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LIGO Laboratory / LIGO Scientific Collaboration

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Upper-Intermediate Mass for ETM Controls Prototype Quad Pendulum Suspension

Product Design Specification

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PRODUCT DESIGN SPECIFICATION

Michael Perreur-Lloyd, Norna Robertson, Calum Torrie

NOTE: This is a working document. Please consult the authors for the latest specifications for the Upper-Intermediate Mass.

Revision 00: First draft of the Upper-Intermediate Mass PDS

1. INTRODUCTION

This product design specification for the Upper-Intermediate Mass (U-I Mass) is written to ensure that no design factors are ignored or missed out during the development of the design. The first draft of this document contains all known specifications at the time of writing. The PDS will however evolve during the design process and, on completion of the physical assembly, match the characteristics of the upper-intermediate mass.

The U-I Mass for a quadruple pendulum is constructed from what looks like, two triple pendulum upper masses (one inverted) joined together one above the other to form something resembling a sandwich. The 'filling' within the sandwich consists of two cantilever blades (that interface with the wires that suspend the penultimate mass) and some clamping fixtures for the wire coming from the middle blades. Alignment at the U-I stage is done via four coil-magnet actuator assemblies located between the main and reaction U-I masses.

The specifications for the U-I Mass are primarily set by the output values from the MATLAB Quadruple Suspension model for the ETM. However, other factors determine the final design of the mass and alter its make-up from the ideal model MATLAB produces. These include ease of assembly, installation and interference of parts.

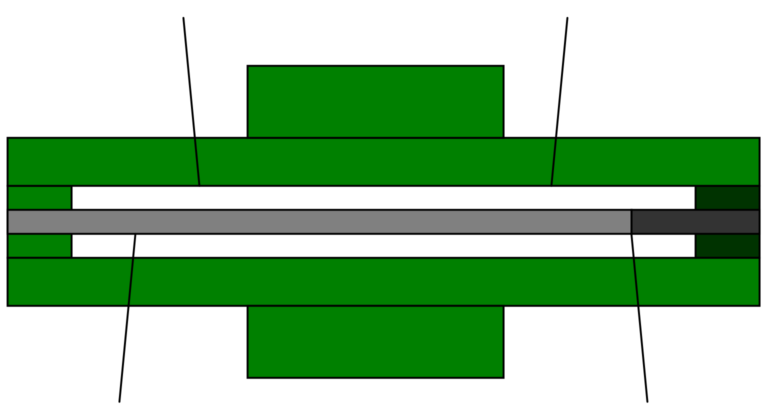

FIGURE 1: Front View of Typical Upper-Intermediate Mass

2. PAST QUADRUPLE PENDULUM UPPER-INTERMEDIATE MASS MODELS

Experience and techniques from the design, manufacture and installation of the MIT Quad model and recent triple suspensions should be considered thoroughly during the design of the U-I Mass.

In the build up to developing a full working ETM Quad Controls Prototype Suspension, a layout design was drawn up in August 2003. This model should be referred to as the starting point for any further conceptual and detailed design.

3. MATLAB QUADRUPLE SUSPENSION MODEL

This mathematical model gives specifications for a suspension design based upon the desired values for isolation and sensitivity in the Advanced LIGO Suspension System Conceptual Design document[1].

All target parameters for geometry, mass and moment of inertia given by the MATLAB model will change as the CAD solid model of the U-I Mass advances. The target parameters are very much the ‘best’ theoretically but not the ‘optimum’ in terms of producing a design for ease of assembly, interfacing or use.

The design of the mass should be seen as an iterative process where any changes or additions to the solid model, and therefore changes to the mass and moments of inertia, will be passed to Norna Robertson to run through the MATLAB model. By so doing, a complex Upper-Intermediate Mass model can be designed that has parameters that are within the allowable tolerance of all targets.

[1] T010103, N.A. Robertson for the GEO Suspension Team + LIGO Suspension Team

4. PERFORMANCE

The dynamic performance of the U-I Mass is dictated by the parameter limits given in the MATLAB Quad Suspension Model. Below are quoted some of the numbers from the initial MATLAB Model[2] but to avoid confusion the most up-to-date numbers can be obtained from Norna Robertson. The symbols shown in brackets, e.g. (ab), are those used in the MATLAB model. A full list of descriptions of these symbols with supporting diagrams are contained within document T040072[3].

- The target geometric and mass values are as follows:
    - The **mass** of the full assembly of the U-I Mass (m1) will be 21.9kg
    - The **dimensions**[4] for the **main body** of the U-I Mass are:
        - Width (nx) = 130mm
        - Length (ny) = 520mm (Changed from 500mm May04)
        - Thickness (nz) = 84mm
    - The **dimensions** for the **T-Sections** of the U-I Mass are determined by several factors:
        - Aiming to best match the MATLAB Model's parameters for Moment of Inertia
        - Avoiding interference with upper/lower wires
        - Large enough to accommodate OSEM coils
    - **Dimensions** for this **T-Section** were given as[5]:
        - Width x = 90mm (was 130mm, changed MPL May 04)
        - Length y = 200mm
        - Height z = 60mm
    - Target **Moments of Inertia** (in kg/m^3) to meet using these parameters are
        - Inx = 0.4678
        - Iny = 0.0436
        - Inz = 0.4858
- The Top Mass must support the suspension of two further masses of total mass 80kg via the bottom blades.
    - The bottom plate of the sandwich, that supports the blade assemblies, should be tested via hand calculation and FEA to ensure that they are stiff enough to support this weight without significant bending.

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[2] August 2003 as shown in document T010103-03-D. Also refer to T040028 'Investigation of Wire Lengths in Advanced LIGO Quadruple Pendulum Design for ETM/ITM'

[3] T040072 'Pendulum Parameters and Naming Conventions'

[4] Where 'x' is in line with the laser beam, 'y' is transverse to the laser beam and horizontal direction and 'z' is transverse to the laser beam and in the vertical direction.

[5] Email from CIT to MPL 02/04/2003

5. Interfacing Sub-Assemblies

- Key interfacing sub-assemblies of the design are as follows:
  - The **blades** for the Top Mass will have/be[6]:
    - Length (l1b) = 370mm
    - Width (a1b) = 49mm
    - Thickness (h1b) = 4.2mm
    - a crossed layout with a ½ break-off separation (n0) = 200mm (see figure below)
    - Positioned within the U-I Mass such that the Penultimate Wires break-off[7] at 1mm below the centre of mass (d1)

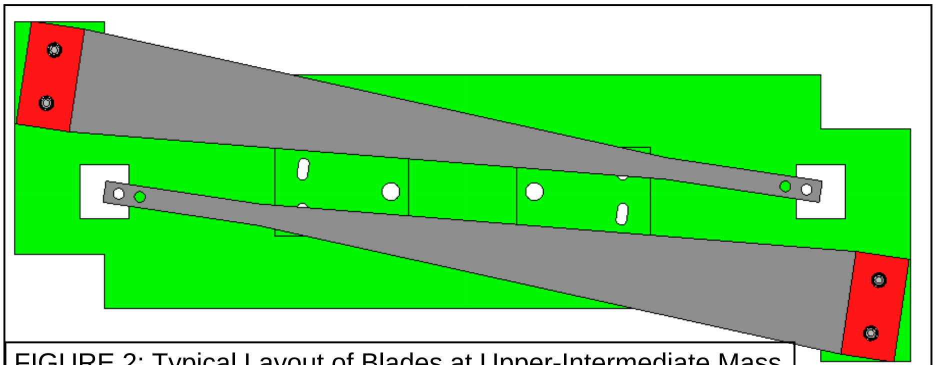

FIGURE 2: Typical Layout of Blades at Upper-Intermediate Mass

  - The **Upper-Intermediate wires** must have suitable **break-off clamps** positioned such that the wire break-off point:
    - Is at 1mm above the centre of mass (dm) [7]
    - Is 70mm from the central y axis (nn1) i.e. 140mm total
  - There are **two** U-I wires at each break-off clamp.

[6] See email from Norna Robertson, April 04 2004 entitled 'revised blade sizes'

[7] The stated break-off point is the wire flexure or bending point and not the physical break-off points where the wire leaves the clamp. For the calculation, see document D040183 Flexure Point of a Steel Wire.

- **Middle Wire Break-off Clamps** may be adjustable as per those in the MIT Quad or the ETM Quad Layout Design (see figure 3 below)

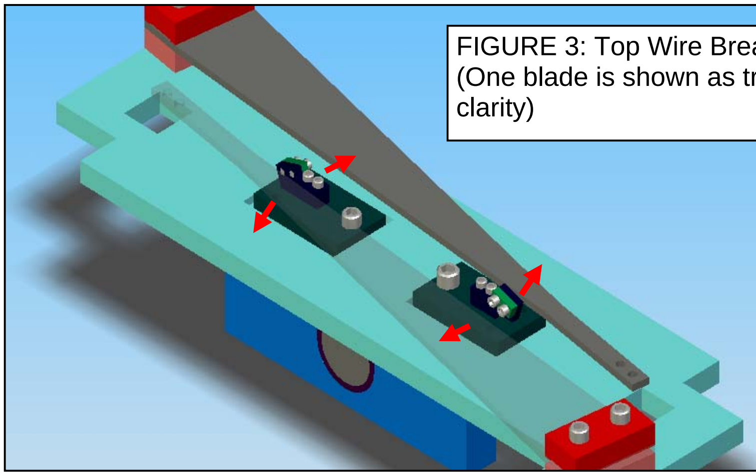

FIGURE 3: Top Wire Break-off Clamps (One blade is shown as transparent for clarity)

- **Middle Wire Break-off clamps** must fit between the two bottom blades and without interference.
- The **Top Plate** of the mass must be constructed such that the bottom half of the mass can be assembled and suspended without it's attachment. Experience from past designs has shown that this makes it easier to attach the unloaded blades and attach of the top wire break-offs. Again, this could be done as per the MIT Quad or the ETM Quad Layout Design (see below)

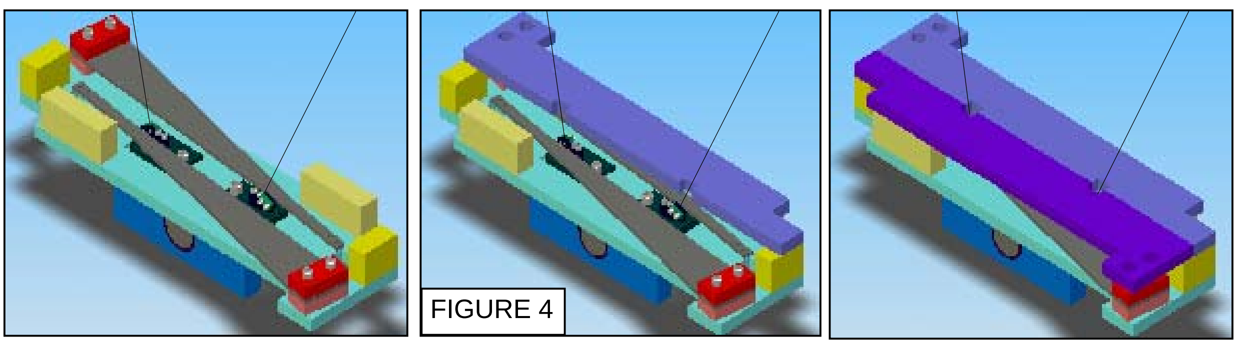

FIGURE 4

- The **T-Sections** of the U-I mass may require some method of **Pitch Adjustment**. This could be similar that in the layout design of the ETM Top Mass (Figure 5).

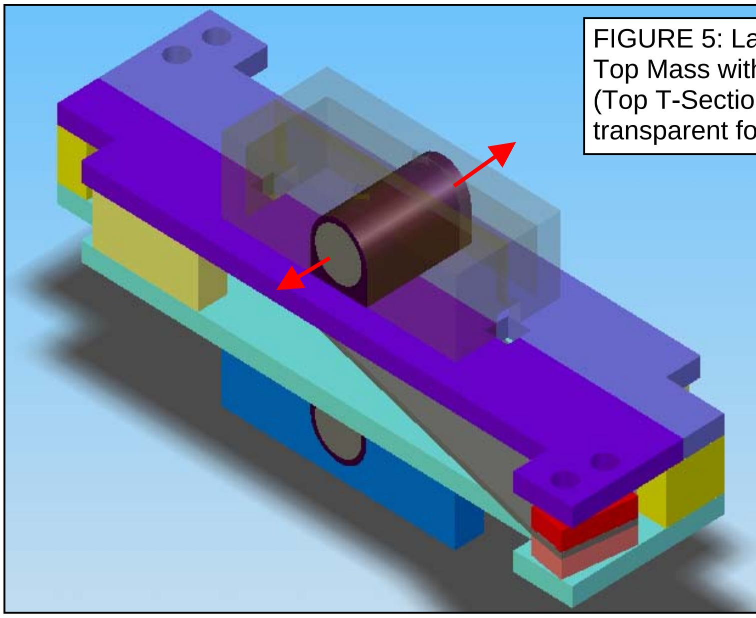

FIGURE 5: Layout design of a Top Mass with Pitch Adjusters (Top T-Section is shown as transparent for clarity)

- These **pitch adjusters** could be developed with a facility for the addition or removal of mass as per the Recycling Mirror concept[8]
- For **global control** in pitch, yaw and longitudinal directions, **coil-magnet actuators** will be positioned between the main and reaction upper-intermediate mass assemblies.
  - There is to be four actuators between the two U-I masses.
  - Magnet-flag assemblies should be fixed on the main U-I mass.
  - Hybrid OSEM coil assemblies should be integrated into the reaction U-I mass. These may incorporate the OSEM brackets used in past suspensions to allow for some adjustment.
  - The coils should be positioned on the front face such as the dimension in the y-direction is the same as that in the z-direction i.e. positioned in a square pattern (see figure 6).

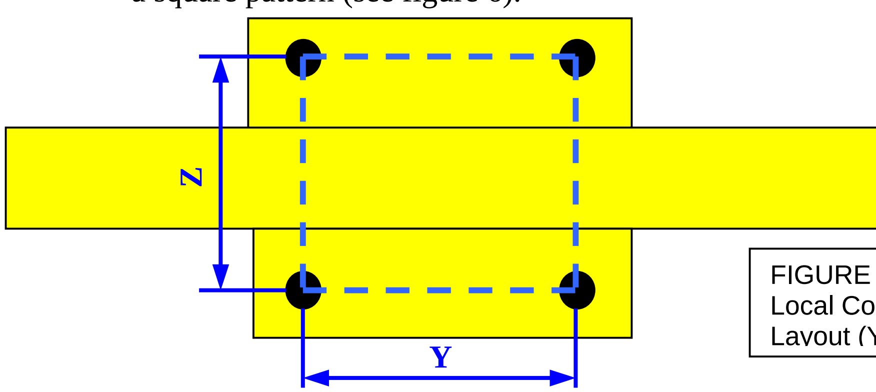

FIGURE 6: Local Control Layout (Y=Z)

8 T030734 Concept for Addition/Subtraction of 500g to/from the Recycling Mirror Intermediate Mass

- The **magnets** that attach to the Main Chain are of diameter 10mm and 10mm in length.
- **Magnets** should be fixed to the Main chain U-I Mass (i.e. no adjustment)
- **Rotational (Yaw) adjusters**, such as those shown in one of the top mass layout design's configurations (Figure 7), should be incorporated if space is available.

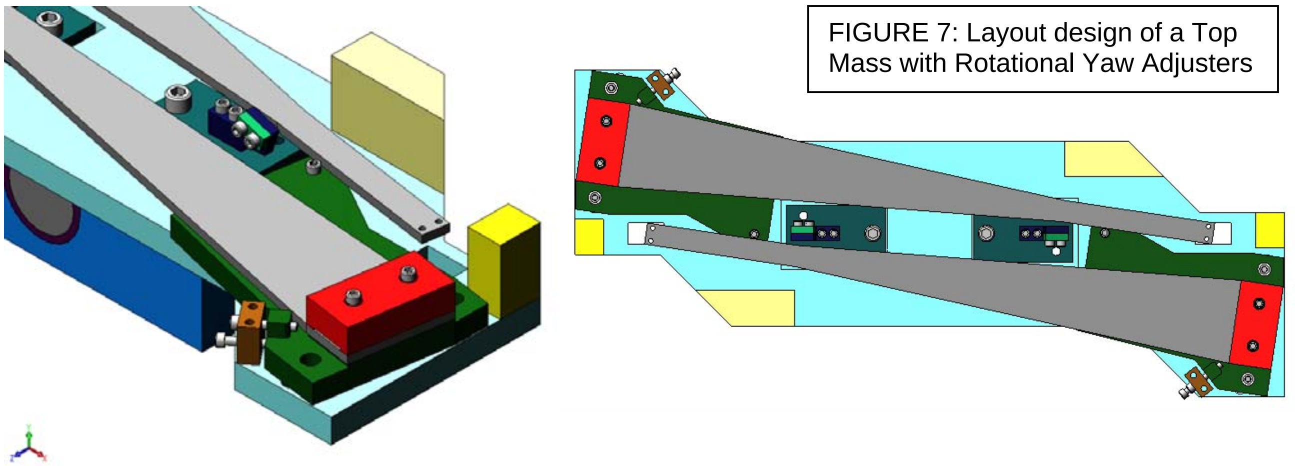

FIGURE 7: Layout design of a Top Mass with Rotational Yaw Adjusters

- The **OSEM coils** must be adjustable in x, y and z directions, and have adjustment for pitch and yaw.

6. Manufacture and Cleaning of Parts

- All parts should be manufactured using water soluble lubricants as specified in the notes of the LIGO 'Smart' CAD Templates[9]
- All parts for the should be cleaned to LIGO Standard[10]

7. Assembly and Installation

- Must be easily assembled preferably using stock imperial fasteners.
- As no lubricants (e.g. grease, oil) can be used during assembly or installation, parts should be designed to avoid cold welding (galling) by the following methods:
    - All threaded holes should use oversized taps
        - +0.003in for #2-56
        - +0.005in for #4-40 and larger
    - Bolts into Aluminium parts should be stainless steel
    - Bolts into Stainless Steel parts should be silver plated stainless steel
    - All clear holes should be specified in accordance with the Advanced LIGO guidelines[11] and ASME guidelines
- Installation of a heavy mass such as this should be considered in the design.
    - Supplementary parts may need design to aid the installation.
    - Modular construction may ease the installation.

8. Environment

- Parts must be suitable for usage in an Ultra High Vacuum environment[10]
- The top mass must be easily assembled and installed in clean room conditions.

9. Materials

- All materials used must be suitable for High Vacuum usage and must be on the LIGO approved materials list[12]
- The MATLAB model assumes an assembly made up of Stainless Steel and Aluminium (not including the blades). A suitable combination of these materials should be selected to achieve the mass, moments of inertia and strength characteristics required.

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[9] D030382 Summary of the Drawing and Data Templates, Macros, Bill of Materials and Customized Toolbox created for SolidWorks and an Introduction to the LIGO Caltech PDMWorks Vault
[10] E960022 LIGO Vacuum Compatibility, Cleaning Methods and Qualification Procedures
[11] T030118 Guide for Specification of Imperial Bolts, Threads and Hole Fits in Advanced LIGO Parts
[12] E960050 LIGO Vacuum Compatible Materials List

- Parts must be manufactured from non-magnetic materials as the performance of the suspended masses can be affected by stray magnetic fields.
  - Stainless Steel 316 is the grade of steel most likely to be non-magnetic, although it cannot be said to be fully non-magnetic, and is the recommended 300 series steel to use in the suspension design.

10. QUANTITY

- A total of two full assemblies are required
- Shelf spares should be manufactured/ordered for all parts – Quantity?!

11. TESTING

- During the development of the design it may be useful to periodically test aspects of the design in relation to interfacing parts (e.g. sub-assemblies, blades, etc)
- On completion of the manufacture of each part, dimensional accuracy should be checked using micrometer, callipers or a height gauge/granite block.