A case study of a high heat load equipment at the Australian Synchrotron

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Abstract

A case study of a front end shutter is presented in this paper. In this study, power density distribution of a super-conducting wiggler photon beam is calculated using synchrotron radiation workshop (SRW) and was input to Ansys workbench as boundary conditions using customized scripts written in Ansys. Two types of absorber, corrugated and flat styles, were verified in this study. Heat flux can be spread between ridges and grooves of corrugated surfaces. As a result, it was found that the absorber with corrugated surfaces had a better performance than the absorber with flat surfaces. Different absorber materials (OFHC and GlidCop copper) were also verified in this study.

1. Introduction

A total of 9 front ends for the storage ring, comprised of 6 Insertion Device (ID) front ends and 3 Bend Magnet (BM) front ends, have been designed, manufactured and installed. The Australian Synchrotron carried out the verification of the front end designs in 2005. One of the verification was to verify the photon absorber with extremely high heat load. The highest heat flux is from insertion devices (ID). Therefore, the super-conducting wiggler has been chosen to verify the design.

The super-conducting wiggler creates very bright photon beams. The photon shutter in the front end assembly is located about 7.5 m from wiggler source point. At this distance, the peak heat load induced by the photon beam is about 260 W/mm^2 on the absorber.

Lots of work has been done to try to reduce the heat flux on the absorbers. A typical way that the power density can be reduced is by positioning the absorber surface at a small angle to the beam [1-5]. The front end absorbers designed for Australian Synchrotron use the same strategy. In addition to the small grazing angle, the absorber surfaces facing the beam were corrugated to reduce the heat density further.

Finite element analyses (FEA) have been used to verify the absorber designs. However, the small grazing angle with corrugated surfaces makes it difficult to apply boundary conditions in the FEA verification. In this study, spatially distributed heat flux was calculated in Synchrotron Radiation Workshop (SRW) [6], and was applied in the simulations by using customized scripts written in Ansys Workbench v10 [7].

Two similar designs were studied in this report. One design uses corrugated surfaces and the other uses flat surfaces for comparison. The first part of this paper presents the design of the photon shutter assembly, finite element analysis methodologies and results. Then, a brief discussion about thermal hydraulics and its implications in designing high heat load front end and beamline components.

2. Thermal stress analysis

1.1. Materials

The absorber is made of GlidCop or OFHC copper (Table 1) and jointed with copper tubes as cooling channels by vacuum brazing. The surfaces facing the photon beam were corrugated to increase the surface area as well as spread the peak heat load. An actuator drives the absorber into or out of the photon beam (Figure 1).

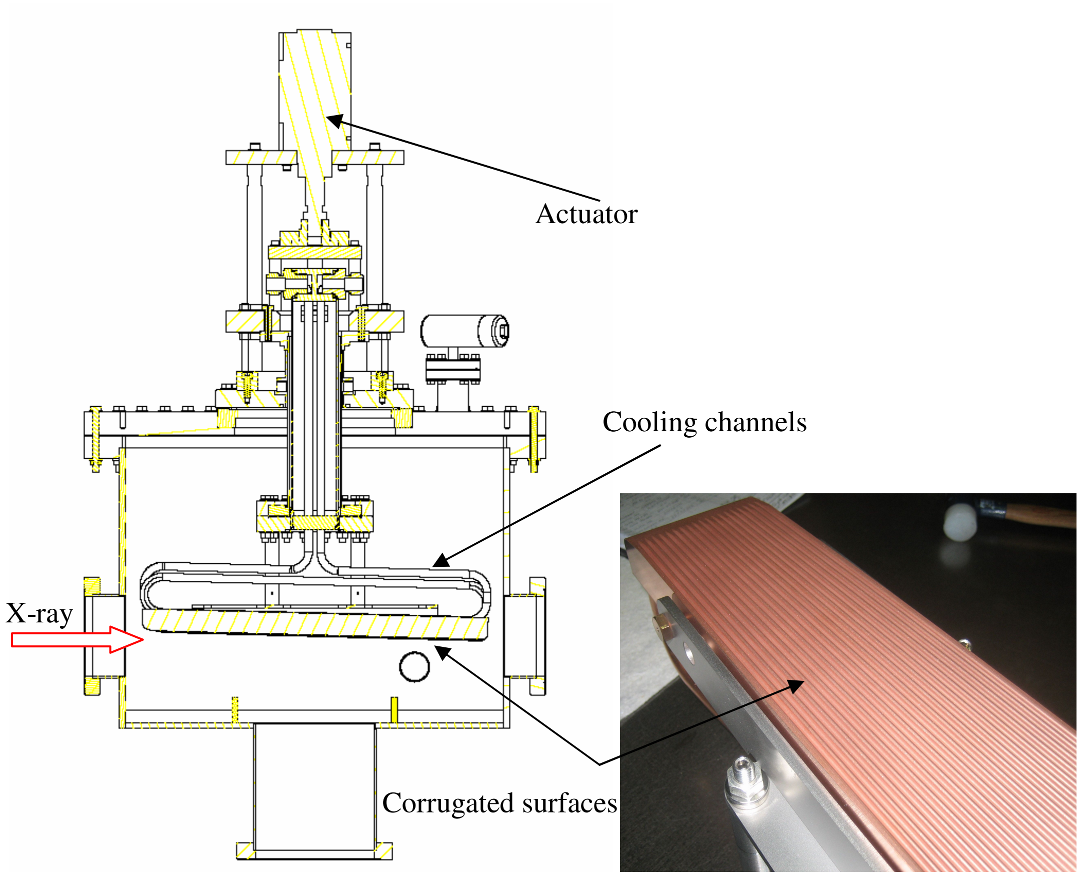


Figure 1 A thermal absorber assembly

Table 1 *Absorber materials*

Material Properties	***ClidCop Al-15***	***OFHC***
Young's Modulus	*130 GPa*	*110 GPa*
Poisson's Ratio	*0.34*	*0.31*
Density	*8960 kg/m3*	*8940 kg/m3*
Thermal Expansion	*1.66e-5 1/C*	*1.7e-5 1/C*
Tensile Yield Strength	*352 MPa*	*195 MPa*
Tensile Ultimate Strength	*414 MPa*	*250 MPa*
Thermal Conductivity	*365 W/m-C*	*391 W/m-C*
Specific Heat	*385 J/kg.C*	*385 J/kg-C*

1.2. Boundary Conditions

The normal incidence power density distribution (Figure 2) from the super-conducting wiggler at 7.5 m from source was calculated in SRW and exported to a formatted table to be used in Ansys. The peak power density is about 260 W/mm^2. The absorber has six vacuum brazed water channels. A velocity of 3.6 m/s and inlet temperature of 25°C were assumed. Therefore, the flow is well in the turbulent region, and the film coefficient can be calculated [8]. Film coefficient used in this study was 14000W/m^2-K.

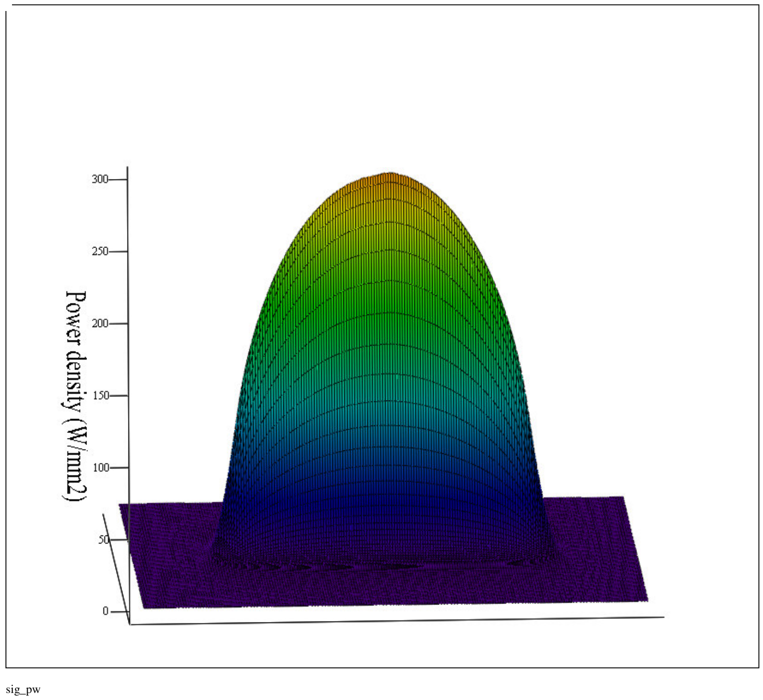


Figure 2 Super-conducting wiggler power density distribution @7.5m from source, W/mm^2

The film coefficient was applied to the cooling side directly. However, it is not straightforward to apply the heat load boundary conditions, because the irregular corrugated surfaces have different angles to the grazing beam. Approximation of the corrugated surfaces as a flat surface resulted in higher than normal peak heat load. Therefore, a more accurate method needs to be used.

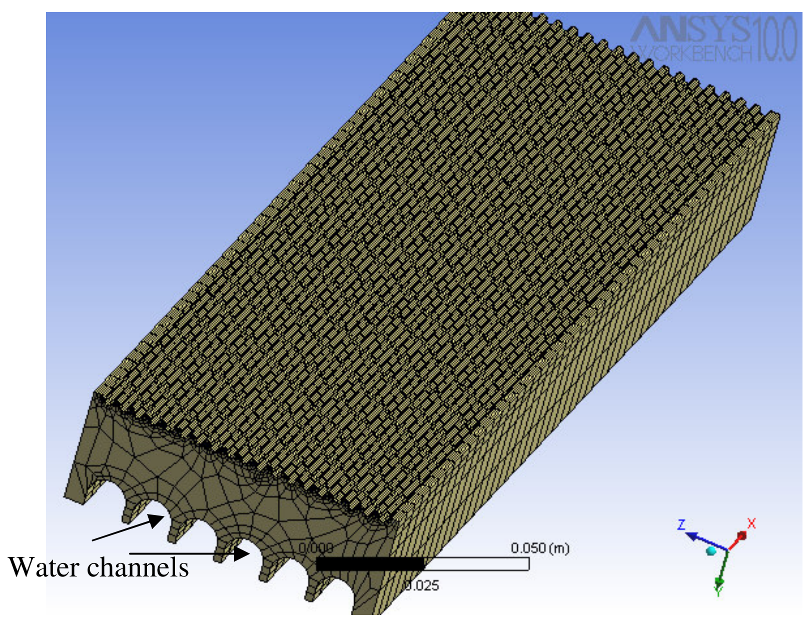


Figure 3 Absorber with corrugated surface and its FEA model

Figure 3 shows absorber finite element model meshed with 20-nodes hexahedral elements. The corrugated surface area was meshed into special surface elements which can take heat flux as boundary conditions. Figure 4 shows one of these surface elements projected normally to the power density distribution x-y plane.

Knowing the position of these elements, power density can be interpolated from beam power density distribution (Figure 2). Then, multiplying the ratio of projected area to physical element area, the result was used as heat flux boundary condition to the surface element. The projected area is a function of beam grazing angle and the topology of the absorber surfaces. The projection operation can be done automatically as grazing angle and topology have been already considered in the programming, therefore, beam power density distribution can be applied to arbitrary absorber surfaces as a boundary condition.

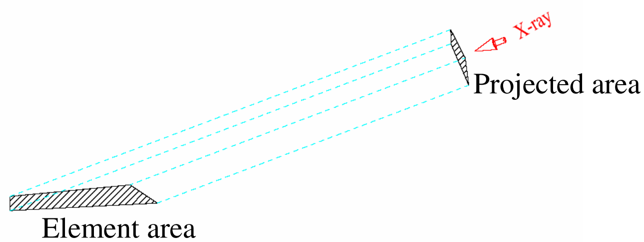


Figure 4 Project surface element area to beam coordinates

1.3. Results

Two similar designs were studied in this paper. One design uses corrugated surfaces and the other uses flat surfaces for comparison. OFHC and GlidCop were used in both of the designs. Therefore, four scenarios were studied in this report. 1.5° grazing angle was implemented in absorber assembly design. However, different angles were also studied to rationalize that the implementation was correct and conservative.

First, to verify the simulations, the total power integrated from the SRW was 20.23kW; and the Ansys calculation was 20.41kW. The Ansys result could be more accurate by refining meshes further; however, the error was less than 1%, and it indicated that the simulations were setup correctly.

Figure 5 shows the heat flux on a corrugated absorber and a flat absorber. The corrugated design (Figure 5 (b)) offsets the heat flux distribution to downstream and covers larger areas than that of a flat-style absorber (Figure 5 (a)). As a result, corrugated designs have lower maximum temperatures, lower stresses and lower strains than the designs with flat surfaces. Table 2 shows the first set of results with 1.5° grazing angle.

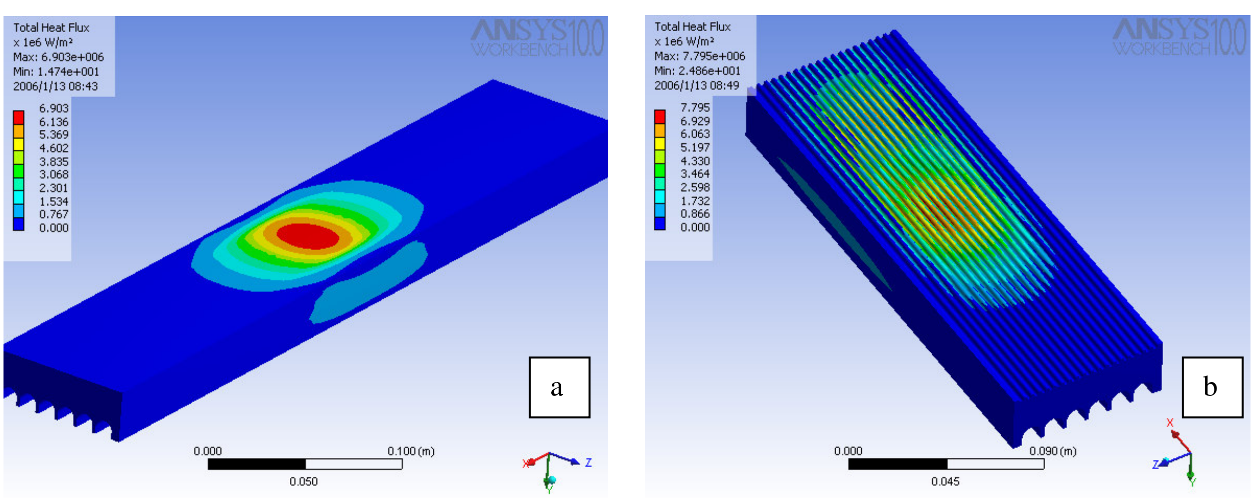
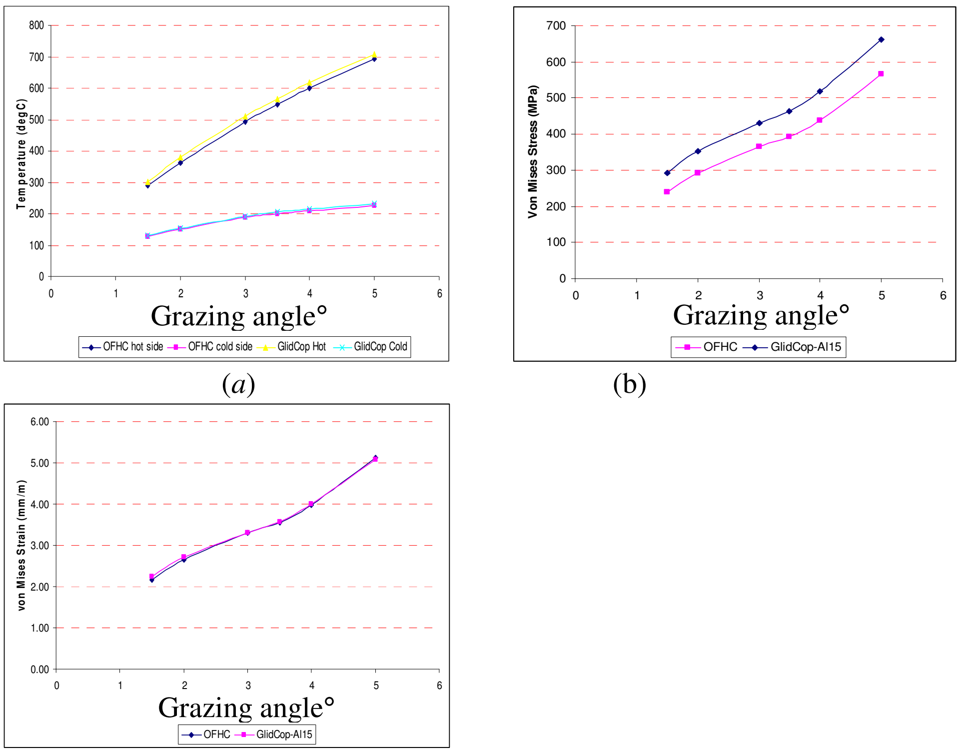


Figure 5 Heat flux, (a) flat design and (b) corrugated design

Table 2 *Simulation results, grazing angle 1.5°*

	OFHC - flat	OFHC - corrugated	GlidCop Al-15 - flat	GlidCop Al-15 - Corrugated
Max temperature:	388°C	289.4°C	403.4°C	302.7°C
Max cooling surface temp:	159°C	126°C	161°C	130°C
Max. von-Mises Stress:	260 MPa	240 MPa	316 MPa	292 MPa
Max. von-Mises Strain:	2.36 mm/m	2.17 mm/m	2.43 mm/m	2.24 mm/m

Because OFHC has better heat conductivity, the maximum temperatures, stresses and strains are lower when using OFHC than GlidCop. However, only GlidCop can withstand the high temperature and stress requirements, therefore, corrugated GlidCop absorbers have been implemented at the Australian Synchrotron.



(*a*) (b) (c)

Figure 6 (a) temperature, (b) stress and (c) strain versus grazing angle

Further studies of the corrugated design were carried out using grazing angles from 1.5° to 5° (Figure 6); In order to satisfy the maximum temperature criterion, it was found that grazing angle larger than 1.5° should not be used. However, if this could be relaxed [9], much higher grazing angles could be used. Furthermore, when pressurized cooling water temperature reaches a certain point, the heat transfer coefficient is dramatically increased. Figure 7 shows the sharp increase in heat transfer coefficient at region 4. This means much more heat is taken away by cooling water when the temperature approaches the boiling point. The simulations were calculated using the film coefficient region 1 with an inlet temperature at 25°C. The heat transfer coefficient would be higher when water was heated up, which also indicated that the simulations were conservative.

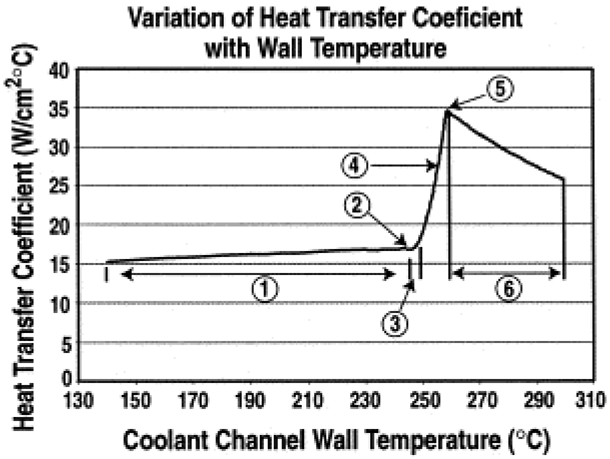


Figure 7 Variation heat transfer coefficient [10]

3. Conclusions and future work

To verify the components with high X-ray beam heat load, FEA studies were carried out in this paper. From the thermal stress analysis, the corrugated absorber design made of GlidCop was proven to be conservative and implemented at the Australian Synchrotron. A FEA methodology was also developed to verify designs with arbitrary surfaces.

Possible future work to quality the device with higher heat load may include non-linear fatigue analysis and cooling water behaviour analysis.

Acknowledgments

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