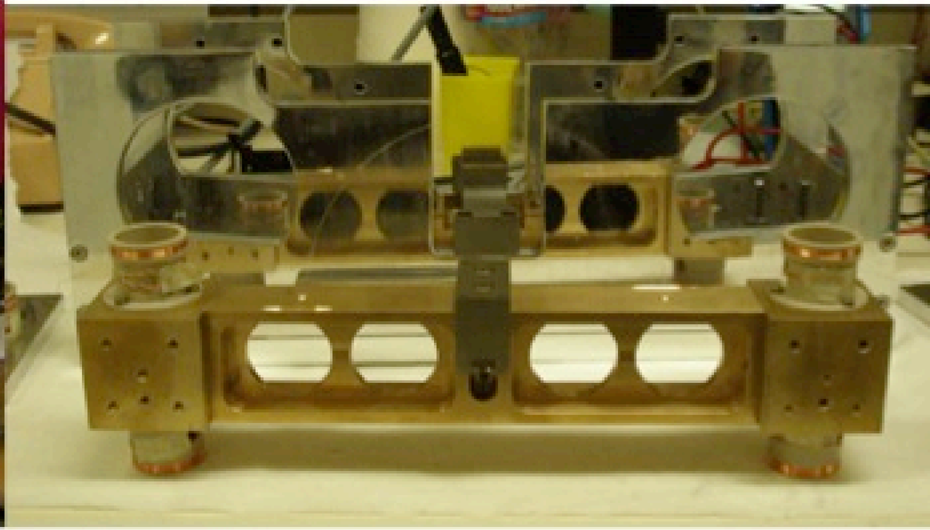
Tiltmeter studies

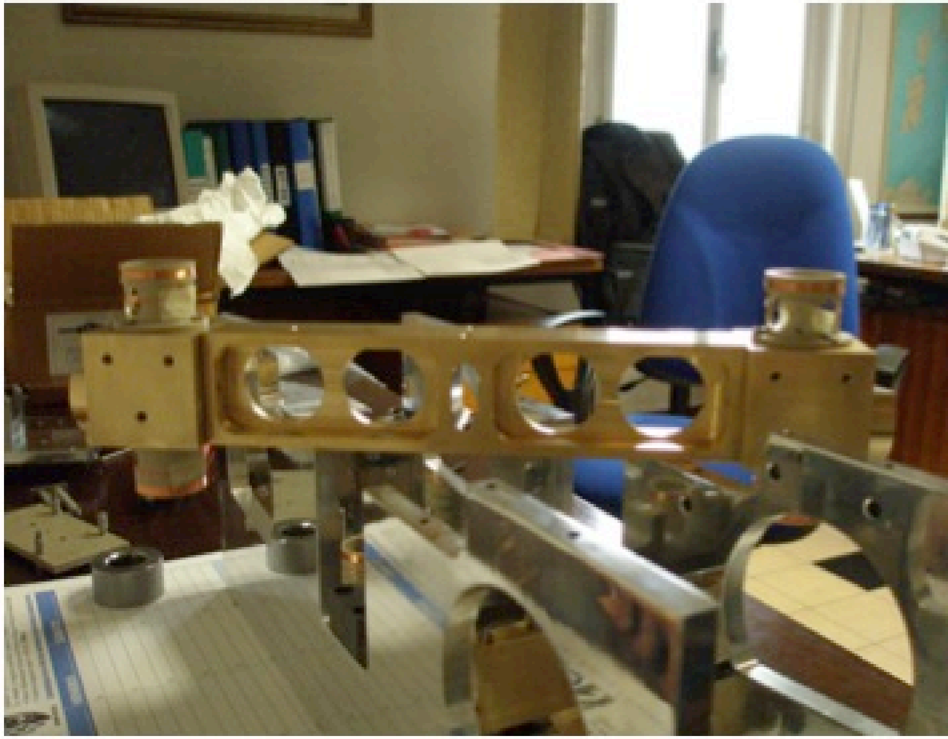



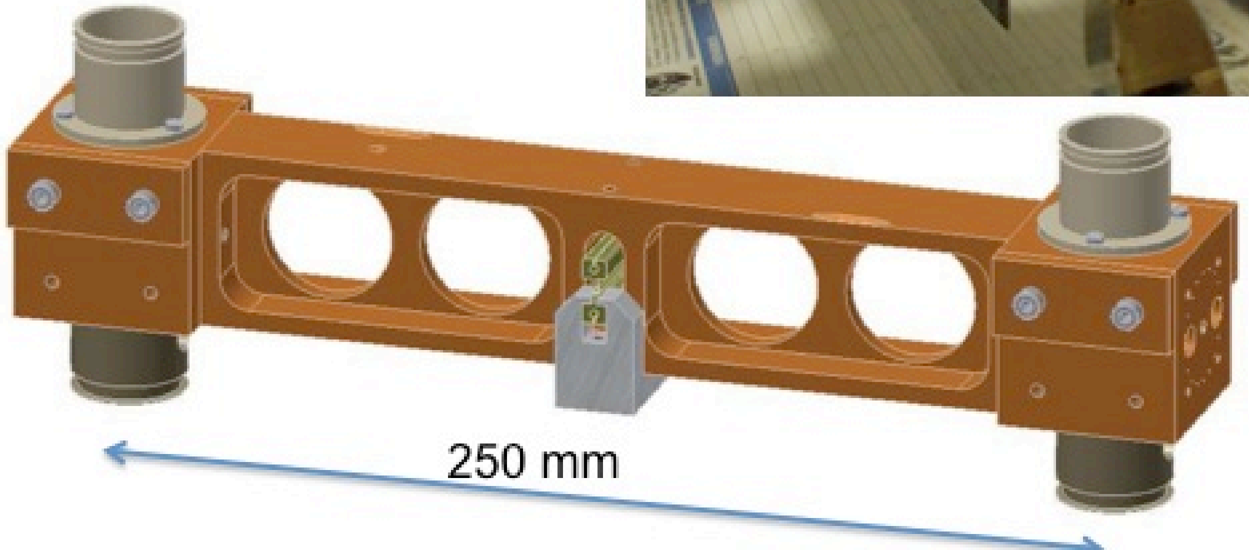
M. Asador, A. Bhawal, R. Desalvo,
V. Dergachev, A. Lottarini, Y. Minenkov,
A. Rodionov, A. O'Toole, G. Pu

LVC meeting, Budapest, September 22nd 2009 LIGO-G0900814

Why a Balance tiltmeter

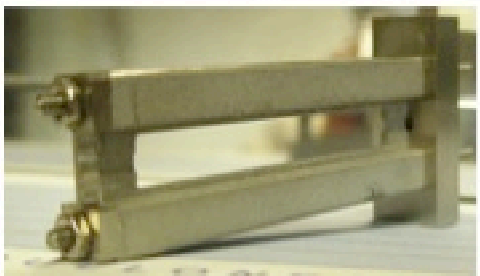
- Compact, portable
- UHV compatible
- Can work inside the Virgo and LIGO vacuum chambers

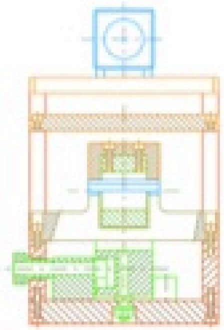


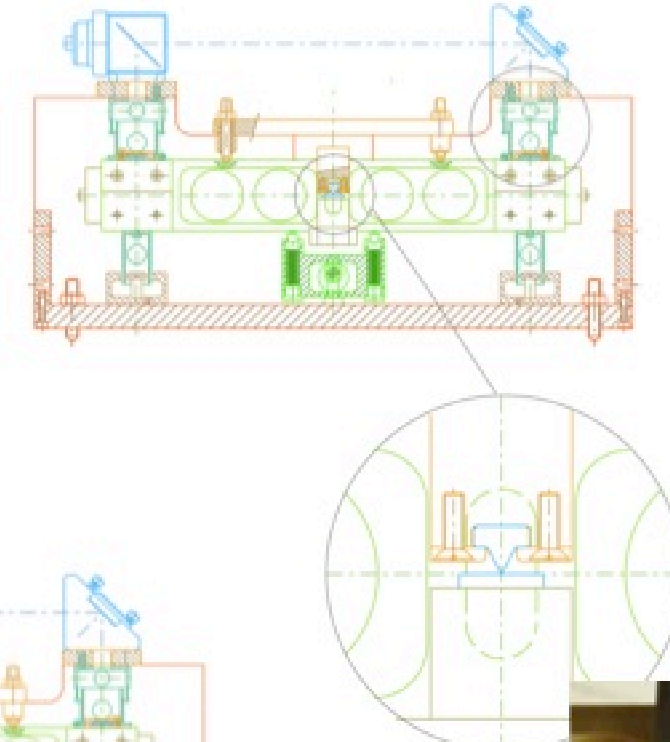


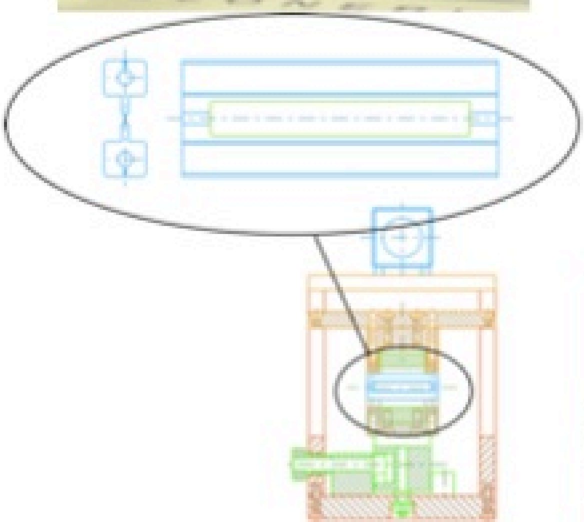
Flexure or knife-edge hinge?

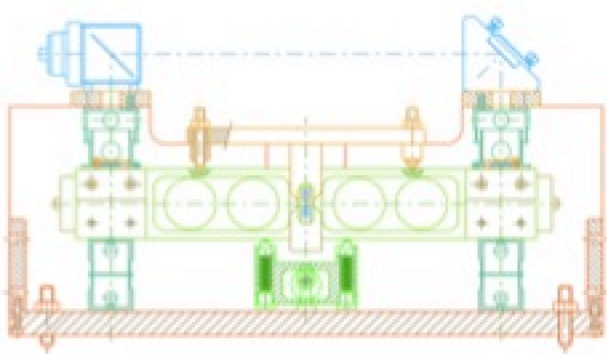
- Mechanics designed to compare the two options

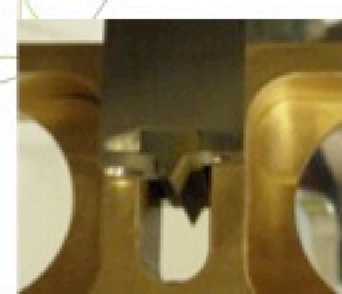




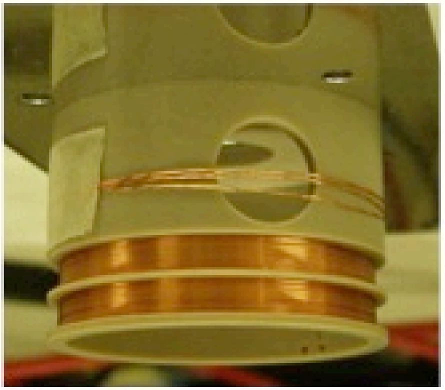




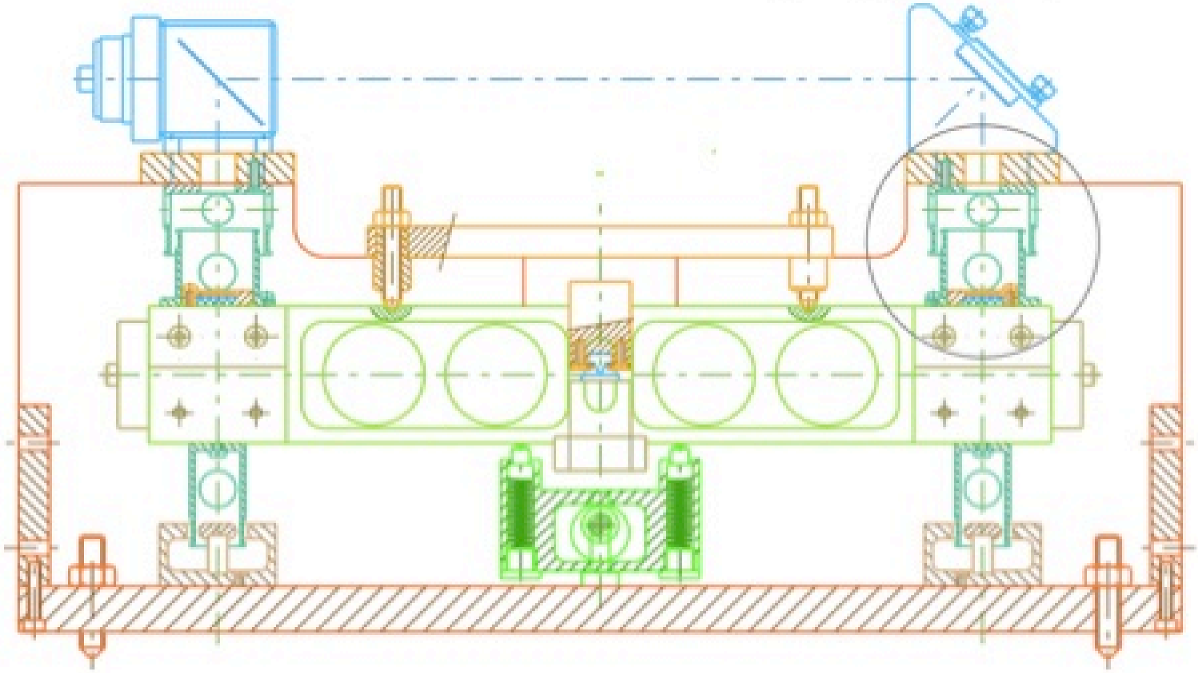


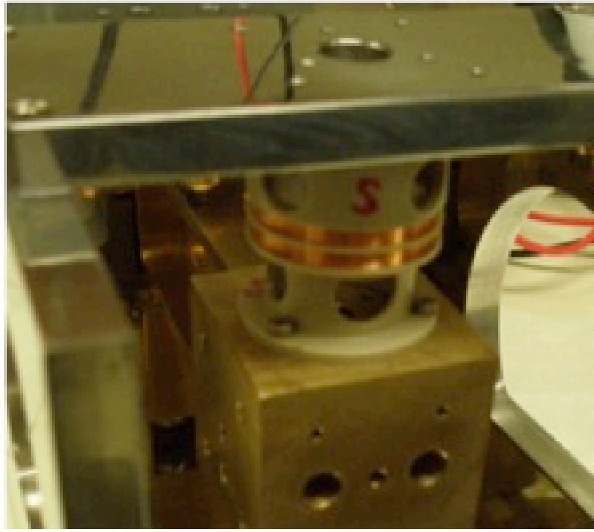


Other features

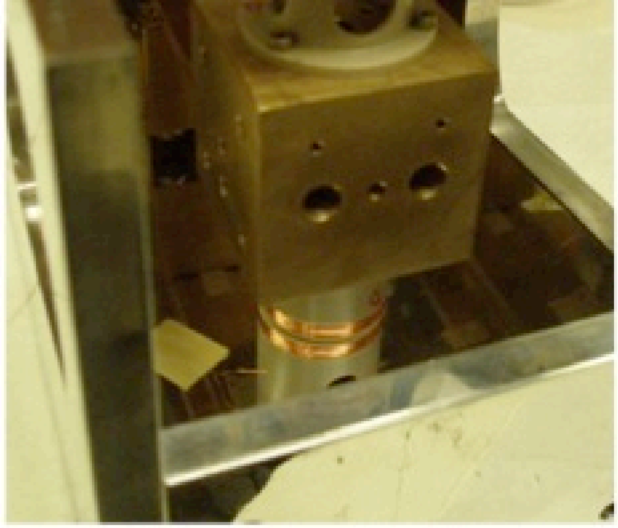


- Diffrential readout
- LVDT readout (easy)
- Michelson readout (higher precision)

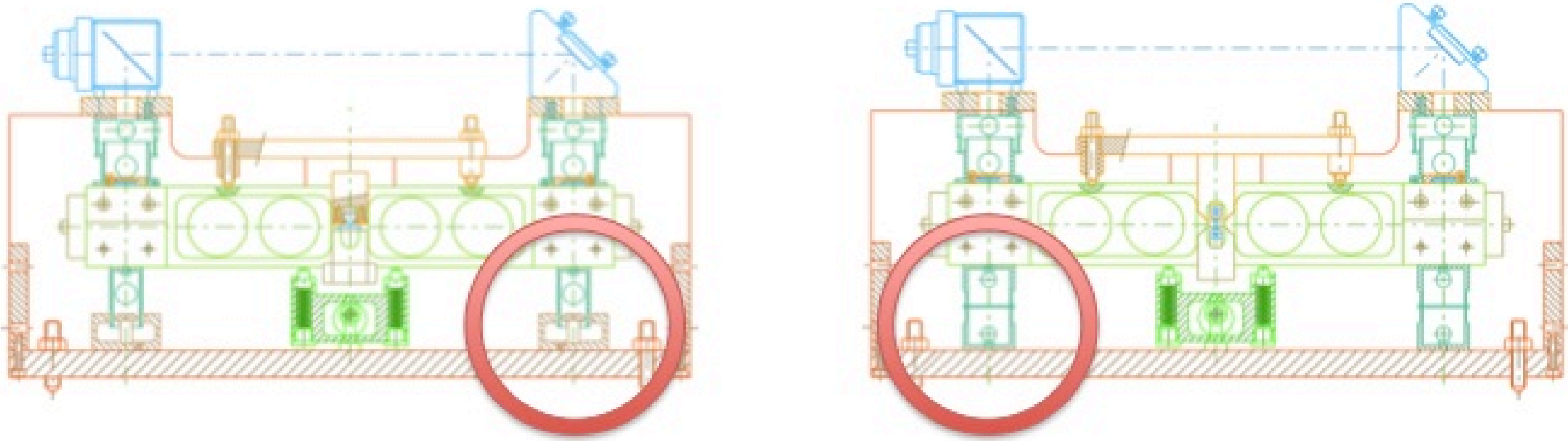




Other features

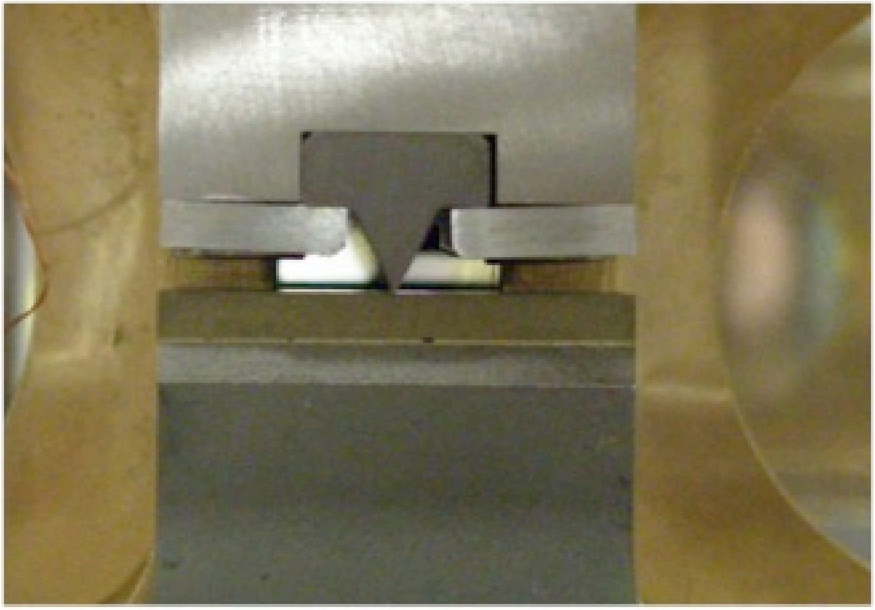


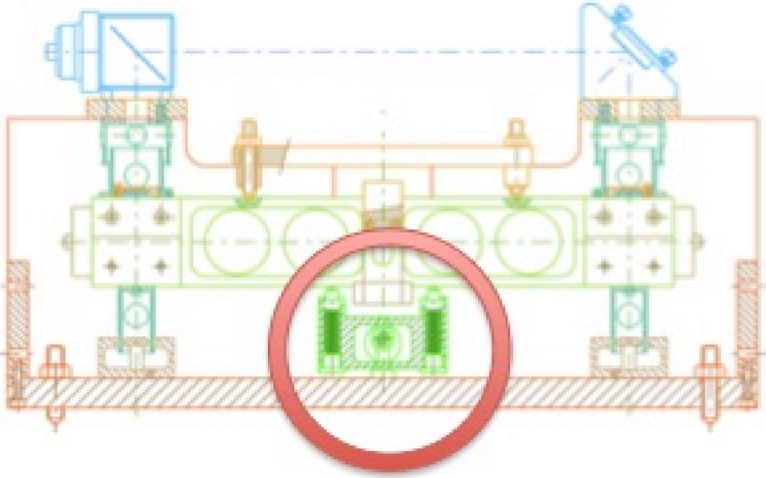
- Differential actuation
- Voice coil actuation
- RF actuation (insensitive to magnetic fields, power lines and solar wind perturbations)

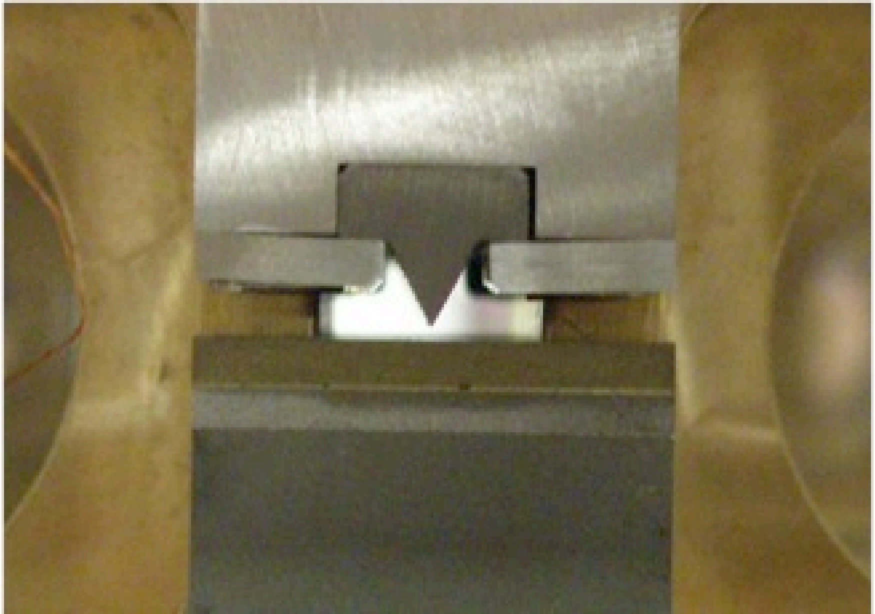


Other features

- Elevation mechanism
- Locks balance arm for transport

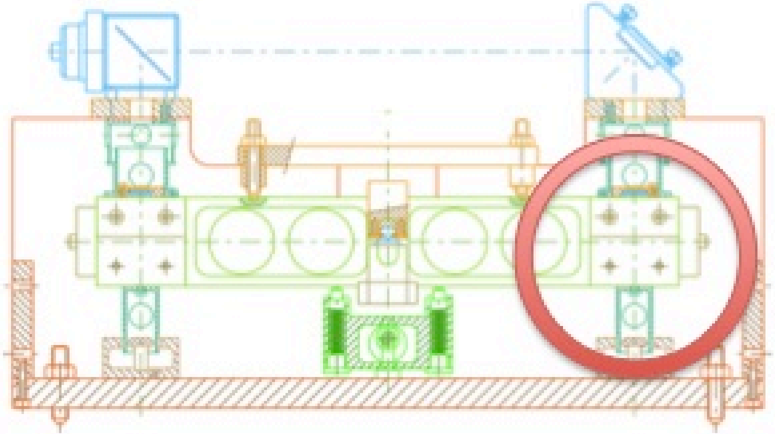


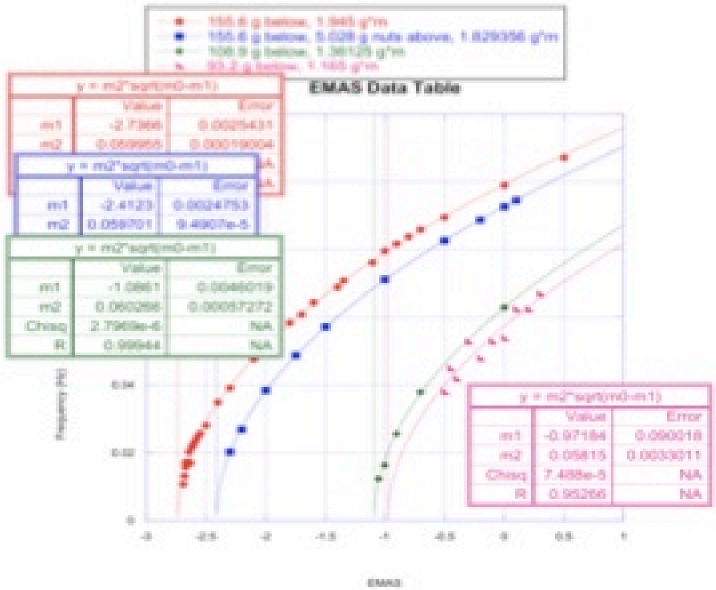


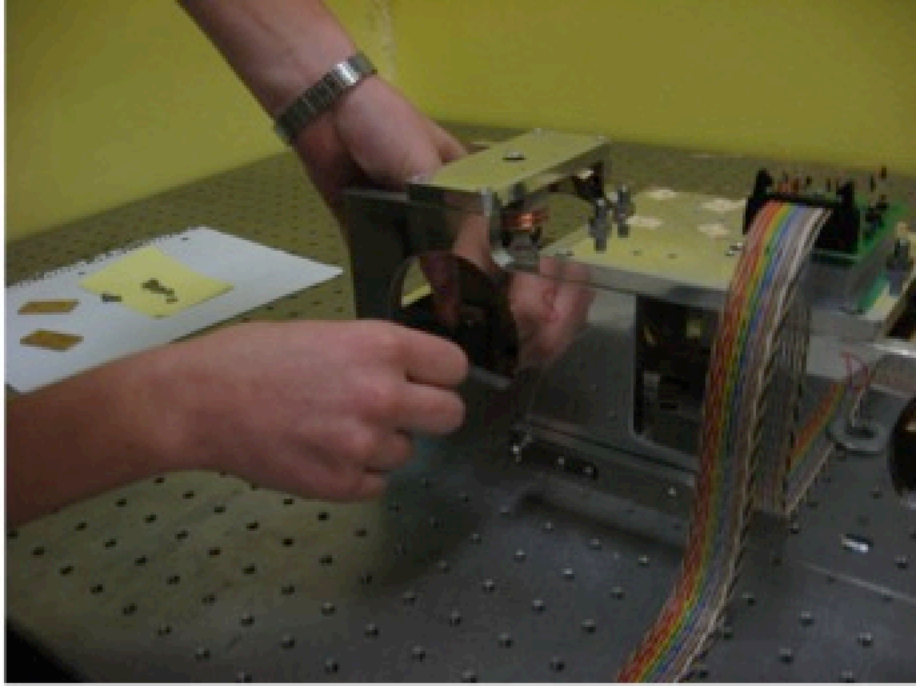


Other features

- Tuning masses to tune resonant frequency

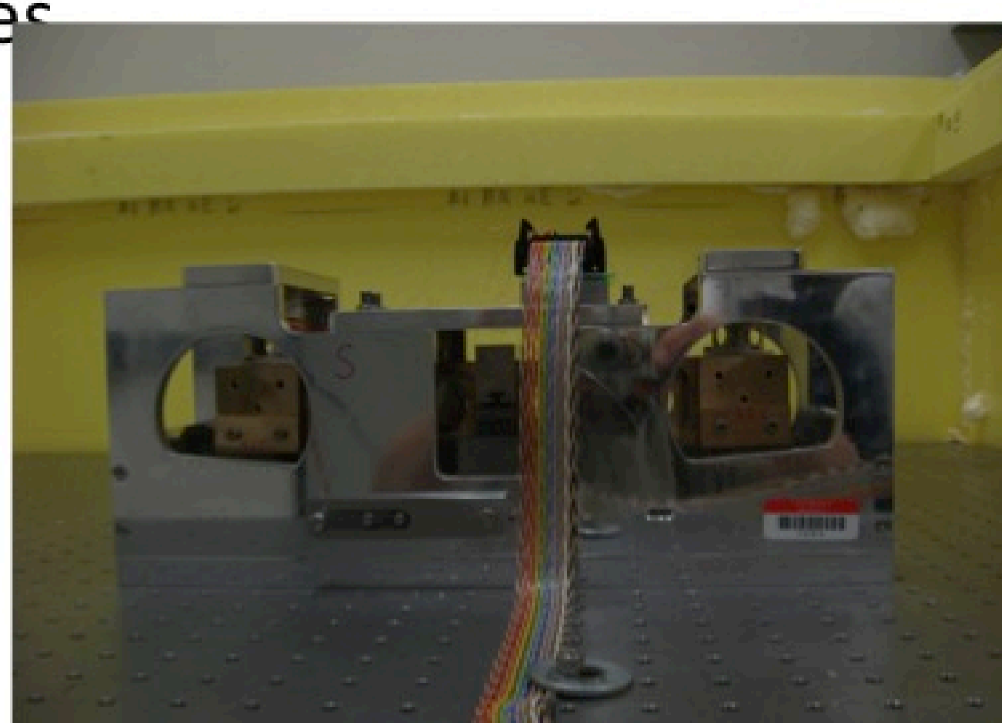






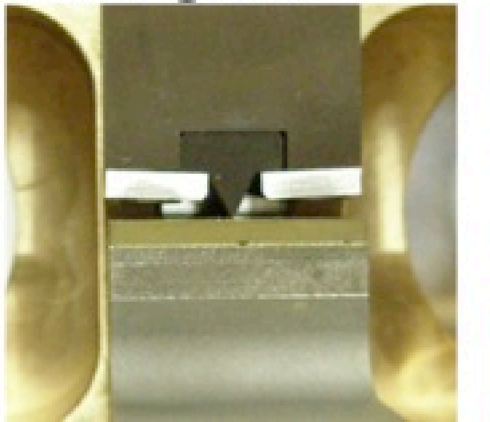
Other features

- Three-level, rigid, Matrioska wind/thermal shields to minimize ambient disturbances



R&D Strategy

- Found SOC controlled dissipation mechanism in metals at low frequency
- Expect larger noise when tuning at very low frequency
- Several flexure tilmeters failed
- Over last few centuries people weighted gold and gems with knife edge scales
- Try knife-edge configuration first



Balancing

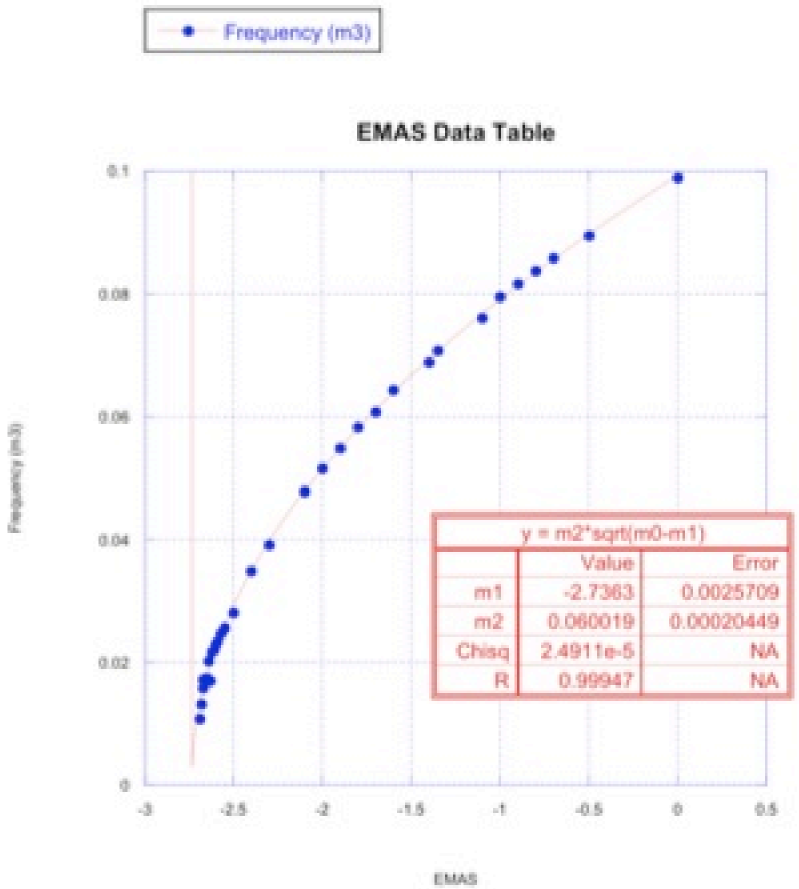
- Mechanically balanced to
- 27.8 microNm balancing torque
- Could have done much better, only lazy

- Applied 0.7125V balancing
- @ 3.9098 $x10^{-05}$ Nm/V

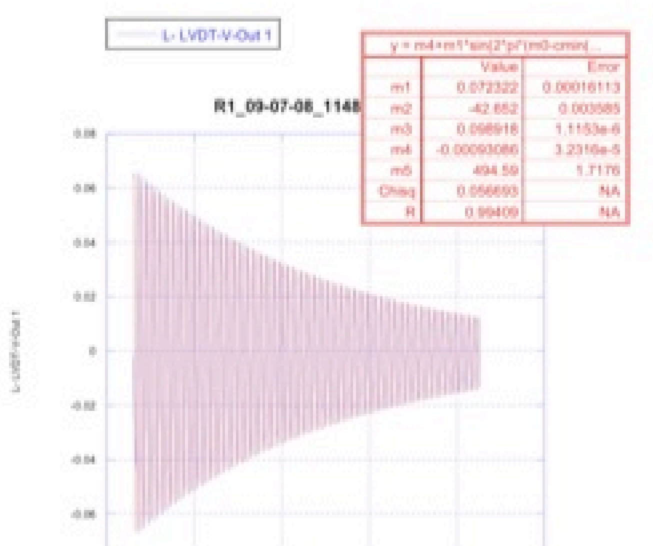
Initial results

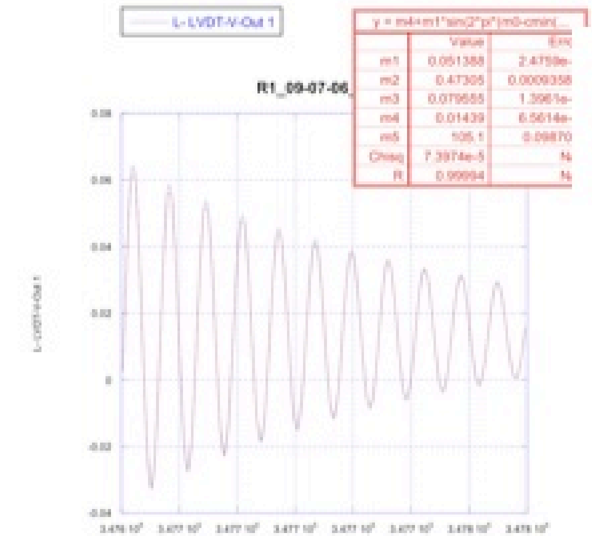
- Frequency tuning with Electro Magnetic Anti Spring (EMAS)

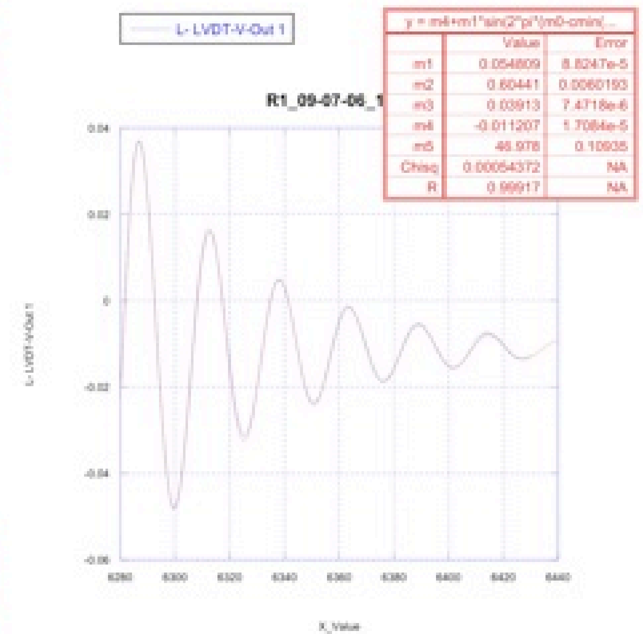
- Behavior as expected
- Easily reach 10 mHz
- Behaves smoothly!

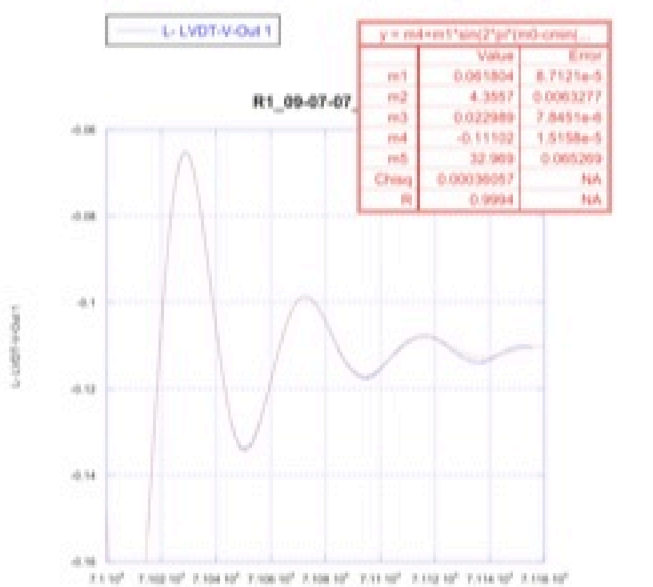


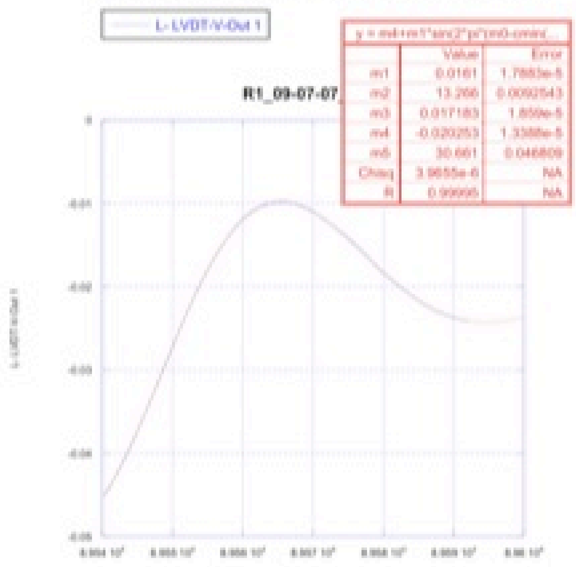
Q-factor vs. frequency (EMAS)







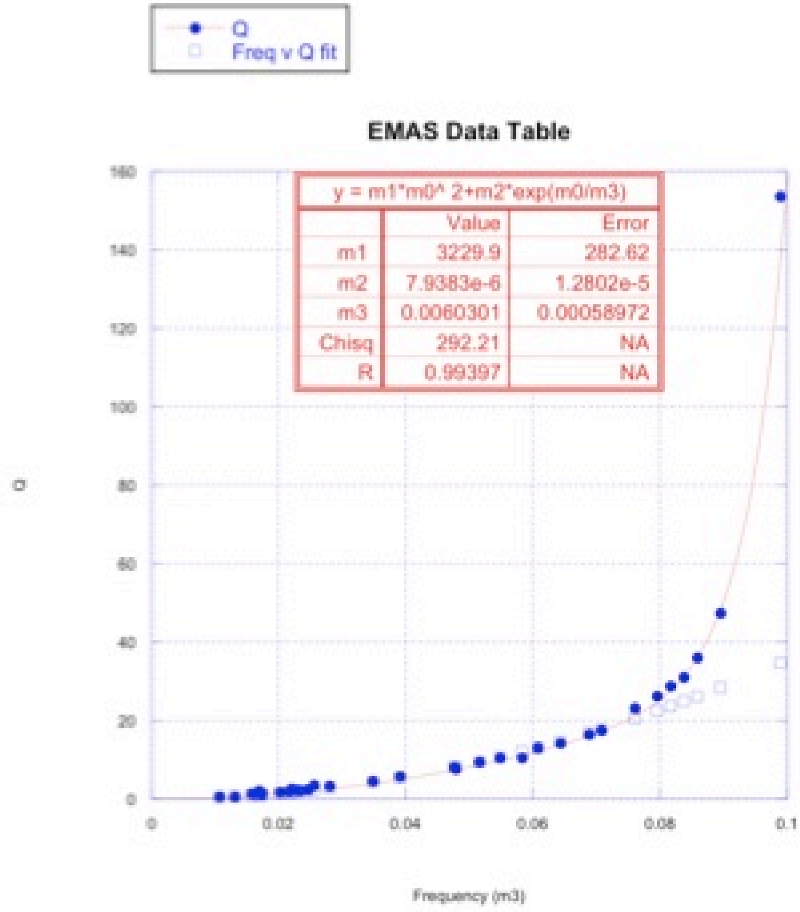




- Bumpiness connected with SOC avalanches seems absent

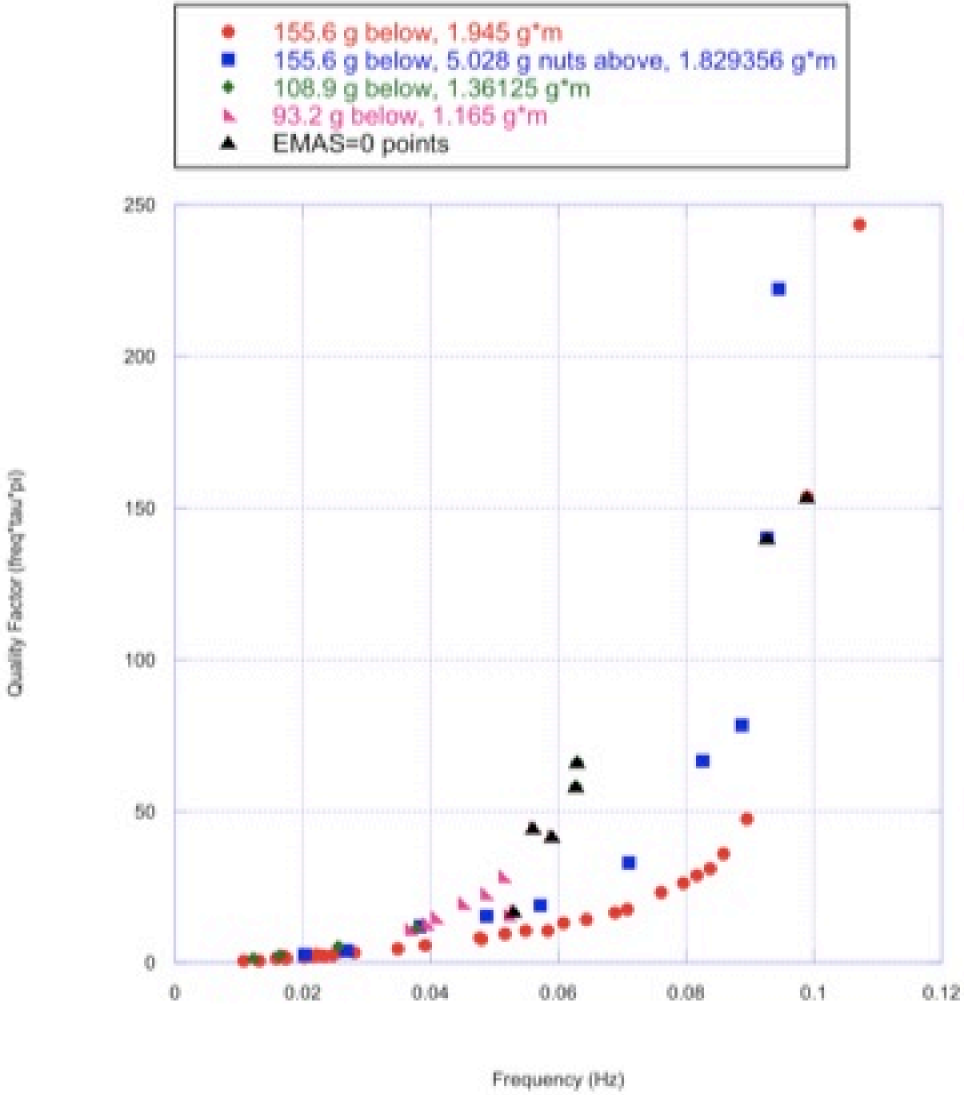
Q-factor vs. frequency (EMAS)

- Apparently quite good
- Low frequency quadratic
- High frequency exponential
- Similar to flexures



Q-factor vs. frequency (EMAS)

- Cross check with Gravitational Anti Springs (more mass above pivot point)
- Fails to overlap above 30 mHz
- Computer Feedback delay falses Q-factor data



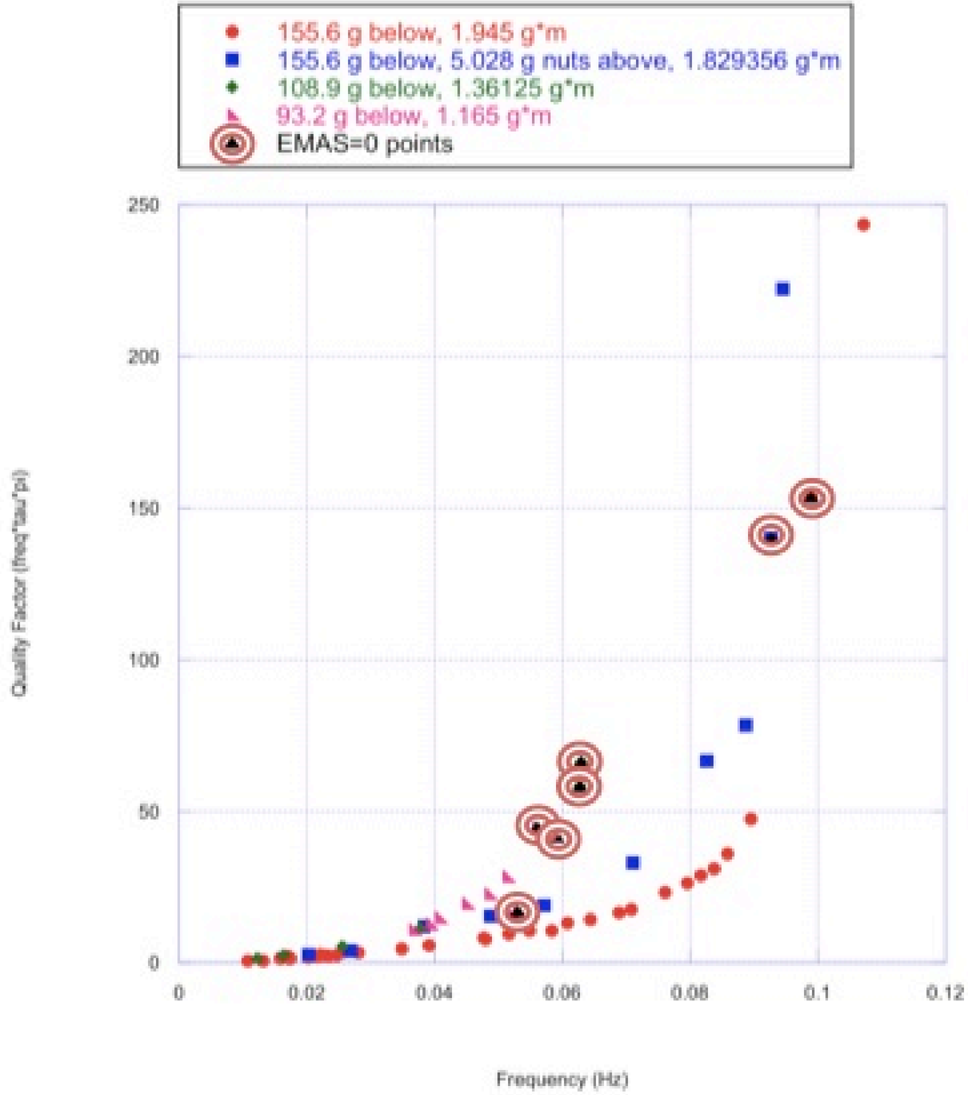
Q-factor vs. frequency (EMAS)

- Need to repeat the scan changing only the mass distribution (no EMAS)
- Or make fast electronics EMAS

- Scatter due to amplitude dependence of losses (see later)

- Below 30 mHz maybe valid data

- More work needed

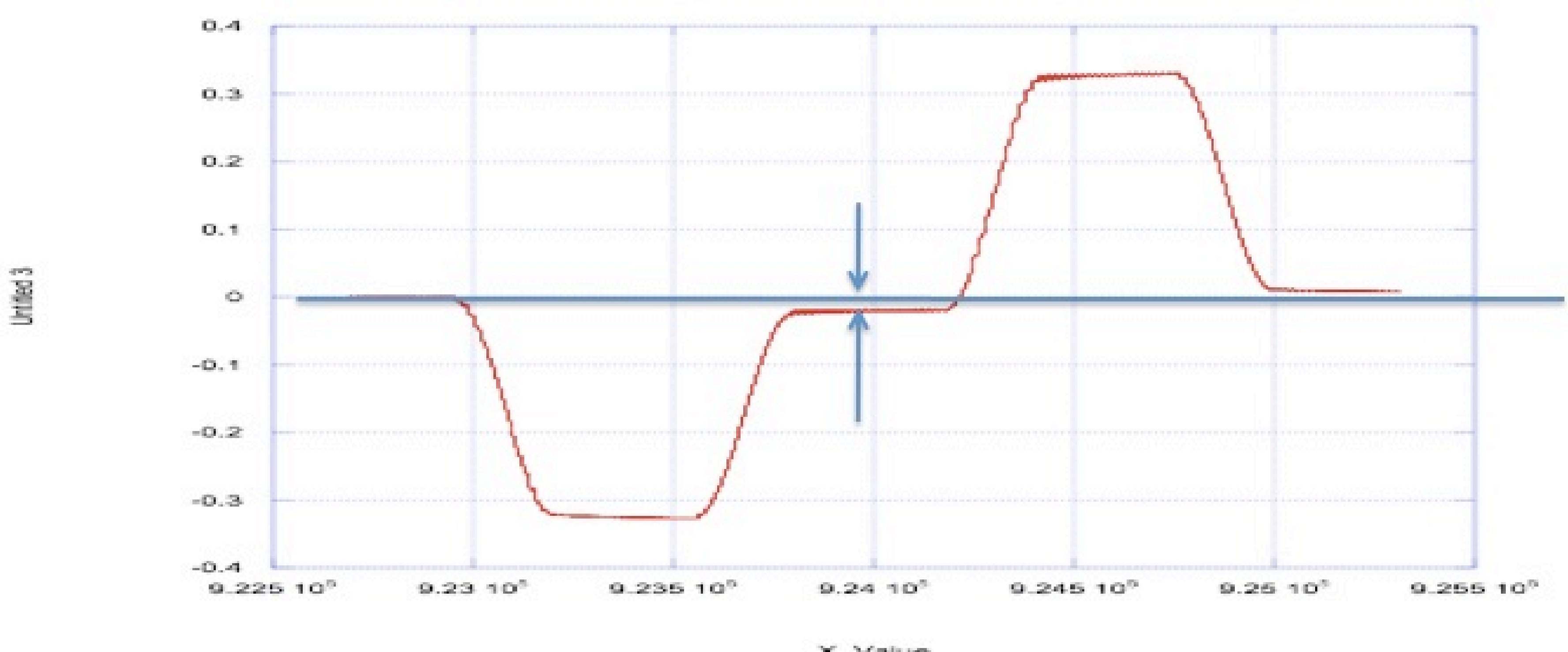


Hysteresis testing

- Key parameter ! !
- In metal springs hysteresis was harbinger of SOC noise

Hysteresis testing

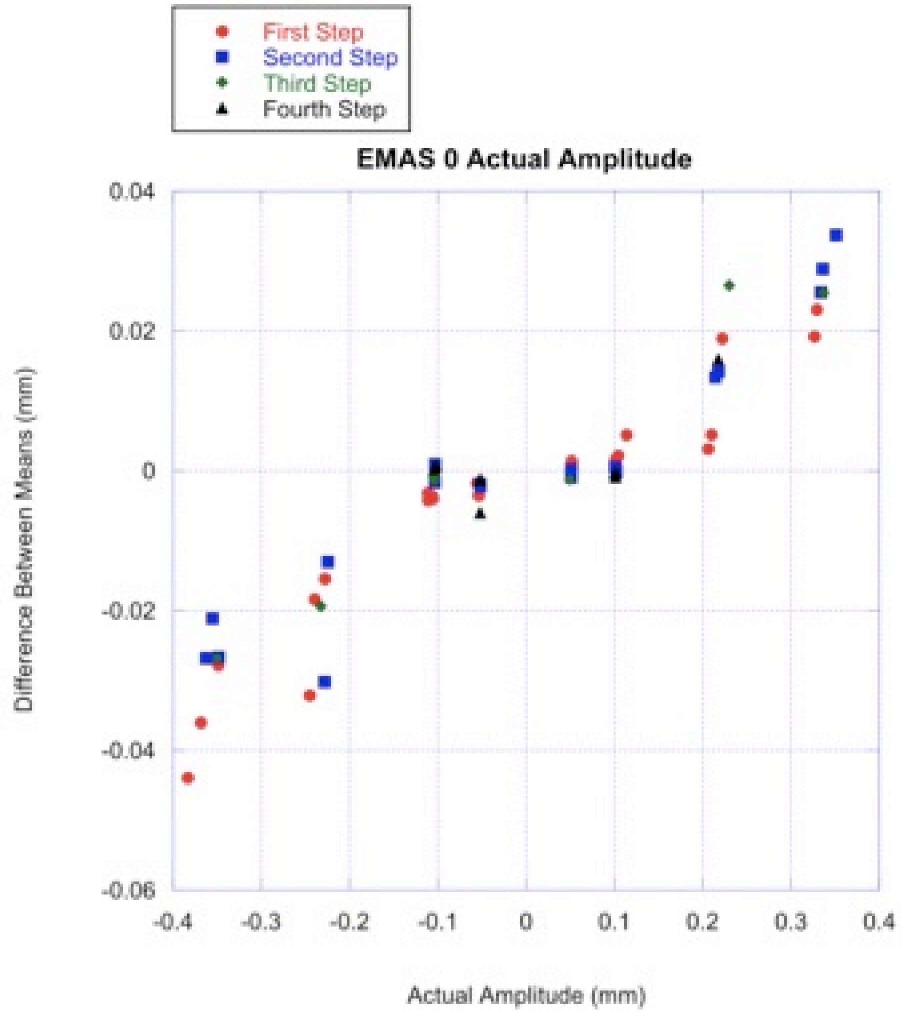
- Slow application and removal of force:
- Compare starting and returning position



- Note: we can use EMAS even with phase delay because we do not measure Q-factors

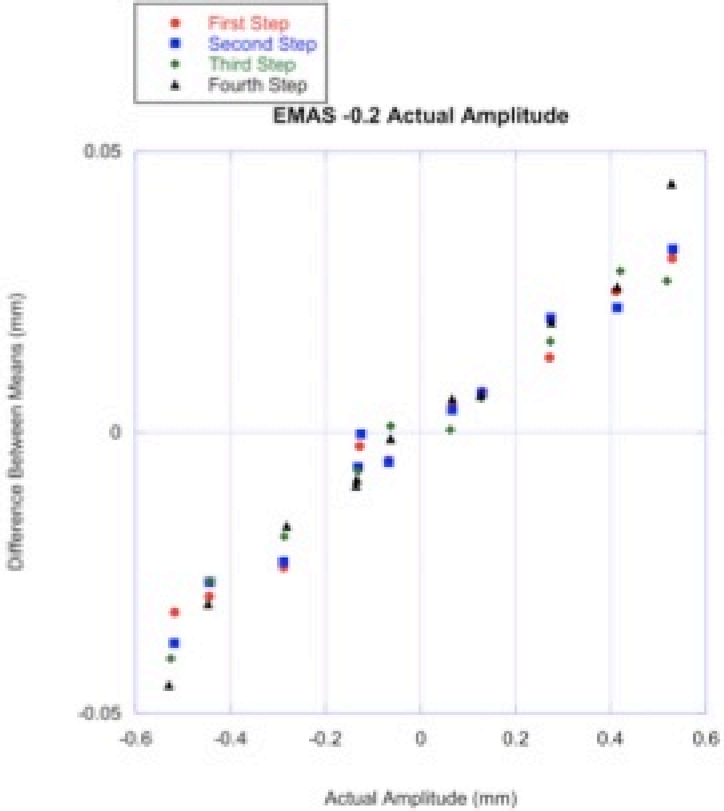
Hysteresis testing

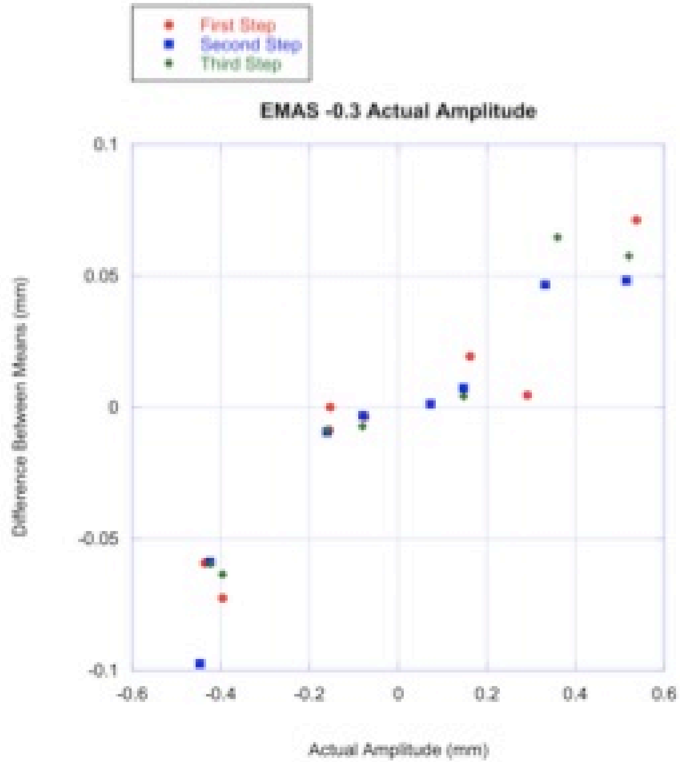
- Hysteresis reduced or may be vanishing for small displacements amplitude



Hysteresis testing

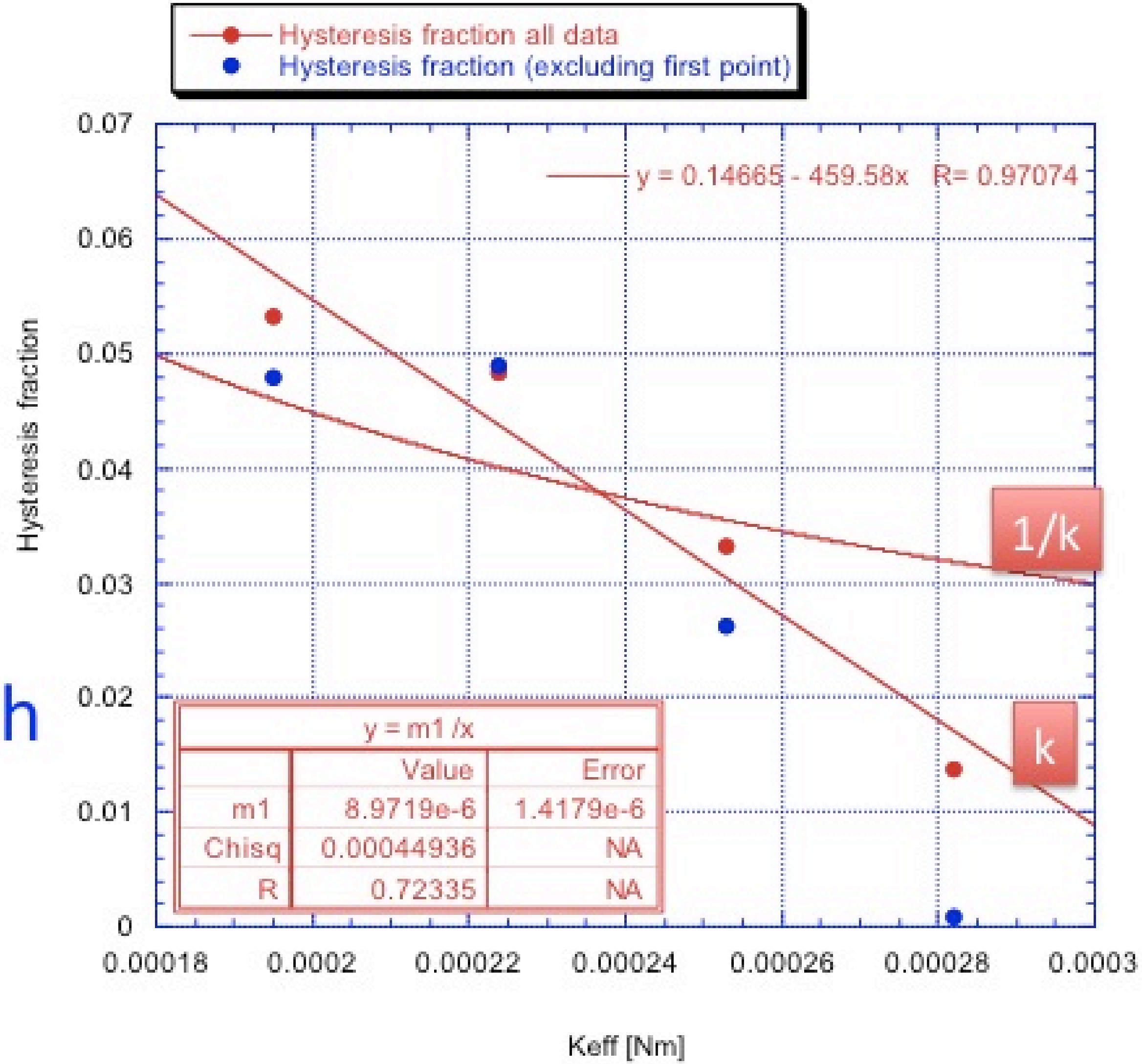
- Flexus less visible in other tunes
- Extract low amplitude slope and plot





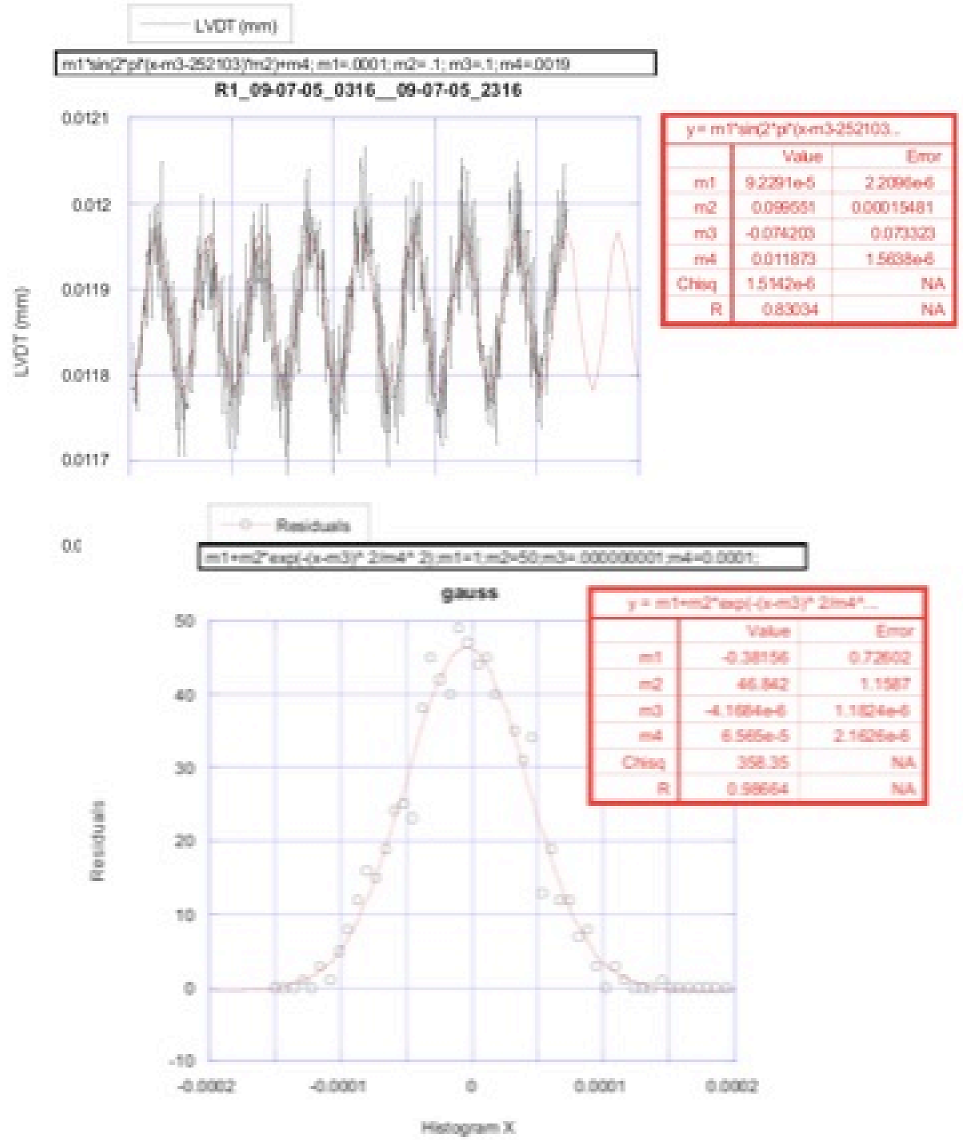
Hysteresis testing

- would expect hysteresis to diverge $1/K_{eff}$ for $K_{eff} \to 0$
- Data more compatible with a converging solution



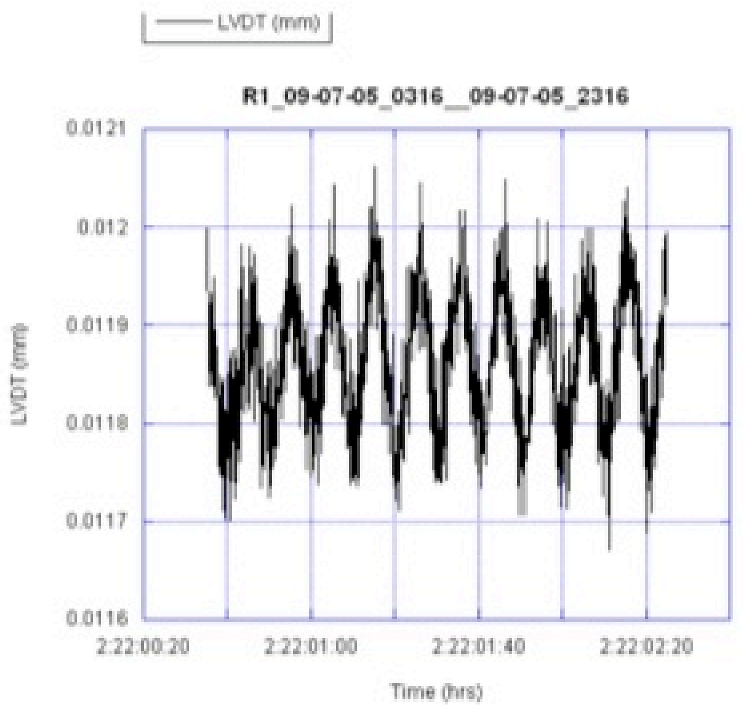
Noise studies

- Fitting over short stretch to eliminate ambient re-excitation (air conditioning + seismic)
- Residual give 65 nm upper limit of noise
- Digitization dominated
- Can improve



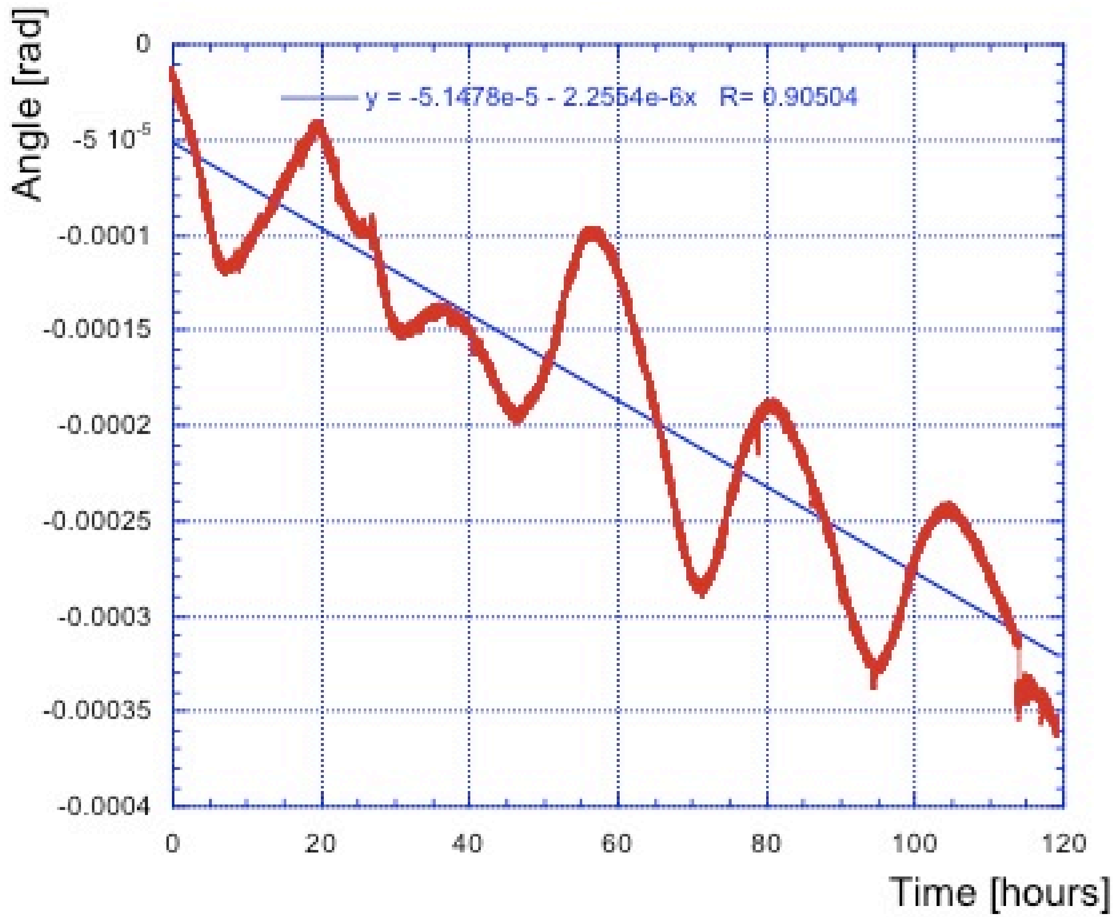
Study of noise

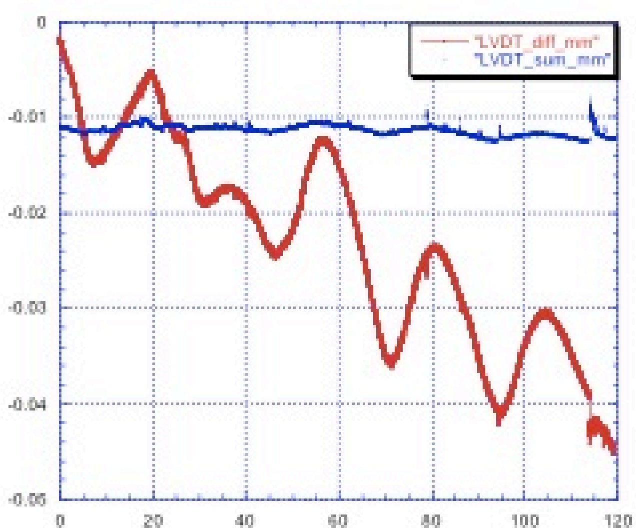
- Data continuously show ambient re-excitation at resonant frequency
- Can suppress by averaging over exactly 1 period



Study of noise

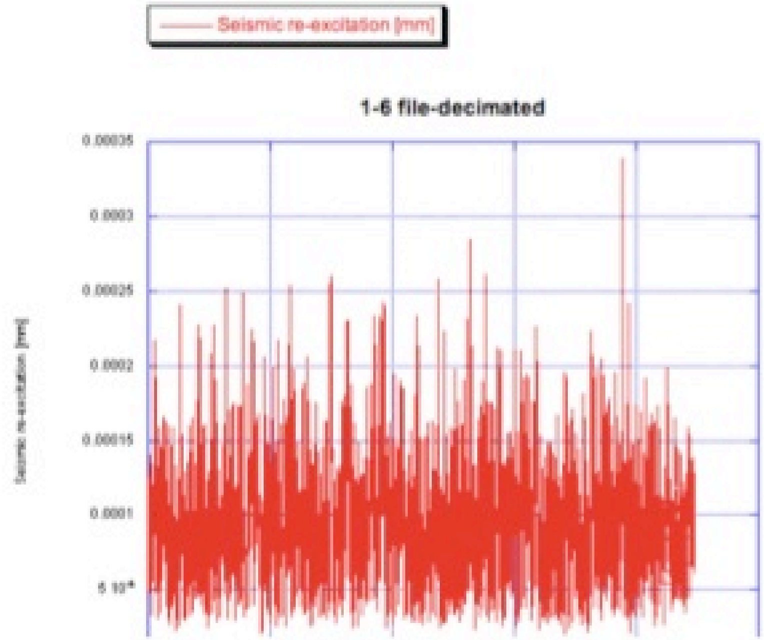
- 0.5 micro-radian daily oscillation trend
- 2 micro-radian per day slope

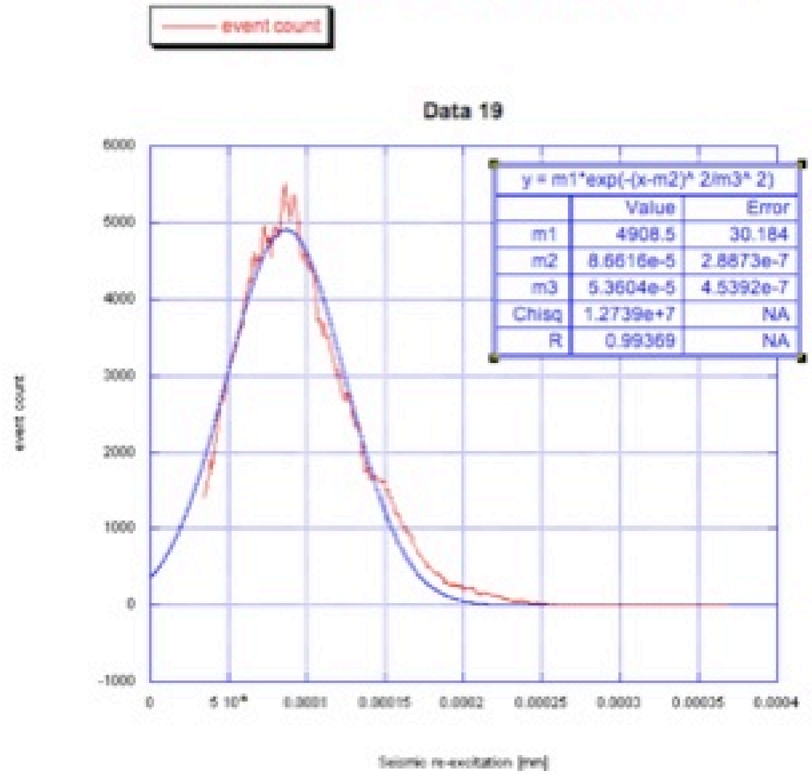




Study of noise

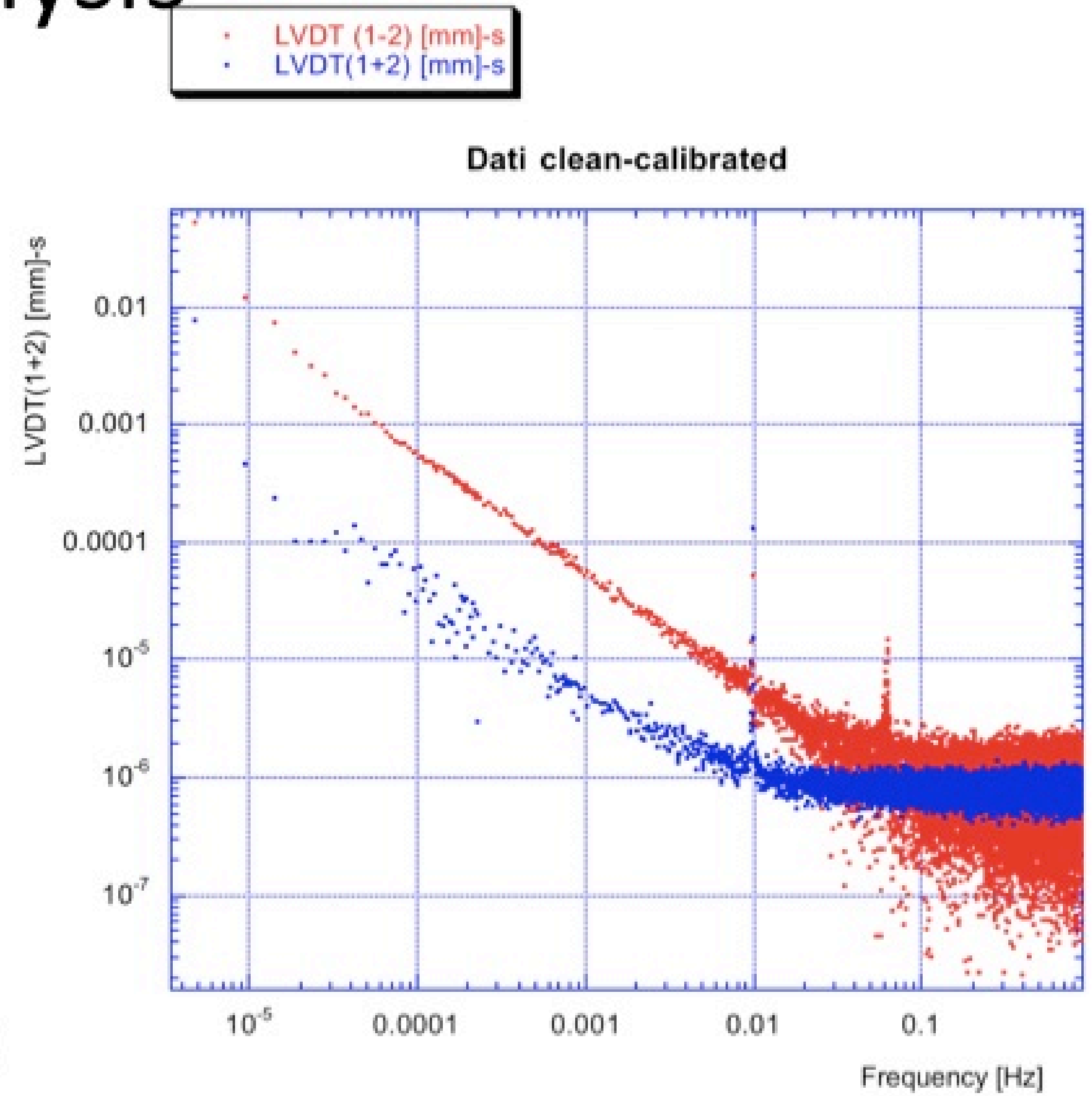
- The average oscillation amplitude around the trend is the ambient re-excitation
- Find:
- 87 nm (696 nradian) seismic re-excitation at 60 mHz
- Accounting for Q= 57
- ~ 12. nradian of ambient noise at 60 mHz

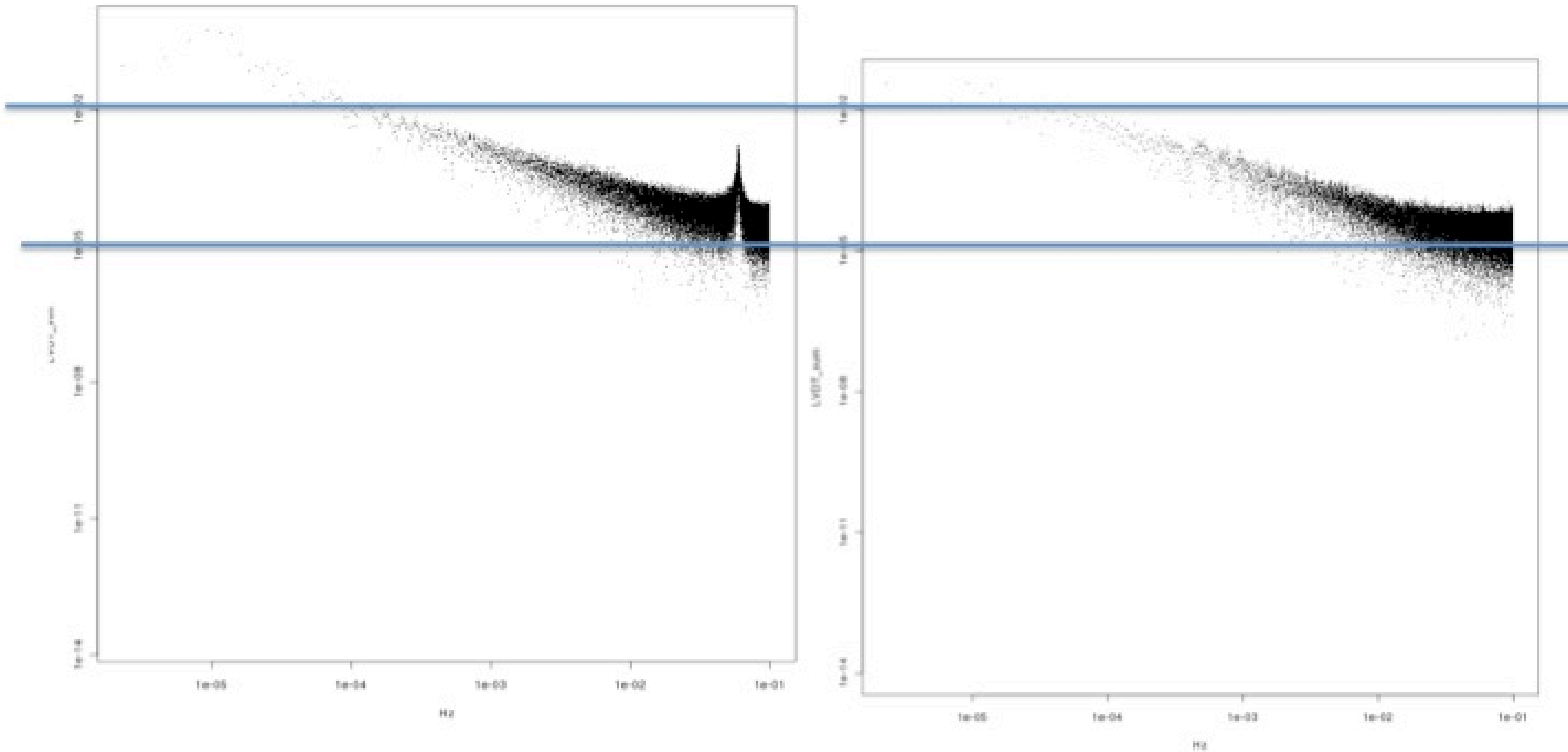




Spectral analysis

- Spectrum R-L (angular motion) follows 1/f over >4 decades
- Spectrum R+L (el. noise) ~nm
- 60 mHz resonant peak
- (@10 mHz numerical problem)




1e-02
1e-05
1e-08
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1e-05
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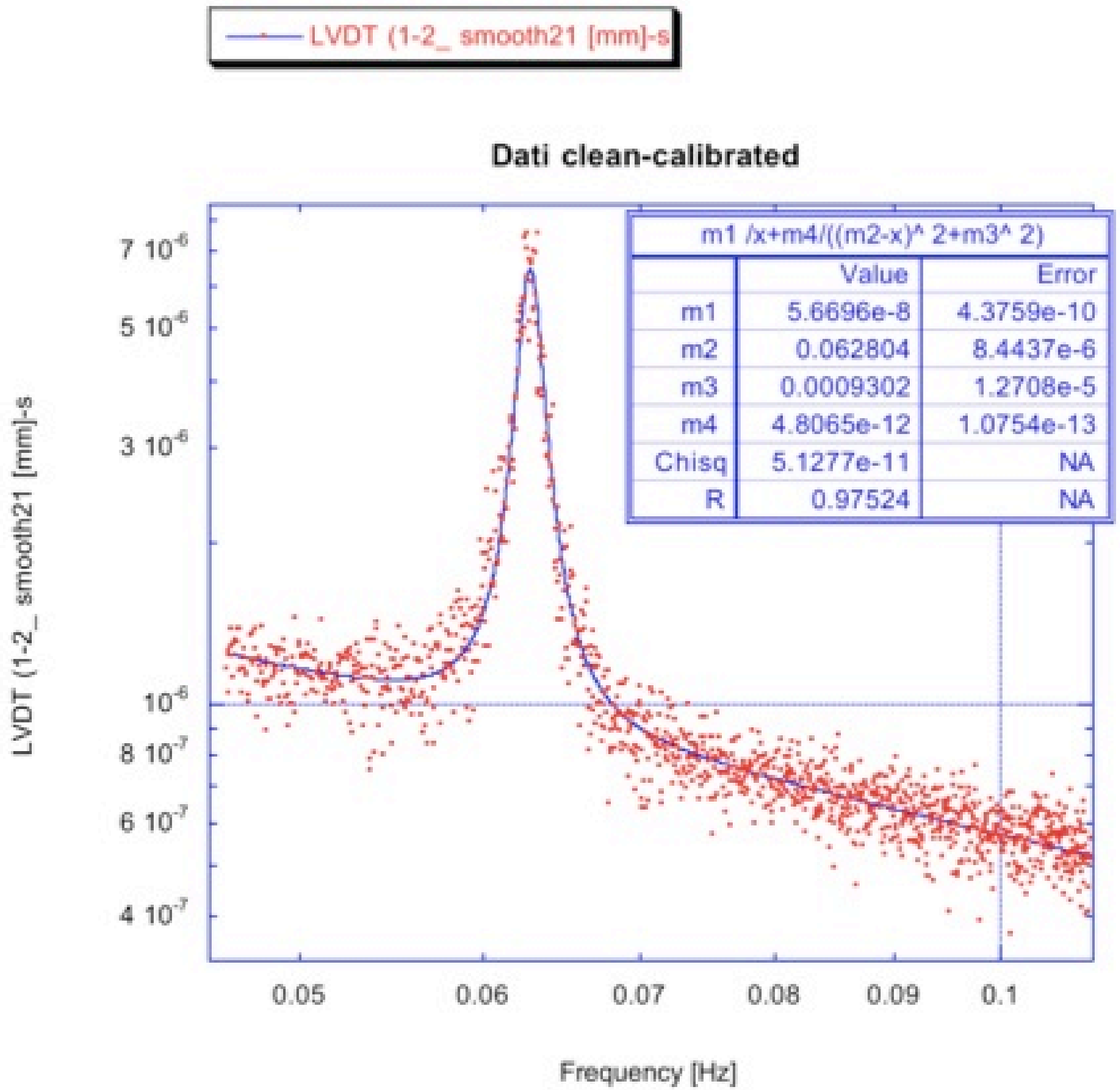
Hz
1e-02
1e-05
1e-08
1e-11
1e-14
1e-05
1e-04
1e-03
1e-02
1e-01
Hz

Resonant peak

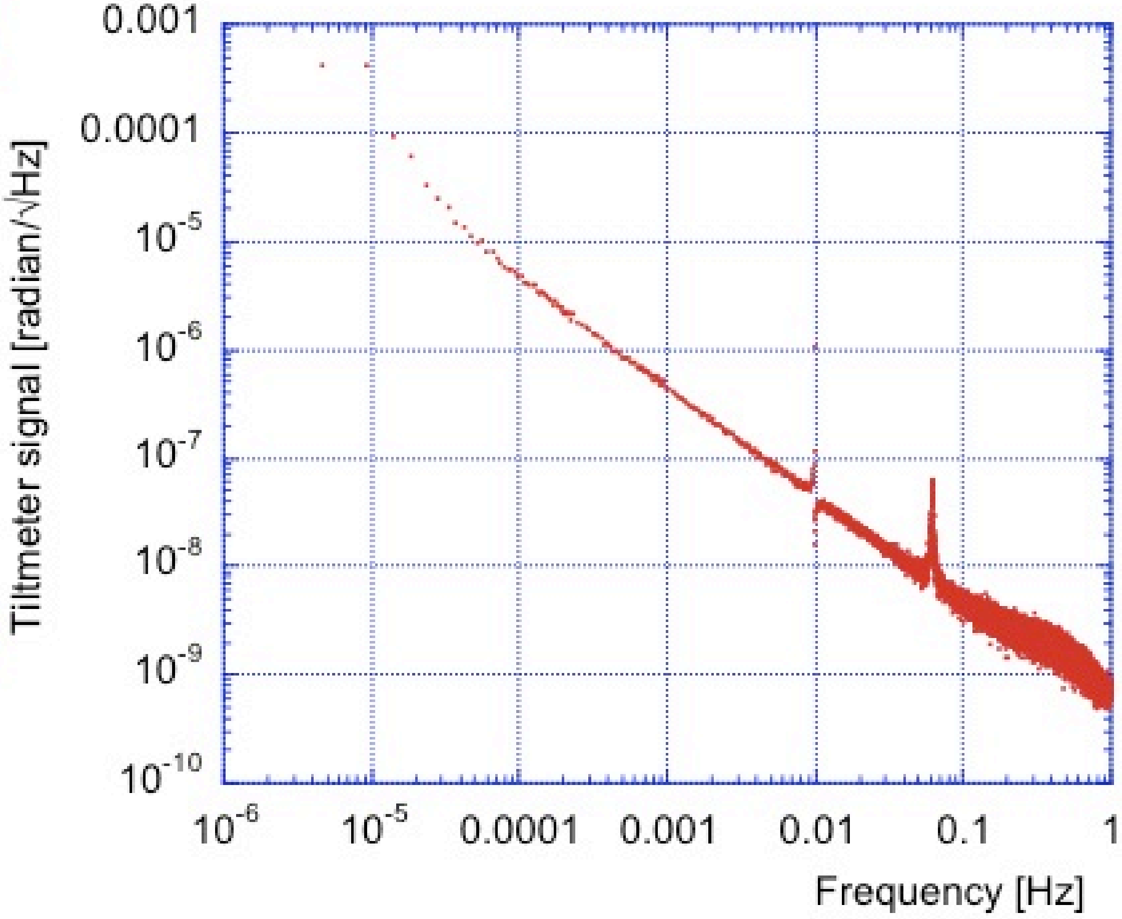
- All kosher



Spectral analysis - radians

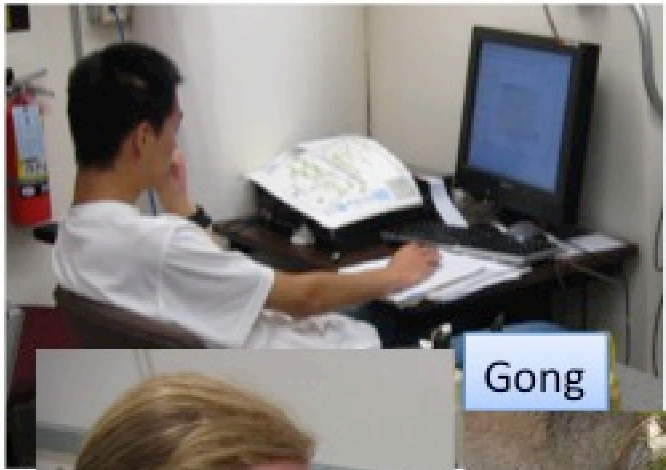
- Is noise driven by internal forces or by ambient re-excitation?

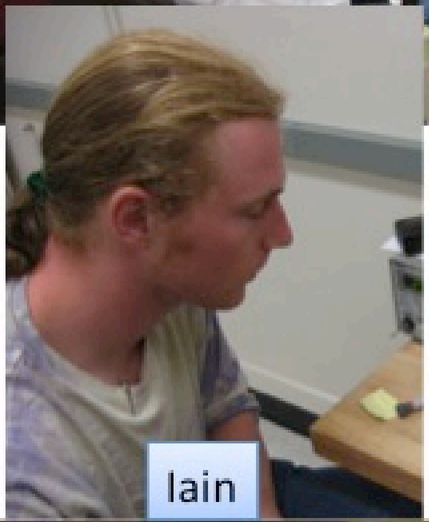
- Need to build couple and cross-test to learn



Conclusions

- Tiltmeter with knife-edge hinge worked well
- Seems not to show
  Self Organized Criticality (SOC)
  low frequency noise
- Used low grade knife
- Space for improvements
- Making sharp knives
- Will try TiN, Diamond, DLC coatings
- Will test flexures to study SOC





And it was a great summer !