PRELIMINARY ABSORBER DESIGN FOR THE ULTIMATE STORAGE RING LIGHT SOURCE

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Abstract

Studies on an ultimate storage ring light source have been undertaken at the ESRF. This paper deals with preliminary consideration on thermal absorber design. A compact crotch absorber design will be presented. Finite element analysis shows that the thermal stress due to high heat load generated by the ultimate storage ring light source is significantly smaller than the thermal stress in the actual crotch absorber of the ESRF. A monolithic structure design for the quadrupole vacuum chamber was also analysed on the thermal mechanical aspects. This quadrupole vacuum chamber is aluminium extruded with NEG coating and synchrotron radiation power directly deposed on the vacuum chamber.

1 INTRODUCTION

A storage ring based synchrotron light source provides its brilliance and permanent high flux of photons simultaneously to a large number of beamline users, with no intrinsic limitation to extend the X-ray energy towards very high values (100 keV). Presently, 3rd generation light sources reach brilliance in the 10^{20} photons/s//0.1%BW/mm^2/mrad^2 range. Another two orders of magnitude of enhancement in brilliance can be envisaged for a storage ring based synchrotron light source. For such a machine, the vertical emittance is very close to the electron diffraction limit. This is the so called Ultimate Storage Ring Light Source (USRLS), on which studies have been undertaken at the ESRF [1, 2].

Table 1 : Parameter list of the USRLS and ESRF

Parameters	ESRF	USRLS
Beam energy E (GeV)	6	7
Beam current I (mA)	200	500
Dipoles radius R (m)	23.366	70
Bending magnet field B (T)	0.857	0.34
Circumference (m)	850	2000
Number of dipole	64	200
Number of cell	32	50
Length of dipole (m)	2.29	2.20
Total SR power (kW)	983	1548
Angular power (W/mrad)	156.4	246.3
Power per dipole (kW)	15.4	7.7
Opening angle per dipole (mrad)	98.2	31.4

Parameters of the machine, such as energy, beam current, bending magnet field, circumference, number of cells and bending magnets are given in Table 1 for both the USRLS and ESRF machines. The number of straight sections is identical to the number of cells, 50 for USRLS (40 for ID beamlines, and the rest for machine utilities). The length of the dipoles is comparable for both machines. The average length of the storage ring per dipole is 10m for USRLS, and 13 m for the ESRF. There is 30% less space and 57% higher power density per bending magnet for the USRLS than for the ESRF machines. The design of the photon absorbers for the storage ring vacuum vessels is a topic to be studied.

As stated previously, the storage ring of USRLS consists of 50 cells. There are 4 bending magnets per cell. A crotch absorber or beam dump is should be installed just on the downstream of each bending magnet. An ID beamline is downstream to the first bending magnet in a cell. The crotch absorber between this ID beamline and the e-beam is the most critical thermal absorber in the storage ring. This is because of the very limited space available for this crotch absorber and an eventual interception of an X-ray beam from a wiggler by the crotch absorber. The design and thermal mechanical analysis of the crotch absorber is one of the subjects of this paper. Another point to be studied is the heat load absorption by a quadrupole vacuum chamber. This is important for the vacuum chamber design from either mechanical or vacuum aspects.

In this paper, preliminary designs for crotch absorber and absorber of quadrupole vacuum chamber will be presented with thermal mechanical analysis.

2 CROTCH ABSORBER

A geometric layout of one cell of storage ring [3] shows a distance of 0.5 m between a bending magnet and its downstream quadrupole magnet. The available space for crotch absorbers is less than 0.5 m in the direction along the e-beam orbit. In the transverse direction, the available space is defined by e-beam and X-ray beam. Taking into account the internal cross section of quadrupole vacuum chambers not smaller than 30 mm wide and 16 mm high and the cross section continuity, the minimum distance between the crotch absorber and e-beam orbit is 15mm. The wiggler beam is wider than the undulator beam. An aperture of +/-0.5 mrad for the wiggler beamline is very

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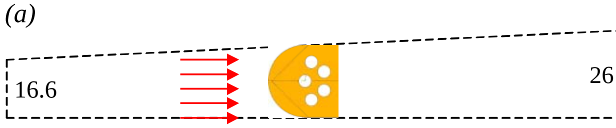
reasonable. As the distance between the middle of the straight section and the middle of the crotch is about 12.3 m, the crotch absorber should be distanced about 6.2 mm from the axis of the ID beamline. The maximum available space for a crotch absorber is thus a trapezoid shape of 400 mm long, 16.6 / 26 mm high.

As an ID beamline source, the undulator is much more widely used. The horizontal aperture of the undulator radiation is normally smaller than +/-0.5mrad, so the heat load on the crotch absorber is only bending magnet radiation.

Various designs of the crotch absorber have been preliminarily studied taking into consideration the very narrow available space. Finally, a loaf shaped design was proposed and analysed. The finite element model with heat load is shown in Fig.1. The crotch absorber is vertically inclined to an X-ray incident angle of α=5°. The length of the crotch absorber is 240 mm. The heat load from the bending magnet is Gaussian in a vertical direction. As the crotch absorber is very close to the bending magnet, the variable distance between them (from 1.5 to 2.3 m) has to be taken into account when calculating power distribution. Both the peak power density and the Gaussian parameter depend on this distance. The heat load on a horizontal plane is also variable.

The heat load is efficiently spread in both transverse and axial directions of the crotch absorber (Fig.1). The projection factor on the crotch absorber is given by $f_{proj} = y\sin\alpha \big/ \sqrt{x^2+y^2}$. The peak power density in normal incidence at the position of the crotch absorber is

(a)



(b)

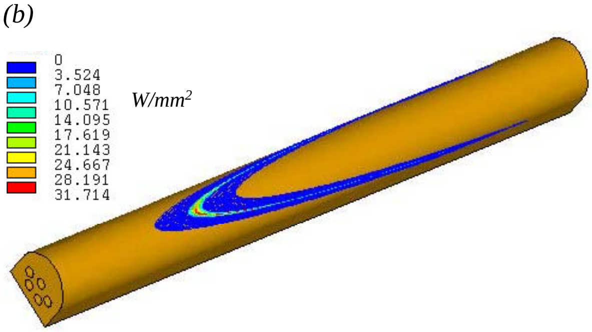


Figure 1: *(a)* Schematic diagram of the available space for the crotch absorber with cross section, *(b)* finite element model of the crotch absorber with heat load distribution

about 580 W/mm^2 on the side facing the e-beam. This peak power density is almost tangentially projected on the crotch absorber on the side facing the e-beam ($y\rightarrow 0$, $f_{proj}\rightarrow 0$). Finally, the maximum projected power density on the crotch absorber is about 31.7 W/mm^2 at incident angle α=5° as indicated in Fig.1.

Finite element analysis has been carried out for the crotch absorber at various inclined angles. A cooling coefficient of Hcv=0.02 W/mm^2/C and water temperature of 20 °C were used in the computation. Maximum temperatures on the crotch absorber T_{max} and on the cooled wall Tw_{max}, and

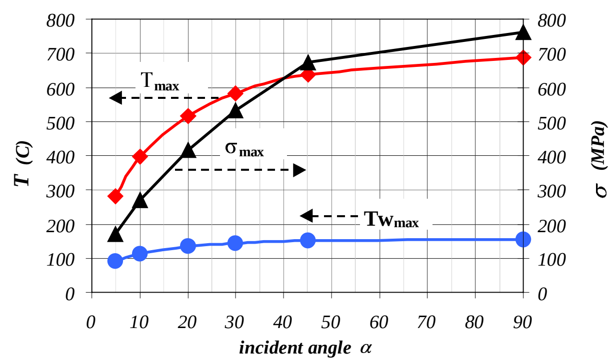


Figure 2: Temperature and stress of the crotch absorber versus incident angle for the case of only bending magnet radiation heat load

maximum Von Mises stress σ_{max} were plotted in Fig.2. Temperature and stress decrease quickly with the incident angle α when this last is smaller than 45 degrees. At incident angle α=5°, the maximum temperature on the crotch absorber and on the cooled wall are respectively T_{max}=282 °C, T_{max}=91 °C. The maximum thermal stress is σ_{max} =175 MPa, which is smaller than 50% of elastic limit of the glidcop. Note that the elastic limit of the copper is a very conservative criterion for the thermal absorber with very concentrated heat load [4]. The crotch absorber for the USRLS is safe at design parameter I=500mA. When the e-beam current is upgraded to I=1A, the power density and thermal stress will be doubled, the temperatures will be T_{max}=544 °C, Tw_{max}=162 °C, and the stress will be σ_{max}=350 MPA. It should still be safe for the crotch absorber.

3 THERMAL ABSORBER FOR QUADRUPOLE VACUUM CHAMBER

The quadrupole vacuum chamber could be an extruded aluminium chamber with NEG coating [5]. Aluminium is good either in electrical or thermal conductivity. Three options were reviewed for the quadrupole vacuum chamber absorber:

1) No special absorber. In that case, synchrotron radiation directly hits the chamber.

2) A lumped thermal absorber made of copper. This requires an anti-chamber.
3) A design similar to the present ESRF one with copper bonded on the vacuum chamber and synchrotron radiation hitting the copper part.

It is obvious that the option 1) is most attractive from mechanical engineering aspects : very simple design, minimum welding or brasing joints, easy to manufacture. This first option is feasible when using a monolithic structure for the extruded aluminium vacuum vessel with a minimum thickness of 3 mm and cooling holes. Taking the proposed beam stay-clear, this leads to a ±25 / ±11 mm external size for the vacuum chamber.

A finite element analysis has been performed for such a vacuum chamber. The cross section is shown in Fig.3. A length of 80 mm of the chamber was modelled. As symmetry condition was applied to one end, the equivalent length is 160 mm. In general, the power density decreases slightly along the quadrupole vacuum chamber due to the increase of the distance from the radiation source. A constant power density Pa=8 W/mm^2 was applied over a height of $\sqrt{2\pi}\sigma = 0.30$ mm and all along the chamber as shown in Fig.3. This power density and beam size corresponds to the values at the entrance of the quadrupole vacuum chamber. The applied power in FEA is higher than the effective heat load. The temperature field is 2D, but the thermal stress has to be calculated with a 3D model. A length of 160 mm is long enough, the variation of the stress with the length is totally negligible. Indeed, the difference of stress calculated with a length of 50 and 80 mm is smaller than 0.1%. The vacuum chamber was supposed to be cooled with water flow in only one channel, the one closest to the heated part. The cooling coefficient and water temperature are respectively 0.02 W/mm^2/C and 20° C.

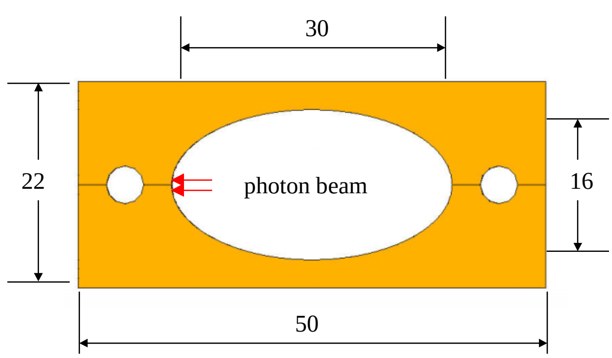


Figure 3: Cross section of the quadrupole vacuum vessel

The calculated maximum temperature T_{max} and maximum Von Mises stress σ_{max} of the quadrupole vacuum chamber is T_{max}=49 C and σ_{max}=28 MPa. The stress is much smaller than the elastic limit of the aluminium at operation temperature. The extruded aluminium quadrupole vacuum chamber should be safe when the e-beam current is be upgraded from 500mA to 1 A.

There are two holes in the quadrupole vacuum chamber as indicated in Fig.3. Only the left hole will be used for cooling. A symmetrical geometry is good for the extrusion operation, so the right hole is added.

4 SUMMARY

The thermal absorber design for Ultimate Storage Ring Light Source was reviewed. The most critical one is the crotch absorber due to the short distance from the source and very limited space for the installation. A loaf shaped design was proposed and analysed. The crotch absorber is vertically inclined to an X-ray incident angle of α=5°. The crotch absorber is 240 mm long, 23 mm wide and high. The heat load is efficiently spread on the crotch absorber. Finite element analysis shows that the temperature and stress of the crotch absorber are in a very safe regime at the machine design parameter I=500mA.

Thermal absorber for quadrupole vacuum chamber was also reviewed. An extruded aluminium vacuum vessel with an elliptical shape inside and cooling holes was studied. The synchrotron radiation directly hits the chamber, no special absorber is necessary. The temperature and thermal stress are significantly lower than the material criteria.

Both crotch absorber and quadrupole vacuum chamber are also safe for e-beam current up to 1 A.

5 ACKNOWLEDGEMENTS

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6 REFERENCES

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