Progress of Surface potential measurement using a torsion pendulum

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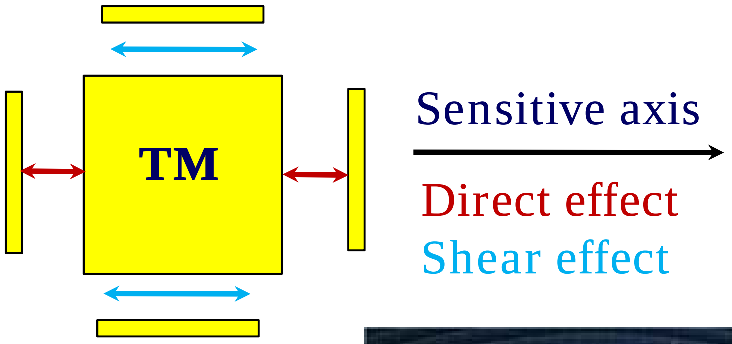
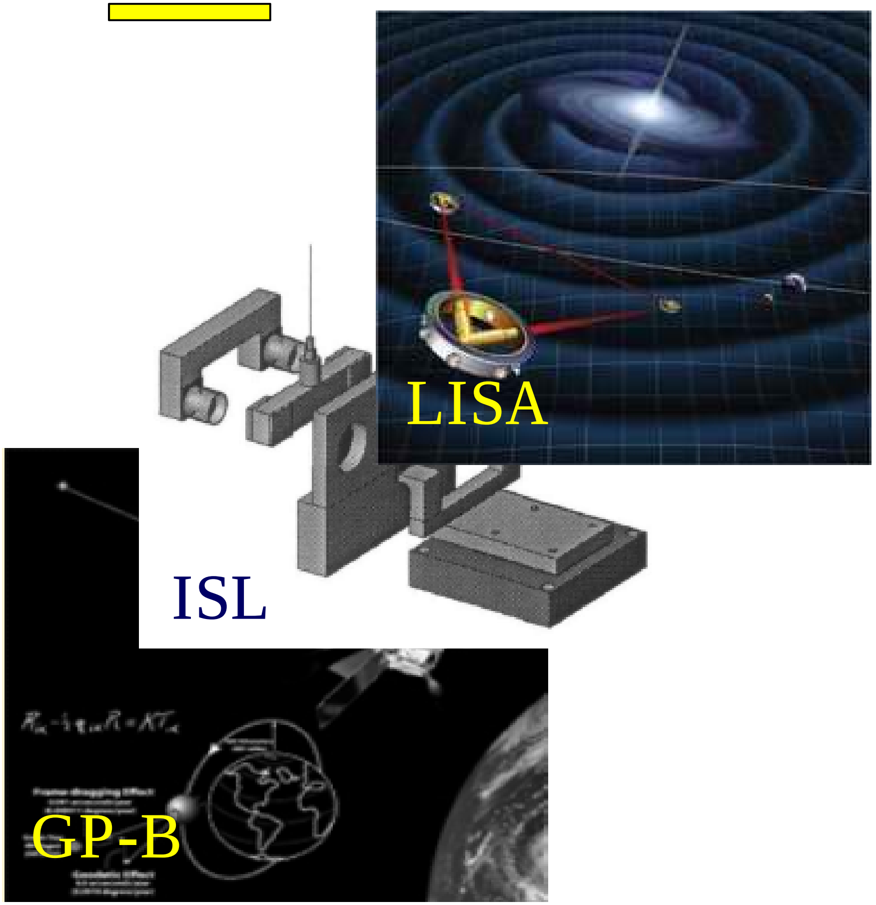
Content

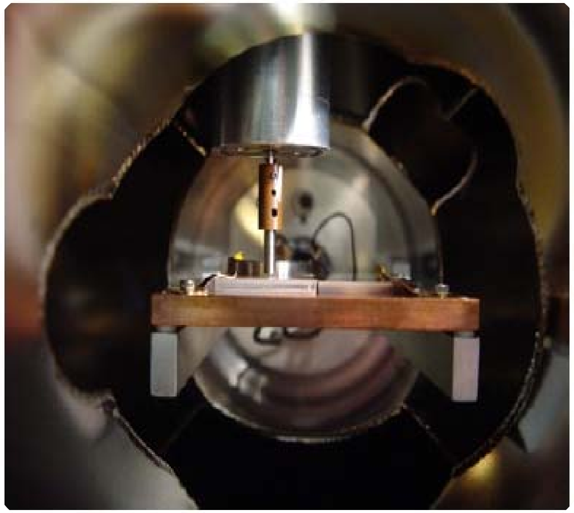
1.Introduction



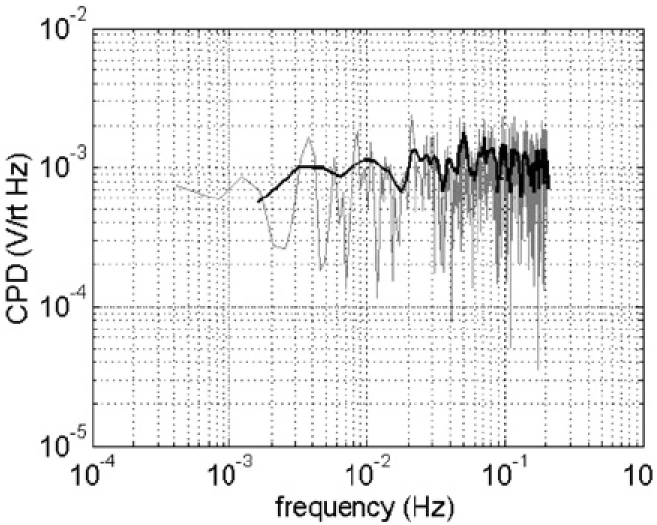


- The metal is widely used for making test mass in precision measurements.
- In the idealized case, the isolated conductor is an equipotential body with the same potential over its surface.
- In fact, impurities and microcrystal structure will lead to a nonuniform dipole layer formed on the metal surface. When two metallic surface at finite distance, the force or torque on each of them will produce.
- The temporal and spatial variations in surface potential is one of the largest contributors of noise in precision measurements, such as LISA, GP-B, Test of Newtonian Gravitational Square Law and so on.
- Investigate the surface potential on test mass carefully is significant.

1.Introduction



Kelvin probe measurements [1]



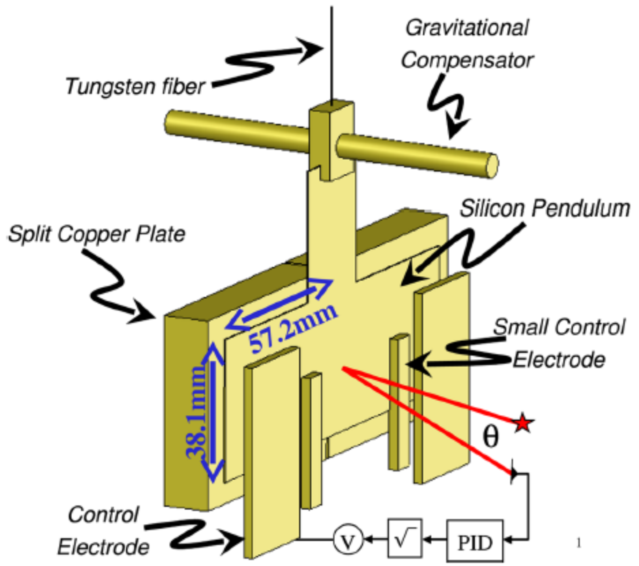
- Kelvin probe is an efficacious way to measure the distribution of surface potential. It is a non-contact, non-destructive vibrating capacitor device measures potential difference between a conducting specimen and a vibrating probe tip.

- Kelvin probe measurements is a null measurement technique. The potential V_b electrically connects the sample and tip. The surface potential will be found by recording the output signal as a function of V_b and fitting the data to find the value of V_b where the signal passes through zero.

- Its sensitivity could achieved $1mV/Hz^{1/2}$.

[1].N.A.Robertson, J.R.Blackwood, S.Buchman, and R.L,Byer et al, *Kelving probe measurements: investigations of the patch effect with applications to ST-7 and LISA*, Class. Quantum Grav. 23(2006)2665-2680

1.Introduction



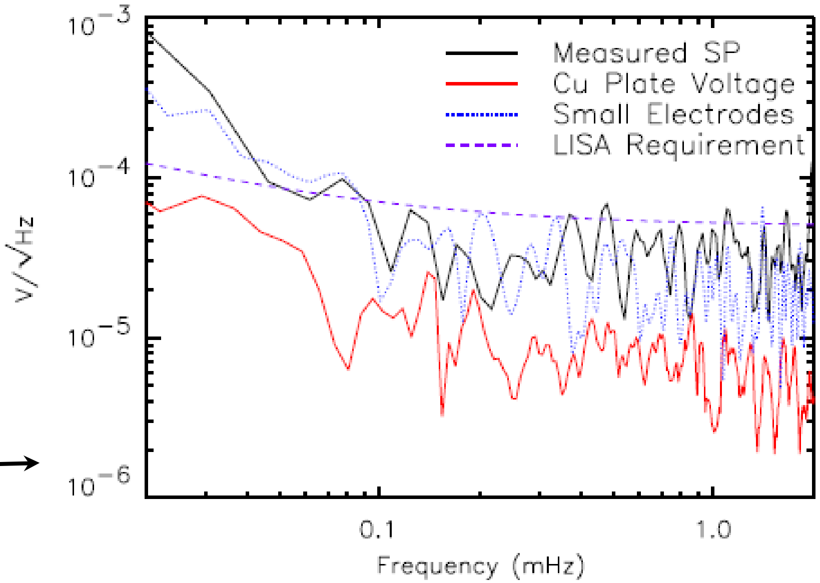
Measure surface potential by torsion balance [2]

- The torsion balance is widely used for measuring all kinds of weak force, because of its high sensitivity .
- The average surface potential and its temporal variations has been measured by University of Washington base on torsion balance.
- Their result shows that this scheme could measure the value of potential accurately.

Electrostatic torque

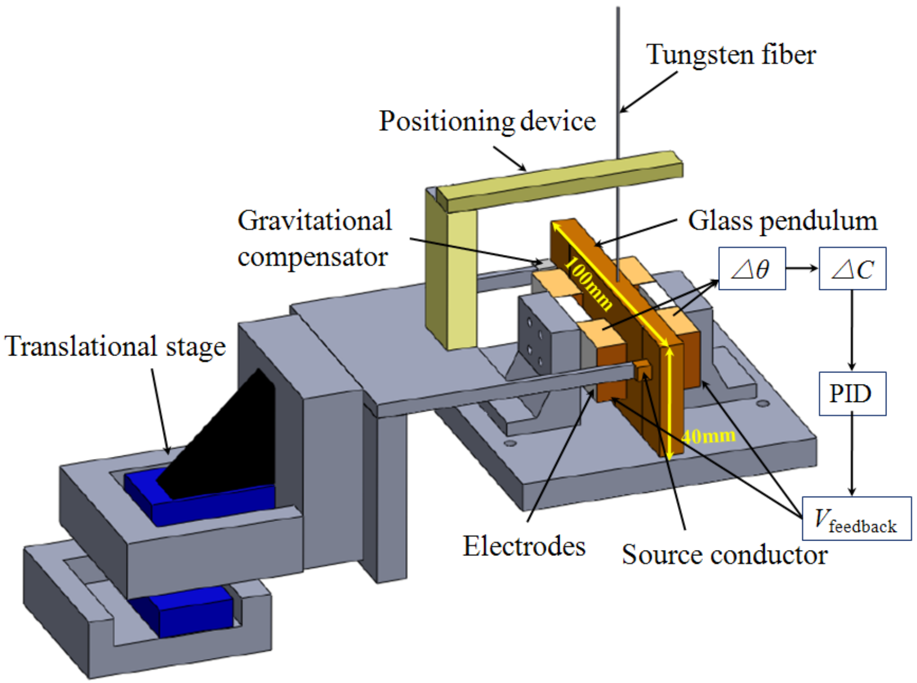
$$N = \frac{1}{2}\frac{dC}{d\theta}(V - V_{SP})^2$$

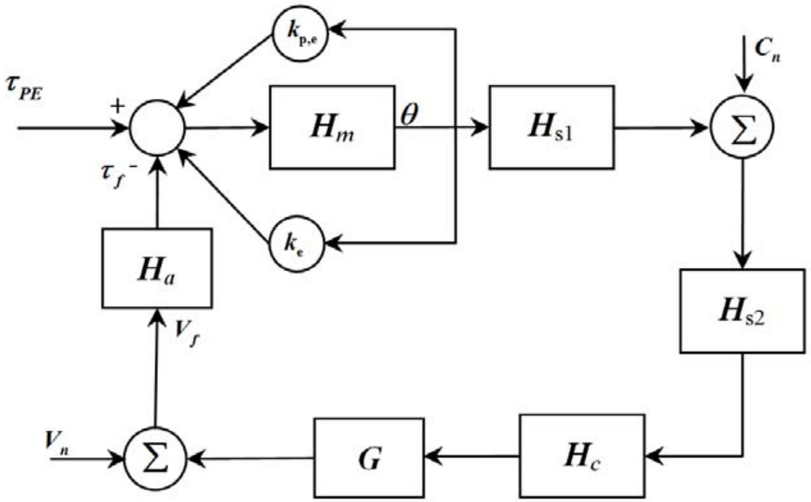
Resolution $30\mu V/Hz^{1/2}$



[2]. S.E.Pollack, S.Schlamminger, and J.H.Gundlach, *Temporal extent of surface potentials between closely spaced metals*, Phys,Rev,Lett. 101(2008)071101

2.Modeling and error analyze





- A scheme has been proposed for measuring distribution of surface potential base on electrostatic controlled torsion balance.
- The apparatus consists of a source conductor (5mm×5mm×5mm),pendulum(100mm×40mm ×8mm), gravitational compensator, two pair of electrodes and a series of translational stages.
- The source conductor with voltage V_s could be moved relative to surface of pendulum. The voltage of feedback V_f will reflect the value of electrostatic torque between source conductor and sample in the appropriate regions.

$$\tau_{\mathrm{PE}} = -\frac{1}{2}\frac{C_{\mathrm{p}} l_{\mathrm{p}}}{d_{\mathrm{p}}}(V_{\mathrm{s}} - V_{\mathrm{TM}})^2$$ Electrostatic torque

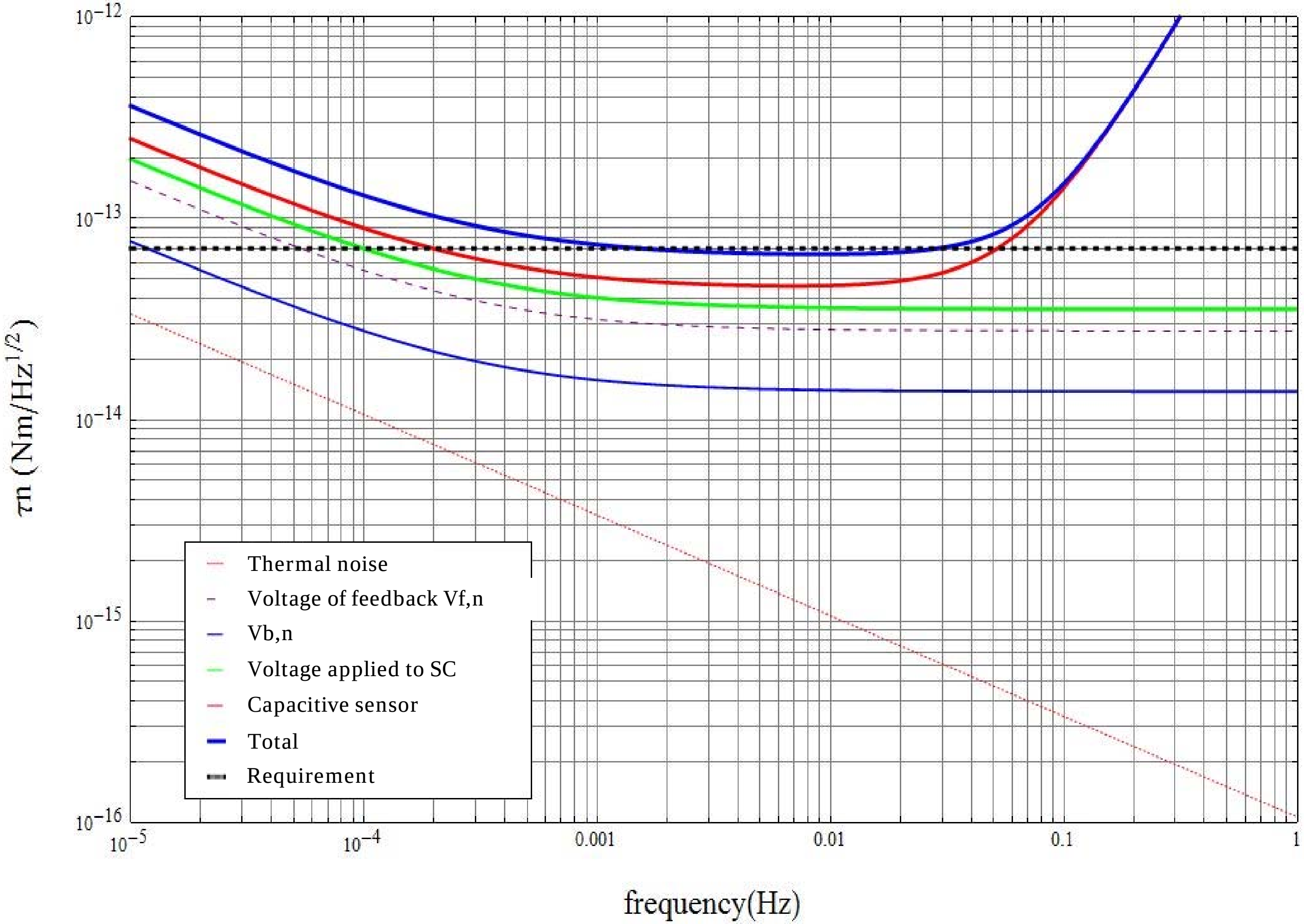
Goal: $10\mu\mathrm{V}/\mathrm{Hz}^{1/2}$

$$\delta\tau_{\mathrm{measure,min}} = \frac{C_{\mathrm{p}}}{d_{\mathrm{p}}}(V_{\mathrm{s}} - V_{\mathrm{TM}}) l_{\mathrm{p}} \delta V_{\mathrm{TM,min}} \approx 7.1\times10^{-14}\,\mathrm{Nm}/\mathrm{Hz}^{1/2}$$

2. Design and Error analysis

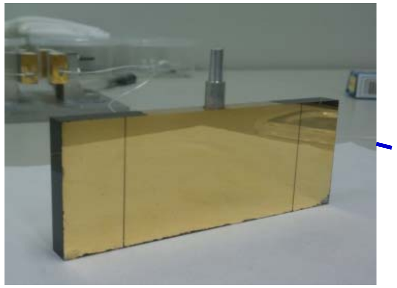
Major factors effecting the resolution:

- Thermal noise of fiber.
- Resolution of capacitive sensor.
- Fluctuation of voltage applied to pendulum, electrodes and source conductor(SC).



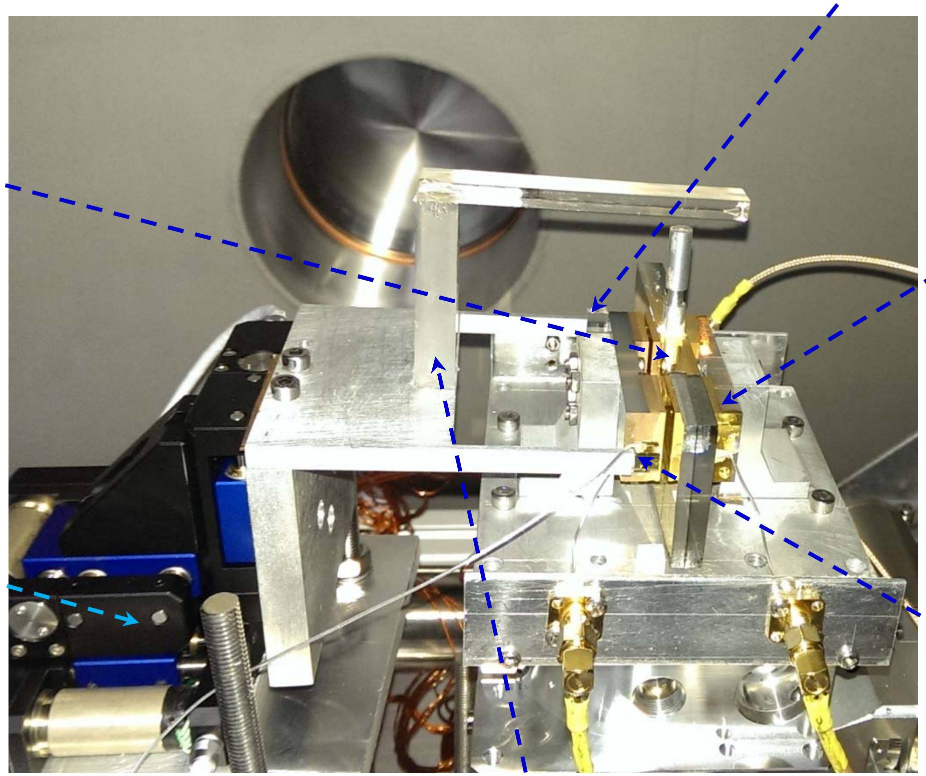
3.Experimental apparatus

Apparatus is made up of a source conductor, pendulum, gravitational compensator, electrodes, magnetic damping, translational stages and other fixtures.



Pendulum

Gravitational compensator



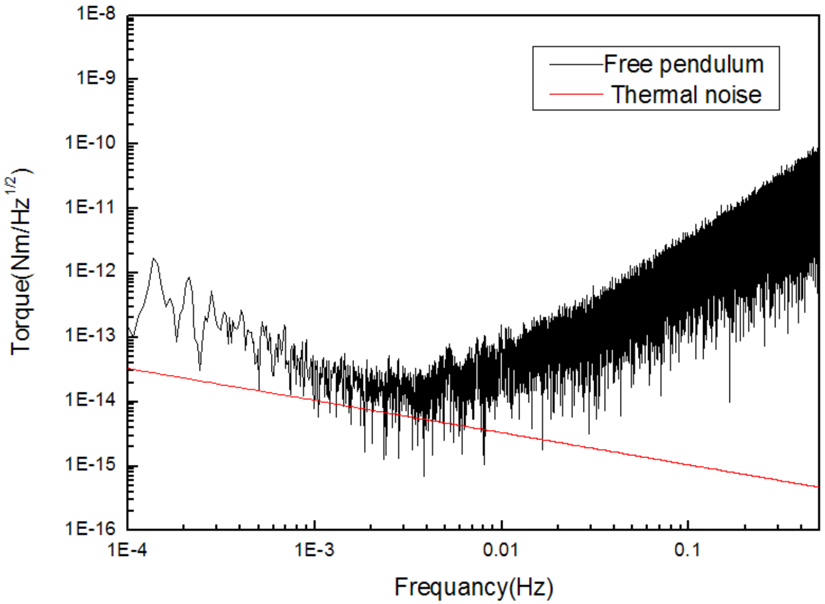
Translational stage

Source conductor

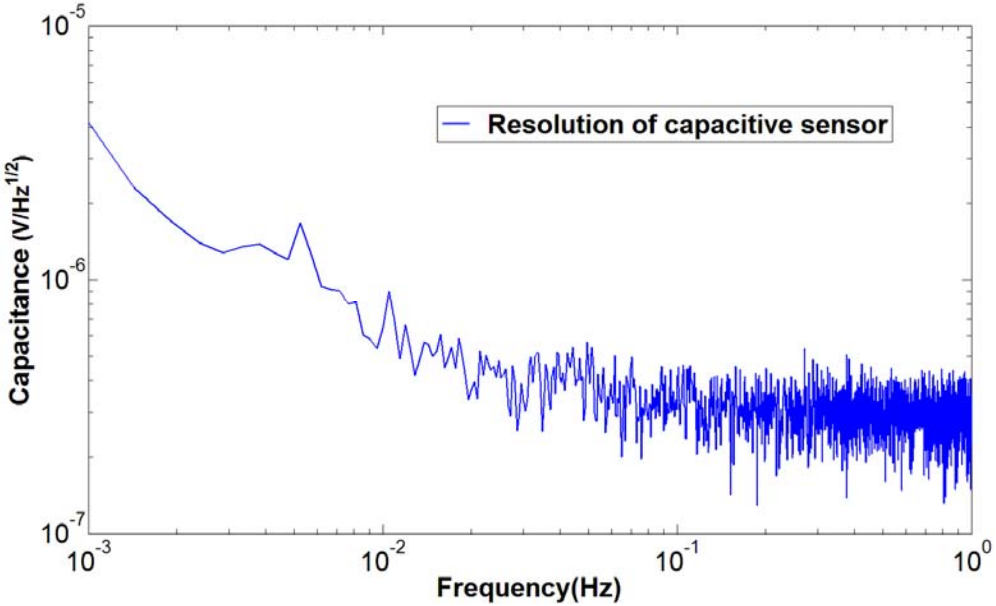
Positioning device

Electrodes

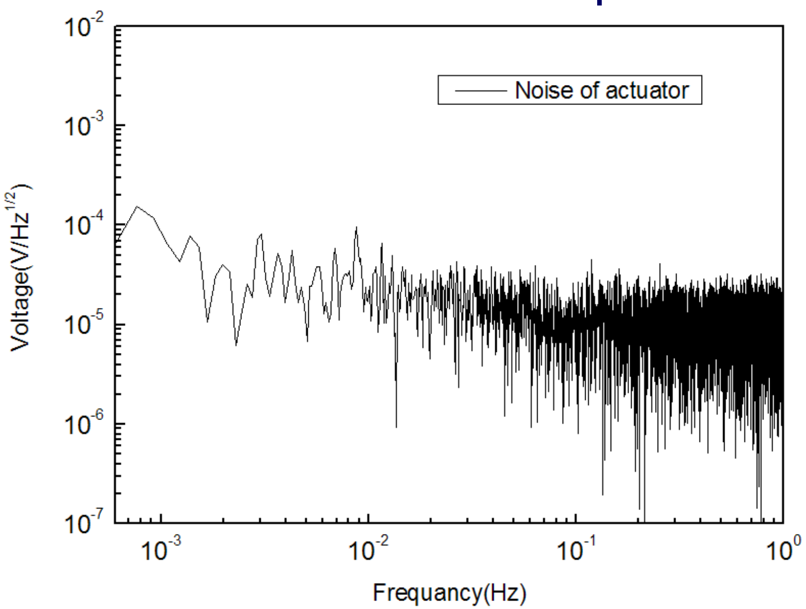
3.Experimental apparatus



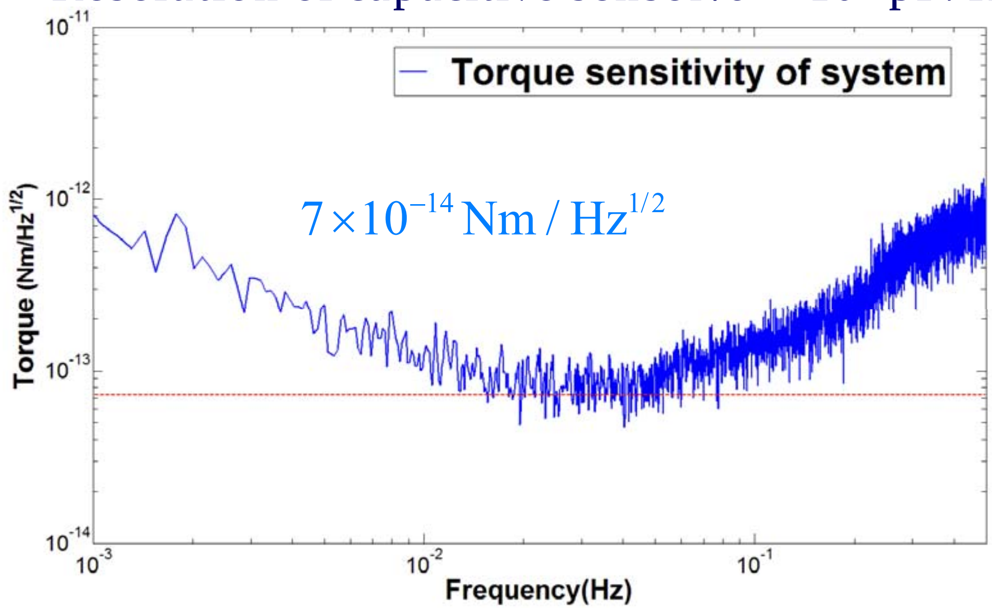
Thermal noise of free pendulum



Resolution of capacitive sensor:6 $\times 10^{-7}$pF/Hz$^{1/2}$



Noise of electrostatic actuator



Torque sensitivity of apparatus is able to achieve our goal

4. Measurements: Static mode

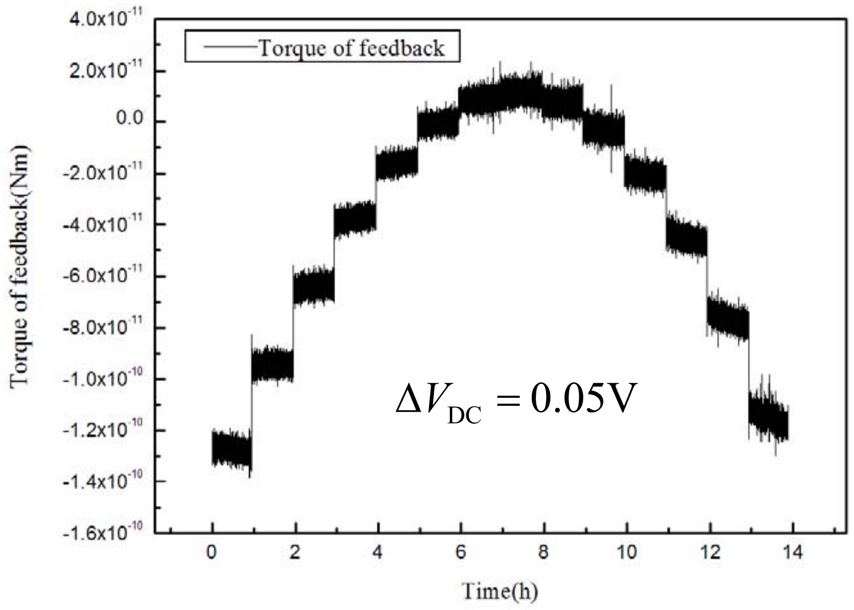
Measurement of surface potential with static mode

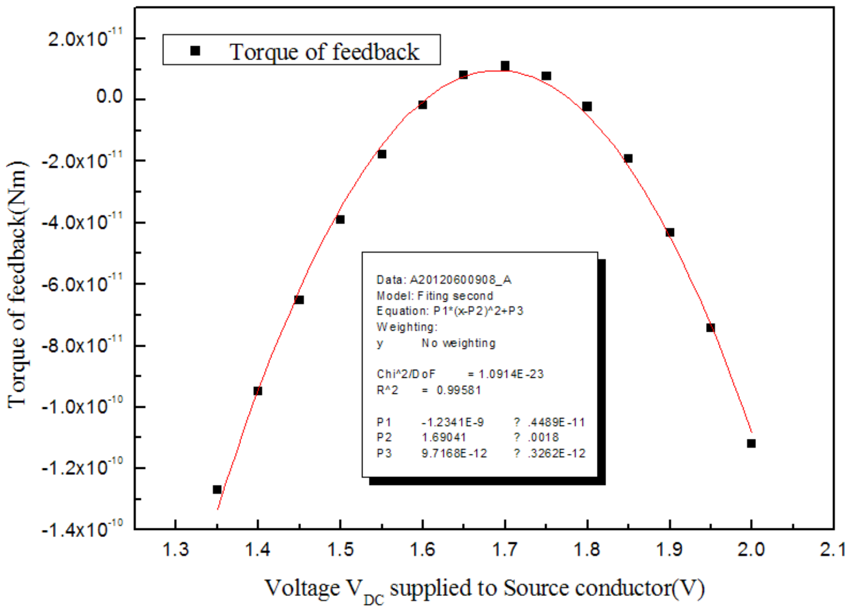
1.DC voltage V_{DC} applied tos source conductor

2.Record the torque of feedback with different $V_{DC.}$

$$\tau_{PE} = \frac{1}{2}\frac{\partial C_p}{\partial \theta}(V_{DC} - V_{TM})^2$$

3. The surface potential will be found by fitting the data to find the value of V_{DC}, where the signal equals to extremum.





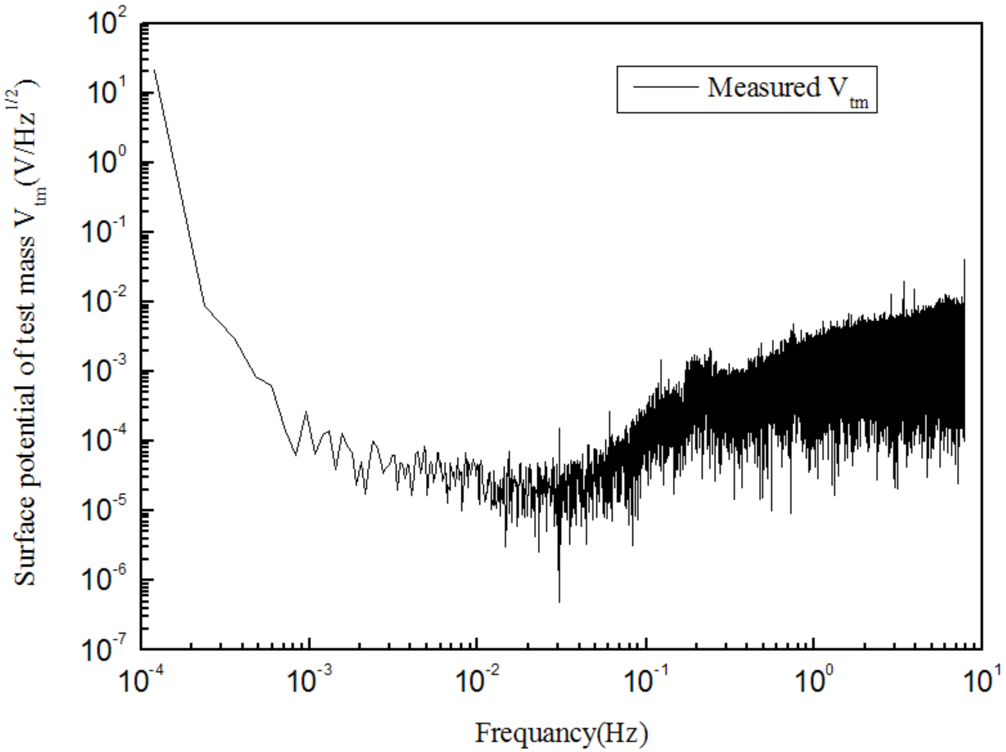
Surface potential $V_{TM} = (1.6904 \pm 0.0018)\,\text{V}$

4. Measurements: Static mode

Resolution of measuring surface potential

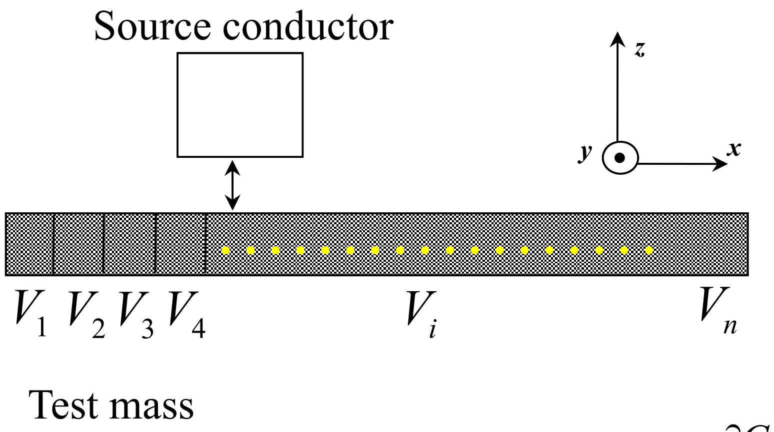
$$\tau_{\text{feedback}} = \frac{1}{2}\frac{\partial C_{\text{p}}}{\partial \theta}(V_{\text{DC}} - V_{\text{TM}})^2 + \tau_0$$

$$\delta V_{\text{TM}} = \frac{d_{\text{p}}\delta\tau_{\text{measure}}}{C_{\text{p}}\left(V_{\text{DC}} - \overline{V_{\text{TM}}}\right)l_{\text{p}}}$$



A measurement of surface potential fluctuations.
The spectrum is white at $15\mu\text{V}/\text{Hz}^{1/2}$ for frequencies above 0.03Hz.

4. Measurements: Scan mode



Total charge on the ith electrode

$$Q_i = \sum_{j=1}^{n} C_{ij}\left(V_i - V_j\right) + C_{is}\left(V_i - V_s\right)$$

Total charge on the source conductor

$$Q_s = \sum_{i=1}^{n} C_{is}\left(V_s - V_i\right)$$

The electrostatic torque $\quad C_{ij}' = \frac{\partial C_{ij}}{\partial \theta} \qquad C_{is}' = \frac{\partial C_{is}}{\partial \theta}$

$$\tau_e = \frac{\partial W_e}{\partial \theta} = \frac{1}{2}\sum_{i=1}^{n-1}\left(\sum_{j=1+1}^{n} C_{ij}'\left(V_i - V_j\right)^2\right) + \frac{1}{2}\sum_{i=1}^{n} C_{is}'\left(V_i - V_s\right)^2$$

Modulation voltage applied to source conductor

$$V_s = V_{\mathrm{DC}} + V_{\mathrm{AC}}\sin(\omega t)$$

DC $\quad \tau_{e\_0} = \frac{1}{2}\left(\sum_{i=1}^{n-1}\left(\sum_{j=1+1}^{n} C_{ij}'\left(V_i - V_j\right)^2\right)\right) + \frac{1}{2}\sum_{i}^{n} C_{is}'\left(\left(V_i - V_{\mathrm{DC}}\right)^2 + \frac{1}{2}V_{\mathrm{AC}}^2\right)$

1ω $\quad \tau_{e\_\omega} = -\sum_{i=1}^{n} C_{is}'\left(V_i - V_{\mathrm{DC}}\right)V_{\mathrm{AC}}$

2ω $\quad \tau_{e\_2\omega} = -\frac{1}{4}\sum_{i=1}^{n} C_{is}' V_{\mathrm{AC}}^2$

$$\overline{V_{\mathrm{tm}}} = \frac{\sum_{i}^{n}\left(C_{is}' V_i\right)}{\sum_{i}^{n} C_{is}'} = V_{\mathrm{DC}} + \frac{\tau_{e\_\omega} V_{\mathrm{AC}}}{4\tau_{e\_2\omega}}$$

Weighting factor $\quad \frac{C_{is}'}{\sum_{i}^{n} C_{is}'}$

A weighted average over all potentials on sample.

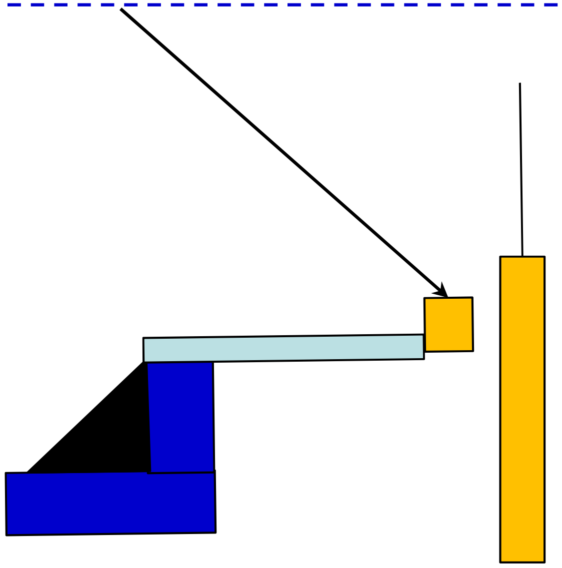
The output could express an average potential over local regions which are face to source conductor.

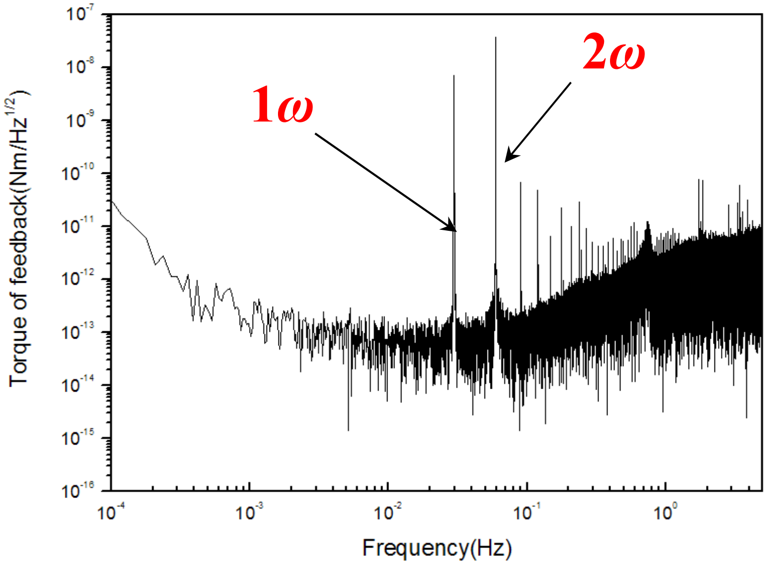
4. Measurements: Scan mode

Modulation voltage applied to source conductor

$$V_s = V_{DC} + V_{AC}\sin(\omega t) \qquad V_{AC} = 1.0\text{V} \qquad V_{DC} = 1.5\text{V}$$

$$\overline{V_{tm}} = V_{DC} + \frac{\overline{\tau_{e\_\omega}} V_{AC}}{4\overline{\tau_{e\_2\omega}}}$$





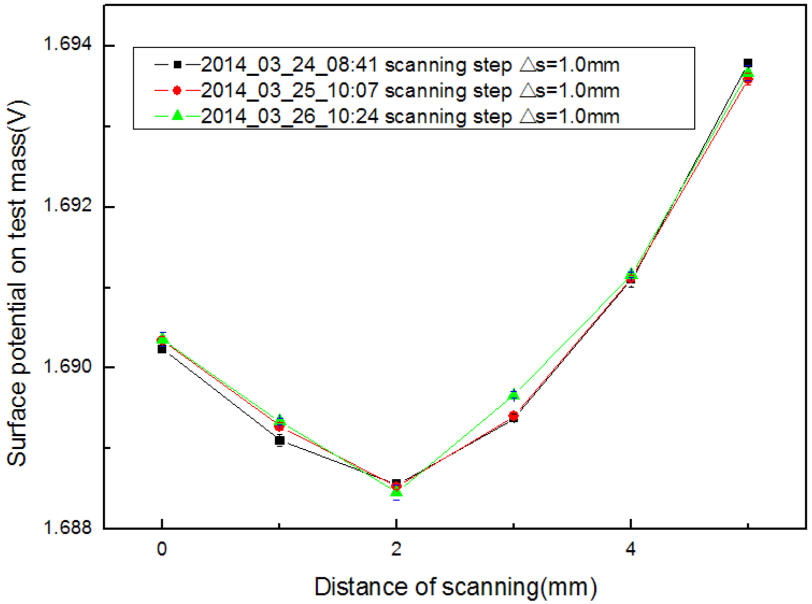
Power spectrum of torque feedback

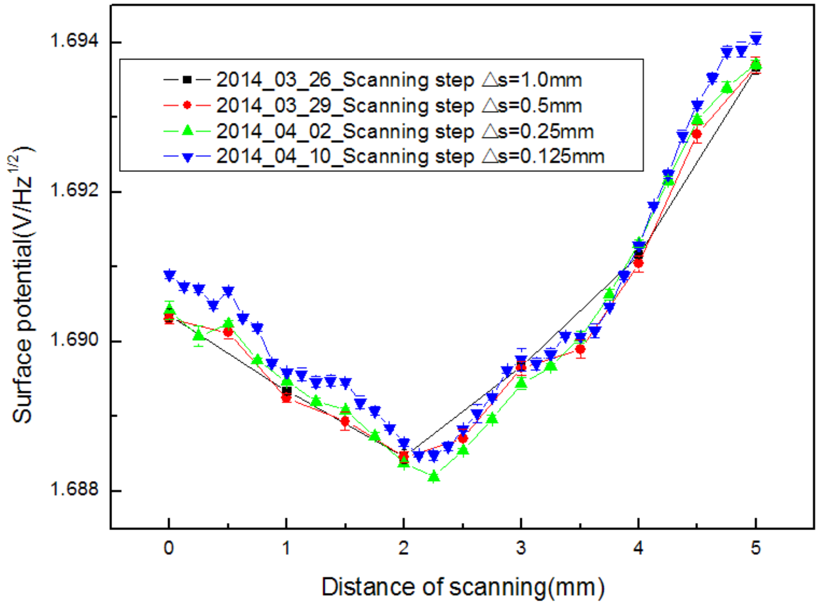
The amplitude of $\tau_{e\_1\omega}$ and $\tau_{e\_2\omega}$ will be obtained by fitting. The fitted equation is expressed as follow.

$$\tau_f(t) = \tau_e(t) = \tau_{e\_1\omega\_a}\cos(\omega_c t) + \tau_{e\_1\omega\_b}\sin(\omega_c t) + \tau_{e\_2\omega\_a}\cos(2\omega_c t) + \tau_{e\_2\omega\_b}\sin(2\omega_c t) + \ldots\ldots + d_0 + d_1 P_1(t)$$

$$\overline{\tau_{e\_1\omega}} = \sqrt{\overline{\tau_{e\_1\omega\_a}}^2 + \overline{\tau_{e\_1\omega\_b}}^2} \qquad \overline{\tau_{e\_2\omega}} = \sqrt{\overline{\tau_{e\_2\omega\_a}}^2 + \overline{\tau_{e\_2\omega\_b}}^2}$$

4. Measurements: Scan mode





Measuring distribution of surface potential with scan mode

Scanning with different step

- The result shows that our apparatus could obtain the distribution of surface potential and experimental data had good repeatability.
- The experimental data with different scanning step reflect more details in distribution of surface potential.
- The variation of surface potential over time(11 days) is less than 0.5mV.

5. Summarize

- Design and install our apparatus for measuring, whose resolution achieves to our goal.
- Measuring the value of surface potential with static mode.
- The spatial variations in surface potential could be obtained by apparatus depend on scanning mode.
- Researching for elements which may influence the variations in surface potential is our focus in the next step.
- Investigating the charge management base on our apparatus will be carried out in the future.

The End

Thanks for your attention!