Development of a High-Heat-Load Compact Photon Absorber for SPring-8 Diagnostics Beamline II

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Abstract. Development of a high-heat-load compact photon absorber of the SPring-8 diagnostics beamline II (BL05SS), which can accept the power of 19 kW from a multi-pole wiggler, is presented. In order to make the whole system compact, the scheme which inserts two water-cooled absorber blocks made of Glidcop with a different tilt angle of surface into the photon beam axis in tandem has been adopted. When the absorber system was installed in the frontend of BL05SS and exposed to synchrotron radiation from an insertion device, the stainless steel chamber of the rear absorber block was heated rapidly by irradiation of the scattered X-rays from the absorber surface. A water-cooled absorber chamber made of oxygen-free high conductivity copper has been newly developed and the temperature rise of the chamber was successfully suppressed.

1. Introduction
The SPring-8 diagnostics beamline II (BL05SS) which has an insertion device (ID) light source [1, 2], has been constructed aiming at investigation of new techniques for accelerator diagnostics and development of accelerator high-heat-load components. Prior to installation of the ID, we started to develop a movable photon absorber to be installed at the frontend (FE). At BL05SS, off-axis synchrotron radiation (SR) including visible edge radiation, generated at fringe fields of bending magnets at both ends of the ID straight section, is also planned to be used. The photon absorber of BL05SS is needed to have not only tolerance against high heat load of SR, but also a large opening aperture. In SPring-8 standard beamline, a Glidcop block, in which an upper SR-receiving part and a lower SR transport channel have been formed, is used as the photon absorber. It is joined to FE components with bellows and moved up and down by using offsets of the bellows [3]. If the photon absorber of BL05SS is designed based on this scheme, it requires unrealistic long bellows with a large diameter to achieve an expected large offset. We will present the uniquely developed, compact photon absorber system, in which two water-cooled absorber blocks made of Glidcop AL-15 are arranged in tandem. And also the water-cooled chamber made of oxygen-free high conductivity (OFHC) copper, introduced for suppression of the temperature rise of the chamber caused by the scattered X-rays from the absorber surface, is described.

2. High-heat-load compact photon absorber
In design phase of a photon absorber, a multi-pole wiggler (MPW) with 45 periods of 77 mm period length has been considered as an ID of BL05SS. The critical photon energy of the MPW...
radiation is 34.9 keV. Total power and maximum power density of the MPW are 19 kW and 722 W/mm² at normal incidence at the photon absorber with the stored beam current of 200 mA. Although the beam current at normal operation for user-time is 100 mA, we plan to increase this to 200 mA. Therefore, the beam current of 200 mA should be assumed in design phase. Considering the arrangement of the other existing FE components, location of the photon absorber was chosen at 21.3 m from the MPW, and the whole length of the system should be kept within 1.2 m. Distribution of radiation power density of the MPW at 200 mA, calculated by SPECTRA [4], is plotted in figure 1.

Figure 1. Power density from the multi-pole wiggler at the stored beam current of 200 mA.

In order to realize the required opening aperture of the photon absorber (60 mm in H × 40 mm in V), we adopted a new concept, which arranged two absorber blocks made of Glidcop with a different inclined surface angle in tandem. Detail of the absorber blocks and the whole absorber system with vacuum chambers are shown in figure 2. Both blocks are driven pneumatically. The front block with a gap of 2 mm height is moved horizontally and stops upper and lower parts of SR. The rear one driven vertically receives central part of SR which passes through the gap of the front block. The angles of the absorber surfaces are designed so that the power densities of the inclined incidence become 15 W/mm² or less at the maximum. Upper and lower portions of the front block and the rear block have four 10-mm-diameter water-cooling channels drilled in parallel with the photon beam axis, in which copper wire coils are brazed on channel surface to obtain an enhanced heat transfer coefficient [5].

They are arranged to surround the high-heat-load part of the absorber blocks so that enough temperature gradient between the irradiated surface and the cooling channel surface and effective heat removal can be obtained. The water-cooling channels are doubly covered with electron-beam-welded copper plates to prevent the cooling water from being leaked into the vacuum.

Figure 2. Surface shape of the absorber blocks (left) and whole absorber system with the stainless steel vacuum chamber (right).

Considering the offset of the photon beam, thermal and stress analysis was performed by using the finite-element analysis program ABAQUS [6]. When there is no offset of the photon beam, 74 % of heat load of SR is concentrated in the rear block. When the offset is 1 mm, on the other hand, 53 % of heat load is concentrated in upper or lower portion of the front block. A heat transfer coefficient of 0.025 W/mm²/°C was applied to the water-cooled surface with wire coils in the analysis [7]. Results are tabulated in Table 1. Maximum temperature of irradiated surface and cooled surface are 497 and
138 °C. They are respectively lower than the melting point of Glidcop and water boiling temperature at the pressure of the water in the cooling channels. Maximum thermal stress of 457 MPa exceeded the yield or tensile strength of Glidcop [8]. We carried out the fatigue life prediction based on the plastic analysis. The analysis showed that, although first heat load of SR causes the plastic deformation on the absorber block, repetitive heat load will lead to no more growth of the strain. According to the ranges of the strain caused by repetitive application of heat load, it was confirmed that the photon absorber has the fatigue strength of more than 5000 times at the maximum heat load of SR from the MPW.

Table 1. Results of the thermal and stress analysis with ABAQUS

|                        | Offset: 0 mm | Offset: 1 mm |
|------------------------|--------------|--------------|
|                        | Front block  | Rear block   | Front block  | Rear block   |
| Maximum temperature    |              |              |              |              |
| [°C]                   |              |              |              |              |
| Irradiated surface     | 167          | 347          | 497          | 305          |
| Cooled surface         | 61           | 90           | 138          | 76           |
| Maximum thermal stress  | 111          | 457          | 439          | 351          |
| [MPa]                  |              |              |              |              |
| Fatigue strength       | -            | 5400         | 6700         | -            |

3. Water-cooled new chamber

In construction phase, the MPW with 51 periods of 76 mm period length was adopted as the real ID of BL05SS. When the photon absorber was installed in the stainless steel chamber (figure 2) of the FE and exposed to heat load of SR from the MPW [2], total power of 10.4 kW at 100 mA, rapid and intense temperature rise more than 200 °C of the stainless steel chamber of the rear absorber block occurred. Heated portion with high temperature are concentrated at the chamber wall below the photon beam axis. Because there is no shielding object between the rear absorber surface and the chamber wall, irradiation of the scattered X-rays from the rear absorber surface to the inner surface of the chamber were assumed to cause the temperature rise. Heating power of the scattered X-rays was roughly estimated to 0.6 kW from the temperature rise and mass of the chamber. Since it was worried that the damage of the chamber caused by heat cycle accompanying opening and closing of the photon absorber gave rise to a serious vacuum accident, introduction of a certain cooling mechanism was required. Attachment of water-cooled copper blocks to the chamber was examined, but it was difficult to cool the chamber uniformly because of the crevice between the chamber wall and cooling blocks and low thermal conductivity of stainless steel. We have decided to develop a new chamber which has a water-cooling mechanism and replace the existing chamber with it. Considering the compatibility with the existing drive mechanism and girder, the new chamber was designed with careful attention to the following three points.

- material with high thermal conductivity
- structure of high heat capacity
- relevant arrangement of water-cooling channels

![Figure 3. Cross section of water-cooled absorber chamber.](image)

Figure 3 shows the newly developed water-cooled absorber chamber. Shadow area of figure 3 is made of OFHC copper which has high thermal conductivity. Other parts are made of SUS304. Main copper body has thick wall more than 59 mm, especially at lower part, and the structure of high heat
capacity has been realized. Three water-cooling channels are formed in the lower thick part and connected in series. Upper two channels (channels A and B) are formed in parallel with the photon beam axis with an offset of 77 mm, and lower one is formed annularly at the bottom of the main copper body as shown in figure 3. The chamber is equipped with two thermocouples (TCs) upstream and downstream of the lower thick part for monitoring of the temperature rise of the chamber.

After installation of the water-cooled new chamber, the thermal performance of the upgraded absorber system has been evaluated. Figure 4 show the temperature changes of the water-cooled chamber and cooling water of 2.5 L/min flow rate, and ID gap change is also shown. At 20 mm gap, the ID produces SR of maximum power of 10.4 kW at 100 mA. Thanks to this water-cooled chamber, temperature rise of the main copper body was successfully suppressed within 10 °C. At that time, temperature of the cooling water rose 4.2 °C which corresponds to the heat removal of about 0.7 kW. It is consistent with the heat load by the scattered X-rays. While the photon absorber fully stopped SR of 10.4 kW heat power, the pressure measured near the photon absorber stayed around $5 \times 10^{-7}$ Pa.

![Figure 4](image_url)

Figure 4. Temperature changes of the water-cooled chamber body (left) and cooling water (right). The heat load of SR is 10.4 kW at the ID gap of 20 mm.

4. Summary

The compact photon absorber for SPring-8 diagnostics beamline II (BL05SS), which withstands high heat load of 19 kW, was developed. By adopting the system using two absorber blocks arranged in tandem, compact structure in longitudinal direction was successfully realized with keeping a large opening aperture. In order to suppress heating of the absorber chamber caused by the scattered X-rays from the rear absorber, the water-cooled absorber chamber made of OFHC copper was newly developed. Thanks to good thermal conductivity, high thermal capacity and water-cooling of the chamber, we succeeded in suppression of temperature rise within 10 °C. When high-heat-load components which receive the SR with shallow grazing-incidence angles are developed, introduction of cooling-mechanism of the chamber should be carefully considered.

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