DESIGN AND TECHNOLOGY OF THE HIGH-HEAT-LOAD PHOTON SHUTTERS FOR THE NEW FRONT ENDS AT APS*

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Abstract

New front ends for beam lines at the Advanced Photon Source are designed to handle the thermal loads of multiple undulators and higher stored beam currents. Photon shutters for these front ends combine functions of masks and beam stops and use a tilting mechanism to open and close the shutter. For the highest required power density (590 kW/mrad2, 21 kW), a vertical rotation axis is used to spread the beam along the length of the strike plate. The canted undulator photon shutters (281 kW/mrad^2, 20.4 kW) must stop two beams separated by 1 mrad and use a horizontal axis. Both explosion bonding and brazing were used to bond a thin GlidCop plate to the cooled copper body of the shutters, and results favor explosion bonding. For the final brazing of all parts, Au/Cu 50/50 brazing alloy was used for one-shot brazing of the two photon shutter halves, cooling channel plugs, water fittings, and the stainless steel ConFlat flanges on both ends. A special brazing fixture was developed that maintains constant force on the joint throughout the brazing process. For the explosion-bonded parts, two different techniques were used. More than ten shutters based on these techniques have been or, are being manufactured to date.

Key Words: synchrotron radiation, photon shutter, high heat load, explosion bonding.

*This work was supported by the U.S. Department of Energy under contract no. W-31-109-ENG-38

1. Introduction

Recent designs of new front-end components combine into one unit functions of the fixed mask and photon shutter and use a tilting system to open and close the shutter. We have developed two different designs: one for the double-canted-undulator front end [1] and one for multiple collinear undulators with the highest power density in the beam (590 kW/mrad^2, 21 kW maximal total power) [2].

2. Design

In both designs, the tilting axis was located on the upstream ConFlat flange of the unit. Combining the mask/shutter functions into one unit and locating the tilting axis upstream has important advantages. Bremsstrahlung scattering calculations showed that such a design decreases significantly the radiation fan in the forward direction. Also, taking into account that the tilting angle is very small (~1°), the upstream location of the tilting axis insures that the entrance aperture of a component is practically always in the same position and will intercept the full fan of the synchrotron radiation.

A general view of the photon shutter with horizontal tilting axis is shown in Fig. 1 and a similar view the photon shutter with a vertical tilting axis is shown in Fig. 2.

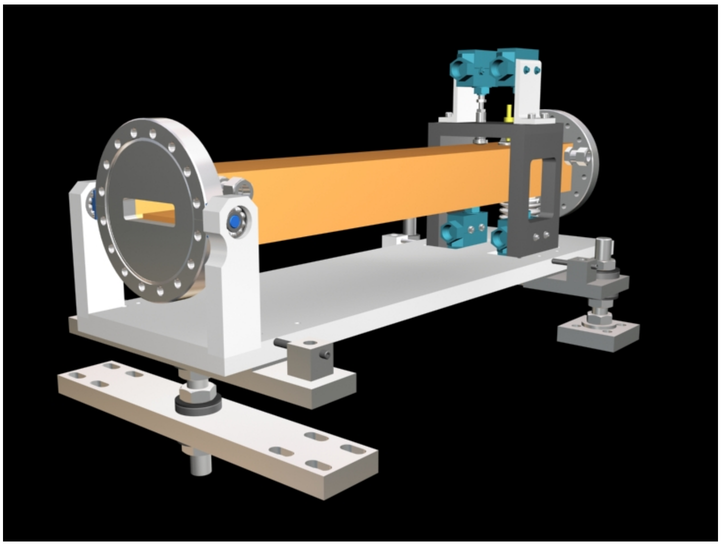


Fig. 1 – Photon shutter with a horizontal tilting axis

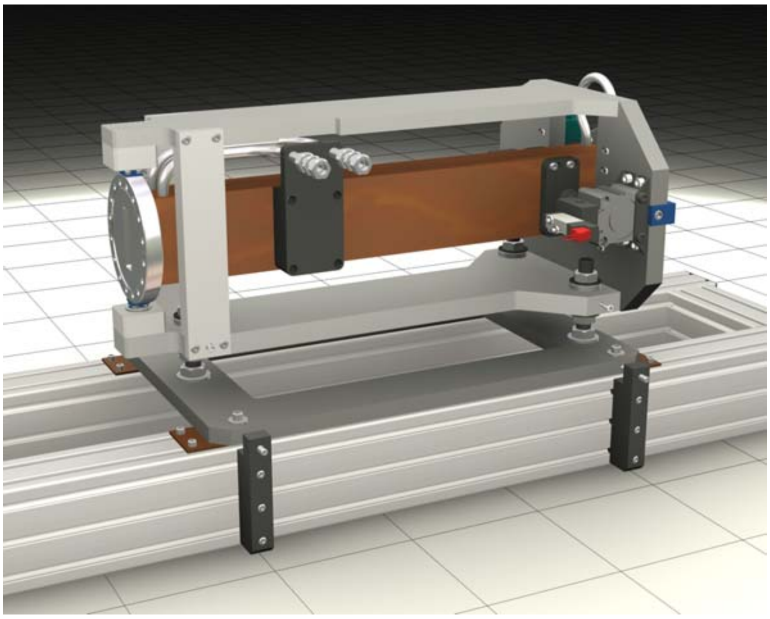


Fig. 2- Photon shutter with a vertical tilting axis

Each shutter consists of two copper halves. The side actually accepting the entire thermal load after tilting has a thin (5-6 mm thick) GlidCop plate attached to the OFHC copper body. Gun-drilled cooling channels are located along both sides of the absorbing surfaces of the shutter (Fig. 3). To enhance water turbulence and the convection coefficient by a factor of 1.5, copper springs were placed inside the cooling channels [3]. The second half is made of OFHC copper and has the same type of cooling. All channels in each half are connected in parallel to minimize the number of water fittings. In the old design of such components at APS a copper mesh was placed inside the cooling channels [4]. It increased the convection coefficient by a factor of 2 but created a huge pressure drop and requires regular maintenance to avoid clogging. Also the huge contact area between DI water and copper mesh resulted in sizable corrosion and even dissolving of the copper.

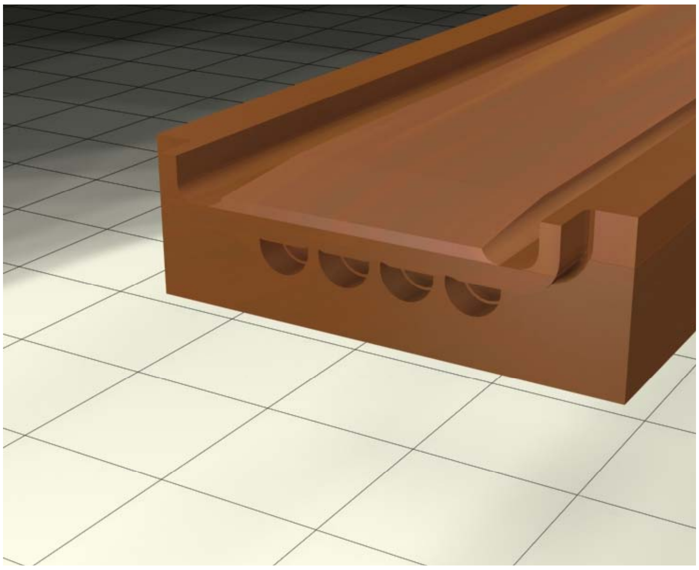


Fig. 3 – Machined half of the photon shutter

3. Fabrication

One of the challenges in the fabrication of these parts was the brazing process. In an effort to limit the number of brazing cycles, we first brazed the GlidCop plate to the copper body. In a second run the body halves, ConFlat (CF) flanges, water-channel plugs and water fittings were joined. The components were brazed in a hydrogen furnace using a .002" to .004" thick copper/gold 50/50 foil brazing filler. Our test showed that Au/Cu 50/50 brazing alloy works very well for both stainless steel-copper and copper-copper joints.

Because the joining surfaces have different volumetric orientations, weight alone cannot be used to produce holding forces. The high brazing temperature prevents the use of springs. Since our brazing furnace is tall and narrow, the photon shutters were brazed in the vertical direction. In this case, weight locked the joints between the CF flanges and the shutter halves, and a fixture applied forces to clamp the halves together (Fig. 4). The fixture consisted of two stainless-steel bars connected by thin molybdenum threaded rods. Wedges were used to apply the initial forces to the joint. Due to the difference in thermal expansion coefficients between copper and molybdenum, these forces increased with temperature rise. This fixture was used successfully in all body-joint braze applications.

The brazing cycle combined an initial slow temperature rise to 850˚C on the parts, a holding time of approximately one hour, a spike temperature of 990˚C on the parts, which was held for 2-3 minutes, followed by cooling at a ramp rate of 100˚C/min.

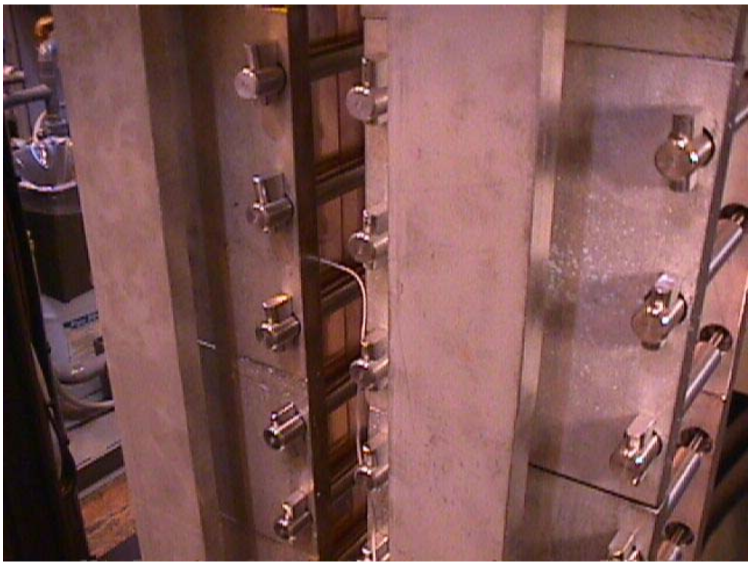


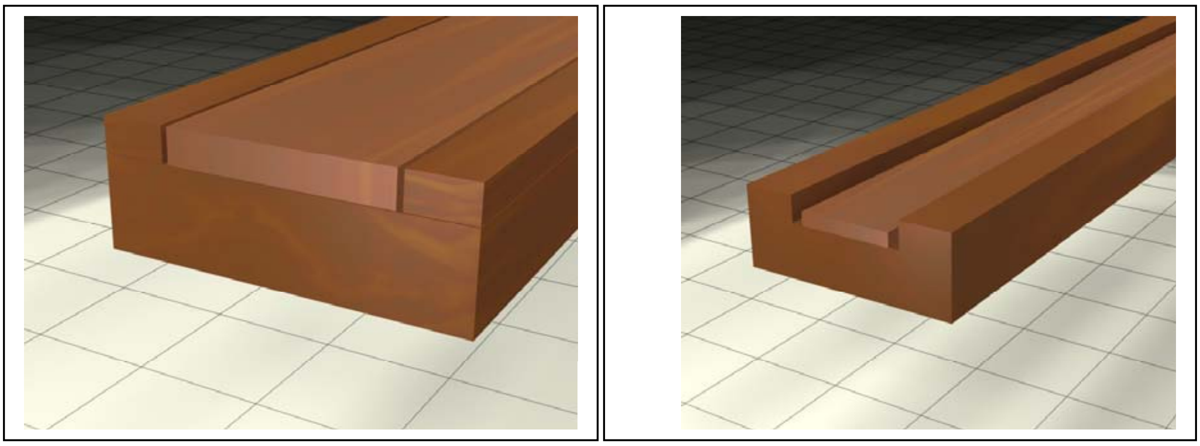
Fig. 4 - Brazing fixture for the photon shutters

Butt joints between copper half ends and a machined recess inside the blank CF flange are the areas were brazing filler was placed. Rectangular outside machining (see Fig. 3) with tight tolerances provides mechanical support for the flanges and takes of the load off the brazing joints.

4. Inspection

Another major challenge of this design was the reliability of the joint between the GlidCop plate and the copper half. While fabricating the first components, we realized that the inspection of the joint integrity was not very simple. A standard ultrasonic test is not 100% conclusive. One part, after negative ultrasonic testing, was subsequently used for destructive testing. In this test, layers of the GlidCop plate were milled away at the joint level and penetrating dye tests showed no evidence of a defective joint. More comprehensive tests, performed by submerging the part in a water bath, are not desirable since this method adds cost and forces the fabricator to ship the assembly to specialized companies. After high-temperature brazing, copper is extremely soft and can be easily damaged during transportation. This actually happened to two of our subassemblies, and, as a result, we opted for an explosively bonded joining technique on later production. For the final fabrication using brazed parts, only those, which definitely passed an inspection, were used.

Two different technological approaches for explosion bonding were tested. In one process we joined a thick copper plate and three strips (two made of OFHC and the central one of GlidCop (Fig. 5 -A). In the second approach the GlidCop plate was attached to a C-shaped OFHC copper housing (Fig. 5 -B). Both technologies provided us with high-quality parts, which have been used for a final machining. There is no visual difference between the parts made from the different raw pieces. After machining of the photon shutter ends, the seams between the copper body and copper side strips are practically invisible.



A B

Fig. 5 – Samples of different explosion-bonding technologies

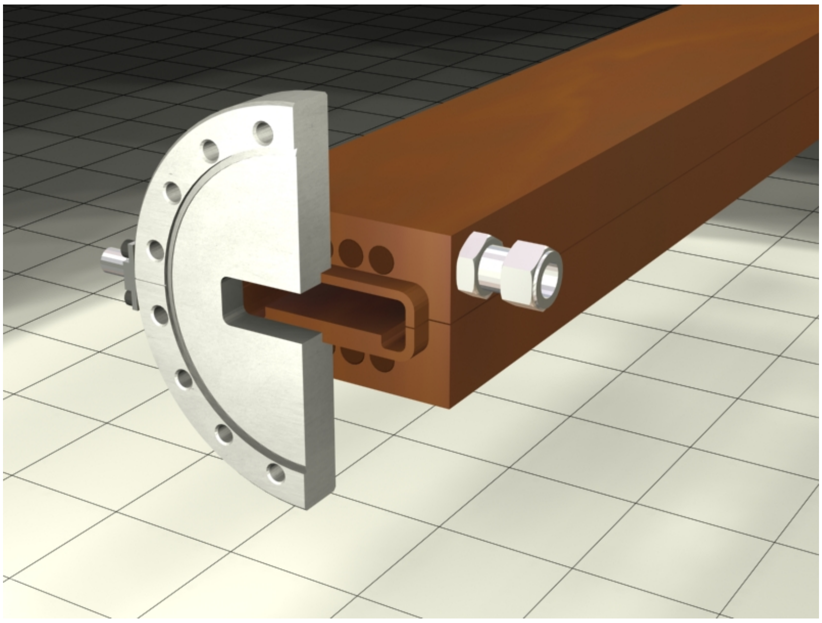


Fig. 6 – Brazing joints of the photon shutter

In Fig. 6, one can easily see all brazed joints: two halves, cooling-channel plugs, water fittings, and CF flange. In the latest version of this design, short stainless-steel tubes were brazed to the photon shutter body instead of water fittings. The reason for this change was that the thread on some of the fittings was slightly deformed during brazing. It was fixed easily, but for the future we have decided to braze just tubes.

After brazing in the hydrogen furnace, the copper body of the photon shutter is extremely soft and can be bent rather easily. Very gentle handling is required during the final assembly, since we use the outside surfaces of the shutter for the fiducialization and alignment of the device

5. Conclusion

Six photon shutters with a horizontal tilting axis are already installed in three different APS front ends. Five photon shutters with a vertical tilting axis are currently in manufacturing and are scheduled for installation during September 2004. In both designs, the photon shutter motion is activated by pressurized air. The shutter with the horizontal tilting axis closes by its own weight if the air supply fails. The shutter with the vertical tilting axis closes under the force of two springs (one inside the air cylinder and one additional outside).

Acknowledgments:
The authors would like to express their gratitude to Argonne welding engineer William F. Toter for the numerous fruitful discussions and for technical support of this work.

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