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DEVELOPMENT OF HIGH POWER DENSITY PHOTON ABSORBER FOR SUPER-B SECTIONS IN SSRF*

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Abstract

There are two symmetrical standard bend (standard-B) sections been upgraded to super-B sections in the storage of Shanghai Synchrotron Radiation Facility (SSRF). Photon absorbers made up of CuCrZr were used for absorbing radiation with very high power density in the super-B sections. Meanwhile, CuCrZr absorbers were also used as beam chamber and pump port for the lattice of super-B section is very compacted. The absorbing surface was designed as serrate structure in order to diminish the power density. CuCrZr was cold-forged before machining to enhance its strength, thermal conductivity and hardness. Friction welding is adopted for absorber fabrication to avoid material properties deterioration. Rectangle flanges of absorbers were designed as step rather than knifer for vacuum seal. These high power density photon absorbers have been installed on the storage ring, both pressure and temperature being in accordance with design anticipation under the condition of 240 mA beam.

INTRODUCTION

The purpose of upgrading 2 symmetric standard-B sections to super-B sections is to provide hard X-ray with the energy of 18.7 keV for users in SSRF [1], as shown in Fig. 1. Moreover, short straight sections in which insert devices can be installed to provide photon for beamline laboratories were added in super-B sections of which the total length is same with that of standard-B sections. Compare to standard-B, much stronger magnetic field can be generated by super-B, the power of synchrotron radiation being much higher. Furthermore, the majority of synchrotron radiation has to be absorbed in much compact space.

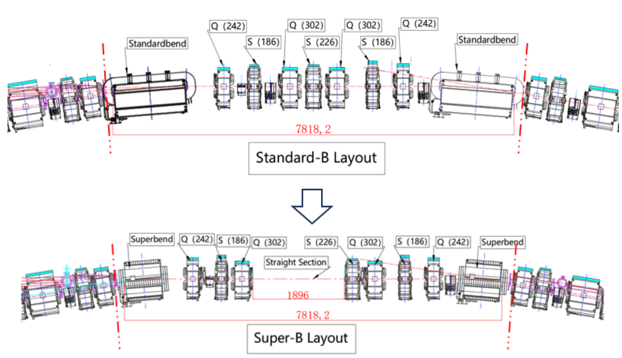

Figure 1: Standard-B section upgrade to super-B section in SSRF.

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The density of photon power is much higher because of limited absorbing space and much stronger magnetic field. CuCrZr photon absorbers were developed to absorb photon with high power density in super-B sections. Friction welding was adopted to fabricate these absorbers with complex structure. The comparison of main specification between standard-B and super-B is shown in Table 1.

Table 1: Main Specification of Standard-B and Super-B

	Standard-B	Super-B
Arc length (mm)	1440	832.5
Magnetic field (T)	1.27	2.29
Magnet gap (mm)	50	30
Bending angle (°)	9	9
Radiation Power (kW)@300mA	10.9	18.8

ABSORBERS DISTRIBUTION AND MATERIAL

There are just five absorbers distributed in each super-B section and downstream because of very limited available installing space. The lattice of super bend magnet 2 downstream haven't been changed. However, original absorbers have been replaced by two new absorbers (absorber 4 and absorber 5) to absorb high power density radiation from super bend magnet 2, vacuum chambers also being redesigned, as shown in Fig. 2.

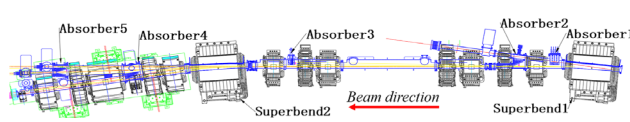

Figure 2: Absorbers distribution on super-B section.

All absorbers were installed at clearance of each couple of magnets. Ion pumps were installed next to these absorbers to enhance pumping efficiency. The maximum heat flux density on absorber 2 is yet up to 43 W/mm^2 @300 mA after structure optimization, as shown in Table 2.

Oxygen free copper (OFHC) is widely adopted to fabricate absorbers on storage rings because of its high thermal conductivity. However, it can't endure so high power density. Glidcop is another kind of absorber material for absorbing photon with high power density in some light source [2, 3]. However, Glidcop imported is very expensive. CuCrZr is attractive material for fabricating high power density photon absorbers because of its high thermal conductivity [4], high softening temperature and good mechanical properties [5-8]. Domestic CuCrZr was chosen as material for these absorbers finally. Properties of the

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CuCrZr are improved apparently after cold forging, as shown in Table 3.

Table 2: Radiation Power on Absorbers

	Absorbing power (kW)	Maximum power density (W/mm^2)
Absorber 1	4.3	16
Absorber 2	11.7	43
Absorber 3	1.1	8
Absorber 4	9.5	34
Absorber 5	5.4	15

Table 3: Properties of Domestic CuCrZr by Test

	Before cold forging	After cold forging
Young Modulus (GPa)	85.3	119
Yield Strength (MPa)	111.6	400.6
Ultimate Limit (MPa)	239.3	434.7
Hardness (HB)	61	151.7
Expansion at 100 ℃ （10^{-6}/K）	15.9	16.6
Conductivity at 100 ℃ (W/(m·K))	283.5	358.5

ABSORBERS STRUCTURE AND FABRICATION

The absorbing face of absorbers were designed as slope with comb shape to dilute heat flux density, as shown in Fig. 3. The typical structure of absorbers was made up of up-absorbing body and down-absorbing body, both of which having comb shaped absorbing face. Up-body and down-body were assembled by friction-welding, their comb teeth engaging together to complete absorbing face.

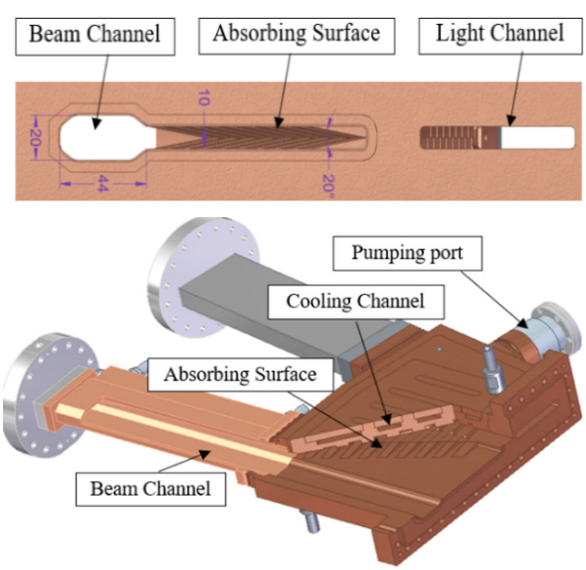

Figure 3: 3D model of the structure of absorber 2.

Knife can be directly machined on CuCrZr circular flange like that of absorbers in ESRF [9] and in TSP [10] for vacuum seal by the advantage of its hardness. Instead, step flange directly machined on CuCrZr absorbers in SSRF is used for vacuum seal because the surface of rectangle flange is very large. Flange sample was test for several times before formal fabrication, the result showing this type of flange is suitable for ultra-high vacuum seal. The sample of CuCrZr step flange and seal test are shown in Fig. 4.

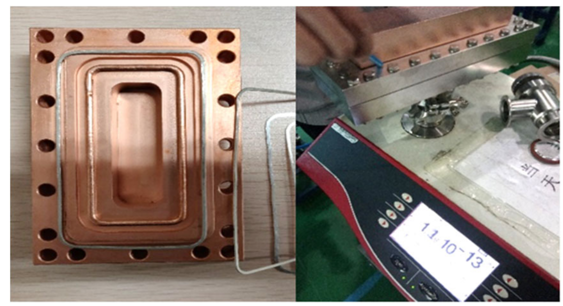

Figure 4: The sample of CuCrZr step flange and seal test.

Cooling channels were formed by grooves on the back of absorbing bodies welding with CuCrZr cover plates. The maximum temperature on absorbing face is about 270 °C under the situation of beam of 300 mA by simulation. The nephogram of temperature and equivalent stress of absorber 2 by simulation are shown in Fig. 5.

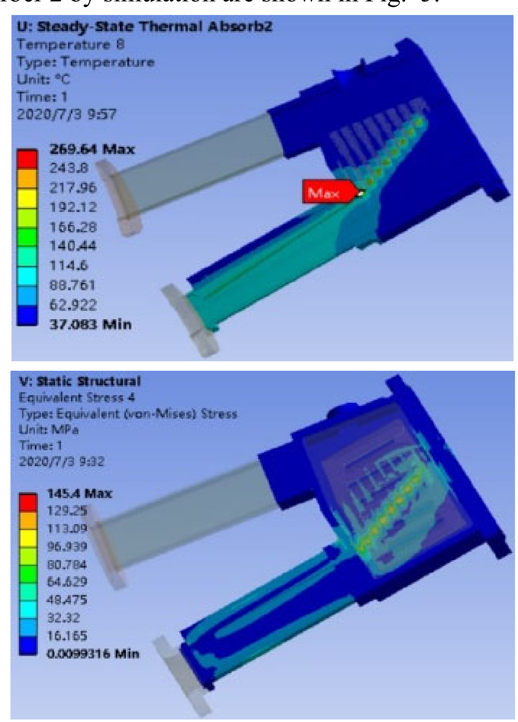

Figure 5: Nephogram of temperature and equivalent stress of absorber 2.

Braze could not be adopted to welding CuCrZr absorbers for properties of the material will be deteriorated at the temperature higher than 500 °C [8]. However, welding can not be avoided for these absorbers in super-B sections because of their complex structure. Several welding

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process were carried out to complete photon absorber 2 fabrication. It can be shown from the reference [11] that the temperature outside the welding seam is already lower than 500 ℃ in welding process. Therefore, friction welding was mainly adopted for absorbers, avoiding material properties deteriorate. Fabrication process for absorber 2 is shown in Fig. 6.

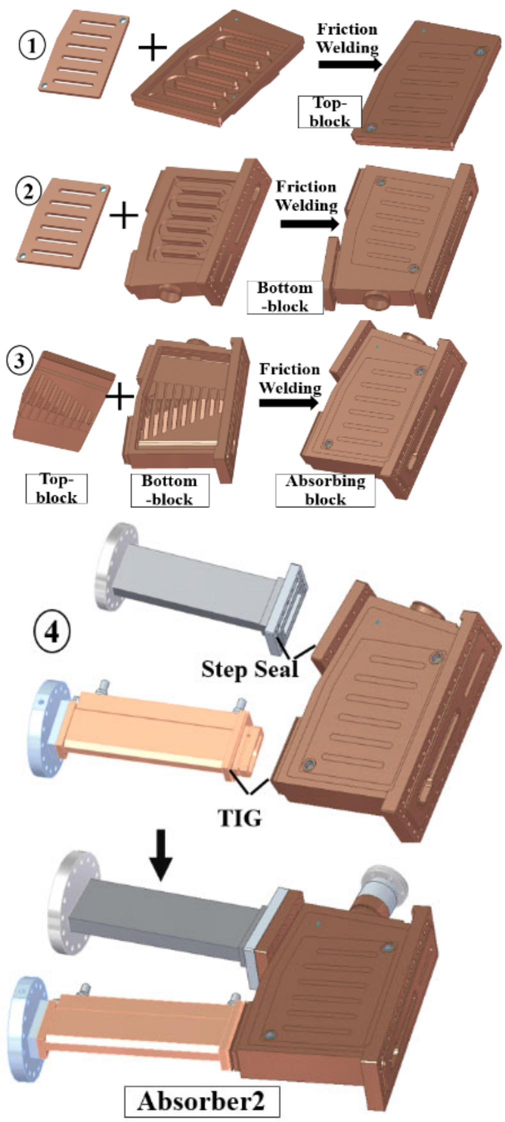

Figure 6: Main fabrication process for absorber 2.

VACUUM PERFORMANCE

CuCrZr absorbers have been installed on the storage ring in August 2019, as shown in Fig. 7. Static average pressure of super-B sections was about 3.3×10^{-8} Pa after vacuum baking in site. Dynamic average pressure has reduced from 1×10^{-6} Pa at the beginning of beam operation to 1.5×10^{-7} Pa @260 mA after 100 Ah of integral current. The curves of per-pressure versus integrate current in the early stage of startup after super-B sections installing completely is shown in Fig. 8. These CuCrZr absorbers have been on the storage ring for several years, Dynamic average pressure being lower than 6×10^{-8} Pa @200 mA now.

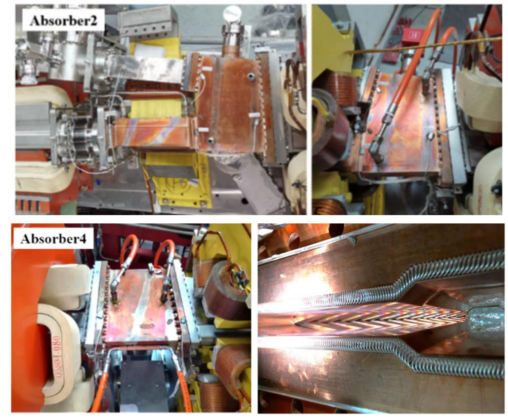

Figure 7: CuCrZr absorbers installed on the storage ring.

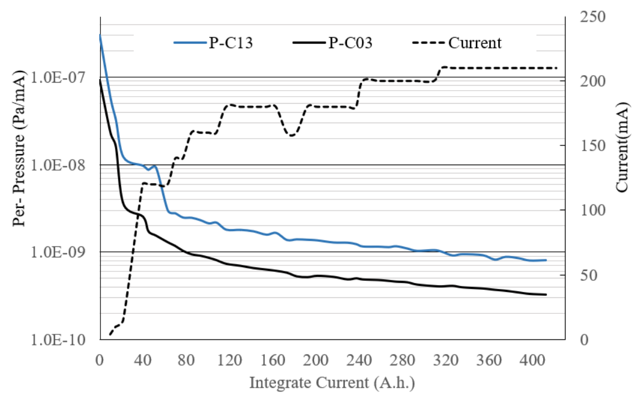

Figure 8: Curves of per-pressure versus integrate current in the early stage of startup.

The temperature on these CuCrZr absorbers rise proportionally to the beam current. The highest temperature measured on outer surface of absorber 2 is about 80 °C @240 mA, which is accordance with the result of simulation, as shown in Fig. 9.

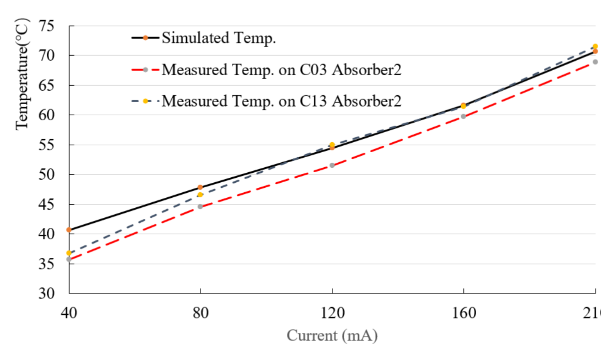

Figure 9: Temperature comparison between simulation and measurement on absorber 2.

CONCLUSION

Friction welded CuCrZr absorbers have been successfully developed and used for absorbing high power density synchrotron radiation at super-B sections in SSRF. It is concluded that the structure of the face of oblique teeth engaged on CuCrZr body for diluting power density and step flange on the body for vacuum seal is feasible from the result of operation in site for several years.

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