LIGO-G1701304

SEARCH FOR AVALANCHES OF ENTANGLED DISLOCATIONS AS A SOURCE OF DISSIPATION AND MECHANICAL NOISE

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PROBLEM

Recent measurements have shown increased dissipation and the appearance of random low frequency noise in metal flexures [1]. These effects have been attributed to avalanches of dislocations, a phenomenon know as Self Organized Criticality. This experiment is trying to detect these strange effects.

INTRODUCTION

In 1927 A.L. Kimball and D.E. Lovell made an experiment with the intention of studying internal friction in solids. They mounted a round rod in cantilever and monitored the sag of the rod end. They found that the sag deviates right (or left) if the rod is rotating clockwise (or counterclockwise) , see Figure 1 . This deviation was observed to be constant above 1 Hz and is now called the material loss angle.

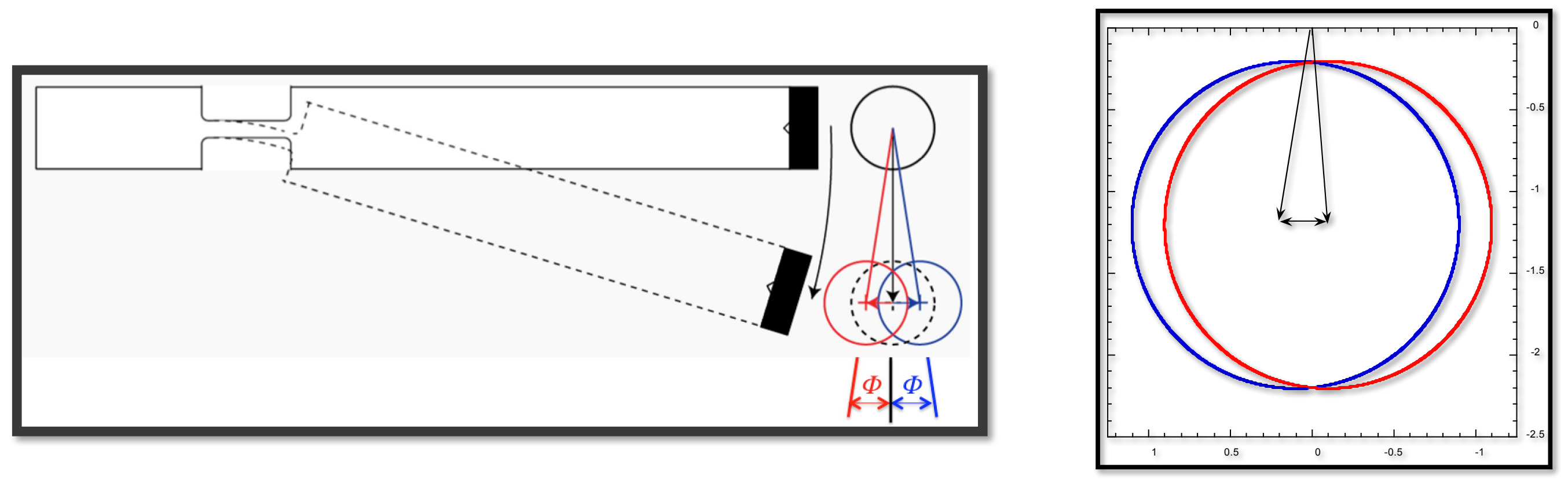


Figure 1: Experiment Schematic (left) and equilibrium position fluctuation (right)

This experiment is a repetition of the experiment with the implementation of a stepper motor to explore arbitrarily low frequencies, a CCD microscope to achieve 60 nm resolution, and a flexure made of the material under study to better localize and control the bend.

MOTIVATION

At frequencies below 1 Hz, it is expected that the loss angle will increase because of collective dislocation movement. The experiment is also attempting to measure the effects of individual avalanches of entangled dislocations which should show up as random motion around an average loss angle at very low frequency. This observation would strengthen the theory of dislocation SOC as the source of excess noise in metal flexures. [2]

THE EXPERIMENT

A test wire is put under stress as shown in Figure 2. On the left, attached to the frame, is the stepper motor used to control the rotation of the test wire. Attached to the motor is the metal flexure with the end connected to the noise reduction system. On the right, is the microscope camera pointed at the end of the flexure for the purpose of capturing images as the flexure rotates.

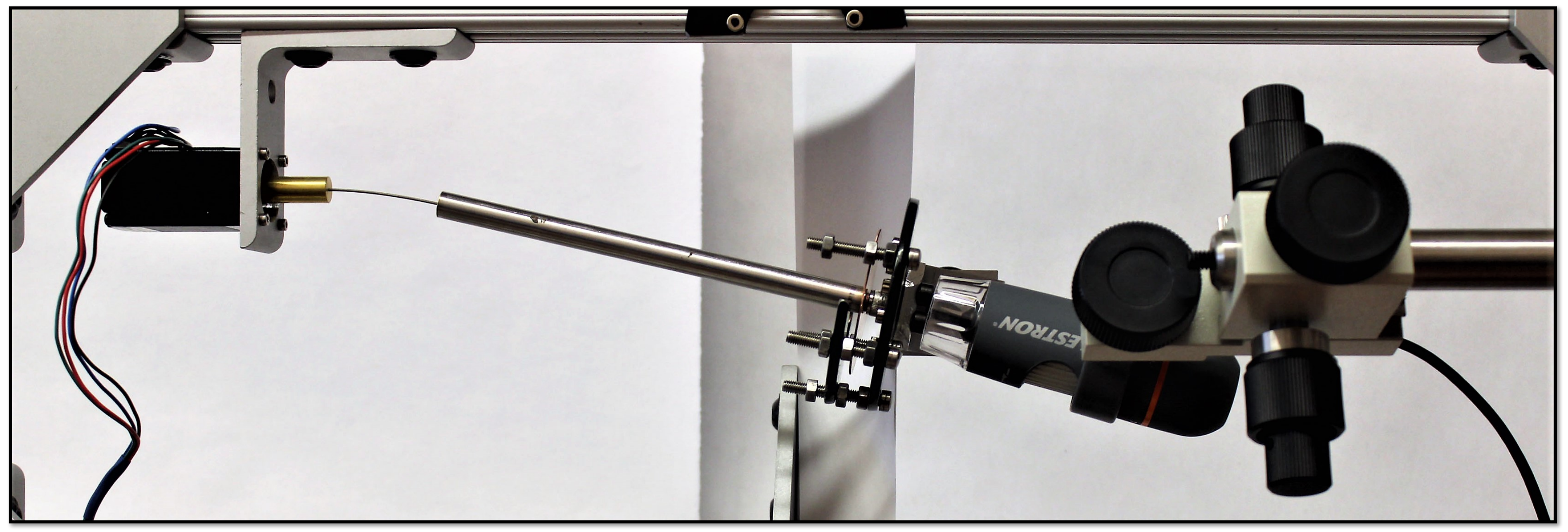


Figure 2: Experimental Set-up. The entire frame is suspended from a GAS seismic filter. The experiment is housed in a thick wall Styrofoam box to mitigate air conditioning wind noise and thermal fluctuations.

TEST WIRE

The wire flexure is easily customizable to test different materials. Excess losses have been observed in high carbon steel, copper-beryllium, tungsten and maraging steel. This experiment will test these materials to check the theory, as well as glassy metals, which being free of dislocations, should not show the problem.

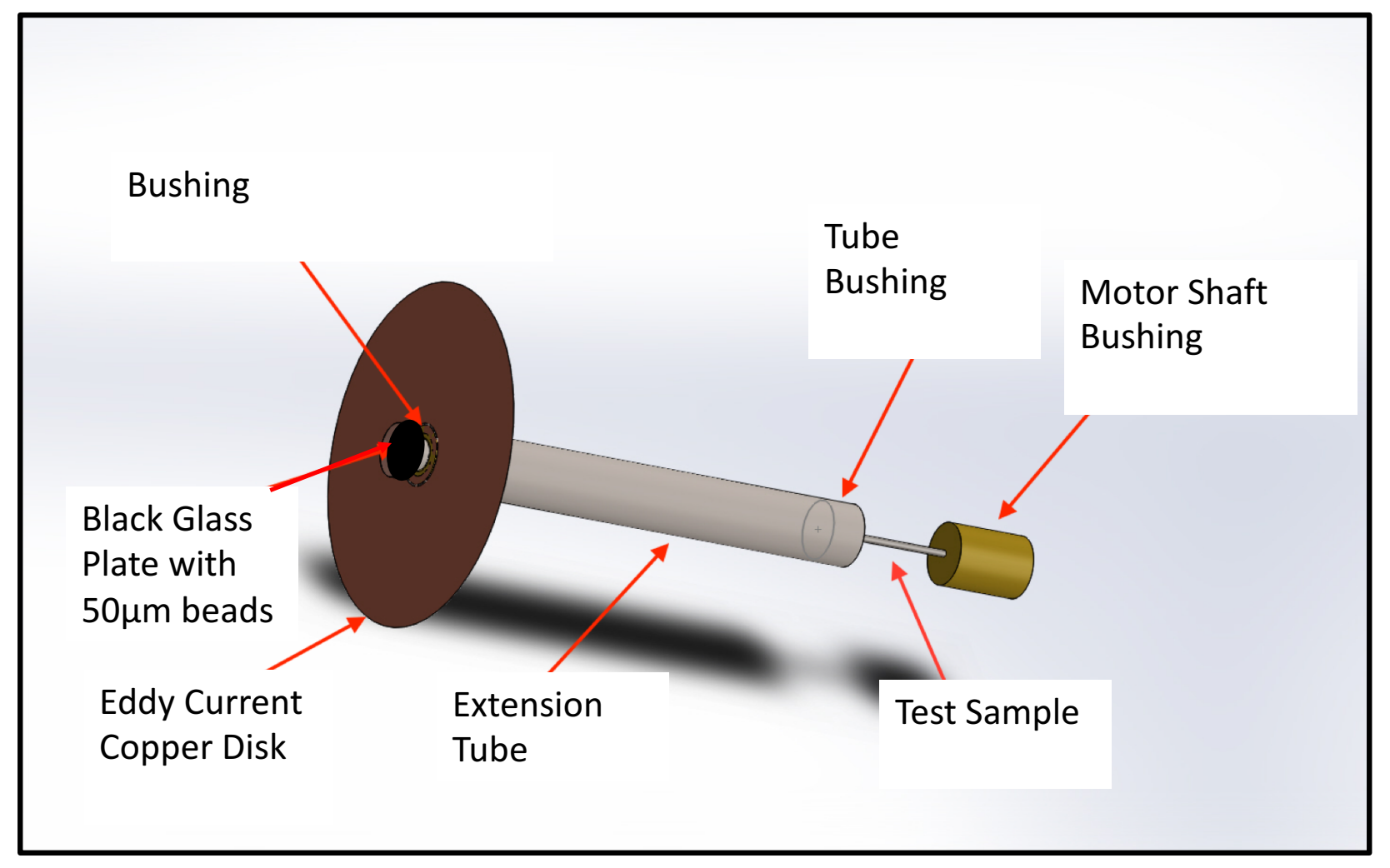
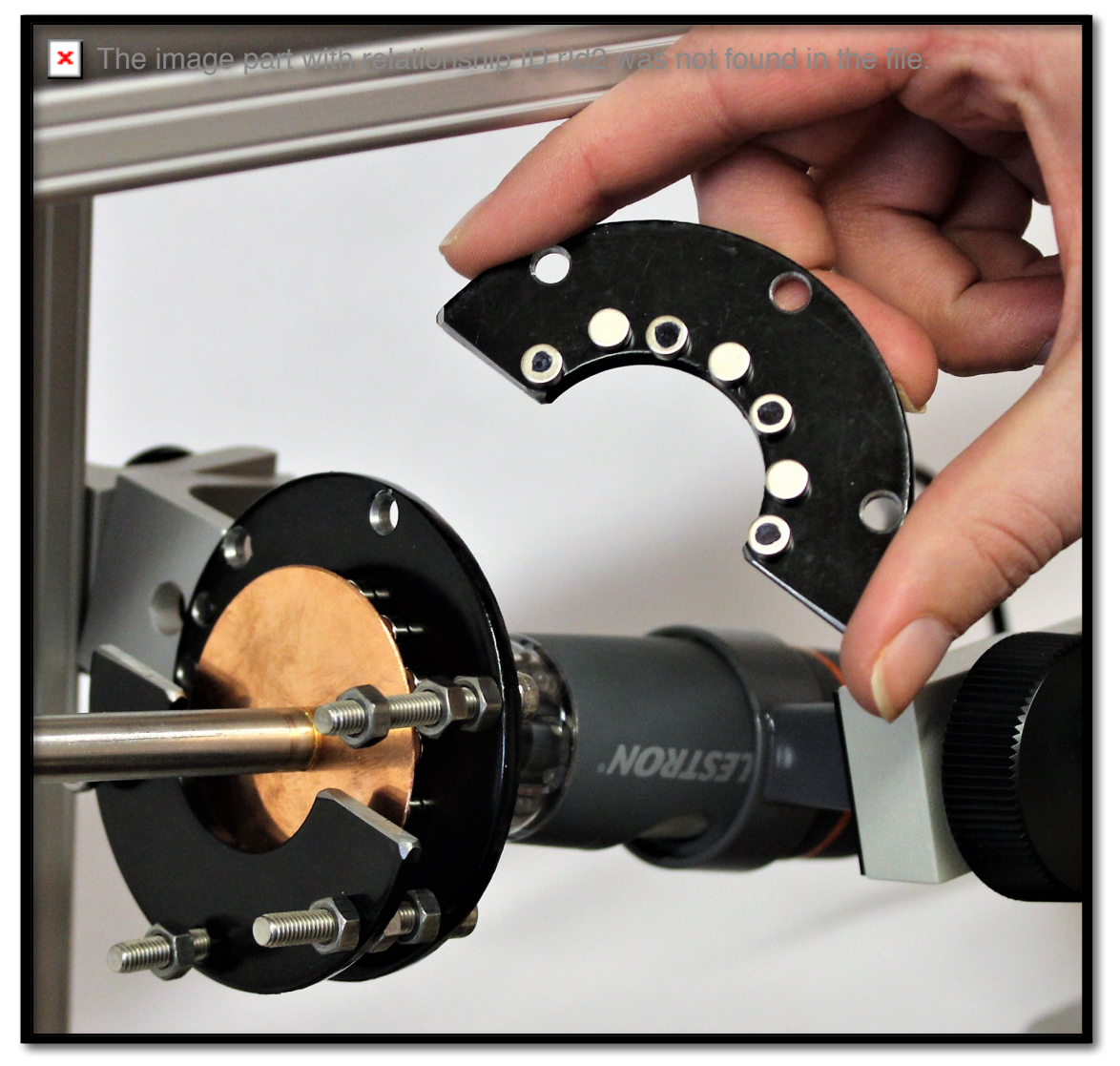
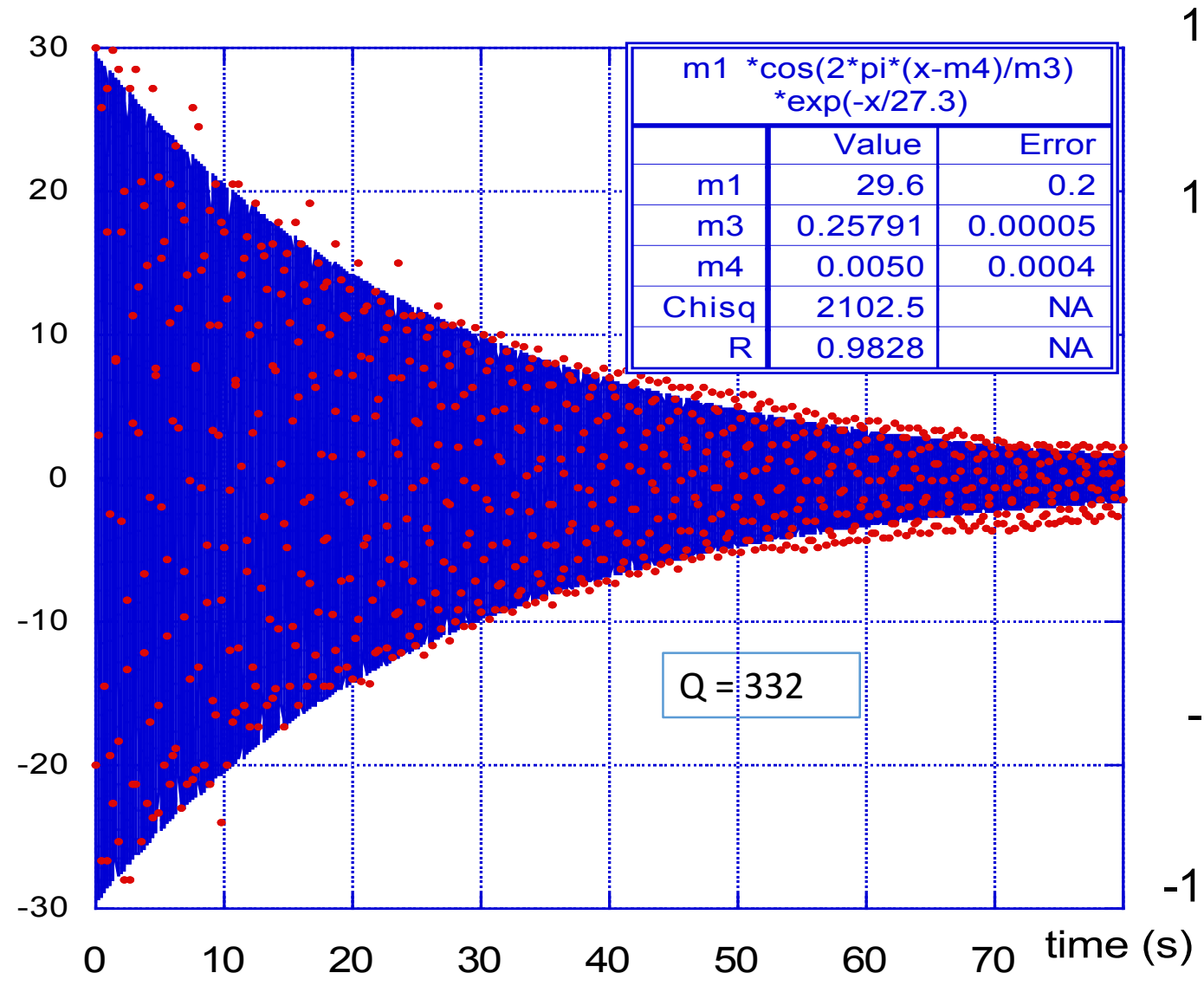


Figure 3: Test wire housing components.

EDDY CURRENT DAMPER

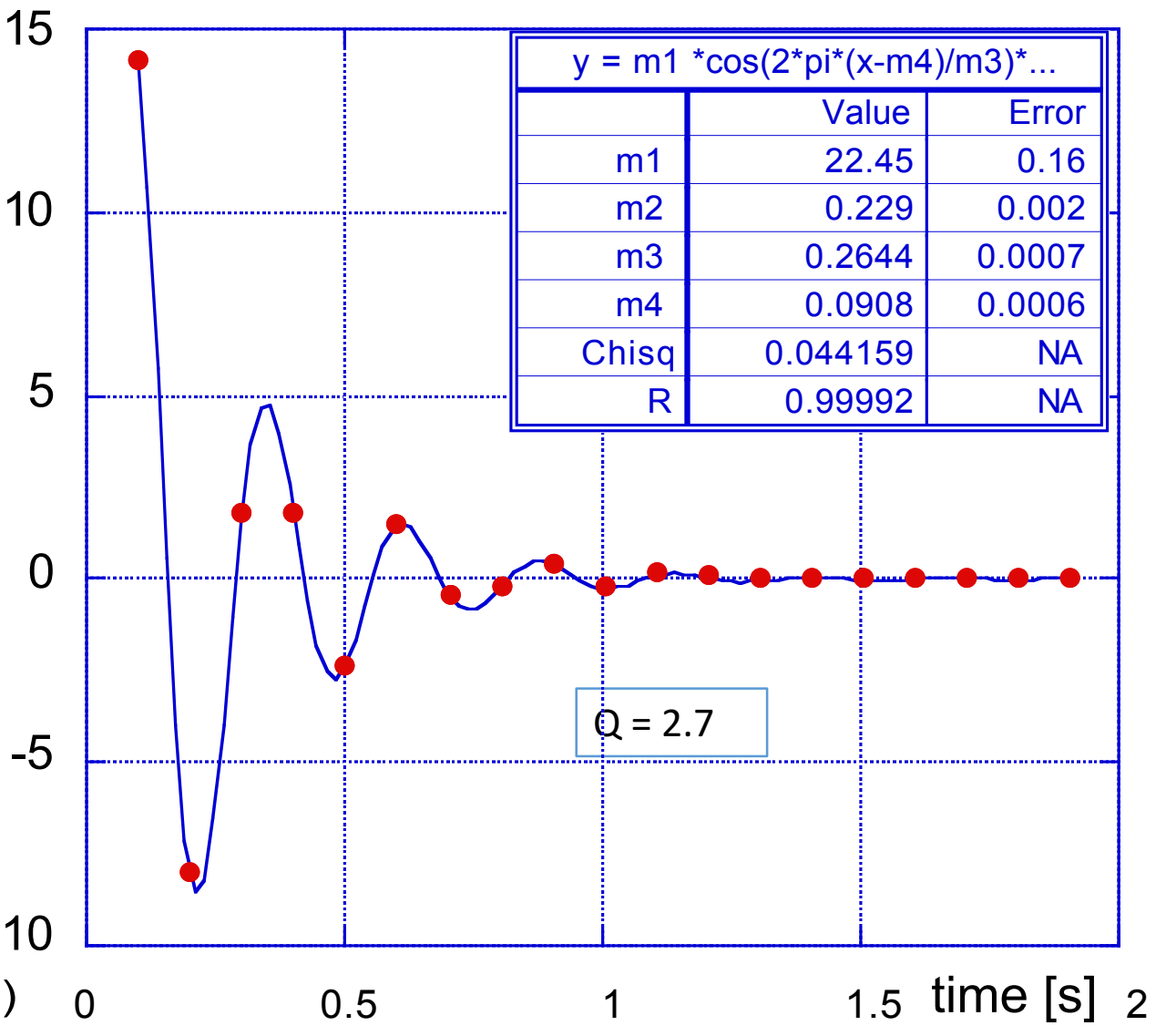
The currents induced by the ring of magnets in the copper ring is sufficient to critically damp the oscillation of the extension rod, as illustrated. This kills all residual seismic and motor vibrations.





m1 *cos(2*pi*(x-m4)/m3) *exp(-x/27.3)	Value	Error
m1	29.6	0.2
m3	0.25791	0.00005
m4	0.0050	0.0004
Chisq	2102.5	NA
R	0.9828	NA

Figure 4: Oscillation without damper.



y = m1 *cos(2*pi*(x-m4)/m3)*...	Value	Error
m1	22.45	0.16
m2	0.229	0.002
m3	0.2644	0.0007
m4	0.0908	0.0006
Chisq	0.044159	NA
R	0.99992	NA

Figure 5: Oscillation with damper

STEPPER MOTOR

The stepper motor has 200 steps per turn, and will be operated in microstep mode with 256 microsteps/step which may produce stepping noise at 51,200 times the chosen rotational frequency and harmonics. Since the motor is not subject to a significant load, it can be operated at low current-low torque. It is expected to be operated at 0.08 A, creating ~60 mW power dissipation in the motor resistance of 9 Ω.

A radiator with thermal bridge to the outside will evacuate the heat of the motor from the Styrofoam box. The heating time constant is 10-15 minutes. It was also measured that the motor's power consumption is independent of the rotational speed, therefore, it is not necessary to implement dead times when the rotational speed is changed.

IMAGE TRACKING

To determine the position of the end of the rod, 49 micron diameter glass beads are adhered with a thin layer of wax on a black glass target. Beads located near the rotation center will be imaged using a microscope and tracked. The microscope has eight LEDs whose reflection on the beads appear as a daisy shape. The daisy will be fitted to a crown of eight ellipsoidal Gaussians to achieve a precision of 30nm, see Figure 9 for a 1D fit. With a sag of 3 cm this results in 1 μradian sensitivity, to be compared to a typical metal loss angle of 100 μradian.

Figure 6: Microscope and LED view.

Figure 7: beads

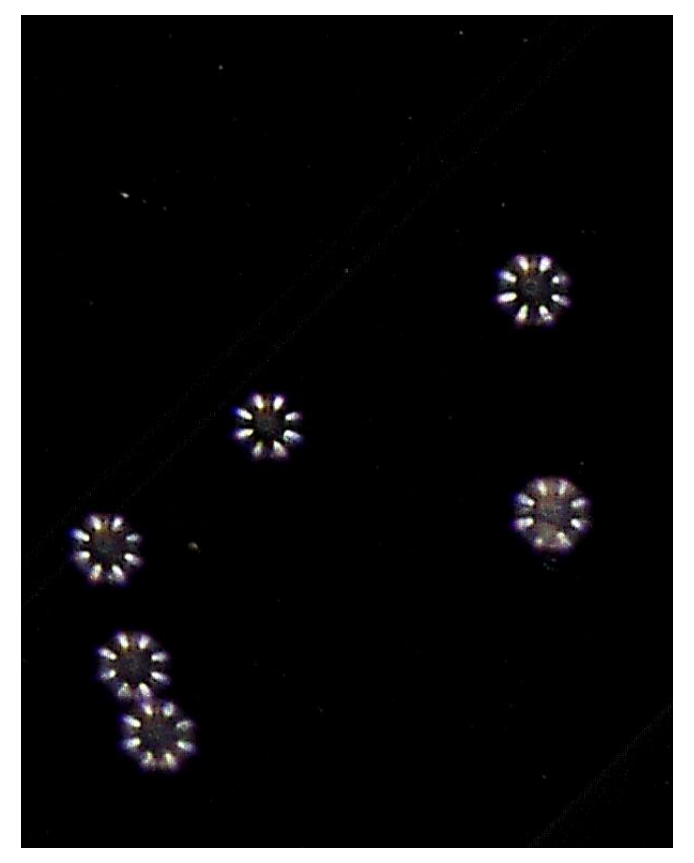


Figure 8: zoomed bead

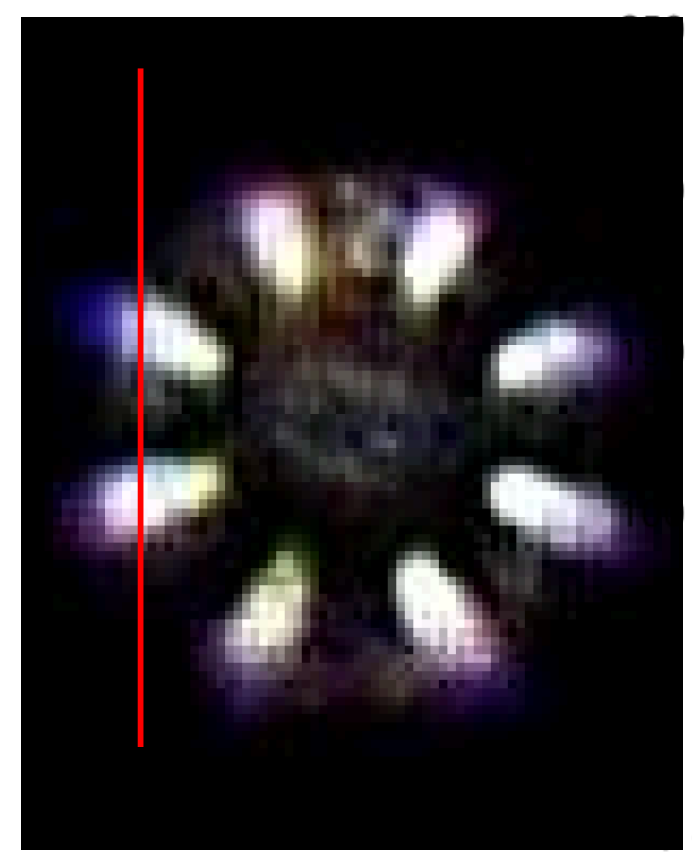
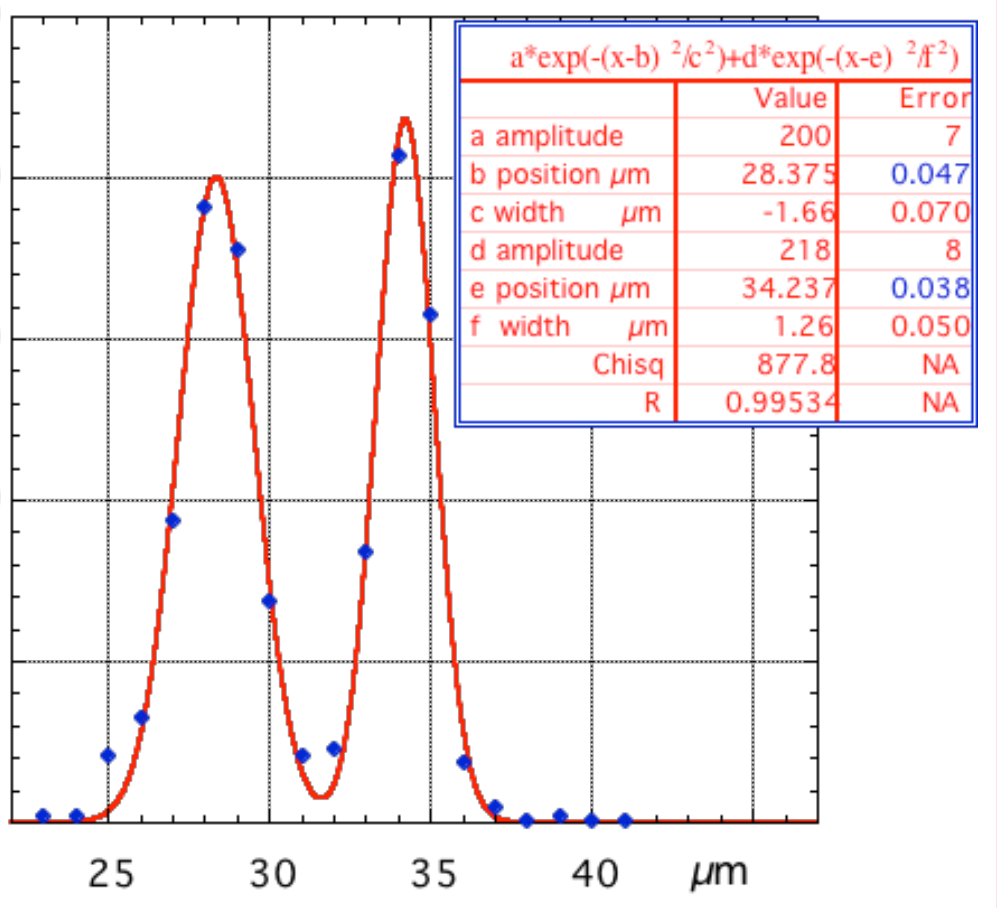


Figure 9 : Fitting of daisy slice achieving 50nm precision.



a*exp(-(x-b)^2/c^2)+d*exp(-(x-e)^2/f^2)	Value	Error
a amplitude	200	7
b position μm	28.375	0.047
c width μm	-1.66	0.070
d amplitude	218	8
e position μm	34.237	0.038
f width μm	1.26	0.050
Chisq	877.8	NA
R	0.99534	NA

CONCLUSIONS

We demonstrated the feasibility of making measurements of loss angle with a precision of μradian with arbitrarily low rotational speed. If dislocation avalanches exist, this experiment should be able to detect them.

[1] *Internal Friction in Solids.* A. Kimball, D. Lovell, Phys. (1927)
[2] *The role of Self-Organized Criticality in elasticity of metallic springs: Observations of a new dissipation regime.* R. DeSalvo, A. DiCintio, M. Lundin, Eur. Phys. J. (2011)
[3] *Unaccounted source of systematic errors in measurements of the Newtonian gravitational constant G.* R. DeSalvo, Phys (2015)