A Conceptual Design and Thermal Analysis of High Heat Load Crotch Absorber*

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Abstract

A high heat load crotch absorber has been designed for the Advanced Photon Source (APS) storage ring curved chambers. The absorber, which uses a beryllium diffuser brazed to oxygen free high-conductivity copper (OFHC) plates, has been optimized to spread the beam power in order to reduce its temperature rise and thermal stresses. Circular copper tubes are brazed to the absorber for water cooling. The absorber design and analytical results from a three-dimensional finite element model are presented in this paper.

I. INTRODUCTION

Crotch absorbers in the curved chambers of the APS storage ring are subjected to extremely high power densities. For instance, at 300 mA beam current the crotch absorbers will intercept 750 watts/mm^2 at normal incidence. Such high power density with Be–Cu composite absorber design was also presented by Dennis Mills and his coworkers [1]. The vertical opening angle ($1/\gamma$) of the x-ray beam is only 0.07 mrad, which corresponds to a beam height of approximately 0.2 mm at the absorber. There are two important constraints in designing a crotch absorber for a curved chamber with an exit port: (1) it is not possible to completely avoid a normal incidence (horizontally) on the surface of the absorber, and (2) since the vertical beam size is very small, inclining the absorber surface vertically to reduce the power density does not reduce the temperature rise significantly. Because of these severe limitations the previous absorber designs [2] did not have a sufficient margin of safety at 300 mA. A new absorber design has, therefore, been developed which is able to sustain the required high heat load.

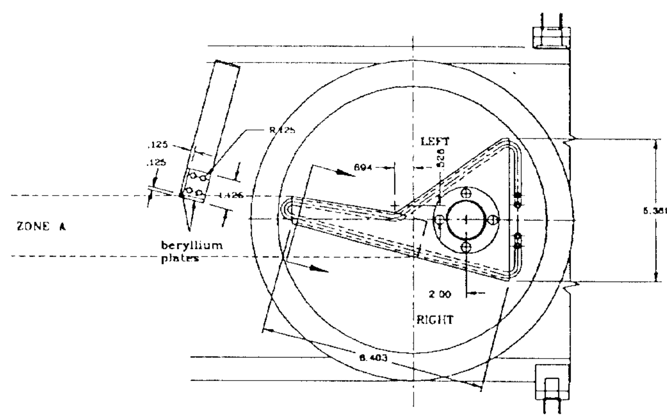

Figure 1a. Top View of the Crotch Absorber.

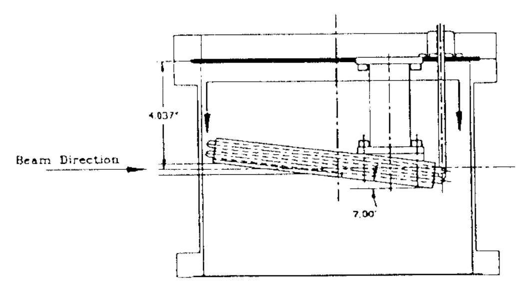

Figure 1b. Elevation of the Crotch Absorber.

II. BASIC DESIGN

The main feature of the present absorber design is a beryllium diffuser which is placed at a vertically shallow angle in the central zone (zone A in Fig. 1a) of normal incidence. The absorber is inclined with respect to the fan of the radiations such that the vertical angle of incidence is 7 degrees. In a 3-mm-thick inclined beryllium diffuser plate, harder x-rays will traverse up to 25 mm inside the diffuser. For the APS bending magnet radiations, the power deposited in the diffuser plate is estimated to be 40 percent of the total beam power. The remaining power is deposited at the beryllium copper interface.

The beryllium diffuser is brazed to an OFHC copper assembly made of upper and lower absorber plates. The plates intercept x-ray radiations at small incidence angles (16 degrees to 32 degrees horizontally) outside the central zone. The temperature rise and thermal stresses in the these plates are, therefore, reduced significantly. Circular grooves are machined in absorber plates for brazing two 3-mm inner diameter copper tubes for convective water cooling. These copper tubes eliminate the need for a water-to-vacuum joint.

III. POWER IMPLEMENTATION

A generalized preprocessing program is used to implement the bending magnet power. For a given chamber geometry, the program calculates the distance from the source l and incident angle δ on the surface being exposed. The power is applied according to the well-known photon spectrum equation:

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$$q\left[\frac{kW}{mm^3}\right] = \frac{1.4107 \times 10^3 B[T] E^4[GeV] I[A] \sin(\delta)}{\ell^2[mm]} \times$$

$$\int_0^\infty \alpha_t \left(\frac{e}{e_c}\right)^2 F \exp(-\alpha_t \xi)\, d\left(\frac{e}{e_c}\right) \qquad \text{in Be}$$

$$q\left[\frac{kW}{m^2}\right] = \frac{1.4107 \times 10^3 B[T] E^4[GeV] I[A] \sin(\delta)}{\ell^2[mm]} \times$$

$$\int_0^\infty \left(\frac{e}{e_c}\right)^2 F \exp(-\alpha_t \xi)\, d\left(\frac{e}{e_c}\right)$$

on Cu-Be interface

where e is the photon energy, e_c, is the critical photon energy (19,500 eV), ξ is the distance the photon travels inside the beryllium, and F is function of photon energy and the azimuthal angle, ψ. A detailed expression for F can be found in text books, e.g., Jackson [3]. The absorption coefficient α_t(1/mm) is function of photon energy and can be obtained by utilizing the program TRANSMIT.

There are three areas which will be subjected to x-ray heating. One is on the leading edge of the absorber where the L-shaped beryllium diffusers are brazed, and the other two are on the sides of the absorber. Therefore, the entire problem can be discretized into two parts: the analysis on the leading edge, and along the two sides of the absorber.

IV. TEMPERATURE RISE IN THE BERYLLIUM DIFFUSER

Figure 2a shows the temperature contours in the L-shaped beryllium diffuser brazed to OFHC copper plates. The contours show that as the x-ray power is transmitted into the beryllium diffuser, it is distributed in the material and efficiently dissipated by the two nearest water channels. As shown in Fig. 2a, the temperature contours are almost parallel to the water channels, which indicates that the highly concentrated power has been uniformly distributed throughout the beryllium material before reaching the water channels.

The maximum temperature rise, 129 °C, occurs in the right angle corner of the beryllium diffuser. This corner is farthest away from the water channels and is subjected to both bottom and side heating. A sectional contour plot is shown in Fig. 2b, in which the top surface represents the horizontal plane coplanar to the photon fan. Since 60 percent of the beam power is incident on the beryllium-copper interface, secondary high temperature contours appear in this region. The maximum temperature rise at the interface is 112 °C.

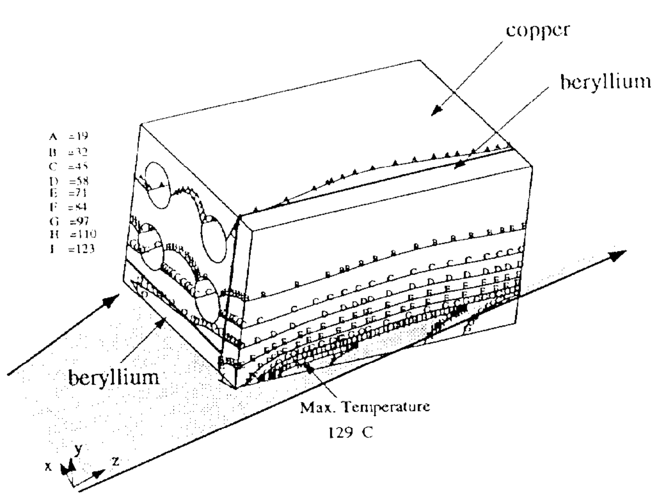

Figure 2a. Temperature Contour in the Leading Edge Crotch Absorber

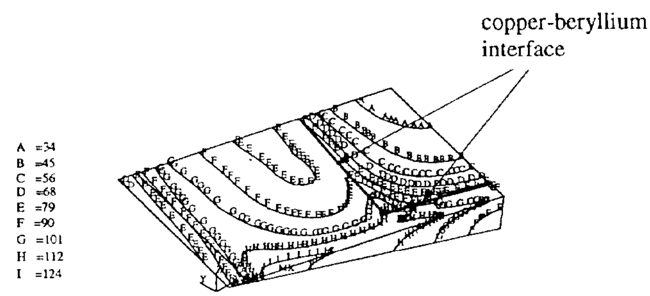

Figure 2b. Sectional Temperature Contour Plot in the Leading Edge Crotch Absorber

V. TEMPERATURE RISE ON THE ABSORBER PLATES

Outside the central zone, the x-ray beam strikes the left and right sides of the absorber plates. On the left side the source distance and the incident angles are 3 meters and 32 °, respectively. The corresponding values on the right side are 1.78 meters and 16 °. These design values were chosen to minimize the temperature rise on both sides of the absorber. Fig. 3 shows temperature contours in the tail region of the right side. At 300 mA beam current, the maximum temperature rise is about 186 °C and drops down to 100 °C at the surface of the water tube. While electron beam experiments [2] have shown OFHC to survive

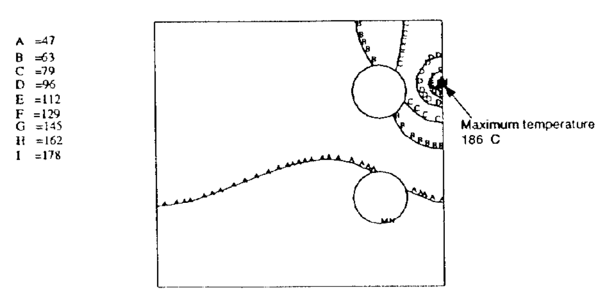

Figure 3. Temperature Contour on the Right Side of the Crotch Absorber Plates

60,000 cycles at a temperature amplitude of 300 °C, significant microcracking can be observed in the test piece.

VI. CONCLUSIONS

A high heat load crotch absorber based on inclined beryllium diffusers has been designed and analyzed. Analytical results show a maximum temperature rise of less than 200 °C for the APS storage ring bending magnet radiation at 300 mA.

VII. ACKNOWLEDGEMENTS

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VIII. REFERENCES

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