LASER INTERFEROMETER GRAVITATIONAL WAVE OBSERVATORY
-LIGO-
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Procedure	LIGO-E1200453-V5	10/Oct/2013

Fine Initial Alignment Procedure of the Transmission Monitor Telescope

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1. References

1. “SOP for Arm Length Stabilization Setup in LVEA and VEA”, M1100040v6.
2. “TRANSMON ISC Table Layout and Opto-Mechanics”, D1000484-V9.
3. “TRANSMON ISC EX Layout”, D1201457.
4. “TRANSMON ISC EYLayout”, D1201458.

2. Tools Required

- One laser sensor card to be used inside the chamber. The card should be wiped thoroughly clean and the part where the worker holds should be wrapped with aluminum foil. Make sure to double fold the foil edge so no aluminum shedding falls inside the chamber.
- One laser sensor card to be used outside the chamber.
- Assortment of class B Allen keys.
- An iris on a small post and post holder. If a sensor card with a 3 to 4 mm diameter hole is available, it is convenient to mount the card on a post and use it as an iris.
- Half wave plate for green beam that is mounted on the ALS table for the red path work.
- Clean aluminum foil.
- D1100613 alignment stabilization tool should be installed in chamber to limit the motion of the TMS. This will also make it easier for a worker to damp the motion by hand by resting his/her hand on the tooling and gently touching the ISC table.

3. Check Before Starting

- Rough initial alignment of the TMS to the ETM should have been done by IAS group outside of the chamber under the test end.
- Fine initial alignment of the ETM should have been done by IAS inside the chamber. (Make sure that HEPI didn't move after ETM alignment was done but before IAS TMS initial alignment..)
- TMS suspension system should be working, i.e. the TMS should be freely hanging with OSEM damping, and the OSEMs should react to various offsets.
- ISC frontend should be working, i.e. green QPDs on the TMS ISC table should be connected to the ADCs, h2iscey should be monitoring these QPDs and MEDM screen should be available for this.
- All the tools should be available.

4. Man power needed

This is a four-persons' job.

- One person to work inside the chamber.
- One person to work as a support outside of the chamber.
- One person to work on the ALS table.
- One person to work on the CDS workstation.

5. Procedure for green path alignment

1. Transition the VEA to laser hazard as per SOP.
2. Turn the laser on.
3. Remove the ALS table panel behind the green beam periscope.
4. Place an iris at a convenient place between the top periscope mirror and the partial mirror splitting the Hartman and the ISC beam path on the ALS table. Exact position doesn't matter, but it should be at a comfortable position for the worker to look at both sides.
5. Free and damp the TMS if it's not.
6. Completely remove the First Contact both on ERM and ETM (the weight of the first contact is large enough to tilt ETM in PIT significantly according to IAS). Ask SUS people for help.
7. Confirm that the ETM and ERM are both free and damped. Ask SUS people for help.
8. Adjust the offset of the green QPDs so the output of all four quadrants become zero when no beam is hitting the QPD.
9. Inject the green beam into the chamber via the West viewport on the South door for EY, or the North viewport on the East door for EX.
10. Adjust the periscope mirror on the ALS table so the beam hits the center of the first steering mirror in the green beam path on the TMS ISC table.
11. Look at the beam position on the viewport. Adjust the table position along the arm until the beam is about 1 inch above the center and centered horizontally.
12. Repeat 10. and 11. until the beam is centered on the first steering mirror and roughly 1 inch above the center and centered horizontally on the viewport.
13. Steer the first steering mirror on the TMS ISC table until the beam hits both of the QPDs.
14. Try to exactly center the beam on two QPDs by slightly adjusting the beam position on the first steering mirror on TMS ISC table and realign. It might not be possible to do this easily, so give up if it takes too much effort. For anything except the first build (i.e. H2 EY), it's worth trying to enable QPD centering servo by copying the servo matrix elements from H2 EY. Note that you might have to flip the sign of YAW loops.
15. At this point, the TMS beam should already be hitting the ETM. Observe how the beam is coming back from the ETM.
16. Move the TMS by adjusting the TMS SUS offset so the beam is roughly retro reflected by the ETM. The forward and the backward propagating beam should meet at the same spot on the secondary mirror. If a large PIT alignment offset is necessary to achieve this, you might want to put a small weight (e.g. 25 or 50 grams) on the TMS/ISC table to relieve it. If there's a large YAW offset, though hopefully there is none, that is relieved by moving the top mass cage using pusher tools.
17. The above step changes the relative alignment of TMS in relation to the ALS table. Repeat steps 10 to 13 until the beam is roughly retro reflected by the ETM while the QPDs are reasonably centered. “Reasonably centered” means that the beam is not on a single quadrant.

18. At this point, look at the iris. Repeat steps 12 to 16 until the retro reflected beam is centered in the iris.
19. Confirm that the beam is still roughly at the position specified in step 11. If not, you need to go back to step 10 and follow all the steps after that again.
20. At this point, the main beam path should be in a good shape. The beam doesn't have to be exactly centered on any of the telescope mirrors, but excessive offsets on the secondary and/or the primary might indicate that something is wrong.
21. Look at the beam position on the top periscope mirror of HWS pick-off path on the TMS ISC table. It's OK if it's somewhat off-centered, but if it looks really bad (e.g. ¼ inches off from the center) you need to adjust the bottom periscope mirror on the TMS ISC table.
22. Adjust the top periscope mirror of the HWS pick-off path ON THE TMS ISC TABLE so the pick-off beam hits the center of the HWS top periscope mirror ON THE ALS TABLE.
23. Look at the HWS pick-off beam position on the viewport. If it's too far off from the center, adjust the top HWS periscope mirror position on the ALS table and repeat.
24. At this point, the HWS pick-off beam path is in a good shape.

6. Procedure for red path alignment

The red beam QPD path will be fine-tuned by using picomotors once the 1064 nm beam from the corner station resonates with the arm, but this path should be aligned at this stage so the beam at least hits both of the red QPDs. Also, the steering mirror to bring the red beam out of the chamber should be adjusted.

Although the red and green beams are not exactly co-axial due to dispersion and the wedges in ETM and ERM, green retro-reflected beam is still usable as an alignment marker because the difference is small enough: The position difference between red and green beam at QPD1 is about 1.3mm vertical and 0.6mm horizontal (the matlab script in the same DCC number as this document) while the QPD diameter is 3mm. The reflectivity of the dichroic (M4 in D1000484) and IR mirrors are not zero for 532 nm light (with one exception which is explained below), and the beam is visible.

The only real problem is the 50-50 IR beam splitter on the IR QPD sled, as the beam splitter coating of this optic was measured to have a reflectivity of about 400ppm for 532nm light for S-polarization. Since the green light is S-polarized in a normal configuration, you have to install a half wave plate on the ALS table to inject a beam such that it is P-polarized on the table.

Also, you'll find it somewhat difficult to find the correct beam (i.e. straight transmission, reflection from HR surface or from beam splitting surface) from the ghost beams as the reflectivity for 532nm of IR AR often is larger than that of IR HR. Don't rely on the brightness of the spot, instead rely on geometry. Once you figure out which beam is the right one for a given optic, it is very helpful to block unwanted ghost beams with make-shift beam dumps made of clean aluminum foils. Be very careful such that nothing falls and hit ETM and its fibers. Inverted T shape was found to be good to make these beam dumps stable enough on the TMS ISC table. Don't use anything heavier, as it tips the balance of the TMS.

Throughout the procedure, do not move any steering mirror on the sled.

1. Place a half wave plate for 532nm light somewhere on the ALS table in the injection path.
2. With the green beam retro reflected from the ETM, find the green beam reflected by the dichroic mirror (M4) into the direction of corner station. With the laser safety glasses this might be difficult. Use sensor card and beam viewer. Raise the laser power if necessary. Adjust the half wave plate on the ALS table such that the intensity of the "wrong" beams are minimized on the red QPD path.
3. If the "right" beams are already coming near both of the QPDs, you can skip steps 4 and 5.
4. Adjust the dichroic mirror so the beam is centered on M12 splitter and M14 steering mirror at the corner. If you cannot center these at the same time, just spread the error. Do NOT move the position of these mirrors.
5. Adjust M14 and M15 steering mirrors so the two lenses L101 and L102 are reasonably centered. A perfect job is not necessary, but try to better center L102 than L101.
6. From here on, use M14 and M15, or M4 if it's necessary, such that the beam hits both of the QPDs. Note that you need P-polarization on the table to be able to see the correct beam on QPD1 (the one that receives the reflection of the 50-50 splitter). Rotate the wave plate back and forth if you are unsure.
7. Even with the polarization optimized, some people cannot see the right beam on QPD1 because it is so weak. If this is the case, you need to dead-reckon the horizontal distance between the highly visible ghost beam and the almost invisible right beam. The ghost beam is horizontally offset towards ETM, i.e. to the right for EX and to the left for EY when you look at QPD1 from the front. Pay attention to the horizontal wedge of the 1" 50-50 beam splitter. An arrow is on the barrel of the optic, showing the thickest point. If this arrow is visible on the open side of the mirror holder, which should usually be the case, the ghost beam should be hitting the retainer ring. If this arrow is covered with the closed side of the mirror holder, the ghost beam should be inside, but very close to the side wall of, the QPD can.
8. Hopefully, this is close enough that the red beam hits both of QPDs in vacuum, and from that point on you can use picomotors to center the QPDs.
9. Put the beam diverter to the "off" position so the path to the vacuum chamber viewport is not blocked.
10. You should be able to see the green beam propagating toward the viewport. Align M12, M10 and M13 so the beam comes out of the chamber.
11. Check before coming out of chamber if you removed all aluminum foil Do the same for the image of M4. This time, adjust M12. At this stage the red path should be reasonably aligned.

Worker Name:

Date:

Green QPD1 values:

Green QPD2 values:

Main green beam position on the viewport:

HWS pick-off beam position on the viewport:

Red beam position on the viewport if visible:

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