5th International Workshop on Mechanical Engineering Design of Synchrotron Radiation Equipment and Instrumentation (MEDSI2008) June 11-13, 2008-CTU Place Saskatoon, Saskatchewan, Canada

Thermal Simulation of Fluorescent Screen of front ends at SSRF

Naxiu WANG Zhong LI Zhongmin XU

Shanghai Synchrotron Radiation Facility, Shanghai Institute of Applied Physics, CAS, Shanghai 201800, China

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 300mA of beam current. The components of the front ends will be submitted to high heat load. In order to investigate the thermal safety of Fluorescent screen used in front end, FEA were carried out. In this report the up-limit of high heat load has been predicted by ANSYS. During the commissioning the Fluorescent screen has been submitted to heat load of 3GeV 100mA and work successfully.

Keywords: Fluorescent screen, 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 300mA of beam current. The components of the front ends will be submitted to high heat load. In order to investigate the thermal safety of Fluorescent screen (FS), FEA were carried out. In this report the up-limit of high heat load has been predicted by ANSYS. The analysis is comprehensive. It contains details of Fluorescent screen model, load cases, maximum temperature.

FS is a type of X-ray position detector, which is used to detect the X-ray position roughly during the commissioning of beam line. The principle of FS is the natural phenomena that the visible light is emitted when X-ray collides with the fluorescent material. The screen can be the manifold with fluorescent powder or YAG or CVD diamond film. In order to increase the capacity of power submitted by FS the standard design of FS is shown in Fig.1. CVD diamond film has been selected as FS substrate, which has good thermal conductivity. In front of CVD there is a graphite filter which has two function of reducing the absorbed power of CVD and the disturbance of visible light from storage ring on FS. CVD and graphite are cooled by water.

As shown in Fig.1, graphite and CVD are installed on an OFHC manifold cooled by water. The manifold can be moved vertically on to the beam axis using a pneumatically driven support on which the manifold is mounted. The normal of CVD surface and the beam axis lie at an angle of about 45 degrees.

The thickness of CVD film is 300um, the outer diameter is 65mm. The diameter of X-ray traverse is 55mm. There is a gold film of 100um thickness between the CVD and OFHC manifold. The CVD, Au film and OFHC manifold are clamped together by bolts.

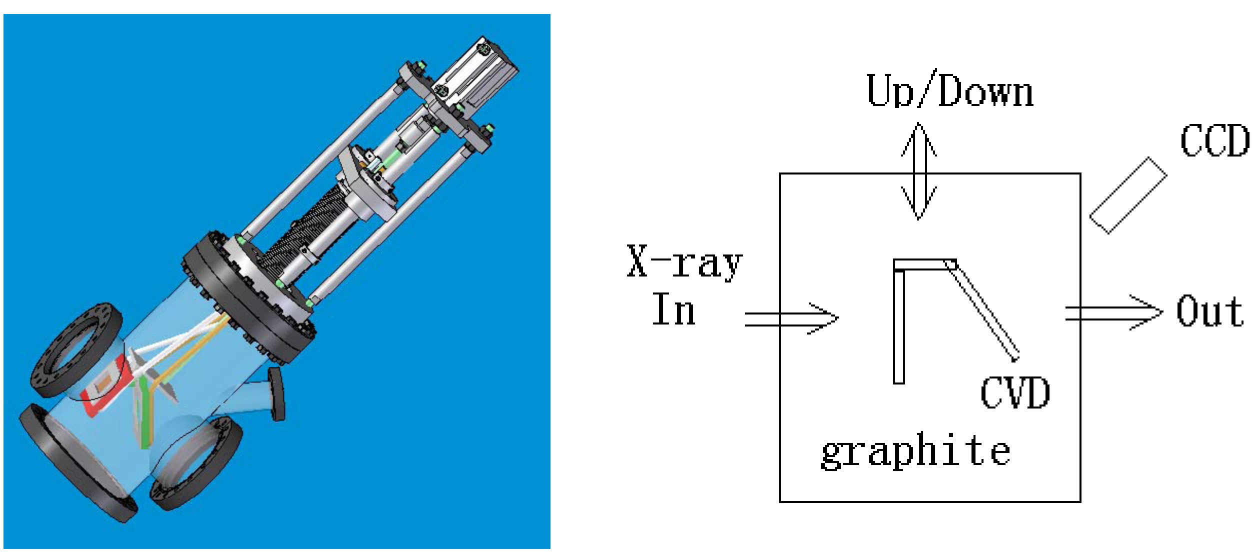

Fig. 1 schematic diagram of Fluorescent screen used in Front end

2. Simulation

2.1. Heat load

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.

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

At phase 1 of SSRF beam line, the smallest distance from the first FS to source is 5.07m, on which the X-ray spot is 17.3mm×7.6mm for bending magnet beam line, the maximum of power density is 12.1W/mm^2, the total power is 232W. The smallest distance from the first FS to source for EPU beam line is 11.93m, on which the X-ray spot is 10.2mm×6.1mm, the maximum of power density is 85.2W/mm^2, the total power is 1948W. The heat load distribution of bending magnet and EPU source is shown in Fig.2a and 2b, respectively [3].

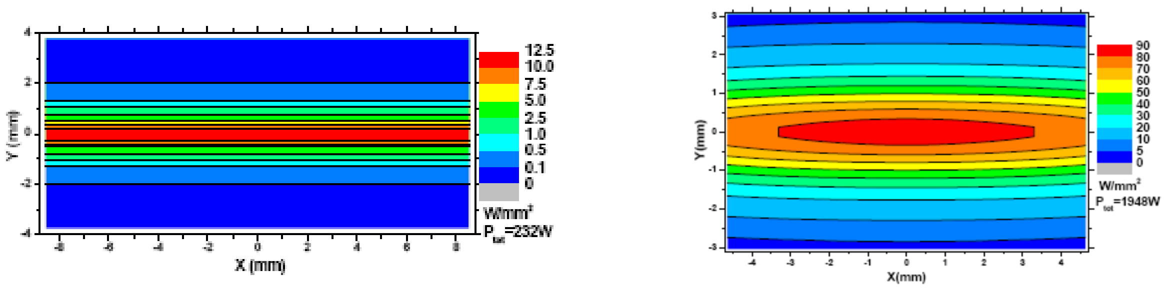

Fig.2a Power Distribution of Bending Magnet Source   Fig.2b Power Distribution of EPU Source

Fig.2 Power distribution of SSRF source

Current of Storage ring is 300mA and Energy is 3.5GeV.

According to the layout of Fig.1, the power emitted from the source is absorbed partly by the CVD diamond film. The absorbed power is decided by X-ray energy. But for conservation we take the all power as the surface heat flux used in ANSYS thermal analysis model.

2.2. Material Properties

The FS substrate is CVD diamond film. The thermal conductivity of CVD is shown in Fig.3.

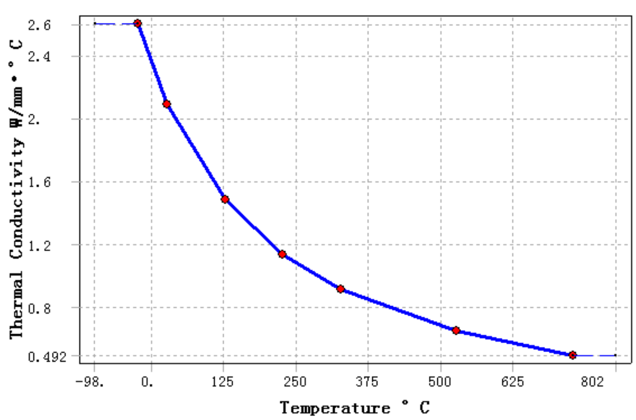

Fig.3   CVD Thermal Conductivity vs. Temperature

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 CVD <1000°C to prevent material damage (phase transition temperature for conservation).

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.

2.4 Analysis

We do the steady thermal simulation by ANSYS Workbench V11[4] . The quarter model is shown in Fig.4. During the process we just calculate the thermal radiation of CVD surface because the temperature of OFHC tube and manifold is about room temperature. The cooling water flow rate of the SSRF font end FS is about 2m/s. Convection film coefficients of 10000W/m^{2o}C for the cooling water channel are used based on their hydraulic diameters. The thermal contact conductivity of CVD-Au-OFHC interface is 2000 W/m^2℃. The thermal contact conductivity between OFHC body and tube is infinite.

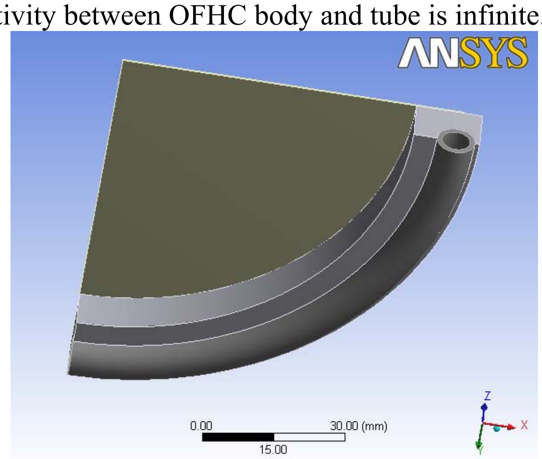

Fig.4 Simulation Model of 1/4

2.4.1 Result of bending magnet FS

The calculations of temperature rise are carried out. The temperature of CVD is shown in Fig.5.

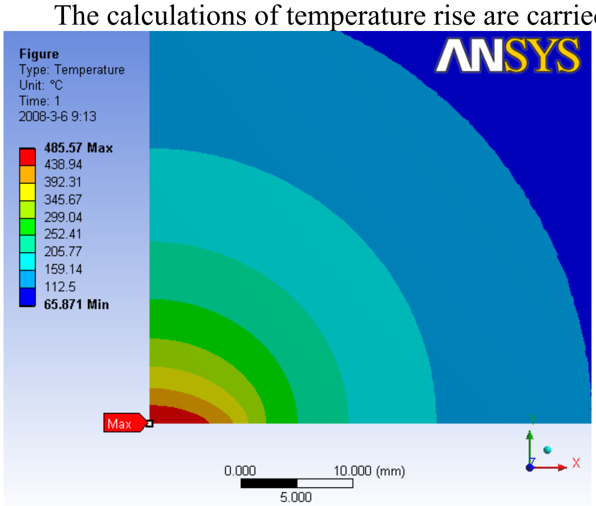

Fig.5a temperature distribution of CVD diamond film

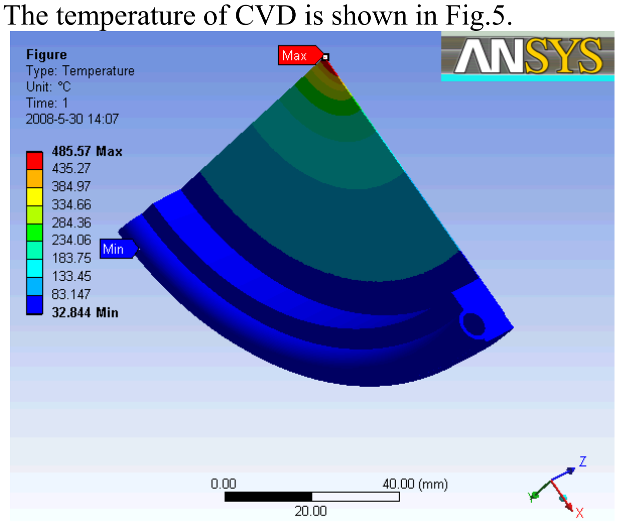

Fig.5b temperature distribution of FS

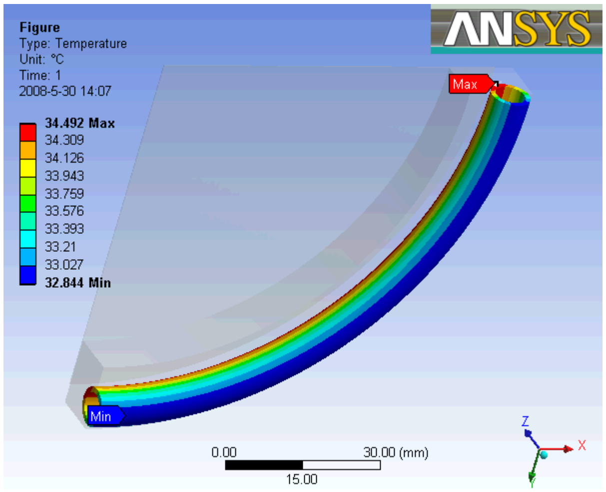

Fig.5c temperature distribution of OFHC water tube

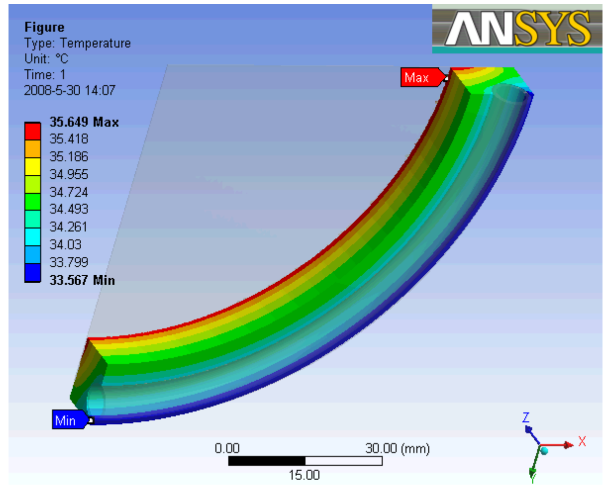

Fig.5d temperature distribution of OFHC manifold

Fig.5 temperature distribution of Fluorescent screen

The maximum temperature of CVD is 485℃, which is smaller than 1000℃. The maximum of OFHC tube is 34.5℃ and the maximum of OFHC manifold is 35.6℃, are smaller than water boiling point. So we can conclude the thermal design of FS is safety.

2.4.2 Result of EPU insertion device FS

The maximum of temperature of EPU front end FS with different electron beam current is shown in Table 2.

Table 2 the maximum of temperature of EPU FS with different electron beam current

current(mA)	graphite(℃)	CVD(℃)	Conductivity (W/cm℃)	power(W)
10	318		1.2	64
20	477		1.2	125
30	900		1.2	194
	1365		0.6	
40	1289		1.2	258
50	1600	679	1.2	264
70		909	1.2	473
		1231	0.6	
80		1017	1.2	544
100	2573	1226	1.2	646
200	3569	2003	1.2	1292
300		3179	0.6	

We can conclude that CVD film can be submitted to the heat load of 3.5GeV of energy and 70mA of storage ring electron current from Table 2 and the graphite film can be submitted to about 30mA.

3. Experiment

During the commissioning of beam line at SSRF, the FS of BL14B is heated by the X-ray heat load which is emitted by 3GeV 100mA for more than 12 hours. After that the X-ray spot image is measured successfully by

FS and shown in Fig.6 [5]. From Fig6b we can draw a conclusion that there is something to interrupt the X-ray partly. After that we also found out that there is the water tube which interrupts the X-ray partly. After modification, X-ray image is shown in Fig6d. The FS work successfully, which indicates the thermal simulation of FS is reasonable.

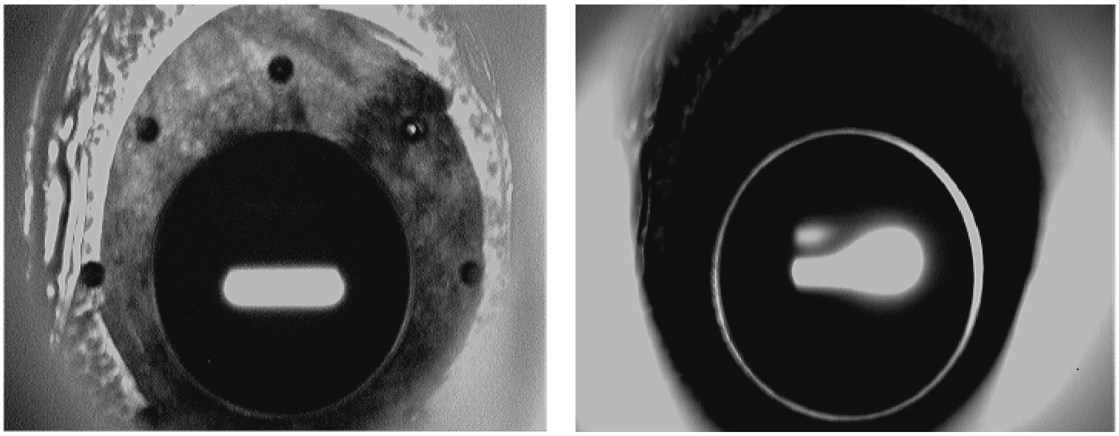

Fig.6a FS1@3GeV 1.6mA (Jan. 2) Fig.6b FS1@3GeV 100mA (Jan. 3)

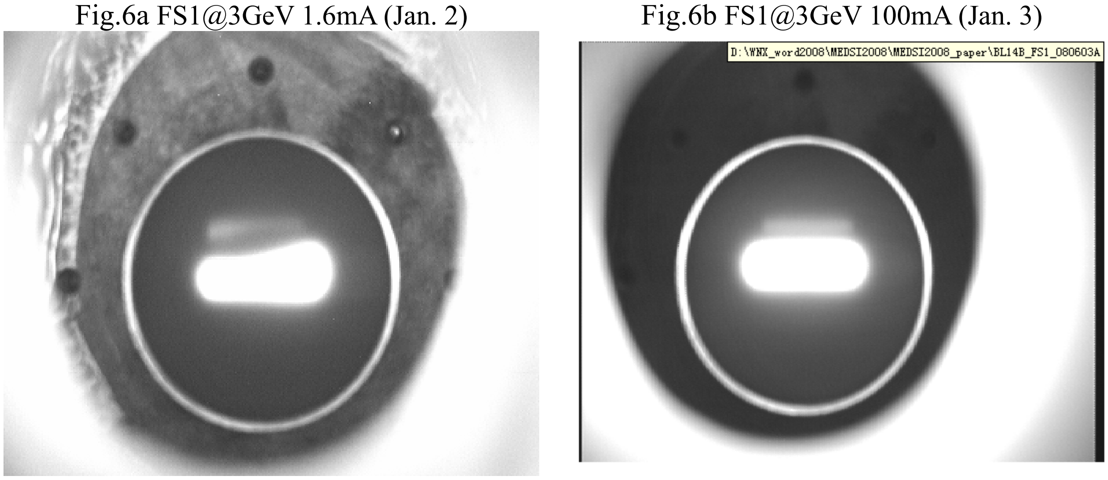

Fig.6c FS1@3GeV 1.6mA (Jan. 21) Fig.6d FS1@3GeV 100mA (Jun. 3)

Fig.6 X-ray spot image of BL14B FS

After FS is radiated by X-ray more than 12 hours

4. Conclusion

The SSRF Fluorescent screen of front end is analyzed by using ANSYS 11 with the design specification of storage ring energy of 3.5GeV and electron beam current of 300mA. The calculations of temperature rise at different current levels are carried out for EPU beam line front end and compared with failure criteria in determining how much the beam current can be submitted by FS. We can draw a conclusion that the FS will be thermal safety when the SSRF storage ring current can be increased up to 300mA for bending magnet source at 5 m and up to 30mA for EPU insertion device source at 11m.

5. Acknowledgements

The author thanks all colleagues for their useful discussion and help.

6. References

[1] M. Sanchez del Rio and R. J. Dejus "XOP: Recent developments" SPIE proceedings, vol. 3448, 340-345, 1998

[2] T.Tanaka and H. Kitamura, J. Synchrotron Rad. 8(2001)1221 SPECTRA V7.1.3

[3]Zhong Li, deign report of X-ray position detector, Feb. 2007, data at SSRF

[4]ANSYS documents

[5]Zhong Li, report of front end commissioning, March 2008, data at SSRF