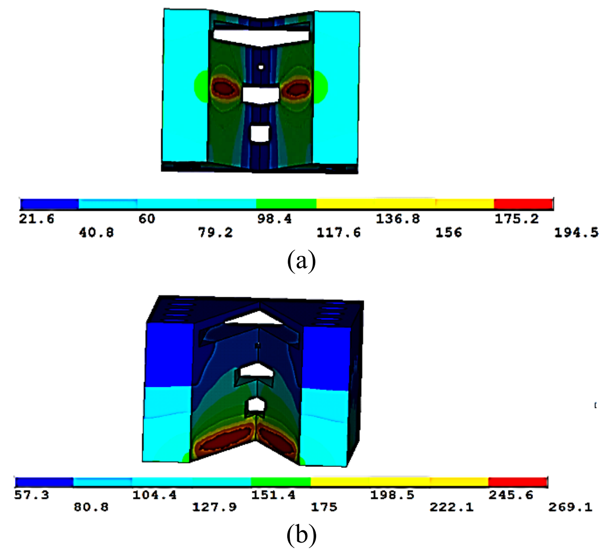

Figure 7: Temperature contours for slit design 2, (a) beam at the center of an aperture, (b) beam on a beam-stop position.

CONCLUSION

Conventional L-shape slit design is not feasible for the closely-spaced HEX wiggler beams. For such beams we have described two slit designs based on discreet vertical apertures and optimized cooling channel configurations. In the first design the cooling channels run parallel to the main inclined surface. Vertical cooling channels between the beams are used in the second design. Custom plugs are used in both designs to connect the cooling channels in series. FE analyses show acceptable temperatures for both slit designs under all beam-intercept cases.

ACKNOWLEDGMENTS

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