Micromechanical Investigations on Crackling Noise

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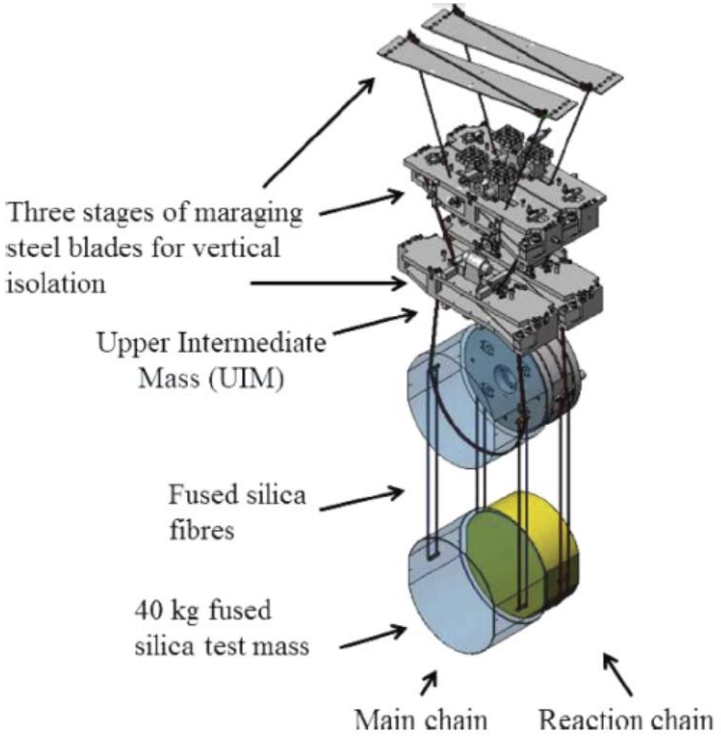
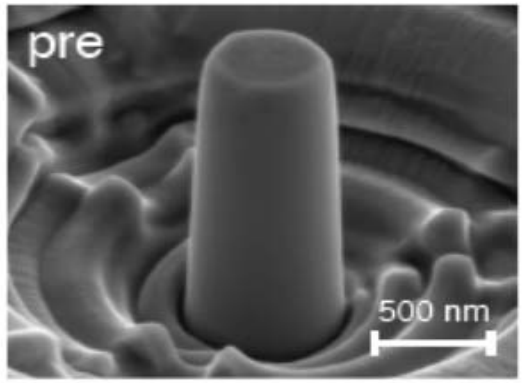
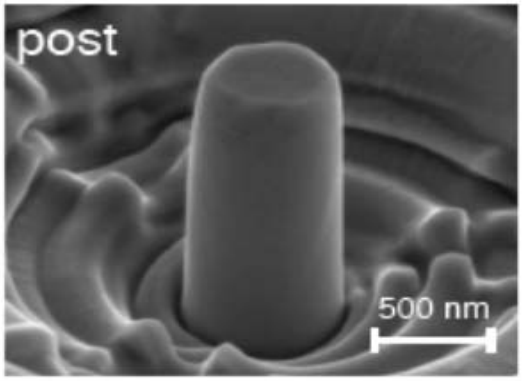
Aim and Introduction

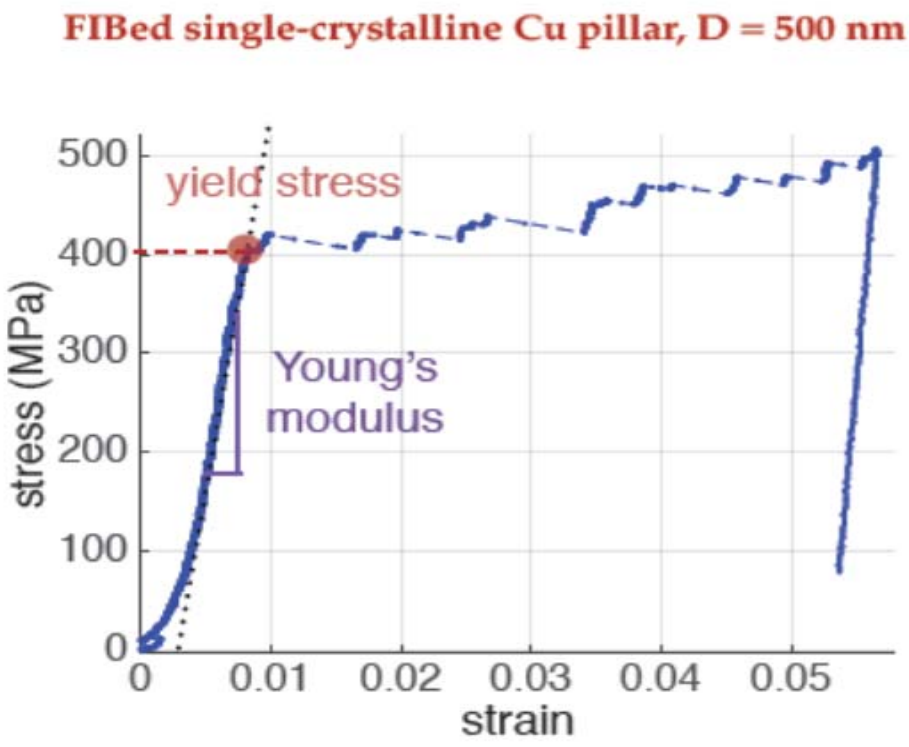


- Components of Advanced LIGO suspension system are loaded within the macroscopically elastic regime, specially about 50% of the Yield Stress.
- Metals, are known to exhibit non linear deviation from a simple linear relation between strain and stress.
- It has been shown that metals respond to varying external stress in a discontinuous way in this regime, exhibiting discrete releases of energy (**Crackling Noise Phenomenon**).
- This non-trivial mechanical noise that can propagate from the maraging steel suspension blades to the test mass is a potential up-conversion noise source for the gravitational wave detector.

Experimental Introduction







X. Ni, "Micromechanical Investigation on Crackling Noise, Crackle Meet @Pasadena" (2016)

Aim and Introduction

Non-Linear Deviation from a simple linear relation

(No Theoretical Model)

Could up-convert low frequency excitations of the metals into high frequency (Audio Band) noise in their elastic regime

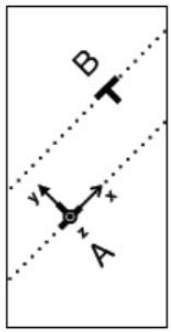
We have adopted a theoretical constitutive model conceived for the plastic regime and translated it into a code

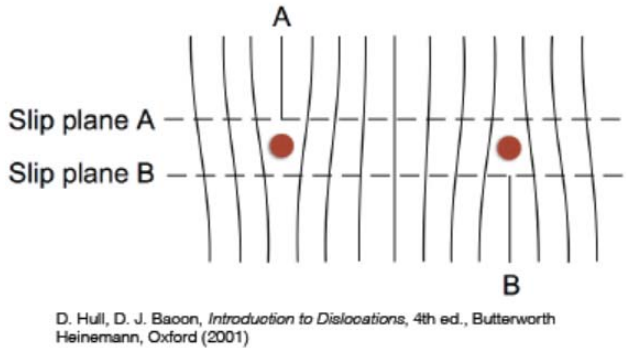
This is a numerical simulation work. The first part is focused on a parametric study where I have run several simulations at a time with varying parameters.

Theoretical Model

$$\dot{\epsilon}(\boldsymbol{r},t) = \frac{D_{const}}{G}\tau_{tot}(\boldsymbol{r},t)$$

$$\tau_{tot}(\boldsymbol{r},t) = \tau_{ext}(t) + \tau_{int}(\boldsymbol{r})$$





D. Hull, D. J. Bacon, *Introduction to Dislocations*, 4th ed., Butterworth Heinemann, Oxford (2001)

$$\tau_{ext}(t) = A\sin(\omega t + \varphi)$$

$$\tau_{int}(\boldsymbol{k}) = -\frac{G}{\pi(1-\nu)}\epsilon(\boldsymbol{k})\frac{k_x^2 k_y^2}{|\boldsymbol{k}|^2}$$

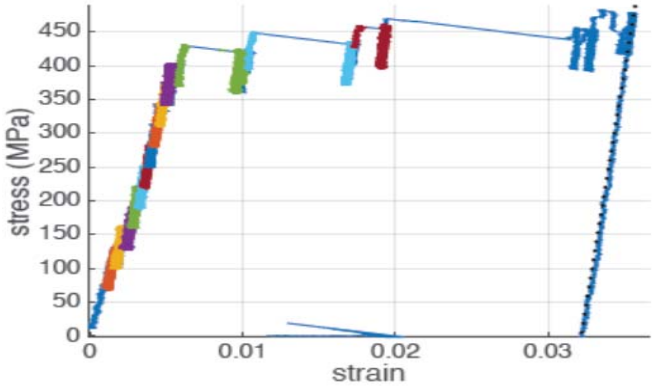
Avalanche Condition:

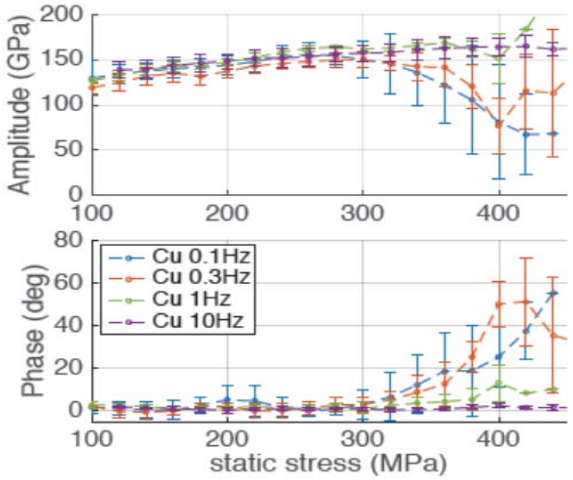
$$\tau_{Aval} = \tau_{ext} + \tau_{int} - \tau_{thr}$$

$$\tau_{Aval} > 0$$

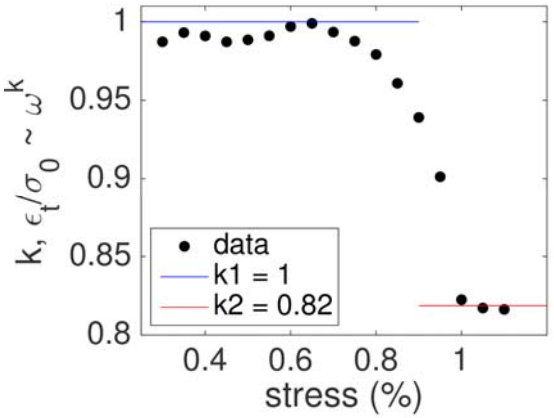
Stefanos, J., Papanikolaou, et. al. Nature 490, 517–522 (2012)
Michael Zaiser, Advances in Physics, 55:1-2, 185-245 (2006)

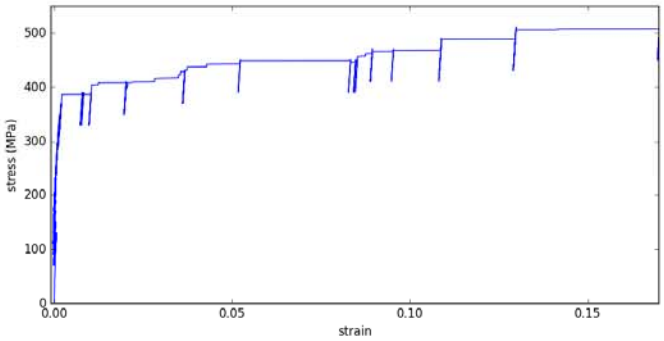
Data Analysis

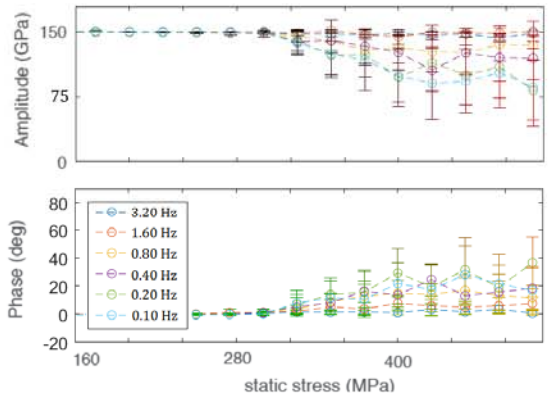




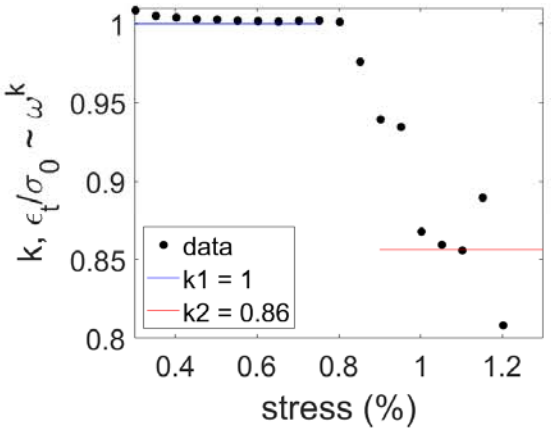
Experiment







Simulation



Fixed Parameters:

- $D = 3.1\ 10^{-4}\ 1/s$
- $C = 3000\ MPa$
- Gaussian D. - $\sigma = 1.00$

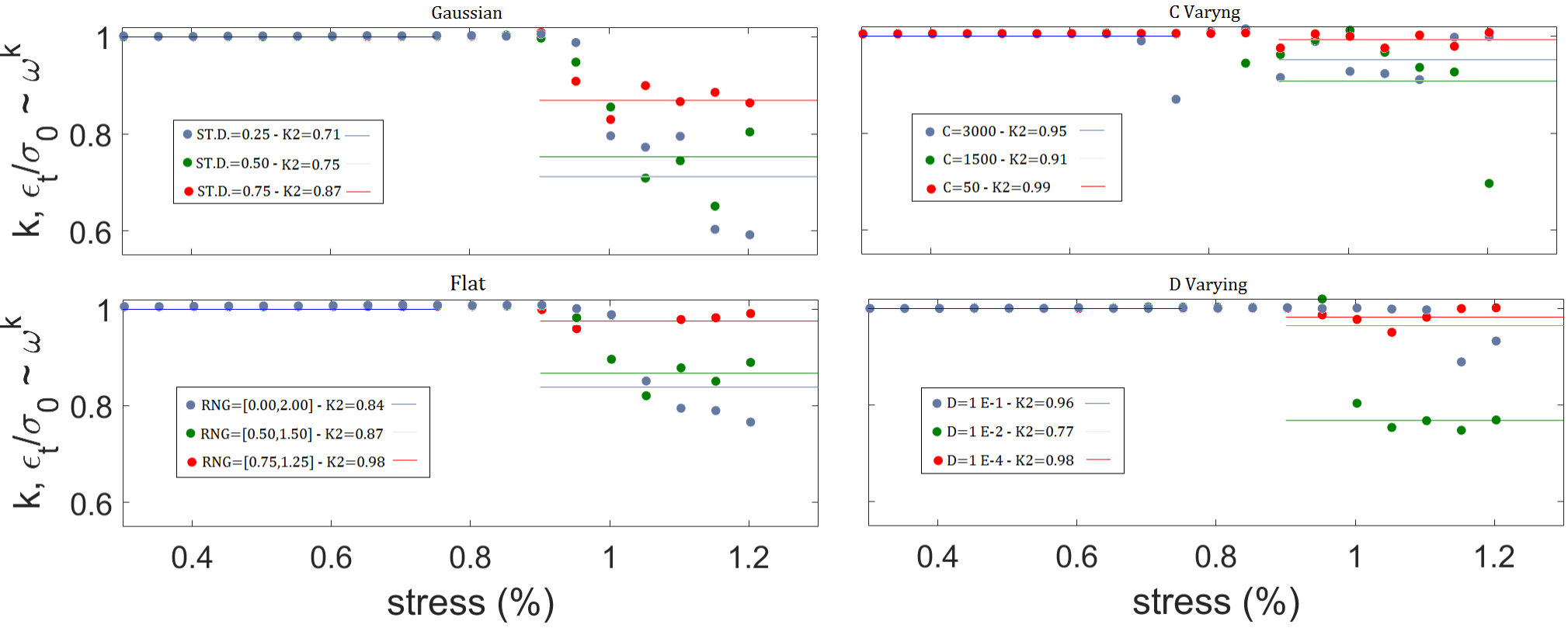
$$H(\omega) = \frac{\sigma(\omega)}{\epsilon(\omega)} = \frac{A - iB}{yr - iyi}$$
$$= H_{Re} + iH_{Im} = Ae^{i\phi}$$

$$\epsilon = \frac{1}{A}\sigma_0 e^{i(\omega t - \phi)}; \quad \epsilon_t = \frac{\omega}{A}\sigma_0 e^{i(\omega t + \frac{\pi}{2} - \phi)}$$
$$\rightarrow \frac{|\epsilon_t|}{\sigma_0} = \frac{\omega}{A} \sim \omega^1, \sim \omega^{0.82}$$

Parametric Study Results

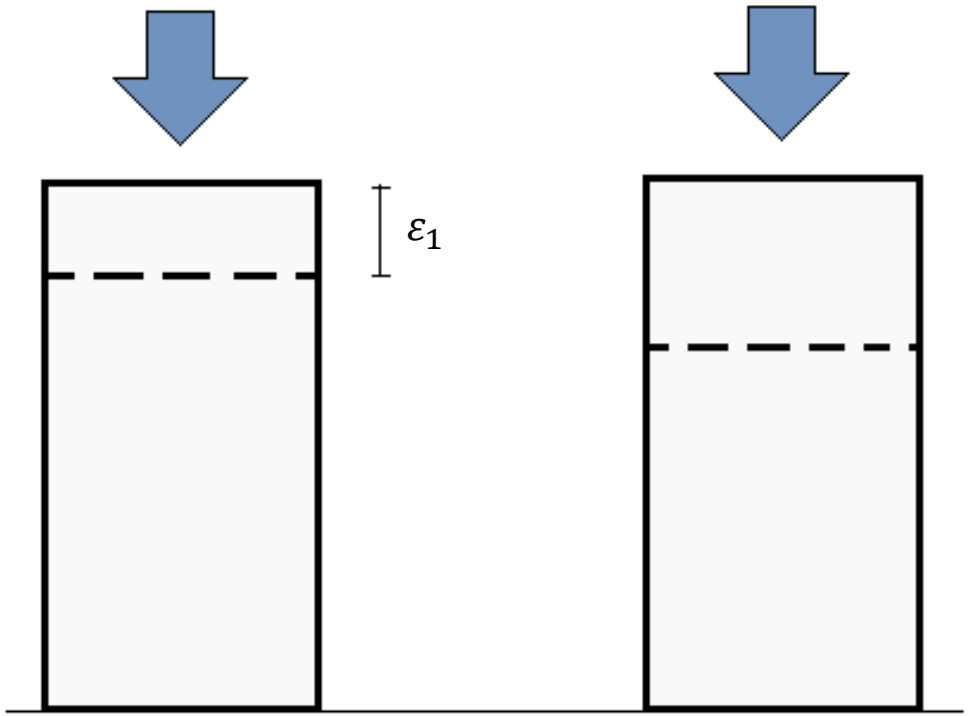
Standard Fixed Parameters:

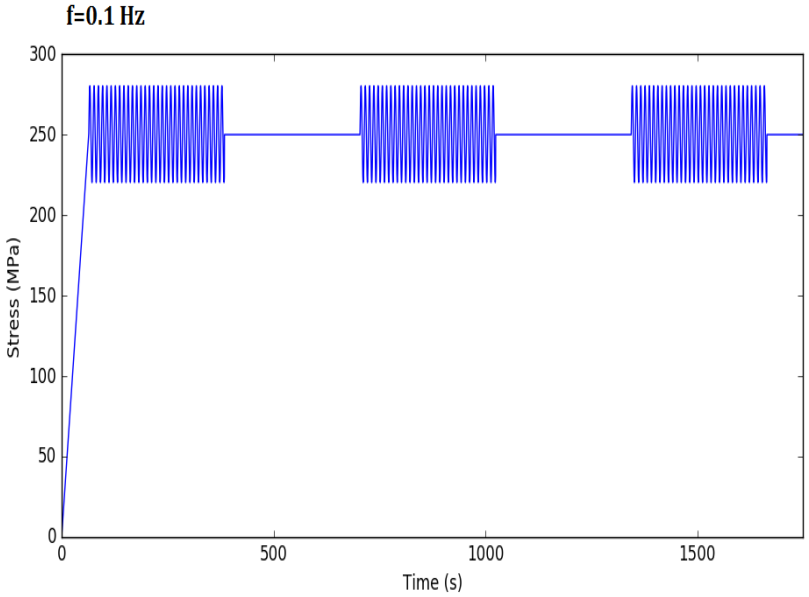
- $D = 5 \cdot 10^{-2}$
- $C = 400.0$
- Gaussian D. - $\sigma = 0.50$



Crackling Simulation

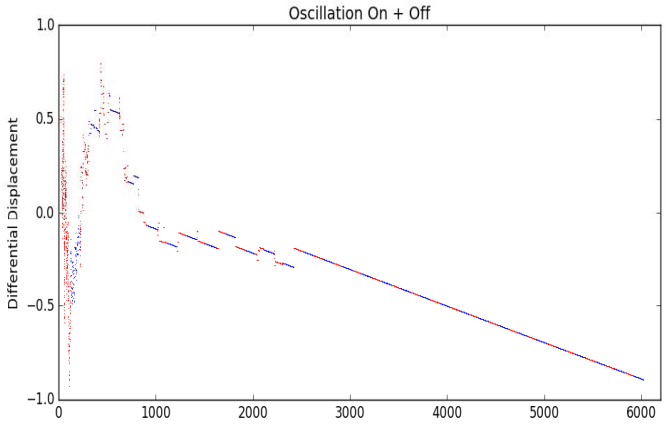
$$\tilde{\sigma}(t) = Re\{\sigma(t)\} = Acos(2\pi f\ t)$$

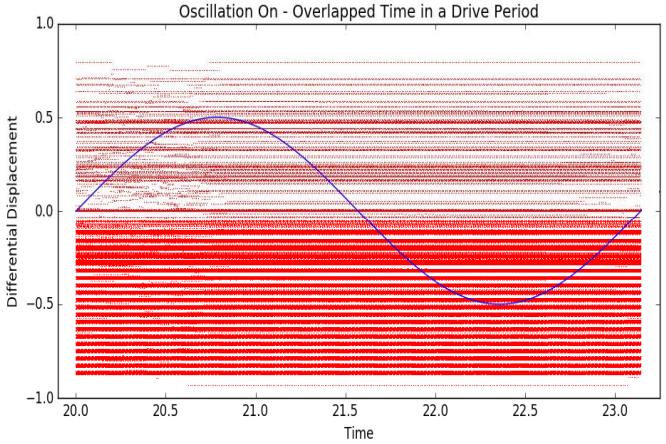


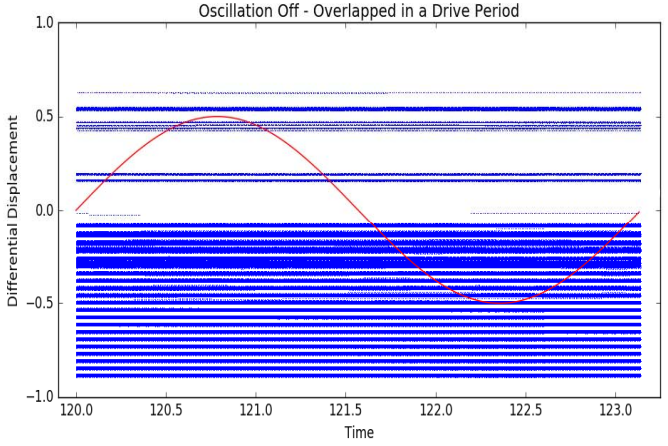


$$\Delta\varepsilon = \varepsilon_2 - \varepsilon_1$$

Crackling Experiment Results







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Future Work

- We want to implement the crackling-noise-experiment like loading condition and carry out different frequency and amplitude driving tests at constant nominal elastic stress, for the demodulation studies of the Crackling Noise;

- In order to directly apply the study in micro/nano scale to LIGO's concern, we want to input the developed micro-mechanical simulation results for the crackling noise form into the scaling model, and predict for the crackling noise propagated to the blade tip under prescribed loading [1].

[1] G.Vajente, "Crackling Noise: Scaling Model", LIGO-T1600246-v2 (2016)

Special Thanks

- **Xiaoyue Ni**, I want to thank you for all you have taught me. The knowledge and wisdom you have imparted upon me has been a great help and support.

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