APPLICATION OF CuCrZr IN THE FRONT-END OF SHANGHAI SYNCHROTRON RADIATION FACILITY

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Abstract

At present, Glidcop® Al-15, oxygen-free high thermal conductivity（OFHC）copper and other materials are mainly used in the front-end of the Shanghai Synchrotron Radiation Facility (SSRF). CuCrZr has high heat load capacity, high yield strength and tensile strength, good thermal conductivity, and low vacuum outgassing rate. At present, it has been used as the heat sink material in the heat exchanger of nuclear reactors. Due to the above characteristics, CuCrZr has the basic ability to be an excellent substitute material for synchrotron radiation heat load. However, there are also some problems in the application of CuCrZr materials. The softening temperature is not high enough. Because the brazing process is needed in the processing engineering of the heat load absorber, the brazing process needs more than 500 °C, so the brazing process cannot be used in the processing of the absorber. In this paper, based on the previous process exploration, the front-end absorber is made of CuCrZr material, and the technical scheme of integral processing of flange and absorber is adopted. The thermal stress and deformation of CuCrZr absorber are analyzed by finite element method, and the processing of CuCrZr absorber is completed, and it is applied to the SSRF BL04U&04W canted front-end. After a period of electron beam cleaning, vacuum and temperature tests were carried out under high thermal load power, and the characteristics of the material in practical use were analyzed, which proved that CuCrZr material can be used for the high heat load at SSRF font end.

INTRODUCTION

The main materials used for thermal radiation absorption in the front end of synchrotron radiation light source are Glidcop® Al-15, oxygen-free high thermal conductivity（OFHC）copper and other materials. OFHC is usually used as a material for synchrotron radiation absorbers, especially in the first and second-generation synchrotron radiation light sources. However, the third-generation synchrotron radiation light source uses more insert devices, and the power density of the synchrotron radiation light source is improved. OFHC cannot handle the higher power and higher power density thermal power. Glidcop® Al-15 material has high tensile strength and is used as the material of high heat load absorber. At present, Glidcop® Al-15 material is used as the fixed mask (FM) at the front end of most beamline in SSRF. Glidcop® Al-15 material is an Al_2O_3 dispersed copper oxide material developed by Hoganas, USA. Generally, it is provided in standard size, non-standard size can only be customized, and the cost of customization is so high. CuCrZr material has high heat load capacity, high yield strength and tensile strength, good thermal conductivity and low vacuum outgassing rate. At present, it has been used as a heat sink material in the heat exchanger of nuclear reactors. Due to the above characteristics, CuCrZr has the basic ability to be an excellent substitute material for synchrotron radiation heat load. The mechanical properties, photo desorption properties and vacuum properties of CuCrZr have been tested [1–3]. It is proved that the material can be used for absorption of synchrotron radiation light source.

However, there are also some problems in the application of CuCrZr materials. The softening temperature is not high enough. Because the brazing process is needed in the processing engineering of the heat load absorber, the brazing process needs more than 500 °C, so the brazing process cannot be used in the processing of the absorber. SSRF is the first third-generation synchrotron radiation light source in China. Most of the absorbers at the front end of the beamline use Glidcop®AL15 material as the main heat absorption material. At present, CuCrZr is a good alternative material to meet the needs of high heat load in the front-end. The main beamlines of SSRF are divided into three types, bending magnet beamline, insert device beamline and Canted beamline. The Canted beamline is generally composed of two insertion beamlines. The general insert device is the undulator, and the angle between the two beamline stations is 6 mrad.

DESIGN OF BL04U&04W FRONT-END

Physical Parameters of Insert Devices

The BL04U and BL04W beamline stations are Canted beamline. BL04U uses a vacuum undulator (IVU20), which is located upstream of the insert device center, and BL04W uses a wiggler, which is located downstream of the insert device center. The angle between the beamlines and the center line of insert device is 4 mrad, and the angle between beamlines is 8 mrad. Incident angle BL04U, BL04W are shown is Table 1.

Table 1: Incident Angle of BL04U&BL04W

Beamline	Insert device	Output angle ($mrad^2$)	Input angle ($mrad^2$)	Power (kW)
BL04W	Wiggler	1.8×0.18	4×1	9.287
BL04U	IVU	0.3×0.15	2×1	2.62

Design of PreM

Generally, the PreM only bears the light source from bending magnet, and the main body adopts OFHC material. However, the horizontal tracing of the BL04U & 04W front-end, the PreM bears the appropriate beam source

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from the insert device can reduce the photon beam size, thereby reducing the component size after the PreM.

The inlet flange of PreM adopts CuCrZr, the cover plate of the cooling pipe adopts OFHC, and the outlet adopts stainless steel flange to weld with the main part of CuCrZr. After brazing the stainless-steel cooling pipe and OFHC cover plate, the electron beam welding is carried out with the main part. It can be seen in Fig.1.

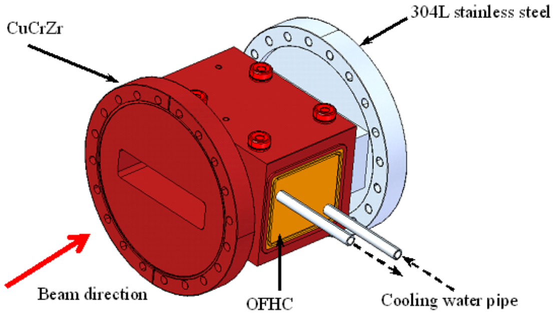

Figure 1: Design of Pre-M (CuCrZr).

Design of BS

CuCrZr is made as the main body of BS. There are two cavities in the body. The middle part is made for absorption of the beam from beading magnet. The mask adopts a double V-shaped. The cover plate adopts OFHC material. The stainless-steel cooling pipe and the OFHC cover plate are brazed and then using electron beam welding into one with the CuCrZr part. The structure of the BS is shown in Fig. 2.

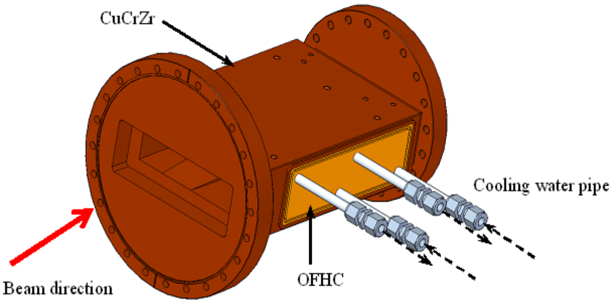

Figure 2: Structure of BS (CuCrZr).

THERMAL ANALYSIS

The PreM is 8048 mm away from the wiggler light source, the incident angle is 4.4 × 1 mrad^2, the distance from the downstream bending magnet is 3203 mm, the incident angle is 16.3 × 2.75 mrad^2, the water cooling is adopted, the water volume is 8 L/min, the thermal convection coefficient is 20000 W/m^2°C, temperature of cooling water = 30 °C, and the water pressure is 8 bar. CuCrZr materials were selected for thermal analysis both. The parameters of OFHC and CuCrZr are shown in Table 2.

Table 2: Parameters of CuCrZr

Materials	**CuCrZr**
Density (kg/m^3)	8900
Thermal Conductivity (W/m°C)	330
CTE (l/°C)	1.7e-5
Young's modulus(GPa)	128
Poisson's Ratio	0.33

The design criteria of materials CuCrZr are shown in Table 3 [1, 4].

Table 3: Design Criteria of CuCrZr

Maximum equivalent stress (MPa)	**Overall maximum temperature (°C)**	**Maximum temperature of the cooling wall (°C) at 8bar**
350	250	160

RESULTS AND DISCUSSION

Thermal Analysis Results

PreM needs to withstand the heat load from undulator, CuCrZr materials is used for thermal analysis.

The FEA results are shown in Fig. 3, all of which meet the design criteria listed in Table 3.

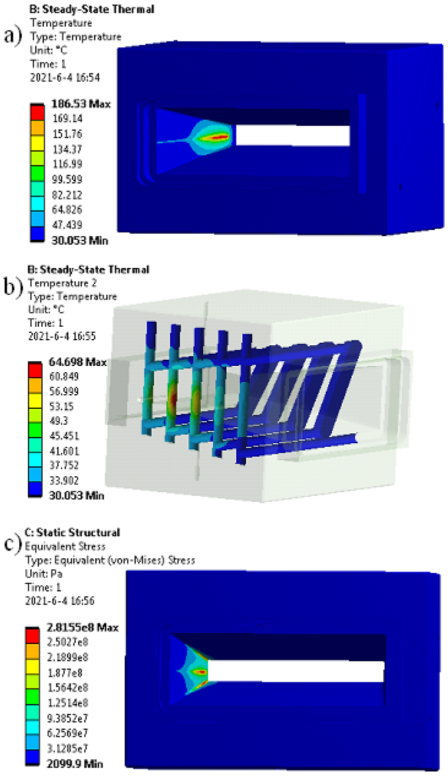

Figure 3: FEA results of PreM (CuCrZr). a) Overall temperature distribution b) Cooling tube wall temperature distribution c) Equivalent stress distribution.

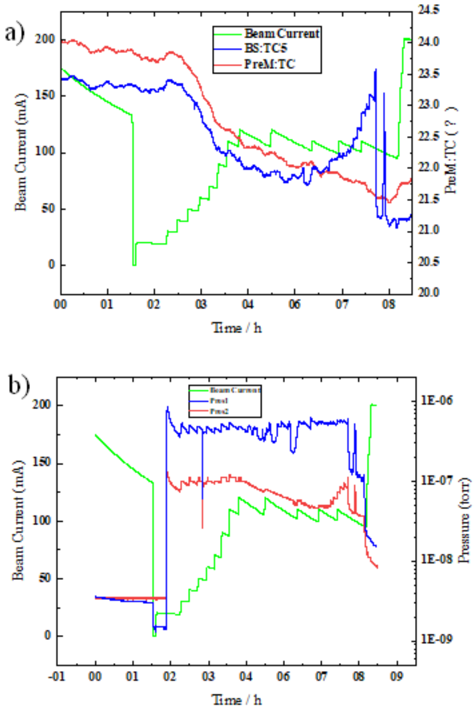

Figure 4: Online results of BL04U&04W front-end. a) Temperature of Prem and BS; b) Vacuum of front-end.

Application Results

On April 26, 2023, the PreM (CuCrZr) and BS (CuCrZr) was tested. Firstly, under the beam current of 20 mA to 120 mA, the temperature of the PreM and the vacuum of the front-end are recorded. Then, under the beam current of 120 mA, the BL04U undulator gap is gradually closed from 20 mm to 6 mm, and the BL04W wiggler gap is closed from 100 mm to 15 mm. From the results of Fig. 4a), the temperature of BS and PreM does not change much, and the temperature rises when the insert device adjusted the gap. From the results of Fig. 4b), the vacuum of front-end changes from 10^{-9} torr to 10^{-6} torr, the vacuum is difficult to maintain, but the vacuum gradually decreases. It shows that the light-induced desorption gasrelease rate of CuCrZr is still large, and it more hours to handle the gas release. The results show that the BS(CuCrZr) and PreM (CuCrZr) of BL04U & BL04W front-end meet the requirements.

CONCLUSION

Glidcop® Al-15 and OFHC are the main materials of high heat load absorbers now. However, Glidcop® Al-15 is expensive and OFHC cannot withstand high heat load. CuCrZr has good mechanical properties and is very suitable for the high heat load absorber in the front-end. This paper introduces the application of CuCrZr in BL04U and BL04W front-end at SSRF. In the design of PreM and BS, CuCrZr is used as main body. Some stainless-steel flanges are used, and the water-cooled cover plate is separately brazed and electron beam welded with the main part. This not only avoids the disadvantage that CuCrZr cannot be brazed, but also CuCrZr is applied to the absorption of high heat load. Then, the FEA of the PreM with CuCrZr the PreM with CuCrZr the BS with CuCrZr are carried out. The results show that the PreM and BS with CuCrZr can meet the demands. Finally, the front-end has been successfully installed and tested.

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