DESIGN AND ANALYSIS OF A BE WINDOW FOR THE APS DIAGNOSTICS UNDULATOR BEAMLINE

I. Ching Sheng, B. X. Yang and S. Sharma
Advanced Photon Source, Argonne National Laboratory
9700 South Cass Avenue, Argonne, Illinois 60439 USA

Abstract

The design of a beryllium (Be) window for use under the extremely high heat load of an undulator beam is one of the challenges for third-generation synchrotron radiation beamlines. A novel design of a Be window is presented for the Advanced Photon Source (APS) diagnostics undulator beamline, whose beam has a peak power density of 150 W/mm^2 (7 GeV/100 mA stored beam). The window has a double concave profile with a thickness of 0.5 mm at the center and is brazed to a water-cooled oxygen-free, high-conductivity (OFHC) copper manifold. Finite-element thermal analysis of the Be window is also presented.

1 INTRODUCTION

The APS diagnostic insertion device (ID) beamline uses both bending magnet and undulator radiation for beam imaging. To maintain the vacuum integrity of the storage ring, windows are required to separate the beamlines from the ring. Since the power density of the undulator beam is extremely higher than that of the bending magnet, the following design criteria are considered:

- Reduced absorption of x-ray beam power.
- Enhanced conductive and convective cooling to reduce the temperature gradient.
- Ability to withstand vacuum force in case of leak in the beamline.
- Large window stiffness to increase thermal buckling threshold.
- Ease of fabrication.

To satisfy the above design considerations, we utilize Be as the windows material for its low absorption of x-ray and high material strength. A concave-shaped window is introduced to meet the other goals above. With a thickness of 0.5 mm, Be absorbs 5% of the 800 W total power of the diagnostic undulator at 100-mA beam current in APS. For the bending magnet radiation a second window, consisting of a 1-mm flat disk of Be, is used because it absorbs much less power.

2 DESIGN AND FABRICATION

Previous studies have shown that the major cause of failure of a Be window in an x-ray beamline is thermal buckling. The design of a conventional, flat Be window is often the result of compromise between two considerations:

- Thicker windows increase the thermal conduction as well as flexural stiffness.
- Thicker windows increase absorbed power.

We introduce a double concave window which significantly improves the thermal conduction and flexural stiffness without increasing the absorbed power. We use 99.4% pure beryllium in our design. As shown in Figure 1, the 0.2-mm undulator beam will pass through at the center of the Be window, where the thickness is only 0.5 mm. This concave Be window has three advantages: it absorbs less power when beam is aligned, it provides larger conductive area for heat flow, and it is structurally stiff which prevents thermal buckling.

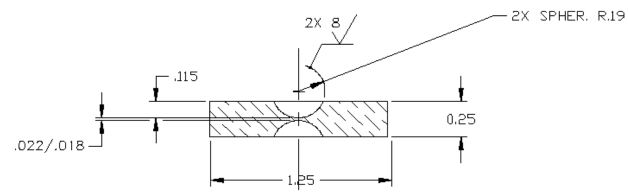

Figure 1: Cross section of the double concave Be window (dimensions are in inches).

The Be window assembly is shown in Figure 2. Two 50-mm 304 stainless tubes are brazed with a water-cooled OFHC copper manifold; Be windows are then diffusion-brazed on the counterbores of the manifold by using silver-copper-based alloy. Three circular water channels are drilled in the copper block for cooling. The assembly is machined and brazed by Brush Wellman Company. Two of the window assemblies are mounted in series (as shown in Figure 3) with an ion pump in between for pumping.

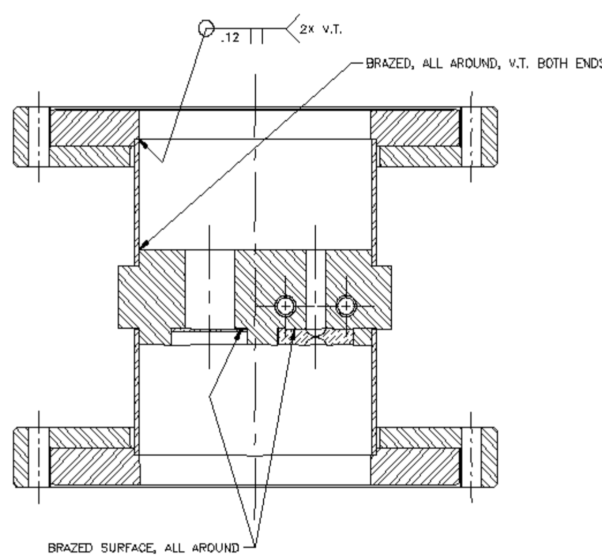

Figure 2: Cross-section view of the Be window assembly.

0-7803-4376-X/98/$10.00 © 1998 IEEE

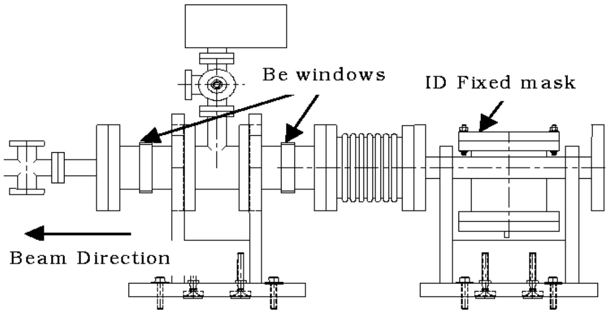

Figure 3: Be windows assembly.

3 THERMAL ANALYSIS

3.1 *Thermal Analysis - Beam at Center*

An axisymmetric finite-element model is used to calculate the temperature rise, assuming a constant temperature of 0°C at the brazed joint. The results are plotted as temperature contours in Figure 4. A peak temperature rise of 61°C is obtained at the center of the double concave area.

The temperature rise between the braze joint and water channels is determined by a simplified one-dimensional model. The brazing area can be treated as a heating strip with area of 1 cm (width) × 9.2 cm (height, parallel to the cooling channel), with incident total power of 40 W. An equilibrium power density (q) on this heating strip is 4.3 W/cm^2. The average conductance path (l) from the braze joint to the water channel is 1 cm. Using 1 W/(cm^2 k) for the water film coefficient (h), the temperature rise between the braze joint and cooling channels is determined as [1]

$$\Delta T = q\left(\frac{l}{k} + \frac{1}{h}\right) = 4.3\left(\frac{0.9}{3.6} + 1\right) = 5.4\ °C,$$

where k=3.6 W/(cm °C) is the thermal conductivity of the OFHC copper. Summing up the two temperature increases, the peak temperature rise on the Be window is approximately 66°C.

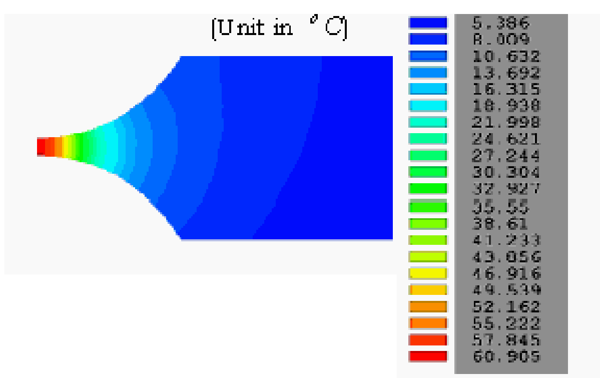

Figure 4: Axial symmetrical temperature contours on a Be window.

The critical buckling load on a circular plate [2] is proportional to t^3/a^2, where t is the thickness and a is the radius of the plate. Since the outer thickness of the Be window is large (6.4 mm) compared to that at the center (0.5 mm), the effective radius a reduces from 32 mm to approximately 3 mm. The buckling threshold is therefore increased by 100 times compared to that of a flat plate with the same 0.5-mm thickness. Detailed analysis for thermal buckling of circular disks under x-ray heating are presented in [3] and [4].

3.2 *Thermal Analysis - Missteered Beam*

A beam missteering situation is also analyzed. We assume that the undulator beam is incident off-centered on the window. A higher percentage of the undulator power is absorbed (30%, or 240 W) because of the increase in Be thickness in the beam path. Figure 5 shows the temperature contour plot where the peak temperature rise is 147°C. Further investigation is in progress to determine the maximum safe temperature rise.

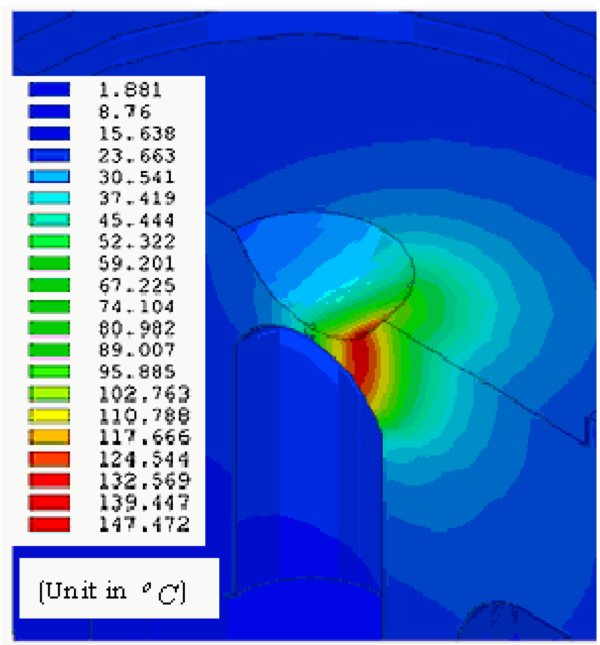

Figure 5: Temperature contours in a Be window due to beam missteering.

4 CONCLUSION

A novel Be window design of double concave geometry has been presented. In this window geometry the absorbed beam power is reduced at the thinner center while heat conduction is increased at the thicker outer periphery. The double concave shape is structurally stiff and prevents thermal buckling. The window has been installed and used in the APS diagnostics undulator beamline.

5 ACKNOWLEDGMENTS

The authors would like to thank Ms. Catherine Eyberger for editing this paper. The work is supported by the U.S. Department of Energy, Office of Basic Energy Sciences, under Contract No. W-31- 109-ENG-38.

6 REFERENCES

[1] J. P. Holman, *Heat Transfer*, McGraw-Hill Book Company, 1977.

[2] S. P. Timoshenko and J. M. Gere, *Theory of Elastic Stability*, McGraw-Hill Book Company, 1961.

[3] H.L. Nian, T. M. Kuzay and I. C. Sheng, “Thermal Buckling Parametric Analysis for a Diamond Disk for an X-ray Beamline at the Advanced Photon Source,” *Rev. Sci. Instrum.* **67** (9), September 1996.

[4] I. C. Sheng, B.X. Yang and S. Sharma “A Be Window on an APS Diagnostic Beamline,” to be published in SPIE97 conference proceedings.