Thermal-Stress Analysis of Photon Shutter of Wiggler front ends at SSRF

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Abstract: The Shanghai Synchrotron Radiation Facility (SSRF) is a third-generation light source that the storage ring will be operating at its specification of 3.5GeV of beam energy and 300 mA of beam current. The components of the insertion device front ends will be submitted to high heat load. In order to investigate the thermal safety of front end components, thermal and stress analyses of the components of the designing front ends at SSRF were carried out. In this report two type of photon shutters with different cooling structure for wiggler front end were calculated by ANSYS. The maximum thermal stress of B-type is less than A-type when the storage ring shifts among the range of ±0.5mrad in horizontal and ±0.2mrad in vertical direction, respectively.

Keywords: high heat-load, FEA

1. Introduction

The Shanghai Synchrotron Radiation Facility (SSRF) is a third-generation light source that the storage ring will be operating at its specification of 3.5GeV of beam energy and 300 mA of beam current. The components of the insertion device front ends will be submitted to high heat load. In order to investigate the thermal safety of front end components, thermal and stress analyses of the components of the designing front ends at SSRF were carried out. This report contains analyses of two type of photon shutters(PS) for wiggler front end. The analysis is comprehensive. It contains details of photon shutter model, load cases, maximum temperature and stress results. A-type PS analyses include details of the aperture profile and beam-missteering scenarios. It will serve as the front-end engineering analysis data archive for the front ends. The temperature and stress data for 300 mA operation are calculated. Once the temperature and stress data for 300 mA beam current are calculated, linear extrapolation is used to derive the temperature and stress data for higher beam currents. By comparing the temperature and stress data to the failure criteria, the maximum allowed beam current is derived.

2. General Information

At phase 1 of SSRF, the W14 for the medicine image beamline has the maximum power and power density among wiggler sources.

2.1. Source Parameters

The smaller source size and divergence will result in a slightly higher peak power density.Zero emittance will result in the highest peak power density. We calculated the power by the source calculation software such as XOP [1] and SPECTRA [2] with zero emittance. The SSRF nominal storage ring parameters are shown in Table 1. The wiggler insertion device parameters are listed in Table 2.

Table 1 SSRF nominal storage ring parameters

Low emittance (nm-rad)	Coupling	source		divergence	
		Σx(μm)	Σy(μm)	σx'(μrad)	σy'(μrad)
3.9	1%	158	9.9	33	3.95

Table2 wiggler parameters(W14)

ID type	description	Kmax	Total power (Watts)	Peak power Density (kW/mrad^2)
Multipole Wiggler(EMW)	λ=14 cm, N=8	25.4	9840	7.6

2.2. Material Properties

The photon shutter are made by wire cut machining from solid blocks of GlidCop. The properties relevant for the analysis for GlidCop is shown in Table 3.

Table 3 Material properties of GlidCop AL-15(as consolidated to 75% cold worked)

	Thermal conductivity (w/mm°C)	Thermal expansion coefficient (μm/m/°C)	Young's modulus (GPa)	Poisson's ratio	Yield strength (MPa)	Ultimate tensile strength (MPa)
AL-15	0.365	16.6	130	0.326	331~455	413 ~ 483

2.3 Failure Criteria

The SSRF has used conservative criteria for establishing the maximum thermal load acceptable for x-ray beam-intercepting components:

1) Maximum temperature on GlidCop < 300°C to prevent material creep.

2) Maximum temperature on the cooling wall < water boiling temperature at channel pressure to prevent water from boiling and to maintain single-phase heat transfer. The typical pressure in channel of a component is large than 2.5atm, and the corresponding water boiling temperature at 2.5atm is about 125°C.

3) Maximum von Mises stress < 400 MPa for photon shutters (the yield strength of the plate stock of GlidCop at room temperature). This method may be considered as conservative since, in reality, PS go through cyclic thermal strain hardening during operation that increases their yield strength values [3].

3. Design

A basic photon shutter(A-type) design is shown in Fig.1. The plane which is submitted to X-ay is inclined vertically by 3.5^o, spreading the beam power vertically. The SSRF wiggler PS intercept 2mrad in horizontal and 0.3mrad in vertical of the power radiated by wiggler(W14). The distance between PS and source point is 13.8m. The power density is 40 W/mm^2 and total power is 2900W at 300 mA beam current. The cooling water channels are approximately 5 mm away from the surface. In order to prevent water leaks from entering into the vacuum system, all bonding of the cooling water channels are faced directly to atmosphere.

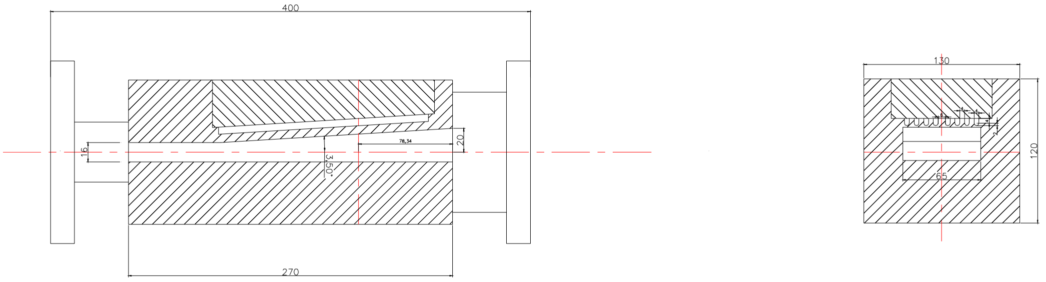

Fig. 1. Drawing of A-type PS.

In order to reduce the complex of machine, another photon shutter(B-type) design is shown in Fig.2. The plane which is submitted to X-ay is inclined horizontally by 9.89^o, spreading the beam power horizontally.

4. Analysis

A thermal-stress (FEA) of photon shutter is conducted by creating a 3-D model of PS using ANSYS 10. The thermal-stress FEA is run at 300 mA beam current, 40 W/mm^2 power density, at 13.8 m distance to the source, 0.3 mrad in vertical and 2mrad in horizontal beam at normal incidence spreading to 4.2 mm on an 3.5^o vertically inclined plate of the A-type PS, 27.6 mm on an 9.89^o horizontally inclined plate of the B-type PS, forming the beam footprint.

The cooling water flow rate of the SSRF wiggler front end photon shutter is about 2m/s. Convection film coefficients of $1.0 W/cm^{2o}C$ for the cooling water channel are used based on their hydraulic diameters.

The temperature rise and Von Mises stress calculations are conducted. The temperature and Von Mises stress of A and B-type PS are shown in Fig.3 and Fig.4 respectively.

From Fig.3 and Fig.4, we know the maximum Von Mises stress of B-type PS is less than A-type PS. We can draw a conclusion that B-type structure is better to A-type. So we take B-type PS as the final design.

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.5). It is observed that the convection film coefficient is inversely proportional to the maximum temperature rise up to about 0.5 $W/cm2^oC$, and afterwards its effect diminishes significantly. Thus, it is not necessary to increase the existing cooling water flow rate, 2m/s, since the convection film coefficient of 1.0 $W/cm2^oC$ is already on the flat portion of the curve in Fig. 5.

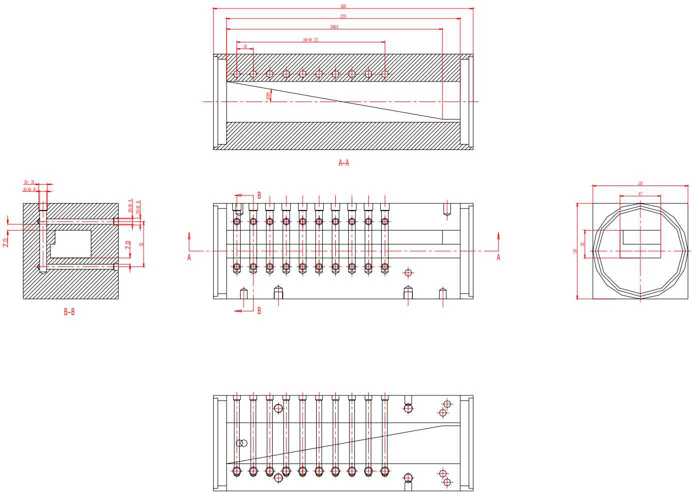

Fig. 2. Drawing of B-type PS.

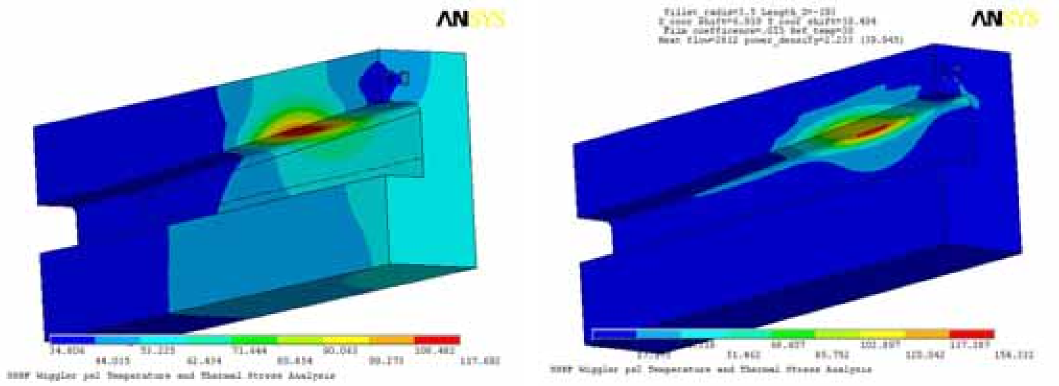

Fig.3 The temperature and Von Mises stress distribution of A-type PS

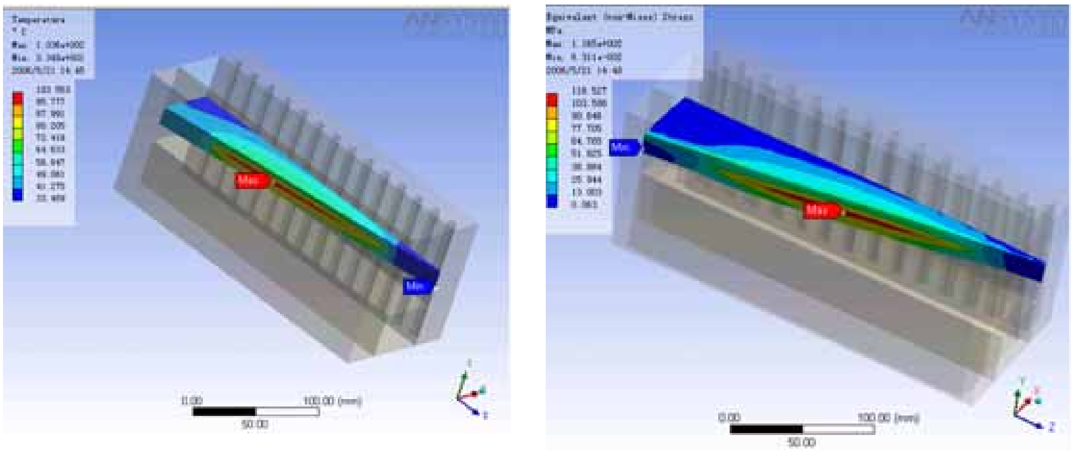

Fig.4 The temperature and Von Mises stress distribution of B-type PS

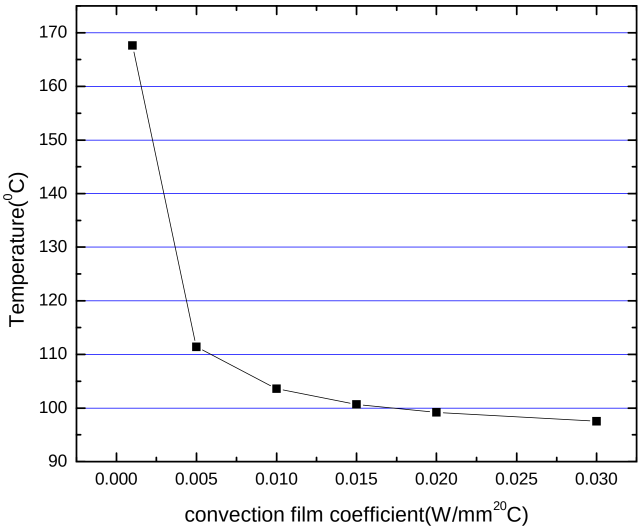

Fig. 5: The relationship of convection film coefficient to temperature.

Once the temperature and stress data for 300 mA beam current are calculated, linear extrapolation is used to derive the temperature and stress data for higher beam currents. By comparing the temperature and stress data to the failure criteria, the maximum allowed beam current is derived. The maximum of temperature and von mises stress of B-type PS with different electron beam current is shown in Table 4.

Table 4 the maximum of temperature and von mises stress of B-type PS with different electron beam current

Electron Current(mA)	Temperature(^{0}C)	von mises stress(MPa)
300	103.6	116.5
400	128.1	155.3
500	152.6	194.2

5. Conclusion

The SSRF photon shutter for wiggler front end is analyzed by using ANSYS 10 with the design electron beam current of 300mA, and two types of design are described. B-type PS has lower temperature and von mises stress than A-type PS. The temperature rise and Von Mises stress calculations at different current levels are conducted for B-type PS and used with failure criteria in determining how much higher the beam current can be increased. We can draw a conclusion that the B-type PS will be thermal safety when the SSRF storage ring current can be increased up to 500mA.

6. Acknowledgements

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7. References

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