LASER INTERFEROMETER GRAVITATIONAL WAVE OBSERVATORY
- LIGO -
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Building a tilt-free seismometer

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1 LIGO

The Laser Interferometer Gravitational Wave Observatory, or LIGO, aims to be the first experiment to directly detect gravitational waves. LIGO works by measuring the relative positions of test masses as they are disturbed by passing gravitational waves. Gravitational waves are produced by large events such as supernovae or the collision of black holes. In spite of the very large magnitude of these events, gravitational waves are extremely small by the time that they reach the LIGO detectors. Thus, the LIGO detectors must have an unparalleled level of noise reduction.

2 Tilt-Free Seismometer

One of the primary disruptive sources of noise in LIGO is ground movements. Ground motion creates relative motion between LIGO's two test masses, which can be read as a false positive detection of gravitational waves. Seismometers are in place to feed-forward information to the test masses and cancel out and ground motion, but these noise reduction devices begin to fail at low frequencies, when the devices cannot distinguish between translational motion of the ground and tilting of the ground.

A typical seismometer works as a mass on a spring. The ground moves, and the mass stays for the most part stationary due to its inertia. The relative motion of the mass and the frame can be measured, which gives the motion of the ground. However, this type of seismometer cannot distinguish between translation of the ground and tilt of the groud; a tilt produces relative motion just as translation does. Tilt is related to the displacement of the seismometer mass by a factor of g/ω^2, so as the frequency decreases, the effect of tilt on the measurements of the seismometer increases greatly. Current seismometers measure the tilt of the ground separately and then subtract it from the overall signal. This project aims to develop a new type of seismometer that is inherently insensitive to tilt, so that no signal subtraction is necessary.

3 Laboratory Work

This summer's laboratory work will consist of work on two major portions of the project: the inverted pendulum and Michelson interferometer that make up the seismometer itself, and a temperature-controlled housing that will minimize noise during the seismometer's operation.

3.1 Inverted Pendulum and Interferometer

The basic design of the new seismometer is an inverted pendulum. The pendulum will be supported inside a structure, called the rhomboid, with a high moment of inertia and a resonance of 20mHz. A Michelson interferometer will be used to measure the distance between the pendulum and the rhomboid, and thus determine translation free of tilt. The rhomboid,

as well as the cage containing the rhomboid and the inverted pendulum, have already been constructed, so this summer's project will focus on construction of the interferometer and creating the control systems to operate it. However, as time permits, the project will also focus on design and construction of the inverted pendulum itself.
The interferometer will be a typical Michelson interferometer, where light travels down two orthogonal arms and is reflected back to the junction of the arms. The resulting interference of the light when it recombines allows you to calculate the relative distance between two objects (in this case the inverted pendulum and its cage). The lengths of the arms of the interferometer must be accurate to less than 1mm, to reduce frequency noise. Fiber coupled light from another optics table goes to the interferometer, where there will be a 10kHz piezoelectric transducer (PZT) actuator. This PZT is used to modulate the length of one of the arms of the interferometer, which produces a known signal to look for at the asymmetric port. This error signal will be fed back to the PZT after being digitized through a control filter and a digital-to-analog converter. All of the sensing programs will be written in the in-house version of LabVIEW.

3.2 Temperature Control

The second component of this summer's project is the temperature control system for the inverted pendulum and the Michelson interferometer. The rhomboid is suspended by thin steel wires, which contract and expand as temperature changes, so the housing is necessary to reduce sources of noise in the seismometer. The first step in this component of the project is to construct the insulative housing for the seismometer. Once the housing is constructed, the next step will be to build a device which keeps the temperature at a desired value. This part of the project will be mostly mechanical and electrical work, because the servo will be an analog device. A current graduate student has built a similar device for another project, so this project's device will be based on their design. Once a control device has been constructed, a control loop will be written to maintain a given temperature.

4 Tentative Schedule

The two main components of this project, the Michelson interferometer and the temperature control system, do not need to be completed in any particular order. Thus, the tentative schedule for the summer is very flexible. That being said, the proposed plan of action is as follows:
Weeks 1-4: Focus on the Michelson interferometer; construct it and its associated programs and control systems. This section culminates in the first progress report.
Weeks 5-7: Focus on the temperature control system for the seismometer; construct the necessary circuits for the control device, and write the control loop program. This section culminates in the second progress report.
Weeks 8-10: Focus on integrating the parts into a working whole system, and on any remaining work that may not have been accomplished in the first two sections. This section culminates in the final report and the final oral presentation.

References

[1] Dooley, K.; Moon, S.; Arai, K.; Adhikari, R., *Towards a tilt-free seismometer design.* Poster at March LVC Meeting (2015).

[2] https://nodus.ligo.caltech.edu:30889/ATFWiki/doku.php?id=main:experiments:tiltfreeseismometer:menu