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MANUFACTURING OF PHOTON BEAM-INTERCEPTING COMPONENTS FROM CuCrZr

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Abstract

Photon beam-intercepting components in synchrotron light sources have usually been made as water-cooled Glidcop® bodies brazed to stainless steel Conflat type flanges. This fabrication method involves many manufacturing steps which result in increased cost, long procurement time and lower manufacturing reliability. A new design approach was recently proposed which simplifies fabrication by eliminating brazing and utilizes a readily available copper alloy, CuCrZr. This paper describes the manufacturing experience gained at NSLS-II from fabricating many components of this new design. Results of an investigation of various techniques for joining CuCrZr to itself, to SS304, and to AL-6061 are also presented.

INTRODUCTION

For over 20 years synchrotron facilities have used Glidcop® material to make photon beam-intercepting components. Glidcop® was chosen because of its good thermal conductivity and because it retains its strength at high temperature. These Glidcop® components require advanced procurement planning because of their high cost, long lead time to produce, and the high risk associated with manufacturing them. Brazing Glidcop® can be challenging due to the tendency of the braze alloy to diffuse into the Glidcop®. Braze repairs are often required to produce vacuum leak-tight joints. This paper is based on the new design approach that was proposed at MEDSI 2014 [1] which eliminates brazing and substitutes Glidcop® with a less expensive and readily available copper alloy, CuCrZr.

NSLS-II CuCrZr COMPONENTS

NSLS-II has installed (1) bending magnet (BM) and (2) 3-pole wiggler (3-PW) frontends to date with total of (24) components made from CuCrZr (Installed components include: Absorbers, Masks, Slits, and Photon Shutters). There are (24) new components currently being manufactured from CuCrZr for future installation of three additional 3-PW frontends. A typical BM/3-PW slit body and fixed mask are illustrated in Fig. 1 and 2, respectively.

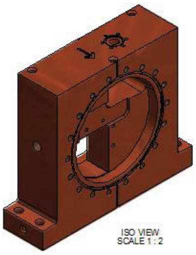

Figure 1: Typical BM/3-PW frontend slit body.

Prototype development of absorbers, masks, slits, and photon shutters based on the new design is ongoing for the insertion device (ID) frontends. The current Glidcop® design for an ID frontend fixed mask is illustrated in Fig. 3 and the proposed CuCrZr design is shown in Fig. 4.

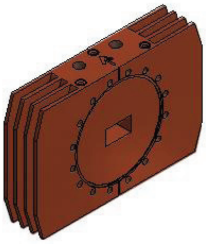

Figure 2: Typical BM/3-PW frontend fixed mask.

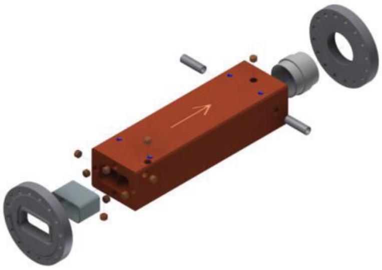

Figure 3: Current design of ID frontend components.

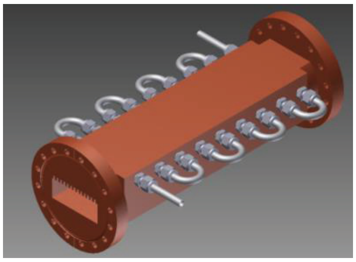

Figure 4: Proposed design of ID frontend components.

EXPERIENCE GAINED AT NSLS-II

General Machining and EDM of CuCrZr

The machinability of CuCrZr was found to be about the same as that for GlidCop® but significantly better than that of oxygen-free copper. Wire EDM of CuCrZr was also straight forward although cutting an aperture into a component 16” long is a slow process as would be expected of a high conductivity copper alloy.

Conflat Flange Knife Edge

The original design incorporated the standard 70° knife edge which is typically machined in stainless steel Conflat flanges. During incoming inspection a number of

BM/3-PW fixed masks made from CuCrZr were found to have vacuum leaks. After a detailed investigation it was determined that the vacuum leaks were caused by small burrs left on the knife edges from the machining operation. The knife edge design was changed from 70⁰ to 90⁰ and a knife edge tip radius of 0.006” [2] was added (see Fig. 5). The machining process was also refined which now utilizes profile machining on a CNC lathe and a new cutting tool with carbide inserts [3].

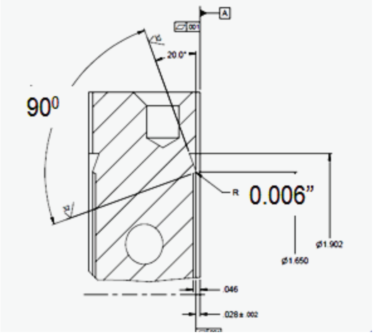

Figure 5: Knife edge angle and tip radius in CuCrZr flanges.

EDM Wire Gap in Fixed Mask

During ½-scale prototyping of the ID fixed mask from CuCrZr the EDM wire gap was measured at 0.032”. This gap would allow an unacceptable amount of beam power to escape through the mask. EDM programming changes were made that reduced the number of passes of the EDM wire to two (one for each of the top and bottom surfaces of the aperture). Based on the EDM machine manufacturer recommendation, a 0.010” diameter zinc-coated brass wire was used for cutting the aperture. These changes reduced the EDM wire gap to 0.020” but the escaped power was still too high and other design options based on the weldability of CuCrZr are under investigation [4].

Welding of Conflat Flanges

During prototyping it was also realized that making integral flanges would require excessive machining in some cases depending on geometry of the mask and its aperture. In addition, long masks for high power IDs would require too many cooling channels and fittings. It was then decided to investigate the weldability of CuCrZr so that the conflat flanges could be made separately and then joined to the main body by welding. As discussed in the Section of “Joining Techniques”, CuCrZr was found to be easily welded.

MANUFACTURING COMPARISON

Because the new design eliminates brazing, the manufacturing reliability of producing the frontend components is greatly improved. In the current GlidCop® design of an NSLS-II ID frontend fixed mask assembly there are (13) brazed joints (2 vacuum and 11 water joints). If any one of these joints is not leak tight the assembly has to be re-brazed. Re-brazing is a high risk as it can open up a leak in another joint. Even suppliers with many years of experience of brazing Glidcop® have to re-braze assemblies, often multiple times, before all joints are vacuum or water leak tight. Table 1 shows a manufacturing comparison between the current GlidCop® and new CuCrZr designs for a typical NSLS-II ID frontend component assembly. Actual cost and time data were used for this compari- son although only a limited amount of data is currently available for CuCrZr.

Table 1: Manufacturing Comparison

	Glidcop®	CuCrZr	Note
# of Assembly Components	16	1 - 4	
Material Price (per pound)	$40.45	$8.99	1
Material Delivery Lead Time	16 weeks	1 week	1
Material Selection (shape & size)	Limited	Large Variety	2
Manufacturing Cost Factor	1.35 (X)	1.00 (X)	3
Production Lead Time (average)	6 months	3.5 months	4
Design Options	Note #5	Note #6	
Note #1 – Based on actual quotes received in August of 2016.			
Note #2 – Glidcop® is available in a limited number of standard sizes, custom sizes can be ordered at a higher cost and extended delivery lead time.			
Note #3 – Based on actual costs which include both material and labor to produce the parts.			
Note #4 – By eliminating brazing and reducing the number of components required for the newly designed CuCrZr assembly, production time is reduced by 2.5 months.			
Note #5 – In the future, front end components manufactured at NSLS-II will only use Glidcop® when brazing cannot be eliminated from the design such as in a beryllium window assembly.			
Note #6 – New CuCrZr designs offers design flexibility; components can be made with all features machined into a single piece or a multiple piece welded construction.			

JOINING TECNIQUES

Processes Used for Joining CuCrZr

Samples were machined and welded to determine the weldability of CuCrZr material [5]. The sample welded joints were evaluated for heat affected zone (HAZ) and base metal hardness, weld size, vacuum leak tightness using a Mass Spectrometer Leak Detector (MSLD), and metallographic analysis. Samples were welded using Electron Beam Welding (EBW) and Gas Tungsten Arc Welding (GTAW). Welding was performed in a manner that would minimize the heat input and still achieve a vacuum tight joint. Weld sample test results are shown in Table 2. It was concluded that joints in CuCrZr are easily fused and reproducible with minimal effect on the base metal. Small vacuum leak tight joints were achievable with both EBW and GTAW processes with very narrow heat affected zones. A picture of the GTAW CuCrZr weld sample is shown in Fig. 6 (top) and micrographs of the excellent quality of the GTAW and E-beam welded joints are shown in Fig. 6 (bottom).

Table 2: CuCrZr Weld Sample Test Results

Criteria	EBW	GTAW
	Vickers Micro Hardness	
HAZ/Weld/Base Metal	87/104/143	88/98/138
	Weld Size (Inches)	
Weld Width / Weld Depth	0.070/0.020	0.071/0.020
HAZ (beyond fusion line)	0.035	0.025
MSLD Results	No response at $1x10^{-9}$ CC/SEC (He)	
Metallurgical Structure	Good fusion, No defects	

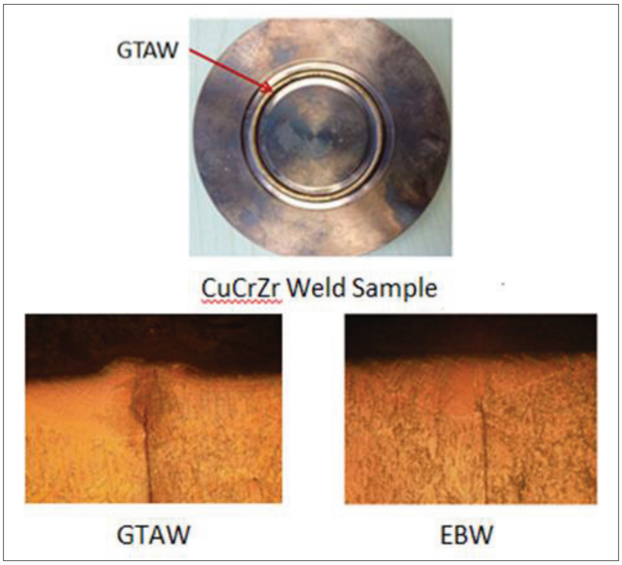

Figure 6: A GTAW CuCrZr weld sample (top). Micrographs of the GTAW and E-beam welds are shown below.

Explosion Bonding

Two types of explosion bonded bimetallic plates (4 pieces of each type) were produced and evaluated. One type with 304L stainless steel bonded to CuCrZr and the other with 6061 T-6 aluminum bonded to CuCrZr, each bonded plate is 12” square x 1.0” thick (each material type is 0.5” thick) . Ultrasonic and dye-penetration testing was performed on each bonded plate by the supplier (High Energy Metals, Inc., Sequim, WA, USA). There were no un-bonded indications found on the 304L/CuCrZr plates and one non-bonded area (1.0” long) was found along one edge on one of the four 6061 T-6/CuCrZr plates.

Additional evaluations including metallographic analysis and tensile testing of the bonded joints are being performed by an independent outside testing laboratory (Dayton T. Brown, Inc., Bohemia, NY, USA). Testing has not been completed so the final results are not available for presentation in this paper. A picture of the 304L/CuCrZr explosion bonded plate is shown in Fig. 7.

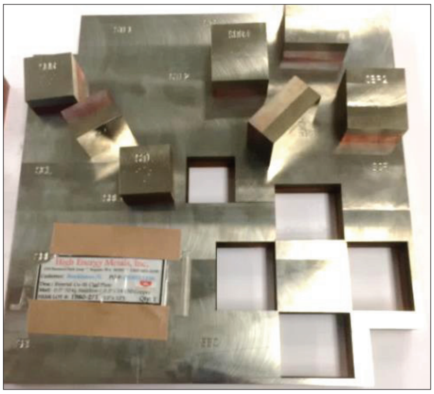

Figure 7: Explosion bonded plate with samples removed.

Summary and Conclusion

CuCrZr material is readily available in a large variety of shapes and sizes and significantly lower in price then Glidcop®. Conflat flanges can be machined directly into the main body or joined to it by welding. By eliminating brazing and reducing the number of components necessary for the CuCrZr assembly, production costs are reduced by approximately 35% and production time is reduced by 2.5 months. Eliminating brazing also improves the manufacturing reliability of the components.

These new CuCrZr designs allow component assemblies to be manufactured in advance with all features except the final aperture. Once the final aperture size is specified it can be added quickly in a simple machining operation. The lead time for manufacturing can thus be reduced from several months to a few days.

Another significant advantage of the CuCrZr designs is that they facilitate standardization of components, for example the number of spares required to support operations is minimized since mask assemblies without apertures can be available as a universal spare to be completed as needed.

CuCrZr offers many benefits as shown throughout this paper without the high cost, long lead time to manufacture, and high risk associated with manufacturing components made from Glidcop®.

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