LASER INTERFEROMETER GRAVITATIONAL WAVE OBSERVATORY

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LIGO Laboratory / LIGO Scientific Collaboration

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Controls Prototype: - Measurements on the Mode Cleaner Triple Pendulum at Caltech

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06: Comments from Calum Torrie added 11th July 2008

05: - Updated section 1.7

04: - Includes updated excel file. 03 rev missed out as changed locally.

02: - Draft now includes comments on as built, referencing E040303-00 and how we should build it for the noise prototype.

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1 Introduction

The input mode cleaner controls prototype suspension is based on the signal recycling suspension used in GEO 600 and the main suspension used in the JIF system at the University of Glasgow. It is a triple pendulum, each stage with ~3 kg.

The upper mass is made from a combination of aluminum and steel. The intermediate and test masses are made from aluminum with holes in order to obtain the same mass and moment of inertia as if it was silica. The production suspensions will have a test mass made from silica. The lower wires are spring steel and are attached to the masses with stainless steel clamps.

Two such suspensions have been built at Caltech, one will remain at Caltech for testing and the other will be delivered to MIT for installation at the LASTI experiment. After testing, the Caltech suspension was delivered to LASTI for a cavity test with the two suspensions.

2 Reference documents

D040391 Overall Assembly Including Assembly Fixtures

D020700 Mode Cleaner Overall Assembly

3 Tests

Mass Estimates of the 3 assemblies: -

	Estimate from SolidWorks, (g)	Measured assembly in Laboratory, (g)
(i) Upper Mass	3133	3218
(ii) Intermediate mass	2985	3008
(iii) Test mass	2963	2978

May 2004

MASSES

Top mass = 3125g.

Upper mass appears to be ~ 100g lighter than before, could be added mass included previously?

Intermediate Mass = 2967g

Test Mass = 2956g + 18g = 2974g

This implies that the mass per upper blade is now ~ 40g / blade lighter than the above numbers in the revision 00 of LIGO-**T030135**-00. We decided to keep existing blade and library of clamp as can add mass later on. For reference, the document that details the library of clamps is **T030125**, Controls Prototype: - Library of Clamps for the Cantilever Blades in the Mode Cleaner Suspension and the document that details the add-on masses is **T030147**, Advanced LIGO SUS Mode Cleaner Spacers & Standoffs for the Top Mass.

It also implies that the mass per lower blade was ~ 10 g lighter per blade, again based on calculation below and comparison with previous numbers decided to keep blade and clamp. The difference was estimated to be small e.g. ~ 1mm for the upper blades which can be easily taken up with the added masses detailed in **T030147**.

BLADES

Upper Blade	180g	6mm
	10g	0.3mm
Implies	4600g	139mm
Lower Blades	65g	2mm
	10g	0.3mm
Implies	1500g	45mm

In the suspension sent to MIT we used the 2mm shim under the top blade at the rotational adjuster.

The purpose of adding the above section is to estimate how accurately we can predict the actual mass of a stage from a Solid Works model.

4 Experiment

Mode Frequencies – pendulum

- cantilever blades ($f_{uncoupled}$ $f_{coupled}$ and $f_{internal}$)

Measurements were made of the uncoupled mode frequency of the blade and the first internal mode of the blade. These were carried out with the blades under load with *m* /*n* mass. Where *m* is the mass suspended in the stage below and *n* is the number of blades in the stage e.g. The upper mass in the mode cleaner suspension weighs ~ 3.1kg and is supported by 2 cantilever blades. Therefore the mass supported is 1.55kg.

We could also do this when the blade is flat and then calculate the uncoupled with the known mass per stage.

We could also load blade until it is flat and then measure the frequency. It is then possible to calculate the uncoupled mode by dividing by the ration of mass.

i) MC upper blade, **D020205**-01

Mass, m	= 1.55 kg	
Frequency, f	= 2.28 Hz	(cf. 2.29 Hz, theory)
Internal Freq, f_{int}	= 86 Hz *	(cf. 90 Hz, theory **)

ii) MC Lower blade, **D020201**-02

Mass, m	= 0.7175 kg	
Frequency, f	= 3.31 Hz	(cf. 3.3 Hz, theory)
Internal Freq, f_{int}	= 226 Hz *	(cf. 261 Hz, theory **)

It should be noted that the accelerometer that is placed on the blade will reduce the actual internal mode of the blade.

Also the wire clamp on the tip of the blade is not modeled into this estimate.

5 Cantilever Blades

Details of the cantilever blade spring analysis may be found in **T030107**, Cantilever Blade Spring Analysis for Advanced LIGO. Another reference for the blade analysis is **T030104,** Mode Cleaner Controls Prototype Blade Length Measurements with Deflection & Thickness Measurements Embedded as an Excel File. For the Caltech # 1 suspension (or MIT suspension) the following upper blades could be used, S2 and S5, with either the 2.5 or 3.0 degree clamps. A 2mm shim was also used under the upper blade clamps. For the lower blades #1,2,3,4 from Superior Jig could be used with 0 degree clamps in the following orientation

#1	#3
#2	#4

SCHEMATIC OF TOP MASS LOOKING FROM BELOW

The further choices and data collected on the blade please refer to the attached excel file.

It should be noted that the MIT suspension is #1 and that the Caltech suspension is #2 and not as is called out on the structures.

6 After Cleaning and Baking

In preparation for the transfer of the mode cleaner suspension to the LASTI experiment at MIT, the cantilever blades were cleaned and baked.

They were cleaned in an ultrasonic bath and the baked in a vacuum oven at 200^0C for 100 hours.

At an SWG meeting on 17th May 2004 we realized that they should not have been baked at this temperature. The blade bake specifications are detailed in **T040108-03**, Blade, Wire and Clamp Process Specification.

In **E960022**, LIGO Vacuum Compatibility, Cleaning Methods and Qualifications Procedures, 200^0C is what is quoted for steels. It may be necessary to ask for a specific call out for Maraging steel, the material used for the blades, and to create a "comb-like" form for the blades to sit in during baking.

In any case, the ones that were cleaned and baked were re-characterized as a check to see what effects if any these processes had on the cantilever blade. The "compare to" numbers are from section 4.

Blade #1 (Lobart 3)

3) Deflection = -6 mm down from horizontal with a load of 4.6 kg (compare to –5.9 mm)

Blade #2 (Lobart 1)

3) Deflection = -6.3 mm down from horizontal with 4.6 kg. (compare to –5.7 mm)

2) Uncoupled mode = 2.3 Hz (compare to 2.28 Hz)

3) Internal Resonance = 85 Hz (compare to 86 Hz)

As shown above, the deflection was only affected slightly by the too-hot bake. If the blade committee decides to increase the blade bake temperature, we should at least discuss whether or not a comb is required to hold the blades in position during the bake.

7 Conclusions: lessons learned and changes needed

The change to steel wires as opposed to silica fibers, as detailed in LIGO-**T060008,** changes a number of items in the design. First, a catcher is not needed for the fiber installation and welding. This and a number of other changes were detailed in RODAs, listed below:

RODA **M060017**, Steel Wires for the Mode Cleaner Suspensions

RODA **M060315**, No Flats on IMC & RM Optics

RODA **M070055**, Dimensions of the Large MMT Mirror (MMT#) and the Recycling Mirrors (PRM & SRM) for the Marginally Stable Recycling Cavities. The baseline now is for a stable recycling cavity, so this RODA is no longer relevant.

RODA **M0800038-03**, Responsibilities for Elements of the Stable Recycling Cavities

RODA **M070119**, HAM Optics Table Height

This section will capture the lessons learned from these prototypes and detail any changes needed from the RODAs above and other noted desired optimizations.

a. The mass numbers in section 3 should be checked to compare like with like. Further, the position of the center of masses should be compared and noted. This is helpful in selection of angled clamps after characterization of the blades.

b. Update magnet/flag assembly to RAL design.

c. Upper Wire Jig needs to be updated. The D020158, Angled Attachment Upper Blade Clamp Piece is easily confused and added wrongly. We have added arrows and counter bored holes to the angled wire jig clamp prototype part so that it is impossible to get confused as to which way round you add the clamp to the jig, but the wire jig assembly drawing or equivalent part need updating.

d. Wire jigs: consider redesigning to allow for an adjustment mechanism to allow for flexibility in wire length.

e. Flexure Point: The quadruple pendulum prototype suspension, which is a later prototype than this one, uncovered an issue of the actual flexure point in each suspension level. The document, D040183, Advanced LIGO SUS ETM CPTYPE Flexure Point of a Spring Steel Wire, details this work. The flexure points for each of the suspension levels needs to be calculated and the suspension model, parts and fixtures need to be redesigned to accommodate the required changes.

f. Structure and non-suspended components changes to consider:

- All structural elements from 1.25” x 1.25” x ,125” thick wall to 2” x 2” x .188” thick wall aluminum tubing, D020023. This is required, at a minimum, to bring the structural resonances higher. Background on structural analysis is found in T050063.
- Tablecloth brackets, D020346, make thinner to reduce weight. Redesign due to larger legs.
- Tablecloth, D020239 – revise bracket mounting holes, per change to brackets. Also, L. Ruet requested more/larger viewing holes to assure earthquake stops are in proper position and osems/magnets are positioned optimally.
- Earthquake stop crossbars, D020420 and D020526, make shorter
- Tombstones, D020417, D030017 and D030018, make thinner and lighter.
- Face brackets, D020523, D030015, D030016, make distance to optic shorter.
- Bottom three horizontal crossbars in front of structure so that they are removable to ease assembly. Consider this change, as it is no longer necessary without a catcher requirement.
- Consider making beam baffles part of structure.
- Change the osems to Birmingham osems, p/n D060218, on the D020535 Upper Mass and Tablecloth Assembly.

g. Suspended components changes to consider.

- Consider redesign of wire clamps to have harder/replacement interface pieces.
- Consider switching to the OMC maraging steel blades to reduce configuration/procurement tracking by adding mass to the suspended masses.
- Check all Matlab parameters relative to the changes needed to the test mass with respect to no-flats.
- Calculate the spacer height requirements (with support from IO), for different HAM table heights per RODA **M070119**
- Change the metal test mass design to have no flats.
- Change break off design to take into account recent research on sapphire prisms.
- Make the t-section removable.

i The following is a copy of an email from Mark Barton on experience gained from the delivery of the MC to LASTI in May 2004.

Janeen and Laurent had unpacked the prototype and set it up in the portable clean room. It seemed to have survived the trip from Caltech without incident. Jay had set up most of the electronics, and on Monday, Rich set up the dSpace hardware and Luke and I set up the rest of the electronics and loaded the software.

We solved the roll balance problem first noted at Caltech by moving the side magnet to the right side.

The LL magnet on the bottom mass seems to have been glued on about 1/8" high, so that the regular tombstone (D030018) is much too short. A medium tombstone (D030017) is a bit longer than ideal but should just work. One is being cleaned and baked and sent off. In the meantime we just left that OSEM off.

The new aluminum hybrid OSEMs were a bit stiff. This was not a problem for adjustment (in fact the SS prototypes were too loose) except that the two screws for pushing the parts apart were cutting into the aluminum and shedding occasional bits of swarf [debris]. Calum might consider rounded screws and/or dimples for the next iteration. We checked for shorts of the coils to ground and there were none.

We debugged a number of problems with the electronics. Several turned out to be due to poor seating of the 64-pin ribbon cable connector at the second satellite box. Everything now works after a fashion except for a few mysterious noise sources:

This is roughly 30 Hz noise in the m1left and m1right channels. We suspect this is physical and due to something like a mechanical resonance of the side of the "tablecloth" the left and right hypbrid OSEMs are mounted on reacting to some subharmonic of 60 Hz from a motor or the like. All the LIGO-I OSEMs (except m3UR; see below) are giving open light voltages of around 0.55 V whereas it's traditionally been 2.2 V. (I noted this at Caltech but didn't flag it an an error). m3UR has an open light voltage of 5.63 V, i.e., ten times the others. (I didn't notice this at Caltech, but it would be easy to miss.)

There is broadband noise and glitching on some of the LIGO-I OSEM channels.

We checked the levelling of the clean room optical table with a small spirit level and set the pitch of the optic with a HeNe optical lever using the table as a reference. The spirit level was not of the highest quality and the length of the lever arm was rather short, so the accuracy may not be great.

We set all the OSEMs to 60% of the open light voltages as measured at the adcraw1 screen of the dSpace software (note that this introduces a divide-by-10 relative to the physical voltages).

For reference, the values were
top1 0.776V 0.466V
top 0.796V 0.478V
top3 0.748 0.449V
left 0.754V 0.452
right 0.740 0.444
side 0.721 0.433
m2UL 0.0513 0.0308
m2LL 0.0557 0.0334
m2UR 0.0588 0.0353
m2LR 0.0558 0.0335
m3UL 0.0544 0.0326
m3LL NC
m3UR 0.563 0.338 (yes, 10x too big)
m3LR 0.0479 0.0287

It was then fairly easy to clamp the optic while capturing the pitch and yaw alignment.

To get the optic in the chamber we mounted a small optical breadboard on the manual forklift, laid out the teflon highway, man-handled the optic onto it, moved it over to the open HAM, cranked the breadboard up level with the optic table and slid it over. Because we had doubts about the slotted brackets for the lifting levers, we didn't use them. Instead we just tilted the structure, pulled out the teflon and rested the structure back down. This was not particularly strenuous or hard on the back even at arm's length but we need a safer strategy for real optics. Also, Dave is worried that the levers would be unworkable on the typically crowded input optics tables.

We put the optic in the dead centre of the table by eye, but didn't attempt any further alignment.

We installed the in-vacuum cabling up to but not including the feedthrough, which is being baked. The free ends of the cables are terminated at a cable clamp on the support table opposite the flange to be used. From left to right as one looks in from outside, the connectors are
B1 (m1top1, m1top2, m2top3)
B2 (m1left, m1right, m1side)
C1 (m2LL, m2UR, m2UL)
C2 (m3UL, m3LL, m2LR)
C3 (m3UR, m3LR)
Spare upper (for geophone)
Spare lower (for geophone)

Some convention needs to be determined for the assignment of connectors to feedthrough ports. The test-stand cables labeled B1-C3 double as the permanent external cables, except that they need to be plugged in through the extensions (lying on the floor near the chamber) to compensate for
the way a DB-25 feedthrough swaps pins 1 and 25, 2 and 24, etc.

Until the missing OSEM m3LL is installed, the position, pitch and yaw values for m3 reported on screen m3state1 of the dSpace display will be nonsense. If it is desired to get preliminary results without it, the sensing and actuation geometry blocks can easily be tweaked to compensate. (Run Matlab, navigate to the dSpace directory (c:\Documents and Settings\Administrator\My Documents\LASTI dSpace\mcfulldiaglive\) and run generate_simulink.m.)

Cheers, Mark B.