Surface requirements for ultra-low loss cavity

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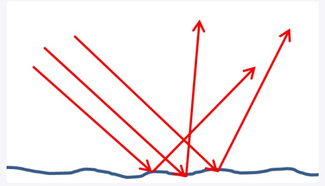
Motivation

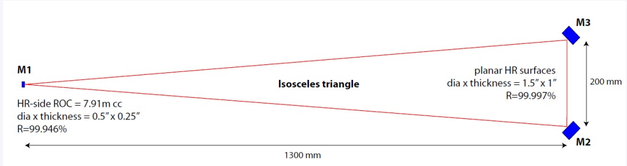
Mirror flatness is one of the most important sources of round trip loss of a cavity. Since the mirror is not perfect, due to manufacturing imperfections, when the beam hits the mirror surface it will be scattered and part of the incident light will never reach the other mirror of the cavity. So it is very important to consider this loss when we want to estimate the behavior of a cavity.

In our analysis we will consider a triangular cavity 1.5m long and with test masses that have the following features:

- ITM: 1cm diameter, 7.91 radius of curvature, transmissivity 700ppm, angle of incidence 4.4°;
- ETMs: 5cm diameter, flat, transmissivity 2ppm, angle of incidence 42.8°.

The round trip loss for this cavity was estimated to be about 25ppm.



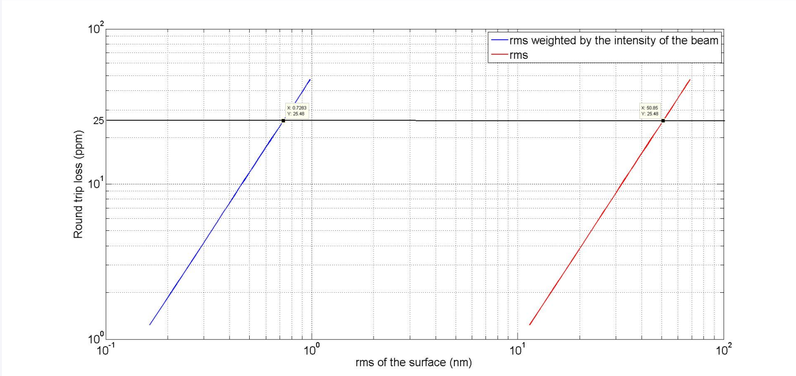


Simulation of requirements

Simulations were made with OSCAR (*Optical Simulation Containing Ansys Results*), a Matlab code that uses the FFT to simulate cavities with arbitrary mirror profiles. Through this code we are able to estimate the round trip loss of a cavity, which is obtained using the equation:

$$\mathbf{RTL} = \frac{\mathbf{P_{in}} - \mathbf{P_r} - \mathbf{P_t}}{\mathbf{P_{circ}}}$$

where $\mathbf{P_{in}}$ is the input power, $\mathbf{P_r}$ is the reflected power, $\mathbf{P_t}$ is the transmitted power and $\mathbf{P_{circ}}$ is the circulating power.



In order to find a threshold value of the mirror flatness that we can effort, we did a simulation of the cavity after having added a map to the ITM.

First of all a simulated map was added to ITM and, changing the scale of this map, we are able to see how the round trip loss increases when the flatness of the mirror surface decreases. We did it considering the simple rms of the mirror surface and the rms wighted by the beam intensity.

This plot shows the maximum surface distortion of a mirror that we can effort in order to have a cavity with a loss comparable to the estimated value.

As we can see the minimum flatness required to have a round trip loss below 25ppm is 50nm.

Characterization of mirror flatness

Using a flat mirror with a diameter of 50mm and a trasmittivity of 1000ppm, the measurements of the mirror surface flatness were made with Zygo. Zygo is a high precision metrology instrument able to measure surface imperfections of optical component.

The mirror was in the set up for about 30 hours and different measurements were made during this period.

The analysis of these maps was made with SimTools, in order to check the reproducibility of the measurements.

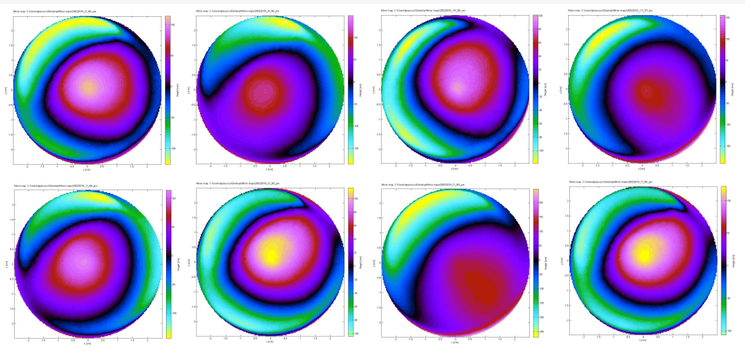


Figure: Surface profiles of the mirror maps measured with Zygo.

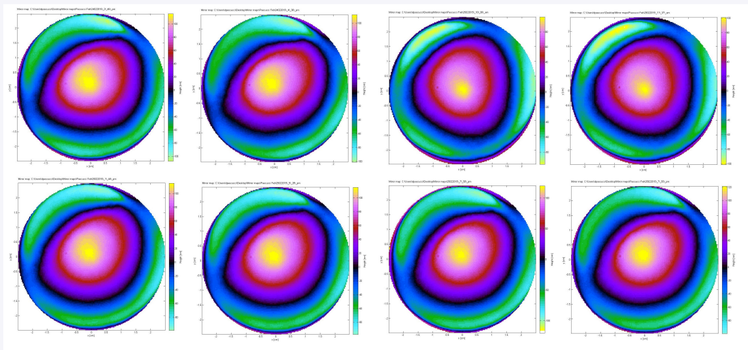


Figure: Surface profiles of the mirror maps measured with Zygo after having removed offset and piston.

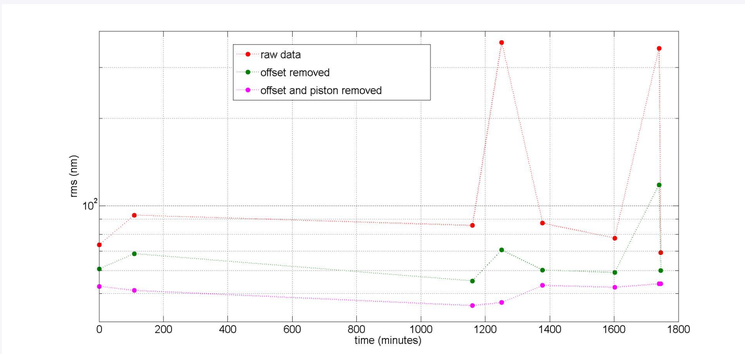


Figure: Flatness of the mirror surface.

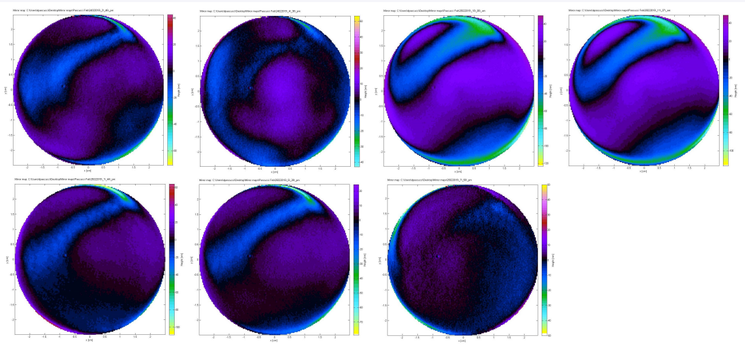


Figure: Differences between the mirror maps and the last map measured.

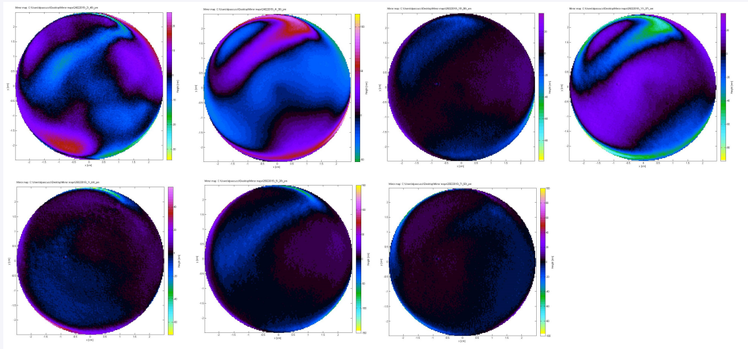


Figure: Differences between two consecutive maps.

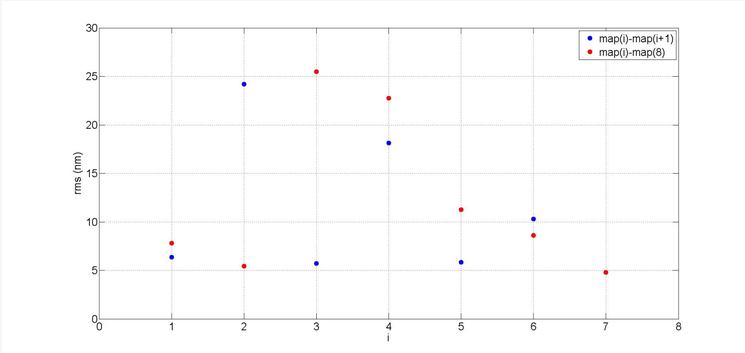


Figure: Flatness of the surface obtained with the difference between two maps.

Through these analyses is possible to understand how the measurement of the flatness of the mirror changes from one measurement to another. At the end we found that the differences between the measurements are all below 25.5 nm rms.

References

1. www.speed-meter.eu
2. http://uk.mathworks.com/matlabcentral/fileexchange/20607-oscar
3. http://www.gwoptics.org/simtools/