Modelling mirror surface distortion effects in low-loss, near-unstable Fabry-Perot cavities

D. Brown, C. Bond, M. Wang, L. Carbonie and A. Freise
School of Physics and Astronomy - University of Birmingham, UK
db@unb.ac.uk, KMCC@unb.ac.uk, JHDO@unb.ac.uk
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This poster shows the result of a preliminary numerical investigation for an optical experiment being conducted at the University of Birmingham. We show how the simulation tool FINESSE v1.0 [1] has been used to model the effects mirror surface distortions will have on our experiment studying near-instable cavities and surface losses. The stability of an optical cavity is quantified by its g-factor, determined by the cavity geometry: L the length of the cavity, R_m the input mirror curvature and R_m the end mirror curvature.

The experimental setup
An experiment has been set up at Birmingham to create a cavity to better understand the behaviour of cavities near to instability and the losses present. A linear cavity is used with the option for a 1m hemi-spherical cavity and a 2m concentric cavity to explore different regimes of cavity stability.

Investigations have been taken to use within FINESSE the simulation tool.

The final aim is to characterise optical losses in variable length Fabry Perot cavity and test near-instable cavity control.

The modal model
For high-precision experiments modelling the effect imperfect optics and other physical distortions have on the beam is required. These distortions however are usually very small due to the high quality optical components. Thus, the modal model is a suitable perturbative expansion of the beam’s shape due to the distortion into higher order modes (HOM). The orthogonal function basis chosen for FINESSE are the Hermite-Gaussian modes.

\[ R(x, y) = \sum_{m,n} a_{mn} H_m(x) H_n(y) \]

As q,q tends to instability i.e. 1 or 0, the HOMs bunch together as the separation frequency is on the order of the Free Spectral Range (FSR). This mode bunching ruins error signals as seen on th left and can make the cavity inoperable even before it has reached instability.

Conclusion and what next...
If the surface profile of an optic can be measured to a significant accuracy it can be used with FINESSE to model its expected behaviour, such as error signals. Using such a method we can determine whether a mirrors surface distortions will limit the reachable stability levels due to the HOMs generated in the cavity.

- Finish collection of experimental setup
- Experimentally measure maximum achievable finesse and instability for different mirror configurations
- Compare results for validation of map measurement and computation in FINESSE

References

Gravitational wave detectors utilise optical cavities in several ways. When squeezed light is injected to reduce the quantum noise, optical losses can significantly degrade its effect, in particular losses in the filter cavities such as from surface defects. At the same time, thermal noise can be reduced by increasing the spot size on the mirrors leading to near-instable cavity geometries. We use numerical models to investigate such low-loss, near-instable cavities with nanoscale defects present on the mirror surfaces and the effect they have on the cavity performance along with the possible effects measurable via an optical experiment.