LASER INTERFEROMETER GRAVITATIONAL WAVE OBSERVATORY

LIGO Laboratory / LIGO Scientific Collaboration

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Action Item Progress for the HLTS

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1 Introduction

This document describes the progress on the action items listed in the HLTS (HAM Large Triple Suspension) Final Design Review committee's report (M1000126-v3). Some action items are short-term (July 2010), while others are longer term (September 2010 and beyond). As the action items are resolved, this document will be revised.

2 Action Item Descriptions and Current Progress

The following is the complete list of paraphrased action items from M1000126-v3 and the current progress on each item. The subsections correspond to the number of the action item on the list (i.e. Subsection 2.1.3 describes Action Item 1, Point c.).

2.1 Mechanical Design/Drawing Changes

2.1.1 Correction of d-value

The d-values for the prototype Upper Mass were incorrect and had to be altered using angled lower blade clamps and additional mass. To resolve this, the lower blade clamps (see D0900681-v2) have been lengthened as part of the overall Upper Mass redesign. Assuming straight, level lower blades, the lower breakoff of the Upper Wire is now positioned 2 mm above the upper breakoff of the Intermediate Wires. The OSEM flags have also been repositioned so that the force from the side OSEMs passes through the center of mass of the Upper Mass, decoupling linear motion from rotational motion. The Upper Mass T-Piece (D020607-v3) has been redesigned so that the mass of the Upper Mass in SolidWorks is now 12.1 kg, as specified in the revised design of the Upper Blades. The redesign of the Upper Mass T-Piece also places the center of mass of the Upper Mass (including all attached wire clamps) so that d0 = d1 = 1mm.

With the completion of the redesign of the Upper Mass (D070335-v3), this action item is now resolved.

2.1.2 Elimination of Self-Clinching Nuts from Structure

The self-clinching nuts have been eliminated from the HLTS structure in favor of threaded holes. The minimum wall thickness of the tubing for the prototype structure was measured to be 0.112". Since all of the self-clinching nuts used on the prototype structure were for #8-32 screws, a tapped hole at the minimum tube thickness would allow for approximately 3.6 screw threads. This is greater than the desired 3 full threads with an acceptable margin.

This action item is considered to be resolved since the changes have been made to the SolidWorks model and drawing. The changes have not yet been posted to the DCC since other changes must also be made to the SolidWorks model and drawing of the HLTS structure.

2.1.3 "Invisible" Earthquake Stops in Coil Holder

The coil holder has some earthquake stops that cannot be viewed. Viewing holes have been added to the coil holder.

The redesign of the coil holder is now complete, so this action item has been resolved.

2.1.4 Consider Alternatives for Earthquake Stops

We have been asked to consider split or sprung bolts or lock nuts, instead of a jam nut, to prevent movement of the earthquake stops. We believe that jam nuts are acceptable. Alternatively, if jam nuts are used, we have been asked to consider designing a tool that holds the earthquake stop in place while the jam nut is tightened. This type of tool has been designed, but multiple lengths may be required to cover all situations.

2.1.5 Chamfer and Deburr HLTS Structure Base Plate

The base plate of the HLTS structure should be chamfered and deburred. This has been completed in the SolidWorks model and drawing. This change is not yet on the DCC since other changes must also be made to the SolidWorks model and drawing.

This action item is considered to be resolved since the changes have been made to the SolidWorks model and drawing.

2.1.6 Consider Alternatives for Mounting Additional Mass

The additional removable masses on the Upper Mass and Intermediate Mass should be mounted in a different way to prevent them from coming loose. The redesigned Upper and Intermediate Masses will be designed to use self-locking helicoils (assuming they are approved for in-vacuum use). The self-locking helicoils will prevent screws holding the additional mass from coming loose. In addition, vent grooves have been added to the additional mass disks. The attachment point for the additional mass on the Intermediate Mass has been moved from the top (where it had a great effect on the location of the center of mass) to the front and back sides (where it has little effect on the center of mass).

This action item is now resolved, pending the expected approval of the use of self-locking helicoils in vacuum.

2.1.7 Redesign Coil Holder Mounts

The mounting of the coil holder to the prototype HLTS structure required ¼" shims. To solve this issue, the coil holder will be mounted using L-shaped brackets instead of S-shaped brackets, which will allow for adjustment in the direction that previously required shims.

The redesign of the coil holder, including the mounting brackets, is now complete, so this action item is resolved.

2.1.8 Plexiglass OSEM Alignment Targets

Plexiglass alignment targets should be used to align the OSEMs to their flags. Since this is a tooling issue, a resolution will be delayed until after the HLTS structure and machined parts have entered procurement.

2.1.9 Change Trim Masses

In order to increase the precision of the adjustment of the Upper Mass trim masses, the sliding masses should be replaced with threaded trim masses, as in the HSTS. The Upper Mass roll trim mass was kept as a sliding plates, just as it is for the HSTS. The Upper Mass pitch trim mass has been changed to sliding block (for coarse adjustment) with a threaded hole to accommodate a ½-20 UNF by 3.5” long set screw (for fine adjustment). This arrangement is essentially the same as that for the HSTS. See Section 2.3 for estimates of the range and precision of the angular adjustment of these trim masses.

With the redesign of the Upper Mass completed, this action item is now resolved.

2.2 Drawing Review

Calum Torrie is to review the final production drawings to ensure that all adjustment and alignment features of the HSTS are present in the HLTS, and to check all key suspension parameters. All drawings of parts and subassemblies up to the HLTS Suspension Assembly (which includes all suspended masses and wires) were submitted to Calum on August 9.

2.3 Adjustment Range and Precision Measurements

The range of each adjustment and the precision of most adjustments on the HLTS prototype have been measured; see E1000232. A summary of these measurements is presented below, along with estimates for the production version, where applicable.

2.3.1 Intermediate Mass – Vertical Adjustment from Additional Mass

The height of the Intermediate Mass can be adjusted by adding mass; the relation is roughly linear. An additional mass of 750 grams decreased the height by 3.969 mm for a relation of 0.00529 mm per gram. With the smallest additional mass disk having a mass of 10 grams, the height of the Intermediate Mass can be controlled to within 0.0529 mm using additional mass.

2.3.2 Upper Mass – Vertical Adjustment from Additional Mass

The height of the Upper Mass can be adjusted by adding mass; the relation is roughly linear. An additional mass of 1000 grams decreased the height by 3.175 mm for a relation of 0.00318 mm per gram. With the smallest additional mass disk having a mass of 10 grams, the height of the Intermediate Mass can be controlled to within 0.0318 mm using additional mass.

2.3.3 Angled Upper and Lower Blade Clamps

The Upper and Lower Blade Clamps are produced in multiple versions with varying angles to angle the blade tips up or down. The Upper Blade Clamps (see D0900665) are produced with angles from 0 degrees to 3.5 degrees in increments of 0.5 degrees. With a distance of 250 mm from the blade clamp to the blade tip, the tips of the Upper Blades can be adjusted to +/-15.26 mm from the horizontal, with a precision of approximately 2.18 mm. The Lower Blade Clamps (see D0900681) are produced with angles from 0 degrees to 3.5 degrees in increments of 0.5 degrees. With a distance of 120 mm from the blade clamp to the blade tip, the tips of the Upper Blades can be adjusted to +/-7.33 mm from the horizontal, with a precision of approximately 1.05 mm.

The Upper and Lower Blade Clamps have been redesigned from their prototype versions. The angles and the resulting vertical adjustments remain the same. The angled clamps are now designed so that the vertical position of the clamped end of the blade is the same if the clamp is placed so that the blade is angled upward or downward; the prototype versions of the clamps caused the vertical position of the clamped end of the blade to change based on whether the clamp is angled so that the blade points upward or downward.

2.3.4 Upper Mass – Roll Adjustment from Sliding Mass

The roll attitude of the Upper Mass can be adjusted by moving a sliding plate in the y-direction; see D030139. For the prototype, the position of the sliding plate for a level Upper Mass was 60.5 mm off-center in the +y-direction, which is very close to maximum adjustment. From symmetry, the total adjustment range of the sliding plate is 121 mm, which corresponds to a roll range of 15 mrad. The measured sensitivity of the roll adjustment is 0.5 mm in movement of the sliding plate (the smallest division of the ruler used), which corresponds to 1.1 mrad in roll. It is estimated that the sliding plate can be adjusted by hand to within approximately 0.25 mm, which would correspond to a roll adjustment of approximately 0.5 mrad.

The redesigned roll mass (D030139-v2) has approximately the same cross-sectional area as that of the prototype (1.00 in^2 for v2 versus 0.98 in^2 for v1) and the same overall length (4.530 in), so that the relation between the adjustment of the roll mass and the roll angle should be very similar to that of the prototype. The set screws that hold the roll mass have been repositioned so that the maximum adjustment is now +/-32.1 mm, which corresponds to a roll angle adjustment of +/-4 mrad. Since this roll offset is still positioned by hand, the precision is estimated to be approximately 0.25 mm, corresponding to an angular precision in roll of approximately 0.5 mrad.

2.3.5 Upper Mass – Pitch Adjustment from Upper Wire Position

The pitch attitude of the Upper Mass can be adjusted by moving the connection of the Upper Wire to the Upper Mass in the x-direction. The total range of this adjustment, from the position where the Upper Wire touches the front of the slot in the Upper Mass (see D020605 for the location and size of the slot) to the position where the Upper Wire touches the back of the slot in the Upper Mass, is 33.8 mrad.

The size of the slot that the Upper Wire passes through has not been changed in the production version of the Upper Mass, so the range of this adjustment should remain the same as the prototype.

2.3.6 Upper Mass - Pitch Adjustment from Sliding Mass

The pitch attitude of the Upper Mass can be adjusted by moving a sliding plate in the x-direction; see D020608. For the prototype, the position of the sliding plate for a level Upper Mass was 2.5 mm off-center in the +x-direction. The total adjustment range of the sliding plate is +/-21 mm (for a total of 42 mm of adjustment), which corresponds to a pitch range of 44 mrad. The measured sensitivity of the pitch adjustment is 0.5 mm in movement of the sliding plate (the smallest division of the ruler used), which corresponds to 4.4 mrad in pitch. It is estimated that the sliding plate can be adjusted by hand to within approximately 0.25 mm, which would correspond to a pitch adjustment of approximately 2.2 mrad.

The redesigned sliding pitch mass (D1001669-v1) has approximately the same cross-sectional area as that of the prototype (1.52 in^2 for D020608-v1 versus 1.54 in^2 for D1001669-v1) and the same overall length (3.780 in) with approximately the same mass (753 grams for D020608-v1 versus 785 grams for D1001669-v1), so that the relation between the adjustment of the pitch mass and the pitch angle should be very similar to that of the prototype. The set screws that hold the pitch mass have been repositioned so that the maximum adjustment is now +/-22.6 mm (for a total of 45.2 mm of adjustment), which corresponds to a total pitch range of 47.3 mrad. Since this pitch offset is still positioned by hand, the precision is estimated to be approximately 0.25 mm, corresponding to an angular precision in pitch of approximately 2.2 mrad.

All of the above measurements are for the redesigned sliding mass only. The redesigned sliding mass also has a threaded hole to accept a ½”-20 silver-plated set screw that is intended for fine pitch control. The 3.5”-long set screw has a cross-section of 0.196 in^2 and a mass of 88.2 grams and has an adjustment range of +/-1.14” (+/-29.0 mm) within the sliding mass. Based on the initial measurements, and taking into account the lesser mass, the set screw alone has a pitch range of +/-3.6 mrad. Assuming that the screw can be adjusted to within a quarter turn (0.0125” or 0.318 mm), the pitch precision is approximately 43 μrad. Since the range of the silver-plated set screw is larger than the angular precision of the sliding mass in pitch, the combination of the two gives a system with a total pitch range of 54.5 mrad with a precision of approximately 43 μrad.

2.3.7 Upper Blades – Yaw Adjustment from Rotational Adjuster

The yaw attitude of the entire suspension can be adjusted using the Rotational Adjuster. The total yaw adjustment available is 33.1 mrad (+25.8 mrad and -7.3 mrad from the balanced position). The yaw in the negative direction is limited by an interference in the push/pull screws.

In the production version of the HLTS, the push plate has been modified (replacing a large clearance hole with a slot) to eliminate the interference described above, so the yaw adjustment in the negative direction should be increased. The push and pull screws have also been changed to stainless steel rounded-end screws threaded into helicoils, which eliminates particulate problems that were encountered with the silver-plated screws used in the prototype.

2.3.8 Upper Blade Clamp Shims

The height of the entire suspension can be adjusted through the use of 1 mm shims (see D070331) in the Upper Blade Clamps. In the prototype, the nominal arrangement included one of these shims on each Rotational Adjuster.

In production, the nominal arrangement will not include the shims, since the optic height can be decreased by flycutting the Mounting Pads where the Rotational Adjusters are attached. A 2 mm shim has also been designed so that the optic height can be increased by 1 mm or 2 mm using one shim, or 3 mm or 4 mm, using two shims. With two 2 mm shims, the 5/16-18 screws securing the Upper Blade have 5 full threads of engagement in the Rotating Plate of the Rotational Adjuster.

2.4 Software Implementation

A separate review of the software implementation in Simulink and MEDM screens should be undertaken. The timing of this review should be determined by Jay Heefner in concert with others.

2.5 Optic/Prism Bonding Testing

Testing of the procedure for bonding sapphire wire prism breakoff to an actual optic must be accomplished early enough to refine the procedure and tooling in advance of installation on the L1 interferometer. This testing is planned for an HSTS-type optic, which is the more difficult of the two HAM suspensions, and should be complete by the end of September.

2.6 Wire Diameter

Suspensions will explore the possibility of purchasing wire with a more closely controlled diameter, so that the vertical bounce frequencies can be better matched. This may be done through a custom order, or by selecting certain wire segments from a spool or spools. This should be complete by September.

2.7 Alignment Procedure

A checklist-type alignment procedure must be developed to reduce the difficulty in aligning the HLTS. Qualitative measures should be replaced by quantitative ones. This should be complete by September in preparation for the first assembly in April 2011.

2.8 Actions for Systems/Facilities

We are awaiting a timeline from Systems for these items.

2.8.1 Damping Struts or Tuned Mass Dampers

Either damping struts or tuned mass dampers will be used with the HAM suspensions.

2.8.2 Structural Bracing

Will adjacent HLTS and HSTS structures be joined across their tops for stiffening and potential damping?

2.8.3 Clamping Suspensions to Optics Tables

The clamping arrangement (number and types of clamps) must be determined for each HLTS.

Changes are being made to the HLTS structure to allow for a much wider range of positions and orientations for clamp placement. Once these changes to the structure are approved, the final clamping arrangement can be determined.

2.8.4 HAM Suspension Installation Tooling

Complete the design of the HAM suspension installation tooling.

3 Questions and Answers Related to HLTS Redesign

In this section are questions and answers, originally asked and answered via email, regarding the redesign of the HLTS (including the action items described above). The questions and answers have been edited to include clarifications of the original versions.

Q1. Could you give the numbers for why wall thickness and tapped holes etc ... is okay?

A1. This is described in Section 2.1.2 of T1000356.

Q2. Are we all signed up for only one jam nut now?

A2. Yes - one jam nut for all earthquake and blade stops.

Q3. Systems will design tool for adjusting / locking all stops. In fact you should now have one for review.
A3. We received the tool a couple of weeks ago - I have not personally used it yet.

Q4. Re the structure the outstanding items are:

- new layout of gussets which you and I have in hand and can present to DC soon
- weld-ability, this is an item you need to talk to MM about

A4. This is covered in T1000452, which I circulated to Norna and Janeen [earlier].

Q5. What is your back up to self locking heli-coils / why are they needed?

A5. They are needed so that screws that hold in additional masses, etc. won't come loose; the back up is to use regular helicoils with all-metal locknuts instead of jam nuts. The most recent version of the drawings call out the self-locking helicoils and jam nuts; if we need to use the back up solution, only the assembly drawings need to be changed (to change part numbers).

Q6. Section 2.3.1 - is not way to much accuracy? - isn't your requirement something like +/- 1mm? I was expecting something like +/-2mm with 0.5 mm accuracy

A6. The accuracy for the Intermediate Mass is 0.00529 mm per gram; for production, the smallest additional mass is 10 grams for an adjustment of 0.0529 mm. The 10-gram additional mass is not designed for this application (it is intended to be used to adjust center of mass) although it can be used, which is why the height adjustment range is so small.

Q7. Section 2.3.2 - is not way to much accuracy? - isn't your requirement something like +/- 1mm? I was expecting something like +/-2mm with 0.5 mm accuracy.

A7. The accuracy for the Upper Mass is 0.00318 mm per gram; for production, the smallest additional mass is 10 grams for an adjustment of 0.0318 mm. The 10-gram additional mass is not designed for this application (it is intended to be used to adjust center of mass) although it can be used, which is why the height adjustment range is so small.

Q8. Section 2.3.4 - did you have cases in the prototype where this (roll adjustment for the Upper Mass) helped?

A8. Originally, the prototype had to have the roll adjustment mass all the way to one side to correct a roll error. This roll error was traced back to the mounting pads being uneven. Once this was corrected, the roll adjustment mass was still used to correct a much smaller roll error (due to a combination of blades not matching exactly and variations in the Upper Mass machined parts).

Q9. Section 2.3.5 - (Upper Mass pitch adjustment by moving Upper Wires) v similar to sliding plate, so should this be something you use to line up during assembly and leave?
A9. This should be set so that the wires are centered, unless there is a very good reason to move them. The main method of pitch adjustment should be the sliding mass/set screw combination.

Q10. Section 2.3.6 - (Upper Mass pitch adjustment using a sliding mass) good, how will the sliding plate be controlled? (maybe I missed something earlier).

A10. The position of the sliding mass should be set by hand, using a ruler as a guide, before the mass is put into the structure. Adjustments (also by hand) may be needed later, but they should be small.

Q11. Section 2.3.7 - (Yaw adjustment of Upper Blades) I assume this is used to align suspension to OSEMS on frame and then any global yaw is done by pushers?

A11. That is correct.