High Sensitivity Torsion Balance Tests for LISA Proof Mass Modeling


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**Motivation**

housing with electrodes

gap: 2-4mm

proof mass (97 cm$^3$, 1.96 kg)

**Acceleration noise requirement**

0.1 mHz - 1 mHz

\[ S_a^{\frac{1}{2}} < 3 \times 10^{-15} \text{ m/s}^2/\sqrt{\text{Hz}} \]
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- patch effects
- outgassing
- charge accumulation
- magnetic impurities

- radiometer effect
- gravitational forces
- actuation cross talk
- ….
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- Torsion fiber $\kappa = 667 \times 10^{-12} \text{Nm/\text{rad}}$

- "Field mass" emulates proof mass

- "Pendulum" emulates housing

- Laser beam for angle readout
Separation (0.05 mm - 8 mm)
Uncertainty 0.05 mm

Field mass (split plate)
Each half can be at different electric potential.

FM can be translated.
Dynamic range ~8 mm

Field mass: gold coated OFHC copper
Pendulum: gold coated silicon
Fiber: tungsten 13 µm diam. 0.6 m

Two types of measurement
(1) Noise mode
(2) Torque mode

Two possible ways of readout
(A) Free running
(B) Electrostatic Feedback
$S_a(t)$

Compensator Bars

$S_{a}^{1/2} (m/s^2/\sqrt{Hz})$

Noise mode, free running

frequency (mHz)
The new torsion pendulum

- Semi-conducting base material (Si)
- Shape allows full overlap with FM
- Sputter coated (21 nm TiW/230 nm Au)
- Better fiber suspension
- Trimable moments
- Thin (0.43 mm) and light (12 g), but large area
The Apparatus

- Fiber positioner
- Vacuum vessel (p = 10^{-5} .. 10^{-1} Pa)
- Inner thermal insulation
- Pressure gauge (~60 cm from pendulum)
- Rotating masses for torque calibration
- Autocollimator
- FM positioner
Features:

- A electric potential can be applied to each of the FM's.
- Separated heaters in FM's allow individual heating up to RT+4K.
- Temperature sensors in each plate and the translation stage.
Pendulum in Feedback

$S_a(f)$ measured with free running pendulum

Thermal limit

LISA limit

$S_a(f)$ measured in FB by the electrodes

Residual motion of pendulum

Calibration Tone

$S_a(f)$ measured with free running pendulum

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$S_a(f)$ measured in FB by the electrodes

Residual motion of pendulum
Noise as a Function of Distance

Thermal noise

No separation dependence for $s > 1 \text{ mm}$

$$S_{a}^{1/2} (\text{m/s}^2/\sqrt{\text{Hz}})$$

No separation dependence for $s > 1 \text{ mm}$
No separation dependence for $s > 1$ mm
Potential Difference

\[ \tau = k_{geom} (V - V_0)^2 \]

- Feedback torque (pNm)
- Applied Voltage (mV)

Diagrams showing the relationship with applied voltage and feedback torque for different gap sizes (s = 0.3 mm and s = 0.5 mm).
Parabola due to left FM, right FM at $V_{0\text{left}}$

Parabola due to right FM, left FM at $V_{0\text{right}}$

Saddlepoint @ 30mV (right) and 130 mV (left)
Potential Difference (time)

- Contact potential (mV)
- Potential Difference (time)
- Day in 2006

- 0.1 mm
- 0.7 mm
- 0.5 mm

- Left FM
- Right FM
Conclusion

- We have built a highly sensitive torsion balance.

- We reach the thermal noise level with or without electrostatic feedback.

- We see a rapid increase ($\sim d^{-5/3}$) in measured noise for distances smaller than $\sim 1$ mm.

- Potential difference is approx. 30/120 mV.

  - Slow Variation of approx. 10 mV.

  - Shows a slight distance dependence.
Outlook

- Measure potential as function of
  - bake out and vacuum history.
  - Position of pendulum (displacement)

- Provide powerspectrum of potential difference at high (1 mHz) resolution.