A HIGH HEAT LOAD FRONT-END FOR THE SUPERCONDUCTING WIGGLER BEAMLINE AT SSRF*

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Abstract

A superconducting wiggler (SCW) will be first employed to generate high energy X-rays for ultra-hard X-ray applications beamline at Shanghai synchrotron radiation facility (SSRF). The front-end will handle a heat load of 44.7 kW with a peak power density of 45 kW/mrad², which is much higher than the commissioned ones at SSRF. Overall design of the high heat load front-end has been completed, including one short absorber with a length of 300 mm and three long absorbers longer than 500 mm. Long absorbers have been designed to be made by medium speed wire-cut electrical discharge machining (WEDM-MS) or electron beam welding (EBW). Thermal analyses of all absorbers have also been done to comply with the failure criteria of SSRF.

INTRODUCTION

Shanghai synchrotron radiation facility (SSRF) is an advanced third generation synchrotron light source with a 3.5 GeV electron storage ring and a designed beam current of 300 mA. A superconducting wiggler (SCW), as source of the ultra-hard X-ray applications beamline BL12SW at SSRF, will be able to generate high-energy X-rays up to 150 keV. Meanwhile, the SCW has an intensive power of over 43.3 kW with a peak power density of 45 W/mrad^2. Overlapping the radiations from upstream and downstream bending magnets, the total power will reach 44.7 kW, which are about 4 to 64 times compared with the commissioned front-ends. This is also the highest heat load for a front-end in SSRF phase-II beamline project.

Overall design of the high heat load front-end, abbreviated as BL12SW front-end, was introduced in this study. Thermal analyses of all absorbers were done to comply with the failure criteria of SSRF. Three long absorbers with lengths bigger than 500 mm were designed to be made by medium speed wire-cut electrical discharge machining (WEDM-MS) or electron beam welding (EBW).

OVERALL DESIGN

Power of SCW

Table 1 is the major parameters of SSRF storage ring and SCW. Power distribution is shown in Figure 1.

Table 1: Parameters of SSRF Storage Ring and SCW

E_e (GeV)	I (A)	B_0 (T)	N	L (m)	K
3.5	0.3	4.2	22	1.08	18.824

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Where: E_e is beam energy of the storage ring, I is the maximum circulating current; B_0 is the maximum magnetic field, N is period, L is total length and K is deflecting parameter of SCW.

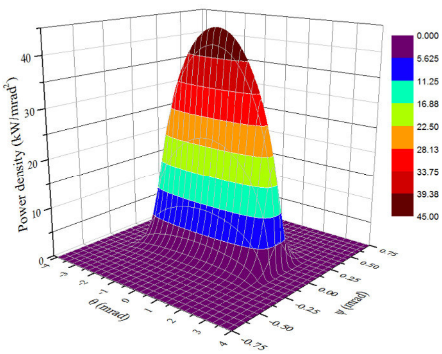

Figure 1: Power distribution of SCW.

Layout of the Front-end

Figure 2 shows the layout of BL12SW front-end with a total length of about 8.9 m. Three fixed masks (FM) confine the photon beam and protect the downstream components from a mis-steered beam. Two photon shutters (PS) intercept the photon beam and protect downstream safety shutter and valves.

Therefore, power from SCW, together with part of the bending magnet, will be absorbed by three FMs and PS2. Technical specifications of these four high heat load photon absorbers are given in Table 2.

THERMAL ANALYSIS

Failure Criteria

Absorbers of FMs and PS2 are all made of Glidcop Al-15. Conservative failure criteria [1] are used as:

- The maximum equivalent stress σ_{max} should be less than 420 MPa.
- The maximum temperature on the Glidcop body T_{max_body} should be less than 300 °C.
- The maximum temperature on the water cooling channel walls T_{max_wall} should be less than water boiling temperature at channel pressure.

Thermal Analysis Results

Direct water cooling and grazing incidence structures are applied to improve heat-absorbing ability for front-end photon absorbers. The temperature and thermal stress distributions of all beam striking components, including pre-mask, FM, PS, fluorescence monitor and XBPM, were simulated carefully and optimized by thermal analysis with ANSYS.

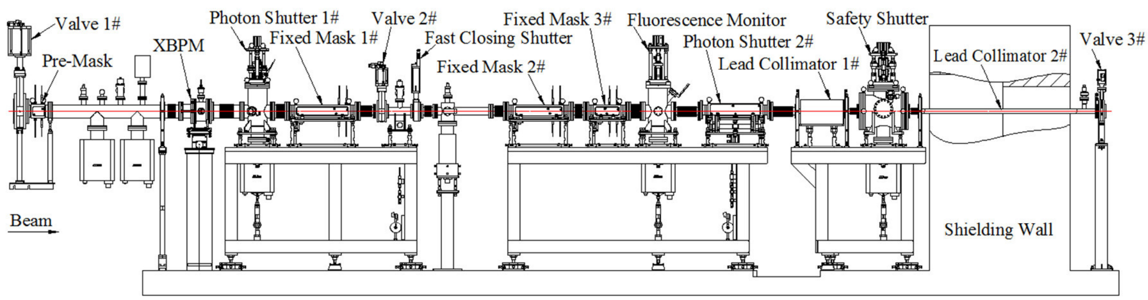

Figure 2: Layout of BL12SW front-end.

Table 2: Technical Specifications of Photon Absorbers

	Distance to SCW (m)	Total Absorbed Power (kW)	Beam Size (H×V, mrad×mrad)		Aperture (H×V, mm×mm)	
			Inlet	Outlet	Inlet	Outlet
FM1	11.404	14.1	5.6×1	3.3×0.5	70×28	39.2×6
FM2	13.191	14	3.3×0.5	1.7×0.4	54×20	23.2×5.4
FM3	13.846	5.7	1.7×0.4	1.2×0.3	34×14	17×4.2
PS2	14.781	10.2	1.2×0.3	0	26×12	0

The optimized parameters for photon absorbers are [2]: diameter of cooling channels is 6 mm, distance of absorbing surfaces to cooling channel walls is 9 mm, corner radiuses of two adjacent absorbing surfaces are bigger than 2 mm, roughness of absorbing surfaces is better than 6.3 μm and directions of cooling channels should be parallel to the beam approximately.

Table 3 shows thermal analysis results of three FMs and PS2 with mis-steered beam, which fairly comply with SSRF failure criteria. Equivalent stress and temperature distribution maps for FM2 are shown as examples in Figure 3 - Figure 5.

Table 3: Thermal Analysis Results

	σ_{max} (MPa)	T_{max_body} (°C)	T_{max_wall} (°C)
FM1	154.1	111	52.2
FM2	182.1	103.2	58.3
FM3	242.1	104.6	63.8
PS2	228.3	144.5	70.9

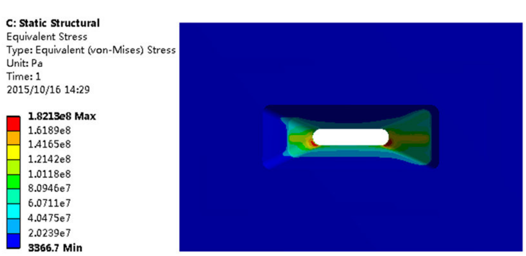

Figure 3: Equivalent stress distribution for FM2.

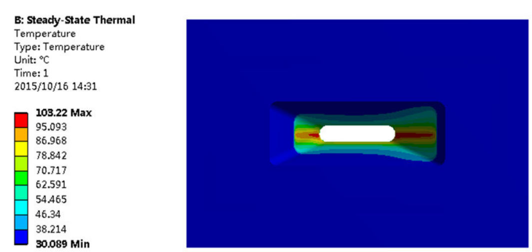

Figure 4: Temperature distribution for FM2.

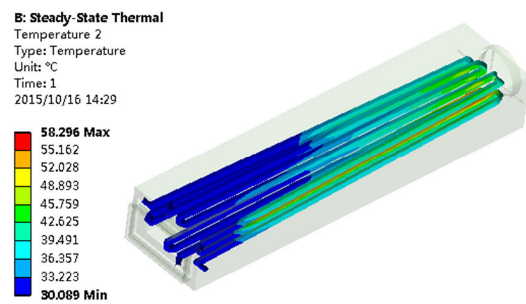

Figure 5: Temperature distribution of the cooling channel walls for FM2.

TECHNOLOGY OF MANUFACTURING

As seen in Table 2, the total power on the exit mask FM3 is 5.7 kW, and FM3 has a short absorber with a length of 300 mm, which is the maximum available length of low speed wire-cut electrical discharge machining (WEDM-LS) in China. While, the total power on

FM1, FM2 or PS2 is higher than 10 kW. These three long absorbers will be longer than 500 mm to minimize the grazing angles. Therefore, technology of manufacturing long photon absorbers becomes a big issue for BL12SW front-end.

WEDM-MS

WEDM-MS is one way to make long absorbers. Unlike WEDM-LS, WEDM-MS is a reciprocating multi-cutting high-speed WEDM to manufacture larger workpieces with less time and a little worse precision [3]. After repeatedly adjusting of process parameters of WEDM-MS, PS2 has been successfully manufactured, as shown in Figure 6. The accuracies of apertures are 0.6 mm and the vacuum degree after baking out is 2.2×10^{-10} Torr, which satisfy the specifications of photon shutters.

Figure 6: PS2 (WEDM-MS).

EBW

EBW is another way to make long absorbers. Figure 7 is a proposal design of FMs made by EBW. Two sub-absorbers will be made by WEDM-LS and then be welded to each other by EBW, thus the accuracies of apertures will be better than 0.1 mm.

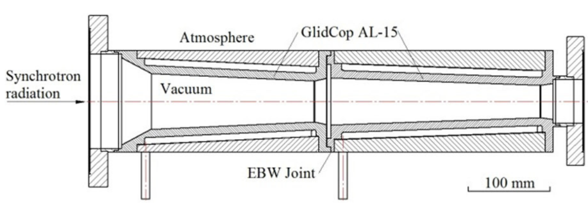

Figure 7: FM (EBW).

Some tests, including vacuum sealing tests and tensile tests, have been done for EBW joints and brazed joints of two Glidcop Al-15 workpieces. Vacuum sealing tests results indicated that both the EBW joints and brazed joints satisfy the ultrahigh vacuum requirements of SSRF front-end.

Tensile tests were done at 20 °C, 100 °C and 200 °C based on GB/T 228.1-2010 specifications (ISO 6892-1: 2009, MOD) and GB/T 4338-2006 specifications (ISO 783: 1999, MOD). Testing results show that mechanical properties of both joints are lower than that of Glidcop Al-15, as shown in Figure 8. Tensile strength of brazed joints is below half that of the base metal and about 70% for EBW joints. Elongation of brazed joints approaches to 0, while that of EBW joints is approximately 15% that of Glidcop Al-15. The trends with changing temperature of mechanical properties of EBW joints are consistent with that of the base metal. Compared to brazed joints, EBW joints have higher tensile strength, better ductility and more stable performance.

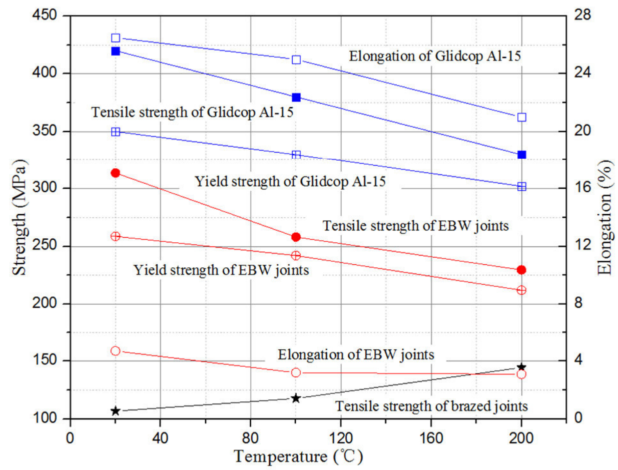

Figure 8: Tensile testing results of joints versus the Glidcop Al-15 base metal.

In practical engineering applications, joints are subjected to low stress and strain as being kept out of direct high power radiation. Therefore, EBW joints of Glidcop Al-15 entirely satisfy the severe thermo-mechanical requirements.

CONCLUSION

Overall design of BL12SW front-end, which is the highest heat load one in SSRF phase-II beamline project, has been completed. Thermal analysis results show all absorbers will comply with the failure criteria of SSRF.

PS2 has been successfully made by WEDM-MS. Vacuum sealing and tensile tests indicate that EBW joints satisfy the vacuum and mechanical requirements; thereby EBW will also be applied to make long absorbers in SSRF phase-II beamline project.

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