DEVELOPMENT OF THE SSRF PHOTON ABSORBERS

D.K. Jiang, L.P. Chen and L.X. Yin
Shanghai National Synchrotron Radiation Center, P.O.Box 800-204, Shanghai 201800, P.R.China

Abstract

Two types of photon absorbers for SSRF have been designed and fabricated successfully. In absorber design, several aspects have been carefully considered including the structure, the thermal transmission, the thermal stress, the operation lifetime and so on. Thermal calculations have been conducted using both the classical thermodynamic formulas and the ANSYS program. Several fabrication techniques have been used including numerical control machining, electric spark machining, electron beam welding, multiple brazing and so on. Photon stimulated desorption yields have been measured for the horizontal absorber prototype at KEK • PF in Japan.

1 INTRODUCTION

The Shanghai Synchrotron Radiation Facility (SSRF) is a third-generation light source with a storage ring of 396 m in circumference. It's beam energy and beam current are 3.5 GeV and 300 mA respectively. The synchrotron radiation (SR), with total power of about 377 kW and power density of 60 W/mrad, will be radiated by the circulating e-beam in the 40 dipole magnets in the storage ring. Only a small part of the SR will be extracted to the beamlines; while the others will be intercepted by the photon absorbers. The SSRF storage ring adopts the discrete absorbers installed either at the horizontal chamber wall or at the vertical chamber wall, namly horizontal absorber and vertical absorber respectively. In R&D, two typical absorber prototypes have been designed and fabricated: one is the horizontal absorber AbH-2 with the power density 14.4 W/mm^2, the other is the vertical absorber AbV-7 with a total length of 300 mm.

2 DESIGN OF PHOTON ABSORBERS

2.1 General considerations

The absorbers have both two functions of absorbing the unused SR and collimating the extracted SR. All the absorbers are designed to form a close optical chain relative to the horizontal 360^0 SR along the ring except some gaps for the extracted SR beam. In this chain, any two neighbouring absorbers, except the ones for the extracted SR, are designed to have an overlap to avoid the SR irradiating directly on the chamber wall. The quantum of overlap is determined by the shifts of beam orbit. The vertical dimensions of the absorber are determined by the inner height of the vacuum chamber. To decrease the number of absorbers and make use of space effectively, some absorbers have their bodies deviated from the flange centers to let their ends as close as possible to the beam channel.

Thermal performance is the most important in absorber design, which in general come down to several facets including the absorber structure, the material selection, the cooling parameters, the maximum temperature, the thermal stress, the thermal outgassing etc..

(1) The surface structure of the absorber body should be advantageous to dilute the SR power. The smaller the surface angle, the better the diluting effects, but the longer the needed absorbing surface. The thickness of the absorber body should be designed according to thermal transmission effects, hard x-ray penetrating probability and so on.

(2) Material selection should depend on thermal and mechanical performance. The two materials generally used for the absorber body are GlidCop and OFHC. The GlidCop's permitted thermal stress (60 kg/mm^2) is far higher than OFHC (10 kg/mm^2). But its machining and welding are more difficult than OFHC and the cost is high. Considering the power density on SSRF absorbing surface, we use OFHC as the material for the prototypes' body. The other parts are made of SS316L and the magnetoconductivity μ should be less than 1.05 after welding.

(3) The design of cooling water channel and the selection of cooling water parameters should be advantageous to the thermal transmission. The welds in water channel should be able to bear 3 times as much as the cooling water pressure. The water should be in turbulent flow. The current velocity should be more than 2 m/s to assure that the convective heat transfer coefficient is more than 1 W/(cm^2 • ℃). At the same time, the current velocity should be limited to less than 3 m/s to decrease shaking and noise. Deion water will be used to prevent the cooling channel from being eroded.

(4) At last, the absorbers should meet the following criteria[1].

① Thermal performance

- Temperature of absorbing surface:
  T_{sur}<0.5T_{melt}=541℃ (OFHC)
- Temperature of cooling water:
  T_{water}<T_{boil}=150℃ (for 5 atm water pressure)

② Structural performance

- Thermal stress:

  $S_{th} < 2 \times S_y$ (0.2% yield strength)

  $S_{th} < S_f$ (fatigue strength for 10^5 thermal cycles)

The surface temperature should be as low as possible to decrease the thermal outgassing load, which should be less than 10% of PSD to assure a good vacuum performance.

2.2 Structural design

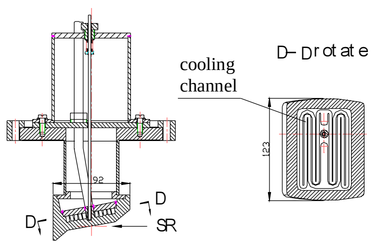


Figure 1: Structure of AbH-2

The horizontal absorber (see Fig. 1) will be installed in the hole of Φ150 mm. The absorbing surface is divided into three zones with different angles of incidence. The middle 10^0 zone absorbs most of the SR. On this surface, the SR power density will be diluted to about 17% of normal incidence and most of the reflected photons and the PSD gas molecules will be directed to the pumping hole. The other two zones have the same incident angle of 30^0, namely upstream zone and downstream zone, with the consideration that the absorbing surface, limited in the direction along z-axis, should intercept all the SR when the beam orbit has a shift of more than ±5 mm in the vertical direction. The cross section of the cooling channel is 7 mm×7 mm. The thickness of absorber body is 10 mm, where the penetrability of 10 KeV hard x-ray is about 10^{-9}. To prevent the cooling water from leaking into the vacuum chamber when the welds is eroded and damaged, there isn't any direct welds between the cooling water and the ultra high vacuum region.

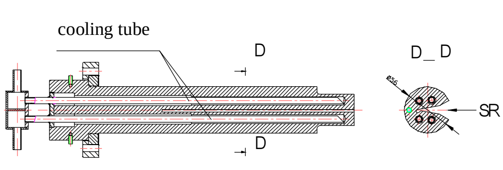


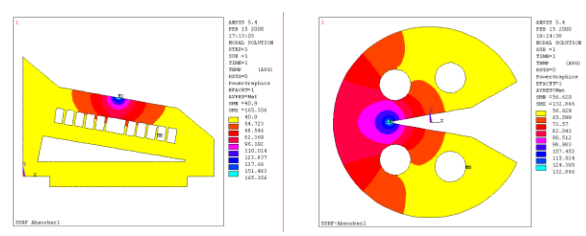
Figure 2: Structure of AbV-7

The vertical absorber (see Fig. 2) will be installed in the hole with CF63 flange. It is a cylinder with a V-type groove. The notch of the groove is against the SR beam. The upper part and the lower part of the groove are symmetrical. Every part is composed of two surfaces with different angle of incidence (10^0 and 30^0 respectively). The SR will irradiate the 10^0-angle surface when the beam is in normal operation. At the end of the V-type groove, there is an arc, which is used to prevent the normal incidence of SR to the end. The cooling channels are four Φ10 mm holes parallel to each other, where four OFHC tubes are installed with external diameter Φ8 mm and wall thickness 1 mm. The cooling water flows into the OFHC tubes with a velocity of 2 m/s, then into the gaps between the hole and the OFHC tube, and at last flows out of the two water taps installed at the side.

Rotatable flanges are used in these two absorbers. There should be marks on the flange shoulders showing the direction of the absorbing surface.

2.3 Thermal analysis

Thermal calculations are conducted for the absorbing bodies using both thermodynamic formulas[2] and ANSYS program respectively. Their results are almost the same. Fig. 3 shows the temperature contours by ANSYS program. When the storage ring is operated at full current, the horizontal absorber AbH-2 will have a maximum temperature of 165 ℃ at the centre zone on absorbing surface and the vertical absorber AbV-7 has a maximum temperature of 132 ℃ at the sharp-angled end of the V-type absorbing surface. Both temperatures can meet the design criteria.



(a) (b)

Figure 3: Temperature contours in absorbing body (horizontal absorber (a) and vertical absorber (b))

According to the fatigue test of OFHC at 300 ℃ in high vacuum[3], the fatigue strength limit at 300 ℃ is 6×10^4 cycles. The fatigue strength limit of OFHC absorbers in SSRF would be higher than 6×10^4 cycles because the maximum temperature is 170 ℃. If we assume that SSRF inject the e-beam twice a day, that is to say, the absorbers will endure two thermal cycles per day. The absorber can be used for more than 80 years before reaching its fatigue limit. This is well beyond the SSRF's scientific lifetime of thirty years.

3 FABRICATION AND TEST

3.1 Machining

On horizontal absorber, the cooling channel and its cover plate were machined by NC milling, which could improve the machining precision and make the two joint planes fit tightly for EBW. EBW was used for the weld of cooling channel. The penetration depth of welds was 5 mm, which avoided the potential trouble of erosion and leakage. Ag-Cu brazing (72%: 28%) was used between SS316L part and OFHC part, which was performed in Ar furnace in several steps.

NC milling was also used to machine the vertical absorber. Mill the V-type absorbing surface to within 1 mm of finish surface, then use electric spark machining to form the final V-type surface and the end shape. Special drilling frocks were designed for the small-diameter and deep cooling holes. These holes were finished at the lathe to guarantee their depth, aperture and parallelism. Ag-Cu brazing (72%: 28%) was used between SS316L flange shoulder and OFHC absorbing body. The brazing region of the flange shoulder should be nickel-plated prior to brazing. To avoid the flange shoulder from oxidising, the brazing was executed under vacuum.

3.2 Inspection and test

The inspection and test of the prototype involves leak detection, dimensional check, water pressure tests, and vacuum test.

Leak detection was conducted after every welding step. During leak detection, specific frocks were used. The leak rate for all welds was less than 5×10^{-11} Pa.m^3/s. Main dimensions were checked and the results met our requirements. The compression resistance of the cooling tube and the channel was tested to 8 atm. The cooling water flow through the horizontal absorber was 9.6 l/min with pressure difference 0.5 atm. At this time the current velocity is 3.2 m/s. At last both prototypes were cleaned and installed in a model storage ring vacuum chamber. The system was baked out and the ultimate pressure was 9.3×10^{-9} Pa.

4 MEASUREMENT OF PSD YIELDS

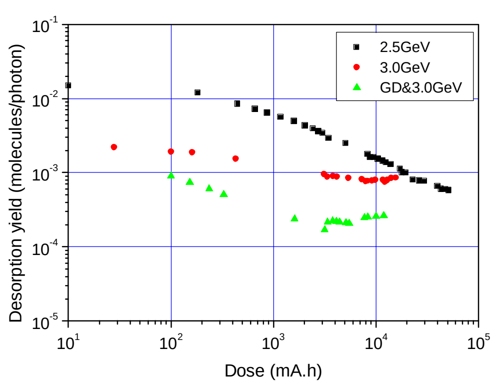


Figure 4: The PSD yields of SSRF photon absorber vs. accumulated beam dose

The PSD yields for horizontal absorber have been measured at BL-21 beamline, KEK • PF, in Japan. Three tests were carried out. In test No. 1, the absorber was irradiated by SR from 2.5 GeV electron beam. Test No. 2 was from 3.0 GeV beam. Test No.3 was performed after N_2 glow discharge.

The results are illustrated in Fig. 4, from which we can draw the following conclusions:

- In No. 1 measurement, the desorption yields are $(4\sim5)\times10^{-3}$ and $(3\sim4)\times10^{-4}$ molecules/photon when the accumulated beam dose at PF are 15 A • h and 51 A • h respectively. These yields are high due to the high outgassing from the surrounding aluminium plate.
- In No. 2 measurement, the desorption yields are $(8\sim9)\times10^{-4}$ molecules/photon when the accumulated beam dose at PF is 15 A • h, which is about 20% of the one for No.1 measurement. This means the desorption yields for SSRF 3.5 GeV ring can be equal to or less than the one in No.2 measurement.
- Without GD, the PSD yields are limited at 15A • h in No. 2 measurement. After GD, however, the limited value is decreased to about half of that in No. 2 measurement, $\sim4\times10^{-4}$ molecules/photon.
- N_2 glow discharge for SSRF absorber is effective and necessary for initial operation. The dynamic outgassing from aluminium chamber should not be neglected during the SSRF vacuum system design and construction.

5 SUMMARY

The R&D of SSRF photon absorbers have been finished sucessfully. The physical design and the structural design have been confirmed to be both reasonable. The main results of the prototypes can satisfy the design criteria well. The necessary techniques for the manufacture of SSRF absorbers have been prepared.

6 ACKNOWLEDGEMENT

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