LASER INTERFEROMETER GRAVITATIONAL WAVE OBSERVATORY
- LIGO -
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Reducing optical losses using actively-tunable adaptive optics

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1 Introduction

Gravitational waves are produced by accelerating masses disturbing the curvature of space-time [1]. The Advanced Laser Interferometer Gravitational-Wave Observatory (aLIGO) is a global collaboration of scientists working on the detection of gravitational waves. They have detected waves created by binary black holes and binary neutron stars [2].

Advanced 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].

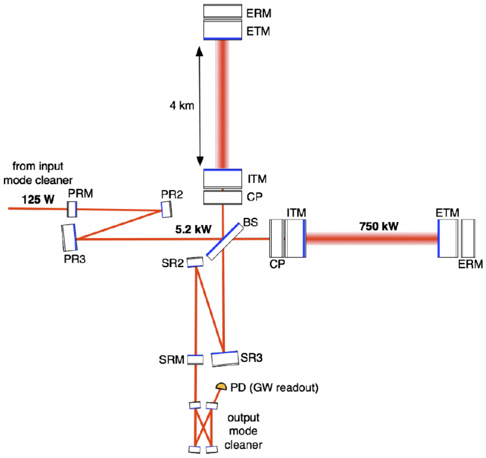

Figure 1: A scheme of aLIGO's L-shaped interferometer with two 4 km Fabry-Perrot cavities and recycling cavities. See [7] for a more detailed description of the image

Due to the weak gravitational waves and high sensitivity interferometer, different sources of noise affect measurements: seismic noise (below 2 Hz), thermal noise by dissipation in the supsension chain (2 Hz - 50 Hz), thermal noise generated by dissipation in the mirrors (50 Hz - 100 Hz), and shot noise (above 100 Hz) [4]. This experiment will focus on decreasing the effects of thermal noise produced by dissipation in the mirrors of the interferometer.

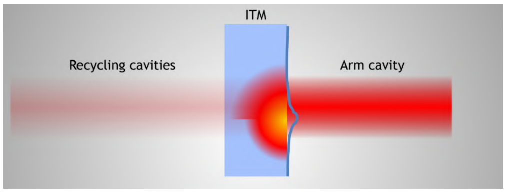

Figure 2: Non-uniform surface distortion of the mirror's surface (figure adapted from [5])

The aLIGO mirrors have non-uniform absorption that create little bumps, called point-absorbers (see Figure 2), on the surface of the mirrors when heated by the high power lasers [5]. Consequently, a small portion of the reflected beam is scattered into high order modes (HOM's) which reduce the cavity gain [5]. The adaptive optics technique used in this experiment is the central heating residual aberration correction (CHRAC) which locally deforms the mirror by projecting a heat pattern to the mirror's surface [6]. Some applications of the CHRAC technique are: projecting the radiation from a heater array to the mirror using an in-vacuum ZnSe lens [6], running current through a nicrome wire wrapped around the test masses' barrels [7], and producing a spatially tunable heat distribution using a CO_2 laser projector [7]. The goal of this experiment is to focus a source of radiant heat to a point on the mirror (1 cm^2) at a certain distance (1-10 m) using a horn.

2 Objectives

The goal of this project is to design a new actuating system that projects a heating pattern on the test mass. The first step is to design a heating array that will serve as a source of radiation which will then be focused to a point on the mirror's surface. Using ray tracing software, we will test different types of horns to determine an optimum shape. Our current assumption is that an elliptical cone will be the best option, since it is also used in focusing waves for Cosmic Microwave Background experiments [8]. Additionally, we will test two different actuating systems consisting of ring heaters positioned around the mirror. We will measure the heating profile projected on the mirror using a Hartmann Wavefront Analyzer (HWA) [9]. At the end of the 10 weeks, we aim to have a detailed design of an actuator that is successful in focusing heat to surface points at a distance and an analysis of the data gathered from the HWA measurements.

3 Approach

After determining the shape of the horn, we will 3D print and coat it with Aluminum foil to simulate a reflector. Additionally, we will build the electronic heater array by running current through a wire. The heat will initially be focused to an intermediate ZnSE lens and then imaged onto the mirror (see Figure 3). The system will be in-vacuum for higher efficiency [5].

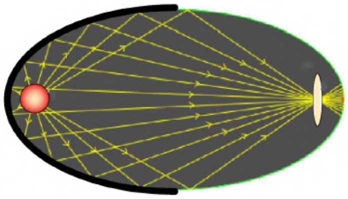

Figure 3: An elliptical reflector focusing heat from a radiation source to an intermediate lens. The lens produces a focused beam which is then imaged onto a mirror

The second design uses ring heaters placed around the mirror, creating a pixelated pattern (see Figure 4). In this way, we can control the thermal aberration of the mirror more precisely. The last design consists of ring heaters suspended on top of the mirror and surrounded by mobile conic sections which enable us to change the direction of the projected heat (see Figure 5).

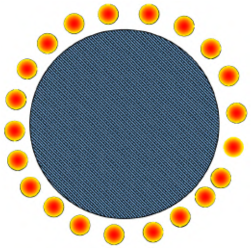

Figure 4: Sketch of the mirror surrounded by multiple ring heaters which can be separately controlled

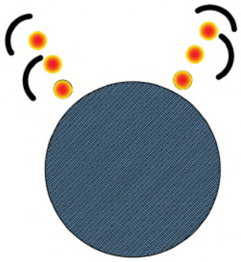

Figure 5: Sketch of the ring heaters suspended on top of the mirror and surrounded by smaller conic sections which control the direction of the radiated heat

The design and testing of all systems will take 3-4 weeks. Depending on how the experiment progresses, we might not have enough time to test the second and third designs. Using finite-element software we can simulate the experiment prior to running it, consequently allowing us to fix any potential problems before setting up the experiment.

4 Project Schedule

During the first week of the project we will simulate the system, design the horns and heater arrays, and set up the experiment. 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 2-3 weeks. The last 2 weeks will be used to work on the final report and if necessary, repeat smaller parts of the experiment.

References

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