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Number of pages to follow this header : 38

Date : 19.3.96

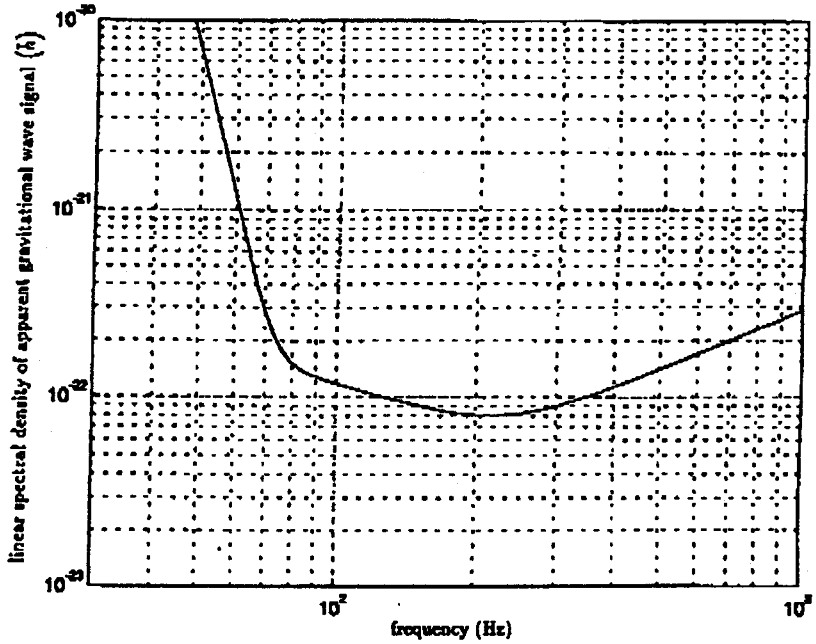
Research towards Isolation and Suspension Systems for GEO 600

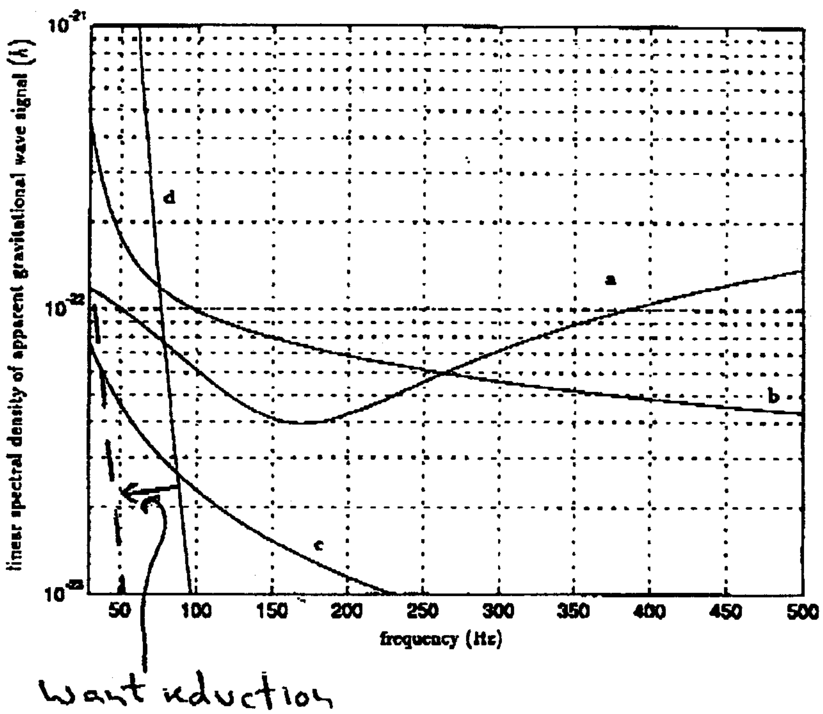
Input from

Glasgow, Hannover, Garching

J. Hough et al
March '96

GEO 600 Design Specification 1995





a - photoelectron shot noise b - thermal noise
c - HUP d - seismic noise

Revised Specification:

$h \sim 2 \times 10^{-22}/\sqrt{Hz}$ at 50 Hz

$\Rightarrow \Delta x/\text{mass} < (7 \times 10^{-20}\ m/\sqrt{Hz})_{50Hz}$

So want $\Delta x_{seismic} < (7 \times 10^{-21}\ m/\sqrt{Hz})_{50Hz}$

Assuming $\Delta x_{ground} \sim 10^{-7}/f^2\ m/\sqrt{Hz}$

$\Rightarrow$ Isolation $\sim 6 \times 10^8$ at 50 Hz

Should be achievable for 0.1% vert. to horiz. cross - coupling with:

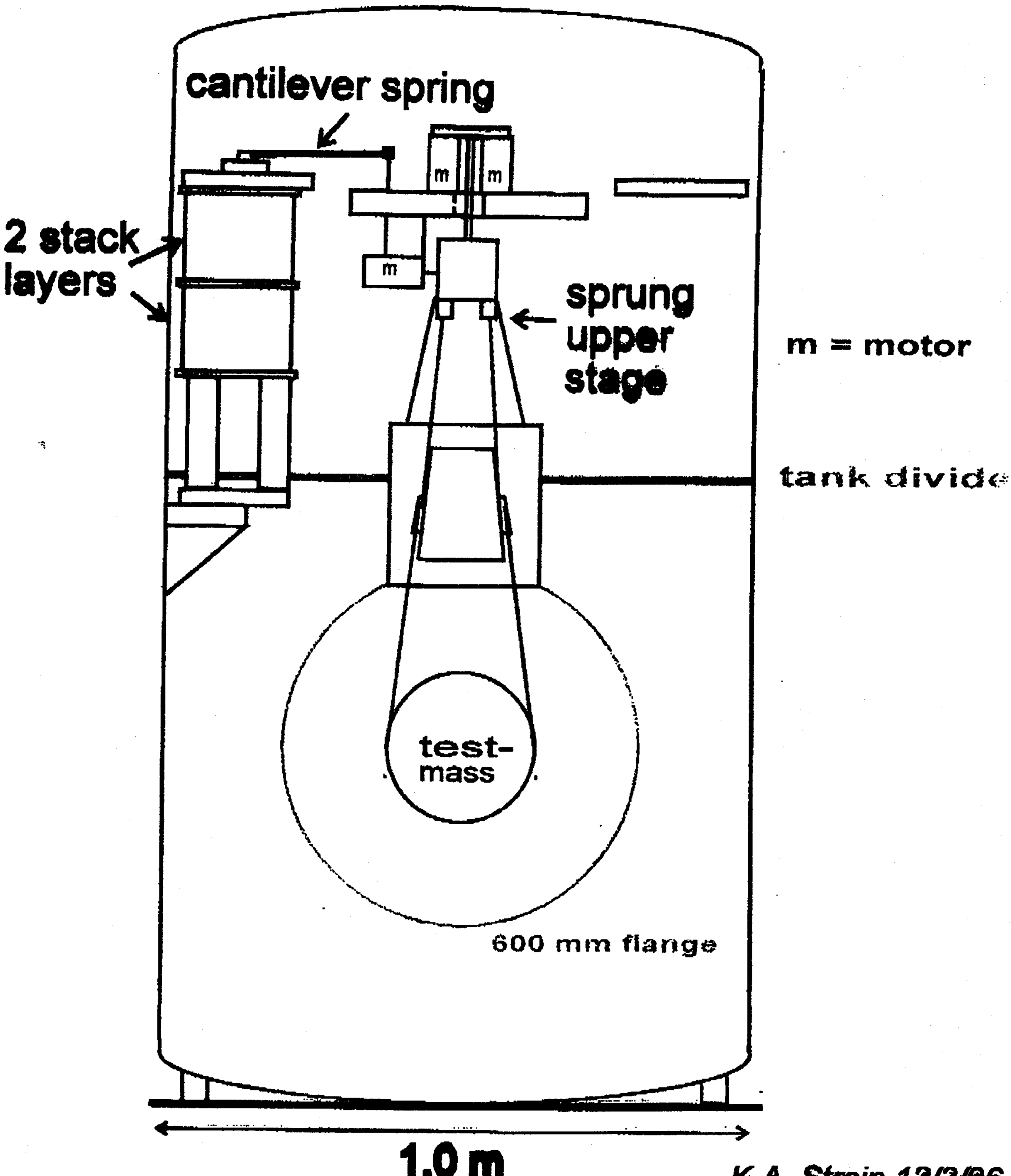
- 2 layer isolation stack +
- 2 vertical spring stages +
- double pendulum

Stack:

- graphite loaded RTV cylinders
- stainless steel masses
- encapsulated in bellows

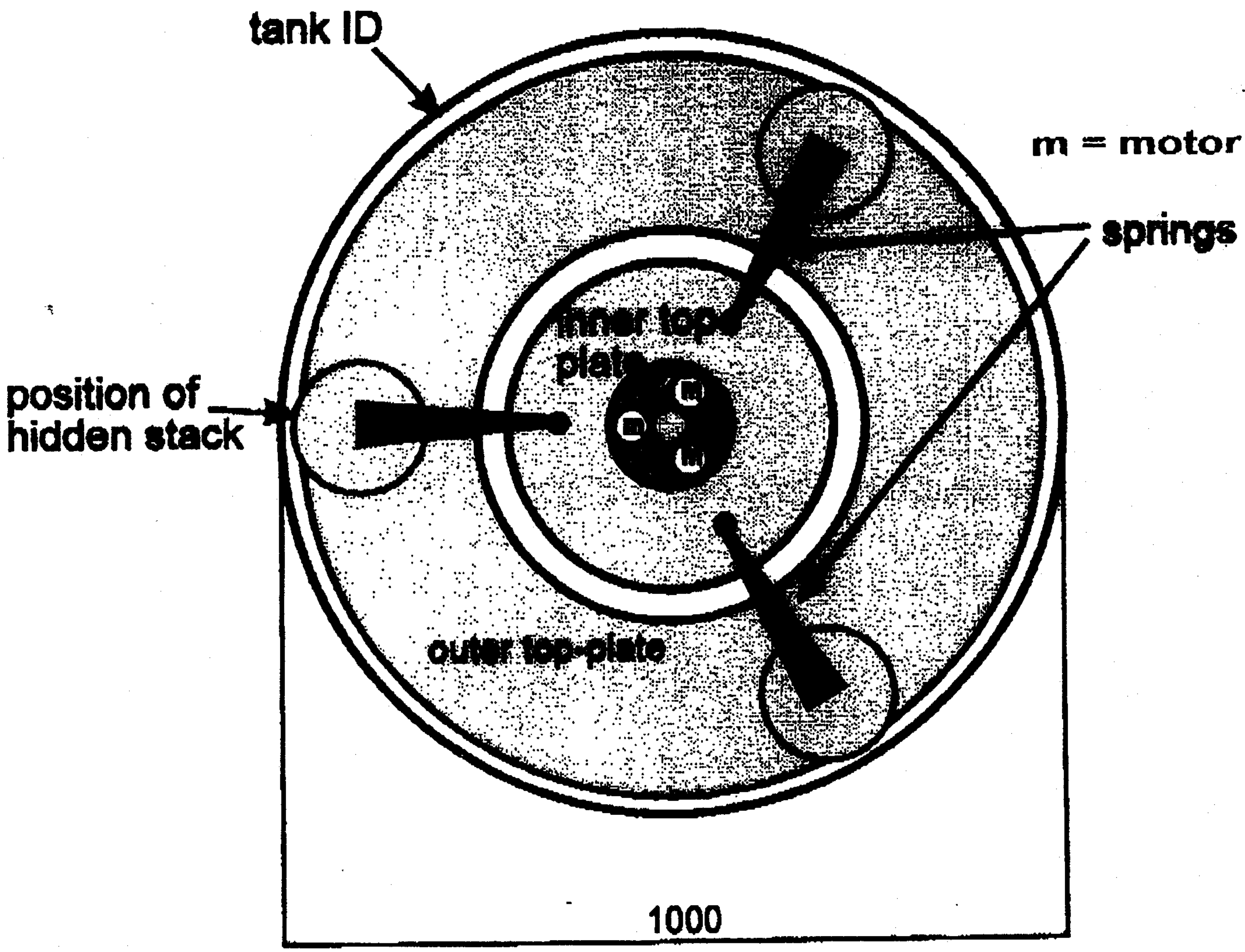
GEO 600 End-mirror Suspension (draft)

2 stacks omitted for clarity

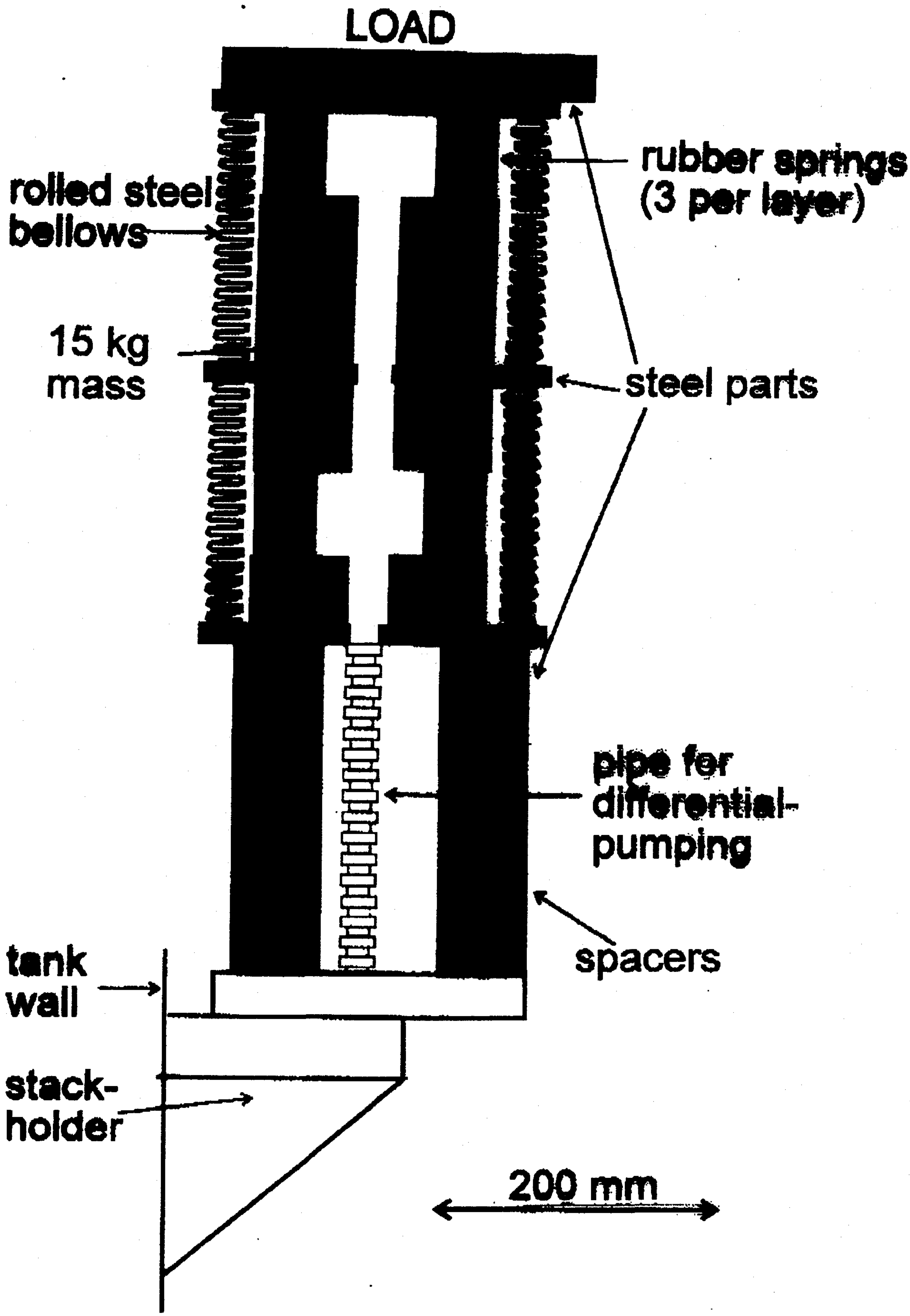


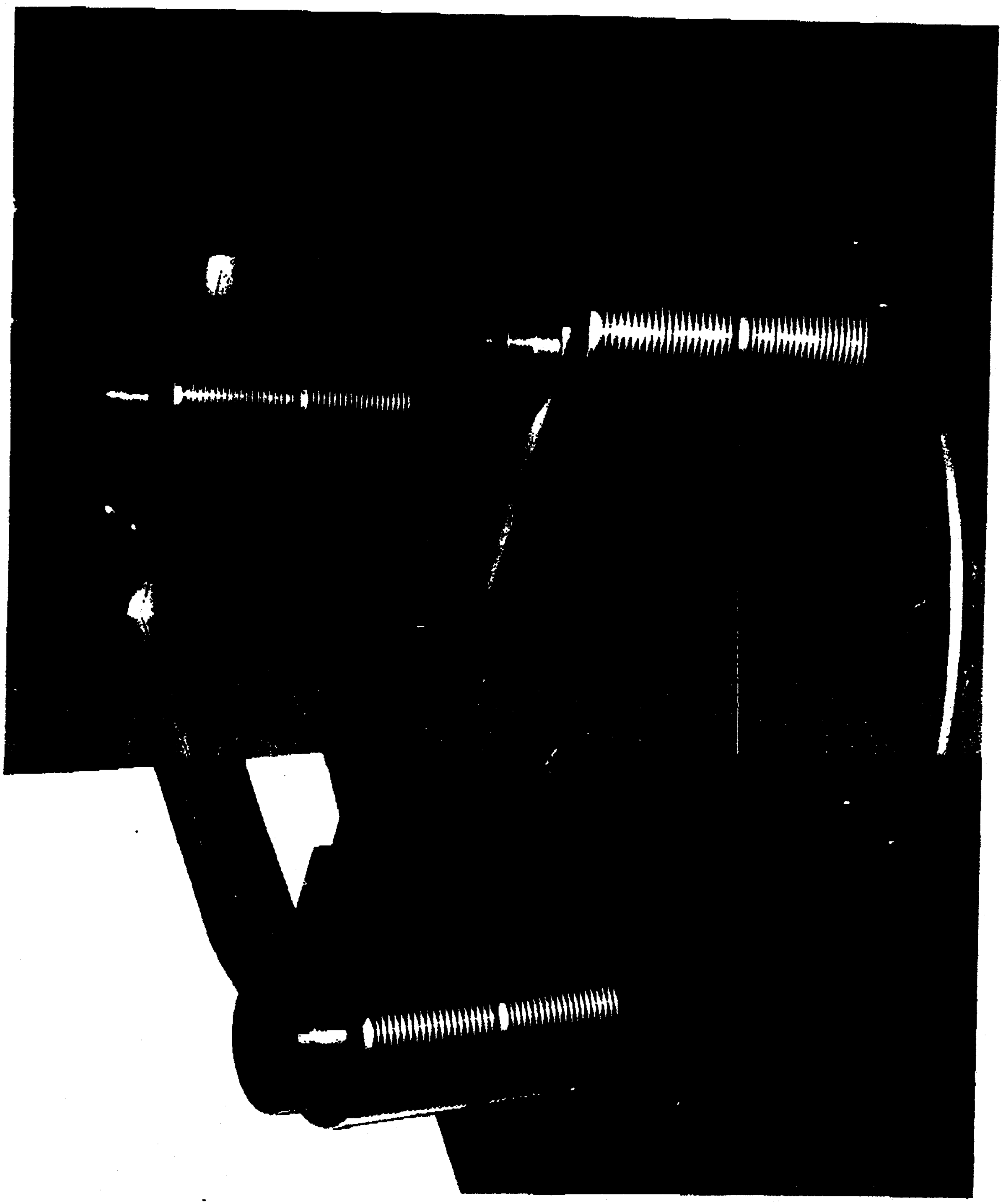
K.A. Strain 12/3/96

GEO 600 End-mirror suspension (plan view)



GEO 600 stack leg (2 -layer)





RTV 615

Set of 3 cylinders of undamped RTV 615, each of diameter 30 mm and height 40 mm, and loaded with 15 Kg.

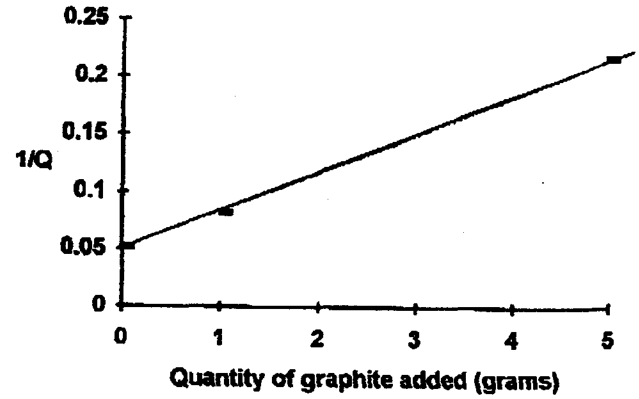
Stiffness constants (of total set):

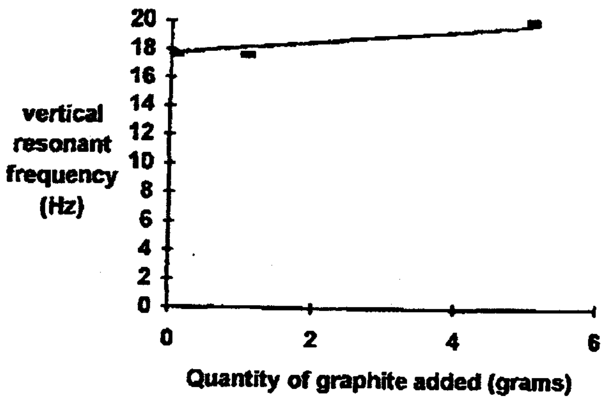
$$k_v = 5.6 \times 10^4\, N/m$$

$$k_h = 0.9 \times 10^4\, N/m$$

M. Punsi

Loading of RTV





M. Plissi

M. PLISSI

Thermal noise requirements for GEO 600:

- Require h sensitivity of $10^{-22}/\sqrt{Hz}$ at 100Hz
- Sets limits on thermal noise from pendulum modes, violin modes and internal modes of suspension

$\Rightarrow$ $Q_{pendulum} > 5 \times 10^5$

$Q_{violin} > 2 \times 10^6$

$Q_{internal} > 5 \times 10^6$

nb: each of these values alone gives $h = 10^{-22}/\sqrt{Hz}$

(assumes structural damping)

Relationship between $Q_{pendulum}$ and $Q_{material}$:

$$Q_{pendulum} = Q_{material} \frac{mgl}{4\sqrt{TEI}}$$ for a 2-loop suspension

where:

m = mass

l = length

T = tension

n = number of wires

E = Youngs modulus

I = moment of mass = $\frac{\pi r^4}{4}$

r = radius of wire

SKODOCK BELLOWS

Bellows dimensions:

wall thickness =0.25 mm

inside diameter =139.3 mm

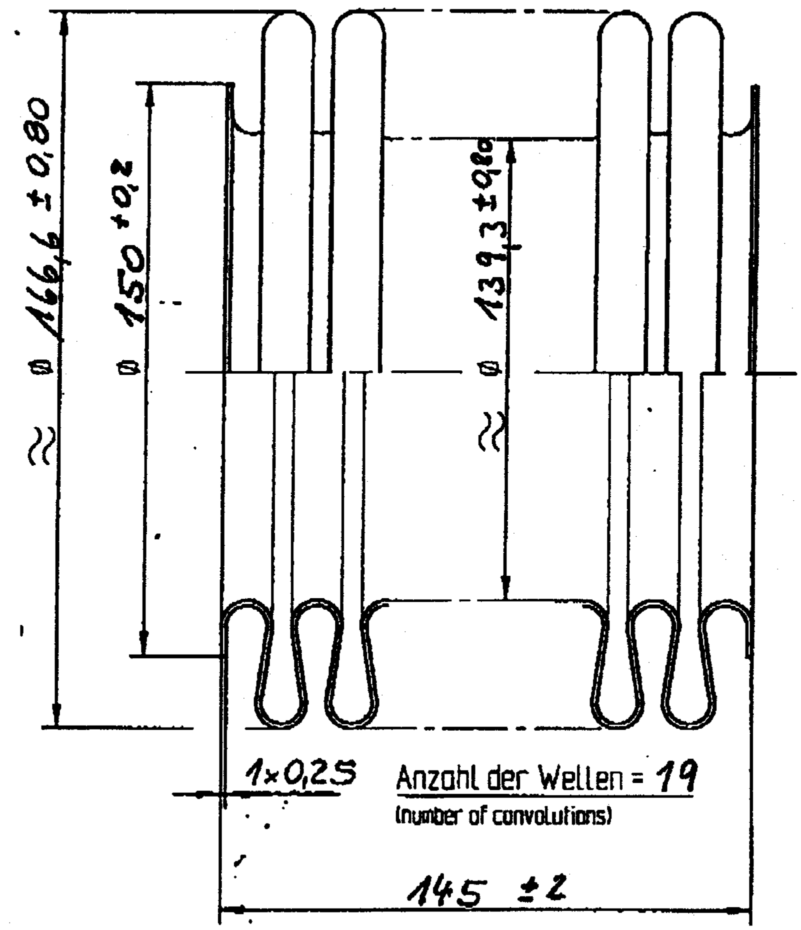
height =145 mm

Stiffness constants:

$$k_v = 0.9 \times 10^4 \, N / m$$

$$k_h = 5 \times 10^4 \, N / m$$

SKODOCK - Form - J-003-1



AW
23. Okt. 95

Unterliegt dem Änderungsdienst
DOKUMENT
rot = Original
schwarz = Kopie

Weitergabe sowie Vervielfältigung dieser Unterlage nicht gestattet. "Schutzvermerk nach DIN 34 beachten".

Technische Daten / (technical data)

Federkonstante : Caxial ≈ 6 N/mm ±25%
(spring rate) Clateral ≈ 17 N/mm ±25%
wirks. Fläche : A_W ≈ 184 cm^2
(active area)
Hub: ± 45 mm axial
Lastwechsel: 1 500
* bei Innendruck max. 1 bar

Betriebsdaten / (working data)

Betriebsüberdruck : 3,8 bar *
(working pressure) - Außendruck
Betriebstemperatur : 20 °C
(working temperature)
Medium :

Prüfdruck : ./. bar
(test pressure)

Maße ohne Toleranzangabe nach DIN 7168 m		Maßstab im Original	—	P55575	
		Werkstoff: 1.4541 (AISI 321)			
95	Datum	Name	Metallbalg (Bellow) NG 166/19		
Bearb.	28.09.	Peters			
gepr.					
Norm					
SKODOCK HANNOVER			SV 280995		Änd.-Stand:
Orig.: 0 89022 00			Ersatz für:	ersetzt durch:	

Nennmaß	Abmaß	Nennmaß	Abmaß

DIN 3141 Reihe 2 / DIN 1302 ISO: 0,1 / 0,8 / 3,2 / 12,5 / roh

For a 16kg mass suspended on 4 wires made from:

- **Carbon steel**

  $E = 210 \times 10^9$

  $T = 160N$ (40N/wire)

  Breaking stress $= 3 \times 10^9$

- **Fused silica**

  $E = 73 \times 10^9$

  $T = 160N$ (40N/wire)

  Breaking stress $= 8 \times 10^8$

> **For GEO:**
>
> let stress = breaking stress/3

Carbon steel:

$$40/(\pi r^2) = 3 \times 10^9 / 3$$

$$\Rightarrow r_{steel} = 113\mu m$$

Fused silica:

$$40/(\pi r^2) = 8 \times 10^8 / 3$$

$$\Rightarrow r_{silica} = 220\mu m$$

Relationship between Q_{pend} and Q_{mat} then becomes:

- Carbon Steel (piano wire)

  $Q_{pend} = Q_{mat} \times 300$

  $\Rightarrow$ need $Q_{mat} \geq 1.7 \times 10^3$

- Fused Silica

  $Q_{pend} = Q_{mat} \times 140$

  $\Rightarrow$ need $Q_{mat} \geq 3.6 \times 10^3$

Necessary Q_{mat} values suggest that steel is *just* good enough - fused silica is much safer choice.

(Typical Q_{mat} for (carbon) steel = few x 10^3)
(Typical Q_{mat} for fused silica = few x 10^6)

Pendulum design must preserve material Q

Possibility of "monolithic" fused silica suspensions:

- Welding of fibre to mass (excellent results for small masses - Braginsky, Traeger)
- Optical contacting of fibres with rod ends

Measurement of Q_{pend} for pendulum (200g) suspended by fused silica fibres

- Fused silica fibres drawn from rods of 3mm diameter - end of fibre still have rods attached
- Rods at top:

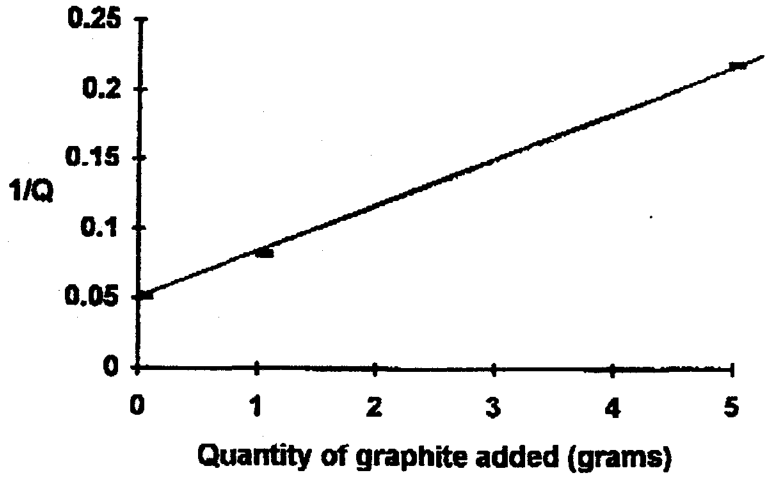
  clamped/glued into brass cylinders using vacuum epoxy

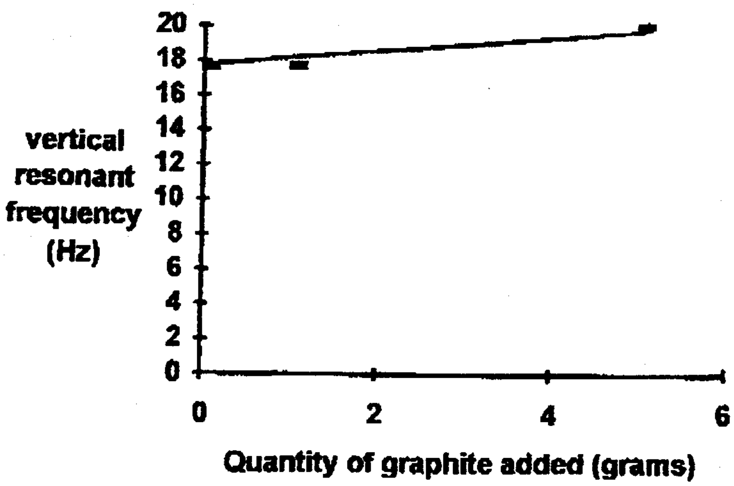
  brass cylinders held in aluminium clamp
- Rods at bottom:

  glued to glass pendulum

  or clamped/glued to macor pendulum

Loading of RTV





M. Plissi

Monolithic suspensions desirable

- Aim: use fused silica fibres to suspend mass - ends of fibre optically contacted to test mass
- Present experiments:

(a) measure Q_{mat} of ribbon fibres $\Rightarrow$ gives Q_{mat} for Q_{pend} thermal noise calculations

(b) measure Q_{pend} of mass suspended by silica fibres

+ comparison of these results?

Measuring Q_{mat} fused silica ribbons

- Fused silica ribbon - drawn from silica slide using RF oven

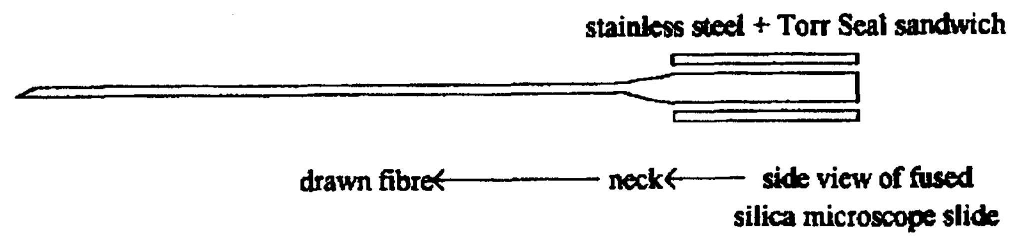
  Dimensions: length ~ 12.5cm

  width ~ 0.3cm

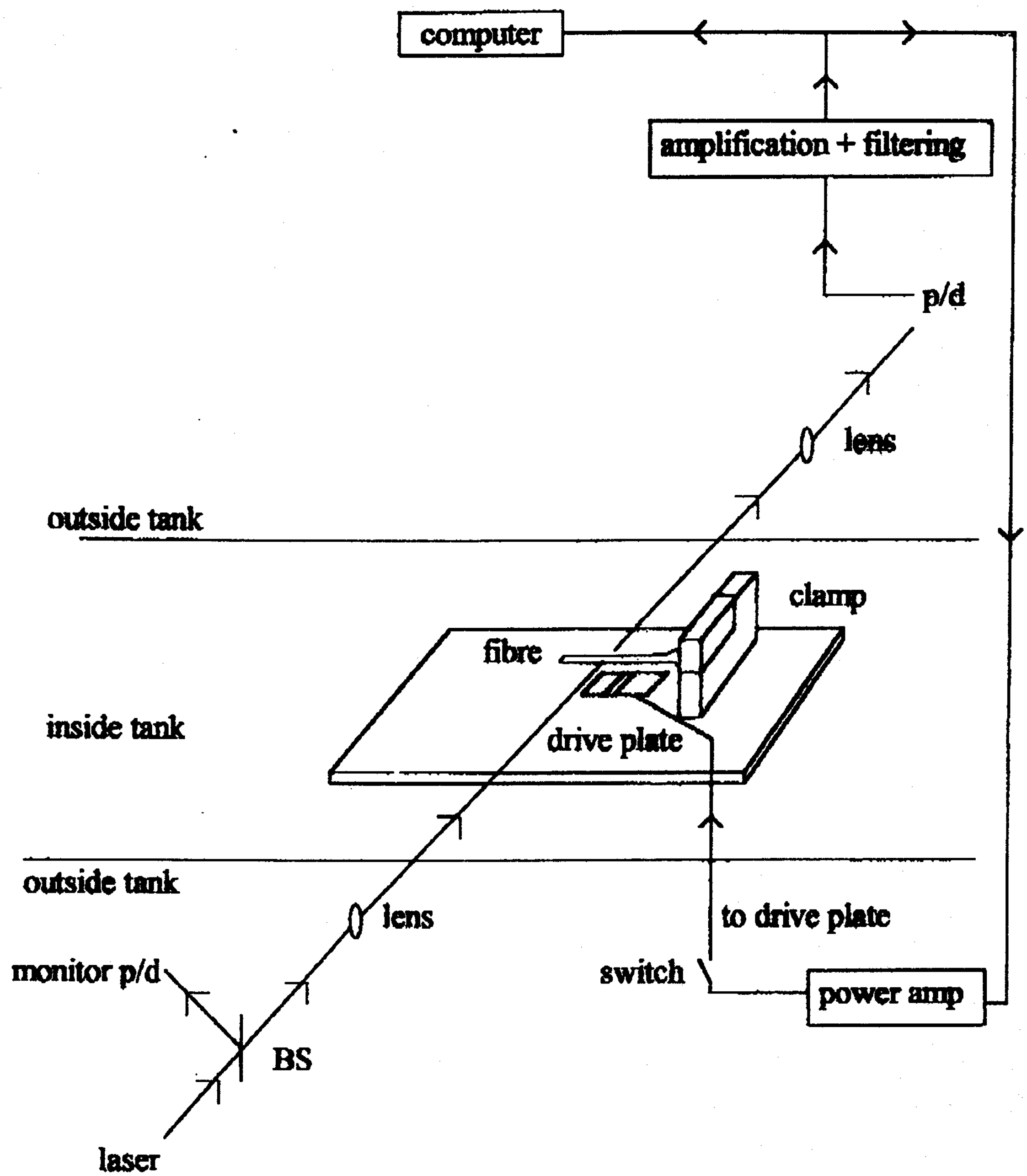
  thickness ~ 54μm

- Use positive feedback and electrostatic drive to excite resonances of fused silica fibre

- Measure decay of amplitude of resonances to find Q_{mat}

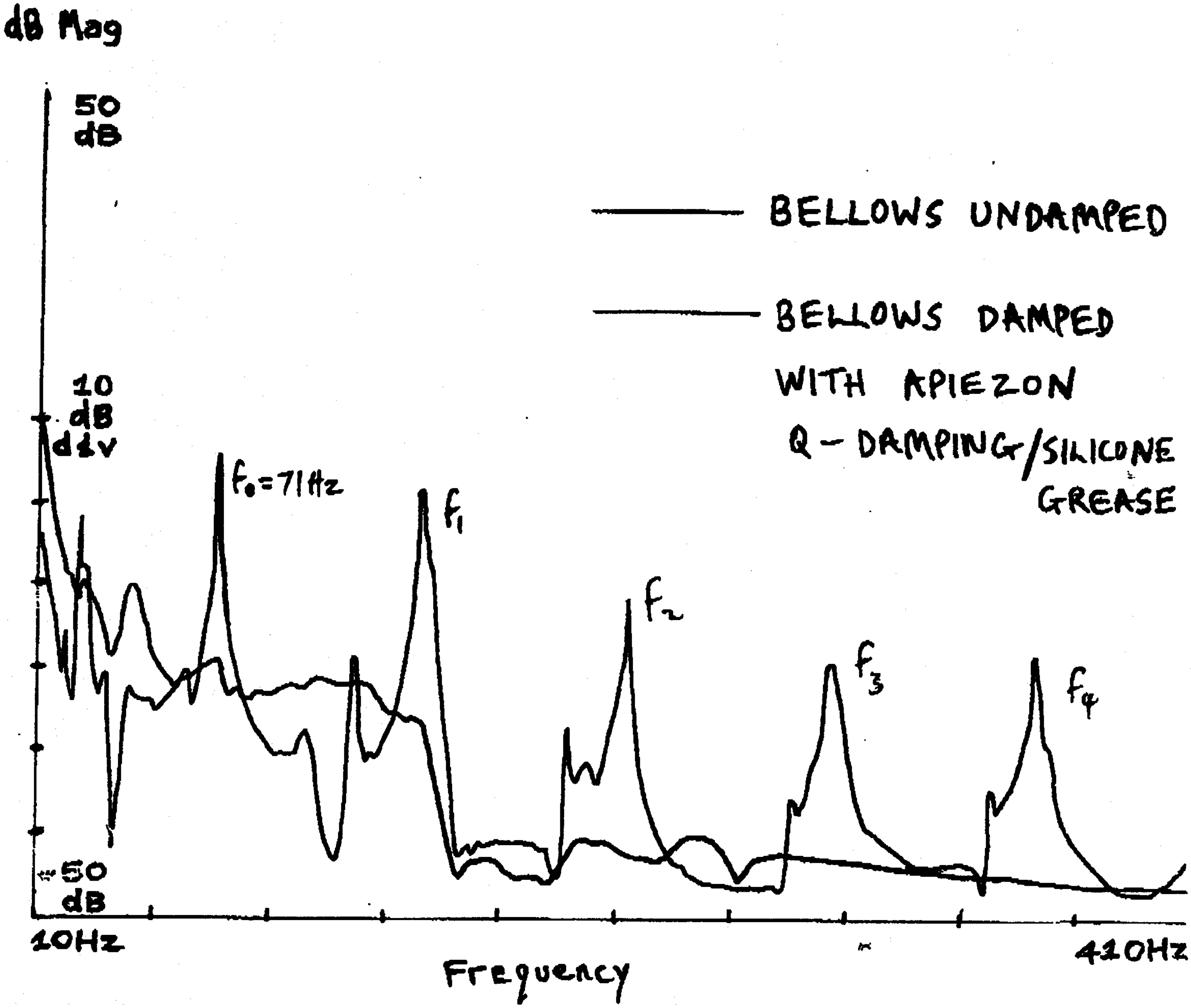


Fused Silica Ribbon Fibre



Q_{mat} fused silica experiment

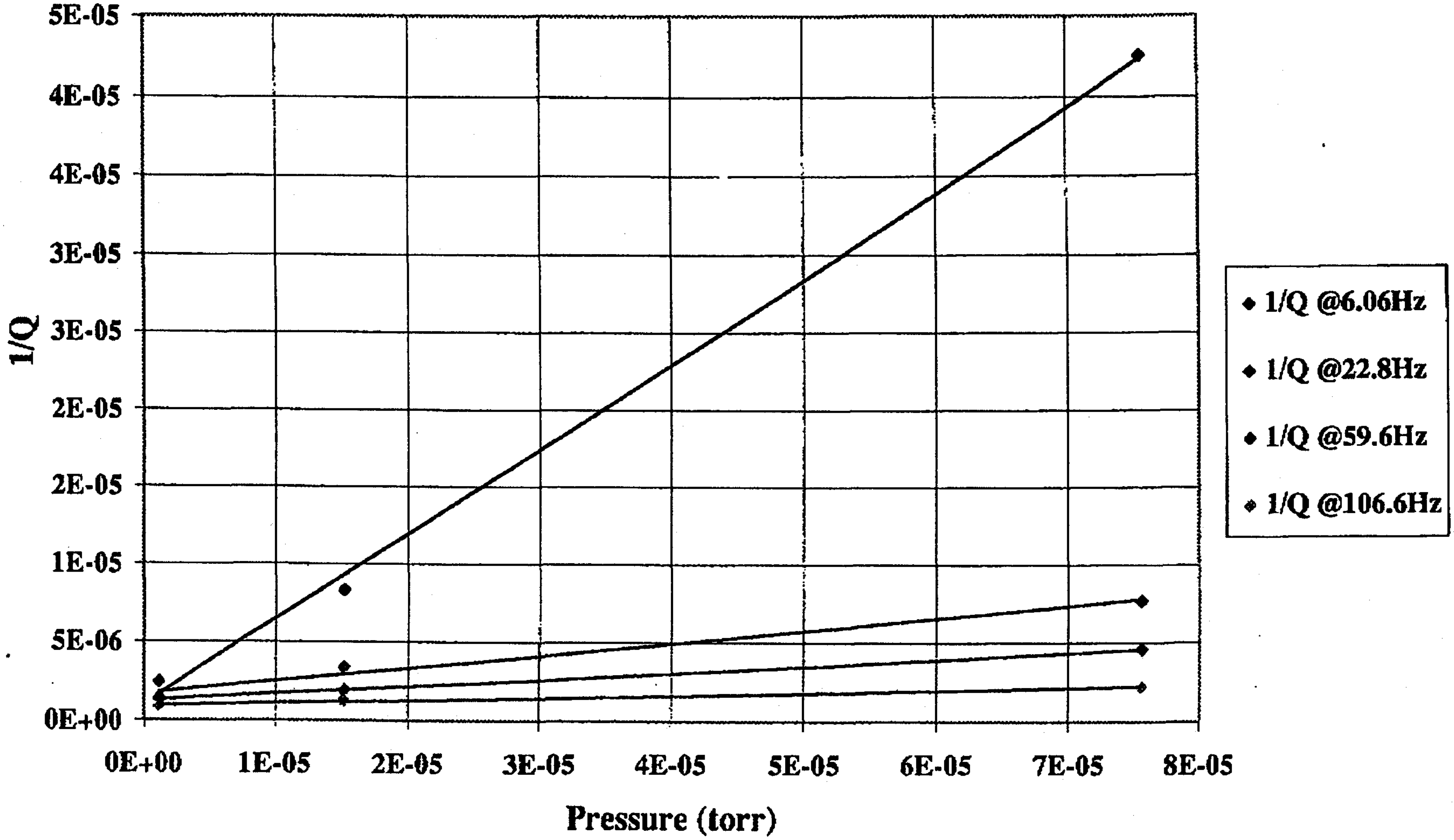
BELLOWS TEST



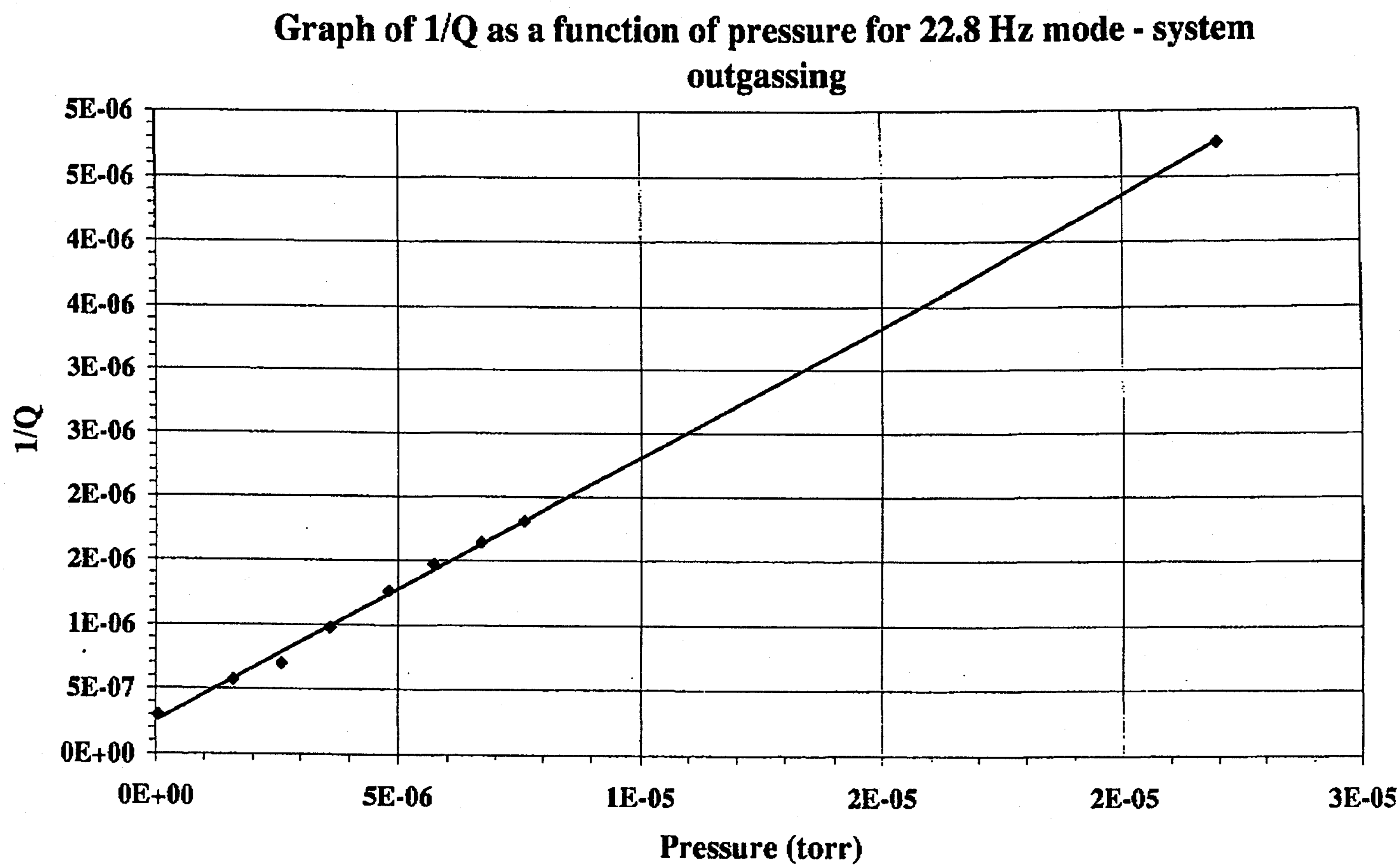
VERTICAL TRANSFER FUNCTION

Sheet1 Chart 12

1/Q as a function of pressure for various frequencies (Oct-Dec '95)

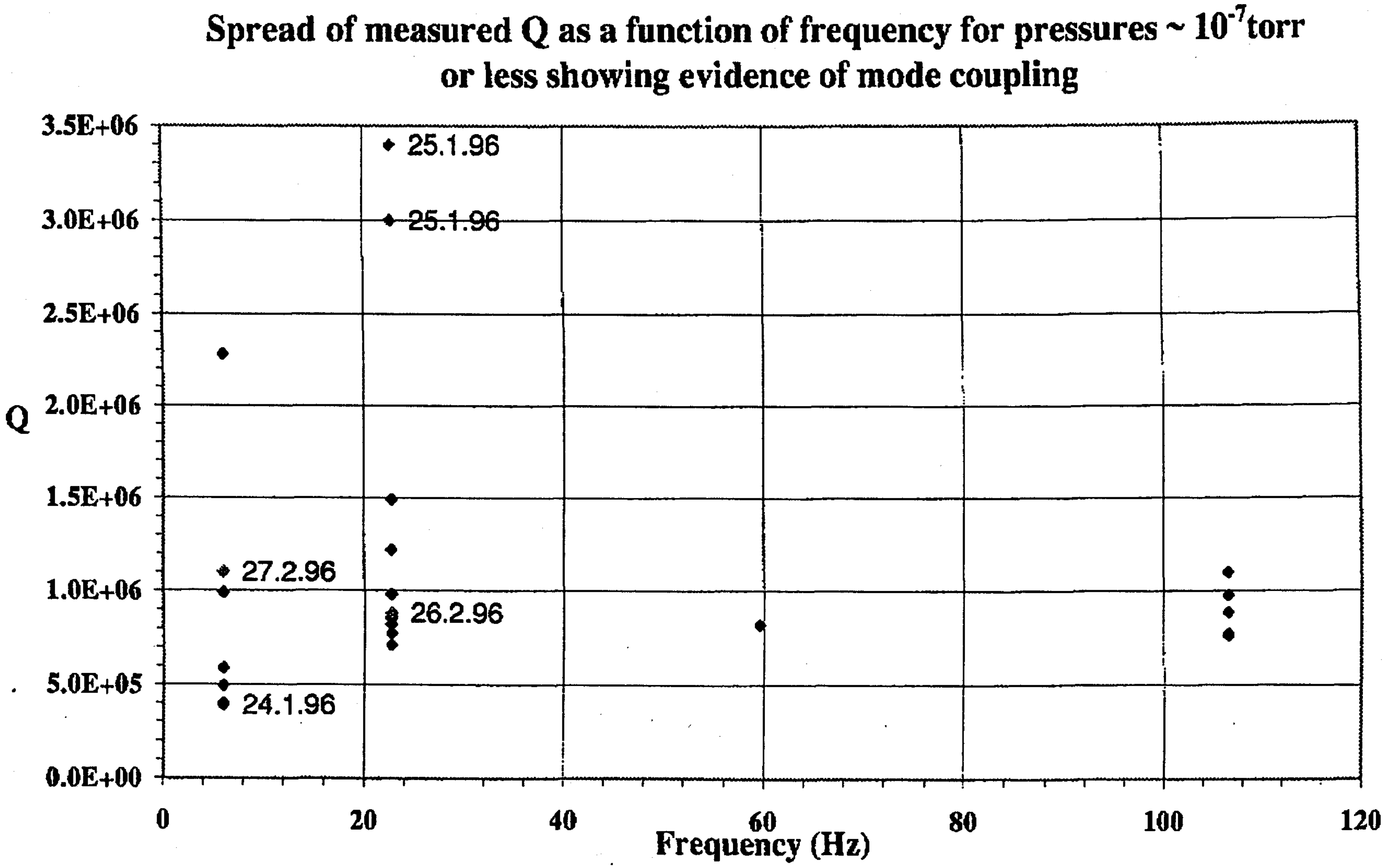


TWYFORD



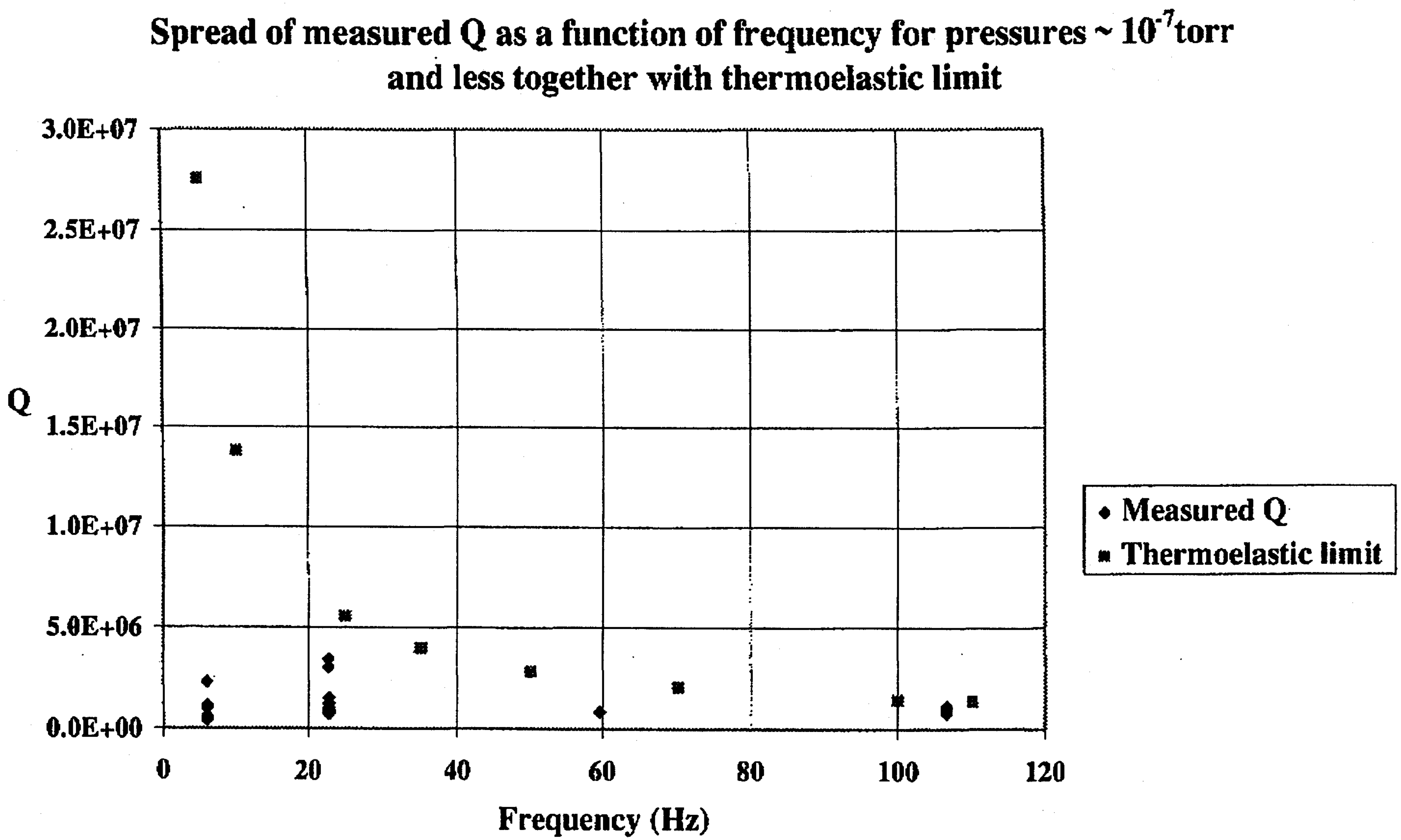
Graph of 1/Q as a function of pressure for 22.8 Hz mode - system outgassing
5E-06
5E-06
4E-06
4E-06
3E-06
3E-06
2E-06
2E-06
1E-06
5E-07
0E+00
1/Q
0E+00
5E-06
1E-05
2E-05
2E-05
3E-05
Pressure (torr)

ROWAN/TWYFO



TUE, 19-MAR-96 9:48 UNI GLA PHYS AND ASTRON +44 141 330 4464 P.27

ROWAN/TWYFC



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ROWAN/TWYFORD

Conclusions

- Q_{mat} of the order of few x 10^6

  $\Rightarrow$

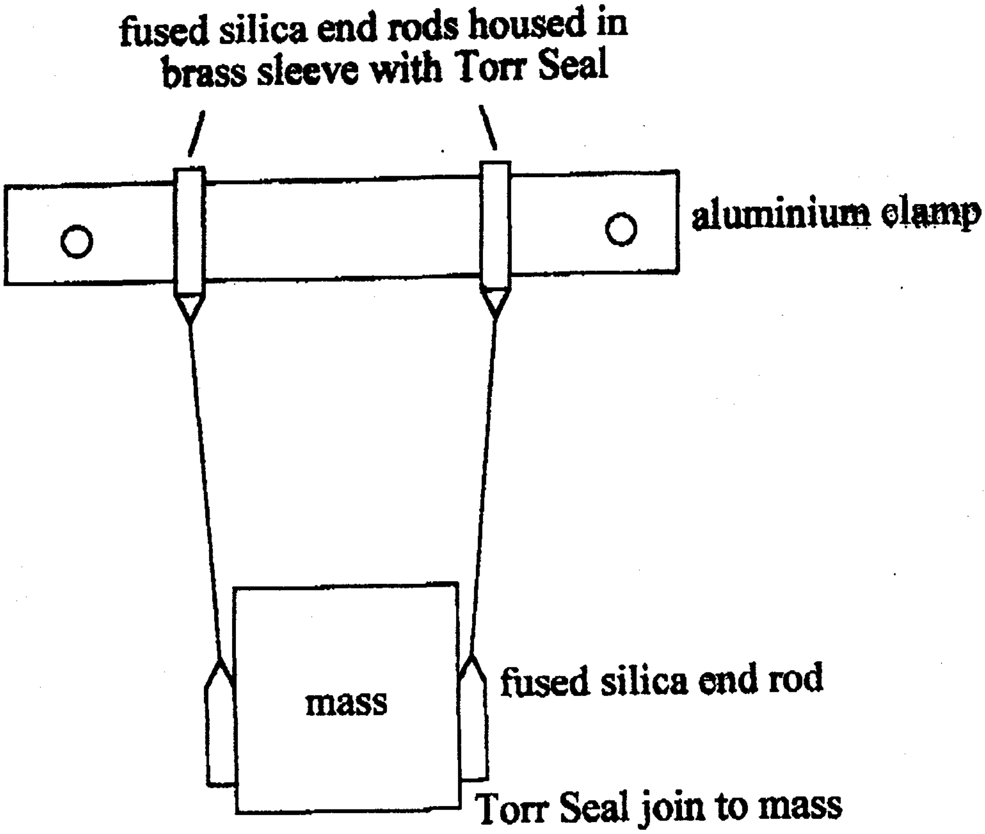
  Limiting Q_{pend} = few x 10^9 - more than good enough

Measurement of Q_{pend} for pendulum suspended by fused silica fibres

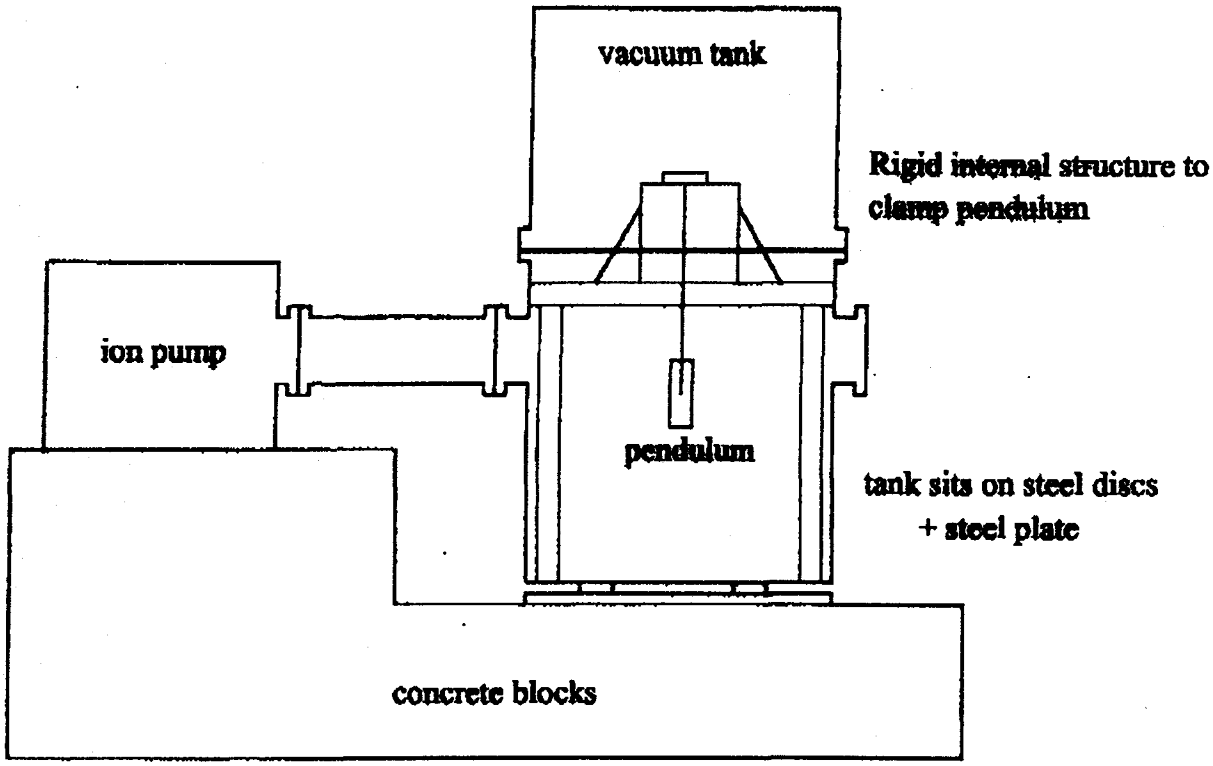
- Experimental set-up similar to that for wire pendulum
- Fused silica fibres drawn from rods of 3mm diameter - end of fibre still have rods attached
- Rods at top glued into brass cylinders using vacuum epoxy
- Rods at bottom glued to glass pendulum
- brass cylinder clamped into aluminium holder

Fused Silica Fibres - pulled in flame or RF oven to leave full rod diameter at ends. Rods clamped firmly at top, glued rigidly to mass at bottom.

Diagram of Test Pendulum



Fibre diameter ≅ 100μm
Fibre length ≅ 0.25m
mass = 0.2kg



LOGAN

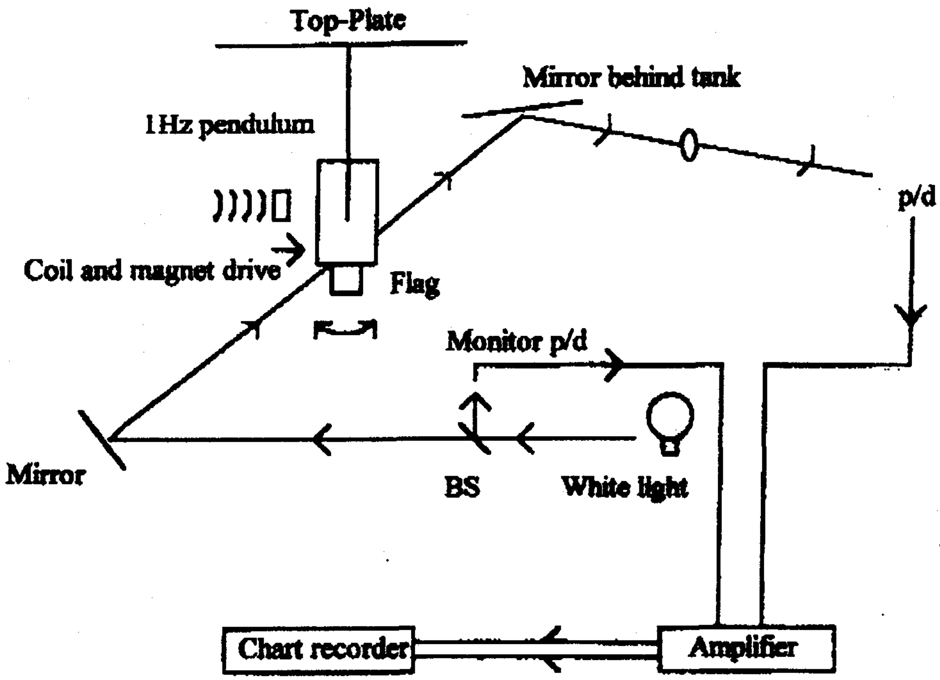
Limit to measurable Q as set by recoil damping:

$$Q_{limit} = \frac{1}{m\omega_0^2}\frac{k}{\phi}$$

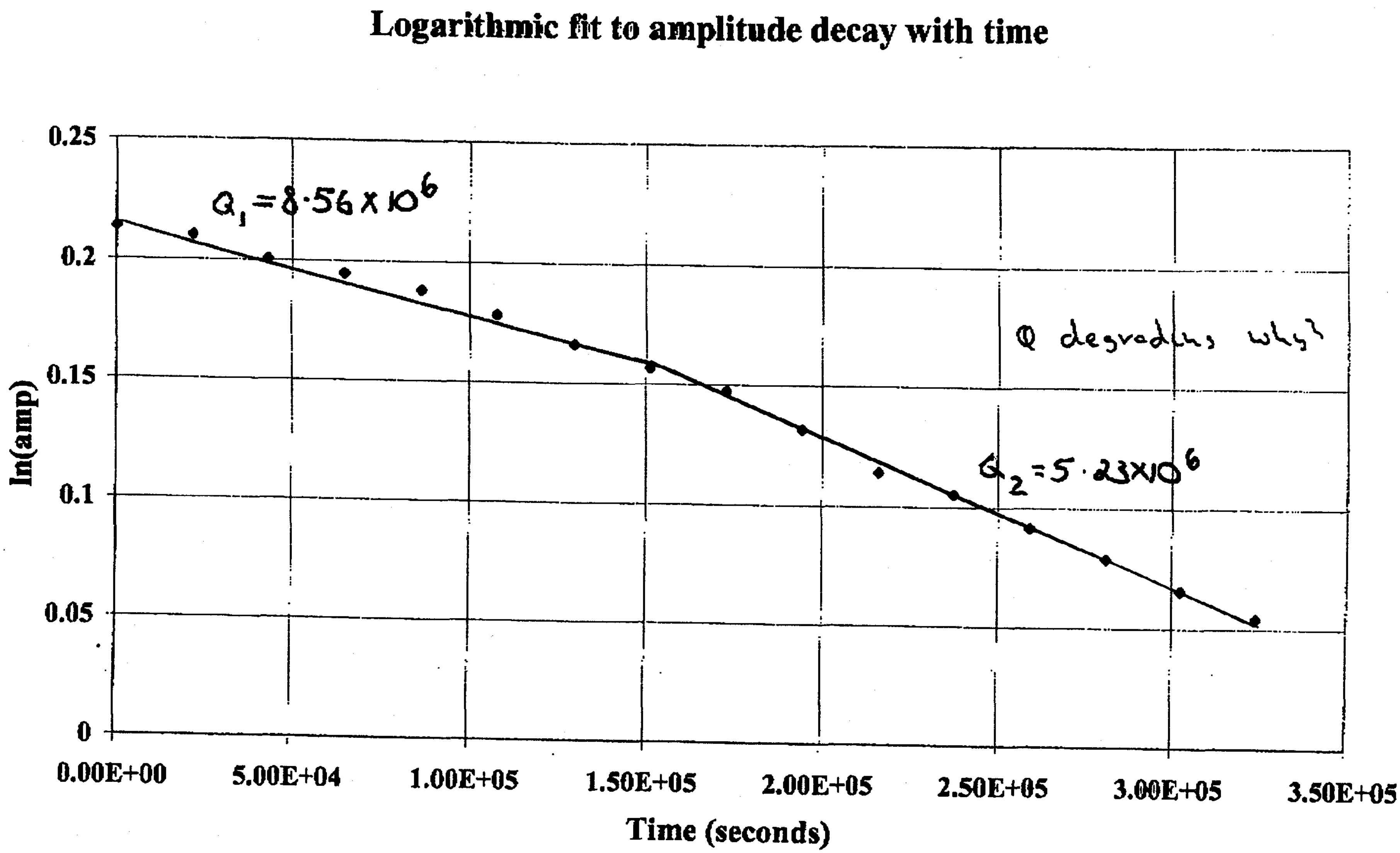
m = pendulum mass = 0.21kg
ω_0 = resonant frequency = 1Hz
k = stiffness of structure = $5.5 \times 10^6 \pm 6.75 \times 10^5$ Nm^{-1}
ϕ = phase angle between the recoil displacement and the drive force = $-1.61° \pm 0.05°$

$$Q_{limit} = 2.36 \times 10^7 \pm 2.98 \times 10^6$$

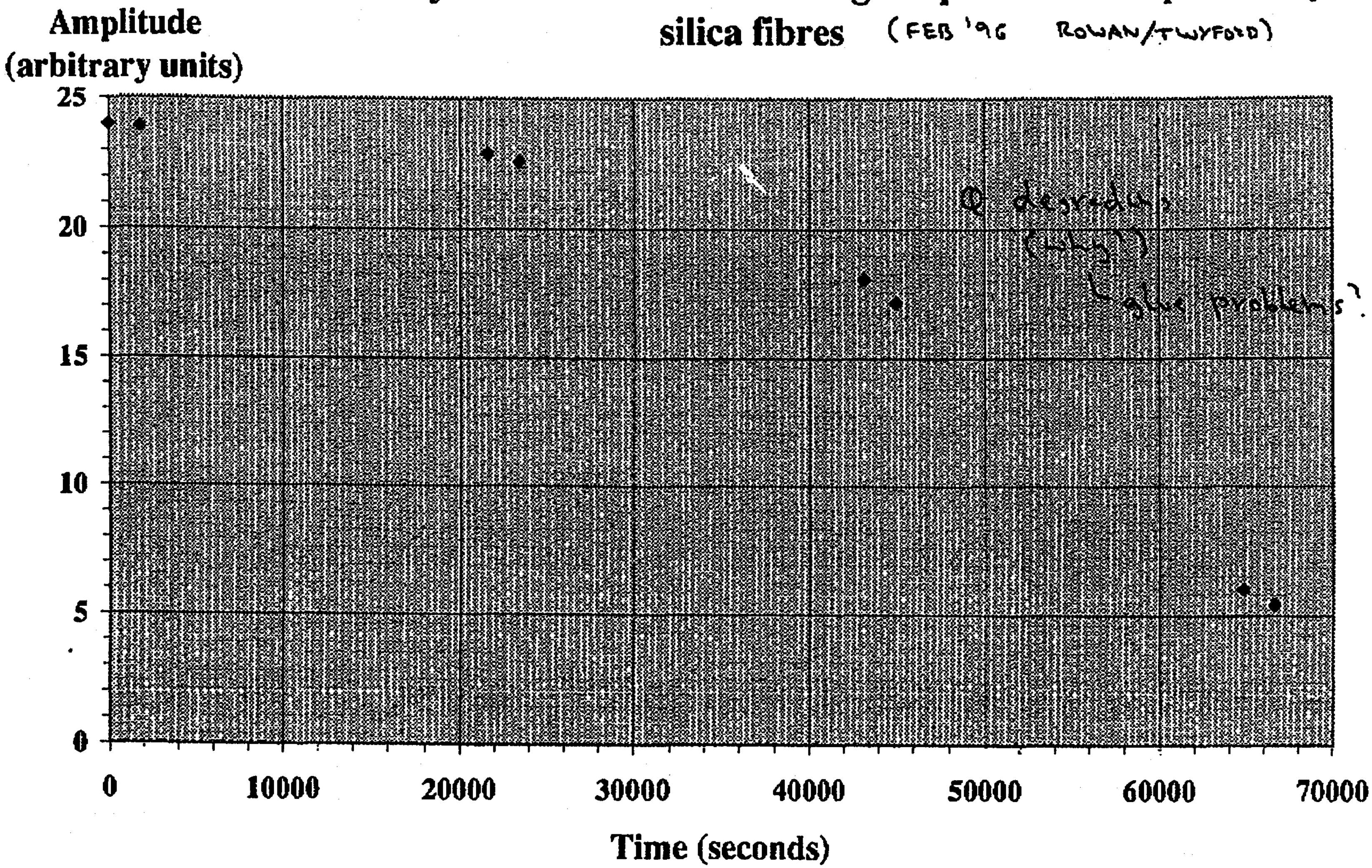
McLAREN/TWYFORD



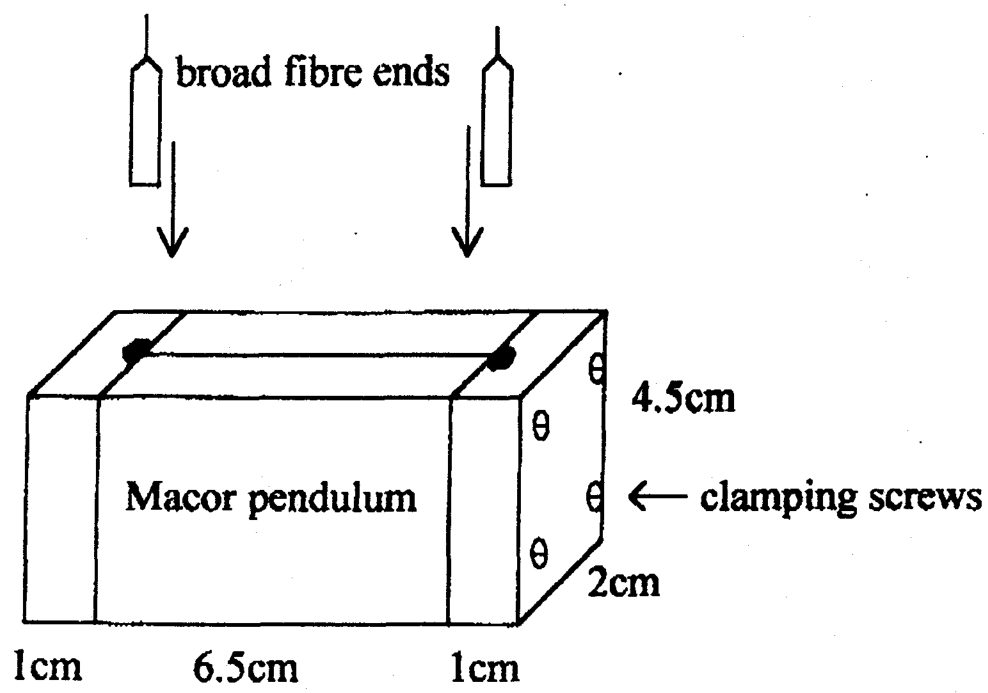
Q_{pend} fused silica experiment


Logarithmic fit to amplitude decay with time
0.25
0.2
0.15
0.1
0.05
0
ln(amp)
0.00E+00
5.00E+04
1.00E+05
1.50E+05
2.00E+05
2.50E+05
3.00E+05
3.50E+05
Time (seconds)
Q1=8.56x10^6
Q degrading why?
Q2=5.23x10^6

Amplitude decay as a function of time for glass pendulum suspended by silica fibres (FEB '96 ROWAN/TWYFORD)

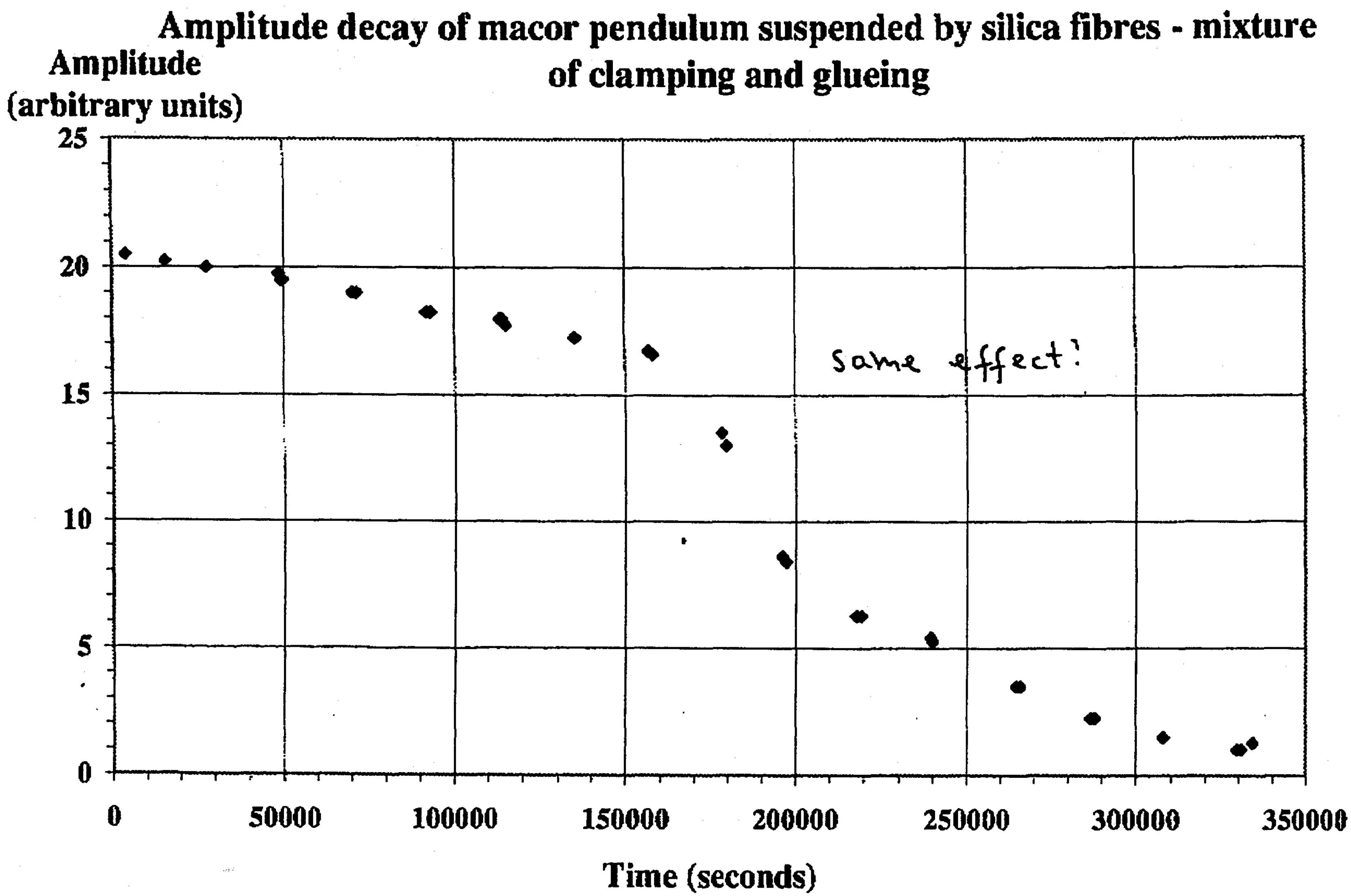


Better clamping



"Macor" machinable ceramic pendulum

$$\rho_{Macor} = 2.52 g/cm^3$$
$$m_{pend} \cong 200g$$



ROWAN/TWYFORD

Investigations:

Found:

- Opening tank and re-tightening clamps further - Q_{pend} initially recovered then degraded again

- Opening tank so pressure = atmospheric *but without re-tightening clamps* then re-pumped tank - Q_{pend} initially recovered then degraded again

Postulate:

- Forces on tank under vacuum causing tank/internal structure to distort/lose stiffness - requires further investigation

Future measurements

- Make fibres from rods with flats

  (in progress)
- Optical contacting of these flats on to small masses - test in system in Glasgow

  (soon)
- Optical contacting of similar fibres to full scale GEO 600 test mass

  (test of this system in Pisa/Perugia?)
- Test of durability of silica suspensions
- Measurement of internal Q of large test mass when optically contacted