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Summer LIGO Proposal: Acoustic Emissions in Metals

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1 Introduction

Advanced gravitational wave detectors are highly sensitive instruments. Therefore, noise must be reduced to accommodate that sensitivity. One potential source of noise in metals comes from crackling events, noise caused by the motion of crystal dislocations due to slow changing external stress [1]. Consequently, high frequency crackling events occur and linear models can no longer be used to describe the metal's behavior. This effect could potentially be a cause of concern in the Maraging steel blades used in a vertical seismic isolation system in gravitational wave experiments.

This summer, I will work with a preexisting experimental setup in order to search for crackling events that could be triggered by an external low frequency force. The experiment uses ultrasonic microphones [3] to detect crackling noise in Maraging steel blades loaded with increments of weight up to the maximum load which is close to material yield stress [2]. My duties will include the operation of the experiment, data collection, and data analysis. Additionally, I will calibrate the microphone output to the amount of energy released.

2 Objectives

The goal of the project is to directly detect crackling events in Maraging steel. Additionally, even if the experiment does not ultimately detect crackling events, it can help set upper limits for the amplitude and rate of such events.

Past experiments were designed to detect crackling. In one, a pair of blade springs supporting optical instruments in a Michelson interferometer are driven by a low frequency force. If a discrete crackling event occurs, a resultant displacement should occur between the detected signals in each blade [4]. This experimental design is limited because the blade acts as a low-pass filter, which can obscure some of the noise. Additionally, in order to keep the optical system close the operating point, the maximum blade motion is limited to few tens of microns. A potential alternative is to use ultrasonic microphones on blades loaded with a range of weights. Although the ultrasonic microphones are not as sensitive as the interferometer, they can be employed at higher frequencies to possibly directly detect single crackling events. Previously, this experiment was run with a variety of materials stressed with a range of weights and no crackling events were detected [2].

This summer, I will be running this acoustic emissions experiment again with the goal of detecting crackling events, ideally improving the experiment along the way. Initially, this will consist of rerunning the preexisting experiment, collecting data, and improving data analysis. Additionally, I will work to find ways to calibrate the acoustic microphones in units of energy emitted by the crackling events. Next, I will work on improvements to the previous experimental design. For example, I can test variable amplitudes in the drive by adapting preexisting experimental techniques to this experiment. The ultimate goal of the project is to detect discrete crackling but the project will still be successful even just by furthering the experiment via the above steps and by finding an upper limit on crackling noise.

3 Approach

Score Dunegan microphones [3] are used to collect data. These piezoelectric contact ultrasonic microphones can detect in-plane and out-of-plane waves in the range of hundreds of kilohertz [3]. They are secured directly onto the blades with an incompressible medium, typically petroleum jelly.

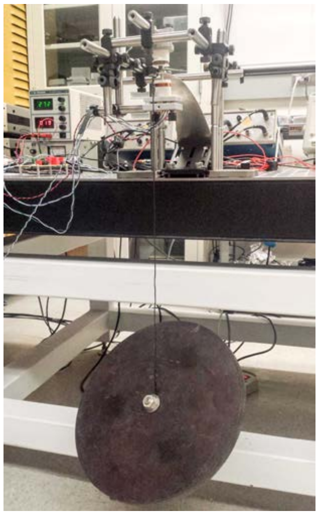
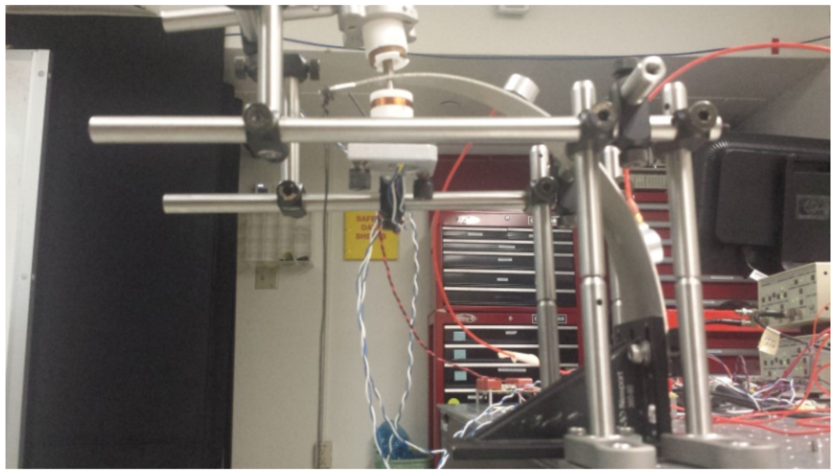

Figure 1: Maraging steel blade loaded with an 11 kg mass (right) and 16 kg mass (left).

In the first set of tests, a Maraging steel blade was loaded with an 11 kg mass, 50% of the maximum weight. An attached voice-coil actuator was driven with a DAC through an amplifier. Additionally, passive low-pass filters were used to prevent and high-frequency events that might be mistaken for crackling events [2].

The system was excited with a sinusoidal displacement of about 500 um at 0.4 Hertz every other hour, with the system off for the alternate hours. No significant change was measured between the on and off periods, implying no crackling noise was excited by the low frequency driven [1].

Lack of evidence of crackling noise was similarly found in a blade loaded with 16 kg, 75% of the nominal yield stress, and clamped vertically. Despite days of data, no difference was detected between on and off periods. Similarly, the experiment yielded the same results when repeated with brass or high carbon steel blades. The results imply any crackling noise that could have occurred did so below the noise floor. An upper limit of $10^{-15}\frac{m}{\sqrt{Hz}}$ from 30kHz to a few hundred kHz in Maraging and high carbon steel blades [1].

This experiment only compares output for when the drive is on or off. This does not test for the possible relationship between the amplitude of the force or the momentum and the rate and size of crackling events. To analyze this, I could vary external force and analyze the resultant rate of variations in the data or changes in the noise floor. There are two possible ways to approach this. The first is to modify an algorithm used in the interferometer experiment [4] in order to find noise modulated coherently with the already running low frequency drive. The second is to look for small events in the microphone data and correlate them with external force. This approach could be done using LIGO software designed to detect transient gravitational waves. I will test both approaches and based on the success of each, decide to mainly pursue either approach, both, or another solution entirely.

Additionally, one way to further the experiment is by calibrating the acoustic microphones' output to energy released in the blade. One way to start doing this is to calibrate the microphones with the known energy release of a simple system, such as dropping a steel ball onto the blade. By comparing the height of the ball initially with its height after one bounce I can calculate the energy released into the blade and use it to calibrate the microphone.

4 Project Schedule

LIGO SURF is a ten week program. Below is a tentative schedule of goals for the ten weeks.

Week	Task
1	Training, familiarization with experiment, setup of previous experiment and microphone .
2	Microphone calibration and data analysis.
3	Microphone calibration and data analysis.
4	Running preexisting experiment and data collection.
5	Running experiment with variable drive forces and frequencies.
6	Data analysis with crackle experiment algorithm and continuous running of experiment.
7	Data analysis with LIGO software and continuous running of experiment.
8	Further analysis with LIGO software and algorithm while running improved experiments.
9	Further analysis with LIGO software and algorithm while running improved experiments.
10	Solving any problems found; final experiments; collecting and synthesizing final data.

References

[1] Paoletti, Federico, Vajente, Gabriele. "Acoustic Ultrasonic Measurements to Investigate Crackling Noise in Maraging Steel Blade Springs." LIGO-T1500510-v1 (2015)

[2] Paoletti, Federico, Vajente, Gabriele, Ni, Xiaoyue. "Acoustic Emissions in Maraging Steel Blades in the Elastic Regime." (2015)

[3] "SE9125-M AE Sensors." Score Atlanta Inc, n.d. Web. 12 May 2016. https://score-atlanta.com/products/AE%20Sensors/SE9125-M

[4] Vajente, G., et al. "An Instrument to Measure Non Linear Mechanical Noise in Metals in the Elastic Regime." (2016): LIGO Laboratory, California Institute of Technology, Pasadena. Submitted to Review of Scientific Instruments.