MECHANICAL DESIGN OF MIRAS, INFRARED MICROSPECTROSCOPY BEAM LINE AT ALBA SYNCHROTRON

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Abstract

The infrared (IR) micro spectroscopy beam line MIRAS has been an in-house project fully developed at ALBA as a result of a collaboration of different teams during the period of 2014 when the design started to 2016 It is composed of a horizontally retractile mirror to extract the IR light from the bending magnet radiation and a system of 8 transport mirrors located by positioning systems designed for a high stability performance, to transport the extracted IR light outside the tunnel until the first End Station.

LAYOUT

The layout was defined by the scientific and the optical teams, in close collaboration with Dr. Paul Duma's team (SOLEIL, France) and Dr. Gary Ellis (IPT CSIC, Spain) , who contributed a lot during the design phase.

The extraction mirror M1 is located inside a bending magnet vacuum chamber. At the beginning of its bending radius, starts the optical layout: This is named the source point. M1 reflects the infrared fan of the synchrotron radiation of the bending magnet where M1 is located as well as a fraction of emission fan of the upstream bending magnet (in addition to the "edge radiation"). The infrared beam is transported through a layout of 4 transport mirrors with a toroidal mirror used to focus the beam at the focal point F1 just outside the tunnel wall. Subsequently, 3 additional mirrors direct the beam to the focal point F2 located inside the 1st End station. The beam line is prepared to be upgraded up to 3 End stations (See fig 1) as the beam splitter mirrors (MBSP1 and MBSP2) are retractile and allow part of the beam to pass through the other possible end stations (F3 and F4). At present, MIRAS is completed up to MBSP1 and F2 with 1st End station being operational.

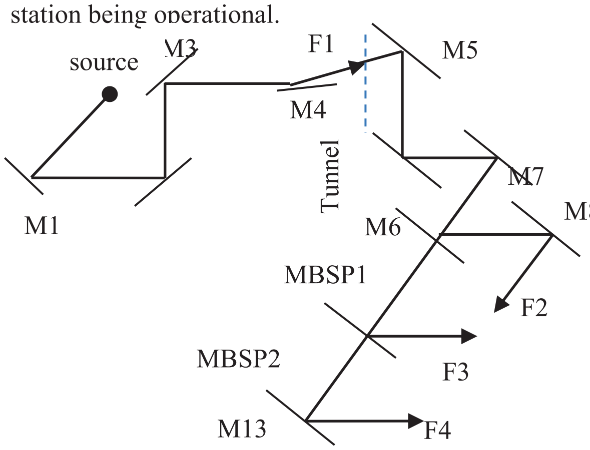


Figure 1: Schematic Layout of MIRAS.

SYSTEMS DESCRIPTION

Extraction Mirror M1

The slotted extraction mirror M1 is inserted inside the Dipole vacuum chamber in a certain angle, facing a portion of the synchrotron radiation coming from the last bending magnet, passing through a 3 mm slot (see fig 2a). In order to maximize the optical performance of the mirror the clearances with the inner face of the dipole chamber are very tight, 2 mm nominally with the inner wall and 1.8 mm with the slot end (see fig 2b).

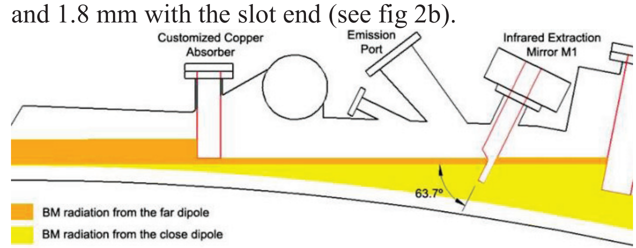


Figure 2a: Schematic of IR emissions collected by M1

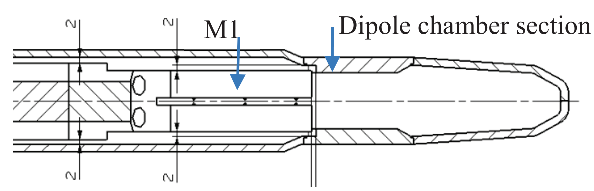


Figure 2b: M1 nominal clearance

The mirror has been manufactured from polished aluminium 6061, and optical surface is gold plated (un protected) (Figure 3).An array of 6 thermocouples is positioned on the back side of the mirror protruding by 0,5 mm into the slot space. With their reading, the vertical position of the extraction mirror in respect to the beam can be fine-tuned. Apart from those, another pair of thermocouples embedded into the non-reflective surface for temperature measurement of the body of M1

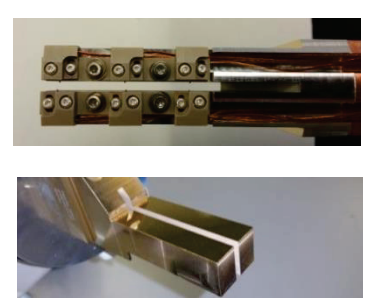


Figure 3: Top: back side of the mirror and portion of the cooper arm. Down: reflective surface.

The mirror is mounted on the extreme of a cooper arm which links the mirror body with its positioning system. The copper arm also acts as a cooler for the mirror and evacuating generated heat. For this reason it has been designed as a hollow cylinder on its air-side part, optimized with brazed ribs on the inner part (see Fig 4). It functions as a heat sink, cooling by natural convection and maintaining the temperature of the body of M1 around 63ºC, with no need for extra cooling system. The FEA analysis has been done considering the main ALBA Storage Ring design parameters: 3 GeV, 400 mA and 1.42 T, which means 15 W of power absorption. Other simulations were done for operation at 200 mA

A temperature of 25ºC was observed during the commissioning phase on the body of M1, (operating at 130mA current in Storage Ring). This corresponded to the previous simulation. More details can be found in a specific report [2] where those simulations are developed

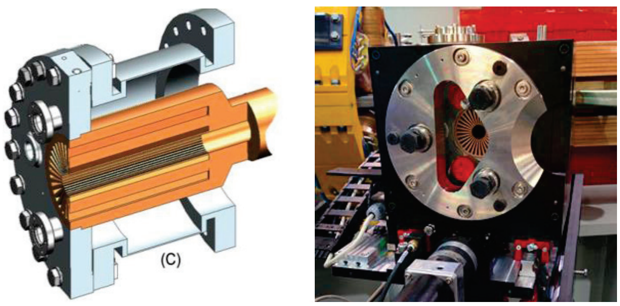


Figure 4: Left: section of the mirror cooper arm. Right: photo of the rear side of the cooper arm showing heatsink.

M1 needs to be retracted and inserted into the dipole chamber. Apart from that, the mirror has to be moved in certain small vertical range of +/- 1 mm in order to adjust it in respect to the electron beam inside the chamber. Both movements have to be motorized. The cooper arm is mounted on a mechanical system composed by a spindle actuator to position the linear horizontal movement, and wedge mount mechanism which will be used as a high resolution positioner, making stiff and stable mechanics.

A modal analysis has been performed in order to establish the Eigen modes on the mechanical assembly, where the maximum deformation of the M1 edge was estimated around 0.15 mm due to the self-weight, and first mode of vibration appears represented in (fig 5), which correspond to a roll at 58.5Hz

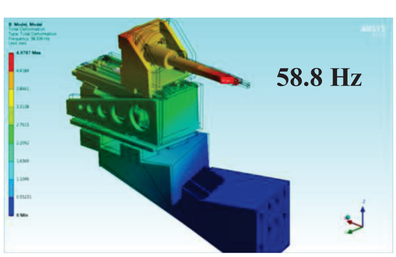


Figure 5: First mode of vibration.

All the assembly is mounted on a support fixed to the girder in order to link M1 to the same support as the bending magnet and the dipole chamber. Fig 6 shows the M1 mechanics assembly mounted on a spare girder mock-up which was used to make stability and performance tests before the final installation in the accelerator tunnel.

The tests showed that a good resolution can be guaranteed after 4 full steps of the motor. According to the displacement per step calculations it corresponds to 1.56µm/step. Accuracy of the real position of the mirror on the linear movement is 15 µm in respect to its theoretical given position in open loop. First significant mode is observed at 61 Hz, after hammer-shock on the girder. The significant results are shown on Fig 7

Figure 6: Top: Mechanics assembly mounted on mock-up girder. Down: Extraction mirror retracted mounted inside accelerator's tunnel.

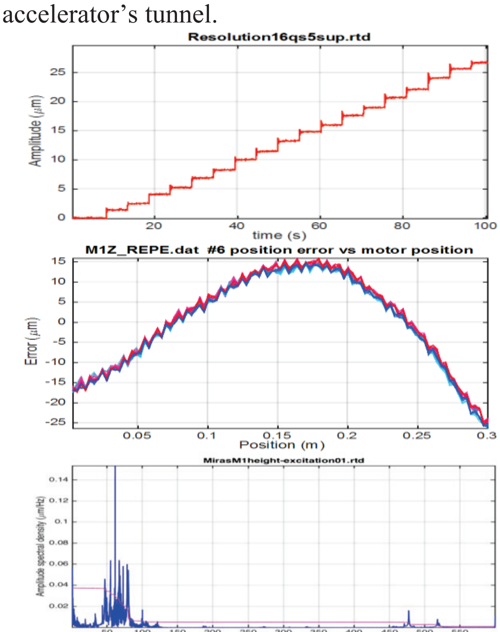


Figure 7: Performance results.

Transport Mirrors M2 to M8

MIRAS is constituted by an array of mirrors of different shapes that make the infrared beam to be focused in two focal points: F1 and F2 (see figure 1). To achieve this, all 8 mirrors are positioned in the space, and have to be adjusted for the pitch and roll according to the following specs (see table 1). The same positioning mechanism design is used for all of 8 mirrors.

Table 1: Specifications

Specification	mrad	deg
Range	± 9.07 mrad	± 0.5º
Resolution	15 μrad	$9 \cdot 10^{-4\,o}$
Accuracy	0.25 mrad	0.014º
Repeatability	32 μrad	$2 \cdot 10^{-4\,o}$

The transport mirror positioning mechanism has been designed as a 2 angle goniometer system, where both angular movements are guided by circular rails. See the scheme at fig 8. The movement on the rails are generated by motorized spindle actuators connected through an elastic articulation (flexure).

Mirror support has to be very rigid and light to have a high stability mechanical system. The mirror itself is inside a vacuum, and the angular movement is transmitted by a bellow.

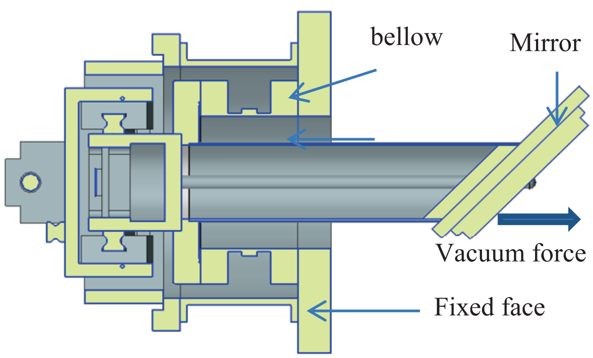


Figure 8: Conceptual design of the transport mirror system.

FEA calculations were performed in order to check the stability of the system and to optimize the shape of the flexure when moving the full range (see fig 9)

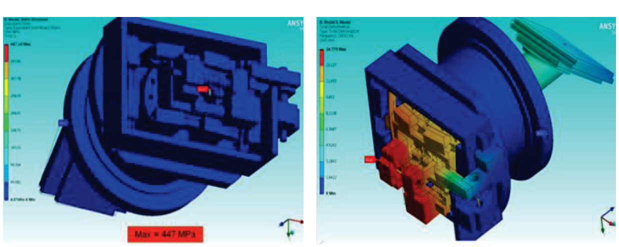


Fig9). FEA analysis

According to the FEA, the flexure of the actuator was loaded with 447 MPa when the mirror was at one extreme position (+/-1º). Flexures were manufactured using high modulus steel. The first Eigen mode is estimated at 135 Hz.

After mounting, one of the transport mirrors was tested to measure the pitch and roll resolution, accuracy and vibration behaviour. The results are presented on the following Fig. 10 and Fig. 11

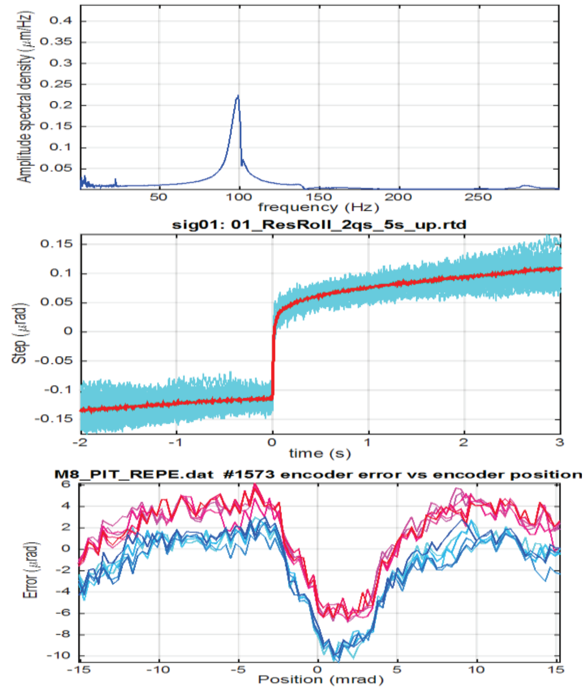


Figure 10: Top: Significant resonance peak. Middle and down: Measurements of the resolution and linearity of the movement in the open loop.

The lowest angular resolution has been measured for the pitch movement of 0.16 μrad for half step, with a window of 2 quarter steps for each 5 seconds. Repeatability with open loop was measured of 1.6 μrad. The worst accuracy error was 57.2 μrad measured in open loop for the pitch, but was significantly improved to 10 μrad with the use of the encoder in a closed loop. Peak resonance is at 98 Hz (see picture 10 above).

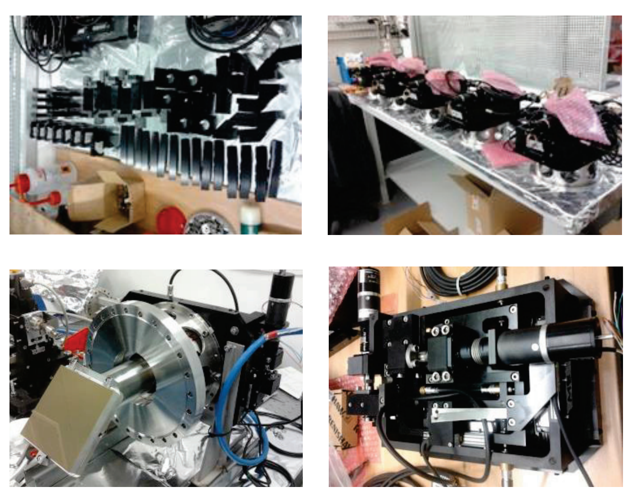


Figure 11: Top: series assembling in ALBA Workshop. Down: detail of the goniometer and mechanical test

BEAM LINE ARCHITECTURE

Supports and Other Subsystems

The transport mirrors are mounted in the vacuum chamber which is supported by a granite block and positioned in respect to the orbit of e-beam in storage ring. All the vacuum layout of up to the focal point F1 maintains 10^{-9} mbar which is common with storage ring vacuum. Just before F1 a brazed CVD diamond window separates the vacuum section of the front end inside the tunnel to the rest of the beam line at the experimental area.

Granite supports have been chosen as a main solution for the full beam line for the stability performance. The alternative of steel supports was evaluated and found complicated. All of them would be thin and high structures to be fitted inside the crowded tunnel area, between the girders and 2 other front ends and cooling pipes. A model of the beam line in tunnel area is presented at Fig 12 with the most significant parts.

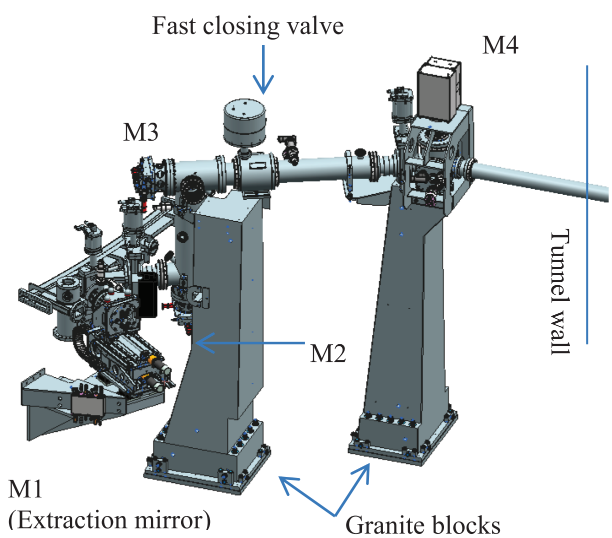
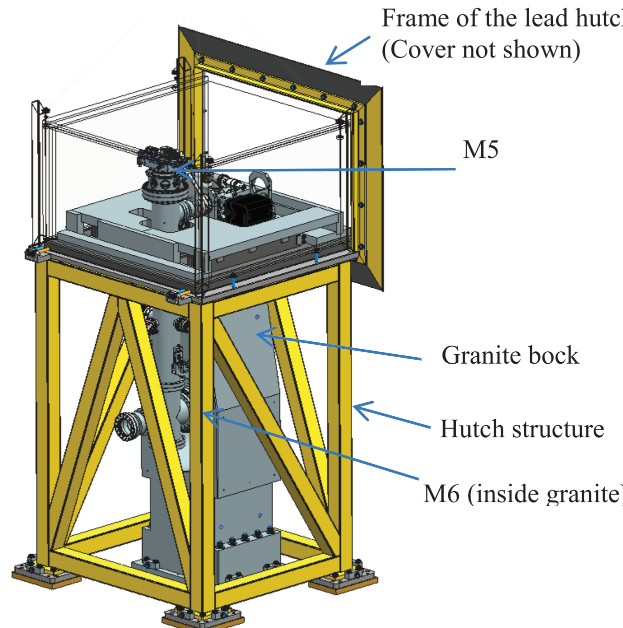


Figure 12: Model of MIRAS inside the tunnel. The significant components highlighted

Downstream the tunnel wall and the CVD window, the IR beam is transported up to the first end station. (See details in Fig 13). This area is a complete assembly with a defined vacuum section. A diagnostic setup consisting of a mirror and a camera are introduced after the focal point F1 to assess the shape and size of the infrared beam. Mirrors M5 and M6 are mounted on the same granite pedestal (see fig 13a). Top part containing M5, CVD window and diagnostics setup is located in front of tunnel wall penetration and are covered by a small lead hutch to protect the experimental area from possible radiation leaks. The tight architecture obliged to fit M6 inside the granite bock (Fig 13).



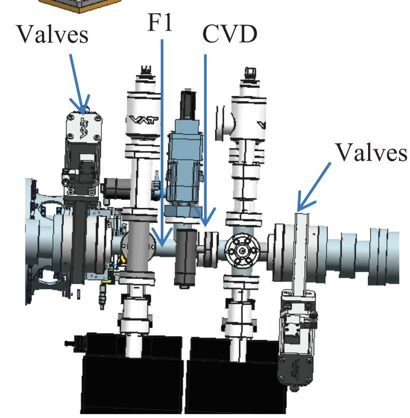


Figure 13: Top: M5, M6 support architecture. Down: Detail of the CVD vacuum section, top view

The beam is transported to the end station inside the experimental hutch by mirror M7. A flat mirror in its goniometric assembly is mounted on top of a linear translation mechanism (see Fig. 14) which intercepts the incoming IR beam (or a part of it) and deflects towards mirror M8 and to the micro spectroscopy End station. The other fraction of IR beam propagates towards 2nd and 3rd End station to be developed in the future (see Fig. 15).

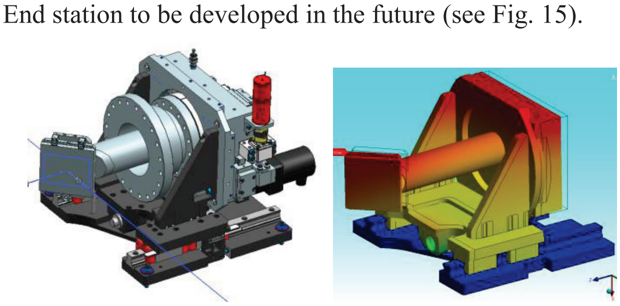


Figure 14: The beam splitter consists on a high resolution actuator that positions the transport mirror in a way that reflects only part of the IR beam.

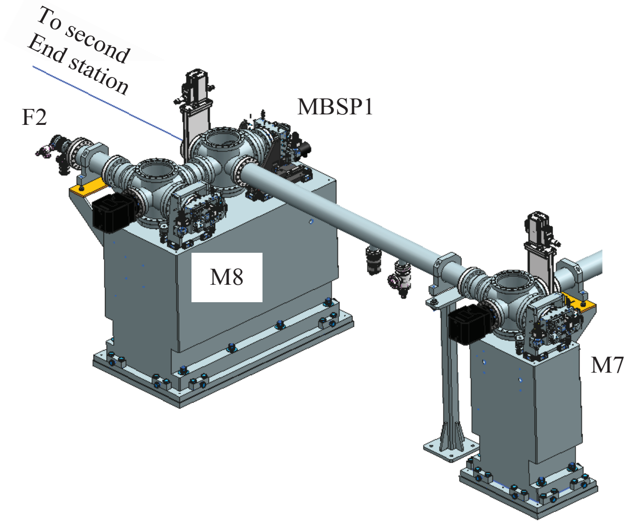


Figure 15: Focal point F2, MBSP1, M7 and M8.

VACUUM PRESSURE PROFILE

From the point of view of vacuum system design the operation of MIRAS requires a moderately high vacuum, except for beam extraction [3] section. In order to eliminate problems due to water vapour and carbon dioxide, pressures of about 100 mbar are sufficient. Vacuum calculation as a part of the comprehensive vacuum system design has been performed by Monte-Carlo simulation code using Molflow+ program, developed by R.Kersevan [4].

A simplified CAD model of the beam line vacuum chambers and transport mirrors were created based on fully developed 3D model. These models were exported to .stl format providing the geometry for simulations. The outgassing rate of materials varies by several orders of magnitude depending on the surface treatment and properties.

The transport mirrors and chambers of MIRAS are made of aluminium grade of 6061 and stainless steel grade of 304L respectively. Thus, thermal outgassing rates of above mentioned materials have been selected for simulations. We consider an outgassing rate for non-baked aluminium because we assume that the heat will be poorly transferred to the mirrors from the chamber walls during the bake out cycle and the mirrors will not be well-baked.

The outgassing rate used for aluminium is $1x10^{-10}$ mbar •l/s•cm^2, while for the stainless steel- $2x10^{-12}$ mbar •l/s•cm^2.The main gas source in the beam line is the thermal desorption which is distributed all over the system. Several simulations have been performed for the residual gases considering highest desorption rate and taking into account the molar masses as well as, pumping speeds of each corresponding gas type. Finally calculated partial pressures of each individual gas were summed.

Figure 15 shows simulation results considering 25 l/s pumps throughout the layout except for the first pump after the diamond window (45 L/s). The optimal pumping speed of 25 L/s was selected .The pumps were defined taking into account the lifetime during the operation and the achievable vacuum level for the beam line. Ion pumps were selected for the ease of maintenance and pressure below 10^{-6}mbar targeted for the pump's lifetime extension.

Comparing the gauge readings with the simulation result which is shown in the Figure 16 (red dots), we can estimate the reasonable agreement of real gauge measurements against simulation result.

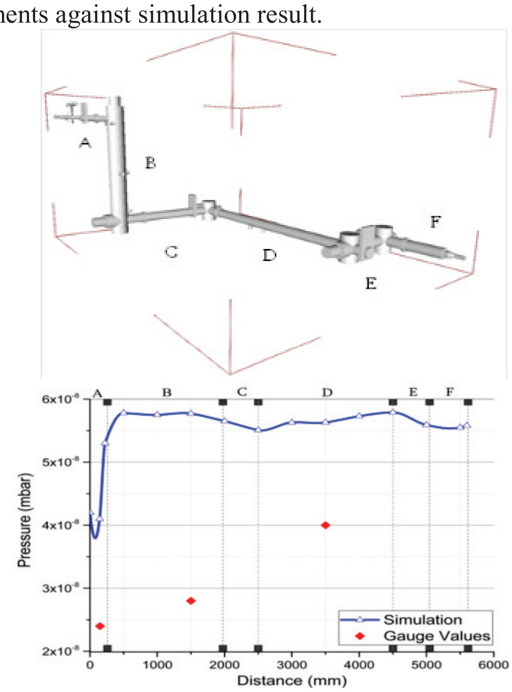


Figure 16: Pressure profile distribution along the beam path.

COMISSIONING

After the first commissioning of M1 at 130 mA, temperature readings on the thermocouples along the slot did not exceed was 32ºC and 25ºC on the mirror's body respectively. This value agrees well with one produced by the simulation at 130mA, where the maximum temperature of the body of the mirror will not exceed 34ºC.

Figure 17 shows the camera image of M1 during operation where the visible light fraction of the radiation emission can be observed illuminating edges of the slot. The thermocouples protruding into the slot can be appreciated.

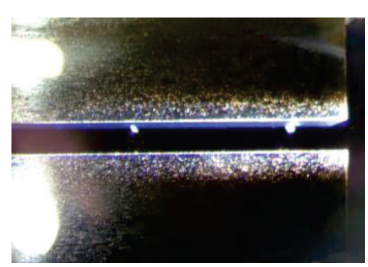


Figure 17: IR beam on M1 surface.

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[3] Antonio Carballedo, Marcos Quispe, Carles Colldelram, Llibert Ribó, Alejandro Crisol.Vacuum and Optical Design of the ALBA Infrared Beam Line MIRAS. Proceedings of the MEDSI 2014 Conference, Melbourne, Australia – October 2014.

[4] http://test-molflow.web.cern.ch/