Thermal-Stress Analysis of the High Heat-Load Crotch Absorber at the APS

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Abstract

The Advanced Photon Source (APS) storage ring operation at higher beam current is one of the potential enhancements to increase beam brilliance. However, this would impact the beamline components and high heat-load crotch absorbers. Thus, this analysis is conducted to better understand the impact of higher beam current on water-cooled crotch absorbers, made out of Glidcop, without introducing any heat-related problems.

Keywords: storage ring, high heat-load, absorber

1. Introduction

Currently, the 7-GeV Advanced Photon Source (APS) storage ring, with 80 bending dipoles of 0.6 T field strength, operates at 100 mA of beam current. The bending magnets emit a horizontal x-ray fan of 4.5^{o} (78.5 mrad), approximately, two-thirds of which is intercepted by a crotch absorber. The APS storage ring operation at higher beam current is one of the potential enhancements to increase beam brilliance. However, this would impact the requirements of several beamline components, accelerator hardware, optics, front ends, and crotch absorbers. The crotch absorbers at APS are water cooled and made out of Glidcop AL 15 (alumina dispersion strengthened copper) with high tensile and fatigue strengths at elevated temperatures and high thermal conductivity.

A thermal-stress finite element analysis (FEA) of crotch absorbers at APS is conducted to better understand the impact of higher beam current on crotch absorbers and to find out how much higher the current and the water flow rate can be increased without introducing any heat-related problems to the crotch absorbers. A 3-D model of a crotch absorber is created using ANSYS 6.1. The thermal-stress FEA is run at 100 mA beam current, 241 W/mm^2 power density, at 1.8 m distance to the source, 0.2 mm vertical beam height at normal incidence spreading to 1 mm on an 11^{o} vertically inclined plate of the crotch absorber, forming the beam footprint. Constraint equations are used to connect the inner fins to the bottom plate when running the thermal-stress analysis, although this may not be the best connection in terms of how effectively the thermal and structural loads were transmitted from the bottom plate to the inner fins, which are part of the cooling channels. The temperature rise and Von Mises stress rise calculations at higher current levels are conducted and used with several crotch absorber design guidelines [1] in determining how much higher the beam current can be increased. Temperature rise of 159^{o}C is obtained at 100 mA thermal FEA. If a temperature rise limit of 300^{o} C [1] is taken as the only criterion, the beam current can be increased to 188 mA without impacting the requirements of existing crotch absorbers.

Another approach is comparing Von Mises stress to the material's monotonic yield strength value although it may be considered as conservative since, in reality, absorbers go through cyclic thermal strain hardening during operation that increases their yield strength values [2]. The Von Mises stress of 120 MPa is obtained at 100 mA stress FEA. The stress calculations showed that the APS storage ring beam current can be increased up to 276 mA without impacting the requirements of existing APS crotch absorbers even if the Glidcop monotonic yield strength is taken as the limit instead of the cyclic stress-strain curve obtaining fatigue life of 20,000 cycles with a safety factor of about 2.

2. Design

A basic crotch absorber design is shown in Figs. 1 and 2. The nose section of the absorber is inclined vertically by 11^{o}, spreading the beam power vertically. The wings on the sides are inclined to approximately 20^{o} by the incident beam, reducing the incident power density by 66 percent.

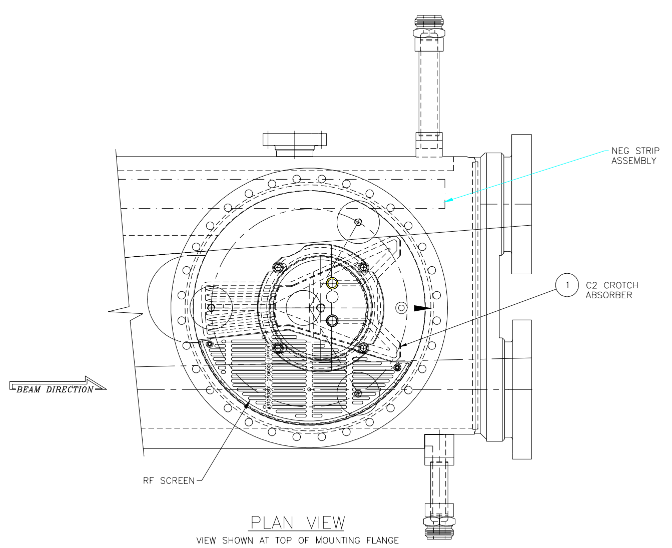

Fig. 1: Plan view of a crotch absorber

The APS storage ring crotch absorbers intercept two-thirds of the power radiated by bending magnets. The linear power density is 48 W/mm at 100 mA beam current.

The external fins, 1.57 mm high and 8 mm apart are located on the nose section of the absorber. They split the beam into two surfaces (fins and grooves) and reduce the temperature rise in the region.

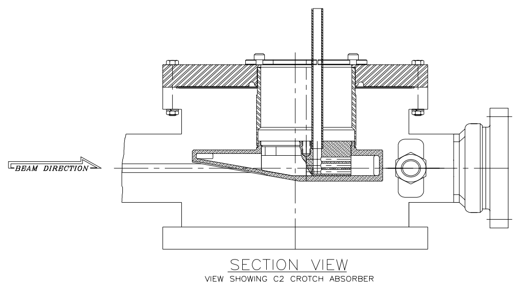

Fig. 2: Section view of a crotch absorber.

There are also internal fins as part of the cooling water channels that are approximately 5 mm away from the surface. The cooling water channels and the internal fins are manufactured by electric discharge machining (EDM) in order to prevent water leaks from entering into the vacuum system.

An oxygen-free high conductivity (OFHC) copper plug is brazed to the Glidcop body of the crotch absorber for directing water flow. The absorber is attached to a flange through a stainless steel cylinder.

3. Analysis

A thermal-stress (FEA) of a crotch absorber is conducted by creating a 3-D model of the crotch absorber using ANSYS 6.1. One-half of the crotch absorber, with nose, middle body section, and a side wing, was modeled using symmetrical boundary conditions. The thermal-stress FEA is run at 100 mA beam current, 241 W/mm^2 power density, at 1.8 m distance to the source, 0.2 mm vertical beam height at normal incidence spreading to 1 mm on an 11^o vertically inclined plate of the crotch absorber.

The cooling water flow rate of the APS storage ring crotch absorbers is 4 gpm. Convection film coefficients of 1.1 W/cm^{2o}C for the nose and 1.2 W/cm^{2o}C for the middle body and side wing sections are used based on their hydraulic diameters.

Constraint equations are used to connect the inner fins to the bottom plate, although it is not known how effective this method is in terms of transmission of thermal and structural loads.

The temperature rise and Von Mises stress calculations at higher current levels are conducted and used with several crotch absorber design guidelines in determining how much higher the beam current can be increased. A temperature rise of 159^o C is obtained (Fig. 3) at 100 mA thermal FEA. If a temperature rise limit of 300° C is taken as the only criterion, the beam current can be increased to 188 mA without impacting the requirements of existing crotch absorbers.

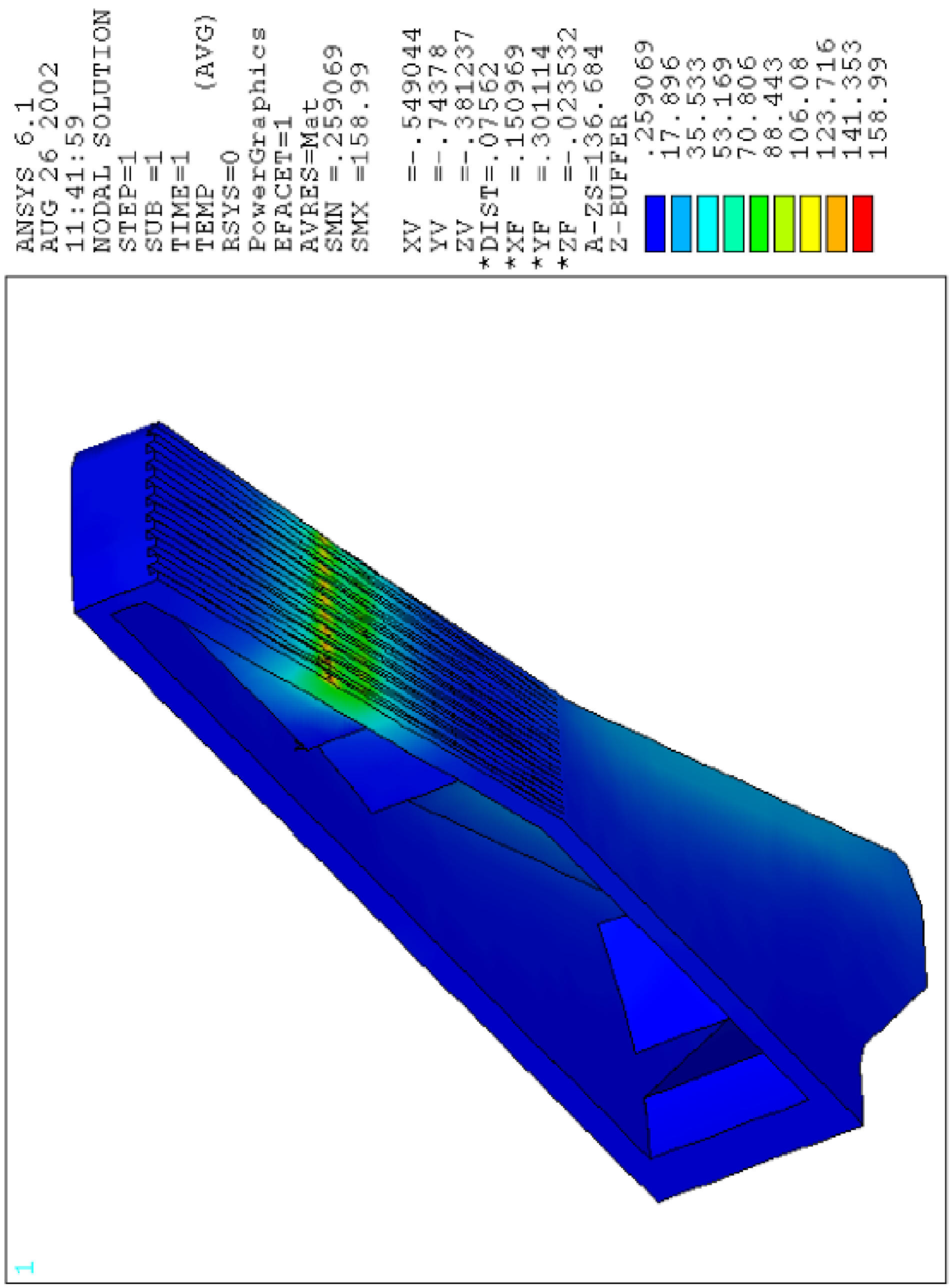

Fig. 3: Thermal analysis of the crotch absorber.

In an effort to minimize the maximum temperature rise, in this study the convection film coefficient, based on cooling water flow rate, is increased incrementally and a corresponding maximum temperature rise was obtained by using FEA; the results are plotted (Fig. 4). It is observed that the convection film coefficient is inversely proportional to the maximum temperature rise up to about 0.5 W/cm^{2o}C, and afterwards its effect diminishes significantly. Thus, it is not necessary to increase the existing cooling water flow rate, 4 gpm, since the convection film coefficient of 1.1 W/cm^{2o}C is already on the flat portion of the curve in Fig. 4.

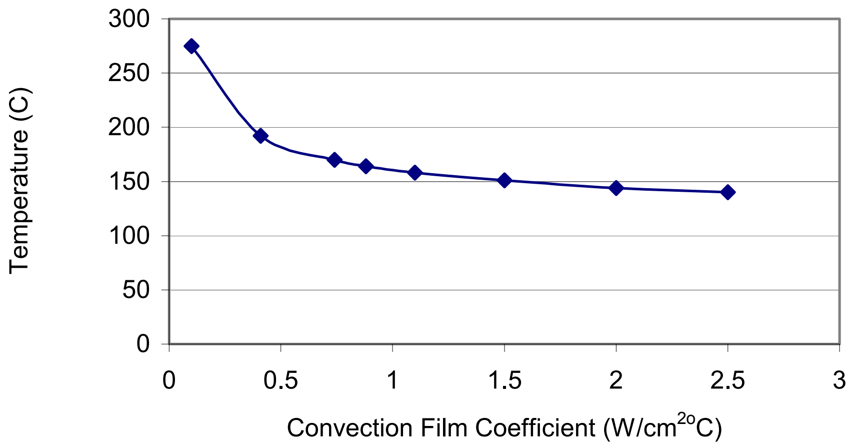

Fig. 4: The relationship of convection film coefficient to temperature.

Another approach is comparing Von Mises stress to the material's monotonic yield strength value although it may be considered as conservative since, in reality, absorbers go through cyclic thermal strain hardening during operation that increases their yield strength values [2]. The Von Mises stress of 120 MPa is obtained at 100 mA stress FEA. The stress calculations showed that the APS storage ring beam current can be increased up to 276 mA without impacting the requirements of existing APS crotch absorbers, even if only the Glidcop monotonic yield strength is taken as the limit instead of the cyclic stress-strain curve, while maintaining fatigue life of 20,000 cycles with a safety factor of about 2.

4. Conclusion

The APS storage ring crotch absorber is analyzed by using ANSYS 6.1 with current operating conditions, and its design is described. The temperature rise and Von Mises stress calculations at higher current levels are conducted and used with several crotch absorber design guidelines in determining how much higher the beam current can be increased. If a temperature rise limit of 300^{o} C is taken as the only criterion, the beam current can be increased to 188 mA without impacting the requirements of existing crotch absorbers. On the other hand, if the fatigue life criterion is considered only with the Von

Mises stress result, APS storage ring beam current can be increased up to 276 mA without impacting the requirements of existing APS crotch absorbers while maintaining fatigue life of 20,000 cycles with a safety factor of about 2.

5. Acknowledgements

The author thanks Sushil Sharma for his continuous support and Catherine Eyberger for editing the paper.

6. References

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