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HAM6 Alignment procedure

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1 Introduction

This document[1] describes alignment procedure of HAM6 optics based on our experience at LLO and LHO.

The procedure here assumes that the following preparatory steps have been taken before attempting alignment.

- All of the optics and suspensions (OM1, OM2, OM3, and OMCS) on the HAM6 ISI table has already been placed close to their designed place. Refer D1000342 for the layout.
- The HAM6 ISI table have been leveled, balanced, and locked.
- The vertex interferometer optics, including the output faraday isolator, have been installed and aligned.
- The IMC is continuously locked. The PSL beam has already arrived at HAM6 chamber. One of the ITMs is intentionally misaligned so that the HAM6 has a beam without any interference. In this document, we assume ITMX is aligned and ITMY is misaligned.
- The in-vacuum cables for the HAM6 optics, mechanics, and electronics have already been connected to the feedthrough flanges and the rack electronics.
- DC readbacks of HAM6 DCQPDs, WFSs are functional in CDS and MEDM.
- The HAM6 fast shutter is ready to be functional. For safety reason, it is required that the shutter is not driven by a fast HV pulse but by a low voltage continuous drive.
- The realtime model of the tip-tilt suspensions OM1, OM2, and OM3 are running. The damping loops are functioning. At this point, the suspensions are not necessary to be fully adjusted as the alignment procedure moves the suspensions and the OSEMs need to be adjusted again at the end.
- The OMC glass breadboard has been installed and suspended at its final position without touching the earthquake stops. The suspension transfer functions were measured and approved by the SUS team.
- The HAM6 doors (+X and −X sides) are open.

[1] https://dcc.ligo.org/LIGO-T1400588

- The viewport emulator has been adjusted and attached on the +X side of the chamber. (The emulator can be difficult to work around, and it may be easier to install it only when needed.)
- Pylons are placed around chamber openings in order to notify working personnels about possible presence of beams.
- **It is desirable** that the main vertex vacuum manifold is already pumped down.
- **It is desirable** that the input power of 10W is incident on the input modecleaner and delivering about 20mW to HAM6. If this power level is not approved yet, the input power of 2W (i.e. about 4mW at HAM6) is still workable but reduces the efficiency.

2 Alignment procedure

2.1 Initial beam alignment

A detailed viewport arrangement is found in T1000746. For appropriate viewport protection, refer M080310.

This process usually requires one clean person to work at the table, another clean person to help the first one, and one dirty person to help in operating a laptop. Use headsets for clear communication.

2.1.1 Beamspot centering on SR2

Use SR2 analog or digital camera to locate the beam at the center of SR2. If the camera is not yet available, use an analog camera on the VP10 viewport at WAMCA2/LAMCA2. The camera should only be able to see a baffle in front of SR2 [2]. Move SR3 such that the beam hits the center of the clear apperture. In order to determine the center of the aperture, move the SR3 alignment value in +Pitch and − Pitch to hit a symmetric reference like the SR2 baffle. Take mean of the alignment values to find the Pitch value for the center. Repeat the same measurement for yaw. Then, repeat the same measurement for pitch to confirm if the pitch center did not change significantly.

Note for the slider values to give the spot on the center of SR2:

SR3	+limit	−limit	mean
Pitch			
Yaw			

2.1.2 Beamspot centering on SRM

Use SRM camera to locate the beam at the center of SRM. If the camera is not yet available, use a temporaly analog camera on the VP9 viewport at WAMCB2/LAMCB2.

[2]Refer D0901125 HAM4-H1 Top Level Chamber Assembly or D0900421 HAM4-L1 Top Level Chamber Assembly for the table layout

The camera should be able to see the SRM face [3]. Move SRM such that the beam hits the center of the clear apperture. In order to determine the center of the aperture, move the SR2 alignment value in +Pitch and − Pitch to hit a symmetric reference. If the SRM optics is mounted on a metal holder, the metal holder provides the alignment reference. If the final mirror is used, use appropriate symmetric reference such as the mirror edge or suspension structure. Take mean of the alignment values to find the Pitch value for the center. Repeat the same measurement for yaw. Then, repeat the same measurement for pitch to confirm if the pitch center did not change significantly.

Note for the slider values to give the spot on the center of SRM:

SR2	+limit	−limit	mean
Pitch			
Yaw			

As long as there is no concern of the beam clipping, this is the beam alignment we are going to work with. To assess the absence of the clipping, we check the clear aperture of the output faraday isolator, as described in the next section.

2.1.3 Beamspot centering on the clear aperture of the output faraday isolator

The center of SRM and the center of the clear aperture for the faraday isolator may not agree, in principle. Check the center of the clear aperture in HAM6 and find the SR2 alignment values for the centering.

Go into HAM6 chamber and look for the beam right after the septum window. Look at the beam with an IR card and find the alignment values where the beam is completely clipped and disappears. Find the values for +Pitch, −Pitch, +Yaw, and −Yaw directions.

Confirm:

- The center of the clear aperture of OFI does not have big deviation (like 5mm) from the center of the SRM.
- The beam is not clipped when the beam is located at the center of SRM.

If it does in either of the cases, consult with the system group.

Note for the slider values to give the spot on the center of OFI clear aperture.

SR2	+limit	−limit	mean
Pitch			
Yaw			

As long as there is no concern of the beam clipping in OFI, go back to the alignment values determined in the previous section.

[3] Refer D0901129 HAM5-H1 Top Level Chamber Assembly or D0900456 HAM5-L1 Top Level Chamber Assembly for the table layout

As a check to verify that the SRC alignment is free of clipping, it can be useful to dither the beam using PR2 or the ITMs and check that the observed intensity in HAM6 is constant. (This check of the alignment can be done easily once the ASC-AS_C QPD is aligned.)

2.1.4 Beam geometry measurement

The installation at LLO and LHO both exhibited a large deviation of the beam in horizontal direction by 25 mm or 50 mm at the location of OM1. This corresponds to the deviation of the angle by 18 $\sim$ 36 mrad. In addition, it was also found at LHO that the beam was downward by 11mm at OM1 (4.3 mrad). At LHO, the septum window was rotated by 120 degree in order to compensate this drop [4].

In order to assess the beam deflection, the beam geometry in HAM6 chamber is measured. We sample the beam geometry right in front of OM1, at the edge of the table close to the septum window, and at additional two points between these. The beam height is measured by a cleaned scale and an IR card. The horizontal location is recorded by the position of the scale on the table. Take photos of these by a digital camera and analyze the measurements to obtain the beam deflection.

It is also useful to take a picture of the septum viewport so that the scribing of the viewport flange is recorded. This scribing mark is supposed to indicate the direction of the thickest side of the viewport wedge.

Consult with the system group if the deviation of the beam at OM1 is more than 1 mm from the design.

2.1.5 Beam power measurement

Measure the optical power of the beam coming from the septum window. The expected value is

$$P_{\mathrm{HAM6}} = P_{\mathrm{IMC\_INC}}\, \eta_{\mathrm{IMC}}\, T_{\mathrm{PRM}}\, R_{\mathrm{PR2}}\, R_{\mathrm{PR3}}\, T_{\mathrm{BS}}\, R_{\mathrm{ITMX}}\, R_{\mathrm{BS}}\, R_{\mathrm{SR3}}\, R_{\mathrm{SR2}}\, T_{\mathrm{SRM}}\, T_{\mathrm{OFI}}\, T_{\mathrm{septum}}, \quad (1)$$

where P_{HAM6} is the expected light power at HAM6, $P_{\mathrm{IMC\_INC}}$ is the incident beam power on IMC, η_{IMC} is the IMC thru-put, T_{PRM}, T_{BS}, T_{SRM}, T_{OFI}, T_{septum} are the PRM, BS, SRM, OFI, septum window transmittances, R_{PR2}, R_{PR3}, R_{ITMX}, R_{BS}, R_{SR3}, R_{SR2} are the PR2, PR3, ITMX, BS, SR3, SR2 reflectivities, respectively.

If the measured power is largely different from the expectation, consult with the local ISC expert to find the cause of the descripancy.

For the LHO case, the rough estimate is $P_{\mathrm{HAM6}} \sim$ 4mW, while the measured was 3.6 $\sim$ 3.8 mW[5]. Here the values $P_{\mathrm{IMC_INC}} = 1.6$W, $\eta_{\mathrm{IMC}} = 0.88$[6], $T_{\mathrm{PRM}} = 0.0305$, $T_{\mathrm{BS}} = R_{\mathrm{BS}} = 0.5$, $T_{\mathrm{SRM}} = 0.37$ were used. Otherwise, the values were assumed to be the unity.

[4] https://alog.ligo-wa.caltech.edu/aLOG/index.php?callRep=13477
[5] https://alog.ligo-wa.caltech.edu/aLOG/index.php?callRep=13499
[6] https://alog.ligo-wa.caltech.edu/aLOG/index.php?callRep=13495

2.2 OMC incident path alignment

This process usually requires one clean person work at the table, another clean person to help the first one. Use headsets for clear communication.

2.2.1 OM1 alignment

Confirm that the OM1 alignment values are neutral (i.e. zero).

If necessary, slide the OM1 suspension laterally so that the beam hits OM1 within 1 mm of its center. Rotate the OM1 suspension to direct the reflected beam to the horizontal center of OM2.

The vertical alignment of the OM1 has to be done with the counter balance screw at the bottom of the mirror holder[7].

We don't touch OM1 for the OMC alignment.

2.2.2 OM1 suspension adjustment

Check the OSEM values if they are at the middle of the range (half of the open light). If not, adjust the corresponding OSEM position until it is satisfied.

Confirm if the damping servo is still working.

2.2.3 OM1 transmission path alignment

In order to establish an alignment reference easier to work with, it is a good idea to align the OM1 transmission path as soon as possible.

- Align the beam on the center of steering mirrors M4, M5, M6, M7.
- Align the beam on AS_C QPD by M7 without the lens. After the adjustment of M7, insert the lens. Complete fine alignment by M7 with appropriate MEDM screen.
- Adjust M6 such that the beam goes through the center of the viewport emulator.
- Align BDV1. The reflection from BDV1 should be properly dumped on the beam dump. i.e. The beam should be in parallel to one of the beam dump glass and hit the center of the other glass.

AS_C QPD is now the alignment reference. If any misalignment on this QPD is seen, the spot should be adjusted by SR2

[7]This is, most of the case, very painful. But this process is inevitable as the alignment range by the coil is quite limited.

2.2.4 Fast shutter and the beam dump

Turn on the fast shutter. This can be done by giving ∼100mA of current[8]. Adjust the position and angle of the shutter such that the beam is at the center of the shutter mirror and the reflection is guided to FS BEAM DUMP.

The beam dump position and angle should be adjusted such that the beam is accommodated in the beam-dump tube well with in the wobbling range of the shutter. Put an index finger on the top of the shutter element and give latteral force to make angular fluctuation of the mirror. Check the spot motion on the beam dump and confirm the accommodation of the beam in it. Do not touch the reflecting surface of the shutter.

2.2.5 OM2 coarse alignment

Confirm that the OM2 alignment values are neutral (i.e. zero).

Rotate the OM2 suspension to direct the reflected beam to the horizontal center of OM3. Adjust the pitching of OM2 to have the spot at the vertical center of the OM3 mirror.

2.2.6 OM3 coarse alignment

Confirm that the OM3 alignment values are neutral (i.e. zero).

Firstly, adjust the pitching of OM3 by the couter balance screw to allow the beam to hit the OMC optical element, at least.

Rotate the OM3 suspension to direct the reflected beam towards the first steering mirror on the OMC. When the beam approximately has the correct incident angle and position, the OMC reflection beam appears about an inch next to the incident beam.

Now place M8 and direct the OMC REFL beam to M9. The OMC REFL has to be leveled. If not, adjust the OM3 pitching further using the counter balance screw.

2.3 Fine alignment of the beam to the OMC QPDs

This process is the hardest and most frustrating part of HAM6 alignment.

This step usually requires one clean person work in the chamber, another clean person to help the first one, and one dirty person to help operating a laptop. Use headsets for clear communication.

The internal optical layout is shown in Figure 1.

The fine alignment procedure here is basically done by aligning the beam spot on the OMC QPDA and QPDB by OM2 and OM3. In fact, OM2 is used for the QPDA alignment, and OM3 is used for the QPDB alignment, although these adjustments are largely non-orthogonal.

[8] The shutter was tested at 150mA of a current in a vacuum chamber and exhibit no excessive heat to cause a problem on the wires.

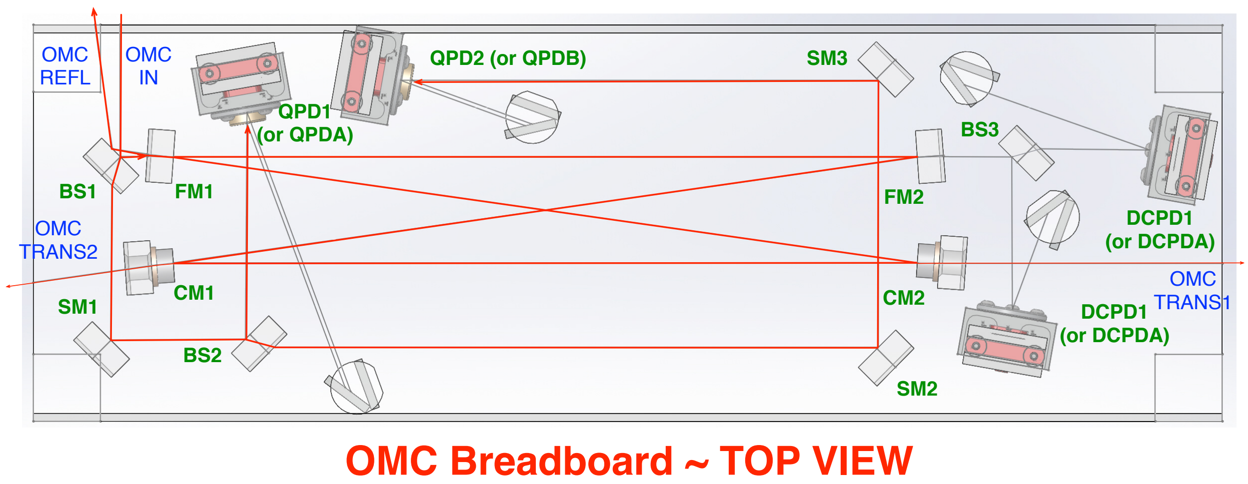

Figure 1: Optical layout of the OMC breaboard

It is advisable to flash the OMC QPDs with a laser pointer to verify that the quadrant assignment matches the expectation from the wiring diagram, and that the values in the OL2EUL matrix agree with the physical placement of the quadrants.

2.3.1 Finding a spot on QPDA

One person ("A") goes into the chamber and lies down on the table at the −X side of the OMC. The other person ("B") stands at the +X side of the table. One person at the outside ("C") can handle the MEDM and StripTool screens to manipulate the alignment values and to monitor the signals on the QPDs.

"A" inserts an IR card between OMC SM1 and OMC BS2 to find a spot. If the spot is found, it is highly likely that the beam is already hitting somewhere on the housing of QPDA. If the spot is not there, ask "B" to disturb OM2 and figure out which way OM2 should be rotated.

Once the spot is on the housing, "A" should be able to observe the spot using an IR viewer. "A" gives directions to "B" how the OM2 alignment needs to be adjusted to make the spot closer to the center of QPDA. Once the QPDA sum start responding, ask "C" to align the OM2 with the alignment values.

2.3.2 Finding a spot on QPDB

In fact, once the spot is found on the QPDA, it is also likely that the beam is already hitting the housing of QPDB. If the beam is not found, locate the beam between OMC BS1 and OMC SM2.

Now we need to touch OM3 to align this spot on QPDB. However, this causes a misalignmet on QPDA. Therefore, we need to give a "gentle" touch for OM3 so that we can track OM2 alignment as well. This gentle touch should be made by a tool like a lever with a long allen key, not by a rotation of OM2 and OM3 by hand.

The actual process is as follows:
"A" turns OM3 in clockwise and then turns OM2 in the same direction until the QPDA spot is recovered. Check the position of QPDB spot. If it is improved the first motion was correct. If it is not improved, change the direction of the first motion. Continue until the spot is on the QPDB.

The beam height should be sufficiently good if the height of the OMC REFL spot was adjusted before. If the spot is largely off the diode, "A" should use differential pitching of OM2 and OM3 by turning the counter balance screws in the opposite directions.

2.3.3 Fine alignment of the spots on the QPDs

Once the spots are found on both QPDs, use OM2 and OM3 alignment values to make them perfectly centered on the QPDs.

This often causes saturation of the coil drivers. Once the saturation happens, "A" should go to the suspension and give an assisting move of the suspension to relieve the alignment values.

Nominaly the saturation happens with the alignment values of ±2500. The requirement for the alignment precision is 1/10 of the full scale. i.e. the alignment values should be within ±250 when the beam spots on the QPDs are centered.

2.3.4 OMC resonance

If the beam is at the center of both QPDs, the beam is supposed to be sufficiently aligned to the OMC cavity to have flashes of the resonance.

Energize the high voltage of the OMC PZT and scan it in order to confirm OMC resonance.

2.3.5 OM2/OM3 suspension adjustment

Check the OSEM values if they are at the middle of the range (half of the open light). If not, adjust the corresponding OSEM position until it is satisfied.

Confirm if the damping servo is still working.

Confirm the beam is still aligned to the OMC QPDs.

2.4 OMC reflection and transmission path aligment

This step usually requires one clean person work on the table, and another clean person to help the first one.

2.4.1 OMC REFL path

- Check the spot position on M8. Also, the reflection from M8 should be directed to M9.

- Align M9 to have the spot on the center of M10.
- The reflection of M10 should be directed to the center of the viewport emulator.
- BDV2 and the associated beam dump should be aligned. The beam dump should have the one glass plate in parallel to the beam and the spot on the center of the other glass plate. This ensures that the reflection in the beam dump is properly dumped.

2.4.2 OMC REFL QPD sled

The alignment of the OMC REFL QPD sled is performed using the fine alignment of M9 and M11. These adjustments are made after the coarse alignment of the OMC REFL path from M8 to the viewport.

Once the reflection from M10 is directed through the viewport, position M11 such that the beam is transmitted through the sled and roughly lands on the housing of OMCR_A and OMCR_B.

Use the fine alignment of M9 and M11 to iteratively align the beam onto the QPDs. M9 should be used for the near-field QPD (OMCR_A) and M11 for the far-field QPD (OMCR_B). In practice, this iteration is not orthogonal and not independent of the alignment to the viewport (which is realized using M10). However, due to the short lever arm of M10 and M11 to OMCR_B, once M9 is aligned such that the beam is well-centered on OMCR_A, it is likely that only M10 and M11 need to be significantly adjusted.

2.4.3 OMC leakage transmission paths

The OMC curved mirrors (OMC CM1 and OMC CM2) have about 50ppm transmission. One of the beams needs to be dumped on HAM6 and the other should be guided to the viewport for the spot monitoring on ICST6.

The leakage beams are extremely dim. Particularly when the OMC is not locked, the beam is just barely possible to see with an IR viewer and a scattering object. Higher input power to the IMC (like 10W) would make the process a lot easier.

Beam dump installation
Scan the OMC cavity. Find the flashes and align the beam dump.

Guiding the OMC trans beam to the viewport

- With the cavity flashing, place the steering mirror M14. Align it approximately.
- Guide the beam towards the viewport emulator.
- Place a temporary analog CCD camera, with an appropriate zoom lens, right outside of the viewport emulator. Try to find a flash of the cavity on M14 in the image.
- At the final state, the CCD camera should be located at the center of the viewport with the flash found at the center of M14 in the image. If the position of the CCD is

off, the angle of the steering mirror should be adjusted. If the flash is not at the center of the steering mirror, the position of M14 should be moved.

2.5 OM3 transmission path aligment

This step usually requires one clean person work in the chamber, another clean person to help the first one.

- The sled has been aligned and the lens and picomirrors should not be adjusted.
- A) Align M13 to have the spot on the center of the far mirror of the sled.
- B) Align M12 to move the spot on the near mirror of the sled.
- Repeat above A) and B) until the spots are both at the center of the mirrors on the sled.
- Check if the spots are at the center of M12 and M13. If not, latellaly shift the mirror until the mirror has the spot at the center. Go back to A) and B) and repeat until the spot is all at the center of M12, M13 and sled mirrors.
- Align the spots on the WFS by the sled mirrors. Use MEDM screen
- Make sure the WFS heads have some non-orthogonal incident angle so that the reflection can be trapped by the black glass beam dump on the sled.
- Adjust the position of the beam dump to cleanly dump the beam. The beam could be dim and invisible with an IR card. It should be visible with an IR viewer and a scattering material (like a glove).

2.6 Miscellaneous

This step usually requires one clean person work at the table.

- Confirm all of the picomotors — there are ten of them — have Kapton washers inserted. Heintze Cut[9] will make the insertion easier.
- Check the beam clearance along the OM1-OM2-OM3 path. Depending on the initial geometry of the beam coming from HAM5, we had to shift the OM1 suspension. This may cause the beam too close to some of the suspensions. The suspension OSEM cables could be very close to the beam. Check and elliminate any clipping risk along the path.
- Check all the clamping of the optics. Confirm there are at least three clamps on the OM1/2/3, and two dog clamps on the optical mounts except for the ones designed to have only one clamping screw.
- Remove all tools from the table.

[9] https://alog.ligo-wa.caltech.edu/aLOG/index.php?callRep=12881

2.7 Final preparation for the chamber closure

2.7.1 ISI adjustment

Before the closure of the chamber, final checking out for the ISI is necessary. Consult with local SEI experts to accomplish the following checks:

- Cable rerouting on and beneath the table
- Unlocking the ISI table
- Finalizing mass balance. Particularly, HAM6 leveling may have to be checked and redone if the displacement of OM suspensions is more than a 5mm from the design location.
- Anything else as required by SEI

2.7.2 Ground loop check

Check all in-vacuum cable shields for ground loops, starting from the electronics racks and moving upstream if a loop is detected. See https://dcc.ligo.org/LIGO-T1200131 for instructions.

Note that the beam diverters are grounded to the ISI table due to the design of the Mighty Mouse connector.

2.7.3 Mechanical transfer function measurement

Transfer functions of the ISI table and teh suspensions (OM1, OM2, OM3, and OMCS) should be checked by SEI and SUS experts.

2.7.4 Door closing / Vacuum system preparation

Consult with local vacuum experts for closing of the chamber doors. ISC personnels should make sure the all of the viewports are in place.

2.7.5 ISCT6 in place

Place the ISCT6 table at the designated location. Connect the table enclosure and the viewports with appropriate tubings.

2.7.6 Pumping the HAM6 chamber down

Make sure OMC PZT HV is turned off. Ask vacuum experts to start the pumping down of the chamber.