Test Mass Orientation Noise in the LIGO 40m Prototype

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ABSTRACT

The dominant source of noise between 50 and 500Hz in the LIGO 40m prototype interferometer has been identified as due to excess noise in the test mass orientation control systems. Angular jitter of the cavity mirrors results in test mass displacement noise because of the offset between the cavity axis and the center of rotation of the test mass. This noise can be reduced significantly by improving the feedback electronics in the servo system.

1. INTRODUCTION

The 40m prototype interferometer at Caltech[1], a testbed for the LIGO gravitational wave observatory[2], contains various kinds of servo systems. Among them are the test mass orientation control systems which hold the Fabry-Perot cavities in alignment.

Each orientation control system employs a He-Ne laser optical lever as an angle sensor and a magnet-coil system as an actuator. Angular jitter of the mass can be caused by current noise in the coil, which originates in the He-Ne laser wiggle, the laser intensity noise, or electronic noise of the circuit. This angular jitter, coupled with an offset between the cavity axis and the center of rotation of the test mass, has been shown to be the dominant source of noise between 50 and 500Hz.

2. MIRROR ANGLE DEPENDENCE OF CAVITY LENGTH

The 40m prototype cavities consist of flat (M_1) and concave (M_2) mirrors. The cavity length along the beam axis (l) depends upon each mirror angle (θ_1 for M_1 and θ_2 for M_2). Typically, the static alignment of the cavities does not have the optical axis exactly on the line connecting the test mass centers. When each mirror has a small angular jitter ($\delta\theta_1$, $\delta\theta_2$), the corresponding cavity length variations (δl) are, to first order in $\delta\theta_1$ and $\delta\theta_2$:

$$\delta \mathrm{l} = \mathrm{d}_{1\mathrm{st}}\delta\theta_1 + \mathrm{d}_{2\mathrm{st}}\delta\theta_2 \quad \cdots (1)$$

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where d_{1st} and d_{2st} are static distances between the beam axis and the center of rotation of M_1 and M_2, respectively.

This model has been verified using one of the 40m prototype cavities. A small angular jitter ($\delta\theta$) was applied to the end mirror at 250Hz, and the corresponding displacement signals in the interferometer (δl) were measured as a function of static beam spot position on the mirror (d_{st}). The result is shown in Fig.1 with the theoretically predicted curve. Their agreement indicates that this simple model is sufficient to describe the response of the interferometer to changes in test mass orientation.

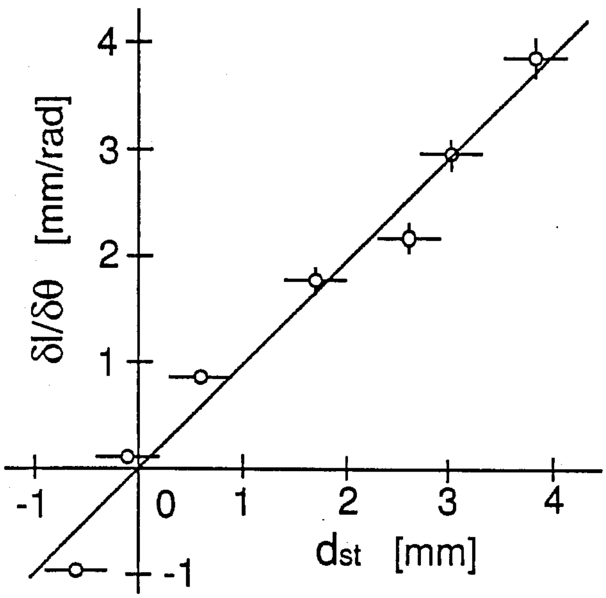

Fig. 1. Linear effect of angular jitter — displacement coupling ($\delta l/\delta\theta$) as a function of static beam spot position (d_{st}). The solid line is the theoretical curve ($\delta l/\delta\theta = d_{st}$).

3. PREDICTED NOISE DUE TO ORIENTATION JITTER

The displacement noise caused by the coil current noise was estimated for the current orientation control system by combining measurements of coil current noise under normal condition and the transfer function of current noise to angular motion. The prediction at a frequency of 100Hz is shown in Table 1 ("Current System").

To reduce this noise contribution, improved orientation feedback electronics have been designed and tested. The new system has a lower unity gain frequency (1–3Hz compared to 10Hz for the current system), much more electronic attenuation above 100Hz, and much quieter electronics as compared with the current system. A drastic reduction in the displacement noise ($10^3 - 10^5$) was attained ("New System" in Table 1).

Table 1. Predicted orientation noise for each mass at 100Hz. The static distance between the beam axis and the center mass is assumed to be 2mm, typical of the accuracy with which the cavities are aligned.

Test Mass	Displacement Noise $(m/\sqrt{Hz})$	
	Current System	New System
End Mass 1	2.2×10^{-14}	1.6×10^{-18}
End Mass 2	2.0×10^{-16}	7.0×10^{-19}
Vertex Mass 1	2.4×10^{-14}	1.7×10^{-19}
Vertex Mass 2	2.3×10^{-15}	1.9×10^{-19}

4. CONCLUSION

Measurements have shown that noise of the 40m prototype between 50 and 500Hz had been dominated by the orientation noise. A new system has been designed and tested, which will enable us to suppress noise from this source to $10^{-18} - 10^{-19} m/\sqrt{Hz}$ at 100Hz.

Noticing the fact that only the feedback electronics were optimized and other elements such as the laser performance, the magnet-coil system and the optical lever were not improved at all, we can expect with further improvements to satisfy the initial LIGO performance goal of $8\times10^{-20} m/\sqrt{Hz}$ displacement at 100Hz (strain sensitivity of 2×10^{-22}).

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References

1. M. E. Zucker, "The LIGO 40m Prototype Laser Interferometer Gravitational Wave Detector", In *Proceedings of the Sixth Marcel Grossmann Meeting on General Relativity, Kyoto, Japan*, (1991).

2. R. E. Vogt, "The U.S. LIGO Project", In *Proceedings of the Sixth Marcel Grossmann Meeting on General Relativity, Kyoto, Japan*, (1991).