The Investigation of Geometric Anti-springs Applied to Euler Spring Vibration Isolators

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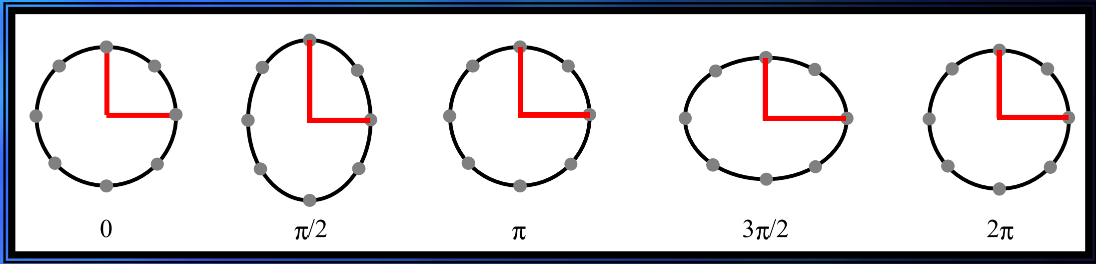
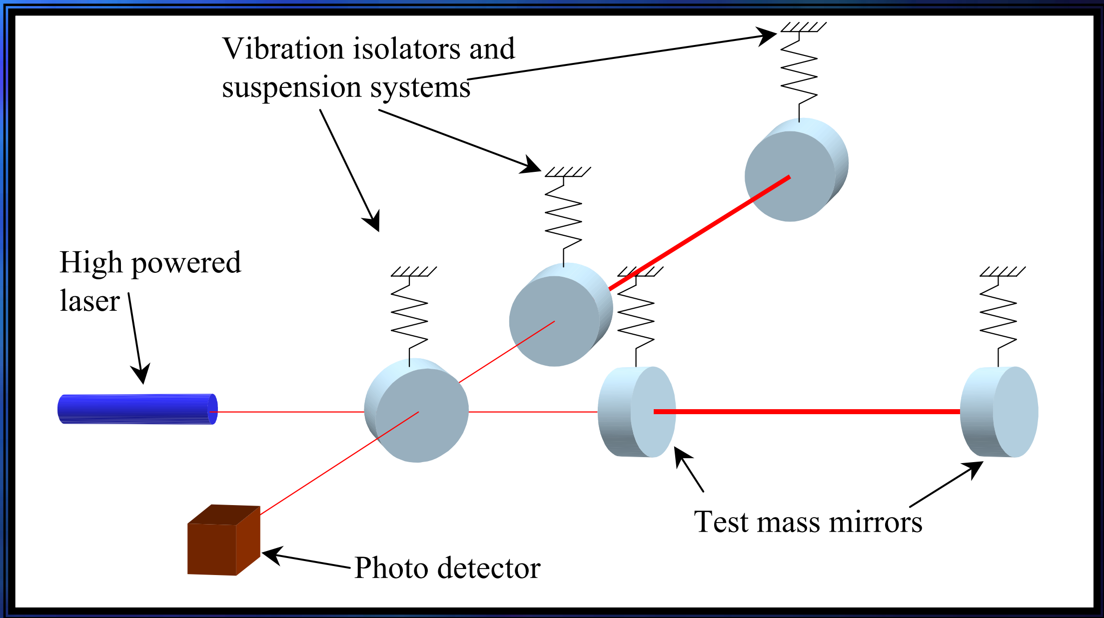
Presentation Overview

- Interferometric Gravitational Wave Detectors
- Project Aims
- Experimental Methods
- Creep Problem
- Improvements
- Project Conclusions

Interferometric Gravitational Wave Detectors

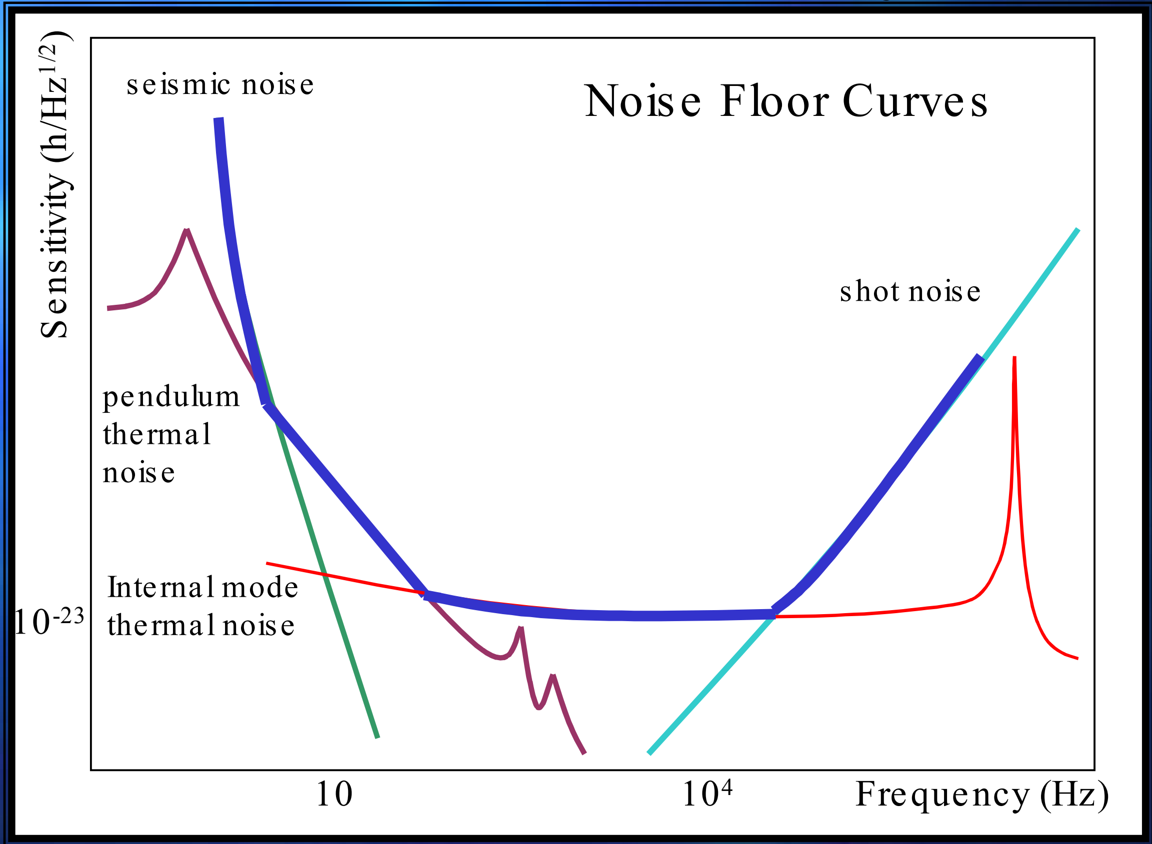
- Gravitational Waves are ripples in space-time
- Detection can be done based on a Michelson-Morley interferometer





Noise sources to overcome

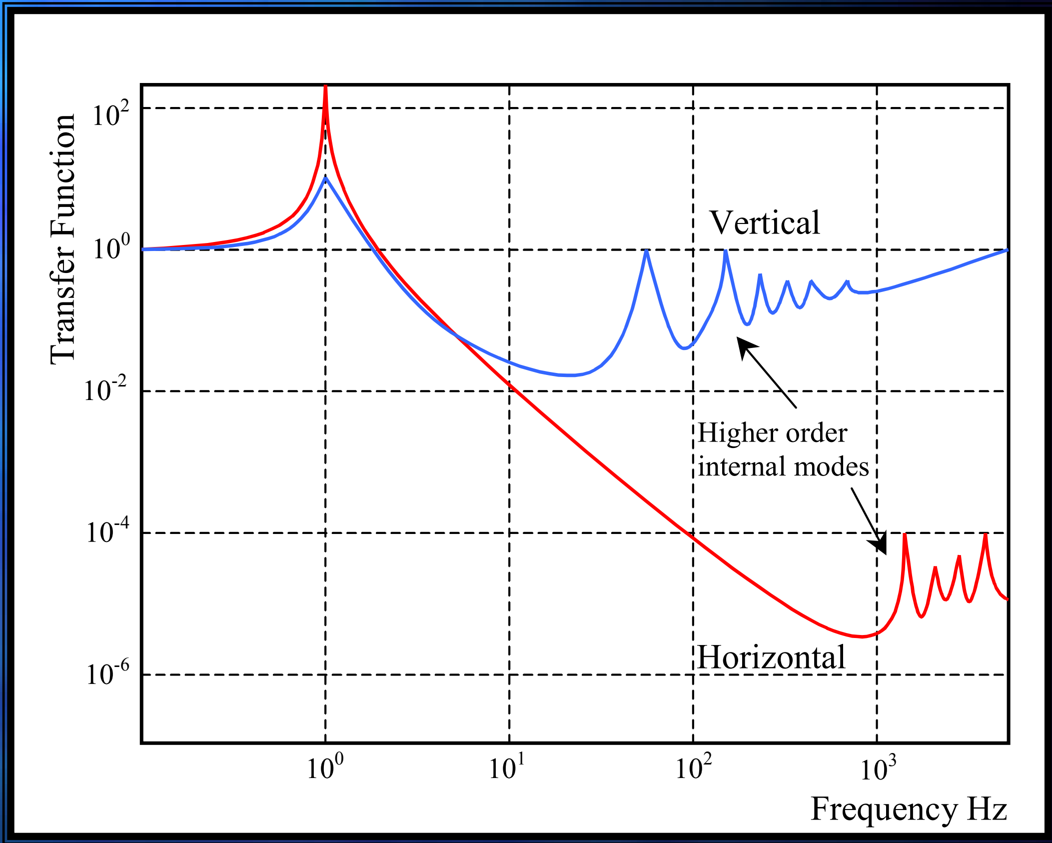
- Sensitivity needed of $h \sim 10^{-22}$ is overcome by noise



Importance of vibration isolation

- Project concerns reducing seismic noise
- Pendulums are used for horizontal isolation
- Springs are used for vertical

- Attenuation goes as $1/f^2$ above resonant frequency, $(f_0 f_1 f_2 \ldots f_N / f^N)^2$ for a cascade of N stages



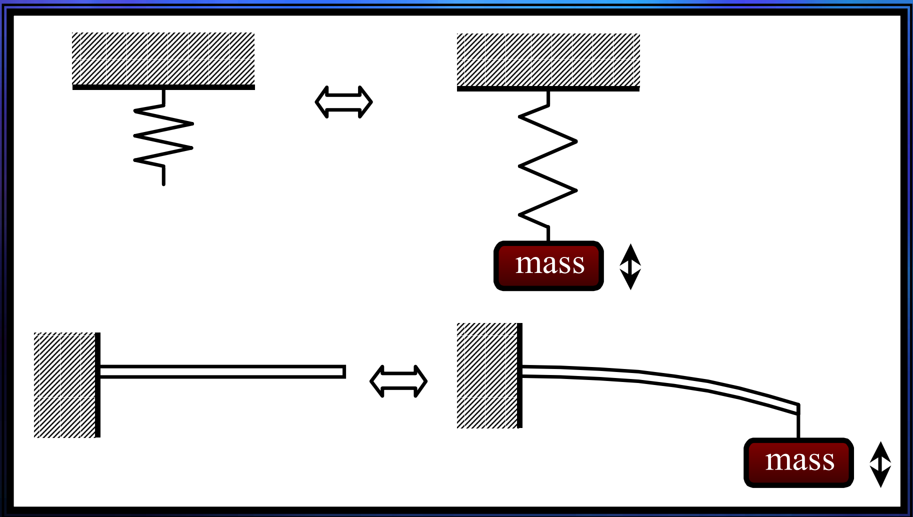
Project Aims

Concentrates on lowering the resonant frequency of a single vertical vibration isolation stage

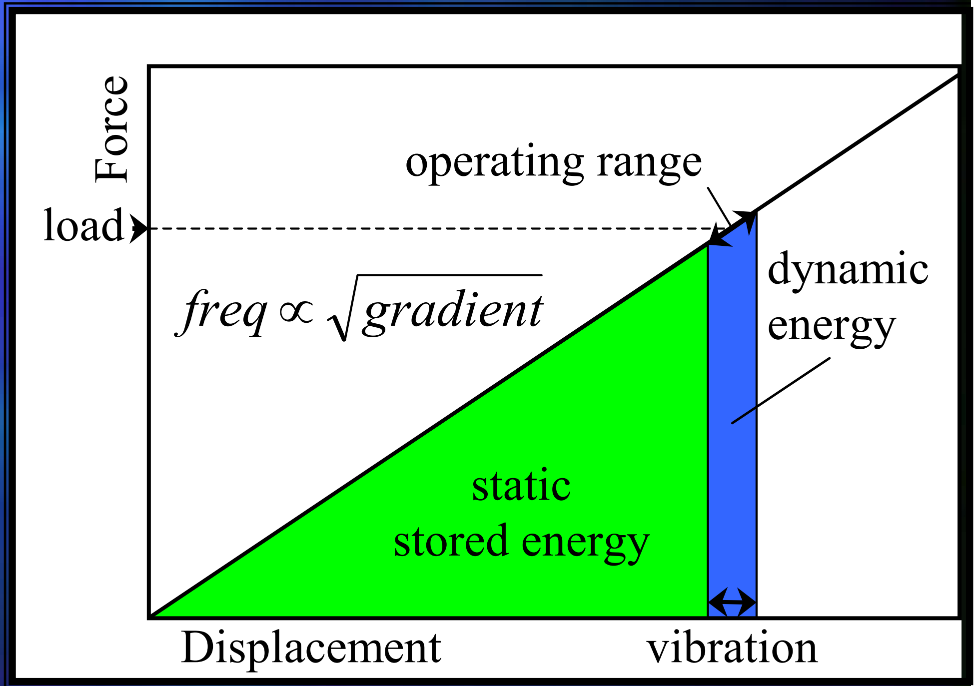
- Euler springs
- Geometric anti-springs
- Euler springs boundary conditions

Conventional Springs

- Why use Euler springs?
- Conventional springs store large amounts static energy



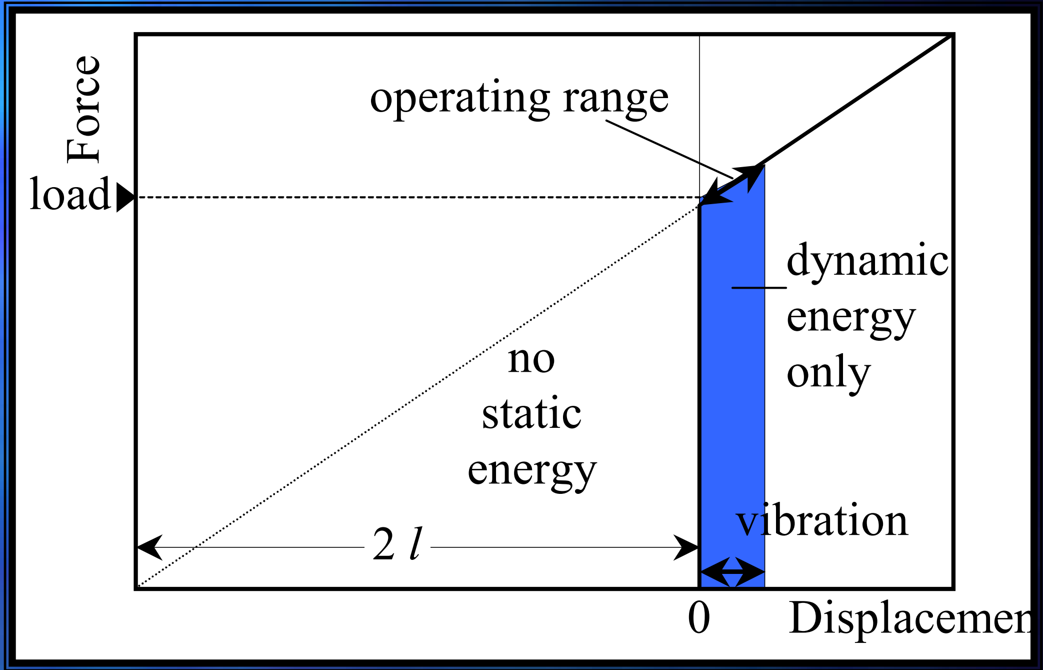
- Stored energy
  ∝ elastic spring mass required



Euler Springs

- Stores no static energy
  ⇒ low mass

- Resonant frequency is also improved:



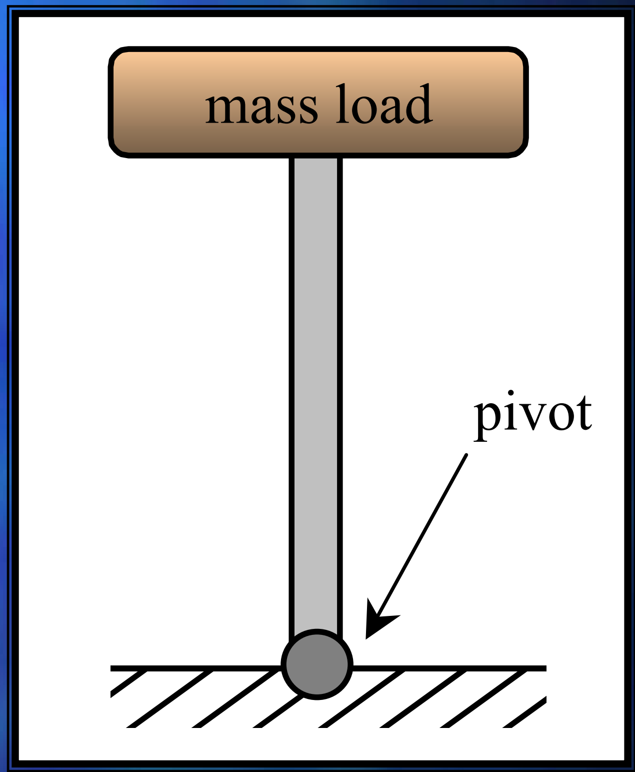
$$\omega = \sqrt{\frac{k}{m}} = \sqrt{\frac{g}{2l}}$$

For a conventional spring:

$$\omega = \sqrt{\frac{g}{\Delta l}}$$

Geometric Anti-Springs

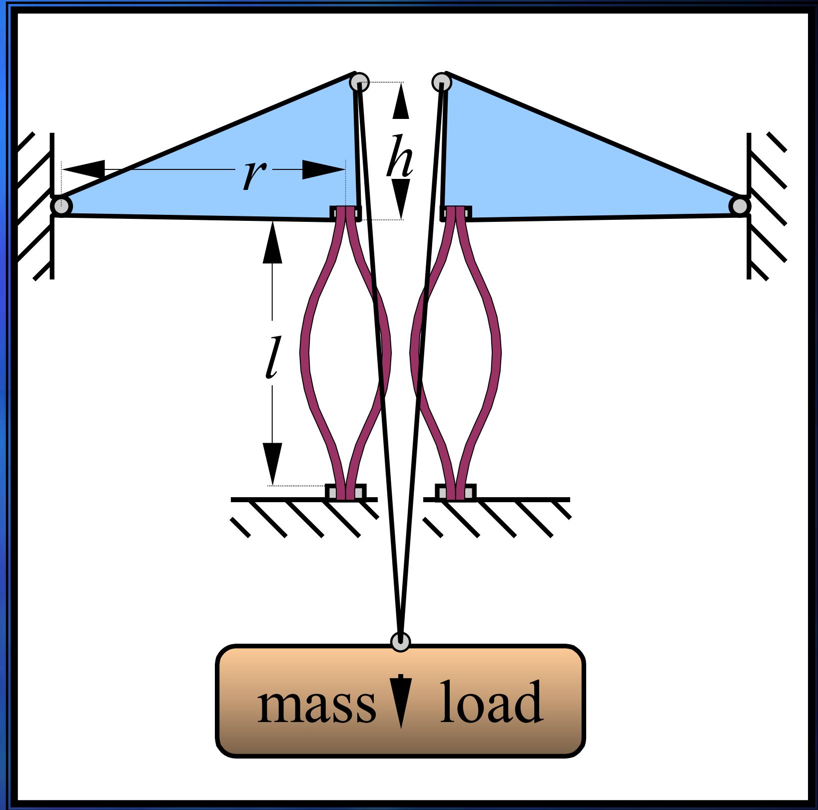
- An anti-spring behaves oppositely to a spring
- The system has a negative spring constant eg. an inverse pendulum



An inverse pendulum

The Vertical Euler Stage

- We have incorporated the inverse pendulum into the vertical Euler stage
- In effect a lower resonant frequency is resulted



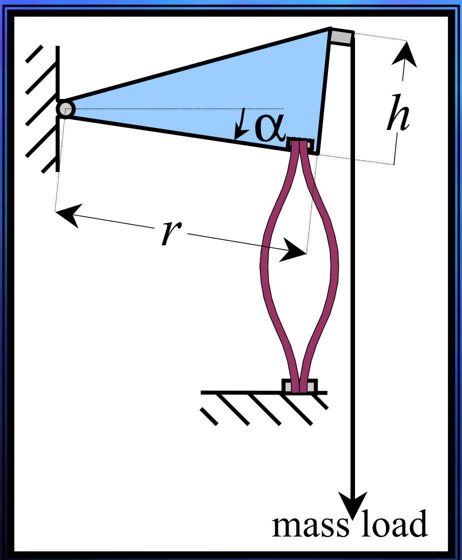
A schematic of the Euler stage

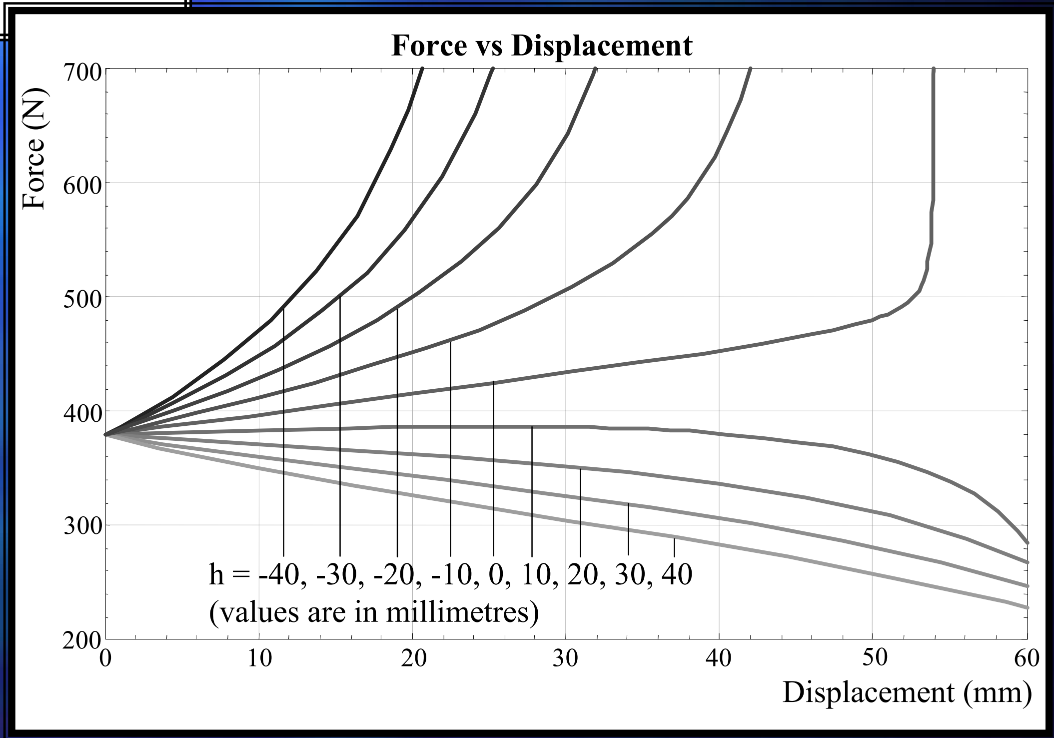
Mathematical model

$$Energy(\alpha) = \frac{1}{2}K_w\alpha^2 + \frac{1}{2}\frac{F_{cr}}{2l}r^2(\sin\alpha)^2 + F_{cr}r\sin\alpha$$

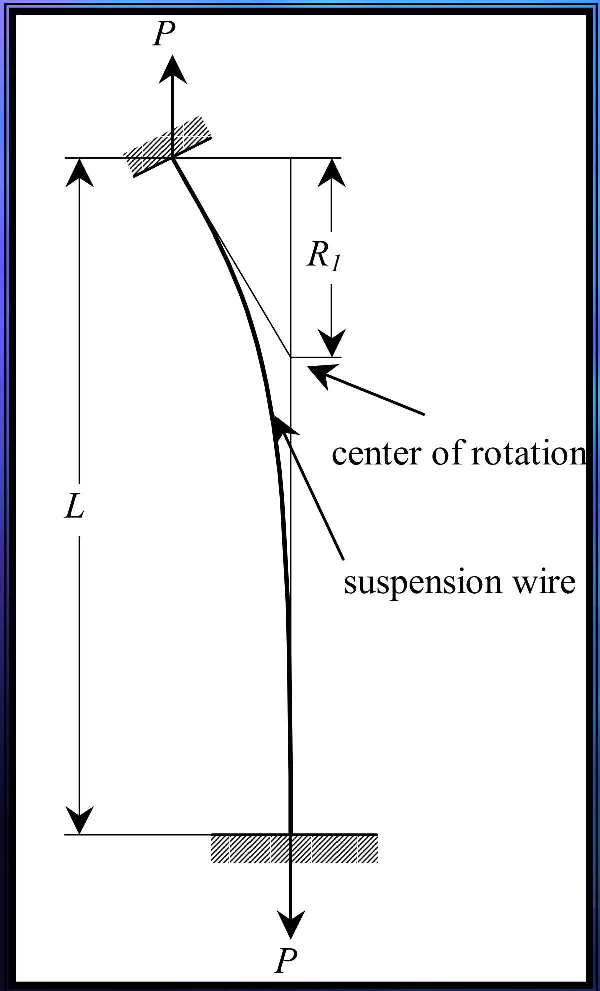
$$F_y = \frac{\partial_\alpha Energy(\alpha)}{\partial_\alpha y(\alpha)}$$

$$y(\alpha) = h - \sqrt{r^2 + h^2}\,\sin(\arctan(\frac{h}{r}) - \alpha) - 0.01\sin\alpha$$



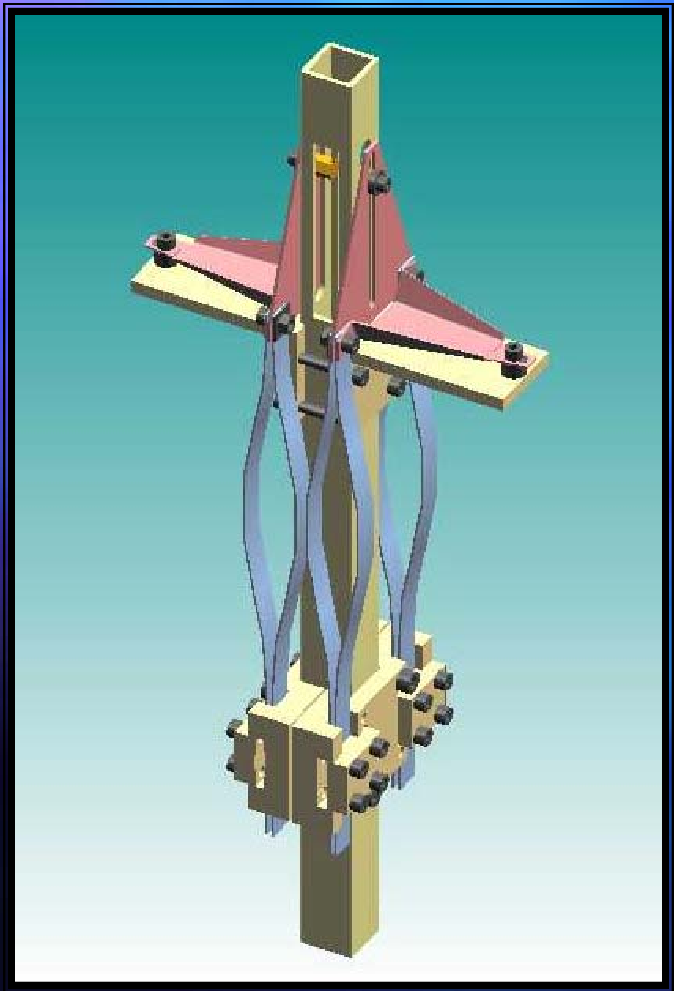


Suspension wire thickness



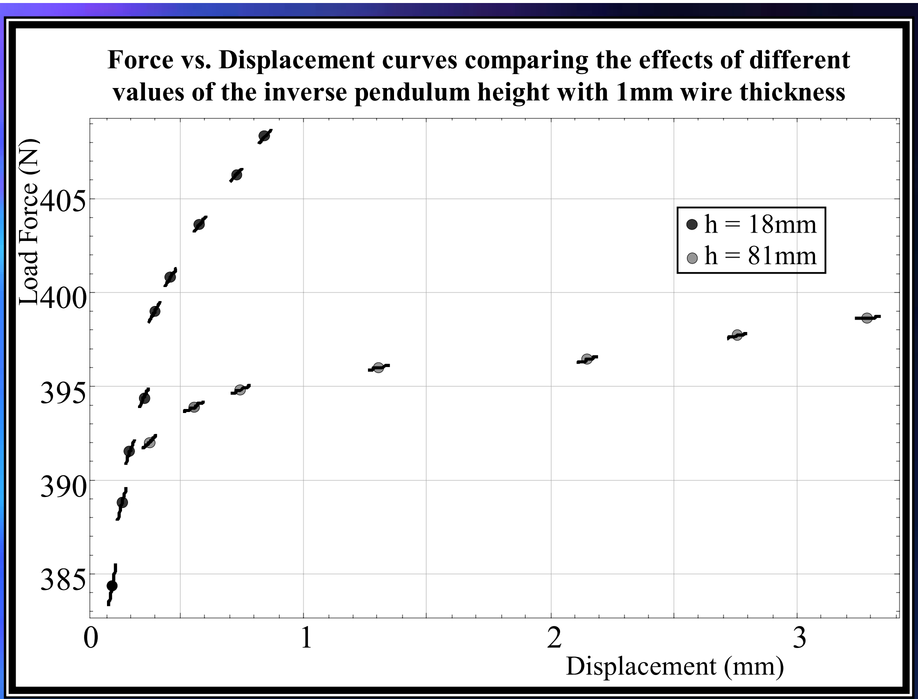
- The performance of the system is greatly effected by the suspension wire
- When the system is in operation it contributes to:
  - an increase stiffness
  - a reduction of the effective h
- Theoretically values of R_1 with a force equal to a test mass (~40kg):
  - 2mm thick wire - 28mm
  - 1mm thick wire - 7mm
  - 0.5mm thick wire - 2mm

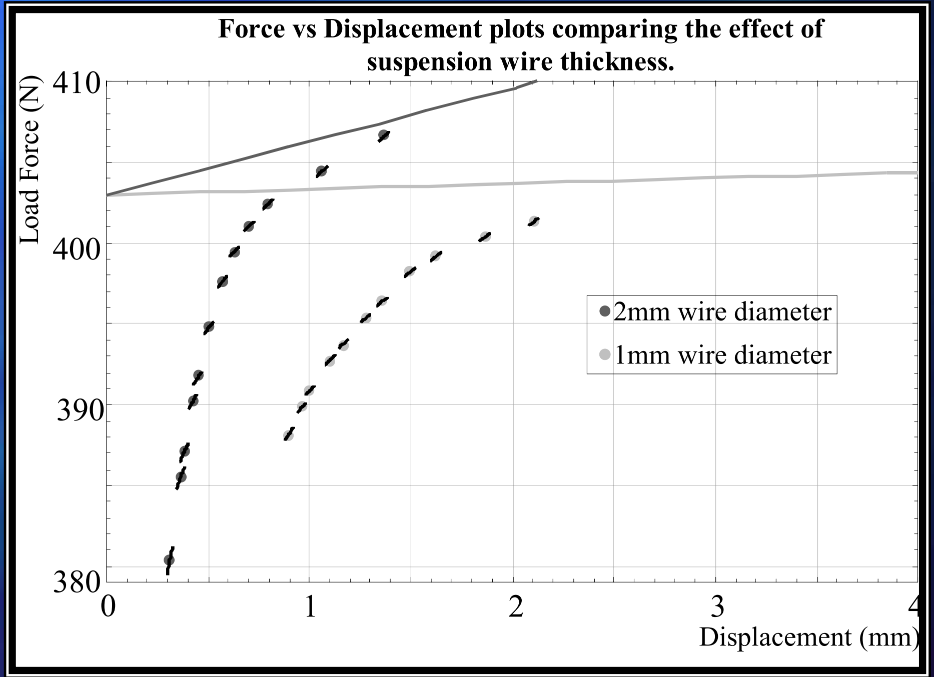
Experimental Set Up



Results

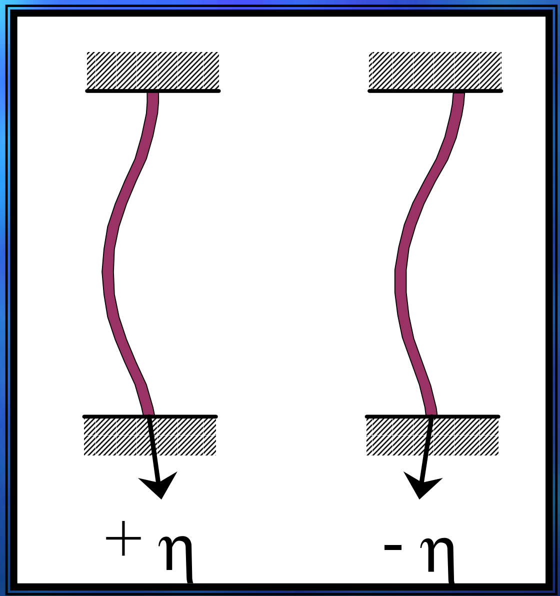
- 1st graph shows strong anti-spring tuning
- A frequency of 0.67Hz with spring constant 720N/m
- 2nd graph shows the effect of reducing wire thickness
- Large curvatures can be seen





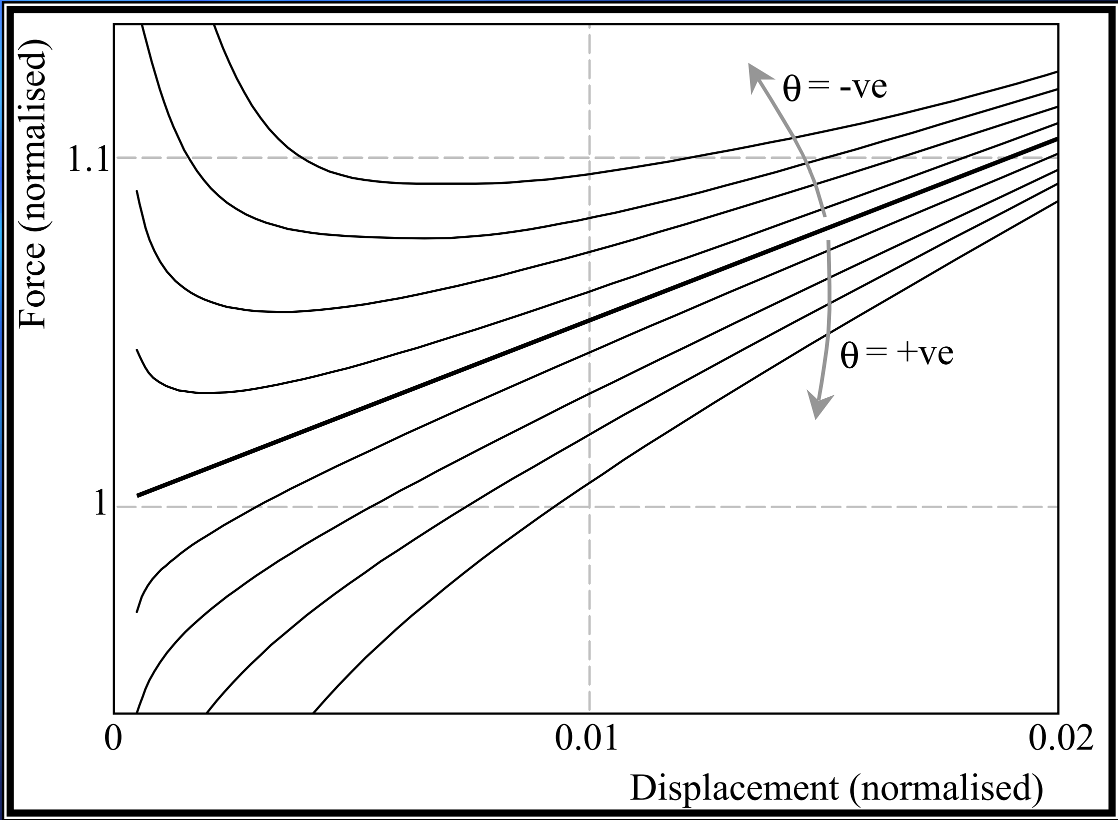
The investigation of launch angles

- The investigation was motivated by the large curvatures
- It was based on the paper written by Winterflood

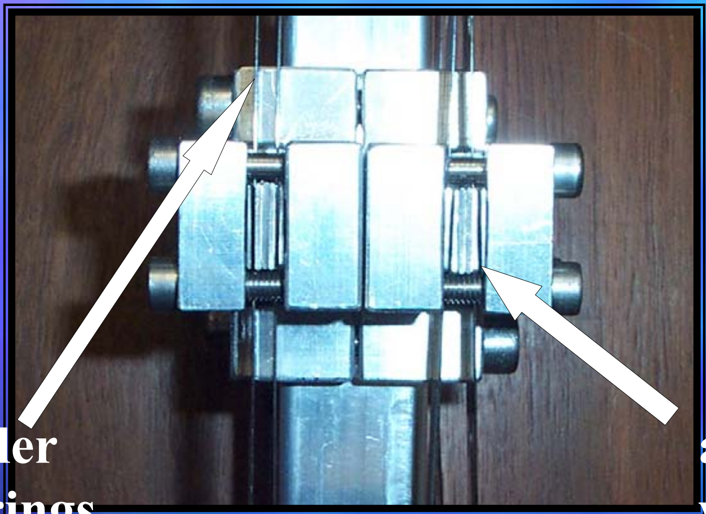


Euler Launching Angles

- Force-displacement graph shows the principle of varying θ

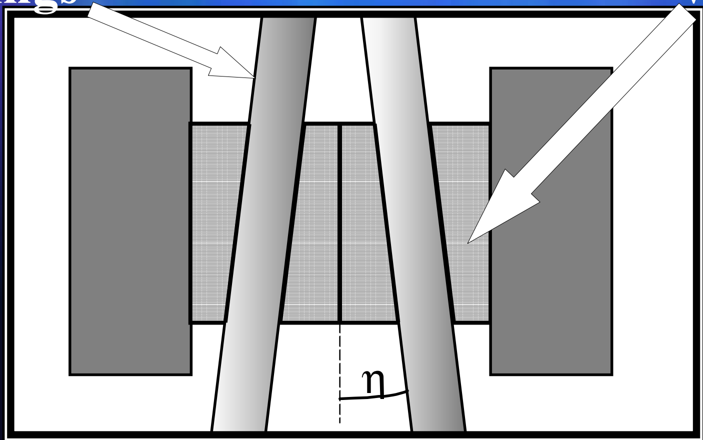


Experimental Set Up



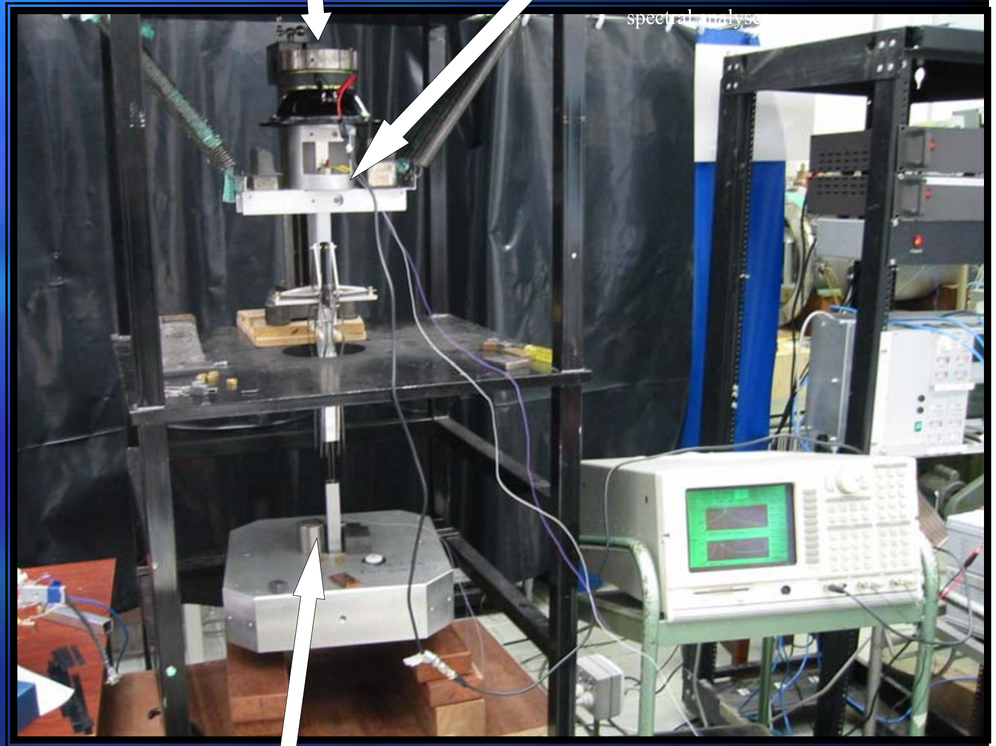
Euler springs

angled wedges



driving loud speaker

geophone 2



geophone 1

Experimental Set Up

- 5 sets of angles were used:
  - a) -0.01 rads
  - b) -0.015rads
  - c) -0.02rads
  - d) -0.0225rads
  - e) -0.025rads
- Each underwent the inverse pendulum heights of 81, 75, 65, 55 and 45mm:

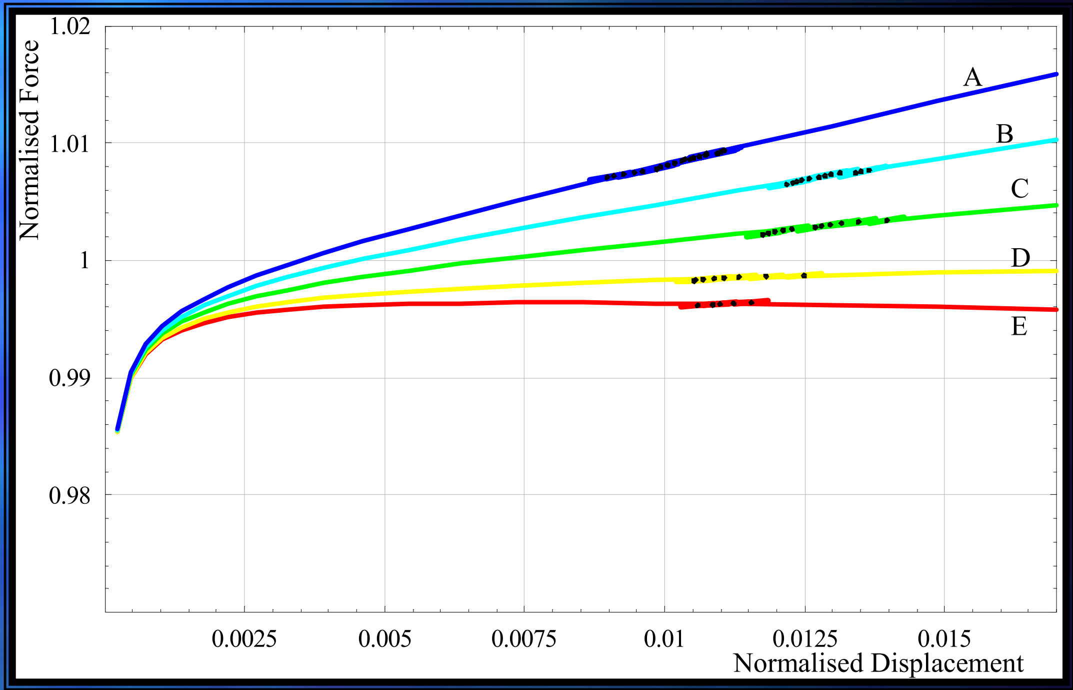
Results

- Showed large deviations from theory
- Applied best fit curves
- Overall showed general trend

- Explanations:

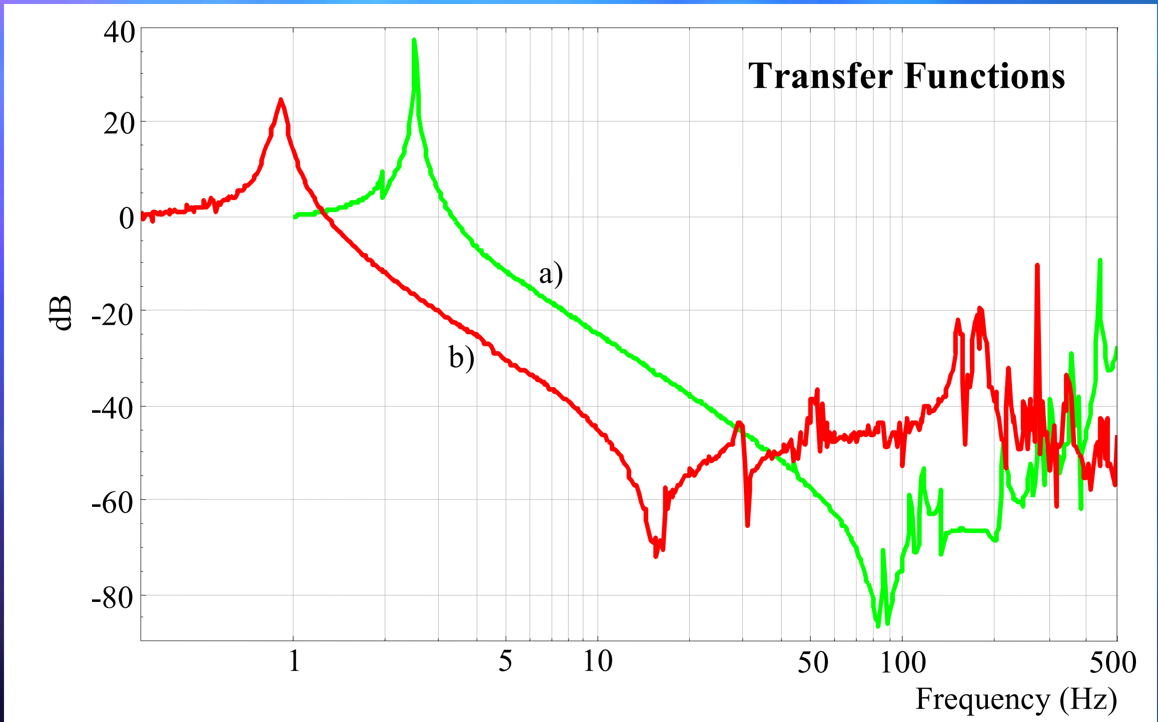
  - non-ideal clamping conditions

  - yielding of the spring



η = -0.0225radians (-0.00070rads), A) h = 45mm, B) h = 55m, C) h = 65mm, D) 75mm, and E) 81mm.

Results

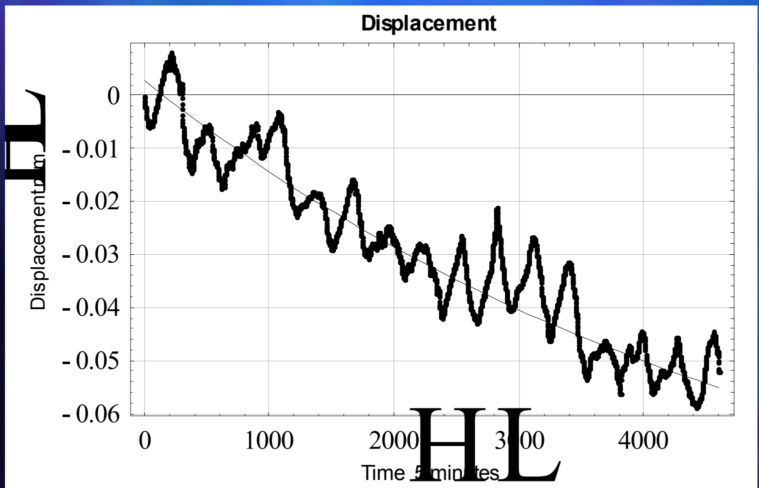


Red shows the transfer function obtained with η=-0.0225 with h=75mm, and green is the transfer function function obtained in the previous year.

- Transfer function shows ~20dB improvement
- High noise floor above 20Hz due to centre of percussion effects

Creep

Test Material	Temperature Coefficient (µm/ºC)	Creep Rate (µm/day)
AISI C1095 tool steel	16	36
CS1075 spring steel	4.5	14
Spring steel with the introduced permanent offset	6	~5 to ~2

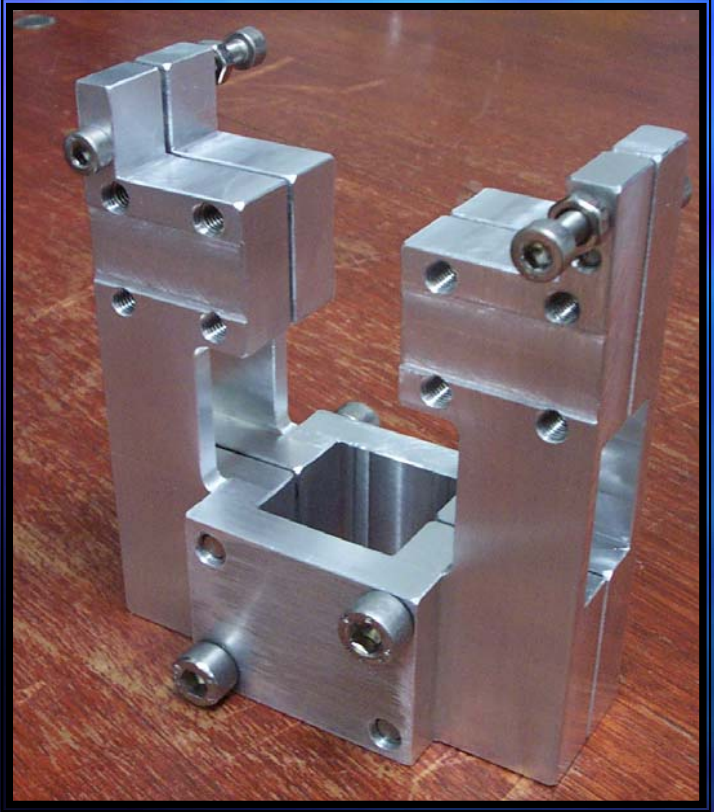


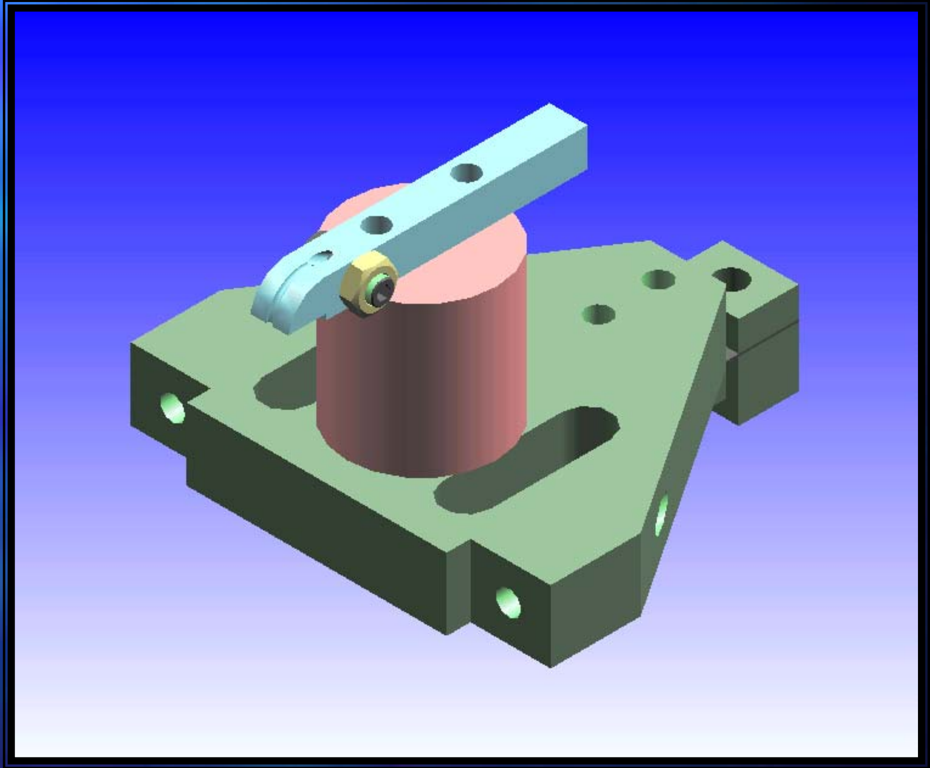
Creep displacement of the third test showing a logarithmic curve

- Creep was constantly experienced during experimentation
- An assessment was made between the current material (AISI C1095 tool steel) and CS1075 spring steel
- Shows that the stability of the Euler experiments can be improved
- Creep rate tends to fit a logarithmic curve

Design for improvements

- A new angle adjustable clamp
- A new wire holding mechanism for thinner wires





Project Conclusions

- A resonant frequency of 0.63Hz was achieved
- Large curvatures in force-displacement plots decreased the performance
- Fine tuning the launch angles proved difficult
- Creeping of the springs was encountered
- Even lower frequencies can be achieved by the design improvements presented