Quad Electronic and Optical Alignment Procedure – for LLO training 5-9 October 2009

1 Pre-aligning steps

Step	What	Where	Time	People	Tools
1	Make sure all the OSEM and ESD cable routing is complete.				
2	Make sure all the electronics and computers are hooked up and appear to be working.				
3	Bring UI magnets and flags close to their final positions to prevent major pitch offsets when the UI mass OSEMs are aligned later.				
4	Install simple, robust damping loops (e.g. a DC zero and two real poles at 20Hz). These are useful throughout the procedure below.				

2 Align top masses and check overall suspension balance

Step	What	Where	Time	People	Tools
5	Align both top masses to the top mass OSEMs.				
6	Roughly set by eye the mirror and reaction mass pitch. This will make the severity of any misalignments at the highest stages most apparent. Thus, the absolute pitch of the top mass and differentials between the top and UI will be highlighted, where most of the iterations are likely to occur.				
7	Measure TFs as a suspension test on both chains. If there is interference, remove it and return to step 4.				
8	Check the damping loops and tweak as necessary.				
9	Turn damping off for now.				

3 Revisiting the pitch balancing

3.1 Main chain

Step	What	Where	Time	People	Tools
10	On the main chain remove any differential pitch between the top and UIM by shifting addable-removable mass and if necessary re-center the blade spring tips.				
11	If the differential pitch was adjusted in step 10, remove the resulting absolute pitch of the chain at the top mass. Moderate pitches can be removed with the pitch adjusting screws. Large pitches can be adjusted by moving the wire attachment points of the top wires at the top mass bottom plate.				
12	Realign the top mass OSEMs and measure TFs as a suspension test. If interferences are found return to step 10.				

3.2 Reaction chain

Step	What	Where	Time	People	Tools
13	On the reaction chain use the large PUM pitch adjuster to remove differential between the UIM and PUM.				
14	Repeat the main chain procedure in steps 10 and 11 for the reaction chain top-UIM differential and absolute pitch.				
15	Realign the top mass OSEMs and measure TFs as a suspension test. If the main top mass OSEMs shifted during the reaction chain work then some interference has developed there and must be debugged.				

4 Aligning the global control OSEMs

- Adjustments will need to be done with the masses locked down. Thus, iterations between locking, adjusting, and observing will be necessary.
- If any transverse-roll misalignments exist, they will become apparent here if the OSEMs do not have sufficient range to line up with their flags.
- Alignment of the magnet along its axis in the OSEM is not as critical as the top mass OSEMs since the photodiode signal will not be used in feedback loops. The signal is useful as a metric for how close the magnet is to the sweet spot along this axis during the procedure below.

4.1 UIM OSEMs

Step	What	Where	Time	People	Tools
16	Lock all the masses in both suspensions with the quad as close to the suspended configuration as possible.				
17	Bring in the OSEM magnets and flags. Make sure the magnet is roughly centered in the OSEM bore by eye. Use the photodiode signal from the flag to check that it is near the 'sweet spot'. For the BOSEMs the 'sweet spot' will result in about half of the magnet sticking out of the OSEM.				
18	Release all the masses in both suspensions.				
19	Check the top mass OSEM signals are still near their midrange and visually inspect the overall pitch of the two chains. If the top OSEMs are still in range damping will help the suspension settle down. Repeat the steps above as necessary. If the top mass OSEMs drift a significant				

Step	What	Where	Time	People	Tools
	amount then it may be necessary to return to Part 3 and revisit the differential pitch.				
20	Measure TFs as a suspension test on both chains. If interferences exist remove them and return to step 16.				

4.2 PUM OSEMs

Step	What	Where	Time	People	Tools
21	Adjust the PUM OSEMs using the same procedure as the UI mass. Note, here all the adjustments are in the OSEM itself. Pitch offsets from movement of the OSEMs can be removed with the PUM pitch adjuster.				
22	Measure TFs as a suspension test on both chains.				

5 Optical test mass alignment

Step	What	Where	Time	People	Tools
23	Optically align the main chain test mass by using the top mass pitch adjusting screw.				
24	Follow the main test mass with the reaction test mass using the analogous pitch adjuster to preserve the ESD gap.				
25	Check the top mass OSEM signals. If they significantly changed then return to Part 3 to revisit the differential pitch. It may also be necessary to rotate the structure if yaw has drifted. The damping loops will help the suspensions settle if the top mass OSEMs are still in range.				
26	Check that the OSEMs in the UI mass and PUM are still roughly aligned.				

Step	What	Where	Time	People	Tools
27	Measure TFs as a suspension test on both chains. If interferences exist, remove and iterate as necessary.				

6 Install the eddy current dampers (ECDs)

Step	What	Where	Time	People	Tools
28	Install a few of the ECDs. If the top mass OSEMs were not carefully aligned before they may need to be adjusted to get the ECDs in.				
29	Measure TFs to check for interference and adjust as necessary.				
30	Repeat steps 28 and 29 until all the desired ECDs are in.				

7 Transfer function debugging matrix

This was an effort to compile the quad debugging experience at LASTI into a convenient format. It was put together for this training session and thus is largely untested, but it is believed a version of this will help speed the process of debugging something as complex as a quad pendulum.

All necessary information can be obtained from measuring transfer functions around the top masses. In fact the top mass is preferable since the OSEMs on the three lower stages couple motion between the main and reaction chains, which makes the problem more complicated than necessary.

The process of using the information below works by measuring a transfer function along a chosen degree of freedom (DOF) at the top mass and comparing it to a known reference. For a newly built pendulum, this will likely involve referencing a previous pendulum that was known to be working properly.

The list of possible interferences is the top row, while the list of possible effects is the left column. And 'X' indicates a definite link between cause and effect. An 'O' indicates a possible link, depending on the circumstances of the particular case. For instance, there is an entire spectrum between a 'rubbing' stop and a 'locked' or 'hard' stop. As a result, the 'Rubbing' column is largely filled with O's.

There is also a distinction between suspended ‘sus’ parts and non suspended ‘non-sus’ parts. For example, an interference that grounds the suspension to the structure (e.g. EQ stop) will have a much different effect than one that connects two stages of the pendulum that are otherwise suspended despite the interference (e.g. blade spring stop).

Each column and row also has a short set of notes appended to the end to highlight important points.

TF Debugging Chart	**Non-sus stop, magnet, or cable: ‘hard’ interference**	**Top stage spring interference: ‘hard’, non-sus**	**Sus spring interference: ‘hard’**	**Rubbing: ‘soft’ interference (sus and non-sus)**	**OSEM/ESD cable tension (sus)**	**Misaligned OSEM**	**Top mass pitch tilts**	Response Notes
Low frequency suppression	X	X				X		External to suspended chain
High frequency Suppression	X	X	X	O	O	X		No low frequency suppression is giveaway for sus interferences.
Resonance and zero movement (TF shape)	X	X	X	O	O			From localized stiffness. Resonances can only go up in frequency.
Resonance frequency cross coupling	X	O	X	O	X	O	X	Coupling limited to a subset of

								DOFs or resonances is a hint
Asymmetric response	X	O	X	O		X		E.g. the left side responds more to left side interferences
Visible in all DOFs	O			O				Giveaway for non-sus interferences touching a mass
Noisy appearance				X		X		If it shows up in many unrelated TFs then probably rubbing.
Bug notes	There is a spectrum between 'soft and 'hard'. Harder interferences show up in all DOFs. Anything touching both structure and suspension.	If both springs are stopped up the response may be symmetric with no added cross couplings. And asymmetries or cross couplings that do appear are limited to z and roll.	UI, top mass: blade stop; UI mass: blade ECD, tip adjuster; top mass: Face 3 magnet/flag standoff bottoming out	Highly variable on case by case basis. Depends where on the 'soft-hard' spectrum and whether sus or non-sus. Stops, cables, magnets, touching	Large stiffnesses or tensions will change the TF shape; usually z and pitch. Small stiffness increases may simply add cross coupling between pitch and z	A particular channel component will appear affected. Other resonances measured by the good channels may poke through as cross coupling.	On its own it only adds pitch to z coupling. Likely caused by poor balancing, but could be cable tension on top mass.	

				main and reaction.				

KEY: sus = suspended, non-sus = non-suspended, X = definite effect, O = possible effect

Low vs. high frequency purposely left vague. Most important low frequency below first resonance, but may also include it.