LASER INTERFEROMETER GRAVITATIONAL WAVE OBSERVATORY
- LIGO -
CALIFORNIA INSTITUTE OF TECHNOLOGY
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Automated Laser Stabilization

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1 Introduction

LIGO detectors in the future may potentially include a phase-sensitive optomechanical amplifier to mitigate readout losses. This amplifier is structured in with a pump and a Mach-Zender IFO to split the beam into two separate triangular ring cavities. [1] The beam becomes amplified within the ring cavities, and high power circulation is achieved if the cavities are properly locked on resonance.

Resonance is built when the frequency of the beam is an integer multiple of the distance it travels within the cavity. Small fluctuations in the frequency of the laser beam and/or changes in the position of the mirrors cause for the cavity to fall out of resonance. One of the most widely used techniques to mitigate this is the Pound-Drever Hall method [2] (PDH). However, if vibrations or disturbances are large enough, it can still bring the cavity beyond range of re-stabilization. Manually implementing a re-lock creates inefficiencies in the process. Currently, in the Caltech laboratory, keeping the cavity on resonance involves a tedious process of manual adjustments and locking.

2 The Current Control Systems

Part of this research will involve becoming familiar with the PDH and temperature control systems. The PDH method works by picking off and modulating the frequency of the input laser. The modulated beam is sent into a mixer, along with the reflected laser beam from the cavity. The mixer creates a product of these two inputs that outputs a beat pattern. This beat pattern is used to produce the error signal, which is sent into a servo amplifier that loops to the laser, and locks it to the cavity. The PDH takes the derivative of the carrier response, which allows one to tell which side of resonance the cavity is on. Close to resonance, the PDH error signal can be approximated as linear, allowing for the PDH lock to perform its functions.

The details of how locking is currently done on site were given by project mentor Aaron Markowitz. The LB1005 locking servos are turned on and then off again until cavity locking occurs on the laser mode. This is determined by observing the ratio of transmitted to reflected light in the photodiode. The photodiode DC levels are recorded and the temperature control servo is turned on to determine these DC levels, and hold the temperature so that the cavity sustains its lock. The set point of the temperature control is then manually adjusted, so that we achieve maximum transmission to reflection ratio. This is not a trivial process. By upgrading the feedback control of the ring cavity and automating the locking acquisition process, it will make the procedure much more efficient.

3 Previous Automation Efforts

There have been several efforts at creating an automated locking acquisition system. An example of a proposed auto-locking system incorporates a microprocessor, that acts to create upper and lower bounds of the feedback error signal received in the PDH lock. When the signal moves beyond the bounds, the microprocessor will activate and pull the frequency back on resonance. Once resonance conditions are met, the system will switch to use its PID controller once again.[5]. Other efforts consist of a microcontroller to give a threshold for the frequency derivation. When the circuit moves above this threshold, the microcontroller halts the locking scan, and begins the slow loop. Once resonance is found, re-locking occurs.[6] All of these systems incorporate both analog and digital circuits in their design. The intent of this project will be to not only to study different methods, but to develop and implement a suitable automation system for the triangular ring cavity model, so that we may enable better locking conditions.

4 Approach

The first steps to take will be gaining a good understanding of the temperature and PDH control servo systems. The project will involve learning the digital systems, outlining the sequence of the upgraded locking system, and scripting the process. Some time will be spent debugging, and determining channels to read/write into. Although there are different methods of automating such a system, it is likely that the system will incorporate both analog and digital circuits [3]. The incorporation of the analog circuits will be useful to increase the speed and bandwidth of the servo system, while the digital circuit will be useful for complex algorithms. A series of digital to analog converters (DAC's) and analog to digital converters (ADC's) will be implemented in the system and connected with a servo controller (Either the Red Pitaya or LB1005). The system will then be checked for stability and control. Once running properly, this will improve the feedback control of the triangular ring cavity in the amplifier.

5 Higher Order Mode-Matching

Another topic that will also be addressed in tandem with the automated PDH locking is a project analyzing higher order mode-matching losses within the triangular ring cavity. As the beam propagates through each optical component, misalignments in the optical axis, or unmatched radii of curvature between the beam and mirror surface create for higher order modes [4]. Higher order modes create different intensity patterns on the mirror, and sets of these modes form families of solutions to the paraxial approximation.

The project will be an analytical/computational study focusing on the accuracy of the paraxial beam and thin lens approximations. The research will involve becoming familiar with using FINESSE and understanding mode-matching. A mode scan of the set up in the lab will be done, and FINESSE will be used to model it with a thicker lens. The mode scans will be compared with analytical/FINESSE calulations. Along with a broader understanding of mode-matching, the accuracy of the thin lense approximation will be studied, and potentially explored in future LIGO research.

6 Project Outlines

- **Week 1:** Control Project: Become familiar with PDH locking and temperature control servo systems. HOM Project: Learn Finesse modeling and higher order modes.
- **Weeks 2 - 4:** Control Project: Learn digital systems, outline sequence, and script process. HOM Project: Create working model of higher order mode/matching.
- **Weeks 5 - 7:** Control Project: Debug outlined sequence and determine channels to read/write into. HOM Project: Continue creating model of higher order mode
- **Weeks 8 - 10:** Control Project: Work on physical model of the control system, loop shaping . HOM Project: Try model with thicker lens. Analyze/compare.

Understanding and developing an automated locking acquisition system, with a combination of analytically exploring mode-matching losses, will create better efficiency to the way the triangular cavities in the optomechanical amplifier are brought on resonance. With over half a year's worth of experience in studying Fabry-Perot Cavities, laser beam transformations through optical components, Gaussian beams, and the PDH locking technique, I am well suited and eager to pursue research that expands upon these areas of LIGO Interferometery. With the help of my graduate student mentors Shruti Maliakal, Aaron Markowitz, along with project supervisors Dr. Rana Adhikari and Dr. Christopher Wipf, I am certain the summer will result in successful research projects.

References

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