Experimental setup for measurement of fluctuating force acting between fused silica torsional oscillator and electrostatic drive

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Introduction

We present description of the experimental setup developed for measurement of fluctuating force acting between models of the electrostatic drive (ESD) and the test mass of the gravitational wave detector. For instance, this noise arises from thermal polarization fluctuations, which relate to the dielectric susceptibility of fused silica $\varepsilon(\omega) = \varepsilon'(\omega) + i\,\varepsilon''(\omega)$ via the fluctuation-dissipation theorem. Our previous measurements have shown that the imaginary part of $\varepsilon(\omega)$, associated with conductivity $\sigma(\omega)$ of fused silica $\varepsilon''(\omega) = \sigma(\omega)/\varepsilon_0\,\omega \approx 10^{-10}$ at frequency of 10 Hz. According to our assessments this value is too small to generate noise which is dangerous for aLIGO detectors. But dielectric polarization of fused silica has rather complicated character including dipole and space charge polarization. Also free electrical charges are always present in fused silica samples and on their surfaces. Therefore, we cannot exclude additional noise. So it is reasonable to carry out direct measurements of noise using the models of the test mass and ESD.

Experimental setup

The key element of the setup is the specially fabricated monolithic fused silica torsional oscillator (see Fig.1) with the ESD model nearby. The oscillator's body is a fused silica plate with two lugs which was cut out from Ø 1" dielectric mirror. The mirror thickness was reduced to 2.5 mm. The sizes of the oscillator's body (without lugs) are 25.4 x 10 x 2.5 mm^3. The plate with two welded fused silica fibers forms the torsional oscillator. The thin part of the fiber has a length of about 7 mm and a diameter of about 300 microns. Small variations of the fiber's diameter allow creating of torsional oscillators with resonant frequencies of 40 – 70 Hz. The torsional oscillator is welded into a fused silica frame by means of a gas-oxygen torch. Several fused silica torsional oscillators were fabricated. In air the measured quality factor Q of the oscillator depends on the separation gap width between the fused silica plate and electrodes of the ESD. The Q was found to be ≈ 1.5 x 10^3 by the gap ≈ 1mm. In vacuum, the measured Q was found to be ≈ 10^6. The torsional oscillator with the resonant frequency of 63.1 Hz was used for the noise measurement.

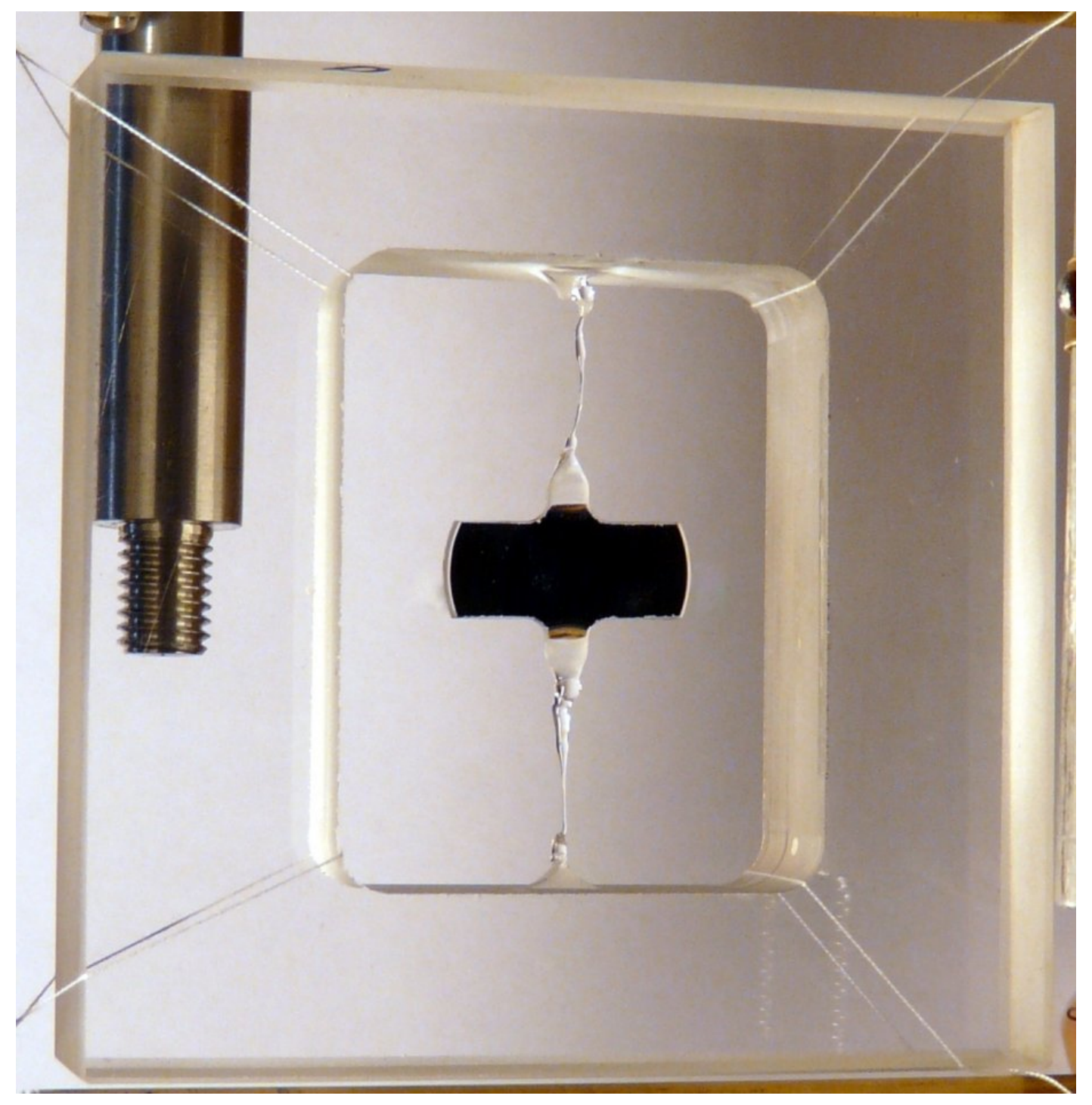

Fig 1.

Fluctuating force associated with the interaction between the ESD and fused silica body of the torsional oscillator results in the additional noise of the oscillator. In order to measure the oscillator's noise amplitude the special interferometric optical sensor was developed.

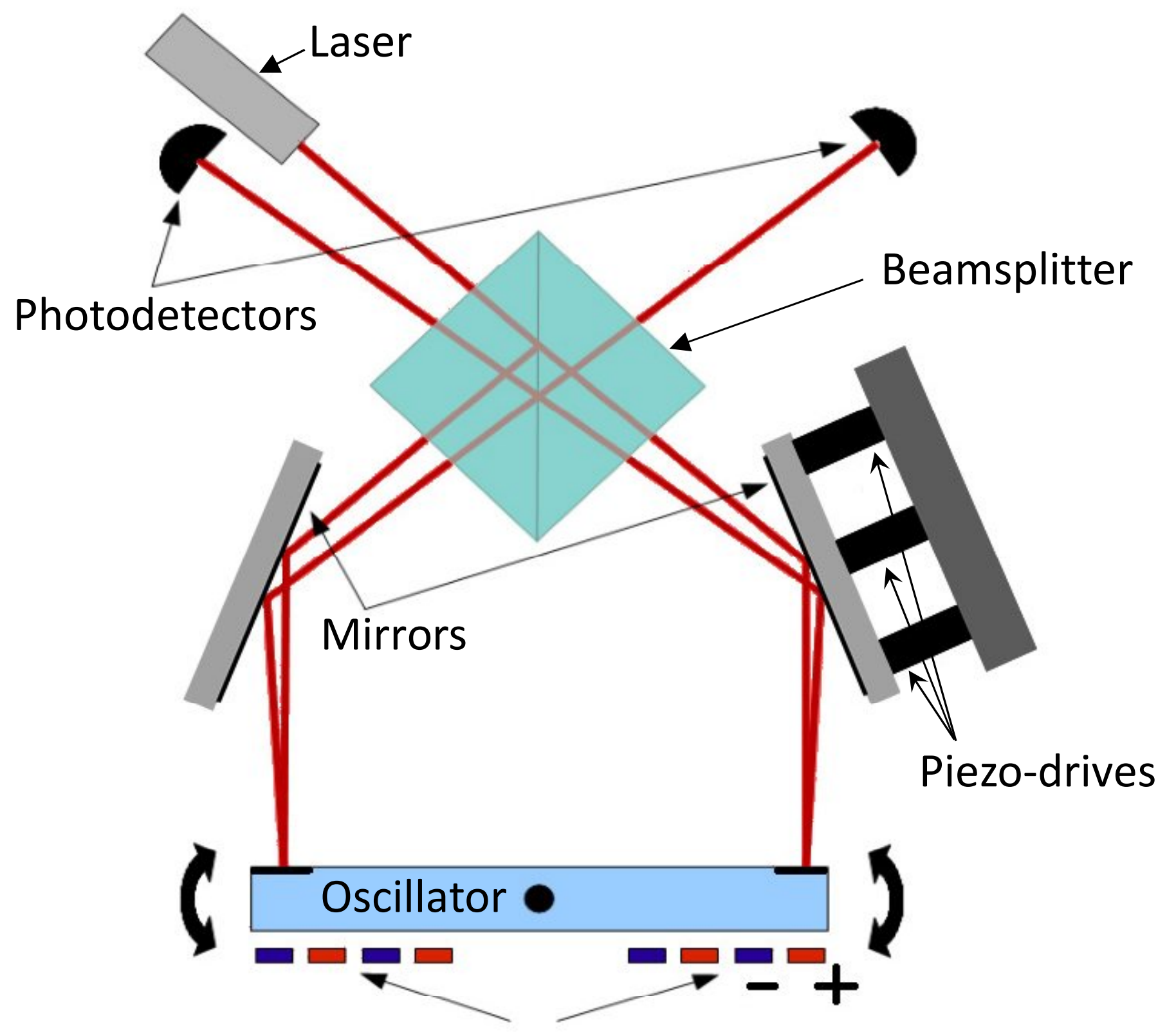

Fig 2.

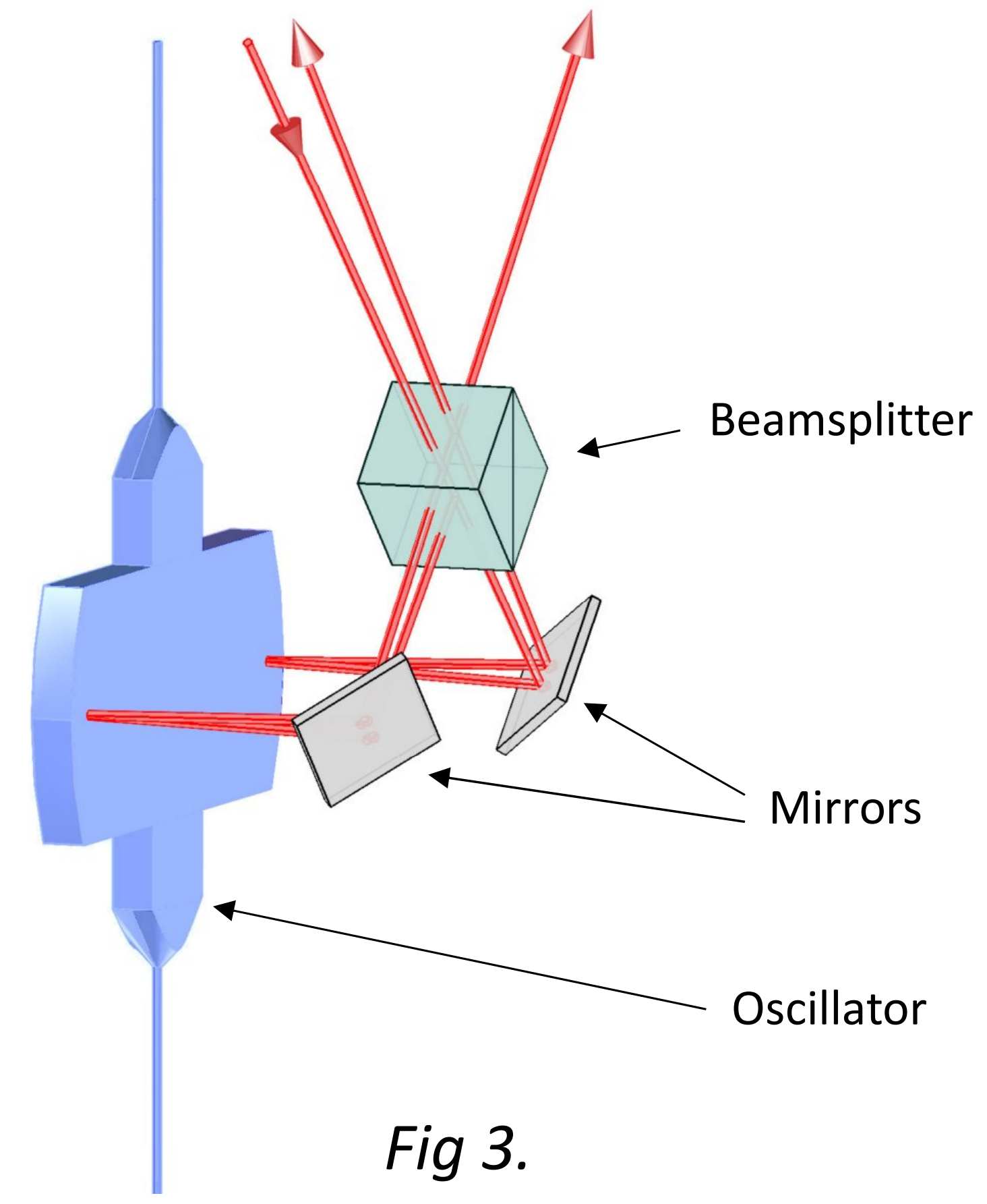

Fig 3.

The surface of the plate (the oscillator's body) forms two moving mirrors of the Michelson interferometer oscillating in antiphase. Schematic of the sensor is shown in Fig.2. Fig.3 gives the 3-dimentional picture of location of the sensor parts. The interferometer's signal processing was performed with LABVIEW.

Results of measurements

In the first stage the setup was tested and adjusted in air. The air measurements have some advantage because all processes associated with charge relaxation run much faster in air than in vacuum due to the relatively high surface conductivity of the fused silica sample associated with adsorbed water. The angular sensitivity of the optical sensor was found to be about 5x10^{-11} rad/Hz$^{1/2}$. Amplitude spectral density of the pendulum free angular oscillations is shown in Fig.4. Noise amplitude of the oscillator was about of ≈ 6x10^{-9} rad and was associated with seismic noise.

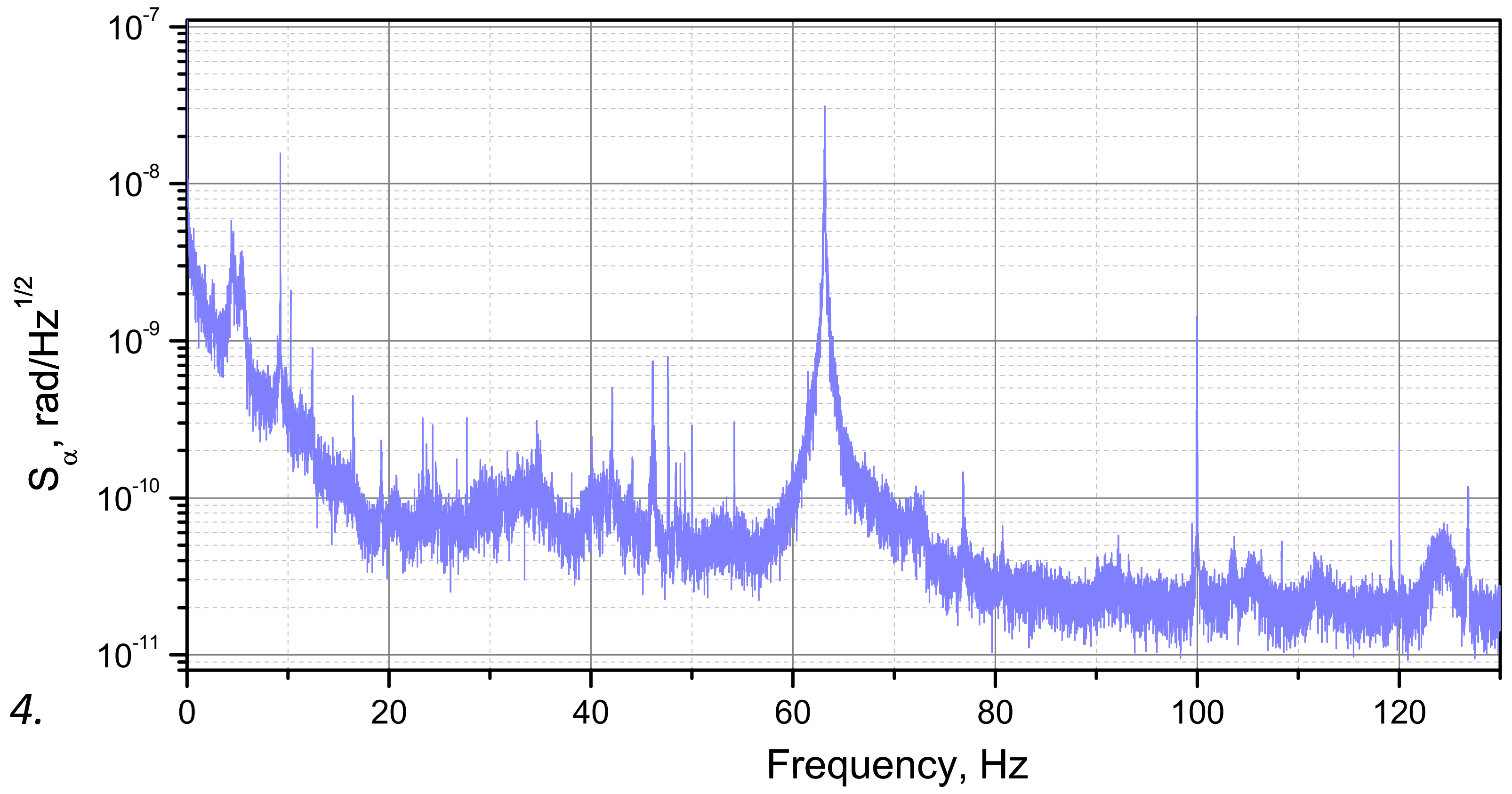

Fig 4.

It was found that long-term energizing of the ESD resulted in the change of the oscillator resonant frequency. Moreover, the forced oscillations amplitude [excited by applying ac voltage to the ESD at the resonant frequency] was found to increase with time when the dc voltage was applied. Such a behavior of the torsional oscillator indicates that charges are accumulated on the fused silica plate of the oscillator against the electrodes when dc voltage is applied to the ESD. Switching off dc voltage results in decay of the accumulated charge. One can monitor the accumulated charge decay by measuring the forced oscillation amplitude when only ac voltage at the oscillator's resonant frequency is applied to the ESD (see Fig.5).

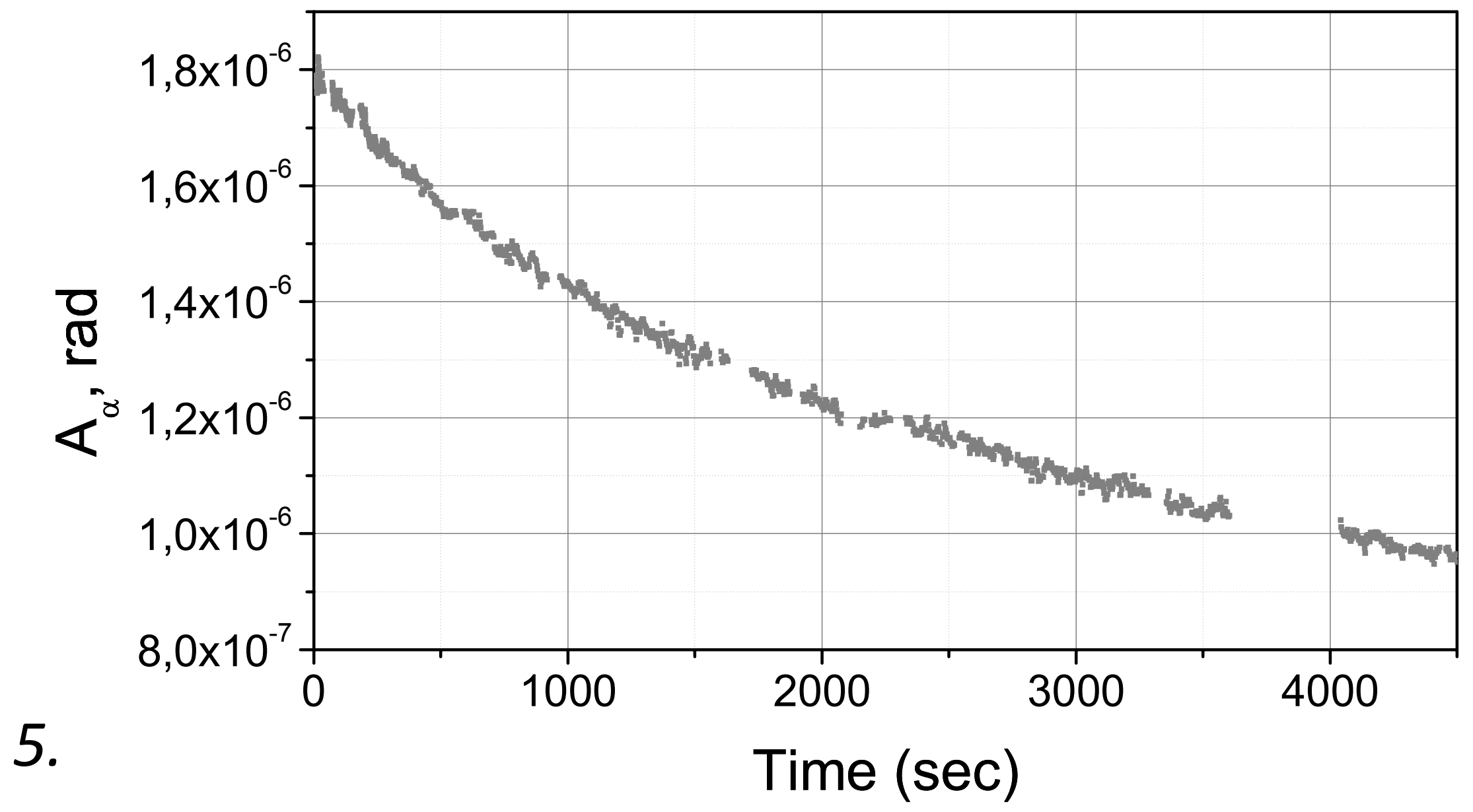

Fig 5.

The preliminary measurements of charging noise associated with interaction of the fused silica plate and the model of ESD were carried out in air. No increase of the oscillator noise was found when dc voltage up to 10^3 V was applied to the electrodes of the ESD. These results allow us to conclude that in our setup the amplitude spectral density of force noise associated with the fluctuating action of ESD on fused silica oscillator does not exceed 2x10^{-12} N/Hz$^{1/2}$.

Summary and Plans

Results of the first measurements allowed us to give the upper limit of fluctuating force acting between the fused silica torsional oscillator and the electrostatic drive in our experimental setup.

In the sequel we plan 1) to develop the vacuum system of seismic isolation for this setup and significantly increase its sensitivity; 2) to determine relation between noise measured in our setup and in aLIGO detector using numerical modelling technique; 3) to develop method of measurement of nongaussian noise associated with interaction of the test mass and the electrostatic drive.

Acknowledgements

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