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Magnet induced losses in LIGO large optics II: indium bonding

Phil Willems

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California Institute of Technology
LIGO Project - MS 51-33
Pasadena CA 91125
Phone (626) 395-2129
Fax (626) 304-9834
E-mail: info@ligo.caltech.edu

Massachusetts Institute of Technology
LIGO Project - MS 20B-145
Cambridge, MA 01239
Phone (617) 253-4824
Fax (617) 253-7014
E-mail: info@ligo.mit.edu

WWW: http://www.ligo.caltech.edu/

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, in addition, the indium bond introduces less thermal noise into the test mass than the epoxy bond, and that therefore indium bonding is a suitable technique for LIGO I.

2 KEYWORDS

LIGO, magnets, mechanical loss, thermal noise, indium

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]. Carri’s test mass was not available for a direct comparison; however, the internal mode losses and frequencies for this mass are comparable to those he 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.

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 [2]. 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.

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 dependence of magnet loss on frequency, due to the test mass internal resonances being below the mechanical resonance frequency of the magnet/standoff assembly. However, this behavior has been confirmed already by Carri for magnets attached using epoxy bonding [1], and so will not be repeated here.

The most interesting result of this experiment is the systematically lower losses induced by the magnets attached using indium bonding, compared to the losses achieved by Carri using epoxy bonding, as shown in Figure 1. For most of the modes studied, the losses with indium are one order of magnitude lower than with epoxy. The comparison of indium with epoxy is even more favorable when one considers that the indium tests were performed with four magnets attached to the test mass, while the epoxy tests were done with only three, one magnet having fallen off during test mass installation and pumpdown. This fact may provide a clue to the lower mechanical loss of the indium bond; the epoxy glue joints in Carri's experiment were fragile and perhaps imperfectly bonded to the mirror surface, so that relative motion between the fused silica and the epoxy may have been responsible for the losses he saw.

This interpretation would seem to be in contradiction to the earlier results obtained by Gillespie and Raab [3], who found that the mechanical losses of magnet attachments were the same whether the glue used for the magnet attachments was a cyano-acrylate adhesive or a vacuum epoxy. They concluded that since the loss was independent of the type of glue used, the losses were not due to the glue at all, but rather due to the magnets. The results reported here indicate that the glue joint was the limiting loss factor in Carri's measurements.

The answer to this discrepancy is that Gillespie and Raab performed their measurement with the magnets glued directly to the test mass without a standoff, so that the losses were in fact dominated by the magnets to values typically 10-1000 times worse than those reported here. Losses due to the glue joints at the levels reported here in comparison to Carri's work would not have been observable in Gillespie and Raab's experiment, and are measurable only because the standoffs reduce the magnet losses to much lower levels.

The hypothesis that the epoxy joints dominate the losses measured by Carri would be consistent with his observed f^4 dependence of the loss on mode frequency. This frequency dependence is based on a model of structural damping in the magnet/standoff assembly, which has its resonant mechanical frequency well above the test mass mode frequencies studied. While the losses are generally assumed to be in the magnet, they could just as well be in the standoff or the bonds.

This measurement does not exclude the possibility that the magnets used themselves had lower loss than the magnets used by Carri, although they were of the same type, because the magnets used by Carri were not available for this experiment. This could be checked by reattaching the magnets used in this experiment with epoxy and repeating the ringdown measurements. Since for either bonding technique the losses in the 10-1000 Hz range are inconsequential, this test was not performed.

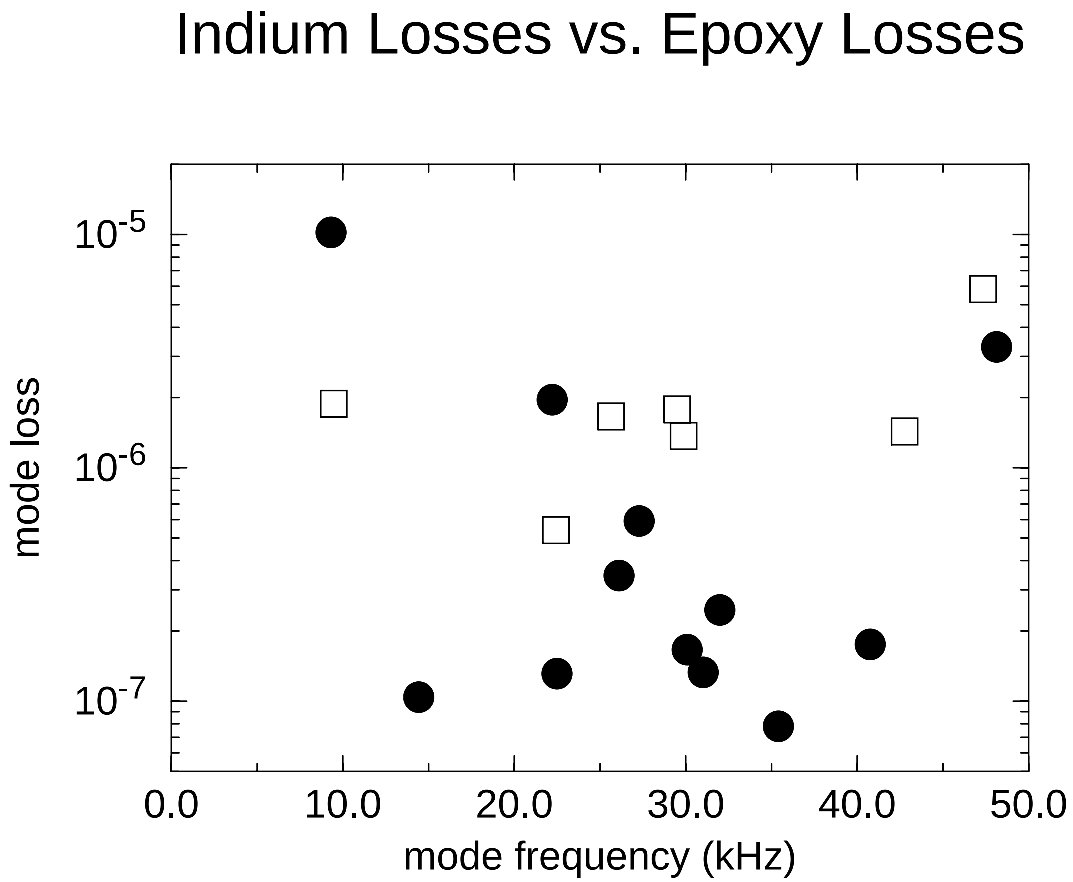

Figure 1: Mechanical losses vs. mode frequency. The open squares are for epoxy bonds, while the closed circles are for indium bonds. The apparent high indium losses at 9.31 and 22.22 kHz are due to coupling of the test mass oscillation to the suspension wires.

For the purposes of LIGO I, however, these discussions are perhaps incidental to the primary result, which is that, if the losses in the gravitational-wave detection bandwidth were insignificant with epoxy bonds, they are even less significant with indium bonds, and that therefore indium bonding is an acceptably lossless technique for attaching magnets to test masses in LIGO I.

5 LIST OF REFERENCES

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