ANNUAL REPORT

Jan. 1997 – Dec. 1997

of the MSU group to LIGO project

SUSPENSIONS AND SUSPENSION NOISE FOR LIGO TEST MASSES

NSF Grant PHY-9503642.

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I. SUMMARY

A. The investigation of excess noise in violin modes of steel wires

During the year 1997 a new set of records of the mechanical vibrations of violin modes was obtained. In contrast with the former measurements of 1996 of the excess noise observed above the Brownian motion in $20\,\mu m$ diameter tungsten wires we have tested now the noise in $80\mu m$ steel wires made of the same material that is used in LIGO prototype. As we expected smaller mean square amplitude of the Brownian motion due to the larger diameter of the wires, we had to improve substantially the optical readout system. The achieved new resolution $2 \times 10^{-11} cm/\sqrt{Hz}$ was sufficient to record Brownian vibration with relative accuracy better than 10% (see details in Appendix I).

The main results of these measurements are the following:

1. We observed the existence of two types of excess noise: the first is relatively rare rises and falls of the mean amplitude over several relaxation times; the second is presence of fast variations (jumps) of the amplitude with the event rate higher as compared to pure Brownian motion.

2. The total intensity and amplitude of the excess noise peaks were remarkably (5-8 times) lower than in case of tungsten wires.

3. We have not observed significant dependence of the excess noise on the stress value within the range of applied loads (see details in Appendix I).

B. Design and development of a new vacuum chamber for the tests of Q-factors in suspension's modes

In our attempts to obtain high mechanical Q-factors in the suspensions' modes (see annual MSU reports 1995 and 1996) we have reached $Q_{viol} \simeq (0.5 \div 1.1) \times 10^8$ and $Q_{pend} \simeq 1 \times 10^8$. In those experiments it is likely that the obtained values are not the ultimate ones for a very pure fused silica suspension because of the substantially large gap between precalculated and the measured values. The origin of the discrepancy was probably due to the insufficient depression of some sources of dissipation (recoil losses, residiual gas losses, surface losses in suspension fibers, electric field losses). These main motivations were the basic ones which led us to ellaboration of a new design and implementation of a new vacuum chamber. We expect to obtain higher quality factors first of all in pendulum modes. During 1997 the design was done and a chamber with the installation attached to a heavy basement wall were manufactured, assembled and tested. The obtained vacuum is 3×10^{-8} Torr (in older chamber it was only 2×10^{-6} Torr). At present installation of special inchamber equipment is in progress. The first tests of losses in new suspension may be realized in coming spring. (See details in Appendix II).

C. The investigation of dynamical and dissipative actions of electric controller on the test mass

It is reasonable to expect that the usage of an electric controller will produce dynamical and dissipative actions on the test masses (although these actions will be much smaller than that from a magnetic actuator). In our previous preliminary experiments we observed the dissipative actions on the test masses due to the following processes:

1. the dissipative processes on the surface of conductors which are connected to the source of electrical field;
2. electrostatic field produced by electrical charges located on the surface of fused silica;
3. Joule losses in resistive part of the controller cirquit.

To obtain the complete necessary information about the role of the processes 1. and 2. and about the possibilities to decrease their dynamical and dissipative actions it is necessary to rearrange inchamber equipment and to make some changes in the chamber itself. This will be done next spring.

In this report we describe the results we obtained about the source 3. The main result of the described in Appendix III measurements and calculations is that this source does not prevent to obtain $Q \geq 10^8$ when the controller tunes the test mass at a distance of the order of 10^{-5} cm. (See details in Appendix III)

D. The analysis of a new principle of intracavity readout system

In 1997 a new intracavity readout system was proposed and analysed. In brief the principle of this scheme is the following. Let in the system the two coupled Fabry-Perot resonators initially be identical. Small variations of its lengths lead to amplified redistribution of energy causing force on central mirror. The resulting mirror displacement may be detected using methods standard for the bar antennas. The scheme provides gain in resolution and allows to beat the standard quantum limit without the use of non-classical pumping. The origin of this key advantage is that the fluctuations in optical part of the meter may be in principle totally excluded and the only source of back action will be the meter, which in case of microwave transducer consumes very small amount of energy.

The ultimate sensitivity and the required optical pump power in this scheme do not depend on the quantum state of the pump field. The required state of e. m. field in the resonator with a well determined energy difference in the two arms of the antenna is forming automatically in the process of monitoring the coordinate of the coupling mirror. (See details in Appendix IV)

E. New SQL free principle of coordinate monitoring of the test mass

The new concept of quantum measurement — quantum variation measurement — is proposed to circumvent the standard quantum limit with meter for continuous coordinate registration. Heisenberg microscope as a variant of coordinate meter is analyzed. The idea can be clarified on the example of two measurements separated in time and space, using apriori knowledge on duration and form of acting force. In the first measurement the linear combination of coordinate and back action momentum should be obtained (it is possible for real coordinate meter) and in the second one experimentalist measures the coordinate. The subtractions of the results of these measurements permit to exclude the response on the back action and thus to circumvent the standard quantum limit. These speculations can be extended on procedure of continuous measurement. (See details in Appendix V).

F. Appendix I

G. Appendix II

H. Appendix III

I. Appendix IV

J. Appendix V