LASER INTERFEROMETER GRAVITATIONAL WAVE OBSERVATORY
- LIGO -
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Technical Note **LIGO-Txxxxxxx–v2** 2019/08/13

Reducing optical losses using actively-tunable adaptive optics

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1 Introduction

The Laser Interferometer Gravitational-Wave Observatory (LIGO) is a global collaboration of scientists working on the detection of gravitational waves [1]. When a gravitational wave passes through spacetime it stretches it in one direction and compresses it in the other [2]. LIGO uses interferometers to detect the path change in the x and y directions produced by a gravitational wave [3].

LIGO's setup is similar to a Michelson interferometer. It includes two 4 km long Fabry-Perrot cavities and a recycling mirror (Figure 1). The cavities are created by adding a mirror near the beam-splitter that reflects light back to the farther mirror, increasing the effective path length of light to 1120 km [3]. To improve the resolution of the interferometer, a partly reflective mirror is added between the laser and the beam splitter, increasing the power from 200 W to 750 kW [3]. The mirrors of the interferometer are suspended, thereby acting as free-falling masses.

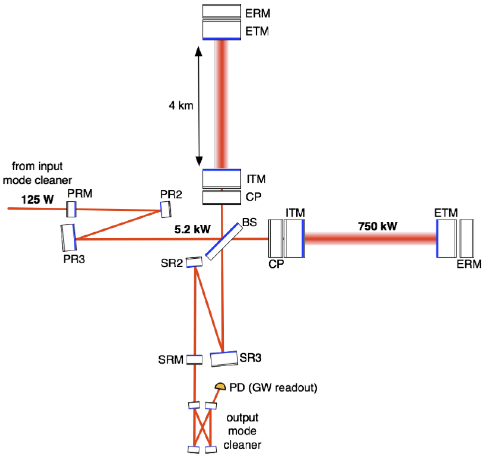

Figure 1: A scheme of LIGO's L-shaped interferometer with two 4 km Fabry-Perrot cavities and recycling cavities. See [4] for a more detailed description of the image

Due to the weak signals of gravitational waves and the interferometer's high sensitivity, different sources of noise affect measurements: seismic noise (below 2 Hz), thermal noise by dissipation in the suspension chain (2 Hz - 50 Hz), thermal noise generated by dissipation in the mirrors (50 Hz - 100 Hz), and quantum noise (above 100 Hz) [5]. This experiment will focus on decreasing the effects of thermal noise produced by dissipation in the mirrors of the interferometer.

Due to non-uniform absorption of the incident laser beam, little bumps called point-absorbers form on the surface of LIGO mirrors (see Figure 2) [6]. Consequently, a small portion of the reflected beam is scattered into high order modes (HOM's) reducing the cavity gain [6]. Although these bumps are only about 3 nm, they significantly limit the laser power inside the cavity affecting the quantum noise of the interferometer.

This experiment uses an adaptive optics technique called the central heating residual aberration correction (CHRAC) to actuate the non-uniform heating of the mirrors. CHRAC locally deforms the mirror by projecting a heat pattern to the mirror's surface [7]. Some

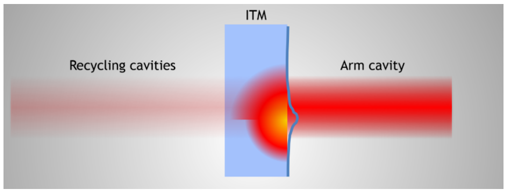

Figure 2: Non-uniform surface distortion of the mirror's surface (figure adapted from [6])

applications of the technique are: projecting radiation from a heater array to the mirror using an in-vacuum ZnSe lens [7], running current through a nicrome wire wrapped around the test masses' barrels [8], and producing a spatially tunable heat distribution using a CO_2 laser projector [8]. The goal of this experiment is to focus a source of radiant heat to a point on the mirror (1 cm^2) from a certain distance (1-10 m) using a spherical reflector.

2 Objectives

The primary focus of this project is to design a new actuating system that projects a circular heating pattern on the test mass. The system consists of a ring heater [4] and a spherical reflector wrapped around it. Due to spherical aberrations and the size of the heat source, there might be difficulties with focusing the heat to a ring of 1 cm thickness. Hence, our goal is to find the right geometry needed to reach that level of precision.

3 Approach

In order to test many different reflector shapes and source sizes, a finite-element analysis software called COMSOL was used. Using the ray-tracing package coupled to the thermal physics modules, we were able to simulate the heat pattern projected onto the mirror.

The previously proposed model used horns and elliptical reflectors, nevertheless due to the difficulty in obtaining accurate elliptical and parabolic shapes in the lab, a spherical reflector was chosen.

Initially, there were some problems with focusing the heat to a certain point due to spherical aberration, however the latest tested geometry produced a heat pattern in the form of a ring of approximately 2 cm thickness (see Figure 3). This was a 2D axisymmetric design simulating a point source of 100W combined with a reflector being a small section of a circle rotated around the z-axis. The reflector was coated with gold due to its lower emissivity in the infrared region than other shiny metals [9, 10]. To improve the accuracy of the simulation, 100,000 rays and an extremely fine mesh were used. The temperature difference between the heated ring pattern and the rest of the surface is roughly 20K, which is satisfactory for this experiment.

The next step is to simulate a ring heater as a source. Due to the different source points on the surface of a ring, there will be more divergence of the heat generated resulting in more heat loss, nonetheless the model is promising in its practicality. Figure 4 shows the radial

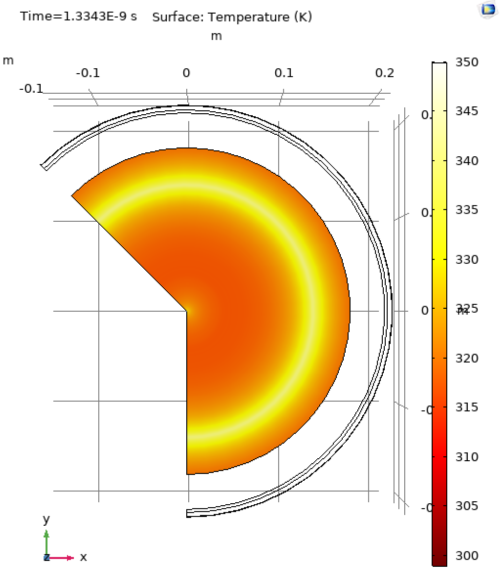

Figure 3: Thermal profile of mirror's surface showing heated pattern in the form of a ring

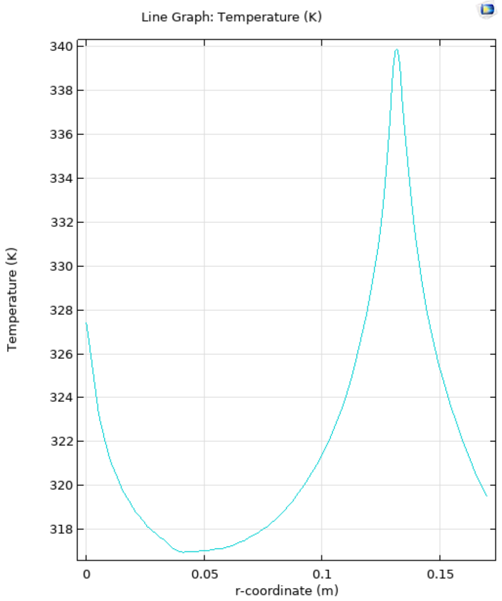

Figure 4: Radial plot of temperature showing a peak of FWHM approximately 2cm

change of temperature with a peak appearing around the middle of the mirror.

After obtaining a working model of a 3 mm thick ring heater, the COMSOL file will be connected to MATLAB in order to optimize the reflector's radius of curvature, as well as the position of the heater and reflector with respect to the mirror and each other.

Finally, the simulated model will be tested in a lab and the thermal profile will be measured using a Hartmann Wavefront Analyzer.

4 Project Schedule

The finite-element analysis simulation has taken 2 weeks and is expected to be finalized in 1 week. The testing and data-taking will take approximately 3-4 weeks. Finally, the data will be analyzed by running a Python program; this step will take 2 weeks. The last week will be used to work on the final report and interpret the results.

5 Acknowledgments

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