ABSORBERS DESIGN FOR THE CANDLE STORAGE RING

S Tunyan, M Aghasyan, V Avagyan
Center for the Advancement of Natural Discoveries using Light Emission
Acharian 31 - 375040 Yerevan - Armenia

Abstract

This paper deals with preliminary consideration on thermal absorbers design. Crotch and distributive absorbers will be presented. Finite Element Analysis (FEA) shows that the temperature due to heat load generated by bending magnets and critical insertion device is significantly smaller than maximum permissible limit. The optimization process on main design parameters has been carried out.

1. Introduction

Taking into account that the CANDLE storage ring vacuum chambers will be made of stainless steel, and that the main portion of synchrotron radiation generated in storage ring will not be used and will remain in vacuum vessels, it requires using many absorbers to protect the walls of vacuum chamber. In general, these thermal absorbers will absorb about 80 % of the synchrotron radiation power generated by bending magnets. These absorbers will be mostly made of OFHC copper, water-cooled and should be designed to withstand the temperature and thermal stress induced by the high head load. The aim of this design study was to reduce the maximum temperature and to define CANDLE storage ring absorbers optimal parameters. The absorbers design has standard procedure, which had been worked-out in development process of third-generation synchrotron light source. The first step to achieve this target is to define the main design requirements. The next stage of this process is determination and calculation of the heat load profile and values, as well as coefficient evaluation of water-cooling efficiency. Thermal analysis and optimization process of main parameters, using computer simulation technology, gives the opportunity to determine completely absorber's material, construction and water rate.

2. Design Requirements

The working-out process of requirements to CANDLE storage ring absorbers was mainly based on materials of such centers as ESRF and ANL [1, 2, 3]. After detailed analysis, the following general guidelines have been approved:

- Water velocity in the cooling channels is kept in the range not above 3 m/s in order to keep flow-induced vibrations within acceptable levels.
- The maximum temperature of the absorber bottom should be significantly lower than melting point of the copper, or brazing temperature.
- The maximum cooling wall temperature should be lower than water boiling temperature at the pressure of the water in the cooling channels.
- The maximum Von Mises stress in the absorbers should be lower than the strength of the material.
- Materials: OFHC copper is used for absorbers at lower power densities when maximum temperature rise, as calculated from FEA, does not exceed 150ºC. Otherwise Glidcop should be used, because of its high strength at elevated temperatures.

- Water-to-Vacuum Joints: Water-to-Vacuum braze or weld joints are not used. This is a general design requirement that was accepted to prevent water leaks from entering into the vacuum system.
- Water channels mustn't be located on the level of the electron beam orbit in order to avoid direct hit of scattered electrons.

3. CANDLE Storage Ring Absorbers

The CANDLE storage ring lattice consists of 16 identical Double-Bend Achromatic (DBA) cells. Except the special regions (the injection and 2 acceleration RF cavities), in 13 of them the absorbers location will be identical. The positions of absorbers in one of such cells, without straight section, are shown in Fig.1.

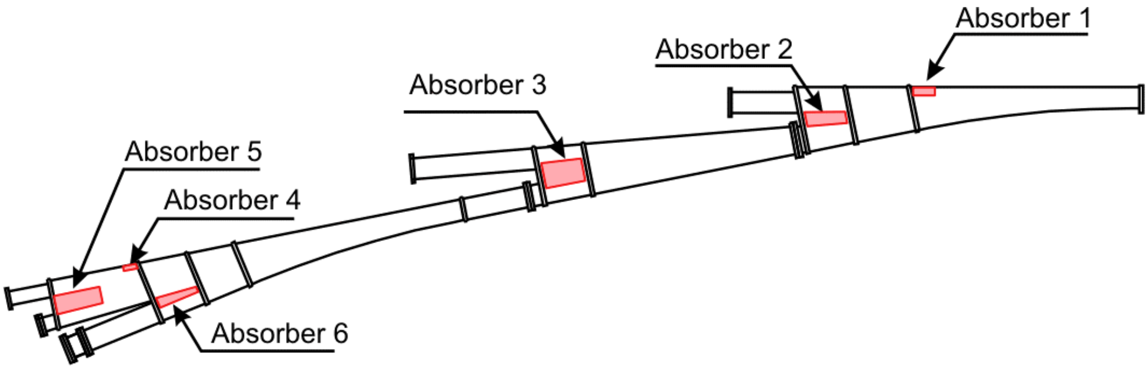

Fig. 1. Position of the absorbers in the chamber.

The same 13 cells have an opportunity to install Insertion Devices (ID) at free straight region. One of such ID photon beam emission tracts that is considered for 3 Tesla wiggler and represents the worst case for CANDLE storage ring vacuum chamber is schematically shown in Fig.2. The first exit port in each cell, mounted on ID on-axis should provide the power outlet generated by ID. Location of distributive absorber along inside wall will allow to increase vacuum chamber ability in regard to synchrotron light emission from ID.

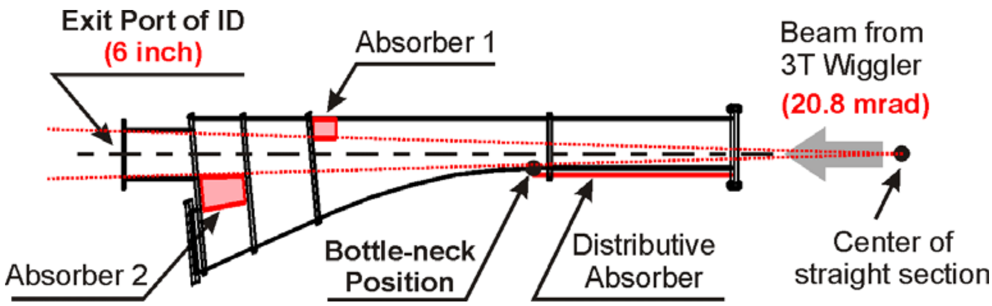

Fig. 2. SL emission tract of ID in CANDLE storage ring.

The thermal absorbers protecting the storage ring vacuum chamber are classified as 1. Crotch absorber – located downstream of the dipole vacuum chamber; 2. Distributive absorber – along the vacuum chambers; 3. Special absorbers – in the injection and RF cavity areas.

3.1 Distributive absorbers

The distributive absorbers are the most common absorbers. They are used to protect the quadrupole-sextupole vacuum chamber and the straight section. A 5-7 mm thick copper plate will be brazed on the inner side of the stainless steel vacuum chamber, and a water cooling copper tube will be brazed on the outside of the vacuum chamber. Other distributive absorbers will be installed in a slot between the electron chamber and the antechamber.

3.2 Crotch absorbers

The crotch absorbers will be made of OFHC copper. Crotch absorbers in the CANDLE storage ring intercept 2/3 of the radiated power from bending magnets at a maximum normal peak power density of 103 W/mm². The crotch absorber consists of two distinct parts: the absorber itself as shown in Figure 3 and the top cover with water manifolds. Water channels and internal fins in the copper body can be made by the electric discharge machining process. The absorption surfaces are inclined to the incident beam by approximately 3º on average, thus reducing the incident power density by 90 percent. In addition, 1.5-mm-deep external surface fins are used to split the beam footprint into two parts.

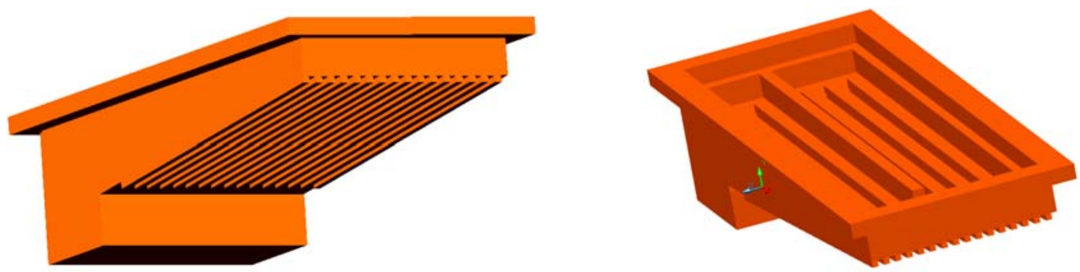

Fig. 3. Crotch absorber

4. Finite Element Modelling and Thermal Analysis

One of the problems while using finite element modeling (FEM) is to define boundary conditions. The main parameters are the heat load distribution and film convection coefficient.

4.1 Heat load distribution

The heat load on the absorbers surface depends on the beam power density distribution. In this design we have used parameters presented in CANDLE design report that provides distribution of power generated as from bending magnets as from insertion devices (in the worst case)[4]. It must be noticed that X-ray beam from wiggler has a complex profile, Gaussian in the vertical direction and parabolic in the horizontal direction. In order to use the closed form solution described above, we have to fit the beam power, which strikes absorbers, to a Gaussian-distributed heat flux in vertical plane ($\sim\exp(-y^2/r^2)$) and parabolic-distribution in horizontal plane (~ $\sqrt{1-x^2/r^2}$). In the case of bending magnet - power density distribution in horizontal direction is constant. Values of heat flux parameters, taking into consideration angle incident on the absorbers, are given in Table 1 and Table 2.

Table 1: Heat load parameters on absorbers from BM

Absorbers	Fan Width (mm)	Fan Height (mm)	Peak Power Density (W/mm²)
Absorber 1	48	33.5	0.19
Absorber 2	102	14.3	2.27
Absorber 3	182	25.3	0.7
Absorber 4	35	22.4	0.42
Absorber 5	135	22.1	0.95
Absorber 6	62	10.6	4.1

Table 2: Heat load parameters on absorbers from 3T Wiggler

Absorbers	Fan Height (mm)	Fan Width (mm)	Peak Power Density (W/mm²)
Absorber 1	23.5	11	5.3
Distributive Absorber	1.58	-	1.66

4.2 Film convection coefficient

The faultless results of the FEA are also dependent on the value of the film convection coefficient assigned on the cooling channel walls that gives a measure of the conductivity between the liquid and the absorber surface. Literature gives correlation relations for specific cases. In particular, in forced convection, as in our case, the film convection coefficient is given as a function h=f(Re,Pr) of the Reynolds number (ratio of inertia to viscous forces, Re) and the Prandtl number (ratio of molecular momentum to thermal diffusivity of fluid, Pr). In the present design the Dittus and Boelter relation has been used [5].

4.3 Thermal analysis

The thermal analysis of presented absorbers has been performed by creating 3-Dimentional model and solving the maximum temperature on absorber impact surface and on water channel wall. Software FEMLAB 2.3 has been used to achieve this target. Computer simulation has been applied on one of each type of absorbers in the storage ring, with maximum power density on each type. Results of maximum temperature of the absorber bottom surface T_{BT} and of the water channel wall T_{CH} and main parameters of the model are shown below (Fig.4).

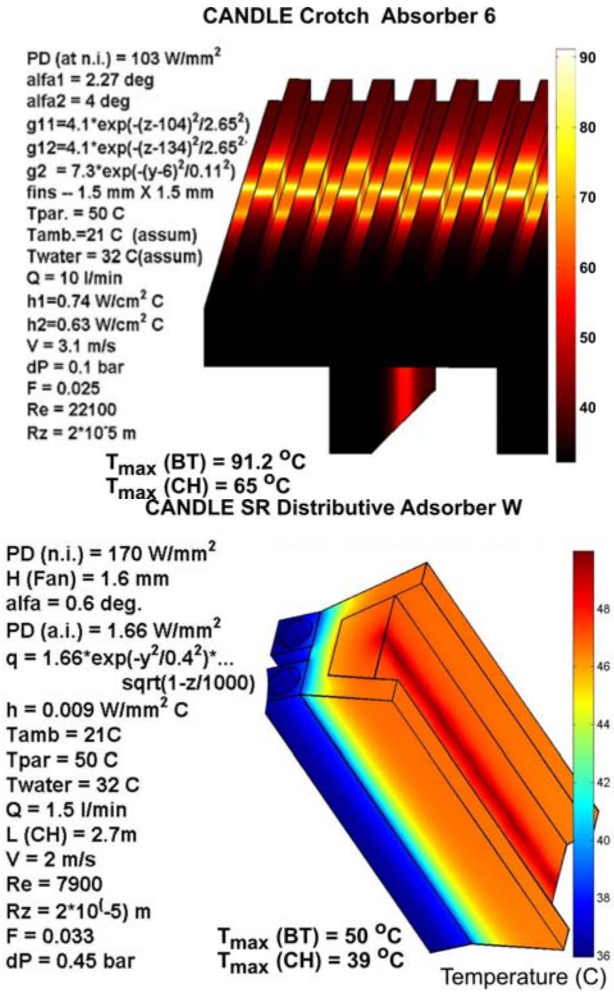

Fig. 4. Storage ring crotch and distributive absorbers design

5. Design Optimization

The design goals for the photon absorbers are to obtain low temperature as well as low water velocity in the cooled channel. Another constraint is the surface incline angle of the absorbers, which impacts on the value of power density and on the geometric dimensions of the absorbers. In particular the objective functions in the optimization process are the maximum temperature on the water channel wall (T_{CH}) and the maximum temperature on the surface of the heated plate (T_{BT}). The imposed constraints are: $T_{CH} < 100°C$ and $T_{BT} < 150°C$. The water velocity must be lower than 3 m/s in the water channel, in order to keep flow-induced vibrations within acceptable levels. To meet these requirements, we have to search for a set of design parameters values, which define the suitable design configuration. The optimization analysis has been carried out with FEA of Absorber 1. The first step is to define the constant parameters in the design optimization. We have fixed the thickness between the water channel and the hot spot on the absorbed surface. This value in 8 mm has been chosen for all crotch absorbers. Such choice has sharply lowered the maximal temperature on the water channel walls. For this reason we have dared to exclude Tmax(CH) from the optimization process.

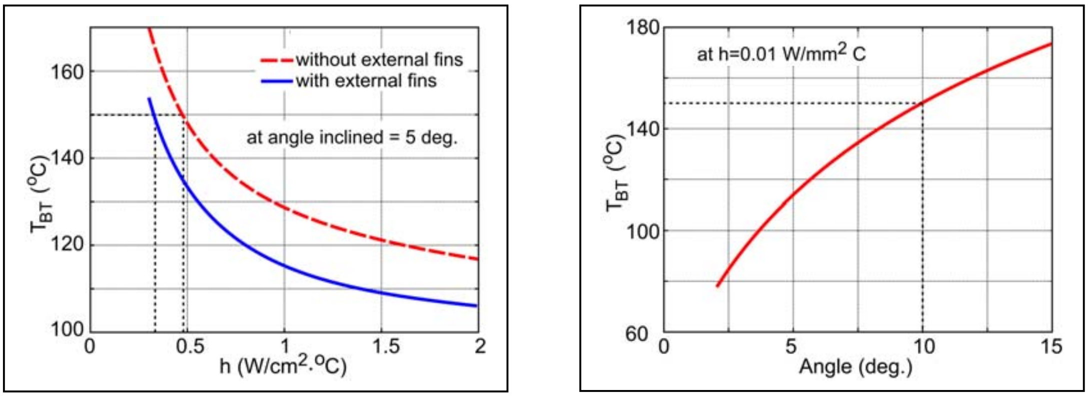

Fig. 5. Dependence of T_{BT} on film coefficient and angle incident for Absorber 1

As shown on the right schedule of Fig.5, dependence of the bottom surface maximum temperature on the incidence angle, at other fixed parameters, reveals an opportunity to increase the incline angle, thus to reduce the absorber's size. On the left schedule of the same figure the dependence of maximum temperature on the film convection coefficient for a surface with fins and without them is submitted. Analyzing this schedule we can determine the bottom limit of film coefficient. At that, the bottom limit of film coefficient of 0.5 W/cm²ºC is suitable to all CANDLE storage ring crotch absorbers. The difference of values T_{BT} between various profiles of the surface reveals efficiency to use the external fins and by that will enable to lower the water flow and water velocity, accordingly.

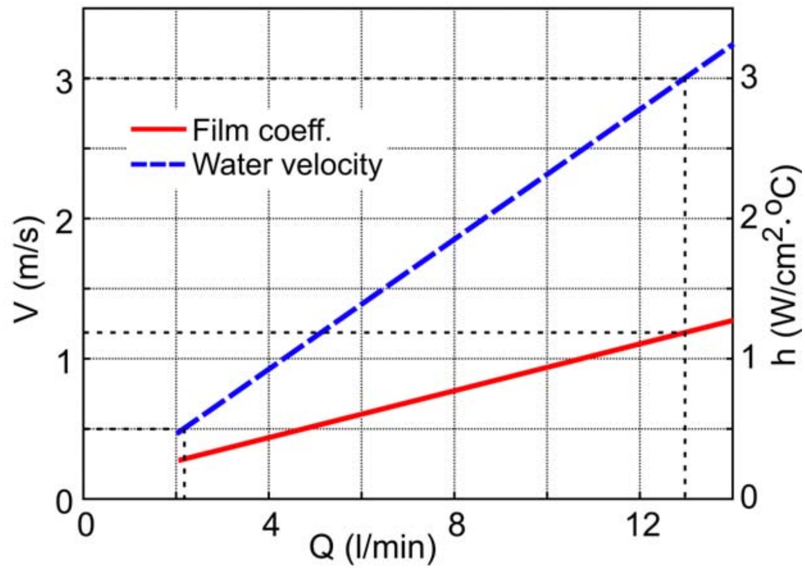

Fig. 6. Dependence of water velocity and film coefficient on water flow for Absorber 1

After the simple analysis of dependence of water velocity value in the channel and the film coefficient on water flow, shown in Fig.6, we can define the top limit of the film convection coefficient. Apparently from schedules, the value of water velocity 3 m/s corresponds to 13 l/min for the water flow and 1.2 W/cm² ºC for the film coefficient.

6. Conclusions

The CANDLE storage ring absorbers have been analyzed by software FEMLAB 2.3. The absorbers temperature analysis has been carried out for critical absorbers from the standpoint of short distance from the source and very limited space for the installation. Finite Element Analysis shows that the temperatures of the storage ring absorbers are in very safe regime at the machine design parameters. It must be added that consideration of the material thermal stress analysis is absent in this study. It's of no interest for presented absorbers. Such analysis will exist in works for more critical components.

7. Acknowledgements

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8. References

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