LASER INTERFEROMETER GRAVITATIONAL WAVE OBSERVATORY

LIGO Laboratory / LIGO Scientific Collaboration

LIGO- T080266-05 *ADVANCED LIGO* Nov 24th, 2008

Suspending optics on steel wire loops

Calum I. Torrie, Norna A Robertson

Distribution of this document:
LIGO Science Collaboration

This is an internal working note
of the LIGO Project.

California Institute of Technology
LIGO Project – MS 18-34
1200 E. California Blvd.
Pasadena, CA 91125
Phone (626) 395-2129
Fax (626) 304-9834
E-mail: info@ligo.caltech.edu

Massachusetts Institute of Technology
LIGO Project – NW17-161
175 Albany St
Cambridge, MA 02139
Phone (617) 253-4824
Fax (617) 253-7014
E-mail: info@ligo.mit.edu

LIGO Hanford Observatory
P.O. Box 1970
Mail Stop S9-02
Richland WA 99352
Phone 509-372-8106
Fax 509-372-8137

LIGO Livingston Observatory
P.O. Box 940
Livingston, LA 70754
Phone 225-686-3100
Fax 225-686-7189

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

Rev 00: Initial Draft

Rev 01: Includes initial comments from NAR. Sent to NAR for additional comments.

Rev 02: Updated on Oct 14th 2008

Rev 03: Released to DC and KAS for comment / review

Rev 04: edited after comments from DC

Rev 05: further mods following discussion with PF

1.1 Abstract

This document summarises the proposed designs for the interface between the wires and the optic for all optics on wire loop suspensions in Advanced LIGO.

1.2 Introduction

In Advanced LIGO all optics, used in optical cavities, except the test masses (ETM and ITM) will be suspended on two steel wire loops. This includes the beamsplitter and folding mirrors, the recycling cavity optics and the input modecleaner optics, all of which are suspended as the final mass in a triple pendulum suspension. In addition the final masses in the quadruple pendulum reaction chains for the ETM and the ITM (i.e. the end reaction mass, ERM, and the compensator plate, CP, respectively) are also suspended by two steel wire loops. In this document we discuss how we propose to suspend the optics within these loops, considering in particular the design of the break-offs attached to the optics. The driving concern for those optics which have low noise requirements is to minimise suspension thermal noise. We build on the work carried out by Rai Weiss, Steve Penn and colleagues who have investigated the design of the suspensions of the Initial LIGO optics. In addition our Glasgow colleagues have investigated material type and method of producing grooves in break-offs which can withstand the forces involved in suspending the heavy masses in the quadruple pendulums.

1.3 Background

The triple pendulum designs for Advanced LIGO are based on the GEO triple pendulum design, with wires instead of silica fibres in the final stage. We can use steel wire since these optics have a more relaxed noise requirement than the test masses. However we cannot afford to introduce excess suspension thermal noise due to poorly designed break-offs. The design involves four wires (or two loops) at the final stage, unlike the one loop design of the Initial LIGO suspensions, to allow us to orient and damp the optics from the top mass in the chain. For accurate positioning of the two loops we investigated using grooves around the metal masses in the modecleaner controls prototypes which we built to test the overall design aspects of the suspensions.

1.4 Brief

The original brief for the work discussed in this document was to investigate the design aspects of the grooves which we were proposing to use on the barrel of the silica optics, as was done for the metal prototype. However after initial research was carried out, the brief was extended to consider the whole approach for low noise suspensions using steel wire loops, including whether grooves were in fact necessary or desirable.

The majority of the following proposal is based on work done by Rai Weiss et al.[1,2]. Their research was dedicated to understanding the losses in the violin modes of the steel wires of the Initial LIGO test mass suspensions.

1.5 Concept for suspensions with low noise requirement

A double prism approach, where the prisms are glued to the barrel of the optic, is in general proposed for suspensions with a low noise requirement. This is discussed further in the sections below. It should be noted that tooling to correctly position the prisms for gluing and to aid with positioning the wire around the barrel will be required.

1.5.1 Groove in the Barrel

Grooves were introduced to the metal masses during the controls prototype phases of several suspensions for Advanced LIGO. They were added to aid with alignment. It is believed that their inclusion in the glass optics (suspended by 2 wire loops) is neutral from a thermal noise point of view, difficult from a manufacturing and reproducibility point of view, and would require consideration from a strength point of view. In a single prism approach they are useful from an alignment point of view. Based on all of these considerations we propose that we do not include grooves in the barrel of any optics (final stage of suspension). Grooves are still under consideration for the penultimate mass in the ITM/ETM quad suspensions. It should be noted that both Initial LIGO and GEO did not use grooves in the barrel of the optic for optics suspended on wires.

1.5.2 Double Prism Proposal

The idea, as shown is figure (1), is that after the wire leaves the barrel of the optic it will pass over a small steel prism and then break off from a sapphire prism – the so-called double prism approach. Weiss et al demonstrated that the presence of the second prism constrains the slope of the wire below the first prism and thus limits motion of the wire from being transmitted to a lossy and ill-defined boundary on the barrel of the test mass.

It should be noted that the inclusion of the metal prism changes the slope of the wire and therefore designers should consider if this affects the length of associated wire jigs. The type of adhesive for attaching the sets of prisms to the optics is TBD. Options include (listed in rough order of preference from a vacuum compatibility standpoint): -

1. Ceramabond #835M (white ceramic)
2. Dupont PI-2525 Polyimide (replacement for Cycom 3001 polyimide); may require use of adhesion promoter such as Dupont VM-652. Requires a 200C cure. Although Cycom 3001 was qualified for the LIGO UHV, Dupont PI-2525 has not yet gone through qualification.
3. Tra-bond 2101 (replacement for VacSeal)
4. Norland #88 UV-cured epoxy (glass only)
5. Tra-bond #2254 (tan/brown)
6. Tra-bond #2151 (blue)
7. Tra-duct #2902 (silver)

Not all of the above adhesives may be applicable for this application. However since the load is compressive we do not need much strength from the bond; We basically just need to reduce the potential for noise due to slippage at the contact interface and to hold the prism into position to maintain wire position/alignment. Rai W et al used VacSeal epoxy in their tests. A thin layer (approximately 1/4 mm) with beads at the corners (1/2 to 1mm diameter) was used.

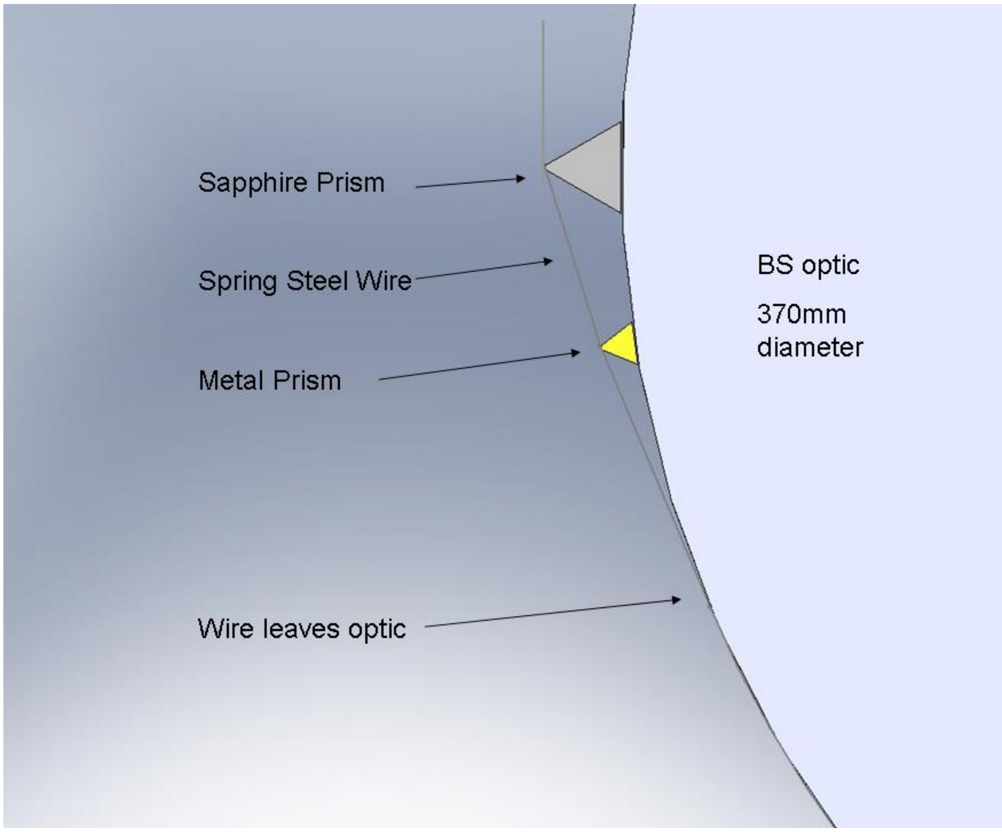

Figure (1): - Draft image of one side of the beamsplitter optic showing both metal(stainless steel) and sapphire prism, for more detail of sapphire prism see figure (2). The path of the wire is also shown. The approximate dimensions of the prisms are as follows. A) Sapphire prism: triangle side 14 mm, base (not shown) 14 mm) B) Metal prism triangle side = 6. 5mm, base (not shown) = 14 mm

1.5.3 Sapphire Prism + Groove

Based on the work done by Weiss et al, sapphire prisms with a smoothed groove are the preferred option for low noise performance. From work done in both the US and the UK it is recommended that laser ablation is used to produce these grooves. This leads to a reproducible design [3, 4,5].

Weiss et al found that fused silica standoffs could not withstand the normal force of the wire (of an initial LIGO suspension) without crumbling. This causes fused silica dust to form between the wire and standoff which is lossy and causes hysteresis and up-conversion in the wire motion on the standoff. They also found that in the case of the sapphire, when it breaks, it cleaves in larger pieces which are not likely to get wedged between the wire and the prism edge.

1.5.4 Sapphire Prism

The following design concepts for both the manufacture and assembly of the sapphire prism are also reported here. Figure (2) shows how the modified sapphire prism is glued to a cylindrical optic producing a 2 point contact

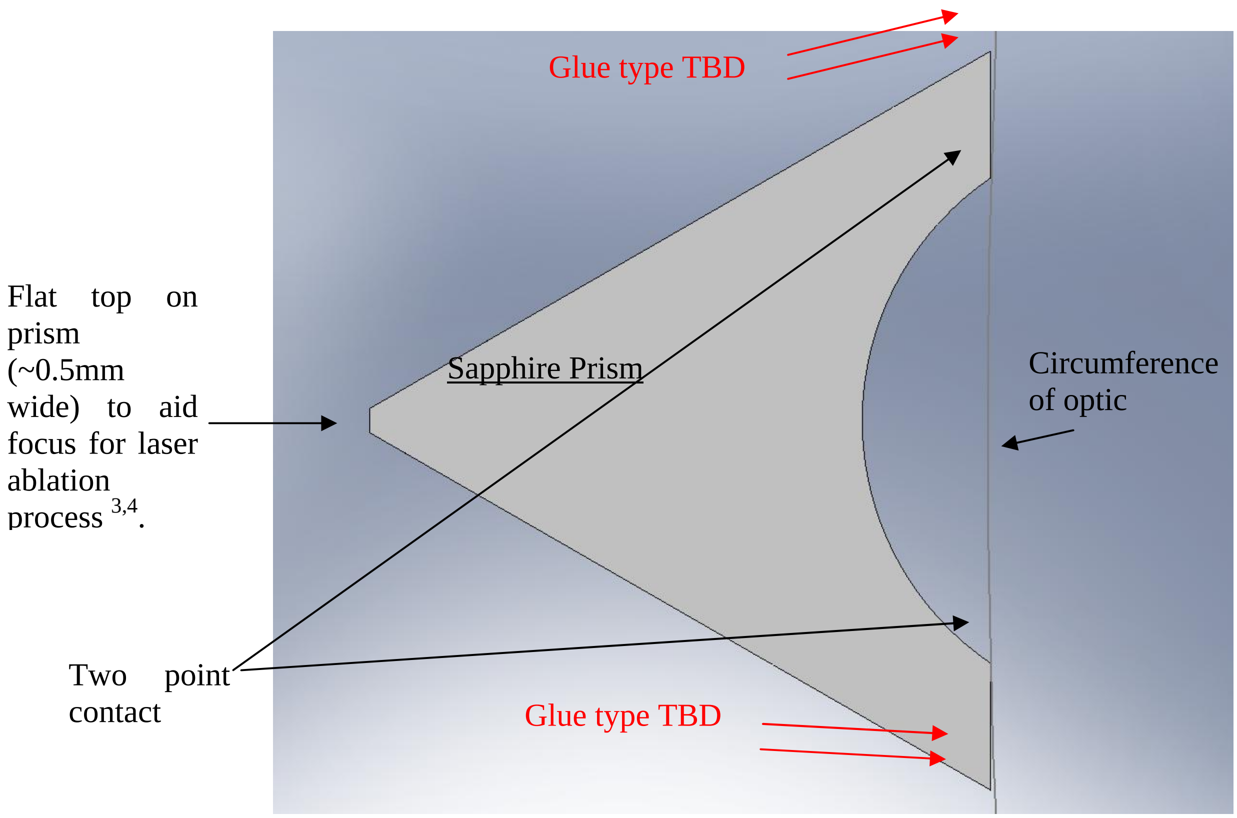

Figure (2): - Close up of a concept showing modified sapphire prism and the detail of the interface between it and the cylindrical optic (optic is represented by a gray line). Sapphire prism: triangle side = 14. 5mm, base (not shown) = 14 mm.

Further discussions on this topic have raised the question of whether such line contacts could damage the optic. A couple of alternative ideas are being considered.

i) Curve the entire inside surface of the prism to fit against the side of the optic.

ii) Use a silica interface piece which is curved on one side to match the optic and flat on the other to mach to a flat bottomed sapphire prism. Such curved silica pieces may be available "off-the-shelf.

For the penultimate mass in the quad, which has flat sides, a flat prism could be used.

In figure 3 we show a detail of the proposed groove in the sapphire prism with the position of the wire indicated in green [1,3,4]. The groove shape should scale with the wire dimension. The shape shown differs slightly from the simple isosceles triangle proposed by Weiss et al, to reflect the fact that using laser ablation produces a large radius in the base of groove. The contact position between the wire and the groove edges is similar to that used by Weiss et al.

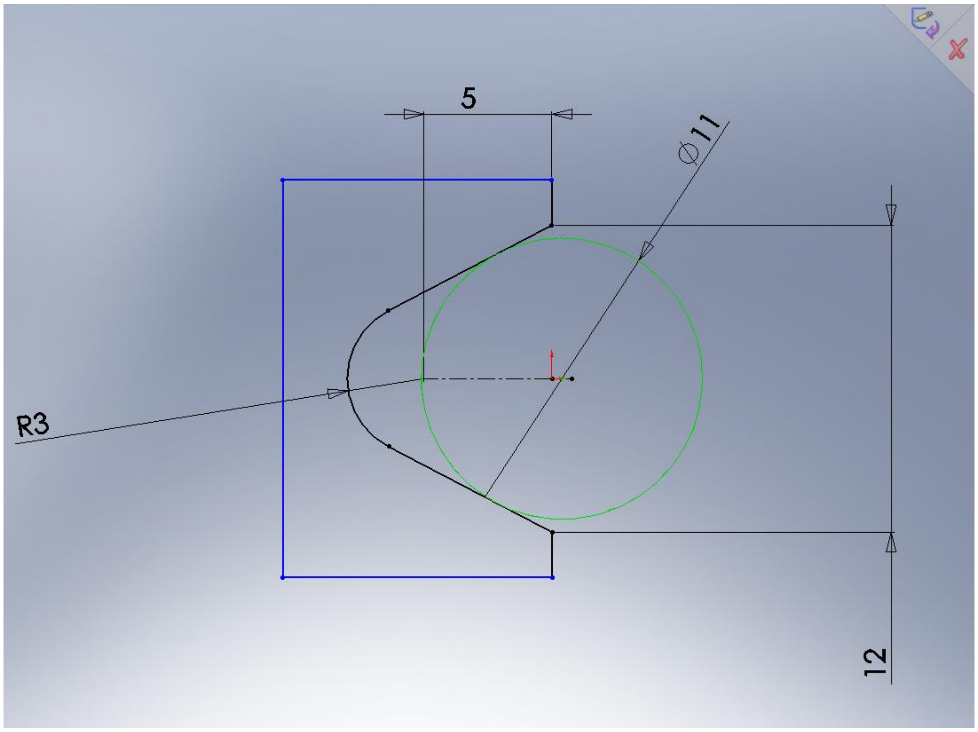

Figure (3): - An example of the proposed relative magnitude of the groove in the sapphire prism with the position of the wire indicated in green. (The groove shape should scale with the wire dimension.)

1.6 Concept for suspensions without low noise requirement

A single set of steel prisms glued to the optic barrel shaped as in figure 2 is proposed for suspensions without a low noise requirement.

1.6.1 Stainless Steel Prism

A preliminary drawing of a CP prism, which would also serve for the ERM, can be found at D070033. (in PDMWorks vault).

1.7 Summary

In table 1 we summarise all the cavity optics which are suspended on wire loops. In general we propose the double prism approach for optics with a low noise requirement. The one exception to this is the penultimate mass in the ETM and ITM suspensions where we propose that only the first sapphire prism is included. In those suspensions the available space for positioning a second set of prisms is limited due to the presence of the silicate-bonded ears to which the top of the silica fibres suspending the test mass are welded. For that suspension, thermal noise at the penultimate mass is isolated by the final stage. Hence even if the single stage prism suspension is noisier than the double prism, the transmitted noise falls off rapidly with frequency.

Optics	**Double Prism Set Sapphire plus steel (Low Noise)**	**Single Prism Set Sapphire (Low Noise)**	**Single Prism Set Steel**
Beamsplitter & Folding Mirror	Yes		
Input Modecleaner Optics (HAM small triple)	Yes		
Recycling Cavity Optics (HAM small and large triples)	Yes		
Penultimate Mass in ETM and ITM suspensions		Yes	
ETM reaction mass (ERM)			Yes
ITM reactions mass (CP)			Yes

Table (1): - List of optics on steel wire loops and proposed approach for suspending

1.8 Further work

We propose to do further prototyping in the USA of sapphire prisms with laser-ablted groovs suitable for use with the HAM small and larger tripel sus0pensions. This work will include consideration of the detailed shape of the interface between the prism and the optic with regard to the optimum gap for bonding.

1.9 References

1) "Summary of Research Results on the Initial LIGO Suspensions" R.Weiss June 23, 2008 LIGO-T080270.
2) Thesis written by L. Merrill, LIGO-P080083.

3) Private communication with Ken Strain
4) Drawings from Russell Jones LIGO-D060099, LIGO-D070033, LIGO-D080479 saved in PDMWorks.
5) Production of grooves in Noise Prototype break off prisms, L Cunningham et al, T080042-01-K