LASER INTERFEROMETER GRAVITATIONAL WAVE OBSERVATORY
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Mode Cleaner Installation & Test Plan

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1 Mode Cleaner Installation

The following set of mode cleaner installation and testing steps starts at the point where the mode cleaner mirrors have been aligned in air, using a HeNe laser that is colinear with the PSL/IOO 1064 nm beam.

1.1. IOT7 Installation

Following the initial, in-air alignment of the mode cleaner (MC), IOT7 will be moved into place and the MC reflected beam aligned with the table optics. The DC outputs of the two WFS's will be recorded for reference.

Q. Can the HeNe alignment laser (used to align the MC) remain in place to aid in IOT7 alignment? If so, we can probably align both reflected and transmitted beams.

When/Duration: Following MC alignment, currently scheduled for 10 February. Will take 1-2 days.
Who: PF will be at Hanford starting 22 Feb; Nergis?; IOO folk?
Special equipment: clean air enclosure for IOT7; low power beam from PSL/IOO; power & DC readout for WFS (can use box supplied by MIT)

1.2. Initial Length Check

Surveying of the WHAM7–WHAM8 optical table separation, and subsequent placement of the mode cleaner optics relative to surveyed marks, should result in the mode cleaner round trip length being known to ± 5mm. One millimeter of length error results in a change of the main resonant modulation frequency of roughly 4 kHz. Before pumpdown of the IOO chambers, the length will be checked optically as follows:

- modulation will be applied to the input beam at the main frequency, 25.5xx MHz
- the reflected light will be demodulated at this frequency; light detection is done on IOT7 using the LSC monitor detector normally in the MC transmission beam line, probably by directing a portion of the reflected beam to this detector temporarily; demodulation probably will be done with the MC Length/Frequency Control demodulator board (if available), or Mini-Circuits connectorized mixer & filter (Note: we may want to arrange for I&Q demodulation, since the overall phase will be changing as the frequency is tuned - see below)
- this demodulated signal will be observed on a scope as the MC moves through resonances (the MC length will be driven, if necessary)
- the main modulation frequency will be tuned until the demodulated signal amplitude is minimized; at this point the modulation sidebands are resonant in the MC – given the 4kHz half-width of the MC, the resonance can probably be found to ~1kHz, so this is already more accurate than the surveying
- correcting for the index of air, the frequency found above is compared with the desired modulation frequency; the difference should be less than ~30kHz, and that is within the allowed fine-tuning range (if larger, may need to move an optic).

When/Duration: Following IOT7 installation; will take 1-2 days (more if a MC mirror needs to be moved)
Who: same possibilities as for IOT7 installation
Special equipment: Marconi signal generator (if not already in place); demodulation electronics (I&Q); cabling for LSC PD; temporary mirrors to direct beam to correct LSC PD; clean air for IOT7

1.3. Initial pumpdown checks

Following, and sometimes during, the initial pumpdown of the IOO chambers, several checks should be made:

- the suspension local position monitors (pitch, yaw, displacement) should be monitored during pumpdown (for all suspensions); these indicate tip/tilt shifts of the optics tables
- Length check: follow the same procedure as in 1.2. Optical and electronics should have been left setup from this.
- alignment of MC reflected beam on IOT7; check WFS DC readouts, compare with 1.1.

When/Duration: following/during pumpdown; all checks will take 1-2 days
Who:
Special equipment: multi-channel data recording for SUS monitors (EPICS 1 Hz should be ok); same equipment as for 1.2.

1.4. Initial MC lock

The mode cleaner is locked – probably at low input power and low bandwidth – in order to perform the following steps:

- rough align the IOT7 optics for the MC transmitted beam
- fine tune the MC alignment by maximizing transmitted power and zeroing WFS error signals
- center beams on WFS
- fine tune alignment of IOT7, both beam lines

When/Duration: follows 1.3.; 2 days
Who:
Special equipment: MC length/frequency controls

1.5. Suspension controller tuning

Having established the nominal orientation of the MC mirrors with respect to their support structures, the controllers can be fine tuned to minimize cross-coupling and to set the damping. The procedure is described step-by-step in a document written by Gabriela Gonzalez (the procedure was developed on the PNI).

When/Duration: follows 1.4.; each optic takes ~1/2 day to tune; at least the three MC mirrors are tuned – taking 2 days; not clear if we should tune the other suspended optics – let's wait

and see what effect the tuning has on the MC mirrors
Who:
Special equipment: audio-frequency signal generator; 4-channel digital scope; dynamic signal analyzer

1.6. Length/Frequency Controls

1.6.1. Testing

For the length/frequency controls testing, we may want to engage the WFS alignment control to stabilize the power coupling over long periods of time.

The length/frequency controls testing will involve the following measurements and adjustments:

- EO shutter: adjust threshold so that shutter works properly at full power; adjust ON and OFF HV values for desired transmission levels
- Measure total closed loop gain and infer loop bandwidth; increase overall gain to achieve design bandwidth
- Measure loop gains of individual paths; adjust crossover gain for desired crossover frequency
- Monitor control signals; check for saturation
- Calibrate error signal, in Hz/V
- Monitor error signal: audio-frequency power spectrum (does error signal go down with gain?); wide-band scope RF spectrum analyzer to look for oscillations and high-frequency noise
- Look for DC offsets; debug if necessary
- Measure sensitivity to laser AM, as a measure of offsets and residual length deviations
- Test automatic modes of EO shutter and length/frequency control servo

When/Duration: follows 1.5.; 1-2 weeks
Who: Peter, Nergis, ...
Special equipment: dynamic signal analyzer; RF spectrum analyzer

1.6.2. Documentation

Test results of the final L/F controls configuration will be documented with the following:

- Table of operational parameters (gain settings, offsets, etc.)
- Closed loop gain measurements: overall loop and individual paths
- Open loop gain plots calculated from the c.l.g. measurements for all paths
- Power spectra of the error signal and the control signals
- Identification of lines in the spectra (as much as possible)
- Power spectra of electronics noise
- Calibration constant of error signal (Hz/V)
- Long time record of control signals

When/Duration: done after alignment system testing and mode matching; 3-5 days

1.7. Alignment Controls

1.7.1. Testing

- Measure loop gains; adjust electronics gain as needed
- Measure Gouy phase separation between detectors (responses to beam shift and tilt); adjust GPT lenses if necessary
- Calibrate error signals in radian/V
- Check PZT controls matrix
- DC offsets
- Monitor error signals – power spectra and time trace; look for correlations with local suspension monitors of MC mirrors

When: follows 1.6.1.; 1 week
Who:
Special equipment: dynamic signal analyzer (DSA)

1.7.2. Documentation

Test results of the final alignment controls configuration will be documented with the following:

- Table of operational parameters (gain settings, offsets, etc.)
- Closed loop gain measurements: overall loop and individual paths
- Open loop gain plots calculated from the c.l.g. measurements for all paths
- Power spectra of the error signals and the control signals
- Identification of lines in the spectra
- Calibration constant of error signals (rad/V)
- Long time record of control signals

When/Duration: done after mode matching; 2-3 days

1.8. MC Mode Matching & optical parameters

Once the MC is under length and alignment control, the mode matching can be fine-tuned. (Note: after the initial MC lock, the mode matching should be checked crudely by using power measurements and comparing to what is expected with perfect mode matching; if the mode matching happens to be really bad, it should be improved before embarking on 1.6. and 1.7.). The mode-matching should be pretty good, so it may be hard to optimize it without a sensor such as a bull's-eye detector; can try to minimize the reflected light power, with only the MC modulation turned on. Then, the following measurements are made to determine the MC losses and input beam coupling:

- resonant reflectivity of the MC
- ringdown measurement of cavity storage time

When/Duration: follows 1.7.1.; 1-2 days

1.9. Set Modulation frequencies

Here we set the main modulation frequency for resonance in the MC. With the MC locked, an audio frequency modulation (~1kHz) is applied to the light (with a test input on the MC controls, e.g.). As in 1.2., a portion of the reflected beam is directed to the LSC PD on IOT7 tuned for the main modulation frequency, and its RF output is demodulated. The audio frequency signal at this demodulator output should go to zero when the RF (main modulation) frequency is equal to (twice) the MC free-spectral-range. This sets the main modulation frequency. The same can be done for the non-resonant sidebands; in this case we can direct the reflected beam sample to the Newfocus wideband PD.

When: anytime after 1.7.; 1 day
Who:
Special equipment: demodulation electronics for the two frequencies

1.10. RF AM/ transmitted beam characterization

After setting the main modulation frequency, we look for RF AM on the transmitted light. We use the LSC PD on the MC transmission beam line, and demodulate its output in I&Q phases. Measurements are made of the DC offsets and the audio-band power spectra of these demod outputs; they will be compared to similar measurements made previously on the on input beam to the MC – ideally there would be no difference between these two sets of measurements, indicating that the MC does not increase the RF AM. One parameter that can be varied for this measurement is the DC offset in the MC length lock.

The following additional measurements will be made on the sampled MC transmission beam, on IOT7:

- measure the optical power at this port to infer the MC transmission, using previously measured values of mirror reflectivities
- measure the residual power fluctuations using an out-of-loop detector on IOT7; this must follow implementation of the PSL power stabilization servo using the post-MC photodetector on IOT7
- measure the RF spectrum of the light using wideband (100 MHz) Newfocus photodetector

When: follows 1.9.; 2-3 days
Who:
Special equipment: demodulation electronics for the main modulation frequency; DSA

1.11. Length-alignment coupling

The coupling of primary interest is from alignment fluctuations of the MC mirrors to MC length fluctuations; this tests the centering of the beam on the optics. The coupling is measured by modulating the pitch and yaw angles of the optics and observing the length modulation produced in the length/frequency servo. The coupling must be less than 3×10^{-3} m/rad.

When: anytime after 1.7.; 1 day
Special equipment: DSA; lots of audio-frequency signal generators

1.12. Lock acquisition & maintenance testing

This task will probably remain ill-defined until we gain experience with locking the MC. The goal for lock acquisition is to come to an operational state ~20 seconds after starting acquisition; studies will be made of the acquisition statistics, and if necessary changes will be made to the acquisition process to speed it up. For lock maintenance, we will make some statistics on lock duration, look for control signal saturations and modify as necessary.

When/Duration: done partly over the course of other tests; probably devote 1-3 days to this

1.13. PSL frequency stability characterization

A byproduct of the results of 1.6. is a measurement of the PSL frequency noise, obtained through measurements of the control signals. Anticipating that the PSL frequency noise may not be up to specification at the outset, we reserve some time for characterization/debugging of the PSL frequency stabilization, using the MC as the analyzer cavity.

When/Duration: anytime after 1.7.; 2-5 days

1.14. Modulation depth calibration

Final calibration of the main & non-resonant modulation depths is done with the optical spectrum analyzer on IOT7, looking at the MC transmitted beam. A calibration table is made of modulation depth versus Pockels cell drive, for each modulation frequency.

When/Duration: anytime after 1.9.; 1 day
Special equipment: OSA must be installed on IOT7; drive electronics for the phase modulator must be in place

1.15. Controls screens

We reserve some time for revising and/or putting the finishing touches on the controls screens for the MC length and alignment controls.

When/Duration: near the end of the MC testing phase; 1-2 days

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