9^{th} *LISA Symposium, Paris*
ASP Conference Series, Vol. 467
G. Auger, P. Binétruy and E. Plagnol, eds.

Improving Angular Deflection Sensitivity of a Torsion Pendulum by an Electrostatic Spring

Y. Z. Bai, H. Yin and Z. B. Zhou*

Center for Gravitational Experiments, School of Physics, Huazhong University of Science and Technology, Wuhan, China
*zhouzb@mail.hust.edu.cn

Abstract. An electrostatic torsion pendulum aiming at improving angular deflection sensitivity without increasing torque noise floor is presented. Theoretical analysis shows that this scheme could be used to relax requirement of angular deflection measurement, and is useful for gravitational experiments with much higher precision requirement.

1. Introduction

Torsion pendulum plays a paramount role in the field of precision measurement and gravitational experiments due to its high-precision sensitivity (ref. Hueller & al. (2002)). The basic detectable torque resolution is limited by the mechanical thermal noise and electrical or optical noise of the angular measurement system. For some high precision experiments, commercial angular deflection transducers could not satisfy basic requirement. An electrostatic torsion pendulum which can greatly increase angular deflection sensitivity without degrade original SNR is presented.

2. Electrostatic torsion pendulum and its potential sensitivity

The electrostatic pendulum is made up of the typical pendulum and two pairs of electrodes, as shown in Fig 1. The motion equation of the electrostatic torsion pendulum, which is set in a high vacuum chamber can be given by

$$I\ddot{\theta} + k_{\mathrm{m}}(1 + \mathrm{i}\phi)\,\theta = \tau_{\mathrm{th}} + \tau_{\mathrm{e}} + \tau_{\mathrm{e,n}}, \tag{1}$$

where I is the inertial momentum, θ is the motion angle of the test mass, k_{m} is the elastic coefficient of the fiber, ϕ is the structure loss angle, τ_{th} presents mechanical thermal noise, τ_{e} and $\tau_{\mathrm{e,n}}$ represent the electrostatic torque and its fluctuation induced by the applied voltage noise on the electrodes, respectively.

The power spectrum of the minimum detectable response torque is given by

$$\tau_{\mathrm{min,e}}^2 = \frac{4k_{\mathrm{B}}Tk_{\mathrm{m}}\phi}{\omega} + \theta_{\mathrm{eq}}^2\left[\left(k_{\mathrm{m}} - k_{\mathrm{e}} - I\omega^2\right)^2 + (k_{\mathrm{m}}\phi)^2\right] + \tau_{\mathrm{e,n}}^2, \tag{2}$$

where θ_{eq} represents angular deflection measurement level. The coupling between of the additional electrostatic electrode and the pendulum contributes a negative stiffness k_{e} which will increase the angular deflection sensitivity. As a result, it can loose requirement of angular deflection measurement.

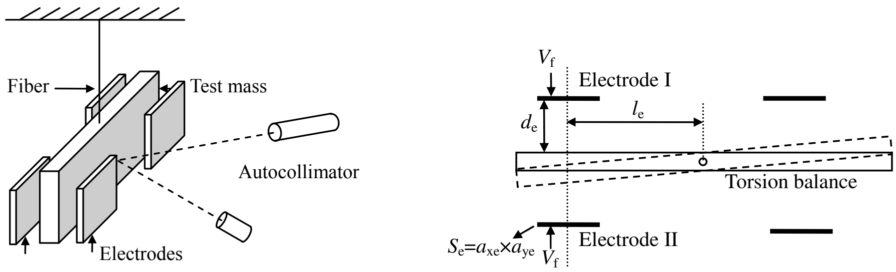

Figure 1. Schematic of the electrostatic pend

3. Example analysis

The torsion pendulum adopted by Washington Univ mass (ref. Pollack & al. (2010)) is used as an examp

Assuming angular deflection measurement no power spectrum density of the torsion pendulum sy ment of torque detection is 5×10^{-15} Nm/Hz$^{1/2}$ abov deflection measurement can be relaxed about two orders, as shown in Figure 3.

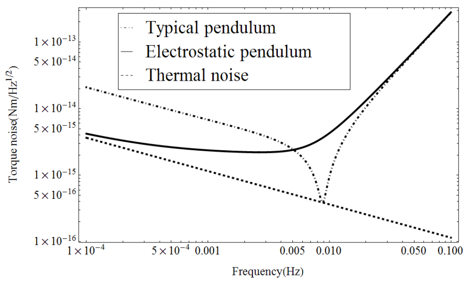

Figure 2. Resolution comparison of the typical torsion balance and electrostatic torsion pendulum.

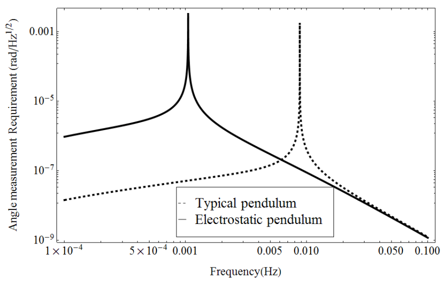

Figure 3. Requirement comparison of the angular deflection measurement aiming at the same scientific torque detection.

4. Conclusion

The electrostatic spring can relax the requirement of the angular deflection measurement of a torsion pendulum, which is very important for the much higher precise torsion pendulum experiments, for instance, to investigate the residual disturbances of a proof mass for LISA and advanced LISA projects.

References

Hueller, M., & al. 2002, Class. Quantum Grav., 17, 1757
Pollack, S. E., & al. 2010, Phys Rev D, 81, 021001