LIGO SURF Proposal

Modeling of Gravitational Wave Detector Suspensions

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Due Date: 5/15/16

Introduction

In 1916, Albert Einstein predicted the existence of gravitational waves from the field equations of general relativity. Gravitational waves travel at the speed of light as ripples in the curvature of spacetime (Aston, et al., 2012). The U.S. Laser Interferometric Gravitational-Wave Observatory, LIGO, has two facilities, located in Hanford Washington State and Livingston, Louisiana. The process of detecting gravitational waves has been the main goal for the LIGO facilities. Enhanced Michelson interferometers are used to detect gravitational wave amplitudes. After upgrading the equipment, advanced LIGO was designed to increase the sensitivity of the LIGO detectors and decrease the amount of thermal noise.

On September 14, 2015, the first direct detection of gravitational waves, associated with a binary black hole merger was made. Both LIGO facilities simultaneously observed a gravitational wave signal from this event (Abbot, et al., 2016). The importance of this research is based on trying to understand the universe's origins. One primary goal of physicists is to uncover the mysteries of the universe in the time following the Big Bang. Roughly 380,000 years after the Big Bang, the Cosmic Microwave Background (CMB) was left over thermal radiation that has now since been decreased in temperature and is shown primarily in the microwave portion of the electromagnetic spectrum. The importance of this discovery is that gravitational waves will be able to travel farther than light. Currently, the eXtreme Deep Field (XDF) picture from the Hubble telescope peers the farthest back into the universe's past at 13.2 billion years. With the discovery of gravitational waves, scientists will be able to explore beyond the CMB and start uncovering further back than 13.2 billion years. To look further beyond the CMB, scientists are in the process of making space-based detectors, such as the Laser Interferometer Space Antenna Project (LISA). LIGO will unlikely be able to see beyond the CMB but it will give a big advantage for astronomy because LIGO will allow us to see "dark" events. The main "dark" events that emit gravitational waves that LIGO will see will come from black hole mergers, neutron star mergers, and "burst" sources such as a supernovae.

My mentor, Dr. Alastair Heptonstall, worked on characterizing the mechanical loss in fused silica ribbons for use in gravitational wave detector suspensions. He also contributed to the project for the Voyager concept to develop third generation detectors using mirrors that are suspended from cryogenic silicon fibers. This work uses Finite Element Analysis (FEA) to investigate the cryogenic suspension fibers. In my contribution, instead of using silicon, I will be looking into using FEA for fused silica. FEA is a technique that allows us to build a computational model and predict how a project reacts to real-world forces, vibrations, and other physical affects. This is important in understanding the breaking point and functionality of the design. The concept of the project may involve using cryogenically-cooled mirrors and suspensions to reduce thermal noise. However, much work remains to be done before we can realize cryogenic suspensions.

Objectives

Advanced LIGO was designed to introduce numerous improvements, but this project is geared towards building a full model suspension system to allow for direct calculation of the mechanical admittance. My goal for this project is to use FEA to build models for the gravitational wave detector mirror suspensions, specifically for third generation detectors using a fused-silica hybrid type suspension for the interferometry mirrors. This project will begin by developing models of gravitational wave detector mirrors. A few programs will be used including Comsol and 3D SolidWorks to help use FEA to analyze the mirror suspension capability. One primary goal of this project is to use Finite Element Analysis to model cryogenic mirror suspensions for third generation detectors. The success of this research will be evaluated on the basis of any developments that it contributes to using FEA to model the final stages of the suspension system.

Approach

My approach for this project involves beginning with basic models that will allow me to make consistency checks with analytical models which can be tested with experimental measurements. Experimental measurements would be based on “real world” tests to make sure that the models respond accurately. The main goal is to construct the sections of the model piece by piece in order to completely model the final stage of a cryogenically cooled mirror suspension made from a hybrid fused silica/silicon material; the fused silica fibers will be attached to a silicon mass. The most challenging aspect of the project is to become familiar enough with the technique to accurately describe each part of the model. However, this challenge can be overcome by asking questions and studying relevant literature. Another challenge will be to use unfamiliar programs because I am not familiar with all the programing languages that will be used such as Comsol. In order to overcome this challenge, I plan on spending a lot of time practicing with the programming language. Another student will be for silicon suspensions instead of fused silica/silicon suspensions. There will be overlap between these efforts which will be helpful to build a strong research relationship with my colleagues and mentors to work towards the ultimate goal of developing a complete model.

Work Plan

My work plan consists of the following steps that will help me work towards my goals.

1. Develop and articulate the minimum goals my mentor wants completed by the end of 10 weeks. (1-2 days)
2. Become familiar with the programming languages that are required. This may include practicing on basic models outside of the project or starting with the basic models to check consistency with the analytical models. (1 week)
3. Continue developing basic models and start constructing sections of the main model piece by piece. (4 weeks)
4. Perform Finite Element Analysis on mirror suspensions being modelled and gather information on their characteristics. (2 weeks)
5. Make final adjustments, objectives, and plans to move forward with the project. (1 week)
6. Prepare written reports periodically throughout the assignments and prepare for the oral presentation scheduled for the final day. (1 week)

References

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