LASER INTERFEROMETER GRAVITATIONAL WAVE OBSERVATORY

LIGO Laboratory / LIGO Scientific Collaboration

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ADVANCED LIGO SUS ETM SUMMARY OF WORK FOR A BLADE TEST FACILITY

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REVISION 01: - Includes comments from MVP, MPL (AND REFERENCE APPENDIX)
REVISION 00: - Includes comments from CIT, JHR and NAR

1.1 Introduction

In order to aid in the understanding of what could be involved in a Blade Test Facility (BTF) it is useful to firstly consider a brief history of the cantilever blade used in GEO 600 and secondly to summarise key aspects of a blade that require analysis.
The cantilever blades that are considered here are those for use in the ETM Controls Prototype Quadruple Pendulum Suspension for Advanced LIGO.

Mike Plissi, Mike Perreur-Lloyd and Calum Torrie were given the task at the Glasgow Suspension Summit Meeting in August 2003 to provide information to Rutherford Appleton Laboratory (RAL) on a Blade Test Facility, layouts of suspensions and a summary of work and requirements for a blade wire clamp. Both this document and a companion paper, *T030107-00,* titled "Cantilever Blade Analysis for Advanced LIGO" by Mike Plissi summarises information regarding the cantilever blade. This is available at http://www.ligo.caltech.edu/docs/T/.

The following document also lists ideas that could be incorporated in a Blade Testing Facility. Further documents covering the other areas will follow.

Mike Plissi has already discussed with both Justin Greenhalgh and Ian Wilmut of RAL the reasoning behind our choice of blade designs and what parameters are important.

1.2 Objective

The objective of the blade test facility is to address aspects of the design and manufacture of blades for the quadruple pendulum suspension building on previous work done.

1.3 History of the application of cantilever blade used in GEO 600 and early Advanced LIGO prototypes

i. Design

For all of the blades designed in GEO 600 and more recently for Advanced LIGO please refer to *T030107-00.*

ii. Manufacture

At present the blades are manufactured to the specification highlighted in section 1.5.

The GEO 600 blades were constructed from sheets of maraging (precipitation hardened) steel of the type Marval 18. The process used involved the blades being manufactured from sheet stock, without additional modification to the stock sheet thickness. In the last year or so a lapping process has been added to machine the material to the desired thickness, see *T030107*.

The first set of blades manufactured for the Mode Cleaner Controls Prototype for advanced LIGO were made from C-250 (hot rolled, de-scaled and annealed) maraging steel. Two different manufacturing methods were investigated. One set was made from sheet stock that was machined to the desired thickness and then bent to the required radius. The second set used an EDM process, starting with a block of material. This is the technique used by the Seismic Group for the significantly thicker blades used in the active isolation system in Advanced LIGO.

iii. Manufacturer, Suppliers and Costs

Mike Plissi bought the Marval 18 for the GEO 600 blades from Aubert and Duval, a French company. Accrofab, a UK Company, manufactured all of the blades for GEO 600.

Janeen Romie bought the material used on the Controls Prototype Mode Cleaner Suspension from MTK Industries. Lobart Company, in Pacoima CA, and Superior Jig Incorporated, Anaheim CA, manufactured the two sets of blades. Sheet material was provided to Lobart and Superior Jig used blocks of the same specification as the sheet. The cost breakdown is as follows: -

Lobart 16 small blades @ $285; 8 large blades @ $345; material @ $1281; expediting @ $900 Total $9501 > ~$396/blade

Superior Jig 16 small blades @ $417; 8 large blades @ $545;

Total $11,032 > ~$460/blade

As can be seen the costs are fairly comparable. Results comparing how these blades performed are outlined in 2 reports, *T030107-00*. The data summarized in *T030107-00* can be found in *T030104*.

Both of these are at http://www.ligo.caltech.edu/docs/T/.

iv. Analysis

Once the blades have been manufactured they are analysed individually in the lab. This involves assessing the thickness at various points on the blade and measuring the deflection of the blade that is clamped, at its base, to an optical bench in a clamp both unloaded and under the desired load. The fundamental and the first internal mode frequency of one blade of each type is measured using an accelerometer and network analyser at this point. The blades are then matched (for deflection) for use as a set in a suspension. A combination of the "library of clamps", "matched masses"[1] and a "Winch" could be used to ensure both that the blade tips are at the required height and also that the optical test mass is at the desired vertical, z, position.

Calum I. Torrie and Mike Perreur-Lloyd are in the process of writing a report, *T030227*, on one possible method of selecting and installing a cantilever blade for use in a suspension, in particular the methods discussed in the previous paragraph.

For small blades, for example the 1 mm thick lower blades used in the GEO 600 main mirror triple pendulum suspension, it has been possible in the past to manually re-work the deflection in a particular blade in order to obtain a set of matched blades. This would prove difficult with the larger quadruple pendulum blades.

[1] Information on the matched masses can be found in T030147 and at the suspension workshop.

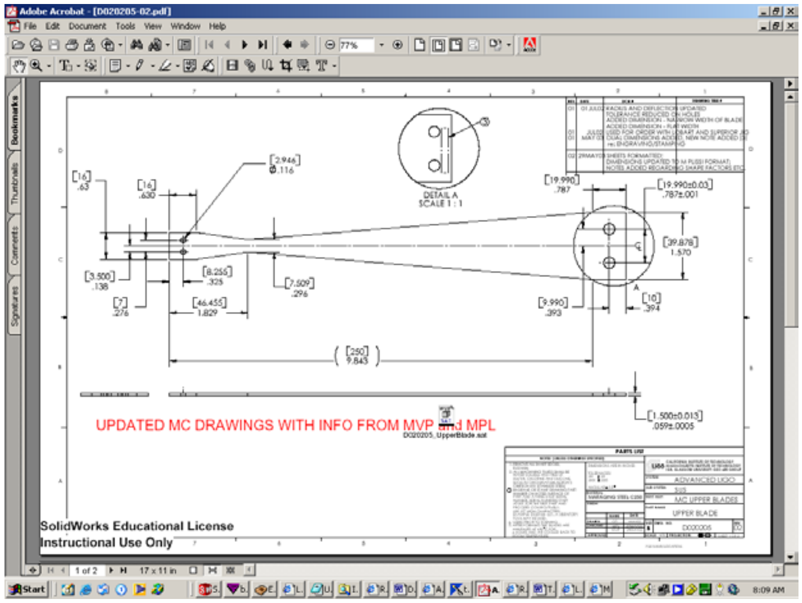
1.4 Cantilever Blade Drawings and notes

The drawings include notes summarising information related to the cantilever blades, highlighted below, and an imbedded .SAT file of the part. Both of the drawing sheets are shown as sketches in the pictures below.

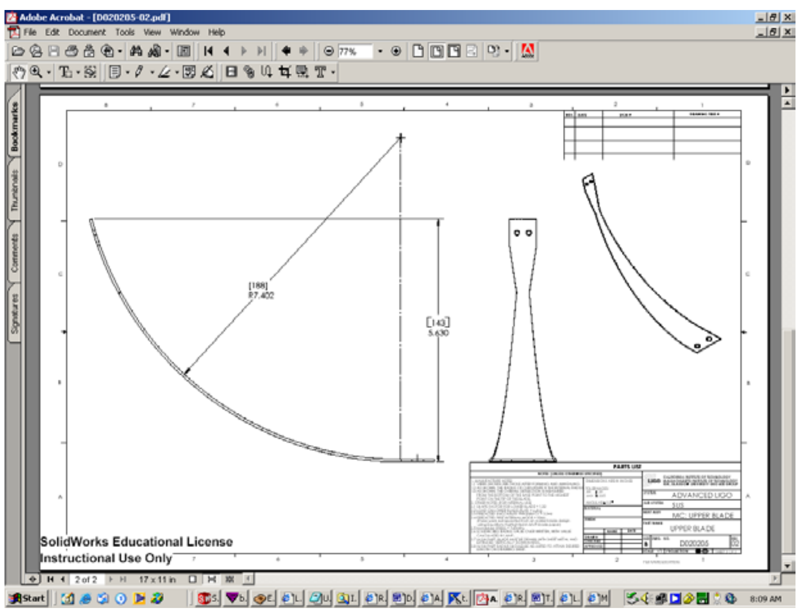
i. Drawings

The drawings for both the upper and lower blades for the controls prototype mode cleaner triple pendulum for advanced LIGO are available on the LIGO Document Control Centre*, D020205-02 and D020201-03.*

Both *D020201-03* and *D020205-02* are available at http://www.ligo.caltech.edu/docs/D/.



Picture (1): - Sketch of sheet 1 of the upper cantilever blade, D020205



Picture (2): - Sketch of sheet 2 of the upper cantilever blade, D020205

ii. Notes

The following notes are included on the two sheets. The addition of all of this information including the annealing process as well as the predicted numbers from the model has proved very useful. On Sheet 1: -

1. REMOVE ALL SHARP EDGES, R.02 MIN.

2. ALL MACHINING FLUIDS SHALL BE WATER SOLUBLE AND FREE OF SULFUR, CHLORINE AND SILICONE, SUCH AS CINCINNATI MILACRON'S CIMTECH 410 FOR STAINLESS STEEL

3. ENGRAVE OR STAMP DRAWING PART NUMBER ON NOTED SURFACE OF PART AND A THREE DIGIT SERIAL NUMBER. SERIAL NUMBERS START AT 001 FOR THE FIRST PAR AND PROCEED CONSECUTIVELY. USE .07" HIGH CHARACTERS. EXAMPLE: D020188- 001. A VIBRATORY TOOL MAY BE USED.

4. VIEWS PRIOR TO FORMING

5. AFTER FORMING THE BLADES ARE ANNEALED AT 490 ^{0}C FOR 4 HOURS AND AIR COOLED BACK TO ROOM TEMPERATURE

And on sheet 2: -

1. MANUFACTURE NOTES

    1.1 VIEWS SHOWN ARE THOSE AFTER FORMING AND ANNEALING.

    1.2 AS SHOWN, THE RADIUS OF CURVATURE IS THE INTERNAL RADIUS.

    1.3 AS SHOWN, THE OVERALL DEFLECTION IS MEASURED FROM THE BOTTOM OF THE BASE POINT TO THE HIGHEST POINT ON THE TIP OF THE BLADE.

2. OTHER NOTES (FOR INTERNAL USE)

    2.1 SHAPE FACTOR FOR LOWER BLADE = 1.54

    2.2 LOAD ON LOWER BLADE (FLAT) = 1.5 kg

    2.3 PREDICTED UNCOUPLED FREQUENCY = 3.4 Hz

    2.4 PREDICTED FIRST INTERNAL MODE = 260 Hz. (These were extrapolated from an earlier blade design using equations highlighted in MVP blade paper)

    2.5 MAXIMUM STRESS = 580 MPa

    2.6 SOLIDWORKS RADIUS VALUE OVERWRITTEN, WITH VALUE CALCULATED MANUALLY BY MVP.

    2.7 IN SOLIDWWORKS PART, BLADE MUST BE DRAWN WITH SHEET METAL AND EXTRUDED VERTICALLY DOWNWARDS.

    2.8 IN SOLIDWORKS PART RADIUS SHOULD BE ADJUSTED TO ATTAIN DESIRED LENGTH ON DRAWING SHEET.

1.5 Blade Test Facility

The following is a summary of ideas for a proposed blade test facility. There are two main aspects, the analysis (and subsequent design) and the testing of the blades.

The analysis could be done using a 3-D cantilever blade profile using Finite Element Analysis (FEA). Investigations should include considering the shape, thickness, deflection under load and the radius of curvature. Eoin Elliffe, a PhD student at the University of Glasgow has a model for the blades used in GEO 600 and advanced LIGO and perhaps he could be used as a useful contact. Contact should be set up through Caroline Cantley. This analysis should also include an investigation of both the Internal and Torsional modes of the blade. Ken Strain and Norna Robertson have written reports on the requirements for the internal modes of the blades. Both ALUKGLA0010aOCT01, and ALUKGLA0007aJUL03 are available on the ALUK Glasgow Document Register.[1]

The tests on the blades should include measuring of the unloaded and loaded deflections. The desired loads for the blades used in the ETM quadruple suspension are of the order of 40 to 60 kg. Further tests should include measuring the fundamental, internal and torsional mode frequencies and the testing of damping of the blades internal modes, as required. In GEO 600 the later is done using eddy current dampers, an assembly drawing, *D030269-00*, and embedded assembly of such a damper is available at http://www.ligo.caltech.edu/docs/D/D030269-00.pdf

1.6 Outstanding Issues

There is a remaining question as to whether we order large numbers of blades and match them or order the correct number and use mis-matched adjustable clamps. (Both concepts would require the combination of adjustable clamps and other adjusters to position the suspension vertically.) Mike Plissi has indicated that the thickness of the blades should be well matched, hence matching the spring stiffness, but that the tolerance on the radius could be relaxed if we relied on adjustable clamps. Further work on the degree to which the relaxation may be estimated is required.

1.7 Related Work

As already mentioned, methods of adjusting the cantilever blade for the vertical position will be addressed in *T030227*.

Mike Perreur-Lloyd, Alastair Grant and Calum I. Torrie have been working on a yaw adjustment mechanism for both the Controls Prototype Mode Cleaner and Recycling Mirror suspension. A concept for such an adjuster for an ETM quadruple pendulum suspension will be included in a summary of this work and could serve as a basis for future development.

[1] (http://www.physics.gla.ac.uk/~caroline/ALUK Glasgow Webpage/Registered Documents Glasgow/Document Register Glasgow.html)

1.8 Comments

Please send comments or info to ctorrie@ligo.caltech.edu

1.9 Appendix

Further work related to the Blade Test facility includes the study and design of the blade clamp, blade wire clamp and blade design for the cantilever blades in the Controls Prototype ETM Suspension for Advanced LIGO.

To aid with this work I have added several references and hyperlinks: -

1) Upper Blade Wire Clamp assembly, D020319, as used in the Mode Cleaner Controls Prototype.
2) Upper Blade Wire Clamp, D030576, main section, as used in the, 2001 MIT Quad Prototype Suspension.

Both are available at http://www.ligo.caltech.edu/docs/D/.

NB: - It should be noted that in the installed suspensions in GEO 600 all of the larger blade wire clamps were made from Titanium.

(REF: ALUKGLA0010aOCT01, and ALUKGLA0007aJUL03)

3) Summary of Cantilever Blade Wire Clamp Testing, T030242, by Mike Perreur-Lloyd, History of the blade wire clamp and summary of designs that have been considered.
4) Blade Clamp, Upper and Lower section. D020690 and D020688 make up the 3.5^0 set used in the library of clamps in the Mode Cleaner Controls Prototype Suspension.

Again these are available at http://www.ligo.caltech.edu/docs/D/. and http://www.ligo.caltech.edu/docs/T/.

5) Norna Robertson includes a set of suspension parameters in the updated Conceptual Design document, **T010103-02**; this includes the parameter set for the cantilever blades in the Controls Prototype ETM suspension in **section C.2.1**.