Seismic Isolation in the LIGO 40 Meter Interferometer

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Submitted to
Proceedings of the Seventh Marcel Grossman Conference

LIGO Preprint PP94–7
LIGO - P940007 - 00 - R

September 1994

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SEISMIC ISOLATION IN THE LIGO 40 METER INTERFEROMETER*

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ABSTRACT

Prototype passive seismic isolation stacks designed for gravitational wave detection were installed in the 40 m LIGO interferometer, and the isolation was measured using the interferometer as a sensor. In agreement with models, the measurements indicate that the interferometer sensitivity is limited by seismic noise below approximately 80 Hz, and by other sources of noise at higher frequencies.

1. Description of Seismic Isolation

The 40 m interferometer at Caltech[1] relies on two cascaded systems of passive vibration isolation to reduce the effect of seismic noise on the interferometer mirrors: a four-layer stack consisting of massive stainless steel blocks separated by Fluorel elastomers, and a pendulum suspension to support the mirror on the top layer of the stack. The design is described in detail elsewhere, including transfer function measurements made on the benchtop with high-power shakers and accelerometers.[2]

Five identical stacks are used in the 40 m interferometer: one for each test mass, and one for the beamsplitter. A schematic representation of a stack, its support structure, and the test mass suspension is shown in Figure 1.

2. Results of Measurement

Figure 2 shows a prediction of the effect of seismic noise on the interferometer output, compared to the total observed noise, as of March, 1994. The prediction $\Delta\tilde{L}(f)$ of the displacement-equivalent noise at the interferometer output is computed as

$$\Delta\tilde{L}(f) = T(f) \cdot \tilde{x}(f) \tag{1}$$

where $T(f)$ is the measured transfer function from induced vibration of the stack support beams to the interferometer output (the latter calibrated in units of displacement of a test mass) and $\tilde{x}(f)$ is the spectrum of ground motion in the absence artificial excitation. In separate measurements, excitation was imposed along several axes and at several locations along the support beams; the feedthrough was most prominent (i.e. $T(f)$ was largest) for vertical excitation, and consequently the prediction of the effect of vertical seismic noise is indicated in the figure. The predicted noise is in rough agreement with the observed noise at spectral frequencies $f \gtrsim 80$ Hz. At higher frequencies other sources of noise, such as thermal noise and shot noise, dominate, and the effect of seismic noise is insignificant.

Separate measurements of the isolation provided by the pendulum suspension were made to extract from $T(f)$ the factor due to the stacks alone; the resulting

*Work performed under NSF cooperative agreement PHY-9210038.

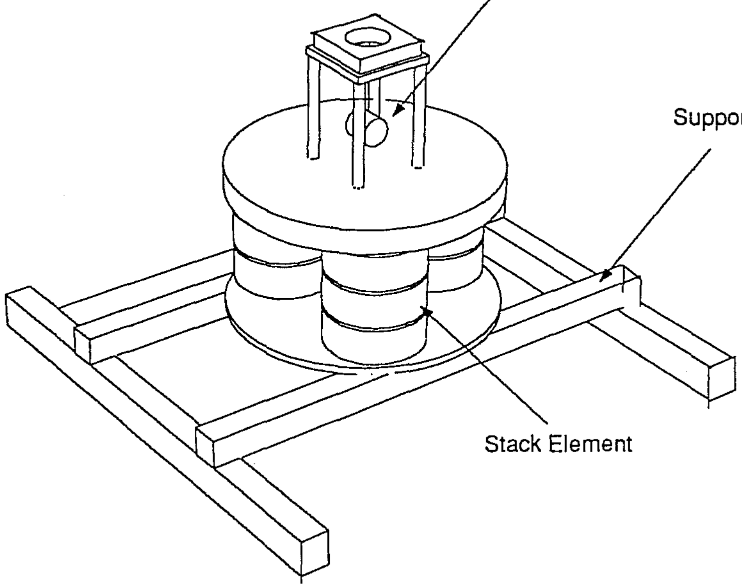

Figure 1: Seismic isolation for a test mass in the 40 m interferometer. The steel support beams penetrate the wall of a vacuum chamber, from which they are isolated by soft bellows. Each of the nine type 304 stainless steel stack elements has a mass of approximately 100 kg; elements are vertically separated by 5 cm high springs consisting of solid Fluorel cylinders. The test mass is a 10 cm diameter cylinder of fused silica, supported by two loops of 75 micron diameter steel wire. The isolation of the stack and suspension combined was measured by exciting the support beams with a commercial vibration exciter (Brüel & Kjaer Type 4809, maximum force 45 Nt) mounted externally to the vacuum chamber. The effect of the vibration exciter and the natural ground motion were measured with accelerometers.

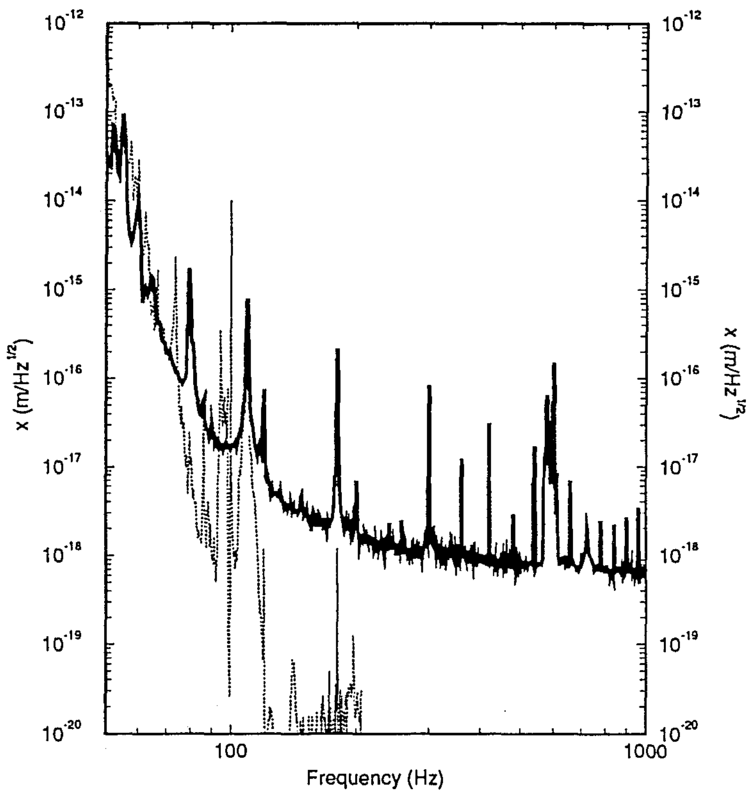

Figure 2: The predicted effect of seismic noise in the LIGO 40 m interferometer (*light line*), compared to measured total noise (*heavy line*), as of March, 1994. The prediction is based on the measured vertical component of seismic noise and the measured response of the interferometer to imposed vertical excitation. Measurements were conducted at one test mass only; the effect of seismic noise entering at all four test masses, assuming that the input noise and the isolation are identical for each of the test masses, can be projected by multiplying the prediction line by a factor of 2.

determination of the transfer function of the stacks was in good agreement with benchtop measurements of the stack, aside from resonances associated with the support beams or the vibration excitation.

References

1. R. L. Savage, "Status of the LIGO 40-Meter Interferometer," these Proceedings.
2. Joseph Giaime, Partha Saha, David Shoemaker, and L. A. Sievers, "A passive vibration isolation stack for LIGO: design, modeling, and testing," in preparation for *Review of Scientific Instruments*.