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Thermal compensation system for the gravitational wave interferometer Advanced Virgo

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Summary. — In Advanced Virgo, the absorption of a small fraction of the YAG laser power will induce two thermal effects: optical path length distortion in the mirror substrate and thermoeleastic deformation of the mirror high-reflectivity surface. These effects can limit the interferometer operation and sensitivity. In order to reduce them, a thermal compensation system must be implemented. The Advanced Virgo system closely follows from that already installed and operating in Virgo. The new system must compensate thermal effects at a level compatible with the Advanced Virgo sensitivity and take into account the need to act on all the Fabry-Perot cavities optics and to monitor their thermal behaviour.

PACS 04.80.Nn – Gravitational wave detectors and experiments.
PACS 95.55.Ym – Gravitational radiation detectors; mass spectrometers; and other instrumentation and techniques.
PACS 78.20.N- – Thermo-optic effects.

1. – Introduction

Thermal lensing due to the absorption of the laser beam in core optics of gravitational wave interferometers can represent a strong limitation to their operation and sensitivity. This effect has already been observed in the present detectors [1, 2] and will become more relevant in the future upgraded interferometers, due to the much higher circulating power. A thermal compensation system (TCS), based on a CO_2 laser projector, has been installed in Virgo, allowing to increase the interferometer input power. TCS is able to reduce thermal effects in the FP cavity input mirrors due to the absorption of a few ppm of the YAG laser on the input mirror coatings. The result of this assorption is a decrease of the matching between the carrier and the sidebands in the power recycling cavity that prevents the lock acquisition at high input powers. As a consequence, shot noise, affecting the high-frequency part of the sensitivity, cannot be reduced. In the

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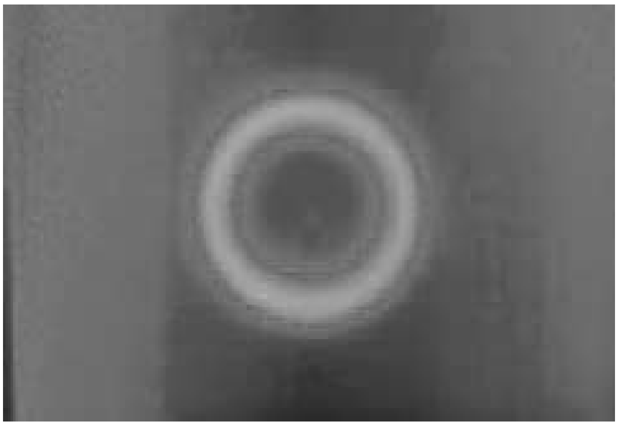

Fig. 1. – The annular heating profile due to the AXICON recorded with a thermal camera.

following, we briefly describe the Virgo thermal compensation system, its main results and the most relevant improvements of the TCS for Advanced Virgo.

2. – Virgo Thermal Compensation System

The Thermal Compensation System uses a CO_2 annular beam that heats the peripheral of the input test masses (ITM) in order to flatten the optical path length inside the mirror substrate. Next to each input tower, a CO_2 laser projector is installed. It makes use of an AXICON lense to convert the laser Gaussian beam into an annular beam (fig. 1); this shape creates a negative thermal lens that compensates the effect of the main beam.

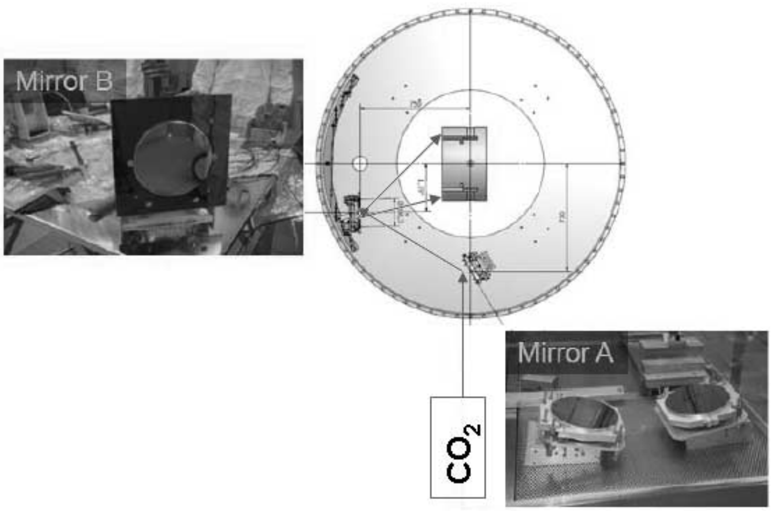

Fig. 2. – The picture shows the position of the two in-vacuum mirrors with respect to the reference mass. The CO_2 beam is entering the tower from the bottom of the picture.

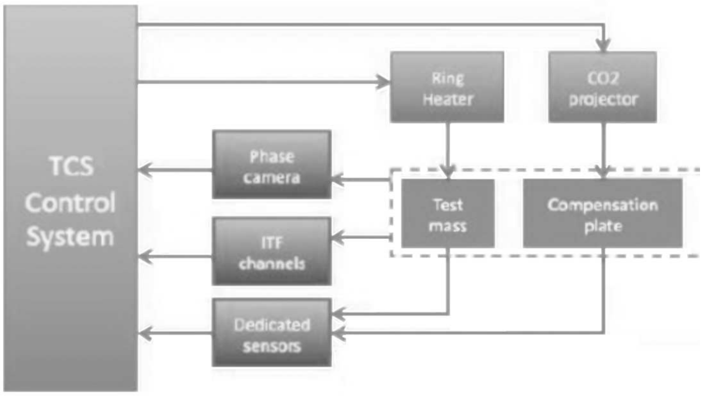

Fig. 3. – Layout of the Advanced Virgo TCS actuation and sensing scheme.

Since no viewport facing the ITM is available, the TCS beam enters the input tower from a lateral window and two in-vacuum optics steer it onto the ITM high-reflectivity face (fig. 2). One of the two in-vacuum mirrors can be remotely actuated, to allow the precise alignment of the heating pattern. TCS can introduce displacement noise by means of several mechanisms. To make the TCS noise compliant with the Virgo sensitivity, the CO_2 intensity fluctuations have been reduced by means of an active control loop [3, 4] and the first results show a reduction of the noise by a factor of 10. The thermal effects in the input mirrors were compensated totally, as if the interferometer were operated at low power.

3. – Virgo Thermal Compensation System performance

A phase camera was installed as diagnostic tool [5]. In this system, one of the optical beams coming out of the interferometer is scanned over a pinhole detector. Using a complex demodulation scheme, the optical phase and amplitude can be obtained for the carrier and both modulation sidebands individually. From these signals, phase and amplitude images can be reconstructed by a software. The camera was used extensively for the fine alignment of the TCS, for the characterization of the mirror absorption and for determining the thermal lensing of the input test masses as a function of TCS power. Experiments were carried out to increase the TCS power to such an extent that the thermal effects in the input test masses are compensated totally, as if the interferometer were operated at low power. This cold state could be confirmed by a higher optical gain, a more ideal transfer function of the fast frequency stabilization loop and by the images of the phase camera.

4. – Advanced Virgo Thermal Compensation System

In Advanced Virgo, beside the thermal lensing, another thermal effect will be relevant due to the high circulating power in the FP cavities (800 kW instead of about 20 kW as in Virgo). The temperature gradient in the mirror substrate will also change the profile of the high-reflective surface, due to thermal expansion (thermoelastic deformation), in both ITMs and ETMs, affecting the FP cavity. TCS needs to compensate for both effects.

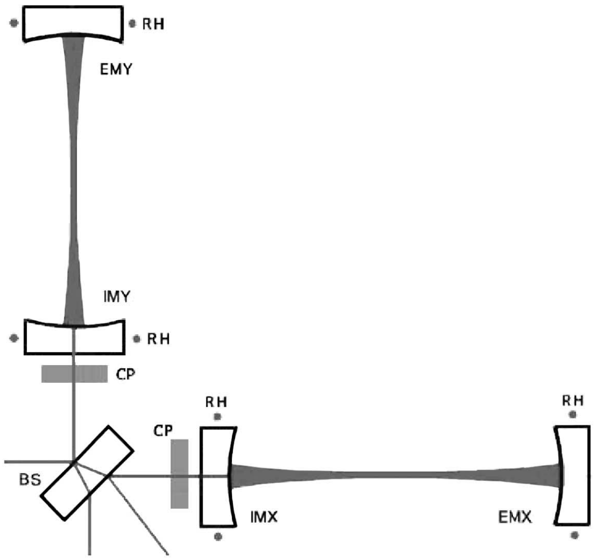

Fig. 4. – Proposed layout of the Advanced Virgo TCS actuators.

The solution proposed for Advanced Virgo is derived from the TCS scheme adopted in Virgo with the following main differences:

– the addition of a transmissive optic placed in the RCs, on which to act with the CO_2 laser. This makes the level of the noise coupling of the CO_2 laser compliant with the AdV sensitivity requirements;

– a ring heater, placed around each TM, to control the radius of curvature;

– dedicated sensors to measure the wavefront distortions and the thermo-elastic deformation of the HR face directly from the optics themselves (fig. 3).

The actuation scheme to be implemented in AdV, using both CO_2 lasers and ring heaters, is shown in fig. 4.

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