LASER INTERFEROMETER GRAVITATIONAL WAVE OBSERVATORY

LIGO Laboratory / LIGO Scientific Collaboration

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Summary of the H1 Input Mode Cleaner Testing

Paul Fulda for the IO Group

California Institute of Technology
Massachusetts Institute of Technology
LIGO Hanford Observatory
LIGO Livingston Observatory

http://www.ligo.caltech.edu/

1 Executive summary of the Input Mode Cleaner testing

The Input Mode Cleaner of H1 was tested over the course of 2013 following the more thorough testing of the L1 IMC. This testing was successful also some of the requirements could not yet been met or tested for. Below is a summary of the specific goals of the testing campaign.

2 Quantitative goals

IMC availability. *Goal: > 90%*
The IMC will remain locked indefinitely; no unintended sources of lock-loss were discovered.

Mean lock duration. *Goal: > 4 hrs*

Achieved. See LHO aLOG entry 7265.

PSL to PRM power transmission. *Goal: >0.75*

Achieved. Measured 83% transmission from the base of the PSL/IO periscope to the parking beam dump. See LHO alog entry 5344.

IMC longitudinal control bandwidth. *Goal: ~40 kHz*
Achieved. Unity gain frequency of ~110 kHz with a phase margin of 15 deg; see LHO alog entry 5865. (Larger phase margin possible by reducing common gain and UGF to ~60kHz).

Frequency/length crossover frequency. *Goal: ~10 Hz*
Achieved. See LHO alog entry 5145.

Transmitted power fluctuations, rms. *Goal: <1%*
Not measured.

Transmitted beam angular motion. *Goal: <1.6 urad rms*

Measured with PSL in commissioning mode. Beam jitter above a few Hz was about an order of magnitude above the requirements. Measurements from LLO indicate that the noise up to ~100Hz is likely limited by AC/HEPA in the PSL, and will be reduced by an order of magnitude or more with the PSL in science mode. See T1300378 and LHO alog entry 8190.

IMC visibility. *Goal: >95%*
Not yet achieved. Visibility of ~94%, see LHO alog entry 8104.

Transmitted light RIN. *Goal: $<10^{-7}$ /$Hz^{1/2}$ above 10 Hz*

Not measured.

Faraday isolation at full power. *Goal: > 30 dB*
Achieved. 33.5dB; see LHO alog entry 8104.

3 Further discussion of testing objectives

The following addresses for the H1 detector the objectives laid out for the L1 detector in Section 4 of T1100201.

3.1 IMC optimization and automation

Angular control was implemented, using both the WFS and in-vacuum QPD (see e.g. LHO aLOG entry 7490). It was found that the inherent angular stability of the IMC was very good, and the global alignment control was only necessary for long term stability (times scales of several hours or more). The design for the angular sensing and actuation was found to be adequate, and it seems unlikely that even longer term operation (longer than several days) will need anything additional.

An auto-locker script ('MClockwatch') was implemented that automates the IMC acquisition and controls optimization. A feed-forward path from the MC2trans QPD signal to the IMC mirrors was implemented in addition to the control scheme implemented for the L1 IMC.

3.2 Performance testing

3.2.1 IMC characterization

The cavity pole-frequency, length, g-factor, and transmission were all measured and found to agree well with their design values. See aLOG entries 5429, 8087, 8089 and 5344 respectively. Frequencies and Q-factors of the MC2 suspension wires were measured. Although the data is awaiting further processing, the frequencies agree quite well with the expected values, and the measured Q-factors are higher than the expected values ($2.2\text{-}2.3\text{x}10^5$ compared to $2.0\text{x}10^5$). See LHO aLOG entry 8040.

3.2.2 Frequency noise

The IMC feedback controls signals were calibrated to provide a measure of the frequency noise coming from the PSL (see LHO aLOG entry 5452 and comments). Below 100 Hz, the frequency noise is close to or is better than the requirements. Between 100 Hz and 500Hz, the noise spectrum exceeds the requirement by a factor of a few around a collection of acoustic peaks. Above 500Hz the noise is about a factor 2 greater than the requirement. This excess noise may not be as problematic as this appears, as the IMC and Common Mode loops may provide sufficient suppression. However, this is an issue that needs to be investigated.

3.2.3 Amplitude noise

The inner loop of the PSL Intensity Stabilization Servo (ISS) was operational, and it performed to requirements. The outer loop detectors have not yet been installed. No measurements are yet available of the RIN after the IMC in its aligned state.

3.2.4 Angular noise

Beam pointing noise in the GW band was measured using a misaligned cavity technique; see T1300378 and LHO alog entry 8190. This measures the angular beam jitter of the input beam to the IMC, and can be compared to the requirements given in T0900142 (v2). Both pitch and yaw jitter exceed the requirements above a few Hz by roughly an order of magnitude. It is expected that the jitter below 100Hz will be significantly reduced with the PSL in "science mode", bringing it below the requirements. Above 100Hz several acoustic peaks dominate the spectrum. We note that the requirement given in T0900142 is a simplified envelope that is fairly conservative above 60 Hz. Nonetheless the acoustic peaks observed bear further investigation.

3.2.5 RF noise

The RF amplitude noise on the beam transmitted by the IMC was not measured.

3.2.6 VCO range

The new aLIGO low-noise VCO was found to have adequate range for IMC lock acquisition and operation (2 MHz range; 5x smaller range than the iLIGO VCO); see e.g. log entries 5452 and 7600. The VCO range was adequate for maintaining IMC lock while locking the Y-arm as part of the HIFO-Y tests; see LHO aLOG entry 7235.

3.3 High power testing

The IMC was not operated above 1W due to contamination concerns regarding the IMC optics.

3.4 Interaction between subsystems

One issue that arose is vibrations on the PSL/IO table, which appear to lead to excess frequency noise and excess beam jitter. No other problematic subsystem interactions were identified.

The active seismic isolation system appears to perform quite well for IMC operation, although we are still awaiting a detailed analysis of the contribution of seismic noise to the IMC length noise as reported for L1 in LLO aLOG entry 6148.

3.5 Adaptive feed-forward for IMC length

This was not implemented in this integration phase, and is being studied off-line for potential future use.

4 Action items

- Excess laser noise. Laser frequency noise and beam jitter are in excess of requirements at some frequencies. Laser intensity noise should be measured after the IMC. Beam jitter into the IMC should be measured with the PSL in science mode. None of these excesses are yet deemed ‘show stoppers’, but they need further investigation.
- High-power testing of the IMC remains to be done. With higher available input power, absorption measurements similar to those described in LLO aLOG entry 8170 and references therein should be performed periodically.
- The digital (GigE) cameras that monitor the beam positions and scatter of the IMC mirrors need to be installed and commissioned.
- The IO laser power control system needs to be implemented.
- RF amplitude noise (static and dynamic) of the IMC transmitted beam needs to be measured (at 9 and 45 MHz).
- Mode matching to the IMC should be improved to bring the visibility above 95%.