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WELDABLE COPPER CHROMIUM ZIRCONIUM MASK

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Abstract

A novel design for a weldable copper chromium zirconium (CuCrZr) mask is being developed for use in the Advanced Photon Source Upgrade (APSU) beamlines at the Argonne National Laboratory (ANL). This alternative attempts to drastically reduce cost and lead time over traditional brazed Glidcop® mask designs. Thermal analysis simulations of the mask have predicted that it will meet mechanical and thermal requirements, even when subjected to the intense white beam of the new superconducting undulators (SCU) of the APSU. As of the writing of this paper, a prototype is being fabricated for testing and eventual installation on the 28-ID Coherent High Energy X-ray (CHEX) beamline.

INTRODUCTION

Photon masks are radiation safety components meant to limit missteering of synchrotron radiation and protect downstream components in beamlines. They are also often used as in-vacuum beamstops and secondary apertures for controlling the size of the beam. Without photon masks, heat-sensitive radiation safety components like collimators would be exposed to the heat carried by the unattenuated beam.

The 28-ID CHEX beamline relies on two separate X-ray beams from the storage ring using a canted SCU configuration. One beam is multiplexed three times creating fixed discrete energy beamlines and one beamline is left fully tunable. This configuration will exploit the coherent flux enabled by APSU to advance the frontier for *in situ,* real-time studies of materials synthesis and chemical transformations in natural operating environments.

The proposed welded mask design will reside on the 5-60 keV tunable branch line, roughly 44 meters from the source in a lead-shielded mini-enclosure (Fig. 1). Its purpose is to protect downstream components from missteered synchrotron beam, define the size of the outboard canted beam, and prevent passage of the inboard canted beam to the 28-ID-B enclosure located downstream of the mini-enclosure.

CuCrZr masks are becoming widely used since it is affordable and simple to fabricate from a single piece of material, however more complicated absorber designs with overlapping internal features are difficult or impossible to machine [1, 2]. Also, brazing CuCrZr will anneal and negate useful properties of the beam intercepting surface and the hardened knife edge. Tests done by Bill Toter, ANL welding engineer show that gas tungsten arc welding (GTAW) is a viable strategy for joining CuCrZr bodies. The heat effective zone should be localized enough to not effect the knife edge and material properties.

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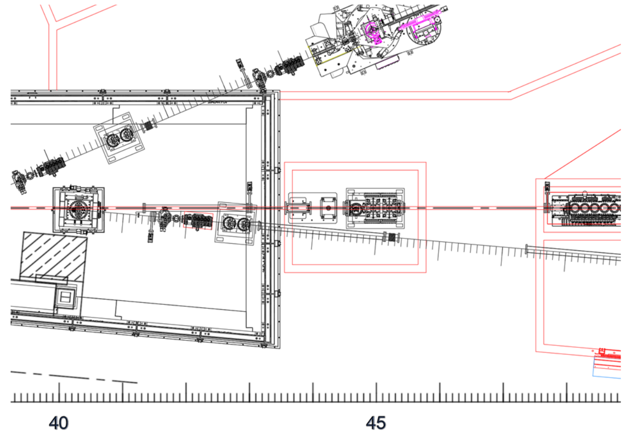

Figure 1: Location of mask in CHEX beamline.

MECHANICAL DESIGN

Absorbing Body

The main absorbing body of the mask consists of two CuCrZr top and bottom halves (Fig. 2). Both halves each contain five .375 in diameter water cooling channels with .25 in NPT threaded holes on either side to accept stainless steel compression fittings and return loops. The channels are drilled perpendicular to the beam direction to maximize the number of cooling channels present.

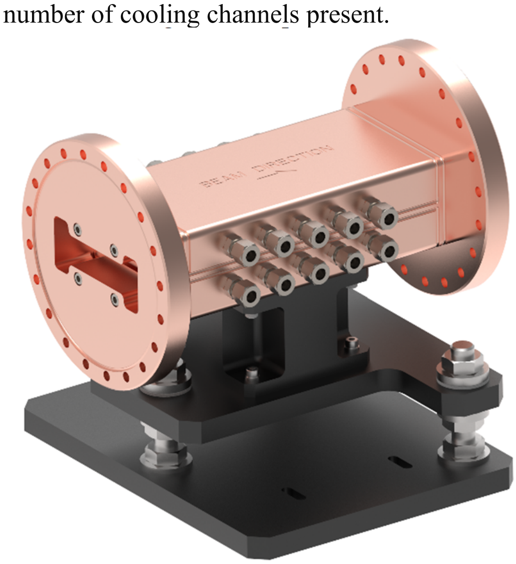

Figure 2: Welded mask assembly.

The top half contains the 2 mm horizontal x 10 mm vertical exit aperture meant to slit the outboard canted beam. The bottom half of the body contains the incident surface meant to absorb the extremal synchrotron rays as well as four M4 tapped holes for securing the assembly to an adjustable-height support table. Both halves also have inside surfaces angled in such a way as to block passage of the inboard canted beam. The inner angled surfaces on both halves are to be cut via wire EDM.

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Flanges

The design is noteworthy in that the flanges are also fabricated from CuCrZr and are bolted to the absorbing body before being welded in place. Four center-vented silver-plated M6 bolts are screwed into the absorbing body to hold the flanges in place during welding (Fig. 3). Each half of the absorbing body has two tapped holes on both the upstream and downstream ends to accommodate this mounting scheme. The bolts remain in place after welding to provide additional structural rigidity.

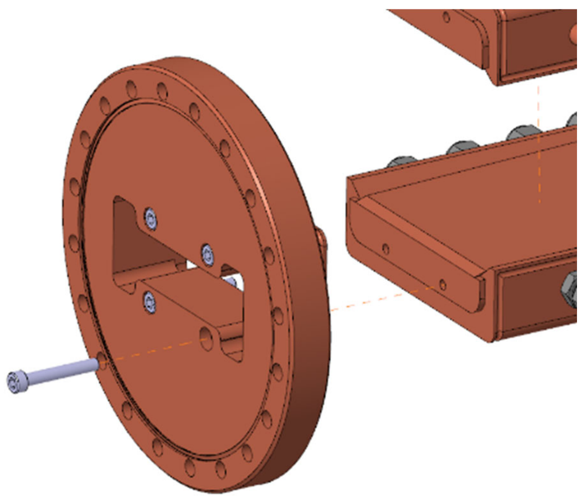

Figure 3: Exploded view showing center-vented bolts holding flanges to absorbing body.

Weld Reliefs

In order to allow both halves of the mask absorbing body and flanges to be united via welding, weld reliefs .125 in diameter are milled along the weld seams on each component (Fig. 4). These reliefs allow the formation of a continuous weld bead of sufficient size needed to provide strength, prevent virtual leaks, and ensure successful fusion of the halves.

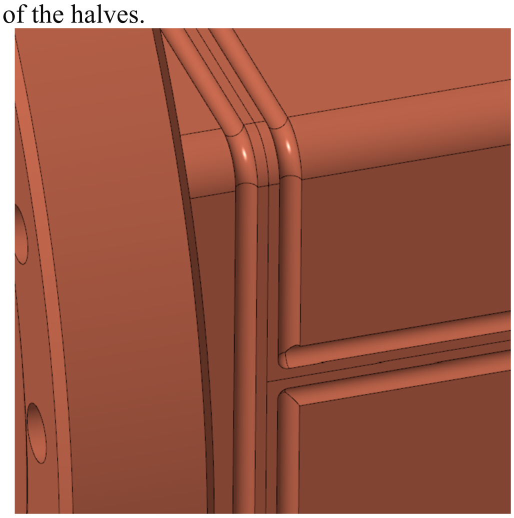

Figure 4: Image of reliefs surrounding the weld seams.

FINITE ELEMENT ANALYSIS

Thermal

The SCU insertion devices designed for the CHEX beamline have an 1.85 cm period and are 4.8 m in length. Calculations were performed when the undulators were tuned to emit the maximum photon energy corresponding to a total power of 1402.7 W at the front-end exit mask located 25.4 m from the source. The beam size at the welded mask was calculated by linearly interpolating the beam size present at the front-end exit mask aperture.

A program created in the Interface Description Language (IDL) development environment version 8.5, known as SRUFF, was used to calculate the undulator power density distribution. In order to perform these calculations, parameters such as the storage ring beam current of 220 mA, photon energy of 6 GeV, relativistic gamma, beam divergence, beam size, and the beam size at the welded mask were entered into SRUFF and the resulting undulator power density was fitted to a higher order Gaussian curve.

ANSYS Workbench 2020 R2 was used in the steady state thermal analysis of the mask. The power density curve was imported into ANSYS and applied as a heat flux evenly distributed between two canted beams projected onto the angled face of the bottom half of the mask body (Fig. 5). The film coefficient was calculated to be 10,000 W/m^2K from the water channel diameter and the minimum water flow rate of 0.5 gpm, allowing a convection selection to be applied to the cooling channels (Fig. 6).

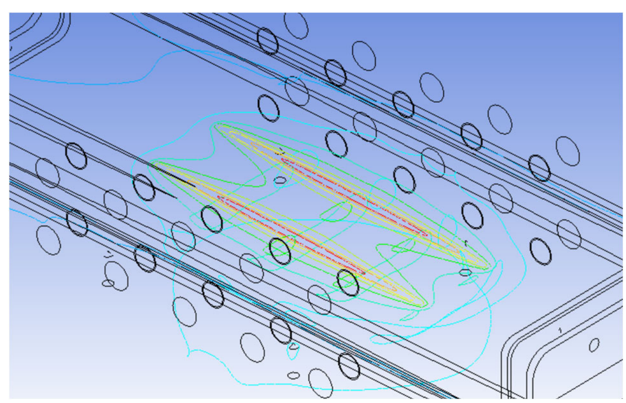

Figure 5: Result of thermal simulation showing canted beams heat deposited on mask interior surface.

The mesh size was set to 0.2 mm at the heat flux and convection selections, while the rest of the model was set to have a mesh size of 2 mm in order to reduce computation time. The beam envelope provided by the beamline ray tracing was used to determine the worst possible positioning of the canted beams and the analysis was run under that assumption. Several temperature and reaction probes were placed on the heat flux selections and cooling channels to measure the maximum temperature and the total dissipated power.

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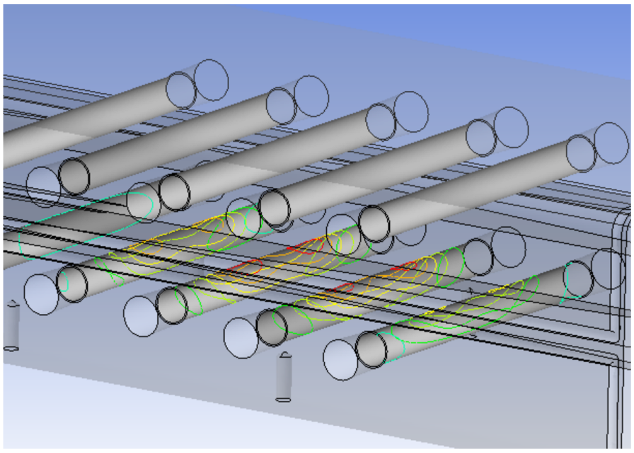

Figure 6: Heat dissipated due to convection in the water cooling channels.

The results of the analysis predict a maximum temperature at the incident surface of 53.1˚C, which is far lower than the failure criterion of 250˚C for CuCrZr. This provides a safety factor of nearly 4.7. The results also predict a maximum water temperature of 81.7˚C, which is also far lower than the failure criterion of 153˚C and offers a safety factor of about 1.7.

Several assumptions were made to simplify the analysis, including assuming that all materials were linear, elastic, isotropic, and homogenous, vibration induced by water cooling lines was negligible, the convection coefficient and supply water temperature were constant, and the water flow was laminar in nature.

CONCLUSION

Based on the positive results obtained from the thermal analysis, procurement and fabrication of the mask will commence and a prototype will be fabricated and tested. As this is an unproven design, there is likely to be further optimization to be realized after installation and testing. Assuming fabrication is successful, its installation into the CHEX beamline would introduce a new method for producing photon masks in an easier and more economical fashion when compared to traditional mask designs.

ACKNOWLEDGEMENTS

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