

STUDY ON THERMAL MECHANICAL DESIGN AND OPTIMIZATION ANALYSIS FOR THE ALBA INFRARED MICROSCOPY BEAM-LINE (MIRAS) EXTRACTION MIRROR BASED ON FINITE ELEMENT ANALYSIS

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Abstract

This paper reports design, modelling, simulation and optimization results for the ALBA MIRAS infrared radiation extraction mirror. Finite element analysis (FEA) was used to simulate the thermal mechanical behaviour of the device. With the aim to ensure a good thermal performance, conservative assumptions were applied: all of the incident Bending Magnet (BM) radiation is absorbed at the mirror surface, constant bending magnetic field and low thermal contact between the mirror Al 6061 and the OFHC copper arm. A novel solution has been implemented in order to provide an effective cooling by a natural convection on the in-air part of extraction mirror assembly. This has voided the necessity for a water cooling that often causes problems due to the associated vibrations. The power conditions were calculated by using SynRad+. The main ALBA Storage Ring design parameters are: 3 GeV, 400 mA and 1.42 T. According to these conditions, the mirror absorbs 15 W with a peak power density of 0.51 W/mm². The peak temperature calculated was 63.2 °C. The real measurements reported during the commissioning stage showed a good thermal performance, in agreement with the results predicted by FEA.

BACKGROUND

MIRAS is one of phase II beamlines, currently under commissioning stage at the ALBA synchrotron light source. It will go into operation with official users in October 2016 and will be dedicated to Fourier Transform Infrared spectroscopy and microscopy [1].

The MIRAS engineering (conceptual design and production drawings), assembly and qualification metrology tests have been performed at ALBA. One of the key elements is the infrared extraction mirror that will collect the infrared radiation and reflect it back to the storage ring tunnel in order to be transported to the experimental hall.

The ALBA infrared extraction mirror is based on the slotted, non-cooled, type. The concept of the slotted mirror not only avoids interaction with the central high energy core of the dipole emissions, but also allows to realize a simple design that functions reliably without additional water cooling that often causes problems due to the associated vibrations [2, 3]. A novel solution has been implemented in order to provide an effective air cooling system

by natural convection on the in-air part of extraction mirror assembly.

THE ALBA INFRARED EXTRACTION MIRROR

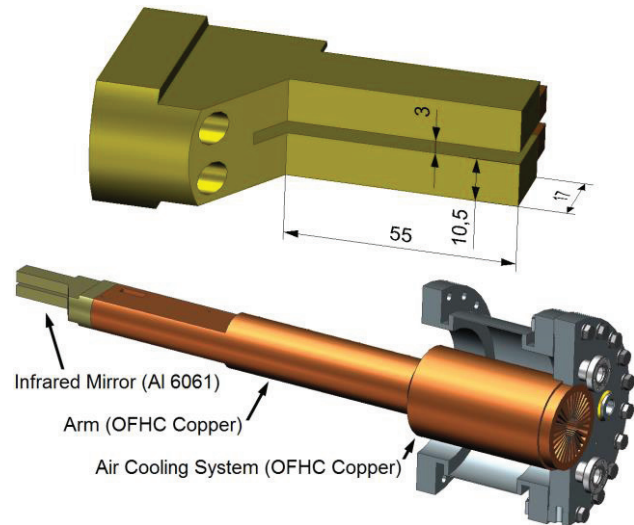


Figure 1: The ALBA infrared extraction mirror. Top: mirror Al 6061, dimensions in mm. Bottom: overall view of the device.

The main parts of the infrared extraction mirror are shown in Fig. 1: the mirror Al 6061, a copper arm and the cylindrical air cooling system made of copper.

The mirror is a rectangular bar 17x24x55 mm with the reflective face at an angle of 63.7° to the electron beam trajectory in the upstream vacuum chamber (see Fig. 2). A 3 mm slot in the mirror allows the high-energy radiation to pass through it. The much wider vertical divergence of the infrared radiation is collected on both sides above and below the slot and redirected towards the emission port. The mirror is attached to the copper arm using screws; indium foil is placed at the interface to improve the heat transfer to the copper arm.

The air cooling system consists of a cylinder made of copper, 65 mm internal diameter, 10 mm thickness and 131 mm long which is provided with 32 longitudinal, straight fins of 1 mm thick and 22.5 mm height. The copper cooling system is brazed into the stainless steel flange providing a perfect contact for the heat transfer.

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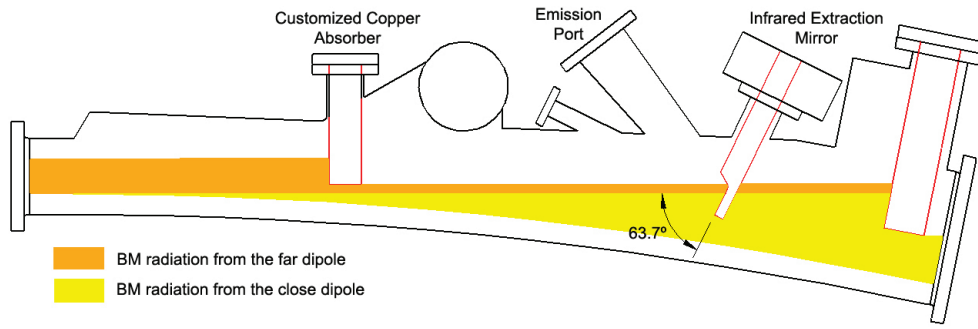


Figure 2: Ray tracing for MIRAS dipole chamber. The orange fan is the BM radiation coming from the far dipole chamber and the yellow zone is the radiation from the close dipole.

FEA STUDIES

Air Cooling Geometries

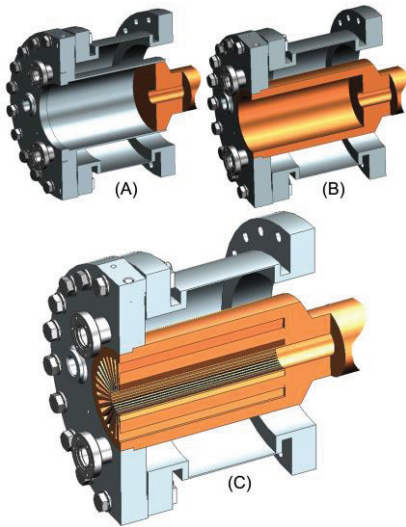


Figure 3: The three types of air cooling system: (A) Stainless steel cylinder, 2 mm wall thickness, (B) Copper cylinder, 10 mm wall thickness, and (C) Case B with internal fins attached.

Numerical simulations (FEA) were used to optimize the cooling performance of the infrared extraction mirror. In order to enhance the heat dissipation on the air cooling system, three geometries are studied:

- Case A: the original prototype, it consists of a simple cylinder made of stainless steel, 85 mm internal diameter, 2 mm thickness and 157.6 mm long.
- Case B: the optimized model after a first modification of case A, a cylinder made of copper, 65 mm internal diameter, 10 mm thickness and 131 mm long.
- Case C: the optimized model after adding rectangular copper fins to the cylinder of case B, as described in previous section.

Figure 3 shows the cross-sectional shapes of the infrared extraction mirror of the three cases mentioned before.

Boundary Conditions

The heat deposited on the mirror is transfer by conduction from the mirror to the copper arm across the indium foil interface. Next it goes by conduction up to the cylin-

der cooling system and finally it is transported by free convection to the environment.

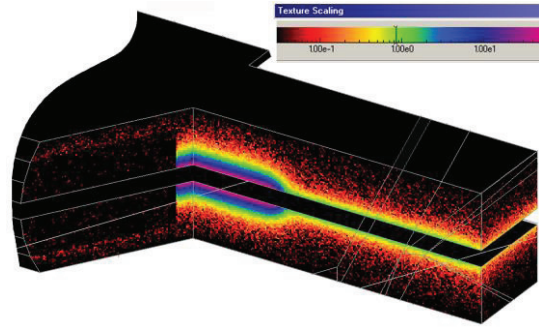


Figure 4: Surface power density distribution using the SynRad+ computer code. The units are in W/cm^2 .

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

The mirror is subject to BM radiation coming from the far and close dipoles. A big amount of heat from the far dipole is deposited on a customized absorber placed upstream the mirror (See Fig. 2). Under these conditions, considering the parameters of Table 1, the power deposited on the mirror is estimated using the SynRad+ computer code (See Fig. 4). The total power calculated is 15 W and the peak power density is $0.51 \text{ W}/\text{mm}^2$. The non-reflection condition has been established as conservative criteria for the mirror surface.

The conservative air convective heat transfer coefficient was chosen to be $5 \text{ W}/\text{m}^2\text{K}$ at 23°C (quiet air).

The thermal conductivities of Al 6061, OFHC copper and stainless steel are 167, 391 and $15 \text{ W}/\text{mK}$, respectively.

At the interface mirror – copper arm the thermal contact conductance of $2000 \text{ W}/\text{m}^2\text{K}$ is selected as conservative design criteria (dry contact).

Results

Comparing numerical results of air cooling geometries in Table 2, it can be seen that the case B exhibits a significant decrease in peak temperature compared to case A

(from 125.6 °C to 76.6 °C). For case C the peak temperature is reduced to 63.2 °C. It can be clearly concluded that geometries B and C improve the heat dissipation from the air cooling side. Among all cases, case C has been found the most appropriate geometry in terms of maximum heat dissipation.

For all cases the maximum normal deformation calculated for the mirror surfaces is below of 2 μ m.

Table 2: Peak Temperature (T_{MAX}) on the Mirror for the Three Types of Cooling Systems

Type	T_{MAX} (°C)
Case A	125.6
Case B	76.6
Case C	63.2

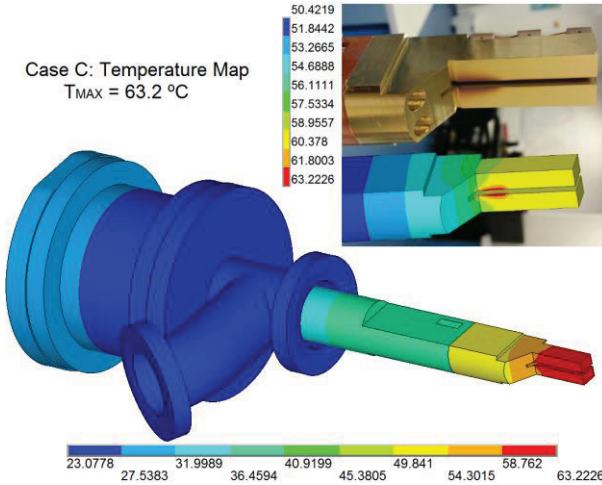


Figure 5: Temperature distribution for case C: isolated mirror with a real photo (top) and overall view of the extraction mirror (bottom).

Figure 5 depicts the calculated temperature map on the mirror for case C. The peak temperature reached is 63.2 °C. The top right shows the temperature distribution for the isolated mirror together with a real photo captured during the commissioning stage. The carbonized zone in the mirror matches the observed BM power deposition calculated by SynRad+ (Fig. 4). The bottom shows the temperature distribution for the complete infrared extraction mirror.

Effect of fin surface on the temperature This effect is studied by means of the variable F_A : ratio between the total fin surface and the case without fins (Fig. 6). Table 3 shows the results. The peak temperature for $F_A = 1$ (case B) was reduced by 17.5 percent when $F_A = 8.1$ (case C).

Table 3: Peak Temperatures (T_{MAX}) as a Function of F_A .

F_A	T_{MAX} (°C)
1.0	76.6
3.0	70.1
5.0	66.5
8.1	63.2

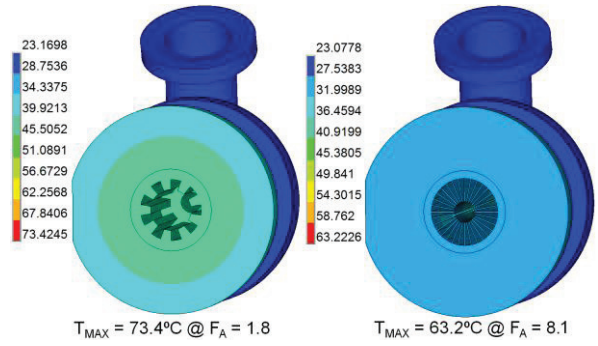


Figure 6: Temperature results for $F_A = 1.8$ and 8.1.

Effect of Thermal Contact Conductance (TCC) on the temperature TCC is one of the important parameters in the thermal design. It depends on various factors, for example surface roughness, the contact pressure and the hardness of the material. Therefore, quantitative evaluation is difficult, and a little information can be obtained for every case. In order to be conservative for FEA studies we used a coefficient of 2000 W/m²K. According to the literature we can expect $TCC > 10000$ W/m²C, in that condition the peak temperature in the mirror should be < 55.1 °C (see Table 4).

Table 4: Peak Temperatures (T_{MAX}) as a Function of TCC.

TCC (W/m ² K)	T_{MAX} (°C)
2000	63.2
5000	57.1
10000	55.1
1.0e5	53.2
1.0e6	53.0

CONCLUSIONS

During the commissioning run held in January 2016 temperatures in the mirror have been reported. Eight K-type thermocouples are installed on mirror. Two sensors are imbedded into the body and six sensors are mounted on the back side of the mirror (downstream) with the heads being exposed to the photon beam.

The local temperature measured in the body above the slot was 25.5 °C with 130 mA. The FEA model predicts $T < 32$ °C for $TCC > 10000$ W/m²K.

The measurements reported during the commissioning stage showed a good thermal performance of the mirror, and the results are in agreement with the conservative results predicted by FEA.

REFERENCES

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