LASER INTERFEROMETER GRAVITATIONAL WAVE OBSERVATORY

*link to excel sheet*

*LIGO Laboratory / LIGO Scientific Collaboration*

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

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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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## 1.1 Introduction

Please reference documents, LIGO-T010103, LIGO-T030125 and LIGO-T030147

Other documents / thesis that should be referenced include: -

LIGO-T030118, LIGO-T030229, LIGO-D040183, LIGO-E990196, LIGO- T030107, LIGO-T030104, Thesis by Calum I. Torrie (University of Glasgow, Dec 1999) and Thesis by Stuart Killbourn (University of Glasgow, 1996).

The mode cleaner controls prototype 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. Wording from my thesis?? Blades etc ...

The upper mass is made from a combination of aluminim 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 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 and the other will be delivered to MIT for installation at the LASTI experiment.

## 1.2 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 |

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MASSES

Top mass = 3125g.

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

Int 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. Decided to keep existing blade and library of clamp as can add mass later on!

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! I.e. 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 |

These numbers should be checked to compare like with like! Further the position of the center of masses should be compared and noted!

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.

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

### 1.3 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.

Could also do this when the blade is flat and then calculate the uncoupled with the known mass per stage!

** 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 estimation.

## 1.4 Alignment

Height, pitch, rotational etc..

## 1.5 Cantilever Blades

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 CIT suspension is #2 and not as is called out on the structures!

## 1.6 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 $200^0$C for 100 hours.

At SWG on 17th May 2004 we realized that they should not have been baked at this temperature.

$200^0$C is what is quoted for steels, it could 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.

Blade #1 (Lobart 3)

1) Deflection = -6 mm down from horizontal with a load of 4.6 kg (cf. -5.9 mm)

Blade #2 (Lobart 1)

1) Deflection = -6.3 mm down from horizontal with 4.6 kg. (cf. -5.7 mm

2) Uncoupled mode = 2.3 Hz (cf. 2.28 Hz)

3) Internal Resonance = 85 Hz (cf 2.3 Hz)

TO DO

There are more blades to test but so far looks good!

## 1.7 Changes that would be implemented for Noise Prototype

### 1.7.1 Length changes

Length, l1 – 30mm and length, l2 + 30mm.

This length change aids in the addition of the catcher associated with the int and test mass.

Note changes to structure to also accommodate the catcher

- Cross bar must be made removable
- Lower base plate should be flat or a central hole cut in it so we can reference the flat surface of the optical table
-

### 1.7.2 Magnet Spacer Steel (A to B)

D030076, made longer to aid with balancing of the mass. The longer version better matches the mass of the magnet and flag on the opposite side of the mass.

### 1.7.3 Upper Wire Jig, D020158 (A to B)

We have added arrows and counter bored holes to the angled wire jig clamp so that it is impossible to get confused as to which way round you add the clamp to the jig.

### 1.7.4 Flexure Point

Reference document, D040183-04 FLEXURE POINT OF A STEEL WIRE & PITCH.xls. Need to include in future design of Mode cleaner. Changes would mean that lengths of wires made in jigs would change.

### 1.75 Structure and non-suspended components - JHR

- Change:
  - 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 to bring the structural resonance higher.
  - tablecloth brackets, D020346, make thinner
  - tablecloth, D020239 – revise bracket mounting holes
  - 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.
  - structure, D020023, add note to machine top of bottom plate to allow locating and attaching catcher.
  - structure, D020023, to include any other catcher attachment points.
- Consider making beam baffles part of structure.

## 2 The following is a copy of an email from Mark Barton on experience gained form 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 aluminium 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 aluminium and shedding occasional bits of swarf. 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.