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Magnet induced losses in LIGO large optics II: indium bonding

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1 ABSTRACT

The suspended test masses in LIGO I will be stabilized and oriented using small magnets attached to the test masses via small aluminum standoffs, despite the known increase in thermal noise caused by these magnets, because this thermal noise is known to be only a small contribution to the total noise in the interesting frequency bandwidth of 10-1000 Hz. However, the epoxy used to attach the magnets and standoffs to the test mass is far from ideal for use in LIGO I for other reasons: the strength of the bond is less than what would be desirable, and the epoxy outgasses in vacuum, contaminating the test mass surfaces and adversely affecting their optical qualities. Indium bonding is a promising alternative technique to epoxy bonding for the magnet/standoff attachments. The indium bond is strong, and indium has a very small outgassing rate in vacuum relative to epoxy. This report will provide evidence that the indium bond introduces thermal noise into the test mass comparable to that of the epoxy bond, and that therefore indium bonding is a suitable technique for LIGO I.

2 KEYWORDS

LIGO, magnets, mechanical loss, thermal noise, indium, standoffs

3 EXPERIMENTAL TECHNIQUE

The mechanical loss data for this experiment were collected by exciting the internal resonances of a test mass into steady-state oscillation using an electrostatic driver (ESD), and then disconnecting the driver from its power supply and monitoring the free decay of the test mass oscillation. The oscillation of the test mass was detected by monitoring the fringe pattern of a HeNe laser Michelson interferometer that was locked to the test mass at low frequency with a simple side-locking servo. The test mass used was number COC-A005, has dimensions 25 cm diameter and 10 cm thickness, and is coated for high reflectivity at 632 nm. This test mass is a Pathfinder LOS optic and is identical in dimensions to the optic used by John Carri in his earlier measurements of magnet losses[1] and by Seiji Kawamura in his measurements of standoff losses [2], with the possible exception of the wedge angle. Their test masses were not available for a direct comparison; however, the internal mode losses and frequencies for this mass are comparable to those they measured. The test mass used in this experiment was suspended by a single loop of steel wire with aluminum wire standoffs glued to the sides of the mirror 1 mm above the center of gravity using vacuum epoxy. The four magnet/standoff assemblies were indium bonded to the back face of the test mass 1/2” from the outer radius at the NE, NW, SW, and SE quadrants by Helena Armandula and Steve Bell. The standoffs used were the dumbbell type used by Kawamura and not the cylindrical type used by Carri.

These measurements were performed with the test mass in vacuum with pressures in the range of 1-40 μTorr, and tests with the lowest-loss modes showed no dependence of mode loss on pressure within this pressure range. Tests were also made to check whether the mode loss was affected by the termination of the electrostatic driver during ringdown; no difference was seen between terminating the ESD with 50Ω and leaving its terminals open.

The coupling of suspension wire losses to the internal mode resonances was a more delicate matter [3]. If the suspension wires had a violin mode resonance too close to the test mass internal mode resonance, then if the test mass was not precisely replaced into the suspension after magnet attachment, the degree of coupling to the violin modes would have varied, making interpretation of the loss as being caused by the magnets uncertain. To counteract this effect, the same wire was used for all measurements without removal and reconnection. In addition, the points where the wire left the test mass standoffs was marked with a small spot of White-Out before the test mass was removed for magnet attachment; these spots were then used to guide the reinsertion of the test mass. Finally, the test mass was rotated slightly in the suspension wire after the magnet measurements were made to look for wide variations in the losses of any mode. As a result of this last test, one mode initially thought to have very large loss (that at 22.49 kHz) was found to have only moderate loss. The modes at 9.31 kHz and 22.22 kHz, which had much larger losses than the other modes, were found to have large (factor of two) variations in loss upon rotation of the test mass, suggesting that their losses are primarily due to coupling with the wires. All other modes varied only 10% in their loss as a result of these tests.

Not all of the modes studied are axisymmetric, so not all of them will contribute thermal noise into the gravitational wave signal unless the laser spot is not centered on the mirror face, ignoring small asymmetries in the modes caused by the wedge angle and by the wire and magnet attachments.

Table 1: Measured Mechanical Losses

Mode Freq (kHz)	ϕ, without magnets ($x10^{-7}$)	ϕ, with magnets ($x10^{-7}$)
9.31	71.9	102
14.43	1.02	1.04
22.22	19.2	19.6
22.49	.775	1.31
26.11	2.86	3.45
27.28	3.65	5.92
30.07	.637	1.66
31.02	.565	1.33
31.99	1.20	2.46
35.41	.529	.78
40.76	.787	1.75
48.13	1.12	33

The data, which are listed in Table 1, show that for the modes with low losses in the absence of magnets ($\phi<5x10^{-7}$), the additional loss induced by the magnets is of the order 10^{-7}, the one exception being the mode at 48.13 kHz, which had a magnet-induced loss of over $30x10^{-7}$. The two modes with initially high losses (at 9.31 and 22.22 kHz), as mentioned before, showed a large amount of dependence for their losses on their position within the suspension, indicating large coupling between the internal resonances and the violin modes of the suspension wire. Therefore, the losses of these modes are probably not reliable indicators of excess loss due to magnets. Instead, they should be considered as upper bounds to any possible magnet loss for those modes.

4 COMPARISON WITH EARLIER RESULTS

A thorough analysis of this data would include a correction to the excess magnet loss for the motion of the test mass at the attachment point to demonstrate the f^4 power law dependence of magnet loss on frequency, due to the test mass internal resonances being below the mechanical resonance frequency of the magnet/standoff assembly. This analysis would be all the more interesting because Carri's analysis of his data confirming the power law dependence appears to be flawed; his tabulated data point at 22.4 kHz is misplotted by a factor of ten in his graph, making the fit of his data to the power law much less good. However, this requires knowledge of the oscillation amplitude of the test mass at the magnet attachment points for each test mass mode, and there seems to be no good way to unambiguously identify the modes studied here before installation of the LIGO optics.

The current data are plotted with the data of Carri and of Kawamura *et al.* in Figure 1. Except for the high loss at 48.13 kHz, the losses presented here are comparable to or slightly lower than the losses measured by Kawamura using the same dumbbell-shaped standoffs and epoxy bonding. Given that Kawamura used six attached magnets as opposed to our four (he had two additional magnets on the sides of the test mass), his data and those here show roughly comparable loss.

The conclusion of this experiment is that, if the losses in the gravitational-wave detection bandwidth are insignificant with epoxy bonds, then they are also insignificant with indium bonds, and therefore indium bonding is an acceptably lossless technique for attaching magnets to test masses in LIGO I.

5 LIST OF REFERENCES

1. “Magnet induced losses in LIGO large optics,” John Carri; LIGO-T960166-C.

2. “Dumbbell-like standoff for magnet/standoff assembly,” S. Kawamura, M. Fine, and Janeen Hazel, LIGO-T970096-00-D.

3. “An investigation of limitations to quality factor measurements of suspended masses due to resonances in the suspension wires,” J. E. Logan *et al.*, Phys. Lett. A 170 (5), 352 (Nov. 1992).

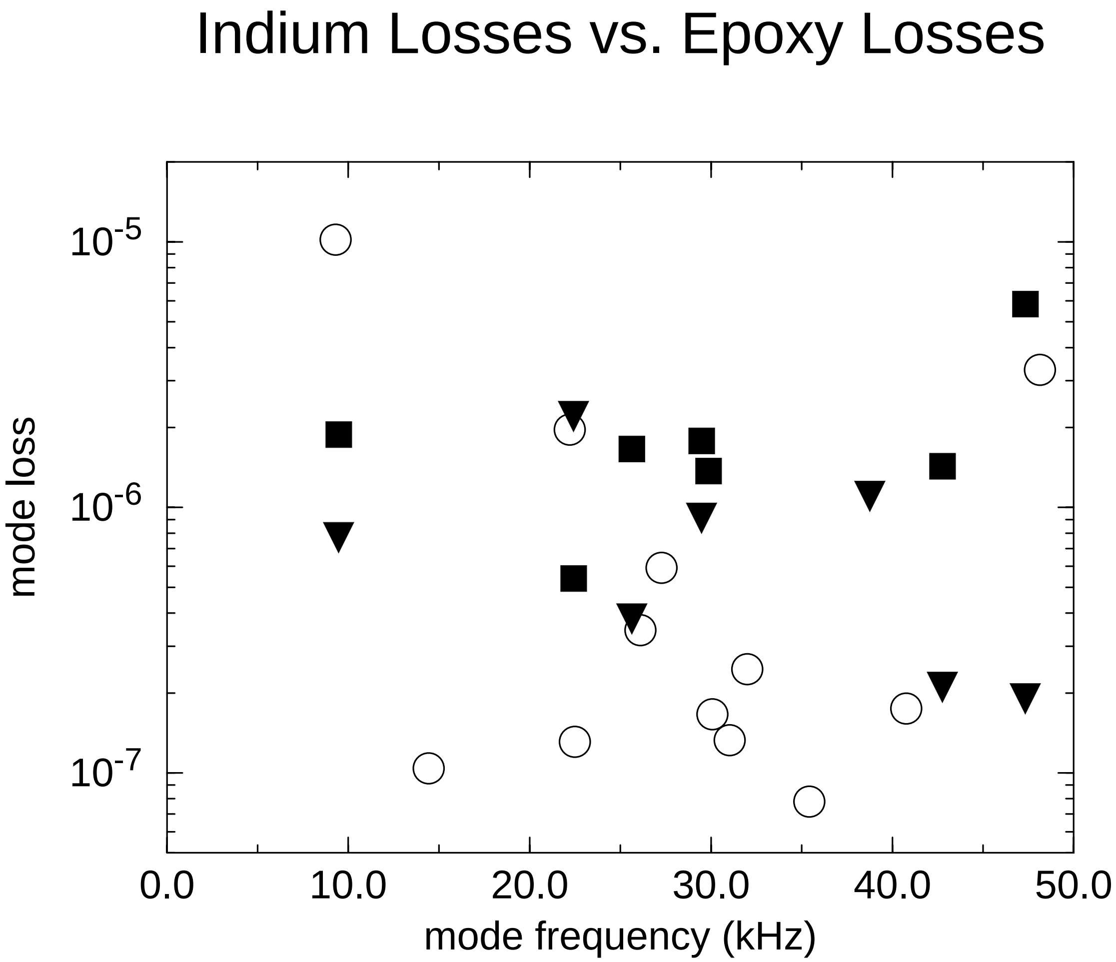

Figure 1: Mechanical losses vs. mode frequency. The closed squares are for epoxy bonds and cylindrical standoffs, the closed triangles are for epoxy bonds and dumbbell standoffs, and the closed circles are for indium bonds and dumbbell standoffs. The apparent high indium losses at 9.31 and 22.22 kHz are due to coupling of the test mass oscillation to the suspension wires and should only be taken as upper bounds to the magnet/indium loss.