Design and performance of ESRF high-power undulator front-end components

Jean-Claude Biasci,* Bernard Plan and Lin Zhang

ESRF, BP 220, 38043 Grenoble CEDEX, France.
E-mail: biasci@esrf.fr

A new high-power front-end has been developed and installed at the European Synchrotron Radiation Facility. The new design consists of the replacement of the X-ray absorber and the filtering system. An upstream pre-slit and a compact high-heat-load absorber have replaced the X-ray absorber. A chemical-vapour-deposition diamond window has replaced the beryllium window and graphite filters usually employed. Commissioning has been successfully performed on the ID23 test front-end equipped with three U34 undulators producing synchrotron radiation with a total power of 11 kW and a peak power density of 1200 W mm^{-2} at normal incidence.

Keywords: front ends; high-heat-load components; absorbers; diamond windows.

1. Introduction

Standard undulators installed in an ESRF (European Synchrotron Radiation Facility) 5 m-long straight section with a minimum magnetic gap of 11 mm can produce powerful synchrotron radiation with a power density of about 300 kW mrad^{-2} and a total power of 11 kW (information on ESRF undulators and beamlines can be found on the ESRF web site, http:/www.esrf.fr/). The high heat load causes thermomechanical problems on existing front-end components such as X-ray absorbers, carbon filters and beryllium windows. The ESRF conventional front-ends can be installed in a simple way. Once the installation has been completed, however, it is difficult to rearrange or replace components in order to enhance their performance. In addition, a minimum change in existing front-ends is preferable in order to maintain a high level of standardization and compatibility between them and thus ease their maintenance. It soon became apparent that a simple replacement of the existing absorber was not the best approach and that a complete rearrangement of the front-end was necessary to allow more freedom at the design stage. We also took this opportunity to improve other parts of the front-ends such as water-cooling circuits and the control system based on PLCs (programmable logic controller). The new X-ray absorber and pre-slit are based on the ESRF crotch absorber design, using tilted surfaces and coolant channels perpendicular to the X-ray beam horizontal plane. They are mounted on a separate support that can be prepared and tested in the laboratory before installation in the storage ring. The installed pyrolitic carbon filters cannot absorb all the low-energy synchrotron radiation produced by three undulators and consequently cannot protect the beryllium window. A CVD (chemical vapour deposition) diamond window was designed to replace the existing pyrolitic carbon-filter/beryllium-window configuration.

2. Design and performance of the high-heat-load X-ray absorber

The opening angle of the radiation produced by an undulator is very small in both horizontal and vertical directions. The total power produced by undulators can therefore be collimated through a pre-slit in order to minimize the horizontal aperture of the X-ray absorber. The absorber and its pre-slit are made using circular pieces of Glidcop AL15 copper (SCM Metal Products), which have been machined into the required shape by the wire-cutting process, to intercept the photon beam at an incidence angle of 1.2° in the vertical plane to the photon beam. The water-cooling channels are not under vacuum. The advantages of this approach are that the manufacturing is relatively simple; there is no water–vacuum joint and only one layer of Glidcop between the coolant and the photon beam, as shown in Fig. 1. There is no vacuum chamber and only three permanent atmosphere-to-vacuum brazed joints are required to make the complete absorber. The absorber moves up vertically by 10 mm, by use of a pneumatic actuator, to open the front-end and down to close the front-end and intercepts the X-ray beam as show in Fig. 2. The absorber closes within 0.2 s. Permanent survey monuments are used to align the pre-slit and the absorber. An alignment error of 0.2 mm on one side of the absorber will give an angle error of only 0.1°. A three-dimensional thermal analysis has been carried out using the *ANSYS* code (Swanson Analysis Systems, Champain, IL, USA). Only half of the absorber was analysed because the absorber is made of two similar parts brazed together to obtain a V shape. The calculation assumes a normal incidence power density of 1800 W mm^{-2} at 14 m from the source, corresponding to a total power of 6.4 kW on this half absorber. Two different incidence angles of the absorber were calculated: 1.5° and 1°. A flow rate of 0.2 m^3 h^{-1} was considered in the 4 mm-diameter cooling channels giving a value of 0.02 W mm^{-2} K for the heat transfer coefficient. Table 1 gives the thermal and stress analysis maximum values for incidence angles of

Table 1
ESRF front-end new high-power absorber thermal and stress analysis maximum values.

The present ESRF front-end absorber has an incidence angle of 4°. $\alpha_{\rm INC}$: absorber incidence angle; P_{A0}: power density at the centre of the beam projected on the absorber; $P_{\rm TOT}$: total power; $T_{\rm MAX}$: absorber maximum temperature; $TW_{\rm MAX}$: cooling-channel wall maximum temperature; $S_{\rm VM}$: Von-Mizes stress.

$\alpha_{\rm INC}$ (°)	P_{A0} (W mm^{-2})	$P_{\rm TOT}$ (kW)	$T_{\rm MAX}$ (K)	$TW_{\rm MAX}$ (K)	$S_{\rm VM}$ (MPa)
1.5	49	6.4	557	366	412
1	33	6.4	472	342	280
4	52	3.3	599	359	456

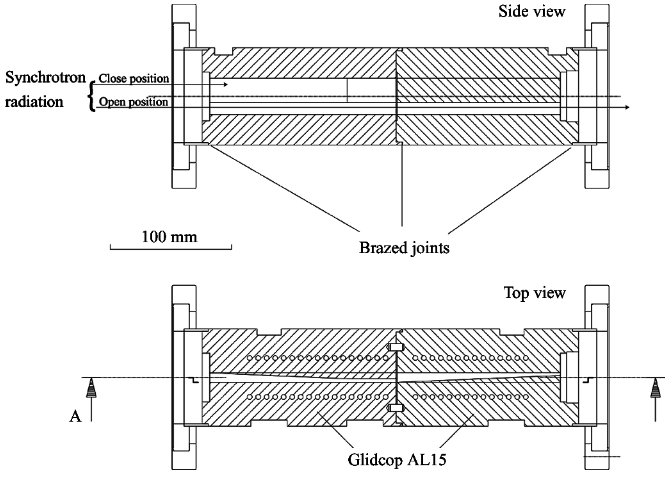

Figure 1
Section of the high-power absorber for ESRF high-power undulator front-ends.

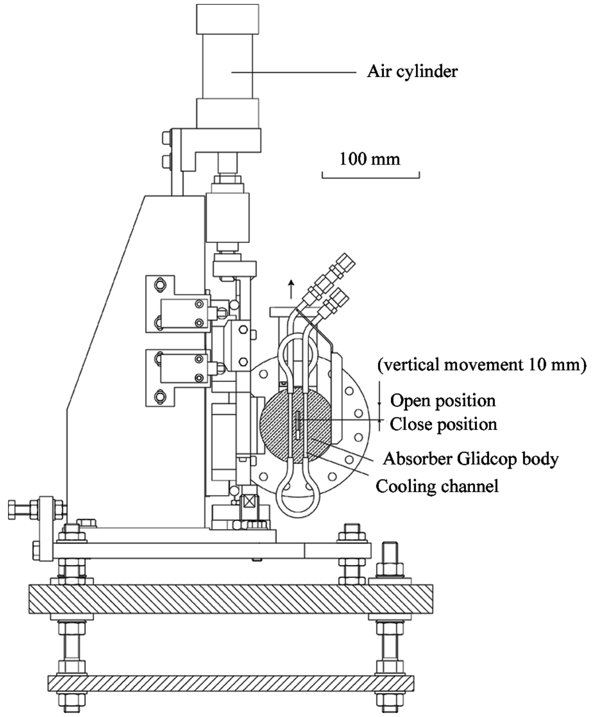

Figure 2
ESRF high-power absorber assembly closed position (front view).

1.5° and 1°. The analysis shows that for a 1.5° incidence angle the temperature and the stress level for the considered heat-load conditions start to become important but remain acceptable compared with the stress level on ESRF absorbers such as storage-ring crotches or the present front-end absorbers which have been in operation for more than five years with a 200 mA current, also shown in Table 1. Nevertheless, a pre-slit with a defined horizontal aperture of 2 mm placed upstream of the absorber intercepts part of the synchrotron radiation outside the central cone as shown in Fig. 3. The total power stopped by the absorber is then reduced by almost a factor of two. An incidence angle of 1.2° was considered as a good compromise for the absorber. This configuration will be able to sustain power densities that can be achieved in the future with smaller magnetic gaps like in-vacuum undulators. The absorber should then be able to sustain a power density of 400 kW mrad^{-2}. The pre-slit and absorber were commissioned at ESRF on the ID23 test front-end over six months. The test front-end is equipped with three 34 mm-period undulators for a total length of 4.8 m. With a minimum gap of 11 mm and a 200 mA current, a total radiation synchrotron power of 11 kW and a peak power density of 1200 W mm^{-2} at 14 m from the source can be achieved. This heat load corresponds to a power density of 25 W mm^{-2} on the surface of the absorber and a total power of about 3 kW on half the absorber, which is lower than the values taken into account for the *ANSYS* calculation. After a few days of vacuum conditioning, all undulators were closed at their minimum gap for this new absorber configuration. As shown in Fig. 3, thermocouples located close to the heated surface between two cooling channels have been installed on the pre-slit and the absorber. The temperature recorded at full power reached a maximum of 318 K, in accordance with a calculated temperature of about 343 K for twice the power. After six months of testing with full power, the absorber was visually inspected and the internal surface was found to be the same as before the tests, *i.e.* without any damage.

3. Design and performance of ESRF front-end CVD diamond window

All non-ultrahigh-vacuum ESRF front-ends are equipped with beryllium windows (grade PF60 from Brush Wellman) protected by pyrocarbon filters (ESRF front-end carbon filter; pyrolitic carbon filters, ‘pyrographite’ quality from Carbonne Lorraine, Department SMA, Gennevilliers, France). The photon flux absorbed on those elements strongly depends on the characteristics of the insertion devices. For many ESRF beamlines the photon flux limitation is a result of the front-end carbon filter and beryllium window configuration which cannot absorb all low-energy X-ray power produced by the undulators. On top of that, most of the elements located on the X-ray path can lead to coherence degradation of the photon source due to the surface roughness, impurities or porosities of the beryllium and carbon foils. A first step consisting of reducing the useful aperture of the photon beam and consequently limiting the total power absorbed on the filters can in some cases solve the heat-load problem. Diamond foils (CVD diamond foils; ‘Diafilm Op’ from De Beers Industrial Diamond Division, Shannon, Co. Clare, Ireland) produced by CVD appeared to be promising for their thermal properties and also to reduce the coherence degradation of the photon source (Espeso *et al.*, 1998). The goal was then to filter the synchrotron radiation and maintain the vacuum separation between the storage

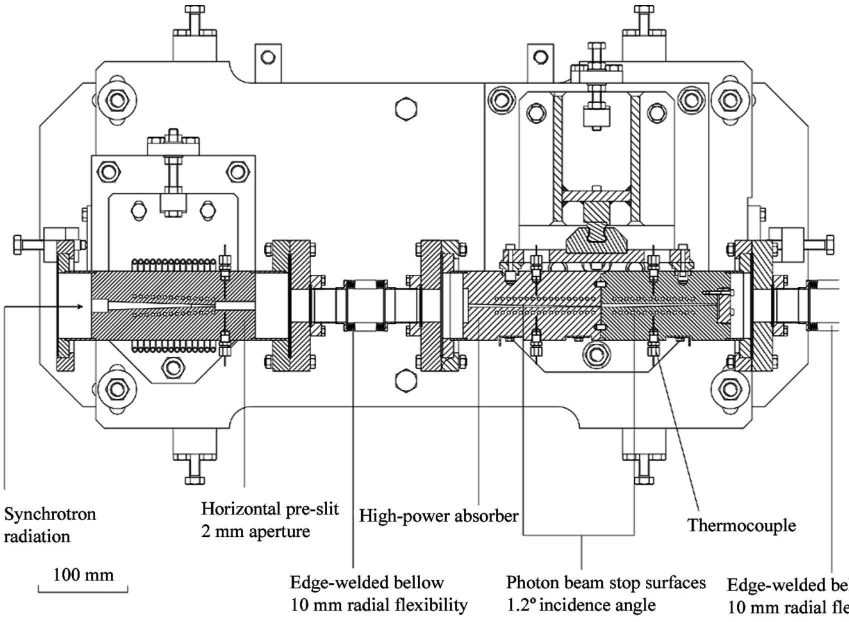

Figure 3
High-power absorber and pre-slit assembly (top view).

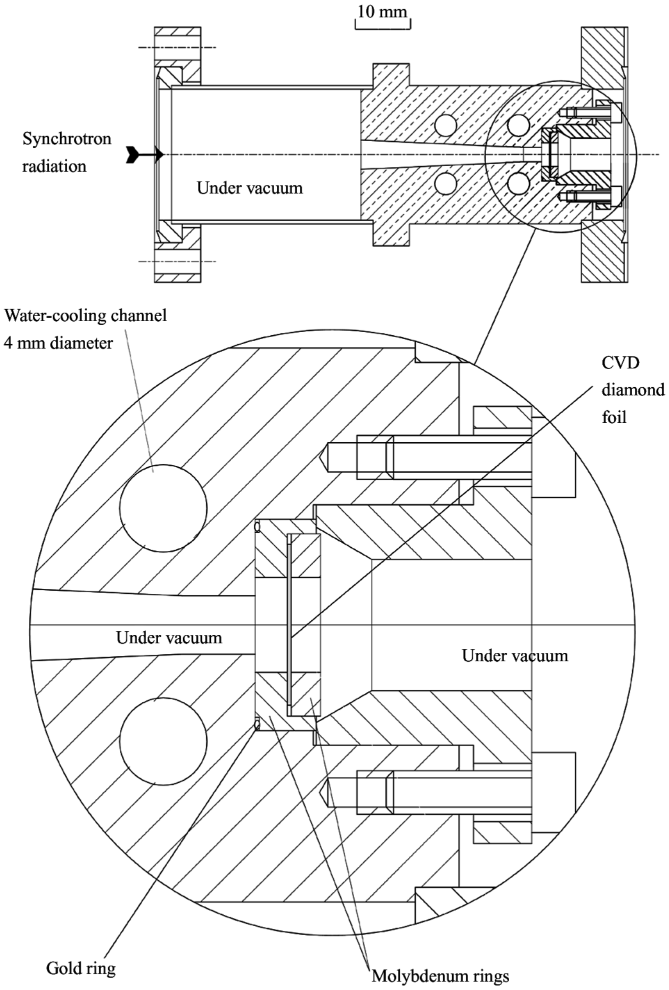

Figure 4
ESRF front-end diamond window.

ring and the beamline. A CVD diamond window was designed to match these criteria. A three-dimensional thermal and stress analysis was carried out using the *ANSYS* code, and after that a prototype of such a window was manufactured and then tested in the front-end laboratory. Its vacuum performance at room temperature and at a bakeout temperature of 473 K was tested. The window is composed of two parts: the diamond window and its water-cooled copper chamber. The diamond part is made of a 300 µm-thick CVD foil that is sealed to two molybdenum rings by a diffusion bonding technique. Molybdenum is used for its expansion coefficient which is close to that of the diamond. Fig. 4 shows the diamond/molybdenum subassembly mounted on its water-cooled chamber using a gold wire to achieve an overall leak tightness lower than 5×10^{-10} mbar l^{-1} s^{-1}. The window was then tested over several months on the ESRF ID23 test front-end at different levels of power density without any damage. A maximum absorbed power density at the centre of the window of 70 W mm^{-2} has been calculated using the *SRW* code (Chubar & Elleaume, 1998; freely available from http:/www.esrf.fr/machine/support/ids/Public/Codes/software.html) for a 300 µm-thick window. The mechanical aperture of the CVD window is limited to a maximum of 0.26 mrad. To achieve an absorbed power density of 70 W mm^{-2} in the centre, however, the useful aperture is limited to 0.09 mrad. A new window allowing a useful horizontal aperture of 0.35 mrad (7.5 mm at 23 m) is being considered for low-beta straight sections that will be equipped with in-vacuum undulators.

4. Conclusions

After these evaluation tests on the ESRF ID23 front-end, the first high-power front-end configuration was installed in January 2000 for the ID10 ESRF beamline (Troika) followed by ESRF beamlines ID28 and ID14 later in the year. The front-end group plans to upgrade four front-ends every year. Other tests are foreseen to better estimate the ultimate performances of ESRF storage-ring and front-end X-ray absorbers.

We are happy to acknowledge all the front-end group technicians for their help and support during the test experiments.

References

Chubar, O. & Elleaume, P. (1998). *Proceedings of the EPAC98 Conference*, 22–26 June 1998, pp. 1177–1179. Bristol: IOP Publishing.

Espeso, J. I., Cloetens, P., Baruchel, J., Härtwig, J., Mairs, T., Biasci, J. C., Marot, G., Salomé-Pateyron, M. & Schlenker, M. (1998). *J. Synchrotron Rad.* **5**, 1243–1249.

Received 7 September 2001 • Accepted 12 November 2001