RECENT PROGRESS ON THE DESIGN OF HIGH-HEAT-LOAD COMPONENTS

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Abstract

A new design was recently proposed for the high power masks and slits of the frontends at the 2014 MEDSI Conference. The main features of the new design are integrated knife edges in high conductivity copper alloys, interception of the photon beam only on horizontal surfaces, replacing Glidcop with readily available CuCrZr, and thermal optimization with internal fins. Numerous components based on this design have been built for NSLS-II frontends and some of the design features have been incorporated into other high-heat-load components such as beamline masks and crotch absorbers. In this paper we describe recent progress at NSLS-II in further advancing this design approach by FE analysis, fabrication and testing.

INTRODUCTION

High-heat-load (HHL) components in light sources have usually been made from GlidCop brazed to stainless steel (SS) flanges. GlidCop has high thermal conductivity comparable to that of OFHC copper, but it can also retain a large fraction of its yield strength after brazing. A new design approach was recently presented [1] that allows a wide flexibility in the design of HHL components. The new designs are cost-effective and eliminate long lead-time for procurement [2]. The main features of the new design and their advantages are as follows:

1. **Integral Conflat Flanges**: Conflat flanges are made directly in high strength copper alloys (such as GlidCop and CuCrZr). This eliminates the expensive and time consuming process of brazing the main body of the HHL components to SS Conflat flanges.
2. **Alternate Copper Alloys**: The elimination of brazing allows the use of other hard copper alloys besides GlidCop (specifically, CuCrZr) which are less expensive and are readily available.
3. **Vertical Beam Interception**: Photon beams are intercepted only vertically (on horizontal surfaces). This leads to a common design for all HHL components because the vertical beam size is usually the same. In addition, the design of these components for canted beamlines is considerably simplified since there is no beam interception horizontally.
4. **Internal Fins**: Fins are machined on the inside (beam intercepting) surfaces which significantly improve the thermal efficiency of the components while trapping the scattered beam.

This new design approach is already under implementation not only at NSLS-II but also at other light source facilities [3, 4]. The progress made at NSLS-II is described in the following sections.

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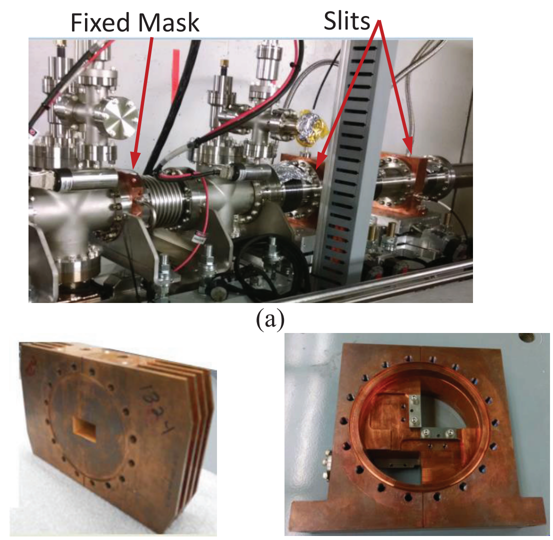
BM/3-PW FE COMPONENTS

One bending magnet (BM) and two 3-pole wiggler (3-PW frontends (FEs) at NSLS-II saw the first full scale implementation of the new design. Approximately 25 components consisting of masks, slits and photon shutters were installed in these frontends in May 2016. They have all been performing well as per specifications. Although intercepting comparatively low beam power, they provided the proof of principle of using CuCrZr components with built-in Conflat flanges.



(a) (b) (c)

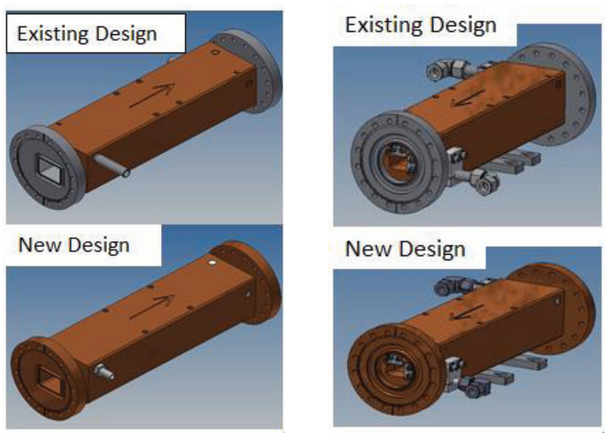
Figure 1: A 3-PW partial FE at NSLS-II, (a) a fixed mask and a pair of slits, (b) air-cooled fixed mask, (c) water-cooled slit.

A partial 3-PW FE is shown in Fig. 1-a consisting of a fixed mask and a pair of slits. Details of the fixed mask and the slit are depicted in Fig. 1-b and Fig. 1-c, respectively. Because of low beam power the fixed mask uses fins for natural convection (air) cooling eliminating the need for flow meters and associated controls. The slits are water cooled for thermal stabilization of the beam aperture. Photon shutters are designed as vertically movable masks. During the pre-installation vacuum processing some of the components were found to have vacuum leaks. This was traced to manufacturing errors resulting in burrs at the knife edges [2].

ID FE AND BEAMLINE COMPONENTS

FE Photon Shutters and Slits

Existing designs of the ID FE photon shutters and slits can be easily replaced with the new designs of very similar overall dimensions. During the prototyping of the new design it was realized that a single piece construction, in which the flanges are machined directly into the main body, would in some cases require excessive amount of machining. It was also found that weld joints in CuCrZr could be easily made [2] either by gas tungsten arc welding (GTAW) or by e-beam welding. This allowed CuCrZr flanges to be machined separately and then welded to the main body. Before welding the flanges water-cooling channels could also be gun-drilled in the main body parallel to the beam path as in the existing GlidCop designs. The two designs are compared in Fig. 2 for photon shutters and slits. As can be seen the main difference is that the flanges in the GlidCop designs, which require both brazing and welding, are replaced with welded-only flanges in the CuCrZr designs.



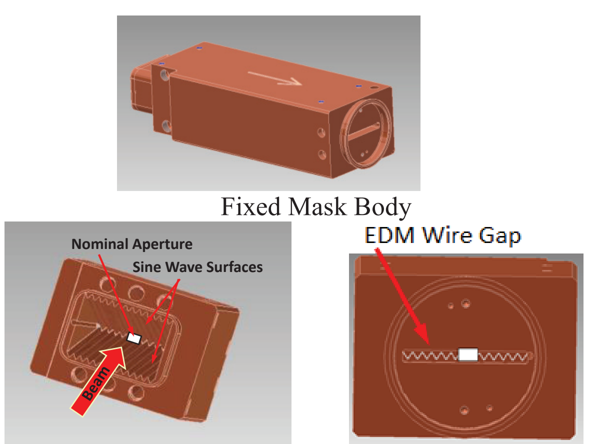
(a) (b)

Figure 2: A comparison of the existing GlidCop designs and new CuCrZr designs, (a) photon shutters, (b) slits.

Fixed Masks

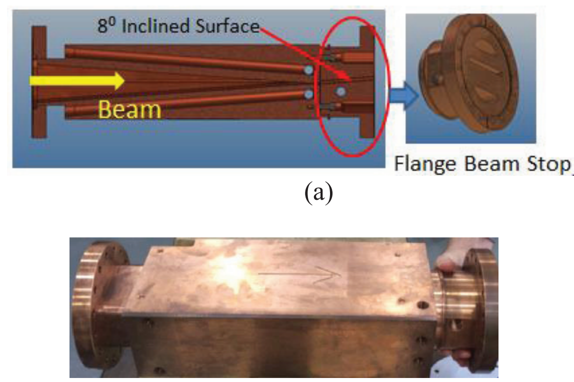
The proposed alternate design for fixed masks in Ref. [1] encountered a challenging problem. The wire EDM process, in which sine waves are created on the top and bottom beam-intercepting surfaces, leaves a wire gap at the downstream end of the fixed mask (see Fig. 3). This gap was at least 0.5 mm with an optimum wire diameter of 0.3 mm. Normally the central part of the photon beam will exit through the nominal aperture, but if the beam is offset then a substantial amount of power (about 1 kW for NSLS-II IDs) can exit through this wire gap. The exiting power will melt even water-cooled copper at normal incidence.

In a ½-length prototype of the fixed mask shown in Fig. 3, the wire gap could not be closed even when a large force (~ 100,000 kgf) was applied. Three different options are being pursued as potential solutions of this problem. In the first option, that is already under implementation for one of the ID frontends, the downstream flange of the fixed mask (Fig. 4-a) is modified to act as a beam stop. It provides a beam intercepting surface at an 8° angle of incidence and has its own water-cooling channel. This flange beam stop is welded to the main body after sine-wave surfaces have been created by wire EDM but before the nominal aperture is machined. The nominal aperture is created in both the main body and the flange beam stop at the same time as the last manufacturing step. A full scale prototype of this design is shown in Fig 4-b.



Upstream End Downstream End

Figure 3: The main body of the fixed mask and views from upstream and downstream ends.

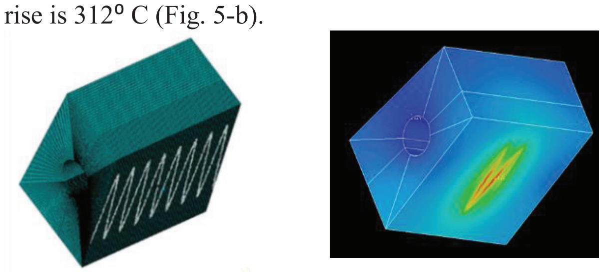


(a)

(b)

Figure 4: Fixed mask – Option 1, (a) model showing downstream flange beam stop, (b) full scale prototype.

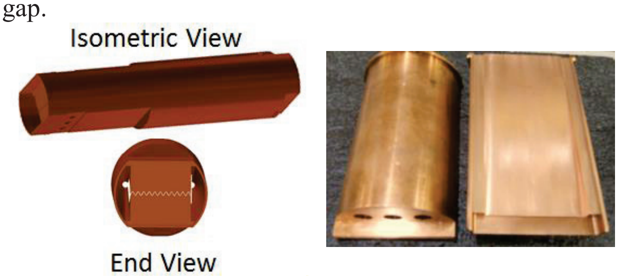
An Ansys finite element analysis was performed to determine the temperature rise in the flange beam stop subjected to the beam power exiting through the sine wave gap. The ID beam has a peak power density of 100 kW/mrad^2 and the fixed mask is located at 17.7 m from the center of the ID. Only the central portion of the inclined surface and the water channel are modelled. Figure 5-a shows the Ansys model and the beam footprint. The sine-wave footprint becomes extended in the vertical direction because of 8° angle of inclination. The beam power has a Gaussian distribution with 68% of the power contained in ± 1σ. The resulting maximum temperature rise is 312° C (Fig. 5-b).



(a) (b)

Figure 5: Ansys finite element analysis of the flange beam stop, (a) Ansys model with beam footprint, (b) temperature contours; maximum T = 312° C.

In the second option, the side walls of the fixed mask are hollowed out (Fig. 6-a) by wire EDM at the same time as when the beam aperture is created. The thin side walls bend when a force is applied at the downstream end causing the wire gap to close. From an Ansys FE analysis a force of 2,200 kgf was found to be sufficient to close the gap.



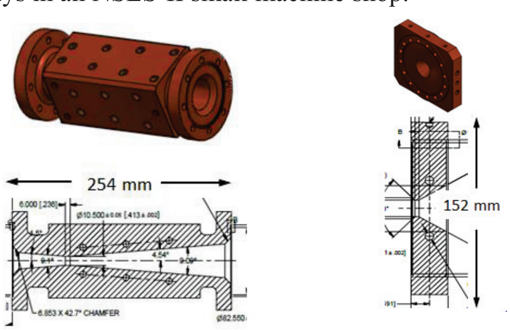
(a) (b)

Figure 6: (a) Option 2 – mask with thin side walls, (b) Option 3 – mask with top and bottom halves.

The third option takes advantage of the weldability of CuCrZr. The top and bottom halves of the masks (without the flanges) are first machined with the required features (see Fig. 6-b). The two halves are then joined by welding the two sides at the mid-plane. Finally, the upstream and downstream flanges are welded to complete the mask. All machining in this design can be done without using EDM process, making it possible to build long masks with arbitrary internal fin geometry.

Beamline Masks and Photon Shutters

The new designs are also applicable to beamline masks and photon shutters. Recently (in June 2016) one of the NSLS-II ID beamline had an urgent situation when one white beam mask and two pink beam masks were not received in time for beam commissioning because the supplier had GlidCop brazing problems. The designs were quickly revised based on the integral Conflat flange concept (see Fig. 7) and the parts were made within 10 days in an NSLS-II small machine shop.

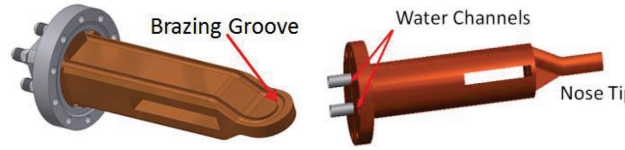


(a) (b)

Figure 7: Components of an NSLS-II ID beamline, (a) white beam mask, (b) pink beam mask.

SR ABSORBERS

SR absorbers including crotch absorbers have been made at ESRF and TPS based on the new design [3, 4]. At NSLS-II temporary absorbers were installed in most of the dipole chambers because of difficulties in brazing bent copper tubes in semi-circular grooves of the GlidCop crotch absorbers (Fig. 8-a). In a new design, currently in prototyping phase, the crotch absorber is made as a single piece machined from a round bar of CuCrZr (Fig. 8–b). Two water channels, in which SS tubes with wrapped springs are inserted, provide counter-flow water cooling. The nose tip is bent after the insertion of tube with spring in the top channel.



(a) (b)

Figure 8: NSLS-II crotch absorber, (a) existing brazed - GlidCop design, (b) new single piece CuCrZr design.

In a partial prototype of the absorber, the nose tip with a spring-wrapped SS tube in the water channel was successfully bent (Fig. 9-a). Results of an Ansys thermal analysis for a dipole linear power density of 22 W/mrad at the nose tip (total intercepted power = 1.18 kW) are shown in Fig. 9-b. The maximum temperature at the nose tip is 131^{o} C.

(a) (b)

Figure 9: Prototype evaluation of a new NSLS-II crotch absorber, (a) test bending of the nose tip, (b) temperature contours under the dipole beam power.

CONCLUSIONS

Recent progress at NSLS-II in the implementation, testing, and extension of the new design concept for HHL components have been described in this paper. The closing of EDM wire gap in FE masks has been discussed in detail. Ansys analyses have been performed to validate the new designs. FE and beamline components based on the new design have already proven to be cost-effective, reliable and easier for production. The design has been extended to SR absorbers at NSLS-II and other light source facilities.

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