Development of Suspension System for GEO 600

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Status of suspension development:

Modecleaner/injection optics suspensions:

⇒ design completed and tested

⇒ elements of suspensions under manufacture

Main mirror suspensions:

⇒ design outlined

⇒ testing underway

⇒ objectives for active vibration isolation fixed

Elements of suspension design:

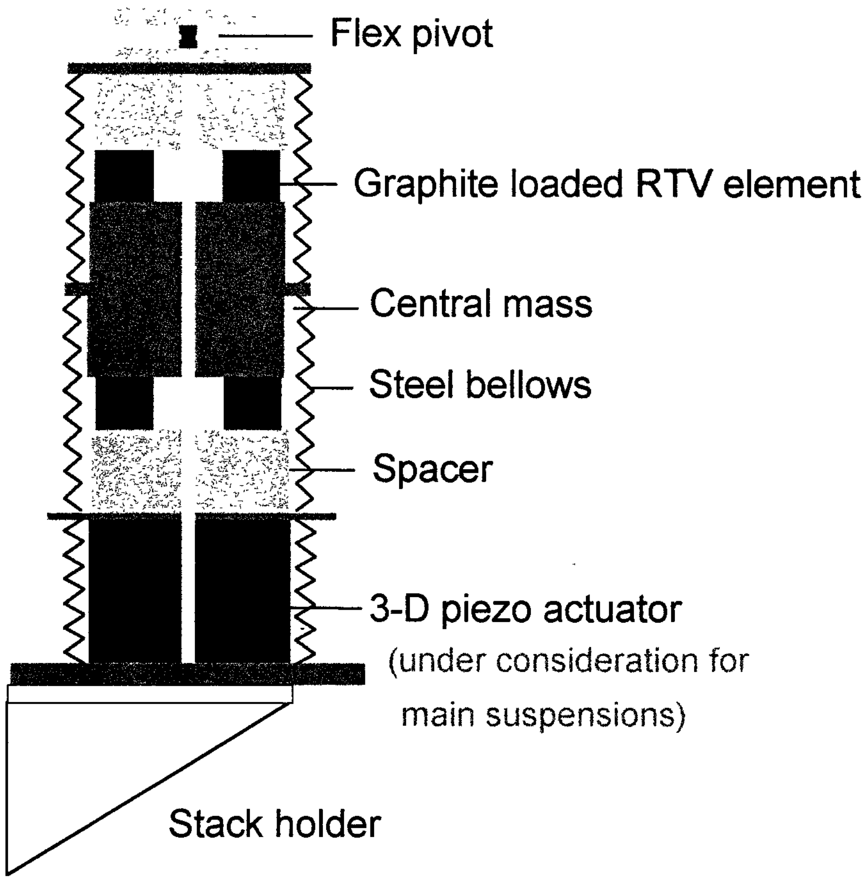
Modecleaner suspensions:

- 2-layer passive isolation stack
- Double pendulum suspension for each optic (reaction pendulums for end mirrors)

Main suspensions:

- 1 or 2-layer passive isolation stack with active stage
- Triple pendulum suspension for each optic
- 2 stages of cantilever springs to improve vertical isolation

Stack design:



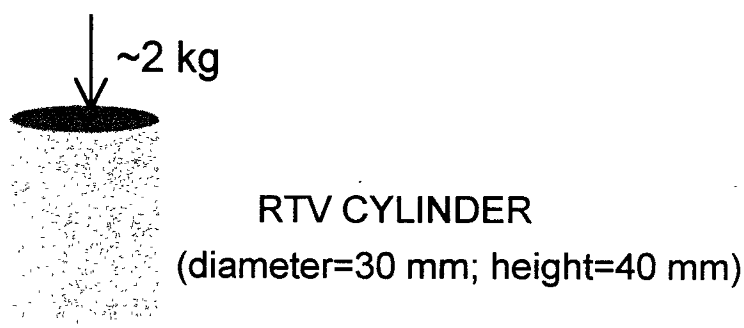
Schematic of single stack leg

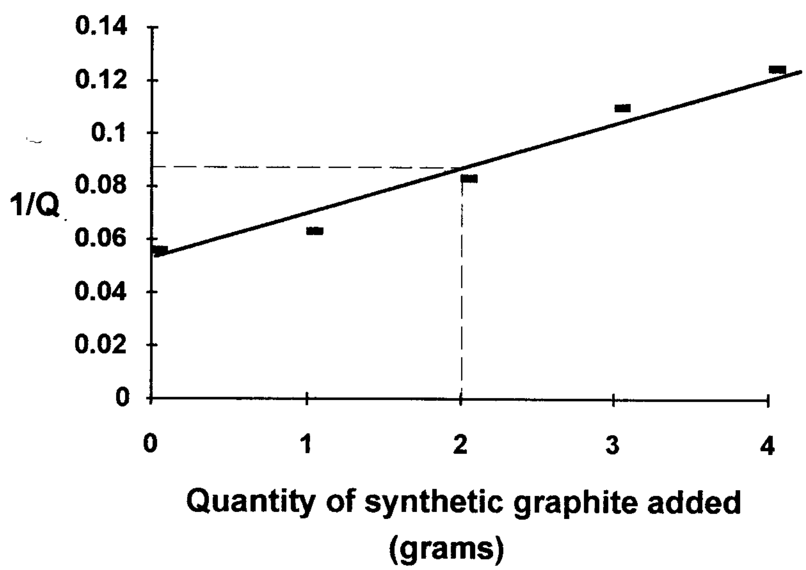
3 legs per tank

- **encapsulated in soft stainless steel bellows**

Damping tests of elements of stack:

⇒ **Investigation of damping of RTV with synthetic graphite filler**





Conclusions:

- best compromise between damping and tear resistance is ~6% graphite by weight leading to a Q of ~12 (c.f ~20 for normal RTV)

- No evidence of creep (to a measured accuracy of +/- 0.1 mm) observed for C-loaded RTV placed under constant and heavy loads over a period of one year

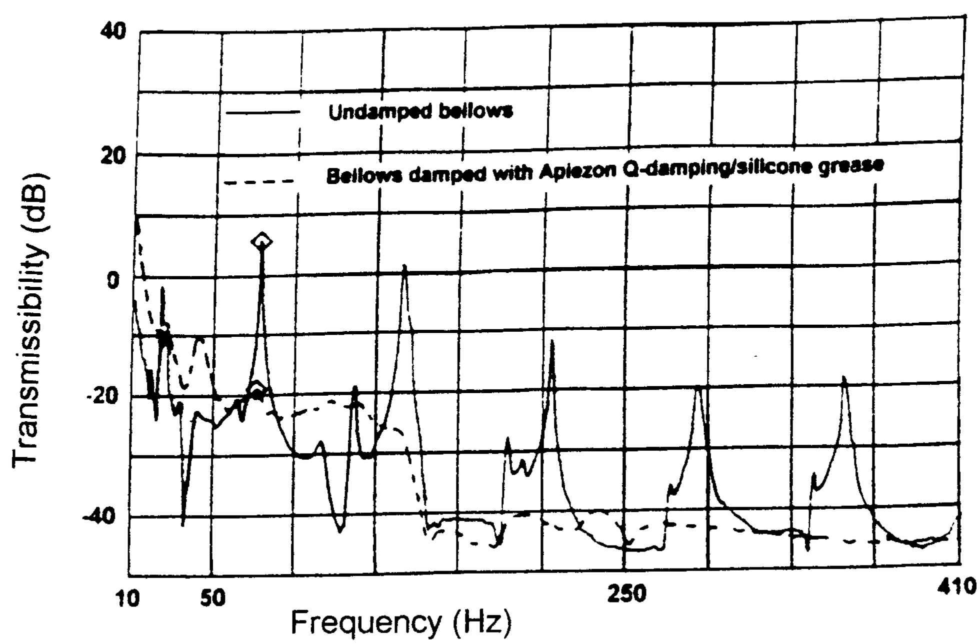
Control of mechanical resonances in stainless steel bellows:

Use of Apiezon Q-damping/silicone grease to line inside of bellows

$\Rightarrow$ reduces amplitude of fundamental mode

$\Rightarrow$ removes higher order modes

Vertical Transfer function of bellows:



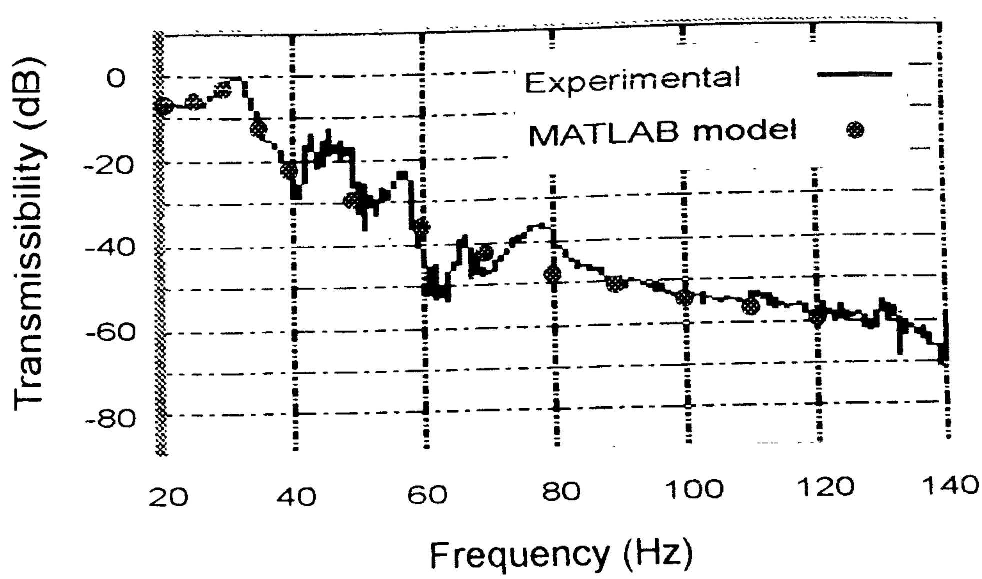
Flex pivot:

To reduce possibility of transmission of ground rotation to top of stack a rotational flexure has been included.

⇒Rotational resonance ~2 Hz (loaded)

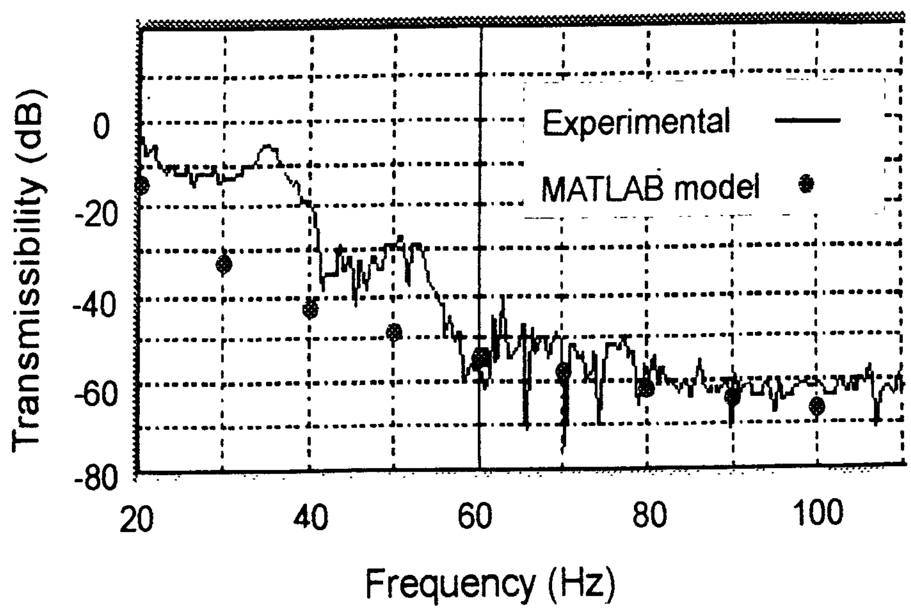
Vertical transfer function of stack leg:

(2 layers of steel/damped RTV, central mass of 10 kg, and top mass of ~20 kg)



Plot indicates a fall off, above the highest resonance, close to $1/f^2$ per stage up to ~ 120 Hz

Horizontal transfer function of stack leg:
(2 layers of steel/damped RTV, central mass of 10 kg, and top mass of ~20 kg)



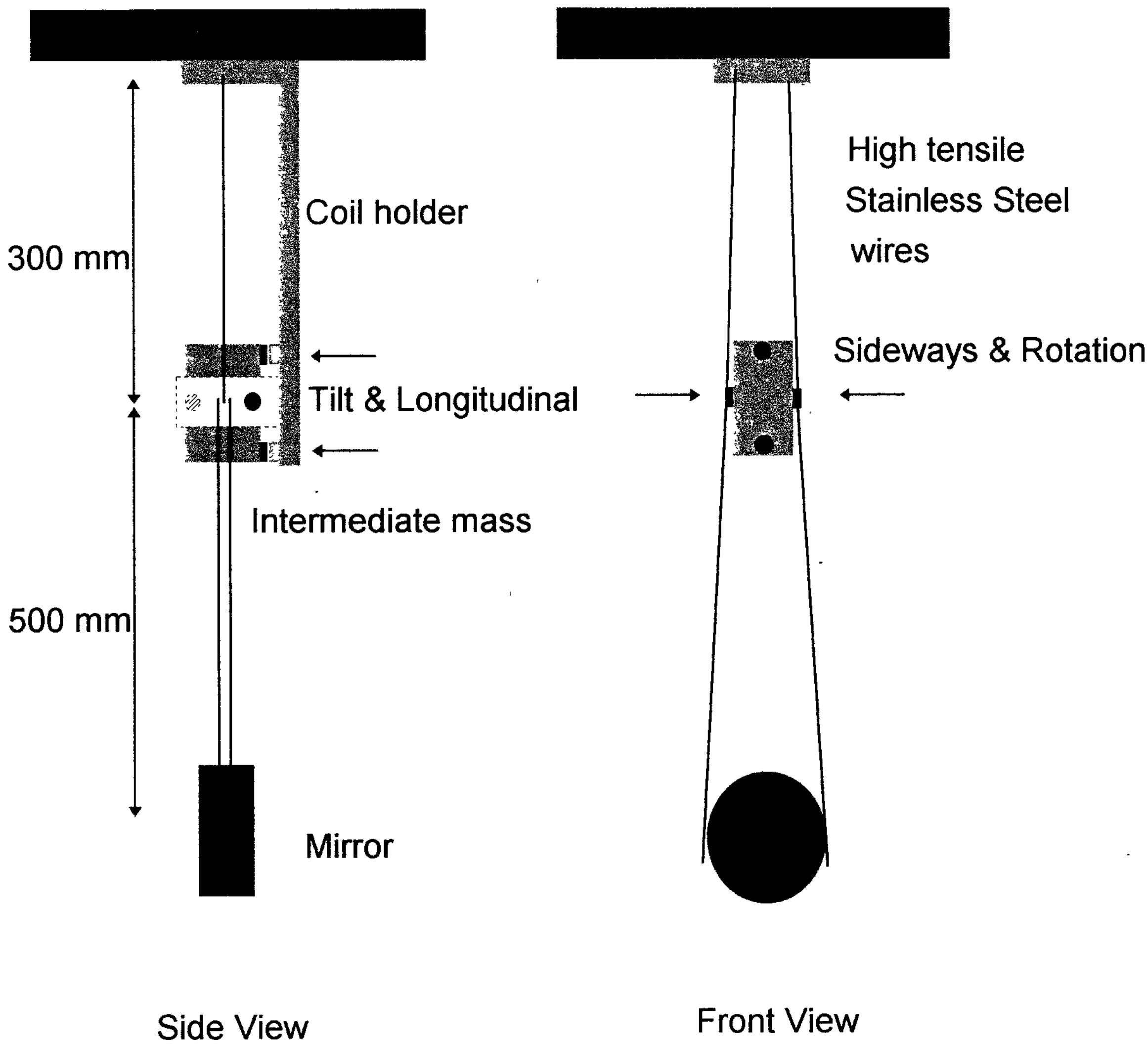
Modecleaner suspensions:

(High finesse Fabry-Perot cavities used to reduce geometry perturbations of laser beam that illuminates the interferometer)

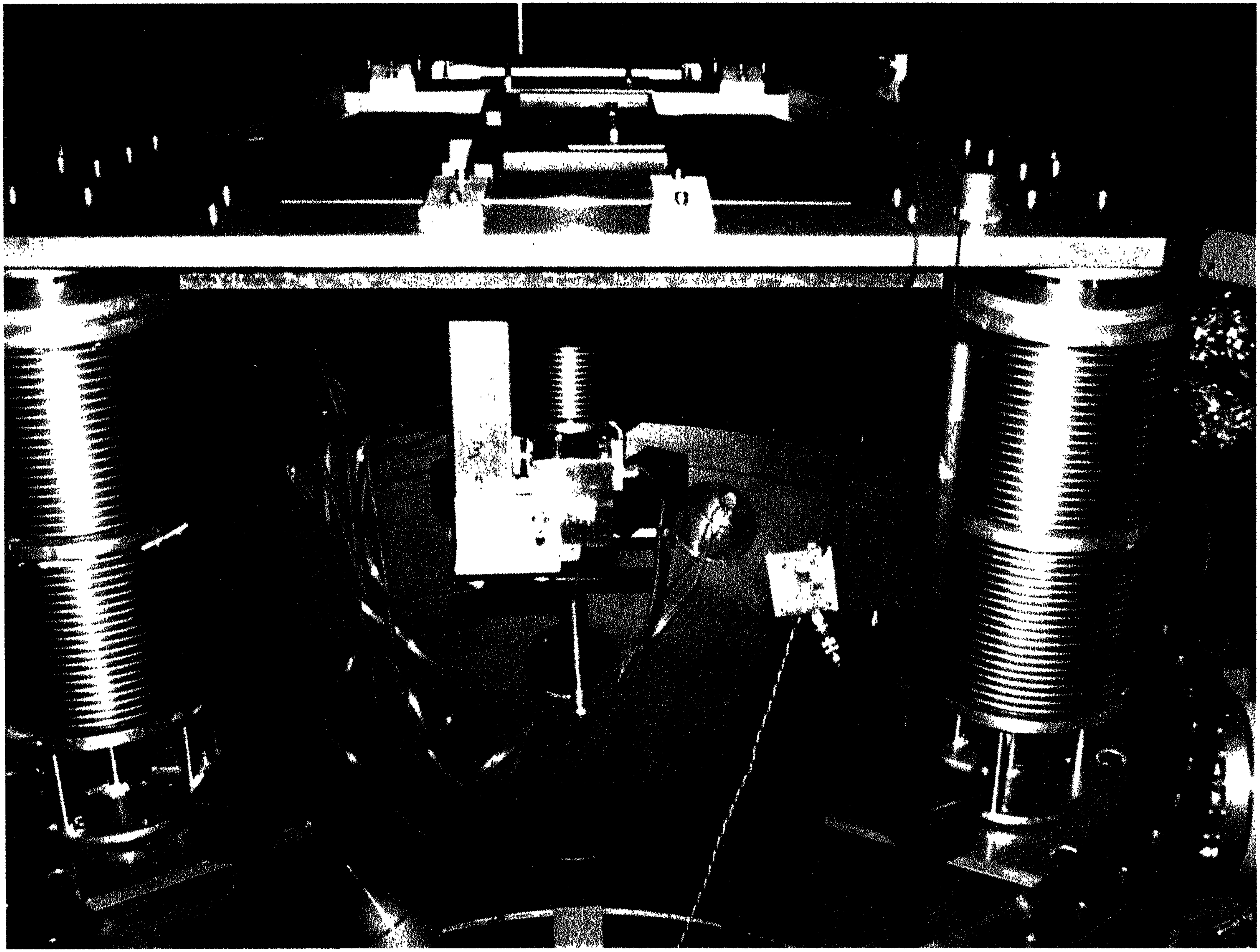
Double pendulum:

- To provide additional isolation from seismic noise
- Allow control forces to be applied at the intermediate mass such that control noise is filtered by lower pendulum stage
- Modelling of local control servos indicate that 8 degrees of freedom of double pendulum can be actively damped

Schematic of modecleaner suspension:



(top plate connected to top of stack legs)



Aims:

To encompass large range of potential sources of gravitational waves

⇒design GEO 600 system such that it is not limited by seismic noise above 50 Hz

Aim to achieve a seismic noise level at each test mass of $(7\times10^{-21} m/\sqrt{Hz})_{50Hz}$

For a typical seismic noise spectrum of

$10^{-7}/f^2\ m/\sqrt{Hz}$ **(measured from 20-300 Hz)**

⇒Require isolation factor of 6×10^9 at 50 Hz in horizontal and 6×10^6 in vertical

(assuming 0.1% cross coupling of vertical to horizontal at the test mass)

Test mass suspensions:

To enhance vertical isolation two additional spring stages will be included:

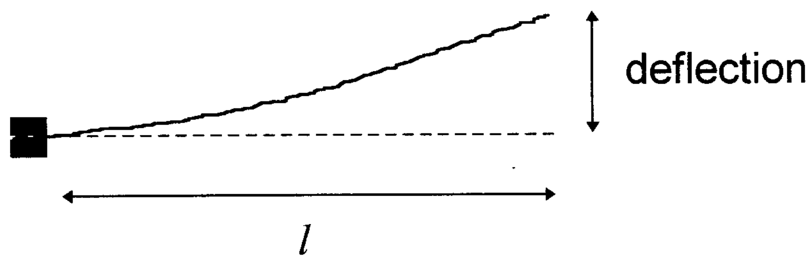
Stage 1: Three cantilever springs supporting an upper mass (transfer from VIRGO design)
One end of spring fixed to outer stabilising ring linking together the 3 stack legs

Stage 2: Two cantilever springs supporting a double pendulum

Proposed GEO 600 test masses will be made from fused silica suspended by fused silica fibres to reduce thermal noise.*

*work on thermal noise/fused silica suspensions reported by Sheila Rowan

Design aspects of cantilever blades:



Frequency for bending mode of spring:

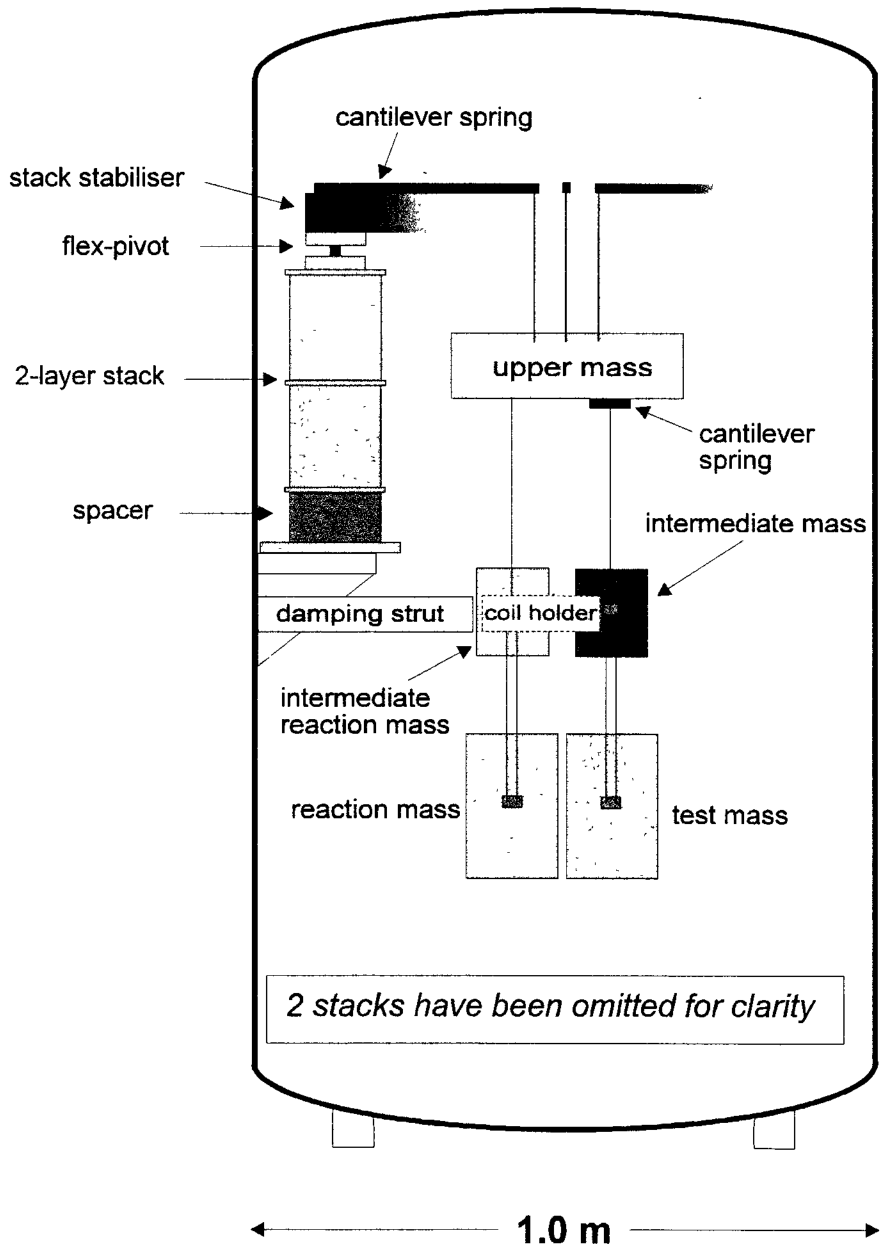
$$f = \frac{1}{2\pi}\sqrt{\frac{Eah^3}{4ml^3}}$$

a = width of blade base (at clamp); h = blade thickness; m = mass suspended; E = Young's Modulus

With *a* = 10 cm, *l* = 30 cm, *h* = 2.3 mm,
***m* = 10 kg/spring**

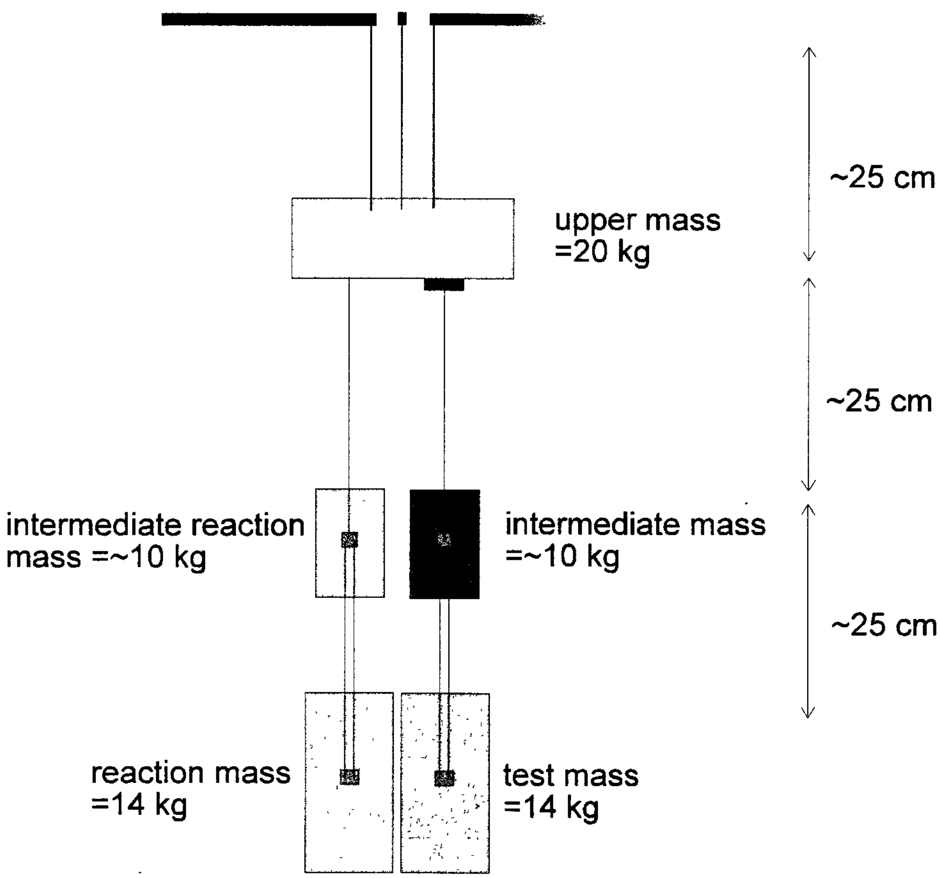
<u>*f* ~ 2.4 Hz </u>(uncoupled frequency)

Schematic of Test Mass Suspension:



View perpendicular to optic axis

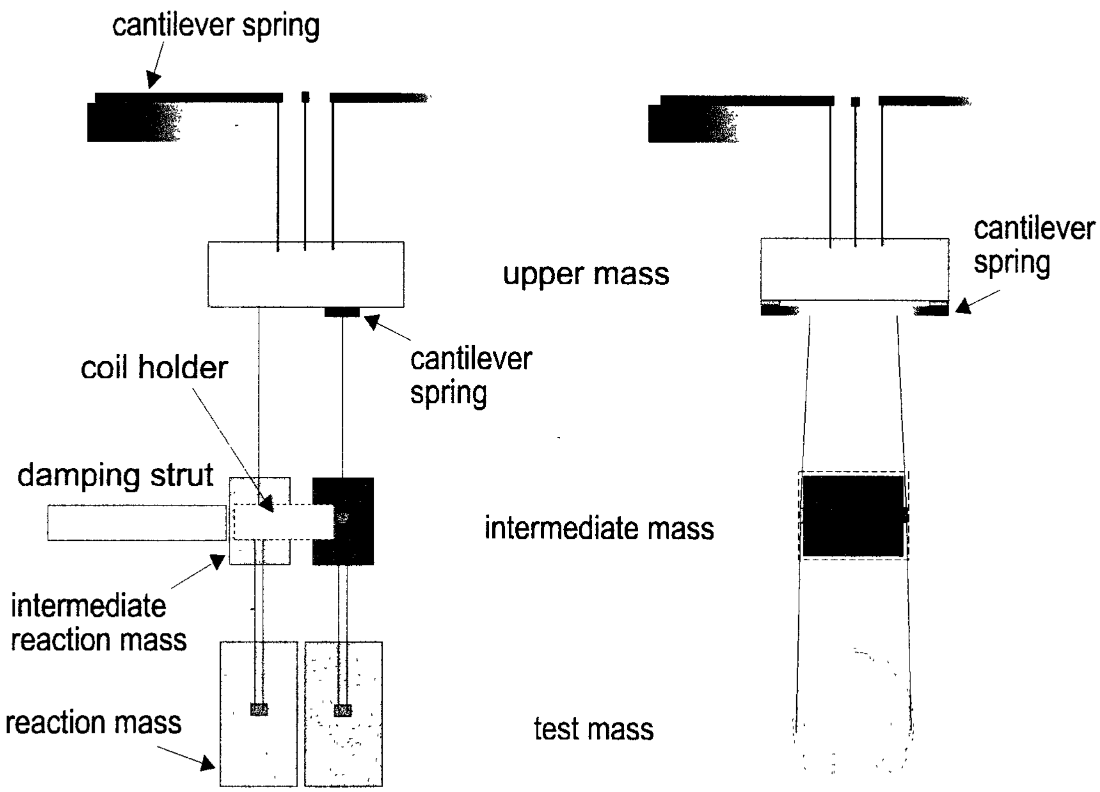
Main mirror suspension (mechanical):



Proposed parameters for masses and lengths of triple suspension

⇒ Optimise damping performance

Main mirror suspension (control):



- **6 degrees of freedom between intermediate masses (dc forces applied for alignment)**
- **4 degrees of freedom from intermediate mass to ground reference (no dc forces applied to minimise coupling of seismic noise)**

Active seismic isolation for GEO 600:

Aims:

- Reduce microseismic noise peak near 0.2 Hz providing improved operation in stormy weather

$\Rightarrow$ reduces bandwidth required in damping servos and eases lock acquisition

- Improve seismic isolation around low frequency limit of interferometer (50 Hz)

Proposed solutions:

- 3 D.O.F PZT actuators at base of each stack leg with co-located 2 Hz geophone sensors
- Active layer replaces spacer at bottom of stack or alternatively one passive layer

⇒loop optimised for 0.1 Hz-30 Hz (horizontal)
3 Hz-100 Hz (vertical)

- Additional 1 Hz horizontal geophones mounted on top of stack to extend system to sub-Hz frequencies

- Tiltmeters possibly required to avoid/control parasitic servo loops due to tilt of top structure

Active isolation work:

Ken Strain – Glasgow

Dave Robertson, Aniello Grado – Hannover