New Folder Name Reduced Displacement Noise

LIGO Technical Report TR94-2

Reduced Displacement Noise in the LIGO 40 Meter Interferometer

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ABSTRACT

Recent improvements to the LIGO 40 meter interferometer have significantly increased its displacement sensitivity, especially at frequencies below 1 kHz. The displacement noise background is below $2 \times 10^{-18}\,\mathrm{m}/\sqrt{\mathrm{Hz}}$ from 200 Hz to 5 kHz (excluding isolated peaks), and reaches a minimum of $7 \times 10^{-19}\,\mathrm{m}/\sqrt{\mathrm{Hz}}$ near 900 Hz.

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The Laser Interferometer Gravitational-Wave Observatory (LIGO) project operates a 40 meter interferometer at Caltech as a science and technology testbed. Here we develop techniques, procedures and hardware for laser interferometers which will be installed in the full-scale 4 km long LIGO facilities (currently under construction). A previous version of this machine (designated the Mk I Interferometer) was decommissioned in September of 1992, and the new improved interferometer, known as Mk II, became operational in July 1993. The need to improve the Mk I seismic isolation stacks was a primary motivation for replacing Mk I, as was the need for a much larger and cleaner vacuum system to proceed with planned tests on full-scale LIGO interferometer components. For the time being, however, the operating parameters, optical configuration, laser system, and many optical elements (including the test masses and beamsplitter) were deliberately not changed to permit a systematic and well-characterized evolution of the interferometer.

The current noise spectrum of the Mk II Interferometer, expressed as the spectral density of the apparent difference in arm lengths (displacement sensitivity), is shown in Figure 1. For comparison, two earlier spectra from the Mk I are also shown, including one taken in June 1992 shortly before it was decommissioned. That spectrum shows approximately the best overall performance achieved with the Mk I; the improvement at low frequencies achieved with the Mk II is clearly evident. Also shown in the figure is the displacement sensitivity goal for the initial 4–km long LIGO interferometers (lower, smooth curve). This comparison with current performance is appropriate for noise sources which cause motions of the test masses such as seismic or thermal noise. It is not readily scalable in regions of the spectrum which are dominated by sensing noise such as photon shot noise.

The Mk II noise spectrum is currently dominated by photon shot noise at frequencies above 1 kHz, as was the Mk I. The interferometer is operated with 30 mA total "bright fringe" photocurrent (corresponding to approximately 150 mW incident on the beamsplitter). The LIGO interometers are designed to operate in a different optical configuration and with higher optical power, which are necessary to maintain the same displacement sensitivity on the 4–km long arms.

Preliminary tests indicate that seismic noise is responsible for the sharp rise in the spectrum below about 70 Hz, as well as for the peak at 109 Hz (a mechanical resonance of the test mass suspensions). Although earlier a significant advance in the low–frequency regime had been achieved by replacing the test mass orientation control electronics in late 1991 (cf. the 6/92 vs. 10/90 spectra), the Mk I had remained limited by seismic noise, transmitted by relatively primitive seismic isolation stacks, at frequencies below 200 Hz. New isolation stacks, developed for the Mk II machine, have reduced seismic noise transmission by at least two orders of magnitude at 100 Hz. Further improvement is expected with the planned installation of redesigned pendulum suspensions and an additional modification of the isolation stacks to lower their resonant frequencies. These steps are expected to reduce seismic noise transmission to a level consistent with our initial LIGO displacement sensitivity goal.

Ongoing work is focused on fully understanding the origin of the observed noise at frequencies between 100 Hz and 1 kHz. From approximately 200 Hz to 1 kHz, the noise spectrum agrees with simple model predictions of thermal vibration in internal modes of the test masses, based upon their measured eigenfrequencies and quality factors. These masses, which were transferred unchanged from the Mk I interferometer, exhibit excessive internal damping (indicated by low measured quality factors). New test masses with lower damping are being prepared for installation in the near future to test this hypothesis. Several candidates for the noise between 100 and 200 Hz are also under active investigation, including residual noise from the mass damping and control systems and thermal noise in the pendulums.

The spectrum includes a number of sharp "line" features. The most numerous are powerline frequency harmonics caused by electrical interference (marked "L" up to the 7th harmonic); these can be systematically diagnosed and eliminated, but to date we have given higher priority to other aspects of the noise. Each of the broad peaks at 600, 1200 and 1800 Hz (marked "W") is actually a set of 16 narrow lines which blend together in this relatively low resolution spectrum. These are the violin-mode resonances of the test mass suspension wires (there are four wires for each mass). The peaks at 80 and 109 Hz (marked "S") are mechanical resonances of the test mass suspensions; these resonances are excited by broad-band seismic noise and/or electronic noise in the orientation and position control systems. These resonances are to be eliminated in the planned upgrade of the suspensions.

Displacement Sensitivity of Caltech 40 m Interferometer