LASER INTERFEROMETER GRAVITATIONAL WAVE OBSERVATORY

SPECIFICATION

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Drawing No Rev. Group

Sheet 1 of 6

ADVANCED LIGO SAFETY STOP DESIGN REQUIREMENTS

AUTHOR:	CHECKED:	DATE	APPROVALS DCN NO.	REV	DATE
J. Romie/M. Barton		**11-05-04**			

Scope

This document details the features and requirements for the earthquake and safety stops for Advanced LIGO suspensions.

Applicable Documents

INITIAL LIGO STOP DESIGNS

D960499 LOS Chamfer Stop
D970311 Safety Stop, Conductive
D970312 Safety Stop, Conductive, Small
D970313 Safety Stop, Conductive, Long
D970562 Beamsplitter Chamfer Stop
D970563 Beamsplitter Safety Stop
D990690 LOS Safety Stop
D990691 LOS3 Chamfer Stop
D010213 40m TM Short Stop
D010214 40m TM Long Stop
D020527 40m TM Stop

ADVANCED LIGO ASSEMBLIES

D020700 Mode Cleaner Overall Assembly
D040400 ETM Suspension Assembly

Function: Initial LIGO Stops

The earthquake and safety stops, called stops for brevity, serve three functions, in order:

1) The stops are used to **facilitate suspending and balancing** of a mass or optic. For example, Teflon-capped screws are positioned under the LOS optic prior to suspending to support the optic. The wire is strung around the optic and then the stops are slowly moved out from under the optic, so that the optic hangs by the wire. The Teflon caps rotate with little friction on the optic. Prior to final alignment in-situ, these caps are removed and replaced with vacuum compatible Viton tips. The stops are used during the balancing process to protect the optic from swinging too much.
2) The stops are used to **clamp** the optic(s) in place prior to transport. This type of stop must secure the optic, in its balanced position within the structure, to facilitate safe transport, either

by cart or by crane. It must secure the optic throughout the structure positioning operations in the vacuum chamber.

3) After the suspension has been moved into position on the optical table, the stops then perform a new function. They are used to **protect** the mass or optic, and the objects around it, in the event of an earthquake or other sudden movement. Generally, the stops are placed within 0.5 to 1mm of the optic.

Function: Advanced LIGO Stops

The functions listed above need to be addressed by some component or assembly for Advanced LIGO suspensions. Currently, the suspending/balancing and the clamping are taken care of with the Catcher Assembly Rig. Mass is removed from the Catcher Assembly Rig after suspension assembly, to leave the Containment Truss. This truss must include the final stop configuration(s) that will protect the mass/optic after the suspension has been mounted onto the optical table, the optic has had its final alignment and the chamber door has been closed. A traditional screw stop may be considered, as it has the advantage of adjustability. However, other approaches are encouraged and may have more advantages.

The ratio of the stop mass to the optic mass is much larger for Advanced LIGO than for Initial LIGO. Therefore, problems in Initial LIGO with respect to the stops may not be so for Advanced LIGO, and vice versa.

Requirements

1) The stops must have sufficient mechanical compliance to keep impact stresses minimal on the mass or optic. ____________________________________

2) The stops must have low runout error so that the contact point does not wander with axial adjustment. We require that the axial variation due to the runout be less than 1/10 of the intended gap or ______________________________. This may be too small given a ¼-20 screw but possible for future designs

3) The stops must have contact geometry that is axisymmetric with respect to the axial adjustment axis.

4) The stops must have very smooth, fine axial position adjustment. Adjustment resolution should be less than or equal to 1/10 of the gap between the end of the stop and the optic. This may be too small too….

5a) The stops must have sufficient conductivity of _______________ to bleed off electrostatic charge, but be resistive enough not to cause eddy current damping.

OR

5b) The stops must have a contacting tip that is the same material as the optic such that electrostatic charge will not be transferred. The tip must be backed by vacuum compatible compliant material so that damage to the optic is minimal. See technical discussion below.

6) The stops must be designed to allow for installation of baffles, targets and other components that are positioned near or on the suspension structure.

7) The stops must be designed to damp the optic in 10 bounces or less, to the point where the stops are no longer contacting the optic. D. Coyne to rewrite

8) The stops must be designed to set a gap between the tip of the stop and the optic reliably, accurately and repeatably. An optical lever, a theodolote or the sensor/actuator readouts may be used to determine the make/break contact event.

9) The stops shall have a non-rotating tip or shall have a maximum coefficient of friction between the stop tip and the optic of 1.

Physical Configuration

The optic or mass must have enough stops to control the movement of the optic/mass in the event of an earthquake and along with expected mass motion. Therefore, the number of stops may and most likely will vary from suspension to suspension and from mass to mass. If there is consideration of a stop on the faces of the optic, optical aperture requirements must be addressed.

Material

All materials and processes used to fabricate the stops must comply with LIGO Vacuum Compatible Materials List, LIGO-E960050. If the stop is removed prior to installation in the vacuum chamber, other materials may be considered, as long as they do not contaminate the optic or other suspension components. Questions about materials should be addressed to the LIGO Vacuum Standards Board.

Background

The PNI suspension at MIT utilized ¼-20 screws with counter bores in the tips for stops. Into the counter bore, a compression spring was pressed. This type of stop is still used on the small optic suspensions (SOS.) It is not used extensively as the spring can cause more bouncing of the optic in the even of a sudden movement rather than damping of the movement.

A number of stop designs have been prototyped. Teflon screws were tried but the material is so soft that it is not appropriate for screw material because, when paired with metal internal threads, it peels away easily (creating “spaghetti”.) In close proximity to fused silica optical material, problems with electrostatic charging becomes worse.

Carbon-doped Teflon stop screws were prototyped. The conductive material removed the electrostatic problem but the screws themselves created particulate matter when screwed into metal threads.

Viton corks were fabricated and pushed into counter bores in metal screws. These corks are used on the LIGO1 LOSs. However, it is difficult to line up the centerline of the cork with the centerline of the screw. This problem may make the positioning of the cork 0.5mm away from the optic’s chamfer difficult for an unseasoned installer. Also, there is quite a bit of friction between the optic and the Viton, so it requires finesse for suspending and balancing operations.

Rectangles made from Viton cable clamp liners are press fit into counter bores in screws. This stop design is used on the SOSs. Again, the centerline of the rectangle is often misaligned from the screw centerline, making positioning difficult. Again, the friction factor makes an alternate for suspending and balancing attractive.

Technical

Conductivity

One limit on the conductivity of the stops is set by eddy current damping between the stops and the magnets on the optics. A discussion of the theory of eddy current damping with application to the suspensions can be found in LIGO-T000119-0, "Use of magnets in the suspension design". There, the following limits on the net force-per-velocity parameter b for the suspensions are derived:

b_{Max,LOS} = $3.6\text{x}10^{-6}$ N/(m/s)

b_{Max,SOS} = $3.1\text{x}10^{-6}$ N/(m/s)

The above limits should be trivial to achieve provided that a few basic facts about eddy current damping are kept in mind. The basic scaling factors are: linear in conductivity, quadratic in magnet strength, linear in the perimeter of the typical loop, linear in the cross-section over which there can be loops and inverse sixth power in the distance from the magnet. Geometrically the force is maximised when the tangent to the loop, the magnetic field and the relative velocity are mutually perpendicular. To give a wildly pessimistic scenario for reference, the above damping would be created by one 1/8" diameter aluminum screw along the axis of an optic magnet with a distance of approximately 5 mm from the center of the magnet to the end of the screw. However using stainless steel instead of aluminum would give a factor of 30 improvements, and every factor of 2 in separation would give a factor of 64.

Other limits on the conductivity derive from the need to reduce electrostatic forces between the optic and the stops, but the limits will depend on the strategy employed. Some general observations:

To have electrostatic force requires charge on both the optic and on the stop. Depending on the scenario, the charge can be either permanent static charge, or induced charge that has been pulled into the area by charges on the other side.

Charge separation will tend to occur by mechanical contact between objects of dissimilar materials (especially glass and Viton) contacting over large areas. Unless some of the resulting charge dissipates, this will cause a strong attractive force between the two objects.

The resistivity of clean fused silica is so high that charge that accumulates on the optic will probably remain there indefinitely. Therefore it's important to minimize the amount that does so. The fate of charge on the stop side is more controllable.

To the extent that charge separation occurs between the optic and the stop, it will generally be better for the stop to be conducting and grounded, so that most of the charge on the stop side drains away (leaving only a small residual component maintained by induction). Since the capacitance of the tip is only a few picofarads, the resistance of the stop could be as much as a giga-ohm and still dissipate charge in an acceptable time. Any metal part will meet this with orders of magnitude to spare.

However if the charge separation is within the tip of the stop (e.g. and i.e., because some sandwich contruction with a glass tip and a Viton elastic element has been used), then it is probably better for the shaft of the stop to be insulating (or contain an insulating section as near as practical to the tip). This is because if the positive and negative components of the charge remain close together they will have almost cancelling effects at the optic.

Quantitative Limits on Motion

Limits on motion are required to protect the magnets in the event of seismic or other unforeseen activity. These limits define the limits of the rigid body motion of the body.

The limits are dependent on the tolerance buildup of the sensor/actuator head itself, the bias range of the electronics, the allowable magnet de-centering due to the magnet gluing fixture and the geometry of the magnets with respect to the optic.

For this analysis, motion of the optic is defined by 6 degrees of freedom; three translation and three rotation. These are lateral (x), vertical (y), position (z), pitch (α), yaw (β) and roll (θ). Note, these axes are different from the global axes definition for LIGO.

Movement Boundaries

Earthquake stops are needed to allow for the bias movement of the optic but to stop/damp the movement of the optic before it hits something and damages the optic or the magnet/dumbbell assemblies. Generally, the maximum translation/rotation is defined by the optic banging into the sensor/actuator or the magnet in the sensor/actuator banging into one of the components. The calculations below define the maximum allowable movement of the optic, in a worst-case tolerance build-up situation.