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LASER INTERFEROMETER EXPERIMENTS AT CALTECH

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ABSTRACT

The status of the Caltech 40 m laser gravitational wave detector is reported, emphasizing the suspension system for the test masses. Preliminary noise measurements are also presented.

I. INTRODUCTION

The gravitational wave detector under development at Caltech consists of three test masses at the corner and ends of a 40 m long L, with a laser interferometer to monitor their separations. This detector serves two major objectives. It has the potential to achieve a sensitivity comparable with the present generation of cooled bar detectors for gravitational wave burst of duration ~1ms and thus could be used for coincidence searches. Furthermor it provides the means to develop the techniques required for kilometer-scale detectors, which could have the sensitivity to detect weaker gravitational wave signals such as those predicted from supernovae in the Virgo cluster and other sources.

Initial construction of the 40 m detector has recently been completed. This paper describes the work to date, with emphasis on the suspension and control systems for the test masses, and gives first results of noise tests for the interferometer. The basic concepts underlying the use of Fabry-Perot interferometers for gravitational wave detection are discussed in the paper by Drever et al. (these proceedings).

II. THE SUSPENSION SYSTEM

The suspension system must isolate the three masses from all but gravitational influences and maintain the optical cavity alignment (see Fig. 1).

To minimize the effects of seismic noise, the masses are isolated from the ground in three stages: a separate concrete floor, a lead and rubber stack, and a wire pendulum suspension. Each of the test masses hangs from its center of mass by wires giving a pendulum frequency of 1 Hz. Position noise of the mass due to motion of the suspension point is therefore attenuated by the square of the frequency for frequencies above the pendulum resonance. The suspension point itself is isolated from the vacuum tank by a conventional isolation stack made of three layers of rubber, alternating with two layers of lead. This stack is expected to attenuate noise above its 5-10 Hz resonance by f^6. Together these two stages provide the principal seismic isolation for frequencies above about 10 Hz.

The three optical tables supporting the interferometer sit on concrete pads separated from the main laboratory foundation. These pads isolate the vacuum system from nearby moving people and equipment. The vacuum pipes connecting the three tanks are themselves suspended at intervals along their lengths by ropes to provide additional isolation. A flexible bellows connects each tank to the pipe providing still more isolation. With the pipes thus free to move, we plan tests to measure how pipe motion limits interferometer sensitivity.

The wire suspension introduces two problems. The 1 Hz pendulum resonance can cause large motion of the mass on resonance. In addition, because the mass is effectively suspended at its center, it is free to rotate about each of three axes. Both of these problems put severe demands on the dynamic range of the sensing and feedback transducers responsible for maintaining the resonance conditions of the two cavities.

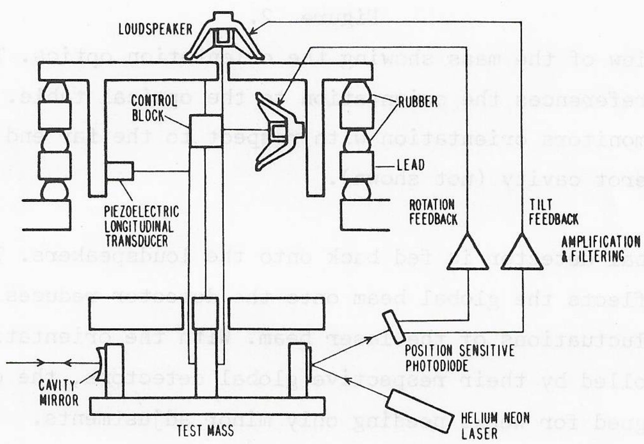

Figure 1.

An end mass, its local orientation servo-loop, the lead and rubber stack and the three wire pendulum suspensions.

In the case of the orientation control, the problem has been solved satisfactorily for current purposes by a combination of ideas adapted from the work done at Glasgow[1] and Munich[2]. Each mass is in fact suspended by three wires which are attached to a small block of aluminum near the top of the pendulum. The weight of the mass is supported by a single wire from the center of the control block to the suspension point. Feedback torques are applied to the mass by means of small wires connecting the control block to the moving cones of loudspeakers.

The orientation signal from the local detector (see Fig. 2) is used to damp large-scale motions of the mass. For fine control, a signal derived

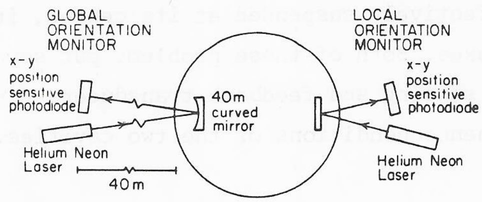

Figure 2.

A top view of the mass showing the orientation optics. The local optics references the orientation to the optical table. The global optics monitors orientation with respect to the far end of the Fabry-Perot cavity (not shown).

from the global detector is fed back onto the loudspeakers. The curved mirror which reflects the global beam onto the detector reduces the effect of angular fluctuations of the laser beam. With the orientations of the masses controlled by their respective global detectors, the cavities have remained aligned for weeks needing only minor adjustments.

III. THE INTERFEROMETER

The optical configuration used in current tests is shown in Figure 3; it is very similar to that described by Hough et al. ([1]. The two Fabry - Perot cavities which form the arms are operated independently, except that they are illuminated by the same laser. The first cavity is used to stabilize the laser frequency. Phase modulation applied to the laser light with an external Pockels cell produces a signal (after demodulation) proportional to the phase difference between the laser light and the resonant light in the cavity. After filtering and amplification, this signal is

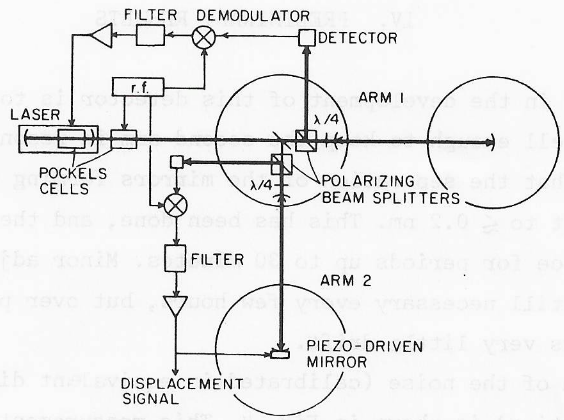

Figure 3.
Schematic diagram of optical cavity interferometer currently in use at Caltech.

applied to an intralser Pockels cell to control the laser frequency and to transducers attached to the wires supporting the test masses to damp the seismically-driven pendulum motion. A signal for the second cavity, derived in the same fashion, controls a piezo-electrically driven mirror to keep the second cavity in resonance; again, a portion of the low frequency signal is used to damp the low frequency mass motion.

This interferometer differs in one significant respect from that described by Hough et al. [1]. Instead of three mirror triangular cavities, we use two mirror cavities which are easier to align and capable of higher finesse. To prevent the feedback of light into the laser, we use polarizing beamsplitters followed by quarter-wave plates to divert the light reflected from the cavities.

At present, the interferometer is operated at low effective power (~ 10 mW) and moderate finesse (~500). To attain the desired sensitivity, both of these numbers must be raised substantially.

IV. PRELIMINARY RESULTS

A key step in the development of this detector is to make the servo-loops operate well enough to keep the second arm in resonance. In our case, this requires that the separation of the mirrors forming the second cavity be held constant to $\lesssim$ 0.2 nm. This has been done, and the cavity has been held in resonance for periods up to 30 minutes. Minor adjustments to the alignment are still necessary every few hours, but over periods of weeks the system shows very little drift.

A spectrum of the noise (calibrated in equivalent differential motion of the two cavities) is shown in Fig. 4. This measurement, taken shortly after the initial operation of the interferometer, is still well above the shot noise. Because of the preliminary nature of these results, it has not been possible to determine the source of the excess noise. From earlier lab tests, however, we expect that motion of the laser beam may be important. If this proves to be true, a mode cleaning cavity [3] should produce substantial improvement.

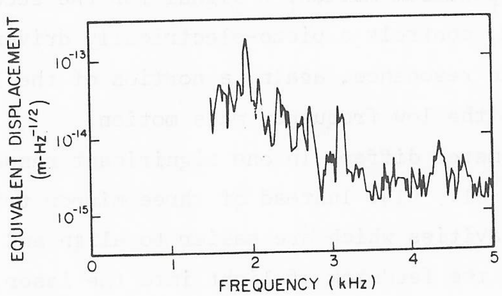

Figure 4.

Preliminary noise spectrum of the 40 m interferometer, calibrated in equivalent differential mass motion. The portion of the spectrum below ~1.5 kHz was not determined in this measurement.

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