Coping with Point Absorbers in Advanced Virgo

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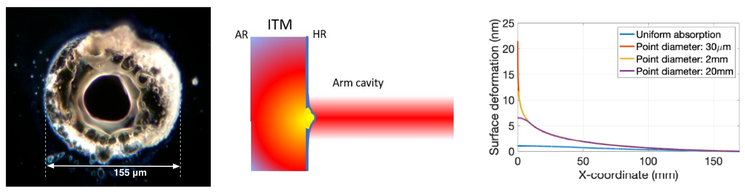
The observation of highly absorbing areas on the surfaces of Advanced Virgo main optics during the O3 observing run, leads the beginning of a big challenge in the field of the ground-based interferometers (ITF). These anomalous micron-scale absorbers produce distortions as additional thermo-elastic deformation of the high reflectivity (HR) mirrors surfaces and thermal lensing in the optics substrates. Their mitigation has a central role in the improvement of the ITF performances and a detailed and quantitative study of their characteristics are required. The information about their position and fraction of absorbed power allows to put the basis for the development of an adaptive actuator, able to correct these aberrations in the Advanced Virgo Plus (AdV+) test masses (TM).

Point Absorber characteristics

What are Point Absorbers?

Characteristic:

- Localized small
- Highly absorbing (HR surface)
- Embedded in the coating
- Can not be cleaned
- Composition of high concentration of Aluminium

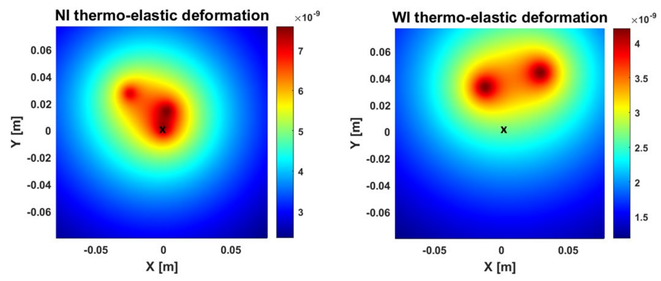


Left image: Dark field microscope image of point absorber measured on Advanced LIGO optics. Center image: Sketch of a Point Absorber. Right image: Cross-section of modeled surface deformation due to uniform absorption and point absorbers of different diameters. [1]

Effects on the ITF:

- Scattering into HOM and increase of RTL
- Limits ITF sensitivity

Point Absorbers in Advanced Virgo

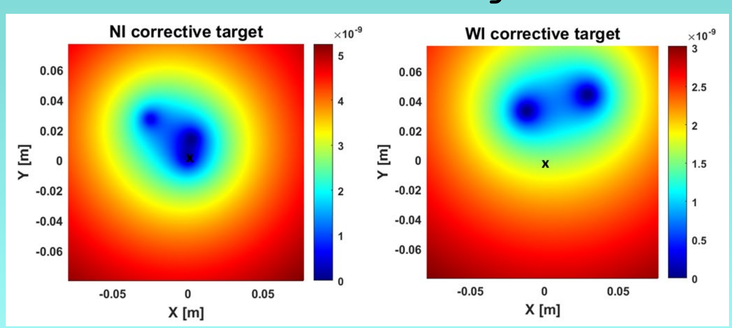


Left image: Thermo-elastic deformation due to the Point Absorber on the NI. Right image: Thermo-elastic deformation on the WI. Black crosses represent the mirror center.

Point	TE deformation [m]
NI	
1	4.0033e-9
2	3.4545e-9
3	3.7778e-9
WI	
1	3.3422e-9
2	2.9070e-9

Point Absorber mitigation

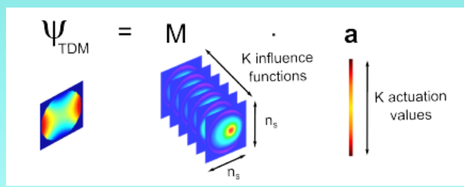
Corrective target



Left image: NI corrective map evaluated from the thermo-elastic deformation. Right image: WI corrective map evaluated from the thermo-elastic deformation. Black crosses represent the mirror center.

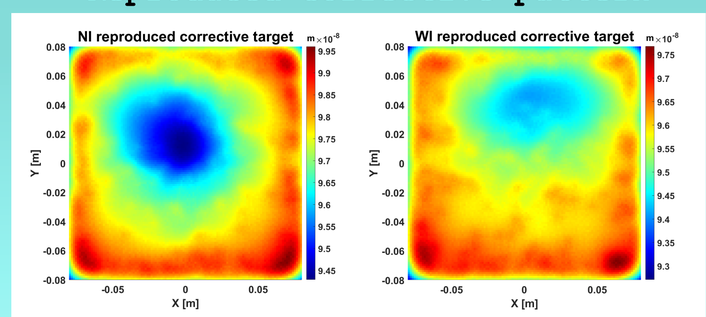
Influence matrix formalism

A matrix of actuators is a suitable solution to reproduce the desired target; the actuation coefficients have been evaluated using the **influence matrix formalism** [2].



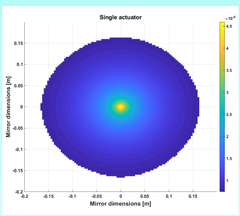
GENERAL IDEA:
Single heating element with a binary mask

Reproduced corrective pattern



Left image: NI corrective target reproduced by a matrix of 40x40 actuators uniformly illuminated. Right image: WI corrective target reproduced by a matrix of 40x40 actuators uniformly illuminated [3].

Step I:
Simulate the effect of a single actuator in the center of the mirror
→ **INFLUENCE FUNCTION** $I_i(x,y)$



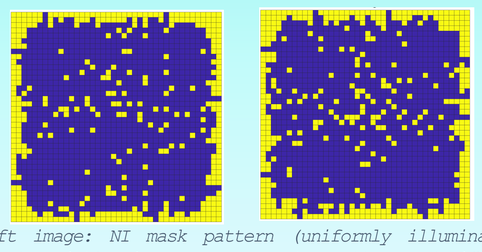
Influence function of a single actuator in the center of the mirror

Step II:
Build the influence matrix $\boldsymbol{M}$

$$\psi = M \cdot \vec{a} = \sum_{i=1}^{N} I_i(x,y)\, a_i$$
$$\vec{a} = (a_1, \dots, a_i, \dots, a_N)$$
$$\min \| M \cdot \vec{a} - T \|_2^2$$

Actuation coefficients allowed: 0 or 1

Step III:
Recover the actuation vector $\vec{a}$



Left image: NI mask pattern (uniformly illumination case) Right image: WI mask pattern (uniformly illumination case)

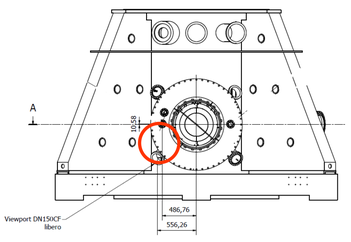
Actuation value: 0

Actuation value: 1

Point Absorber actuator

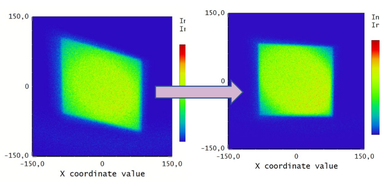
Actuator requirements

The actuator will be installed on both input and end towers. To guarantee a better adaptivity, it will be placed out of the vacuum system, and it will face the HR mirror surface through a ZnSe viewport.

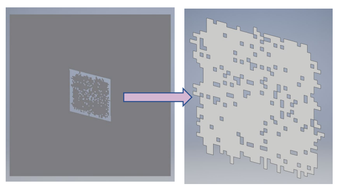


Sketch of the tower external part. In the red circle, the selected viewport

Viewport faces the mirror with 2 AOI
→ To have a squared shape a romboidal mask is required

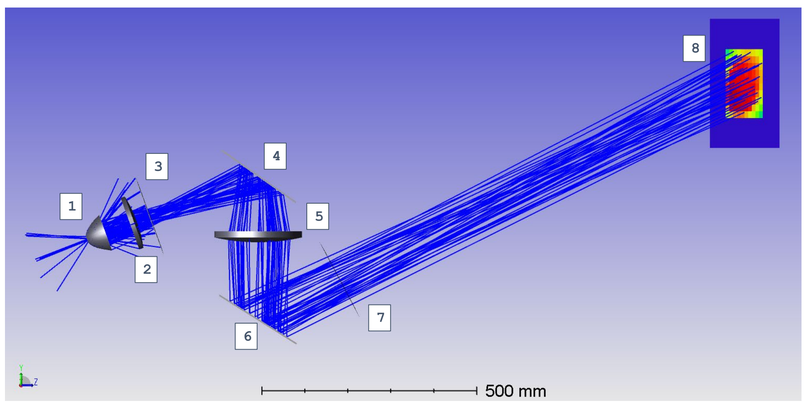


Left image: Representation of a squared mask on the TM Right image: Representation of a romboidal mask on the TM [4-5]



Left image: executive design of the mask Right image: detail of the NI mask

Optical layout



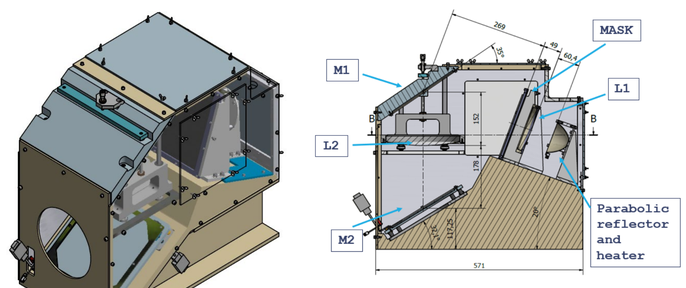
Picture of the entire optical layout

Components:

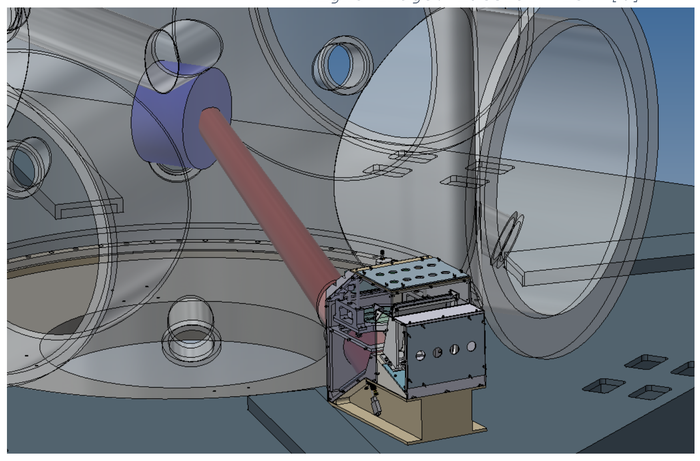
1: Parabolic reflector and ceramic heater
2: Lens (L1) → focus the power on the mask
3: Binary mask
4-6: Steering mirrors
5: Lens (L2) → magnification on the TM
7: ZnSe viewport
8: Test Mass

Closed loop picomotors have been added for the alignment procedures and the remote control

Executive design



Left and bottom images: executive design of actuator (3D view) Right image: Lateral view [6]



Conclusions and future plans

The actuator will mitigate the effects of Point Absorbers on the ITF performances.

- Point Absorber analysis is an open task in the AdV+ project → further studies on mirror maps will allow to set more precise constraints for their mitigation
- The optimization on the mask design is ongoing to improve the quality of the correction and the system efficiency
- The executive design is completed
- The components procurement is ongoing: the first tests will start in the next weeks
- The entire setup will be tested and validated during summer 2022 → the installation is scheduled in the same period before the start of O4 observing run

References

[1] A. Brooks, G. Vajente et al., *Point absorbers in Advanced LIGO*, 10.1364/AO.419689, (2021).
[2] Allocca A., Thermal projection system for surface figure correction of core optics in Gravitational Waves interferometers, Ph.D. thesis, Siena (Italy), (2012).
[3] Cifaldi M. on behalf of TCS teams, VIR-0828A-21, Virgo internal notes, (2021).
[4] Cifaldi M. on behalf of TCS teams, VIR-1253A-21, Virgo internal notes, (2021).
[5] Cifaldi M., Fafone V., Nardecchia I., Rocchi A., *TCS: Technical Design Report for Point Absorbers Mitigation System*, VIR-1332C-21, Virgo activity report, (2022).
[6] Cifaldi M., Fafone V., Nardecchia I., Rocchi A., VIR-0377A-22, Virgo internal notes, (2022).

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