LASER INTERFEROMETER GRAVITATIONAL WAVE OBSERVATORY
- LIGO -
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Sensing and control of suspended optic breadboard in Crackle2 experiment

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1 Introduction

In metals, dislocations are ’pinned’ by obstacles like grain boundaries or other surfaces. (Dislocations are dis-junctions in the periodic lattice structure.) Under small oscillatory stress, these dislocation lines bow in and out, but the response of the complex network on the whole is known to act nonlinearly through long-range interactions between dislocations. This nonlinear behavior, among a broad class of other nonlinear phenomena, is known to be the cause of ”crackling”. ”Crackling” here refers to impulsive releases of energy, acoustic emissions, or changes in the geometry of attachments between suspension elements. It has been suspected that this ”crackling noise” in various components and suspensions might produce excess noise in aLIGO. [1]

Many possible locations of crackle (PLoCs) have been identified, some of which are:

- The maraging steel blades used for vertical isolation
- The silica fibers which suspend the test masses from the penultimate masses
- The welds which attach the fibers to the ears
- The clamps which hold the suspension wires to the steel blades

The figure below shows the test mass suspension scheme in Advanced LIGO.

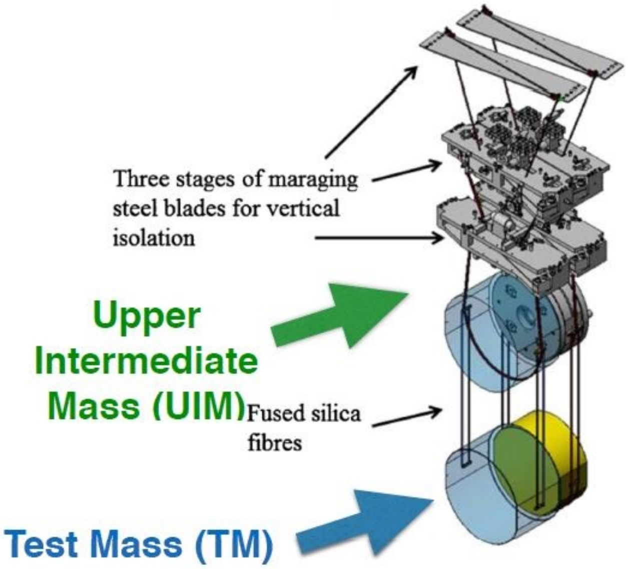

Figure 1: Suspension scheme in Advanced LIGO

The maraging steel blades have been under investigation in the first crackle experiments, as they present a mechanical system which can be driven and stressed easily. In addition, mechanical crackling noise is sufficiently generic that an experiment capable of measuring this noise in maraging steel blade springs will be well suited for investigating crackling in other components used in aLIGO as well.

As crackling noise is inherently nonlinear, there is the potential for noise to be upconverted. Specifically, motion of the suspension at sub-Hz microseismic frequencies may induce blade motion, causing the blades internal stresses to fluctuate, resulting in an avalanche of crackle events with high-frequency content. As we do not currently possess a reliable analytical model to predict the magnitude, or frequency dependence, of the these events, we hope to do so experimentally directly at the frequencies of interest. [1]

2 Story so far

2.1 Measurement strategy

With reference to figure 1, below the upper intermediate mass (UIM) in the quadruple suspension system, there is no more spring blade isolation, thus any crackling noise in the UIM maraging steel blades will propagate directly to the test mass. Therefore, one would want to ensure low enough crackling noise at the UIM blade tip itself.

A direct measurement of crackling noise is very difficult. However, one can make measurements of the blade displacements directly using a Michelson interferometer with end mirrors mounted to loaded blade springs which are driven with a low frequency, common-mode force. Since crackling noise occurs incoherently in each blade, it will show up in the Michelson's displacement signal. In order to ensure repeatability and applicability of results, the setup has been made to be similar to the existing aLIGO configuration.

2.2 Experimental design

The setup consists of a Michelson interferometer using blade-suspended masses as end mirrors. A crackle event will change the differential displacement of the mirrors, and hence be reflected in the interferometer output. The events are excited by a low frequency, common-mode, drive on the two blades. The apparatus is housed in a vacuum chamber to mitigate acoustic noise. [1]

2.2.1 Optical layout

The figure below shows the optical layout of the setup.

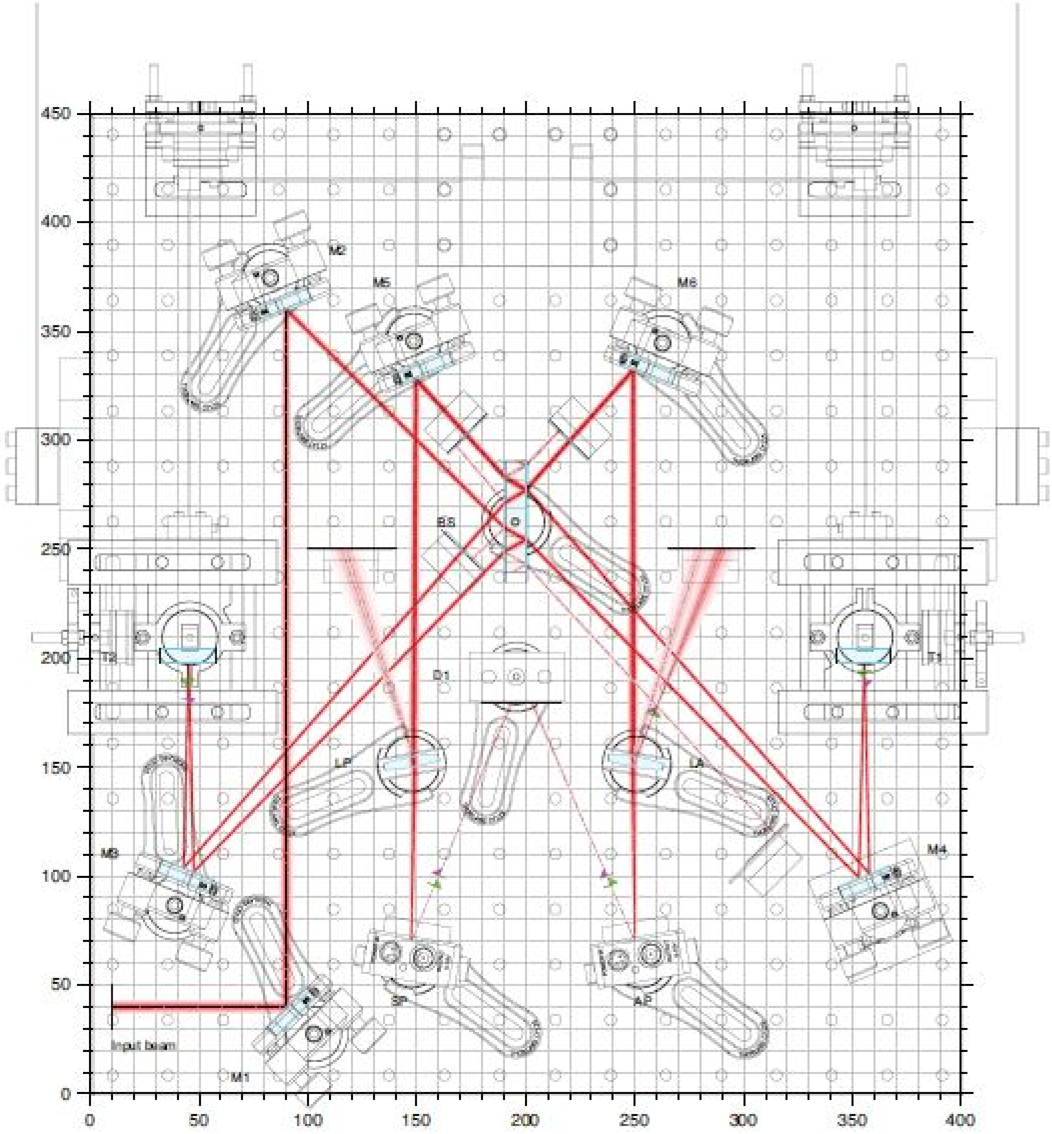

Figure 2: Optical layout

Light from the laser comes in from the bottom left corner through a viewport. Two folding mirrors then redirect the beam to the beam splitter. The two arms of the Michelson interferometer are folded in such a way that the beams impinging on the end mirrors are almost vertical, but tilted enough so that the beams propagating in opposite directions (before and after reflection from the mirror) are separate. The end mirrors of the Michelson arms are horizontal.

2.2.2 Seismic isolation system

Earlier versions of the setup consisted a stack of two steel plates resting on blocks made of rubber to provide isolation of the Michelson from the ground motion. Ideally, seismic motion of the optical setup wouldn't couple to the Michelson signal because the motion would be common to both mirrors. However, any differential motion of the blades would result in a spurious signal.

Lately, a suspension system has been employed for the breadboard with the Michelson interferometer. A basic control of the breadboard has already been established, and a more detailed modeling of the system and damping in all six d.o.f. is to be implemented.

Figure 3 below shows a simplified scheme of the suspension system. Vertical isolation has been achieved using maraging steel spring blades. A two stage system has been designed. The upper stage is composed of four such blades, each one supporting a wire which are attached to an intermediate stage.

Poor seismic isolation has been one of the bigger sources of noise, which hindered measuring crackling noise. A good isolation system is hence the need of the hour.

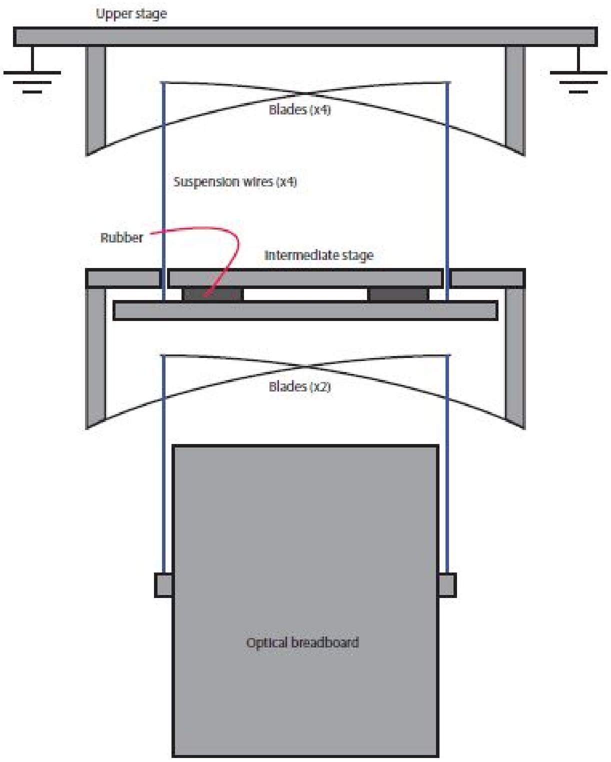

Figure 3: Scheme of the suspension system

3 Goals for my project

3.1 Problem statement

As mentioned, earlier versions of the setup were mainly limited by seismic noise at all frequencies below 100Hz. Since the aim now is to move the sensitive band to frequencies around 10Hz, a better seismic isolation system is necessary. A dual stage suspension system has already been commissioned, as already mentioned above, and the breadboard has been fully suspended in air. Simple velocity damping has been implemented, and in my project, I aim to model the system in more detail and implement damping in all six degrees of freedom.

3.2 Methodology and approach

The breadboard is now free to move in all six degrees of freedom (x, y, z directions, and 3 Euler angles). The task at hand is to sense and control the motion using Optical Shadow Sensor and Electromagnetic Actuator (OSEM). The approach can be briefly summarized in the following points:

- Employing OSEM on the breadboard for sensing motion in all six degrees of freedom,
- Reconstructing complete motion from data collected from the sensors
- Study the effect of the suspension system (this is through the Michelson signal) - whether it has served the purpose
- Applying appropriate feedback damping control to stabilize the breadboard

Figure 3 below shows the current scheme of placing of the OSEM sensors on the breadboard.

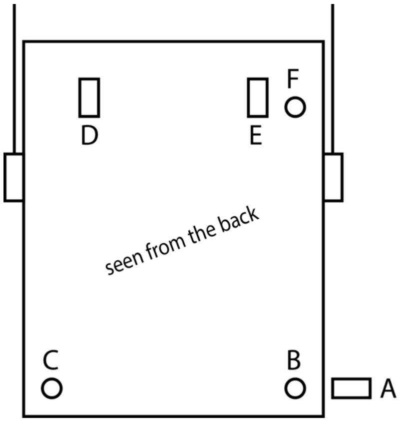

Figure 4: Scheme of OSEMs

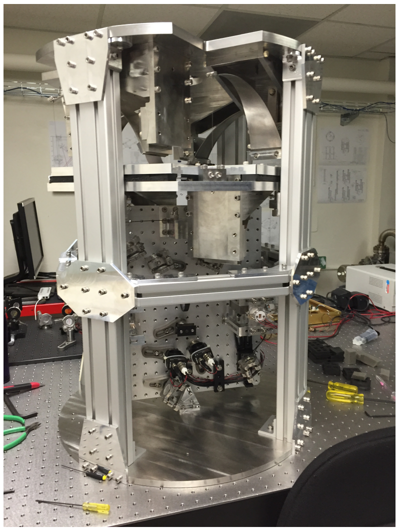

Figure 5: Current setup

With reference to figure 4, reconstruction can be roughly thought of as follows: data from pairs of sensors D & E, B & C, B & F can be used to calculate z motion & roll, y motion & yaw, and pitch respectively, and A for x-displacement, upon using appropriate transformations. (In fact, once the exact positions of the OSEM are known, one can write down precise transformation matrices and do the job.)

3.3 Timeline

The dates of my program are May 18 - July 23, this makes for a period of about 10 weeks. I plan to use the 10 weeks as follows.

Table 1: Timeline

Week(s)	**Planned task**
1	Interface with sensors, studying the existing system
2-3	Build analytical model of the breadboard motion, construct transformation equations
4	Measure breadboard motion using sensors and reconstruct in physical d.o.f
5-6	Measure response of all actuators in physical d.o.f
7-8	Model the system, design feedback control
9-10	Implement feedback system, characterize it

References

[1] Xiaoyue Ni, E. Quintero, G. Vajente, ”Proposal for an upgrade of the Crackle experiment”, LIGO-T1400407-v1 (2015)

[2] E. Quintero, E. Gustafson, R. Adhikari, ”Experiment to investigate crackling noise in maraging steel blade springs”, LIGO-T1300465-v2 (2013)