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FEA SIMULATIONS OF THE ALUMINIUM VACUUM CHAMBER FOR LOREA INSERTION DEVICE AT ALBA SYNCHROTRON LIGHT SOURCE

M. Quispe†, A. Gevorgyan, ALBA – CELLS Synchrotron, 08290 Cerdanyola del Vallès, Spain

Abstract

For LOREA, the new beamline at ALBA, the Insertion Device Apple-II helical out-vacuum undulator requires the installation of a suitable narrow – gap aluminium chamber.

The chamber design is based on the standard ALBA aluminium chamber which has an internal elliptical cross section, where NEG coating is deposited and bending magnet (BM) radiation from the upstream dipole is dissipated on the chamber walls. For the standard chamber the upstream distributed absorber cannot protect the entire chamber from direct BM radiation because there is a limitation for its design: the beam impedance of the machine.

Based on new studies of collective effects it has been concluded that it's possible to implement modifications on the upstream distributed absorber and protect the chamber from lateral collision of BM radiation keeping the beam impedance of the machine inside of a safe range. In spite of that still there is a contribution of the tails of BM radiation.

In this paper we describe the behavior of the new aluminium vacuum chamber for different thermal load conditions using water and air for refrigeration. Also we present the design of the modified OFHC upstream distributed absorber.

BACKGROUND

The Insertion Device (ID) for LOREA, the new beam line at ALBA for Low-Energy Ultra-High-Resolution Angular Photoemission for Complex Materials, will operate with a suitable chamber, a narrow-gap, NEG-coated, extruded-aluminium vacuum chamber.

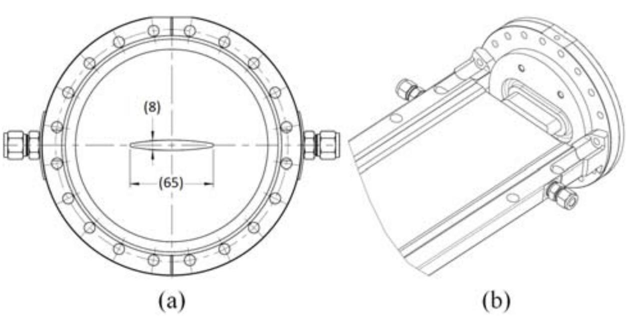

Figure 1: The ALBA narrow-gap, NEG-coated, extruded-aluminium vacuum chamber. (a) Internal elliptical cross section of 65 mm by 8 mm. (b) Detail of the end chamber joined to the flange.

The design model of this chamber is based on the standard aluminium vacuum chambers installed at ALBA. It has an internal elliptical cross section of 65 mm by 8 mm, where NEG coating is deposited (See Fig. 1).

Synchrotron radiation from the upstream dipole is dissipated on the chamber, thus two water cooling channels with 7 mm diameter each is used for cooling. The material used for the manufacturing is aluminium 6061 T6. At each end of the chamber, the aluminium extrusion is welded to an explosion-bonded bimetallic (stainless-steel/aluminium) flange to enable to make a joint to the flange (Spigot flange). The inlet and outlet flanges are bimetal made of AISI 316LN and aluminium 6061 T6. Flanges are CF type, fixed with a DN160 size.

In order to integrate the chamber into the straight section two vacuum components must be implemented: the OFHC upstream distributed absorber and the downstream tapered chamber connected to the current bellows (See Fig. 2).

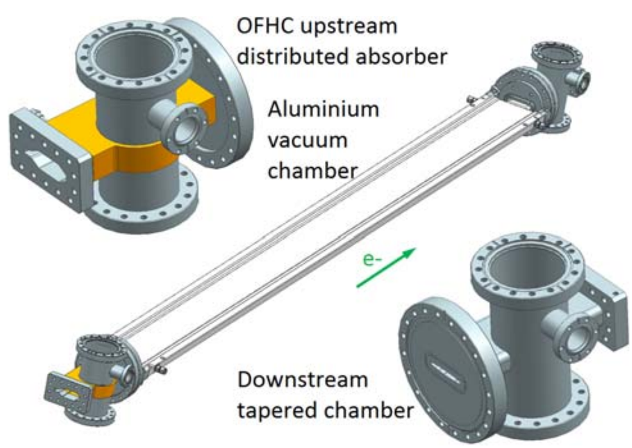

Figure 2: ALBA 3D model of the aluminium vacuum chamber, the OFHC upstream distributed absorber and the downstream tapered chamber.

For the current aluminium vacuum chambers at ALBA the BM radiation hits the wall laterally because the chamber is only partially protected by the upstream distributed absorber. This unwanted configuration is due to a geometrical restriction imposed for the design of the absorber: in order to keep the beam impedance of the machine inside of a safe range a minimum distance between the sharp end of the absorber and the electron beam trajectory must be fixed to 28.5 mm.

For LOREA, new studies of collective effect confirm the possibility to reduce the minimum distance from the sharp end of the absorber to the electron beam trajectory. Then it will be possible to avoid a lateral collision of BM radiation.

† mquispe@cells.es

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For this new condition, still there is a contribution of the tails of the radiation on the upper and lower walls of the chamber. This radiation can be significant because of the very narrow gap of the chamber.

In this paper we present the thermal behavior of the LOREA aluminium vacuum chamber for different conditions: radiation heating the lateral, upper and lower walls, including misalignment effects, and using water and air cooling as thermal solutions. And finally details of the new OFHC upstream distributed absorber are included.

ALUMINIUM VACUUM CHAMBER

Lateral Collision

This case corresponds to the standard aluminium vacuum chamber at ALBA. The BM radiation hits the wall laterally. Because of this a maximum power and peak power density calculated are 250 W and 0.17 W/mm^2, respectively. These thermal variables have been obtained according with the design parameters defined in Table 1.

For the water cooling 23 ºC is fixed as inlet temperature and the average velocity in the tubes (7 mm internal diameter) is kept in 2.2 m/s. For these conditions the calculated convective heat transfer coefficient is 10300 W/m^{2}K.

Table 1: 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

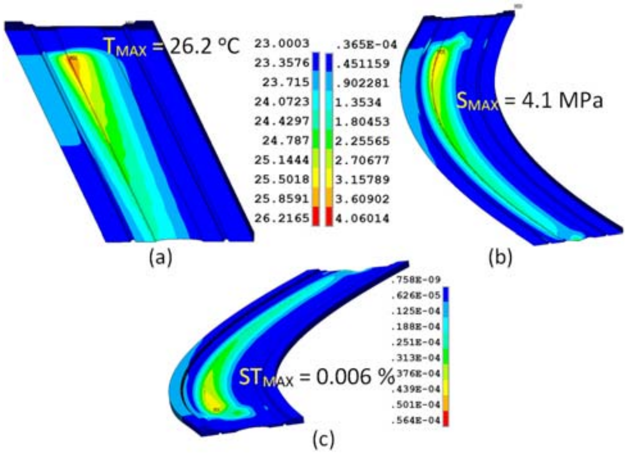

Figure 3: FEA results for the aluminium vacuum chamber for lateral collision of BM radiation. (a) Temperature map, (b) Stress map, and (c) Strain map.

FEA has been performed to estimate the maximum stress, strain and temperature on the chamber, in order to estimate the cycles that the chamber can withstand before failure. The results of this analysis are: the maximum stress is 4.1 MPa, the maximum strain is 0.006% and the maximum temperature is 26.2 °C; the results are within the design criteria of the vacuum aluminium components [1]. Figure 3 shows the FEA results for the chamber.

Collision on the Upper and Lower Walls

The thermal conditions because of the tails of BM radiation are calculated by using the Monte Carlo software SynRad+ [2]. For the thermal characterization the design parameters in Table 1 have been applied. With the aim to guarantee an asymptotic behaviour of the SynRad+ model, the beam trajectory on the dipole chamber has been discretized with steps of 0.01 cm and surfaces of 0.0004 cm^2 has been defined for the discretization of the walls of the chamber. In order to be conservative the effects of the reflections have been omitted for this study.

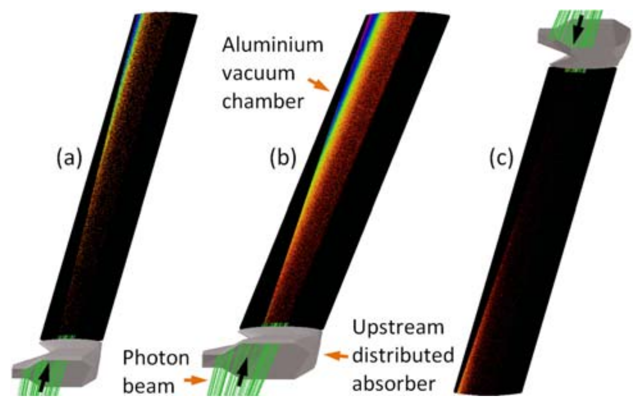

Figure 4: Footprint of the tails of BM radiation on the upper and lower walls of the aluminium vacuum chamber. (a) Nominal trajectory of the beam, (b) Radiation on the upper wall under vertical misalignment effect, and (c) Radiation on the lower wall under vertical misalignment effect.

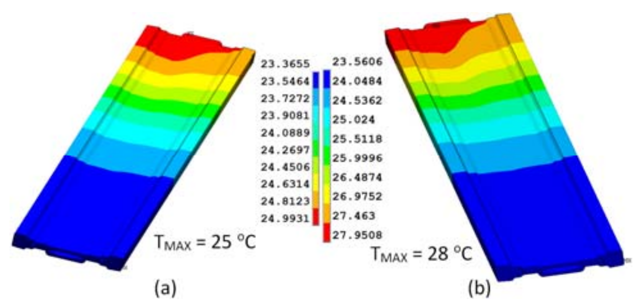

Figure 5: Thermal results for the aluminium vacuum chamber. The BM radiation is deposited on the upper and lower walls. (a) Temperature map for nominal trajectory of the beam. (b) Temperature map for trajectory of the beam under vertical misalignment effect.

The thermal behaviour for nominal trajectory and vertical misalignment of the beam has been studied. For nominal condition a maximum power and power density distribution are 2.34 W and 0.0006 W/mm^2, defined for each surface (the upper and lower walls). For the worst condition, the misalignment case, a vertical deviation of the beam of +1 mm has been imposed as a conservative criteria, then for the upper wall the thermal variables are 4.74 W and 0.0031 W/mm^2 while for the lower wall the parameters 1.6 W and 0.00019 W/mm^2 are calculated (See

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Fig. 4). For both cases air natural convection is applied as fluid boundary condition. The convective heat transfer coefficient is calculated for quiet air: 3 W/m^{2}K at 23ºC.

Figure 5 shows the thermal results. The maximum temperatures of 25 and 28 ºC are obtained for nominal and with misalignment effects, respectively. These thermal results are similar to the case for lateral collision. The studies of thermal stress and strain have been omitted considering that these cases are a better situation with respect to the results obtained for the case with lateral collision.

UPSTREAM DISTRIBUTED ABSORBER

Boundary Conditions

The OFHC upstream distributed absorber is subject to BM radiation coming from the upstream dipole. Based on the parameters of Table 1 the power deposited on the absorber is estimated using the SynRad+ computer code (See Fig. 6). The total power calculated is 596 W and the peak power density is 7.3 W/mm^2. The non–reflection condition has been established as conservative criteria for the surfaces. In order to guarantee an asymptotic behavior size elements of 0.0001 cm^2 are used for the discretization of the surfaces.

The absorber is cooled by water at 23 ºC inlet temperature. The velocity in the cooling channels is kept in 3 m/s and the calculated convective heat transfer coefficient is 13888 W/m^{2}K.

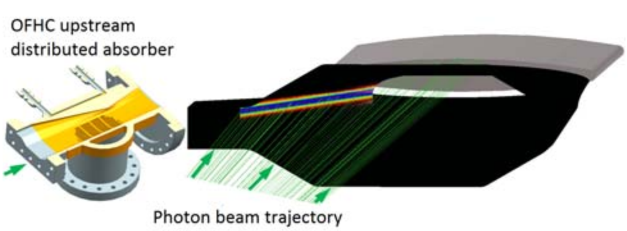

Figure 6: Representation of the surface power density distribution using the SynRad+ computer code.

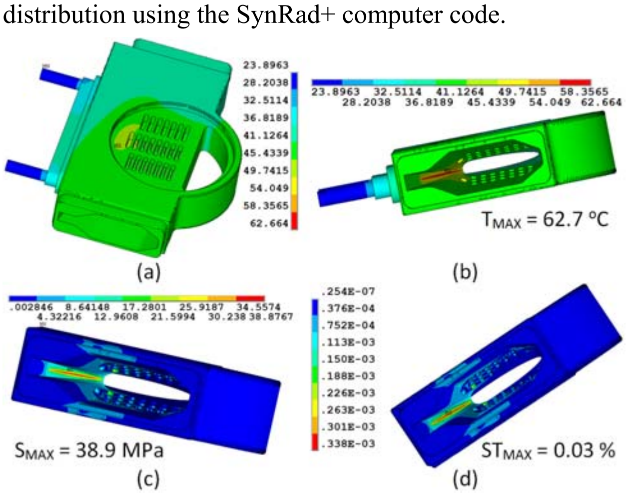

Figure 7: FEA results of the OFHC upstream distributed absorber: (a) and (b) Temperature map, (c) Stress map, and (d) Strain map.

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 [3]. The maximum temperature, stress and strain are 62.7 ºC, 38.9 MPa and 0.03%, respectively (See Fig. 7).

CONCLUSIONS

The narrow-gap, NEG-coated, extruded-aluminium vacuum chamber at LOREA has been simulated under different BM thermal load conditions.

When the BM radiation hits the lateral wall of the chamber, water cooling is needed to dissipate the power; this is the current scenario for the aluminium vacuum chambers installed at ALBA.

When the BM radiation hits only the upper and lower walls of the chamber, that is the power load is because of the tails of the Gaussian profile of the BM radiation, the power can be dissipated only by air natural convection; this is a particular situation for LOREA because the conventional OFHC upstream distributed absorber has been modified to protect the aluminium vacuum chamber completely from any lateral BM photon collision. The absorber has been modified following the new geometrical constraints defined in a new study of collective effects made at ALBA, which confirm the possibility to reduce the distance between the end sharp of the absorber and the electron beam trajectory, keeping the beam impedance of the machine inside of a safe range.

As is well-know, because of corrosion problems the water cooling circuit for aluminium components must be separated from the water cooling circuit for cooper components. Then the dissipation of the heat on the chamber by air free convection avoids the implementation of a particular cooling circuit for the aluminium chamber.

The simulation of the new OFHC upstream distributed absorber has been made and the thermal structural results obtained are inside of the design criteria.

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