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Addendum to Report on Vibration Isolation Requirements for LIGO...

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March 6, 1989

We have analyzed the noise that results from transverse motion of the beam with respect to the test masses or vice versa, coupled via mirror surface irregularities. Our findings and their impact on vibration isolation are summarized as follows:

1. Only mirror (test mass) irregularities with spatial periods between 0.6 cm and 3.6 cm (spot diameter) matter. The diffraction pattern corresponding to irregularities on a smaller scale exceeds the size of the opposite mirror and therefore does not participate in the interference process in the resonator.

2. The effect of mirror irregularities when the test mass moves with respect to a fixed beam is similar to that of a mirror tilt. The largest irregularities turn out in practice to be those on the scale of a spot size or larger, and can therefore be counteracted by suitable mirror (test mass) alignment.

3. The requirement on mirror alignment has to match or exceed the slopes associated with the mirror irregularities. A surface accuracy of $\lambda/100$ over 3.6 cm defines a slope of $1.8 \cdot 10^{-7}$ rad[1]. It follows that the mirrors (test masses) ought to be pointed with an accuracy of $\sim 10^{-7}$ rad.

4. If the above pointing requirement is met, what drives the requirement for isolation in the transverse motion of the test masses is the anisotropy

[1] the wave length used by the industry to specify surface accuracy is $\lambda = 633$ nm.

of the suspension combined with the curvature of the Earth, whereby the angle between the suspension and the mirror surface is ~ 0.7 mrad. Therefore, the uneven mirror surface moving transversely to the laser beam does not set an additional requirement for test mas isolation.

5. Since, as mentioned above, all that mirror irregularities do is redefine the orientation of the mirror surface, the effects related to the beam moving across such a surface are no different from beam wiggle generating frequency noise by excitation of higher order modes. That effect and its impact on isolation requirements has been already analyzed elsewhere.

A detailed explanation concerning the preceding statements will be written soon.

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Report on Vibration Isolation Requirements for LIGO Optical Components

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March 2, 1989

1 Summary

Peter Saulson has reviewed Alex Abramovici's memo on vibration isolation requirements for LIGO optical components. He found the method basically sound. With only a few changes, he agrees with the calculation presented in the memo. A revised version will follow soon.

One important addition is the recognition that the axial motion of the mode cleaner mirrors must be extremely small, to keep the frequency noise at the output low.

Two additional mechanisms linking component motion to interferometer noise have been studied. They are magnetic field inhomogeneity in a Faraday isolator coupling transverse motion to the beam, and the Fizeau effect in a moving compensation plate. Neither of these effects sets a limit more stringent than those previously considered.

2 Findings

Components can be divided into two classes.

1. Test masses and other components downstream from (and including) the recycling mirror, and the mode cleaner mirrors. These components need "test mass grade" isolation systems.

2. Components between the mode cleaner and the recycling mirror need various degrees of isolation, much less stringent than for the test masses.

   The most critical components are the beam expander lenses. The isolation requirements are listed in Table 1.

3 Comments

1. Safety margins are not included in Table 1.
2. The two high frequency requirements in Table 1 are easy to meet. The 50 Hz requirement is relatively easy to meet. The 10 Hz one may be difficult.
3. The sensitivity requirements used here were the "Advanced Detectors" curves in the December 1987 proposal. We feel that especially the 10 Hz requirement is not sufficiently physically motivated. For example, proper consideration of thermal noise will likely force an increase of the expected 10 Hz noise in the interferometer by at least one order of magnitude (if not more). In that event, the required isolation for "non-critical" components may be substantially relaxed from the low frequency entries in Table 1.
4. Although the last line in Table 1 corresponds to the Advanced Detectors, we have neglected the additional dewiggling associated with recycling. If the dewiggling benefit of recycling were taken into account, the requirements on isolation of components outside the recycled system could be relaxed by the factors given in Table 2.
5. In view of the above, we believe that relatively simple vibration isolation systems will suffice for all of the "non-critical" components. Even though their individual isolation requirements vary, it may be simplest to develop just a single suspension design for all of them.
6. The requirement that the mode cleaner mirrors be isolated roughly to the same degree as test masses follows from the requirement that frequency noise at the mode cleaner output be dominated by shot noise. We might need to meet this requirement if the wiggle noise in future

lasers is small enough. The isolation requirement for the mode cleaner mirrors could be relaxed to the extent that frequency noise at the mode cleaner output is higher than shot noise.

7. Isolation requirements for "non-critical" components are driven by the translational degrees of freedom, since tilt noise never dominates. Tilt larger than the expected ground noise would *still not dominate*.

Table 1

f (Hz)	10	50	215	1000
Shot noise equivalent comp. motion $\left(\frac{m}{\sqrt{Hz}}\right)$	$1.3 \cdot 10^{-12}$	$1.2 \cdot 10^{-14}$	$1.2 \cdot 10^{-14}$	$5.4 \cdot 10^{-16}$
Ground motion $\left(\frac{m}{\sqrt{Hz}}\right)$	$4 \cdot 10^{-10}$	$1.6 \cdot 10^{-11}$	$8.7 \cdot 10^{-13}$	$4 \cdot 10^{-14}$
Isolation factor needed.	320	1300	80	80

Table 2

f (Hz)	10	50	215	1000
Dewigglin factor from recycling	16	76	52	239