LASER INTERFEROMETER GRAVITATIONAL WAVE OBSERVATORY

LIGO Laboratory / LIGO Scientific Collaboration

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LMA coating effect on HOM in aLIGO arm

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1 Introduction

Effects of the LMA coating on the higher order mode resonances in the aLIGO arm is studied, together with the effects by the clipping due to the finite aperture size. The resonance frequency, mode shape and loss etc are studied.

2 Setup and definitions

A FP cavity with aLIGO arm parameters are used with and without actual surface phasemaps. The coated aperture is 32.6cm, and a larger aperture of 60cm is also used to study the clipping effect.

A pure LG(p,0) mode is injected to a FP cavity, p = 0~5, and the resonant cavity length is found with which that the round trip phase of the stationary field (includes the injected source) is 0 in modulo 2π. The power in the arm was scanned as a function of the cavity length (dl) or frequency (df(Hz) = -70.6Hz x dl(nm)) and the resonant point found by using the round trip phase matches with the length at which the cavity power becomes maximal (see below for the precise meaning of maximal).

The loss of the mode is defined in the following way. First, find the resonant cavity as is explained above. Then, a field on the ITM HR surface, with the amplitude of the resonating state on ITM, (E1), is propagated to ETM , reflected by ETM, propagated from ETM to ITM, and reflected by ITM (E2) (no injected source included). The round trip loss is defined as

$$loss = 1 - \frac{power(E2)}{R_{ITM} R_{ETM}} / power(E1) \tag{1}$$

This is essentially identical to the sum of clipping losses on reflections at ITM and at ETM when the resonating field is used for the clipping loss calculation.

3 LG40 case

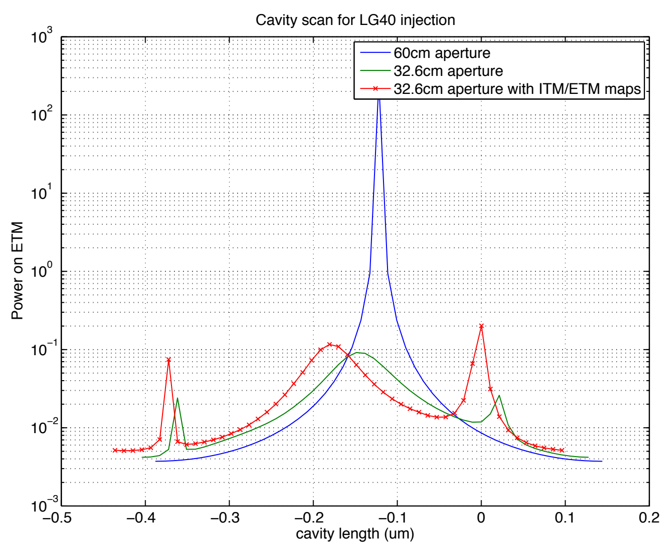

Figure 1 Power as a function of the cavity length

Fig.1 shows the power in a cavity with LG40 injected as the source. The blue line is a case with large aperture (60cm), while the green and red are the cases with real aLIGO test mass aperture of 32.6cm. The green line is a result with perfectly smooth mirror surface (or no phase maps), and the red is a result with ITM and ETM mirror phase maps are used.

For the large aperture case (blue), there is one resonance at the length corresponding to 9 x η_{00}. In a cavity with smaller aperture size (green), the peak position shifts by 1.15kHz. Also found are two peaks on two sides. These are excitations of LG20 (left one) and LG30 (right peak) modes due to the clipping by the finite aperture. When the surface maps are included in the calculation (red), the peak position moves further more (3.39kHz) and the peaks for LG20 and LG30 got more enhanced. The resonance found by the round trip phase corresponds to the peak of the broad resonance of LG40, not the peaks on two sides.

The plateau structure of ITM and ETM are known to generate LG20 and LG30 modes. (Fig.2)

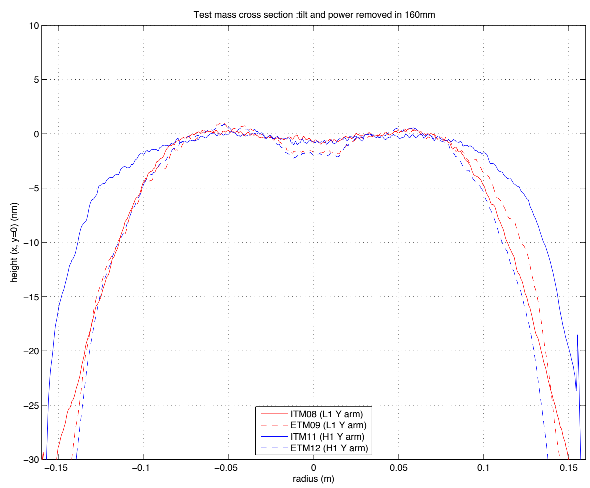

Figure 2 ITM and ETM phasemap

Fig.1 indicates that the clipping by the finite aperture and the LMA coating induce mixing of LG40 and LG20, LG30 modes. If they simply excite other modes, the two peaks can be simply treated studied separately. But the strong mixing of modes can distort the resonating mode.

Fig.3 shows the power distribution on ITMs and ETM, together with the idealistic LG40 power distribution (dashed line). The beam sizes are different on ITM and ETM, and the axis is scaled so that the beam size on ITM becomes that on ETM to make the comparison easy.

In a cavity with 60cm aperture, the power distributions at the resonance are identical to the idealistic LG40 power distribution, both on ITM and ETM. When the actual aperture is used, the power distribution on ITM (red) shows a dip at the center, in addition to the overall shape change. The power distribution on ETM does not show this kind of dip. When the LMA coating is added to the calculation (green), the dip is further enhanced.

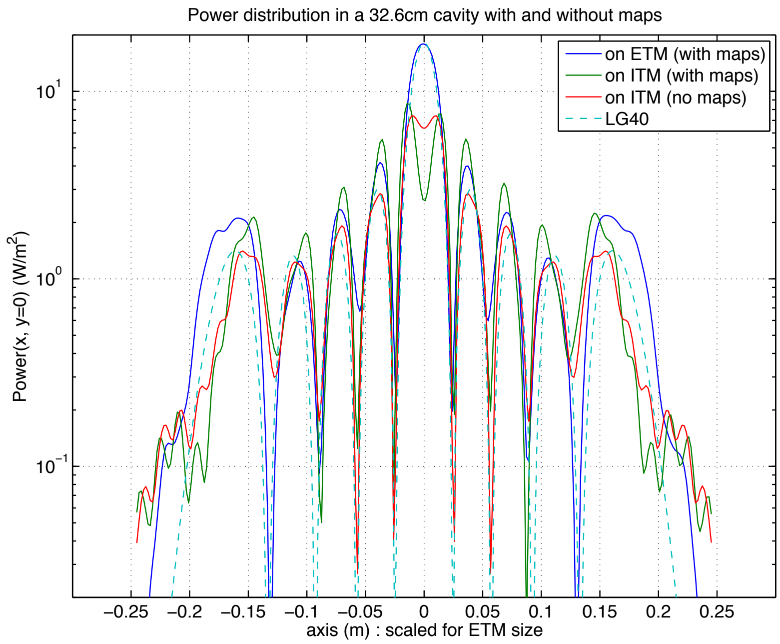

Figure 3 Power distribution vs LG40 mode

4 Mode dependence

In this section, dependence on the LG mode is summarized.

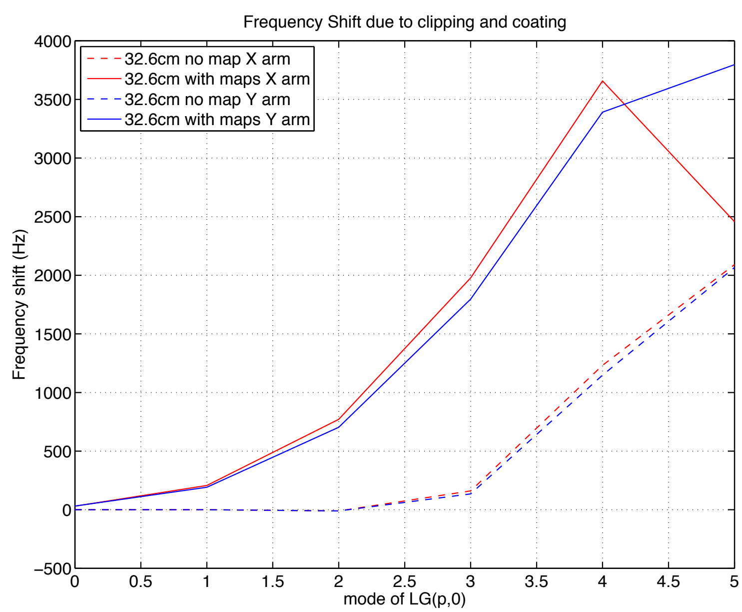

Figure 4 Mode vs resonance shift

Fig.4 shows the change of the resonance frequency found using the round trip phase explained in Sec.2. The horizontal axis of the LG(p,0) mode injected and dominant in the cavity. Vertical axis the frequency of the resonance in finite aperture cavities subtracted by the resonance frequency with 60cm aperture, i.e., undistorted LG mode frequency, $(2p + 1) * \eta_{00}$. The frequency shift due to the finite aperture (dashed lines) becomes important after LG40 mode and higher, while the coating structure (solid lines) affects even for lower order modes.

In the same figure, the frequency shifts in two arms are compared. The difference of the LMA coating makes the frequency shift different between two arms. The last point of the solid red line will be due to the failure of the resonance fining.

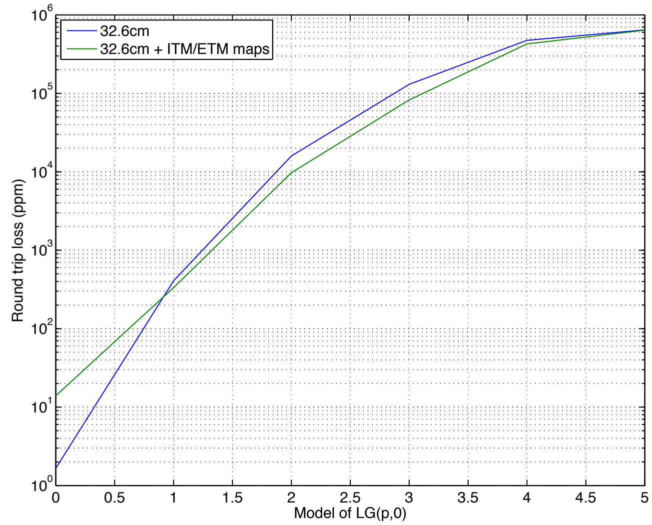

Figure 5 Mode vs loss

Fig.5 shows the round trip loss for each mode. This is essentially 0 for the 60cm cavity. The blue line is the case without phasemaps and the green line is a result with both ITM and ETM maps included.

The loss in a cavity with phase maps (green) tend to be less than the loss in a cavity without maps (blue). I cannot find easy explanation for this complex system.