LIGO Laboratory / LIGO Scientific Collaboration

LIGO-T040004-04-D

ADVANCED LIGO

14th January 2004

Review of GEO 600 Blade Eddy Current Damper

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Revision 00: Limited release (R.Jones to C.I.Torrie)
Revision 01: Amendments by R.Jones sent to CTI form comment
Revision 02: Comments from CIT
Revision 03: Updates based on rev02 comments (R.Jones)
Revision 04: With comments from CIT and NAR

1.0 Introduction

This document summarises a design for a blade eddy current damper that, if necessary, could be used to damp the internal resonances of upper blades in the mode cleaner (MC) and recycling mirror (RM) prototypes for the LASTI experiment. The first internal mode frequency of the MC upper blade is predicted at 90Hz[1], and that of the RM upper blade at 139Hz[2]. The theory used to estimate these internal resonances of the blade does not take into account the effect of the blade wire clamp or the magnet, both of which add mass to the blade and therefore reduce the frequency. The first internal resonance of a prototype MC upper blade was measured to be 90 Hz. With the addition of a wire clamp and a magnet this reduced to 78 Hz[3]. There are several concepts that can be considered in order to increase the internal resonance if required.
The design is a direct translation from the blade damper successfully employed in GEO600, and the authors would like to thank the GEO 600 team for supplying a damper assembly for our assessment.

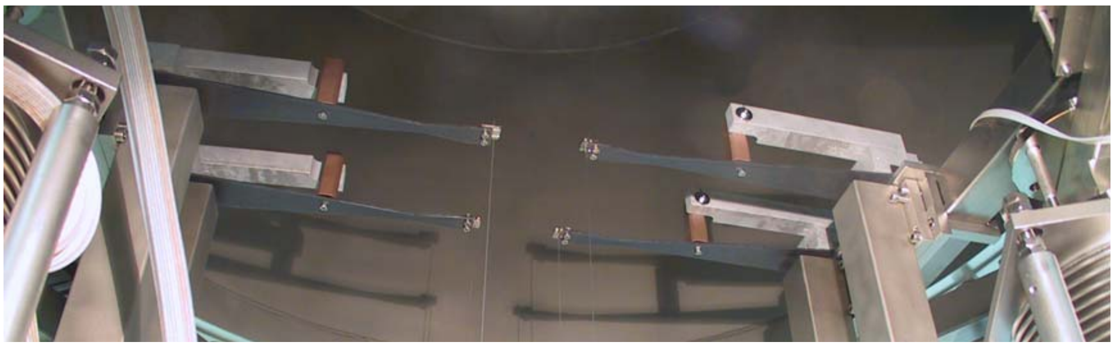

Figure (i): The GEO 600 Blade ECD design in position

Figure (i) shows the damping of the GEO 600 upper blades applying the damping via a magnet attached to the upper surface of the blade moving within a copper block. An alternative would be to have the magnet attached on lower surface of blade from above, however it is also possible that damping could be applied from below

For the case of the LIGO-MC suspension it will be possible to incorporate the dampers into the existing blade guard assembly.

Damping of blade internal resonances may be necessary in Advanced LIGO. Firstly the required isolation performance could be compromised at those frequencies and secondly the presence of high Q modes below 150 Hz could impact on the performance of the active isolation platform. Thus we are investigating the design of a blade eddy current damper that, if necessary could be used to damp such modes. The design currently under investigation is for application to damping the top blades in the MC and RM prototypes at LASTI.

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[1] EXCEL document: "Bladespec_MC" (M. Plissi, N. Robertson, C.I.Torrie)
[2] EXCEL document: "Bladespec_RM" (M. Plissi, N. Robertson, C.I.Torrie)
[3] LIGO-T030273

2.0 General Arrangement of ECD Design

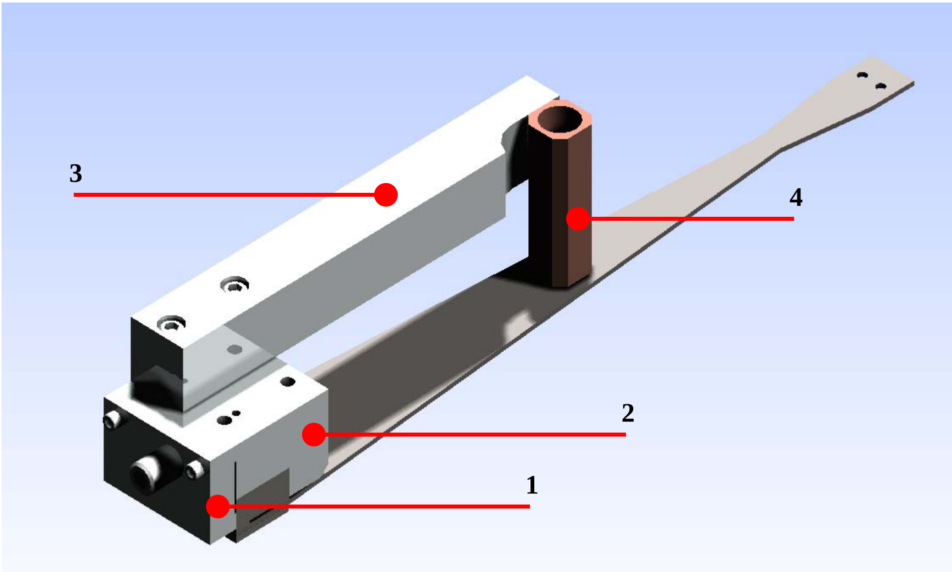


Figure (ii):
CAD rendering of the Blade ECD design, LIGO-D030269

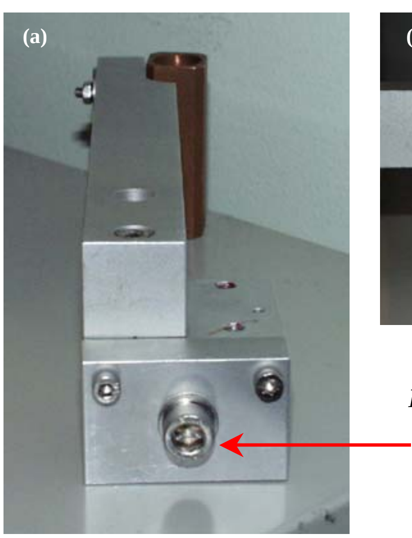
The basic requirements for the damper design were:

- Ability to fix to a blade clamp without altering any existing suspension components
- Stiffness/rigidity
- Adjustability
- UHV compatibility

Following an assessment of the GEO design, it was clear that it fulfilled all of the above requirements.

The GEO assembly was constructed with four major components (plus fasteners), and these can be seen in figure (ii): #1 and #2 combine to form a 'vice' that grips onto a blade clamp; #3 is a rigid aluminium arm that supports #4, the copper sleeve.

The method of fixing the damper to a blade clamp (that ensures no alteration to existing hardware) is highlighted below in figure (iii).



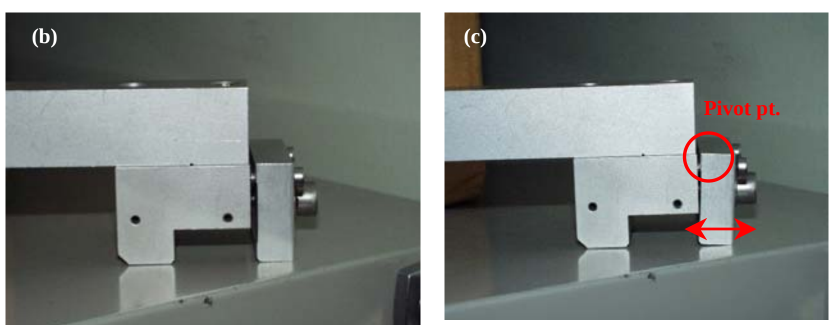


Figure (iii): Manipulating the M6 bolt highlighted in (a), operates the 'vice' clamping mechanism. This concept can be seen in the transition form (b) to (c) above.

Stiffness has been maximised, particularly in the case of the damper arm, through the use of ~3/4 inch thick (square section) aluminium bar , #3 in figure(ii).

Adjustability is achieved most notably at the interface between the copper sleeve and the damper arm. The 3mm threaded rod which is part of the copper sleeve, locates inside a 10mm hole in the damper arm - see figure (iv). This enables +/-3.5mm of adjustment in the ‘x’ and ‘y’ directions as well as almost unlimited freedom in rotation, which is very important, as the design must have the ability to damp a blade that may not be entirely flat along its length. In this configuration the manipulation and removal of the copper sleeve is straightforward, but this will be affected by the existence of the blade guard. However it is unlikely that this will be a problem, and as mentioned previously it may be possible to mount dampers from the blade guard itself.

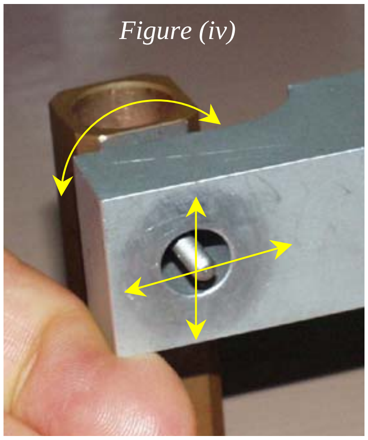


Figure (iv): - Close up of the end of the damper arm with the copper sleeve locating via a threaded rod.

3.0 Testing of the Adapted Design

The authors have adapted the GEO 600 Blade Damper design for use in the Advanced LIGO Controls prototypes. The assembly drawing (LIGO-D030269) and associated part drawings are all available on the LIGO DCC.

Two prototype assembles (both LIGO-D030260-00) were manufactured at Caltech and tested on the experimental setup shown in figure (v).

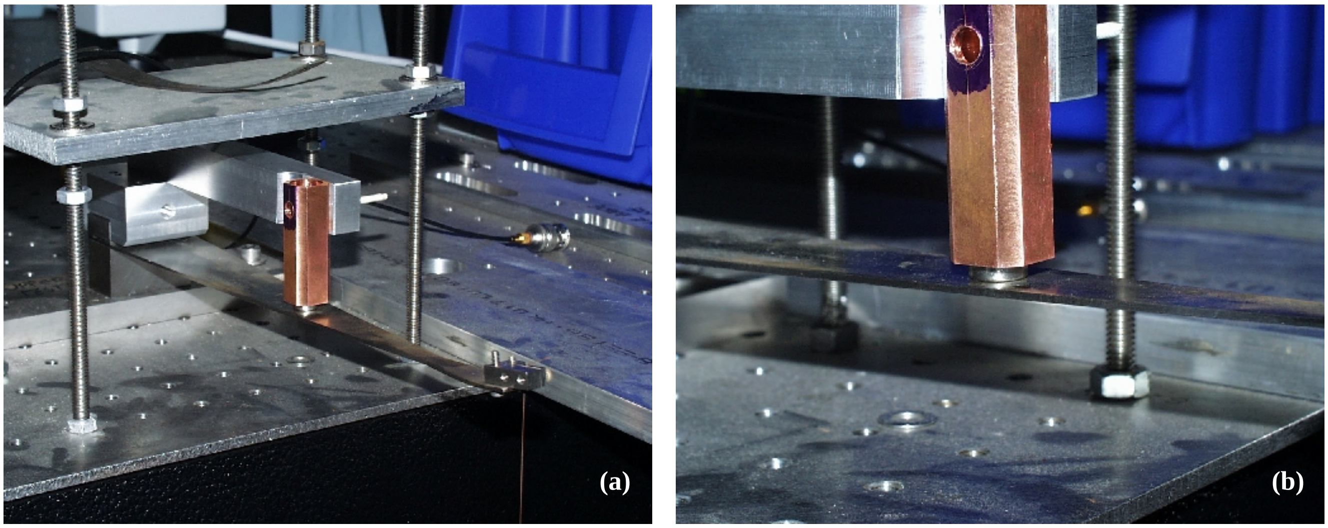


Figure (v): The experimental setup
(a) Overview, and (b) Close-up of copper sleeve (D030263)

The design tested by Calum Torrie, and was then discussed (by the authors) at CalTech on the 10th November 2003, and the resulting comments were as follows:

- Assembly was tight fit onto top of the MC blade clamp

(Action: increase diameter of counter bores for cap screws)

- There is an insufficient gap between the 'jaw' (D030262_Clamp_Lshape) of the Damper and the top surface of the MC blade

(Action: remove some material from D030262 to account for this)

- There is no design for magnet/spacer that is mounted on the blade

(Action: consider with reference to the following comment)

- There are no holes in the blades for attaching the magnet/spacer

(Action: discuss the need to rework MC blades? Check RM upper blade design)

- Introduce continuity probe to test alignment of copper/magnet during assembly – this will require the copper sleeve to be isolated from the remainder of the ECD assembly

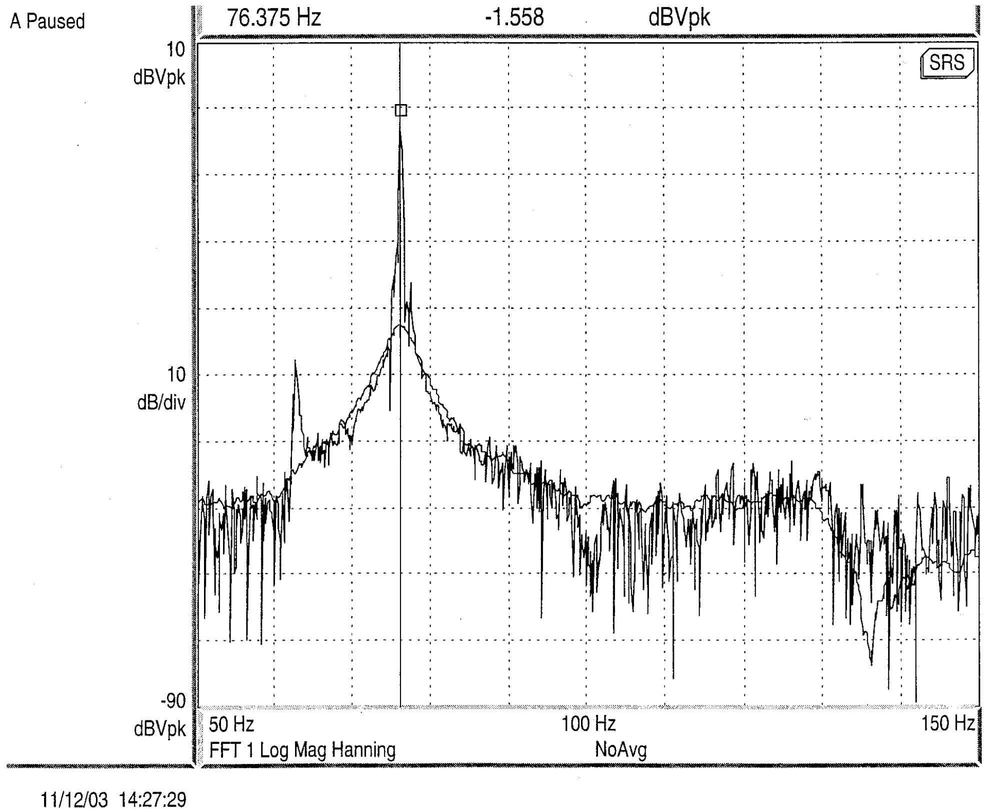
(Action: introduce 'PFA 440HP' Teflon shoulder/sleeve)

- Increase the range of adjustability of the copper with respect to the Damper Arm, following the last point

(Action: suitably increase diameter of 10mm clear hole in the damper arm)

4.0 Results of tests

The following trace shows both the damped and un-damped cases.



With reference to figure (1) and figure (5) we measured a Q ~ 15 ± 5 for the first internal resonance of the upper MC blade in air. This was done using an accelerometer attached to the blade, as shown in figure (1) and measuring the FFT response on a Spectrum Analyzer.

The magnet used, 10mm diameter by 10mm thick, was offset from the blade using a small Aluminium spacer of diameter 5mm and thickness 2mm. A hollow copper tube/sleeve of internal diameter 12mm and with a minimum wall thickness of 1.5mm, surrounded ~ 70% of the magnet.

It should be noted that if a longer spacer was used between the magnet and the blade that it would be easier to fully enclose the magnet in the copper and hence improve the damping.

5.0 Internal Resonance of a Cantilever Blade

It is possible to increase the internal resonance of a cantilever blade by firstly considering the geometry. A good example of this is in section 6.5.7 of Calum Torrie's thesis, Glasgow 1999. In that case considered the internal resonance of a particular blade that flattened under a given load was increased from 55 Hz to ~ 120 Hz simply by changing the geometry.

In a recent experiment at Caltech Mike Perreur-Lloyd and Calum Torrie compared two blades with identical geometries. The first was bent to a given radius and the second was flat, in the unloaded state (and became curved under load). When loaded with identical masses each had approximately the same internal resonance.

6.0 Conclusions

We have a design that (without much extra effort) can be fully adapted and built for both the MC and RM prototypes. It is also possible that this design could also be adapted for use in quadruple pendulum suspensions.

The assembly drawing, parts and individual drawings have now been updated as per the comments in this documents and they have all been submitted to the Caltech PDMWorks vault.

7.0 TBD

The assembly has to be incorporated into the MC and RM assemblies. The prototype assembly will be updated as per the drawing changes and tested on the bench at Caltech.

Appendix 1: Private (email) communication from Janeen Rome, 07/01/04

Date: Wed, 07 Jan 2004 14:32:01 –0800
From: Janeen Romie <romie_j@ligo.caltech.edu>
To: Calum Torrie <torrie_c@ligo.caltech.edu>, Michael Perreur-Lloyd <m.perreur-lloyd@physics.gla.ac.uk>, r.jones@physics.gla.ac.uk, c.cantley@physics.gla.ac.uk, Helena Armandula <armandula_h@ligo.caltech.edu>
CC: janeen@ligo.caltech.edu

Subject: Design for assemblies in vacuum

Dear All,

The following rules for designing asseemblies for in-vacuum use are probably second nature to you all but I thought I'd send these along.
The main problem is out gassing - which affects the cleanliness of the mirrors, the interferometer phase noise budget, and the capacity of the vacuum pumps. The secondary problem is that to maintain the low out gassing rate, all materials are cleaned and vacuum baked to reduce contamination. This cleaning and baking dramatically increases the chances of cold welding of threaded and rubbing components. So, here's a quick list:

Use dissimilar materials for all threaded and dynamic contact applications. Generally, use a combination of stainless screws in oversize alum. threads and silver plated stainless screws in oversize stainless threads.

No adhesives. If no alternative, Vac Seal epoxy and Aremco Ceramabond may be used but must be used sparingly and as far away from the test masses as possible. Cured Vac Seal and Ceramabond must be baked (outgassed) prior to installation in the vacuum chambers.

No plastics except PFA 440HP (a type of Teflon), PEEK and Fluorel. Also take care to keep these as far away from the test masses as possible.

Metals - Stainless, aluminum, maraging steel, carbon steel only for suspension wires, beryllium copper, copper-nickel alloys, electroless nickel, gold, silver, platinum, titanium. There are some others but they are exotic/expensive. The updated LIGO Vacuum Compatible Materials List document that Dennis Coyne will send around soon has all the info.

Specify that all welding shall be full penetration. Vendors should provide certifications that testing has been done to validate full penetration.

Design modules such that if one part of a sub-assembly fails, it may be removed from the suspension and replaced as opposed to removing the entire suspension from the vacuum chamber. This makes forays into the vacuum chambers shorter which makes pumpdown times shorter.

Do not use fine or ultra-fine pitch screws of any material. Past experience has shown us that they always gall.

Design in removable or cleanable catchers for all debris, especially debris from screws under high load.
Use vent holes in female threads or vented screws in applications where the female thread is blind as opposed the through.

Thank you, Janeen