LASER INTERFEROMETER GRAVITATIONAL WAVE OBSERVATORY
- LIGO -
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Developing Phase Map of Cavity Mirrors using Laser Mode Spectroscopy

Project Proposal - SURF 2018

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1 Introduction

The existence of gravitational wave was predicted by Albert Einstein in 1916 with the help of his general theory of relativity. According to Einsteins relativity presence of mass or energy bends the spacetime and accelerating massive objects like neutron star or blackholes produce time varying ripples in the spacetime. These ripples are known as the Gravitational Waves[1]. These waves would travel at the speed of light through the Universe. Study of these waves will give us information about the origin of these waves, nature of gravity and also a better picture of the universe.

The Laser Interferometer Gravitational Wave Observatory (LIGO) is a large-scale physics experiment and observatory to detect cosmic gravitational waves. It works with the help of two detectors located in Livingston, Louisiana and in Hanford, Washington. The first direct detection of Gravitational Waves was done by LIGO on September 14, 2015 [2]. This work earned three scientist the 2017 Nobel Prize in Physics.

The interferometers work on the principle of merging of two or more waves to create an interference pattern, which contain information about the object or phenomenon influencing it. This technique can be used to make extremely small measurements that are not achievable using other techniques. The detectors used in LIGO are modified Michelson interferometer with Fabry-Perot cavity introduced to it. Michelson interferometer has a L shape, in which each arms are of 4 Km length. Each arm of the detector forms a Fabry-Perot Cavity capped by a semi-transparent Input Test Mass (ITM) and an End Test Mass (ETM) [3].

In the absence of gravitational waves, both arms of the detector are of same size and thus laser beam takes the same time to travel through each one. When a gravitational wave passes through the detector it changes the length of the arms by making it contract or expand. The interference pattern that we will obtain now will be different from the one we obtained when both the arms were of same length. Thus, these interference pattern can be used to make the precise calculation of the change in length occurred and also the nature of gravitational waves causing this change.

The change in length of the interferometer arm caused by the gravitational wave is about 1/10,000 of the diameter of proton. Measurements of this scale is done by increasing the interaction time of Gravitational Waves with each arm. This is done by introducing a Fabry-Perot cavity inside each arm in which, laser beam undergoes multiple reflections. But this increases the chance of power loss due to unwanted scattering from the mirror surfaces (ITM and ETM). The scattering can be due to point defects, scratches, sleeks, contaminations and Figure error of the mirrors [4]. The aim of this project is to develop a method to reduce or remove the figure error of the mirrors and to obtain a more reliable interference pattern. If we can reduce the power loss efficiently, it will also help us to detect gravitational waves of even lower intensity.

2 Objectives

Mirror figure errors are the low frequency surface defects present on the test masses which results in the low angle scattering of the light. This causes power loss in the optical cavities, which ultimately leads to destruction of squeezed state of light. Through this project we are trying to develop a in-situ technique to remove the mirror figure error from the optical setup.

Mirror figure error can be characterised by using mirror maps. Mirror maps are those diagrams that show us the imperfections in the surface of mirror which contribute towards the power loss through scattering. The conventional technique to create these mirror map is Fizeau interferometry. But this cannot be done inside the original LIGO interferometer without disturbing the output. Thus, we are interested in developing a technique which can be used in the original LIGO interferometer. Such techniques are classified as In-situ measurement techniques.

Few students have already worked in this project and the in-situ technique they used for developing mirror map is known as Mode Spectroscopy. This project work will be done as a continuation to their work. The aim of this project is to get a more accurate and precise cavity scan data and to improve the measurements.

3 Approach

Cavity scan data of the Fabry-Perot cavity can be collected with the help of various cavity scan techniques. Few of the techniques used by the previous students include simple cavity scan, cavity scan using Electric Optical Modulator (EOM), cavity scan using Additional Slave Laser (ASL) and Arm length stabilisation scheme [5]. These cavity scan data includes the effect due to mirror figure error also. The benefits and drawbacks of each method will be studied in detail and a suitable technique will be adopted for the purpose.

The parameters of the system used for obtaining the cavity scan need to be recorded and they need to be fed to a software for the production of ideal cavity scan data. The software which we will be using here is the Finesse. The cavity scan produced with the help of Finesse software is free from errors due to mirror figure error and thats the reason for calling it the ideal cavity scan. The ideal cavity scan data and the experimental cavity scan data will be compared and any shift from the ideal scan data will be noted. The reason for the shifted modes appearing in the experimental data is the figure error of the mirror. Using the Finesse software, we introduce figure errors to the ideal scan in the form of perturbations [6]. The process will be continued till the cavity scan from software and that from the experiment match. The collective perturbations are equivalent to the figure error present in the original mirrors and it can be plotted as a Phase/Mirror Map.

4 Project Schedule

Different stages involved in this project are shown as a flow chart in Figure 1. For obtaining the experimental cavity scan, lab facility is needed. The comparison and developing phase map part can be done with the help of computers. If we are able to give a feedback to the cavity mirrors which nullify the effect of figure error, with the help of this phase map, we can get neater interference signal.

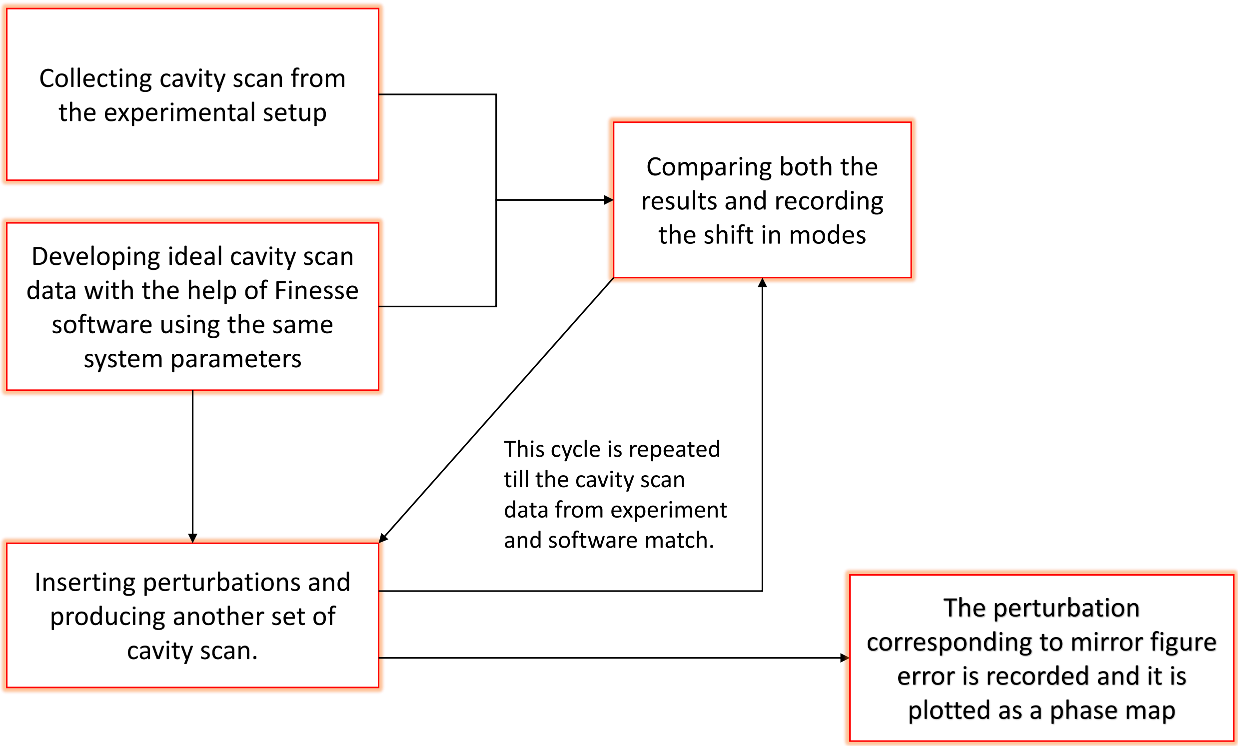

Figure 1: Flow chart showing various stages of the project.

References

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