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Top 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 Top Mass.

Revision 00: First draft of the Top Mass PDS

1. INTRODUCTION

This product design specification for the Top Mass is written to ensure that no design factors are ignored or omitted 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 top mass.

The Top 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 upper-intermediate mass) and some clamping fixtures for the wire coming from the top blades. On the outer surfaces of the Top Mass, provision must be made for the attachment of components that interface with the Local Control Dampers.

The specifications for the Top 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.

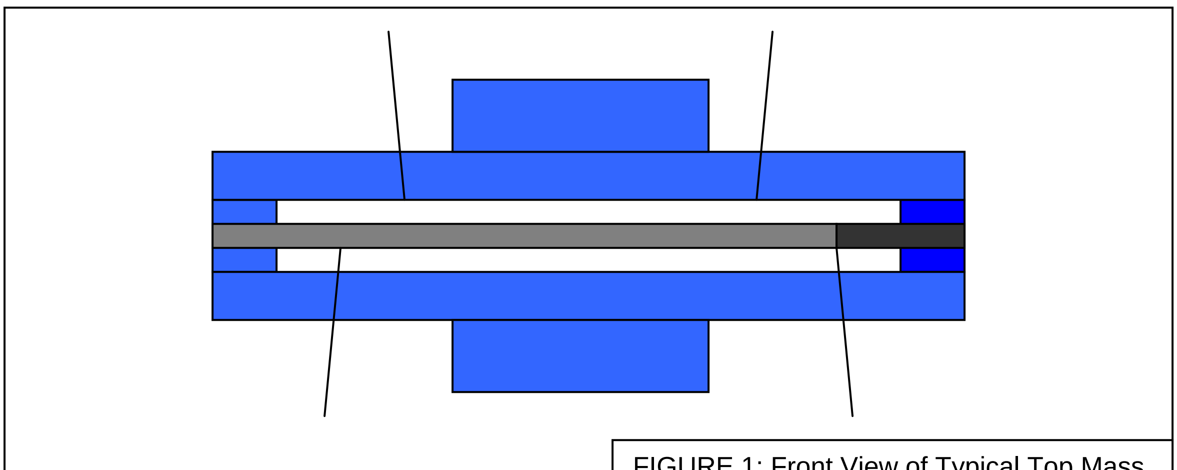

FIGURE 1: Front View of Typical Top Mass

2. Past Quadruple Pendulum Top 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 Top 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

The MATLAB Model is a mathematical model that gives specifications for a suspension design based upon the desired requirements for isolation and sensitivity. These requirements output specifications are shown in document T010103[1] (the numbers have since been updated in document T040028[2]).

All target parameters for geometry, mass and moment of inertia given by the MATLAB model will change as the CAD solid model of the Top 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 Top Mass model can be designed that has parameters that are within the allowable tolerance of all targets.

[1] T010103; Advanced LIGO Suspension System Conceptual Design; N.A. Robertson for the GEO Suspension Team + LIGO Suspension Team
[2] T040028; Investigation of Wire Lengths in Advanced LIGO Quadruple Pendulum Design for ETM/ITM; N.A.Robertson

4. PERFORMANCE

The dynamic performance of the Top 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 (refer to footnotes 1 and 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:

Dimensions for CPTYPE ETM Top Mass (D040370)   Date: July 13, 2004

Dimension		Target Value	Actual Value	Notes
Mass	m	21.9kg	22.04kg	Will aim for 22kg to suit blade design
Width of main body	nx	130mm	130mm	
Length of main body	ny	500mm	500mm	
Thickness of main body	nz	84mm	84mm	
Width of t-section	tnx	130mm	90mm	at thickest point
Length of t-section	tny	200mm	163mm	
Thickness of t-section	tnz	60mm	60mm	
Moment of Inertia X-dir	Inx	0.474 kg-m^2	0.478 kg-m^2	
Moment of Inertia Y-dir	Iny	0.0713 kg-m^2	0.0727 kg-m^2	
Moment of Inertia Z-dir	Inz	0.490 kg-m^2	0..478 kg-m^2	

- The Top Mass must support the suspension of three further masses of total mass 102kg via the middle blades.
    - The bottom plate of the sandwich, that supports the blade assemblies, should be checked via hand calculation and FEA to ensure that they are stiff enough to support this weight without significant bending.
- The Top Mass will be a universal design that can be used for both Main and Reaction Suspensions.
- The main chain top mass must be able to be suspended within 5mm of the reaction top mass without interference.

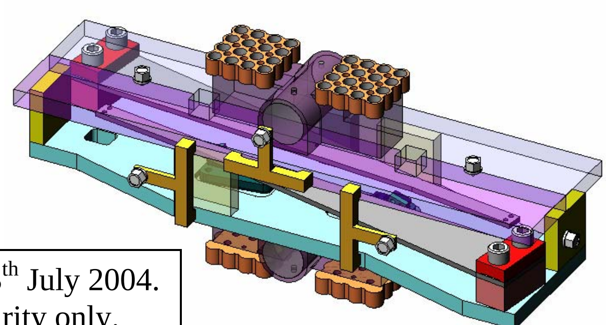

Figure 2: Top Mass as of 13th July 2004. Transparent parts are for clarity only.

[3] T040072; Pendulum Parameters and Naming Conventions'

5. INTERFACING SUB-ASSEMBLIES

There are a number of interfacing subassemblies that need to be considered in during the design of the top mass. It is worth noting that the persons responsible for design of the sub-assemblies in the CPTYPE ETM are specified in the 'Task List' document, T040016.

Key interfacing sub-assemblies of the design are as follows:

- The **middle blades,** D040297, for the Top Mass will have/be:
  - Length (l1b) = 420mm
  - Width (a1b) = 59mm
  - Thickness (h1b) = 4.9mm
  - a crossed layout with a ½ break-off separation (n0) = 200mm (see figure below)

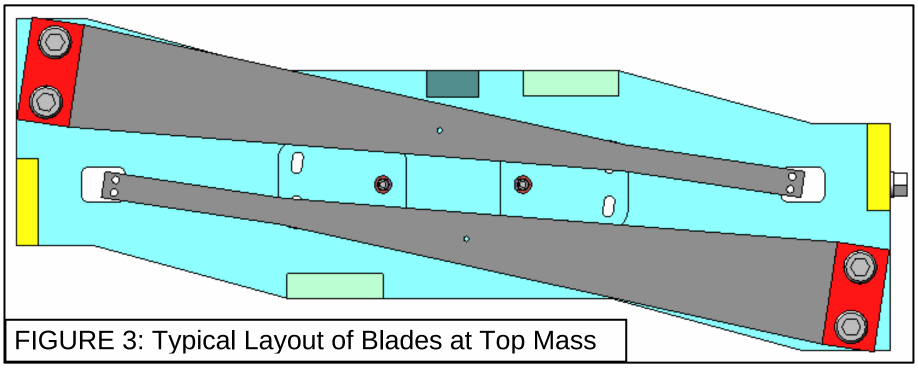

FIGURE 3: Typical Layout of Blades at Top Mass

  - Positioned within the Top Mass such that the Upper-Intermediate Wires break-off[4] at 1mm below the centre of mass (dn)
- The **top wires** must have suitable **break-off clamps** positioned such that the wire break-off point:
  - Is at 1mm above the centre of mass (dm) [6]
  - Is 90mm from the central y axis (nn1) i.e. 180mm total
- **Top Wire Break-off Clamps**:
  - must be adjustable so as to correct any pitch/yaw effect caused by small bolt misalignments during assembly. These could be similar to those used in the ETM Quad Layout Design (see figure right)
  - must fit between the two middle blades and without interference.

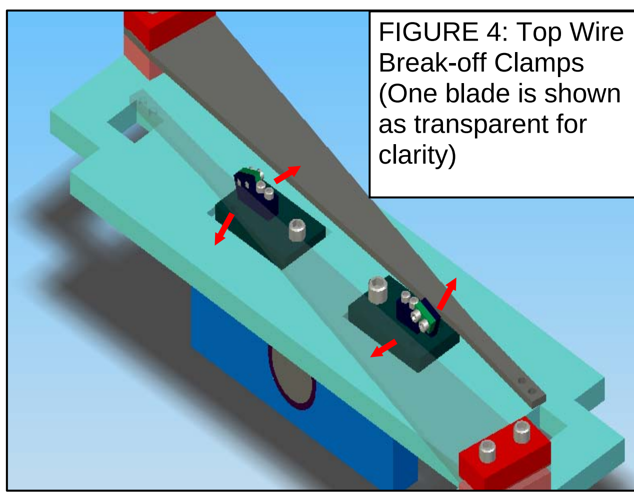

FIGURE 4: Top Wire Break-off Clamps (One blade is shown as transparent for clarity)

[4] 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.

- The **Top Plate** of the mass must be constructed such that the bottom half of the mass can be assembled and suspended without its 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 ETM Quad Layout Design (see below)

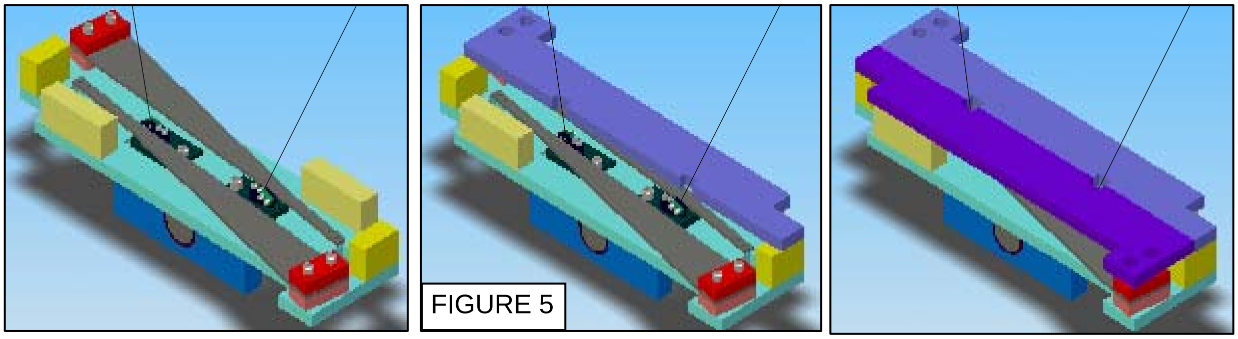

FIGURE 5

- The **T-Sections** of the top mass should incorporate some method of **Pitch Adjustment**. This could be similar to the ETM Quad layout (as shown in Figure 6).
- These **pitch adjusters** could be developed with a facility for the addition or removal of mass as per the Recycling Mirror concept[5]

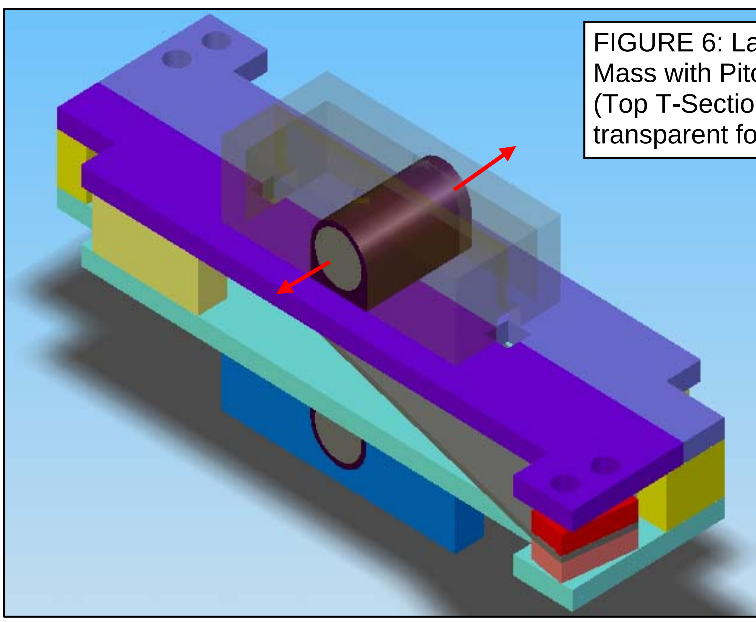

FIGURE 6: Layout design of Top Mass with Pitch Adjusters (Top T-Section is shown as transparent for clarity)

- The **local control and damping** at the top mass will be a combination of Hybrid OSEMs and Eddy Current Dampers:
  - There will be six **magnet-flag/coil assemblies** at the top mass. Assemblies of spacers, magnets and flags should be fixed to the mass such that they can be removed and replaced should a flag be broken.
  - The **magnet-flag assemblies** must have universal locations so that they can be positioned correctly on both the main and reaction Top Masses.

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

- As per the Mode Cleaner upper mass (D020535), a **tablecloth** (or similar) attached to the Suspension structure will hold Hybrid OSEM coils that interface with the top mass magnet-flag assemblies.
- The **OSEM coils** will be held in some kind of adjustable mechanism attached to a tablecloth, thus the magnet/flag assemblies need not be adjustable.
- There will be two **4x4 Array Eddy Current Dampers**. The copper of which, D020476, will be attached to the mass whilst the adjustable magnet array assembly will be attached to the tablecloth.
- The positions of the coils and ECDs should be as follows:

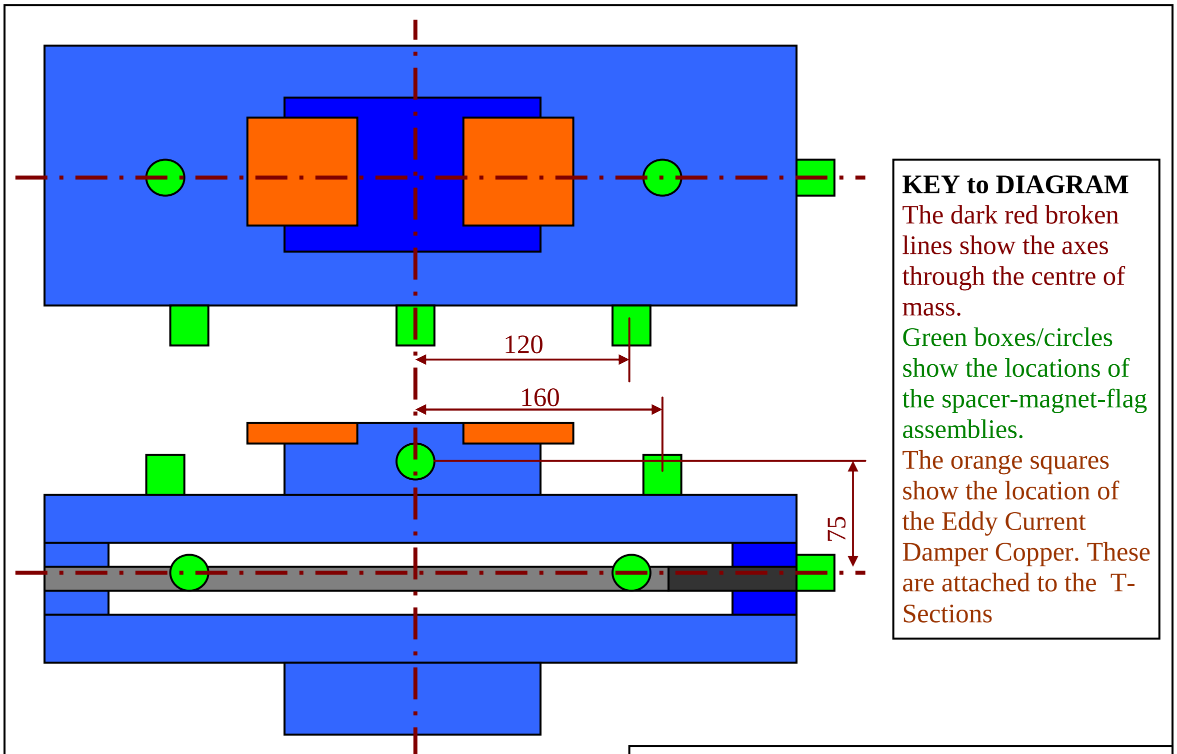

FIGURE 7: Top Mass Flag/ECD Locations

- **Eddy Current Dampers** should be placed apart such that there will be no interference between the adjustment mechanisms that are attached to the tablecloth.

- If possible a method of **adjustment at the blades to allow for pitch and yaw** should be incorporated in the scope of the design. This may be similar to the **rotational adjuster** used at the top stage blades **or** may be a separate **mechanical device (mechanical finger)** that can move the blade tip.
- The top mass must have a facility to fasten 32 fine copper wires coming from the global controls lower in the suspension chain. This will likely consist of a suitably positioned, non-conductive clamp, fastened to the mass via two bolts.
- The Main Chain Top Mass will have to hang parallel and at a distance of 5mm from the Reaction Chain Top Mass without interference.

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[6]
- All parts for the Top Mass assembly should be cleaned to LIGO Standard[7]

7. ASSEMBLY AND INSTALLATION OF THE TOP MASS

- 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[8] and ASME guidelines
- The top mass will be assembled on an optical bench top and installed like as a cartridge assembly likely to also include the table cloth.
  - Refer to the Mode Cleaner Top Mass installation document, E030518.
- Supplementary parts may need to be designed to aid the installation, e.g.
  - Mechanical finger for blade tip adjustment
  - Blade bending mechanism.
- Disassembly, on a bench top or within the structure (due to component failure), should be considered for some parts of the design, e.g.
  - Spacer-magnet-flag assemblies my need removed to replace a broken magnet;
  - Wires may need replaced thus access to the blade wire clamps and wire clamps will be required.
- Consideration should be made for how much the tablecloth affects the accessibility of parts during disassembly. Refer to PDS for the Tablecloth (T040…)

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[6] 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
[7] E960022 LIGO Vacuum Compatibility, Cleaning Methods and Qualification Procedures
[8] T030118 Guide for Specification of Imperial Bolts, Threads and Hole Fits in Advanced LIGO Parts

8. Environment

- Parts must be suitable for use in an Ultra High Vacuum environment (see footnote 9)
- The top mass must be easily assembled and installed in clean room conditions.

9. Materials

- All materials used in the Mass must be suitable for High Vacuum Usage and on the LIGO approved materials list[9]
- 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.
- 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 of the top mass are required to act as main and reaction masses.
- Shelf spares should be manufactured/ordered for all parts
  - There should be enough shelf spares for at least one spare mass
  - For smaller parts and wire clamps numerous spares should be manufactured as these are often lost or damaged during the controls prototype build and disassembly process.

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.

[9] E960050 LIGO Vacuum Compatible Materials List