Thermal and Excess noise in suspension fibers.

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Abstract.

We present a progress report on the measurement of mechanical noise on the mirrors suspension prototypes. The excess noise in the metal wires was detected. The advanced technique for the fused silica fibers test was developed.

Introduction.

The sensitivity of large scale gravitational wave detectors [1] can be limited by the stochastic forces applied on the interferometer mirrors. The random motion of suspension structure can be a source of the force acting directly on the mirrors. In the present interferometric detectors (LIGO-I, TAMA) steel wires are used as a final stage of test mass suspension. It is expected, that the fused silica fibers can be a good alternative in the future detector (LIGO-II, GEO-600). The main advantage of the fused silica is a low acoustic losses, which make it possible to increase the quality factor of all modes of mechanical vibration in test mass suspension system. Recent investigations have shown that this value can reach 10^8 for fused silica fibers [2,3]. The rms variation of the amplitude for oscillator with the resonant frequency ω, quality factor Q, effective mass m^* measured over the time t is:

$$\Delta A_{rms} \sim \sqrt{\frac{kTt}{m^*\omega Q}}$$

This means that the spectrum density of the equilibrium thermal noise induced by the fused silica suspension can be reduced by the factor of $\sim 10^3$ as compared to the steel wires design. From the other hand, the existence of an extra (excess) noise of the nonthermal origin is possible. Their source can be the development of microcracks, the migration of dislocations and other defects in the suspension matherial. There is a big difference between the structure of steel (metal) wires and fused silica (glassy) fibers. In our former experiments [4,5] it was observed, that the mechanical noise in the steel and tungsten wires depends on the applied stress. It is well known, that the mechanical properties of metals change abruptly then the applied stress overcome the yield point. It is not clear, if a threshold stress value exists for the fused silica. Thus, the experimental

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investigation of this type of suspension is important for the design of the next generation of gravitational wave detectors.

1. Excess noise in the steel wires.

The existence of additional mechanical fluctuations has been demonstrated in our experiments with tungsten and steel wires. The short bursts (as compared to the relaxation time) and spontaneous increase of the effective temperature has been observed. The Michelson interferometer pumped by He-Ne laser was used. The displacement resolution $\Delta x_{\min} \cong 2\times 10^{-11} cm/\sqrt{Hz}$ was sufficient for the observation of the thermal oscillation on the fundamental violin mode avereged over the time t=0.2 s short as compared to the relaxation time τ^{*}~5-12 s. As a result, the excess noise bursts was observed. On the Figure 1 the amplitude variation intensity cumulative histogram for the various stress value is sown. One possible explanation for the noise burst origin is an avalanche-like grains displacement process within small part of the sample that originally contains some type of inhomogenety.

2. Towards the measurement of mechanical noise in the fused silica fibers.

The main goal of this part of our our project is to check if any mechanical excess noise exists in high Q fused silica suspension fibers violin modes and investigate the dependence of this noise on the applied stress. As far as one expect to obtain much lower thermal noise using the high quality factor fused silica suspension, much better technique for the excess noise measurement have had to be developed. Our efforts were focused on the two main problems:

1. how to reach sufficient sensitivity of the readout system keeping the fiber untapped (saving the high quality factor of the violin modes)
2. how to keep the high value of quality factor and constant strain along with the applying vibration isolation well enough for this readout system (we must have done it without an active position control which itself can be a noise source).

After the several different approaches had been tested [6], it was decided to use a conventional Fabry-Perot resonator (optical meter) with a small flat mirror (4x2x1 mm) made of pure fused silica welded in the middle of the tested fiber (see Figure 2). The surface of this mirror was coated with high reflective multilayer which provides high finesse. Two short fused silica sticks were welded to the opposite "corners" of the mirror before coating. The "free" ends of these sticks were used for welding the fused silica fibers which noise will be measured. This design already was tested and the finesse higher than F~50 was obtained. It is important to note that the coating was not damaged by the welding of fibers. For the W=1 mW, λ=0.6 μm He-Ne laser the sensitivity of this method is:

$$\Delta x^{f}_{\min} \sim \frac{\lambda}{4F}\sqrt{\frac{\hbar\omega}{W}} = 5\times10^{-14}\, cm/\sqrt{Hz}$$

This value is good enough for the resolving of thermal noise with the averaging time $t<10^{-2}$ s while the relaxation time is expected to be $\tau^{*}>2\text{x}10^{3}$ s in the standard fibers (10 cm long, 100 μm in diameter).

We also managed to design the method of attachment of the fiber to the support structure which allows to keep the quality factor of violin modes as high as $1.5\text{x}10^{7}$ and to measure effective temperature related to the fundamental violin mode using the simple “knife and slot” technique [7]. The preliminary measurements gives an evidence that the effective temperature is close to the room temperature, that means that the violin mode oscillations averaged over the time long as compared to the relaxation time can be described as a pure Brownian motion.

Conclusions.

The progress report on the measurement of mechanical noise on the mirror suspensions prototype is presented. To date the excess noise in the metal wires is observed and the advanced technique for the fused silica suspension test is prepared.

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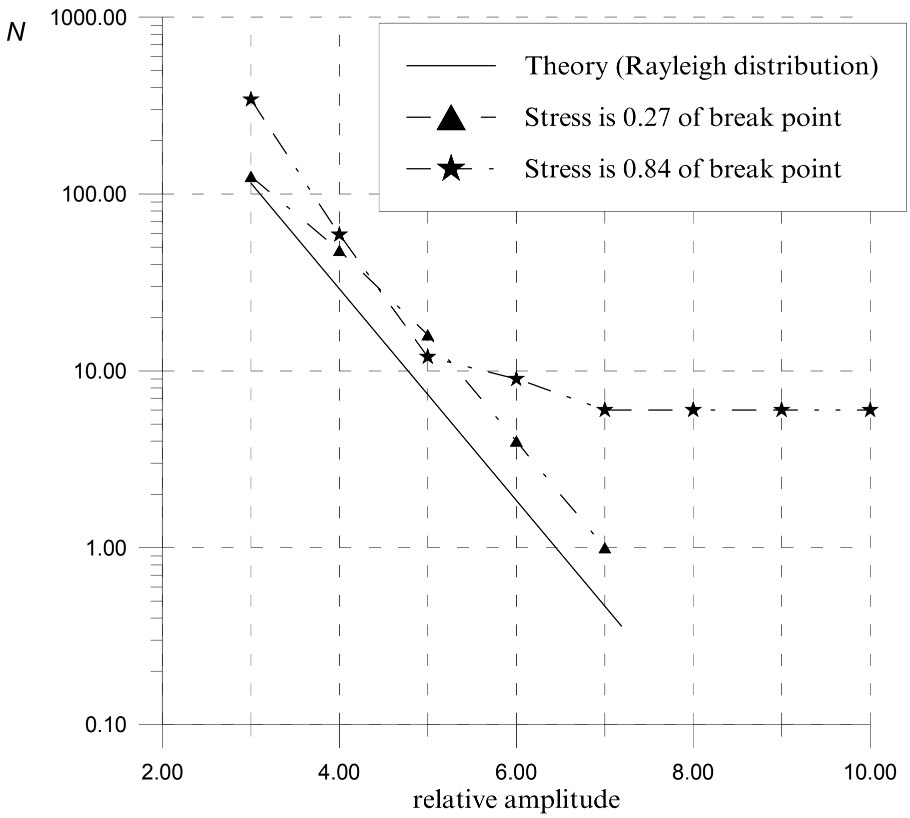

Figure 1.
Amplitude variation intensity cumulative histogram for the steel wires oscillation on the fundamental violin mode. N is the relative number of variations per hour with amplitude exceeding the threshold A.

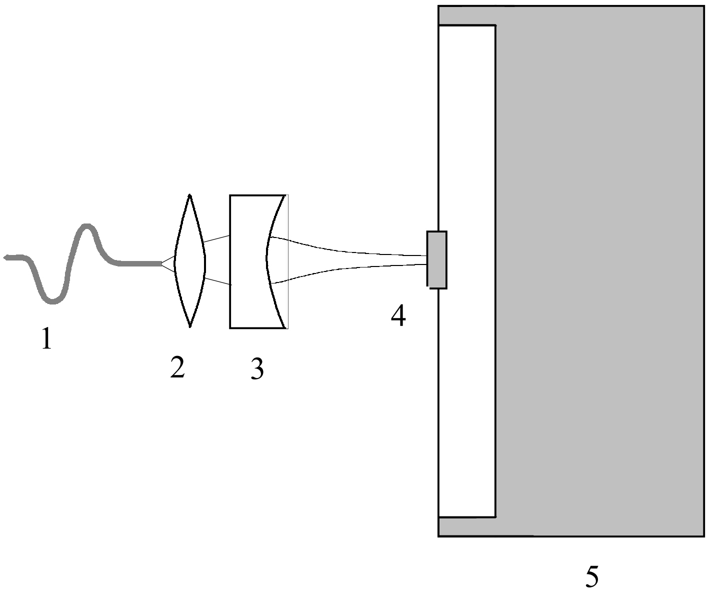

Figure 2.
Design concept for the Fabry-Perot cavity based sensor. 1 – optical waveguide, 2 – matching lens, 3 – fixed mirror, 4 – tested fiber with a small mirror in the middle, 5 – fused silica support.