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STUDY, DESIGN AND OPTIMIZATION ANALYSIS OF THE ALBA LOREA DIPOLE VACUUM CHAMBER AND CROTCH ABSORBERS BASED ON FINITE ELEMENT ANALYSIS

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Abstract

This work deals with the FEA study, design and optimization of the LOREA dipole vacuum chamber and Glidcop Al-15 crotch absorbers. At present LOREA is the ninth beamline being designed at ALBA with an Insertion Device (ID) consisting of an Apple II-type helical undulator. For the standard dipole chamber the vertical polarized light hits the walls because of the very narrow vertical aperture between the cooling channels. In vertical mode the ID vertical divergence equals +/- 2.2 mrad and the peak power density and total power are 5.6 kW/mrad² and 5.5 kW, respectively. Due to the high power a temperature as high as more than 600 ºC is calculated. In consequence the dipole chamber has to be modified and the absorbers have to withstand the Bending Magnet (BM) and ID radiation. The new absorbers have to be thicker and its cooling channels are farer from BM power deposition than the standard absorbers. The thermal mechanical simulations show good results, the new absorbers are in a safe range, the maximum temperature, stress and strain are 309.2 ºC, 164.2 MPa and 0.14%, respectively. The main ALBA Storage Ring design parameters used in the simulations are: 3 GeV, 400 mA and 1.42 T (BM).

BACKGROUND

LOREA is the ninth beamline being designed at ALBA synchrotron light source. It will deliver photons with high resolution and high photon flux for Spin and Angle Resolved Photoemission Spectroscopy. Its Insertion Device (ID) consists of an Apple II-type helical undulator (EU125) [1]. This type of EPU can produce horizontal, circular and vertical modes of polarization of the magnetic field.

The radiation emitted by the ID at low photon energies has a very large angular divergence. Although the large divergence is not a problem in case of horizontal and circular polarization, it is instead a problem, considering the “V profile” of the dipole vacuum chamber. Here, the “V profile” necessary to allow the cooling channels produces a very narrow aperture, and the vertical polarized light hits the chamber. This problem is described in Fig. 1: the green fan depicts the ID radiation in a vertical plane at the middle of the cone radiation. The schematic fan is calculated for vertical mode polarization which vertical opening is +/- 2.2 mrad. Because of this large angular divergence there is an interference with the cooling channel and a big amount of heat is deposited on the dipole vacuum chamber.

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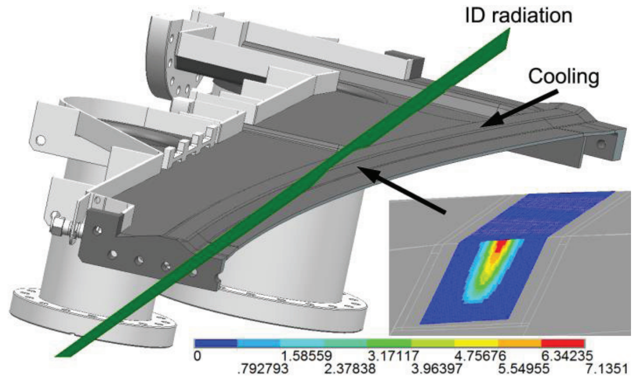

Figure 1: Schematic cross-sectional view of standard dipole vacuum chamber, displaying the lower longitudinal cooling channel and ID radiation interference for vertical mode polarization. The footprint is in W/mm^2.

THERMAL STUDIES OF THE STANDARD DIPOLE CHAMBER SUBJECT TO ID RADIATION

Thermal Boundary Condition

Thermal simulations (FEA) were used to study the effect of the ID radiation (vertical mode) on the standard stainless steel dipole chamber.

The power deposited on the chamber is calculated with the parameters of Table 1. It is imposed a nominal trajectory of the beam. The power calculated for each cooling channel is 693 W and the peak power density is 7.1 W/mm^2. Figure 1 shows the footprint for the lower cooling channel.

Table 1: Main Parameters of Insertion Device for LOREA (vertical mode). The Emitted Power and Power Density are Computed for an Electron Beam Current of 400 mA.

Parameter	Magnitude
Maximum magnetic field	1.06 T
K	12.37
Power density	5.6 kW/mrad^2
Total power	5.5 kW

Fluid Boundary Conditions

The cooling channels have originally been designed to dissipate the reflected heat radiation from the crotch absorbers. Under this condition the amount of power is very low, the heat is spread uniformly on the chamber and a laminar regime of water flow is sufficient for heat dissipation.

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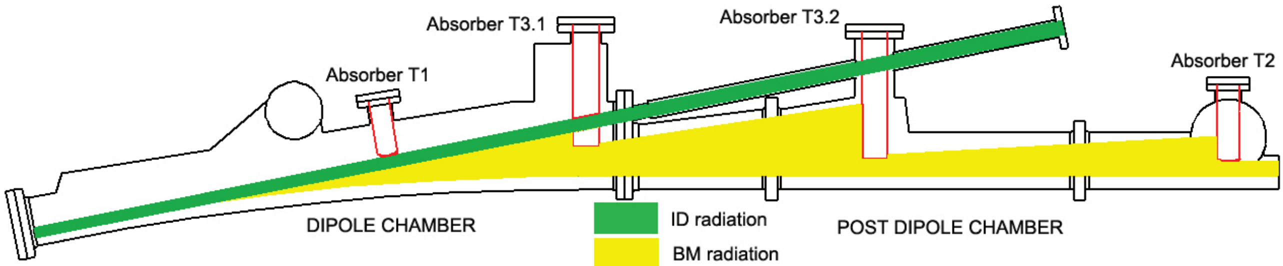

Figure 2: Ray tracing for LOREA dipole chamber. The green fan is the ID radiation and the yellow zone is the Bending Magnet (BM) radiation from the close dipole.

In order to study the thermal behavior of the dipole chamber, three water flow conditions have been imposed: laminar regime, which is the current flow condition (case A), and turbulent regimes (cases B and C). The cases are defined in terms of the convective heat transfer coefficient "h" (see Table 2).

Results

Table 2 shows the results. Even for turbulent conditions the maximum temperature is non – acceptable. Due to the very high power a temperature as high as more than 637 ºC is calculated. Figure 3 shows the temperature distribution in the dipole chamber for the worst case.

Table 2: Peak Temperature (T_{MAX}) in the Dipole Chamber for Different Water Flow Conditions.

Case	h (W/m^{2}K)	T_{MAX} (ºC)
A	1500	961.2
B	5500	717.2
C	13000	637.1

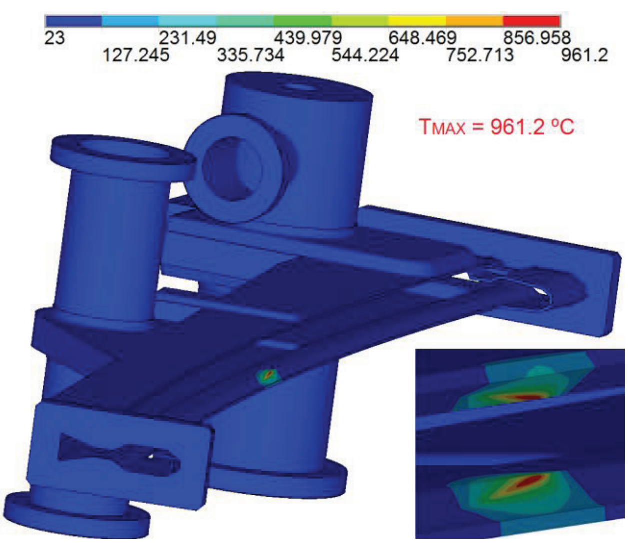

Figure 3: Temperature reached on the dipole chamber (upper and lower cooling channels) due to interference of ID radiation in vertical mode. The maximum temperature is 961.2 ºC (case A).

Because of the thermal results two main modifications have to be introduced on the chamber as follows:

- The longitudinal cooling channels have to be removed to increase the vertical aperture. This modification allows the cone radiation going toward the first Glidcop Al–15 crotch absorber T3.1 (see Fig. 2), which also has to be redesigned.
- The biggest rectangular port has to be modified to accommodate the new crotch absorber T3.1.

THE NEW GLIDCOP AL–15 CROTCH ABSORBER IN THE DIPOLE CHAMBER

The new crotch absorber follows the standard design done at ALBA. Some modifications to the design have been implemented in order to improve its thermal and mechanical performance.

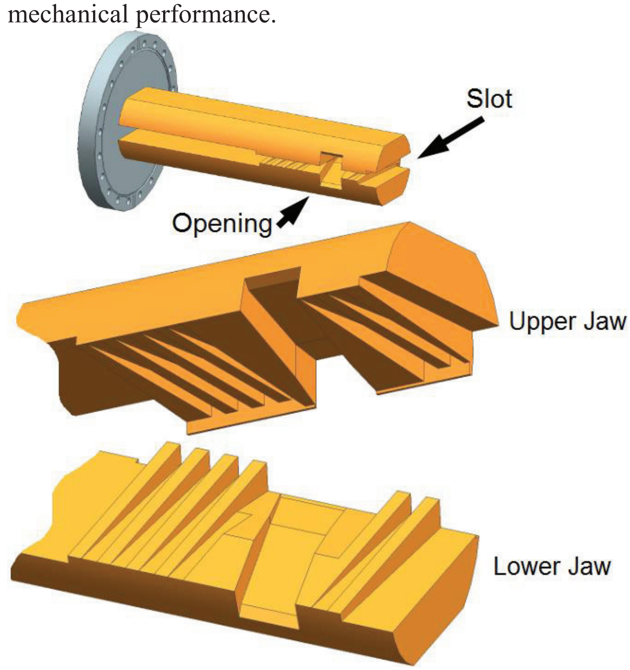

Figure 4: The assembly and two jaws of new Glidcop Al–15 crotch absorber for LOREA dipole chamber.

The proposed geometry is shown in Fig. 4. The main characteristics are as follows:

- An opening is provided through the two jaws to allow ID radiation passing to the front end. Part of the radiation will be collected on the upper and lower jaws. The sizing opening has to avoid interference between the ID radiation and the post dipole chamber.
- The new absorber has to stand ID and BM radiation at the same time, so the inclination of surfaces on the opening has to be optimized in order to reduce the power density of the ID radiation.

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- A slot is provided at the end of the absorber. This aperture avoids radiation impinging at the end of the absorber, since the cooling in that region is not efficient. With this modification the radiation passes through the absorber T3.1 and is deposited on the downstream absorber T3.2, but in a region with a better cooling (see ray tracing in Fig. 2).
- The cooling efficiency will be also optimized with a different design of the cooling channels.

Figure 5 shows a comparative description of the geometries for the standard and new crotch absorber. The main differences are as follows:

- In the new absorber the vertical distance (L) between the footprint (BM radiation) and the cooling channels (22.5 mm for the worst case), is longer than the standard absorber (11.6 mm). This constraint affects the thermal mechanical performance of the new absorber.
- The height (H) of the new absorber is longer than the standard case: 71 and 49 mm, respectively. This modification affects the design of the dipole chamber,
- The cooling channels are aligned in a horizontal (standard absorber) and in an inclined straight line (new absorber).

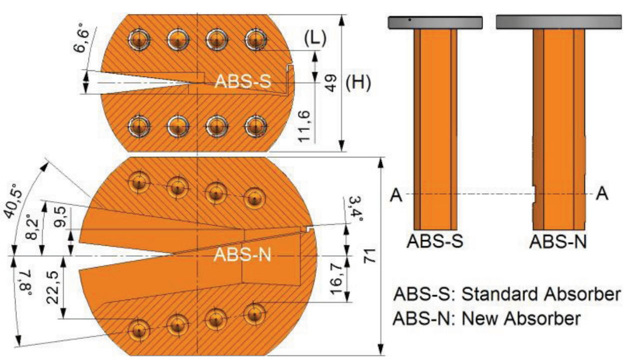

Figure 5: Comparative study between the dimensions of standard (ABS-S) and new crotch absorber (ABS-N). View for the cross section A–A. Dimensions are in mm.

FEA STUDIES OF THE NEW ABSORBER

Boundary Conditions

The main parameters which characterize the LOREA ID (vertical mode) and BM power on the absorber are shown in Tables 1 and 3.

For all the FEA studies only the upper jaw is simulated. This jaw is subject to the maximum power load conditions, in comparison with the lower jaw.

For the ID power deposition the vertical misalignments, angular (+/- 0.11 mrad) and displacement (+/- 0.16 mm), have been imposed. For these conditions the ID power on the upper and lower jaws are 610.7 and 296.2 W, respectively, and the ID peak power density is 19.8 W/mm^2.

The total power (ID and BM) on the upper jaw is 2729 W and the maximum power density is because of BM radiation: 43 W/mm^2.

Table 3: Main Parameters for ALBA Storage Ring

Parameter	Magnitude
Beam energy, E	3 GeV
Design current, I	400 mA
Dipole magnetic field, B	1.42 T

The crotch absorber is cooled by water at 23 ºC inlet temperature. The velocity in the cooling channels is kept in 3 m/s and the imposed convective heat transfer coefficient is 15000 W/m^{2}K.

Results

The temperature, stress and strain distribution have been calculated based on linear elastic analysis. The thermal mechanical simulations show good results, the new absorber is in a safe range according to the design criteria [2]. The maximum temperature, stress and strain are 309.2 ºC, 164.2 MPa and 0.14%, respectively (Fig. 6).

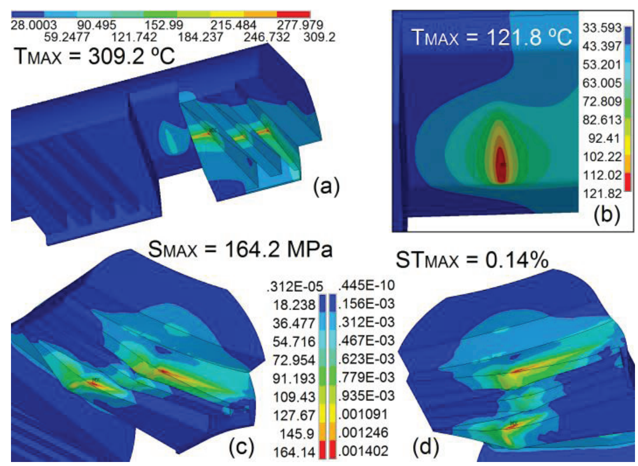

Figure 6: FEA results for the new Glidcop Al–15 crotch absorber in the dipole chamber: (a) Temperature map, (b) Local detail of the temperature distribution at the ID power deposition, (c) Stress map, and (d) Strain map.

CONCLUSIONS

The study confirms the necessity to do a modification of the dipole vacuum chamber. From the ray tracing it resulted that the post-dipole vacuum chamber should not be modified, but the two Glidcop Al-15 crotch absorbers (T3.1 and T3.2) should be designed anew. The new absorber T3.2 has to be modified following the same design criteria for absorber T3.1. The FEA results of the new crotch absorber show a good performance according with the limits of the design criteria.

REFERENCES

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[2] *E. Al-Dmour et al*, “The conceptual design and thermal analysis of ALBA crotch absorbers”, *PAC07*, MOPAN065, p. 299–301, 2007.