Micromechanical Investigations on Crackling Noise

SURF Project 2016 - California Institute of Technology - Pasadena

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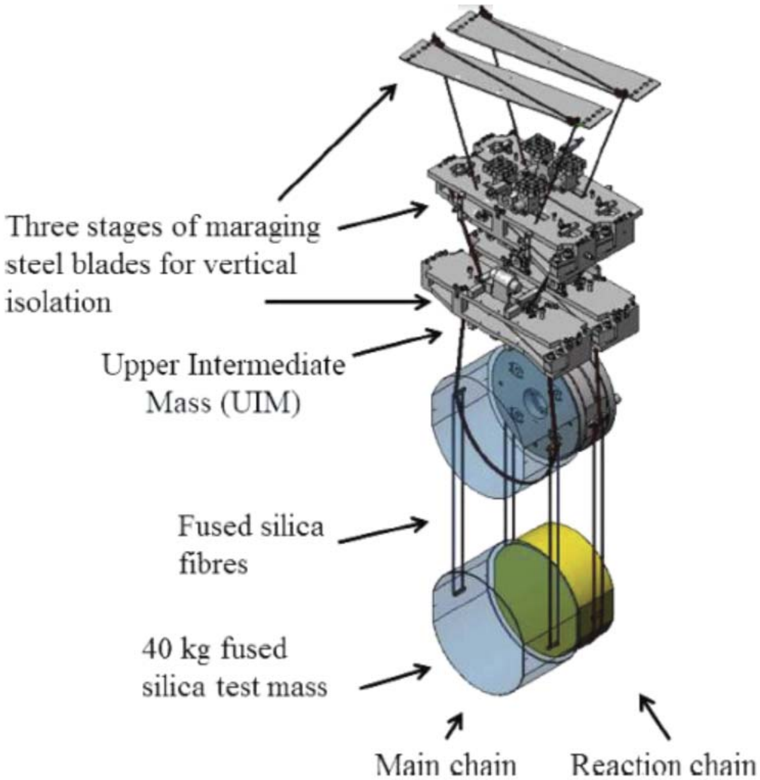
Aim and Introduction



- Advanced LIGO suspensions are loaded within the macroscopically elastic regime
- Non linear deviation from a simple linear relation between strain and stress.
- Discrete releases of energy (**Crackling Noise Phenomenon**).
- Noise can propagate to the test mass and it is a potential up-conversion noise source.

Aim and Introduction

Non-Linear Deviation from a simple linear relation

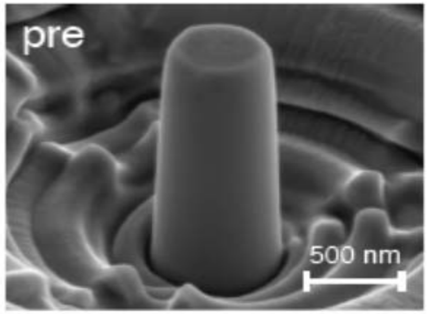
(No Theoretical Model)

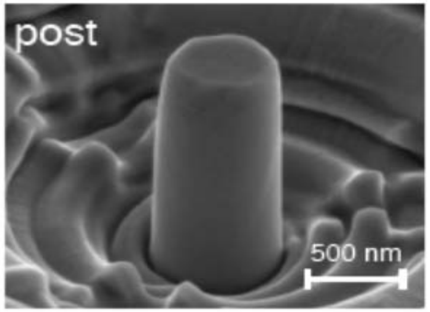
Could up-convert low frequency excitations of the metals into high frequency (Audio Band) noise in their elastic regime

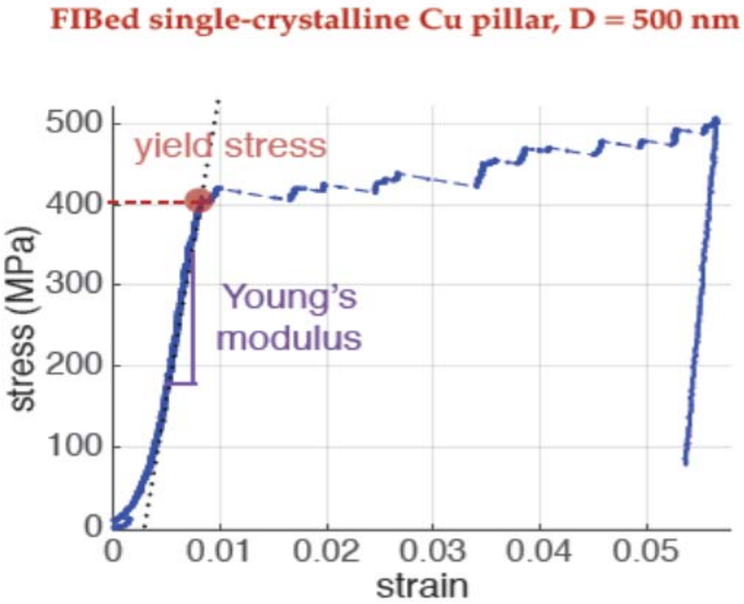
We have adopted a theoretical constitutive model conceived for the plastic regime and translated it into a code

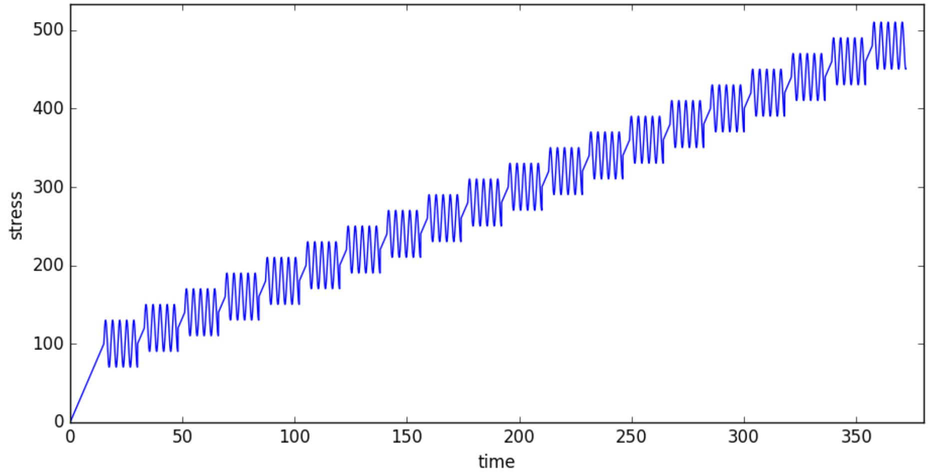
This is a numerical simulation work. The first part is focused on a parametric study where I have run several simulations at a time with varying parameters.

Experimental Introduction





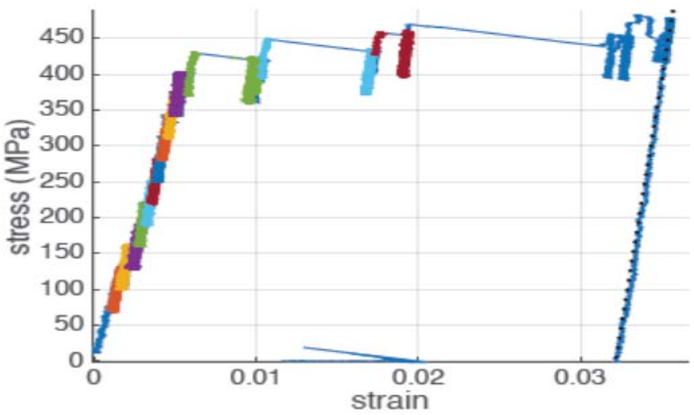


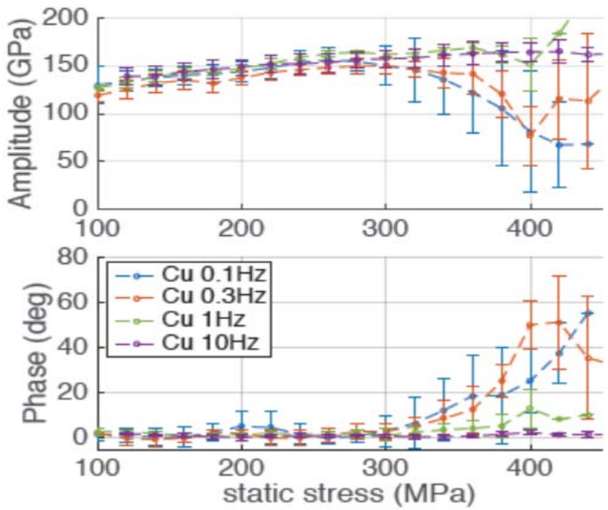


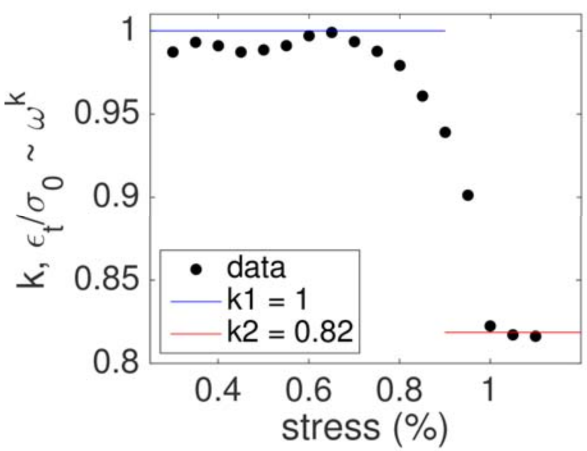
X. Ni, "Micromechanical Investigation on Crackling Noise, Crackle Meet @Pasadena" (2016)

Data Analysis

Experiment







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

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

Theoretical Model

Microplasticity:

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

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

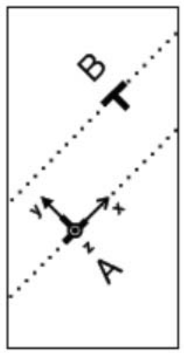
$$\tau_{ext}(t) = A \sin(\omega t + \varphi)$$

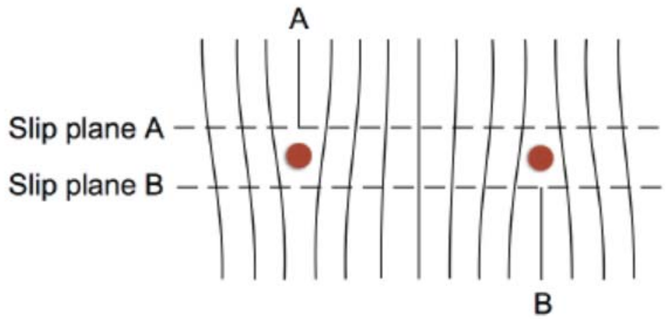
$$\tau_{int}(\boldsymbol{k}) = -\frac{G}{\pi(1-\nu)} \epsilon(\boldsymbol{k}) \frac{k_x^2 k_y^2}{|\boldsymbol{k}|^2} = -C\, \epsilon(\boldsymbol{k}) \frac{k_x^2 k_y^2}{|\boldsymbol{k}|^2}$$

Avalanche Condition:

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

$$\tau_{Aval} > 0$$



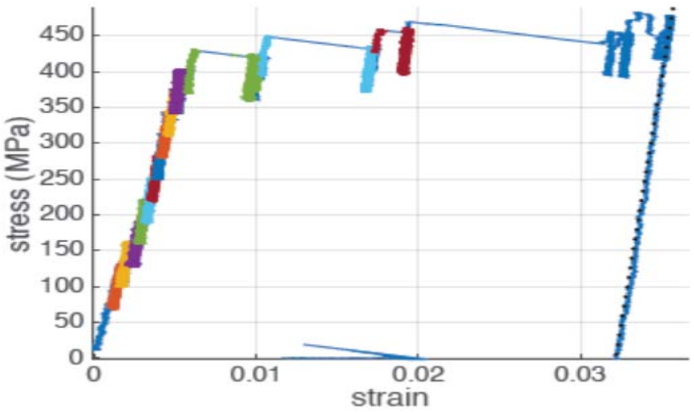


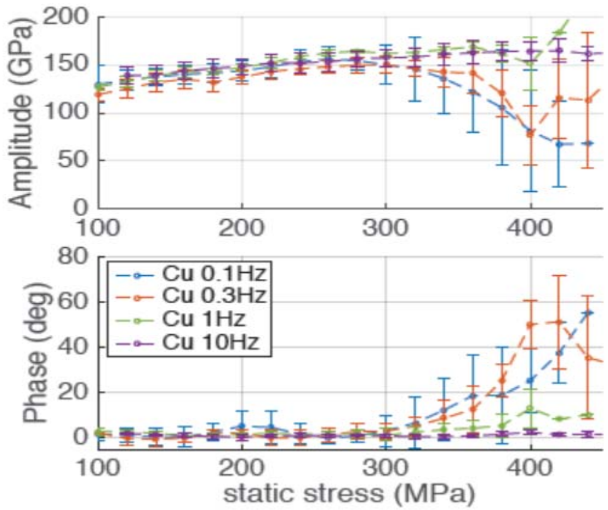
D. Hull, D. J. Bacon, *Introduction to Dislocations*, 4th ed., Butterworth Heinemann, Oxford (2001)

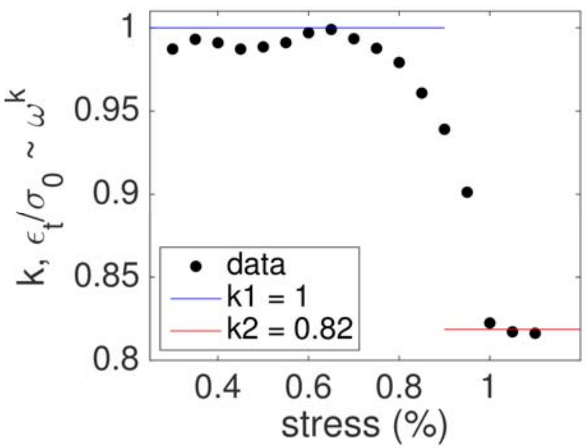
Stefanos, J., Papanikolaou, et. al. Nature 490, 517–522 (2012)
Michael Zaiser, Advances in Physics, 55:1-2, 185-245 (2006)

Data Analysis

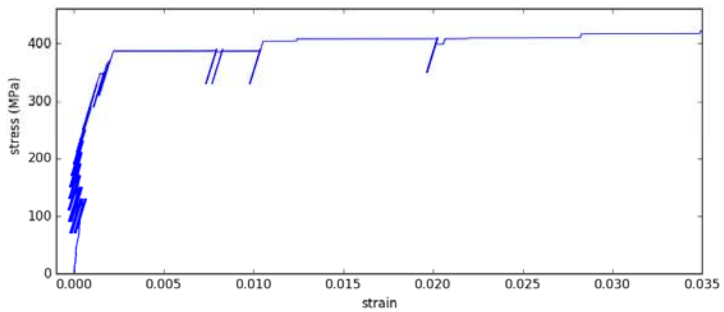
Experiment

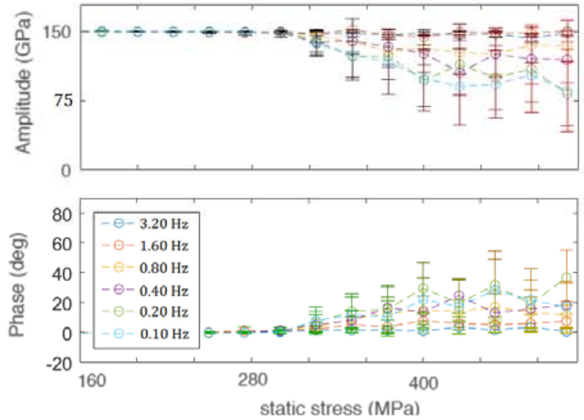


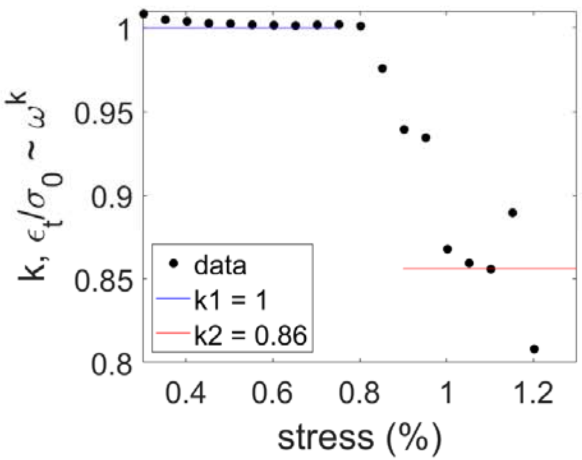




Simulation







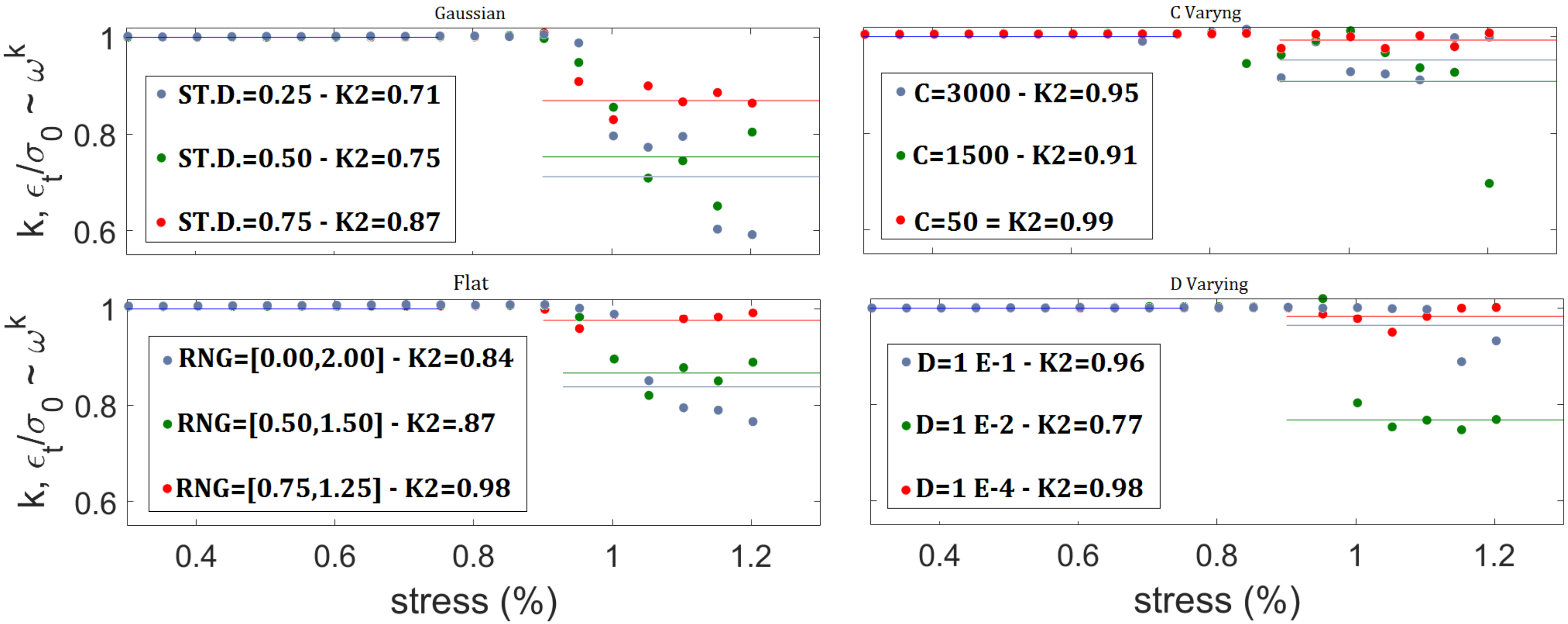
Fixed Parameters:

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

Parametric Study Results

Standard Fixed Parameters:

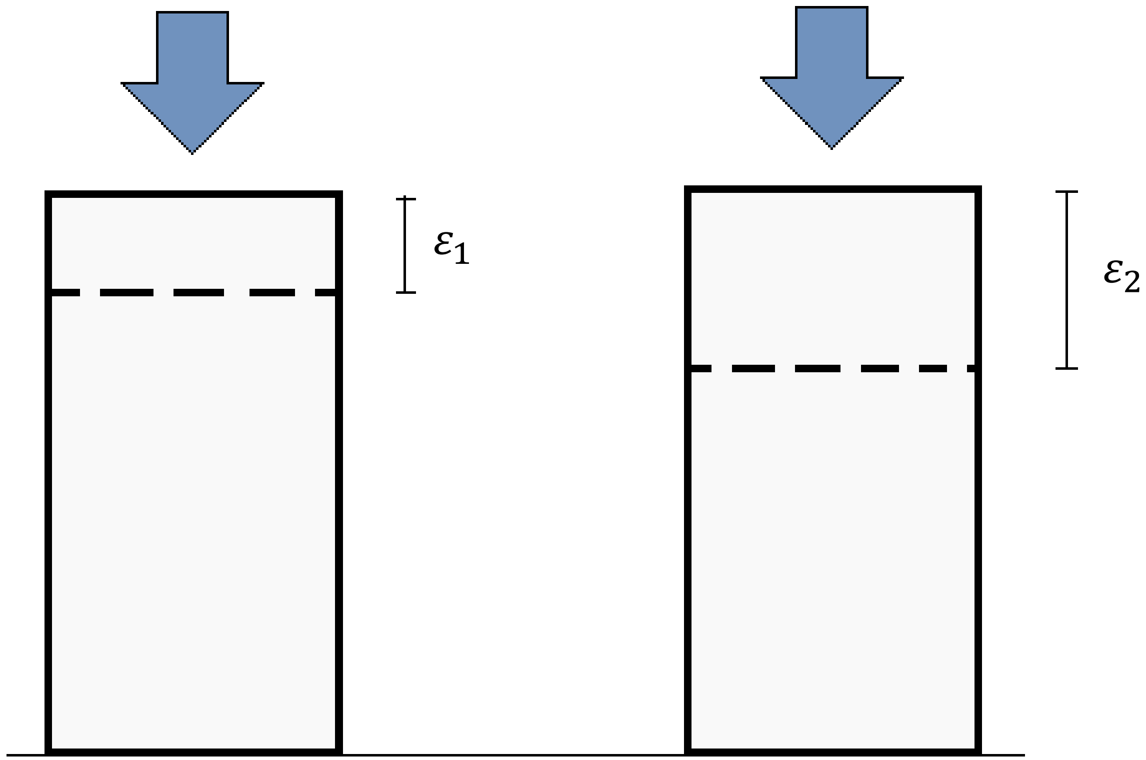
- $D = 5 \cdot 10^{-2}$
- $C = 400.0$
- Gaussian D. - $\sigma = 0.50$



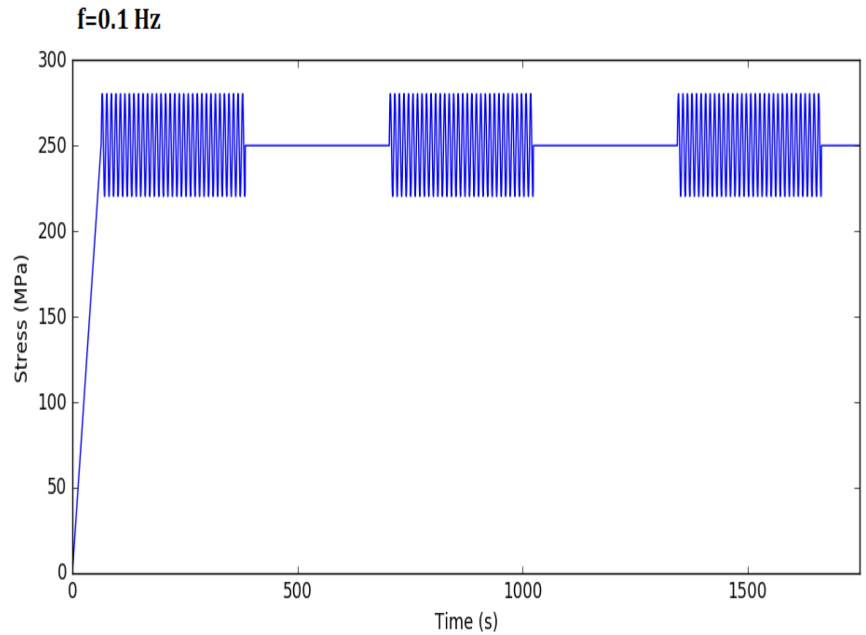
$$\dot{\epsilon}(\boldsymbol{r},t) = \frac{D}{G}\tau_{tot}(\boldsymbol{r},t) \qquad \tau_{int}(\boldsymbol{k}) = -C\,\epsilon(\boldsymbol{k})\frac{k_x^2 k_y^2}{|\boldsymbol{k}|^2}$$

Crackling Simulation

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



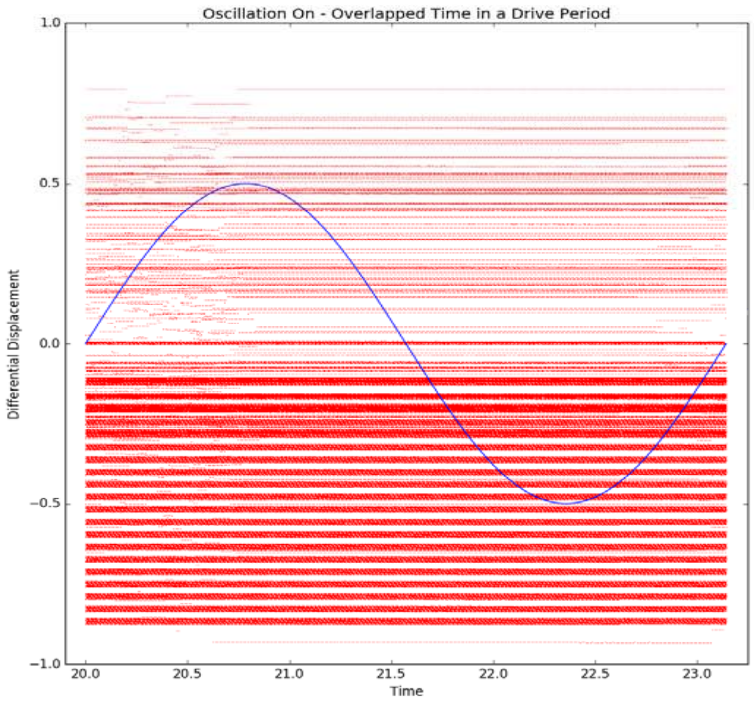
$$\Delta\varepsilon = \varepsilon_2 - \varepsilon_1$$

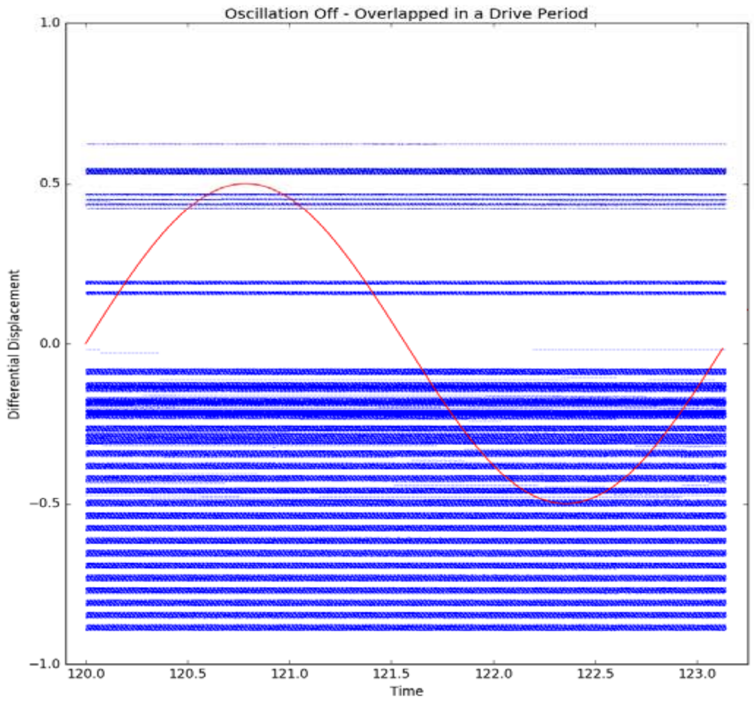


Crackling Experiment Results

Fixed Parameters:

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





Future Work

- Implement the crackling-noise-experiment like loading condition and carry out different frequency;
- Imput the developed micro-mechanical simulation results into the scaling model [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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