LASER INTERFEROMETER GRAVITATIONAL WAVE OBSERVATORY
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# Preliminary E2E-simulation studies of lock acquisition with misalignments

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# Model studied

A Lock acquisition model for Hanford 2Km LIGO interferometer has been developed by Matt Evans using the End-to-End (E2E) software package. The following study is based on the Full000907 version of it, which has the same parameter values of servo system as was used at Hanford in mid-September, 2000. [Ref. "Han2k -End Users' Guide'' by Matt Evans and Hiro Yamamoto, LIGO document no. T000094-00- (Sept, 2000)].

Some minor changes are made in settings of this version in order to study misalignment effects.

# Aim of this preliminary study

(i) To investigate effects of misalignments on lock acquisition time,

(ii) finding a limit on misalignments in various mirrors upto which locking could be achieved using only the longitudinal mode of locking mechanism.

(iii) To test validity or to find out existence of any limitation in the background C++ code of various E2E modules utilized in lock-acquisition model.

# Questionable parameter values used in this study:

**(i) Radius of curvature of recycling mirror :** This value is taken as 9838 meter, which was the value in old design before thermal lensing effect (mostly in input mirrors) was taken into account. The number 9838 is obtained by dividing the radius of curvature of input mirror, 14450 meter, by the refractive index of Fused Silica, 1.47, thus taking care of the fit of the TEM00 mode of the arm cavity in the recycling cavity. After the thermal lensing effect in input mirrors is taken into account, the final design recommends a radius of about 14900 meter for the recycling mirror. In E2E, we have not yet introduced the capability of studying thermal lensing effects and so, for the time-being, this's the best we can do.

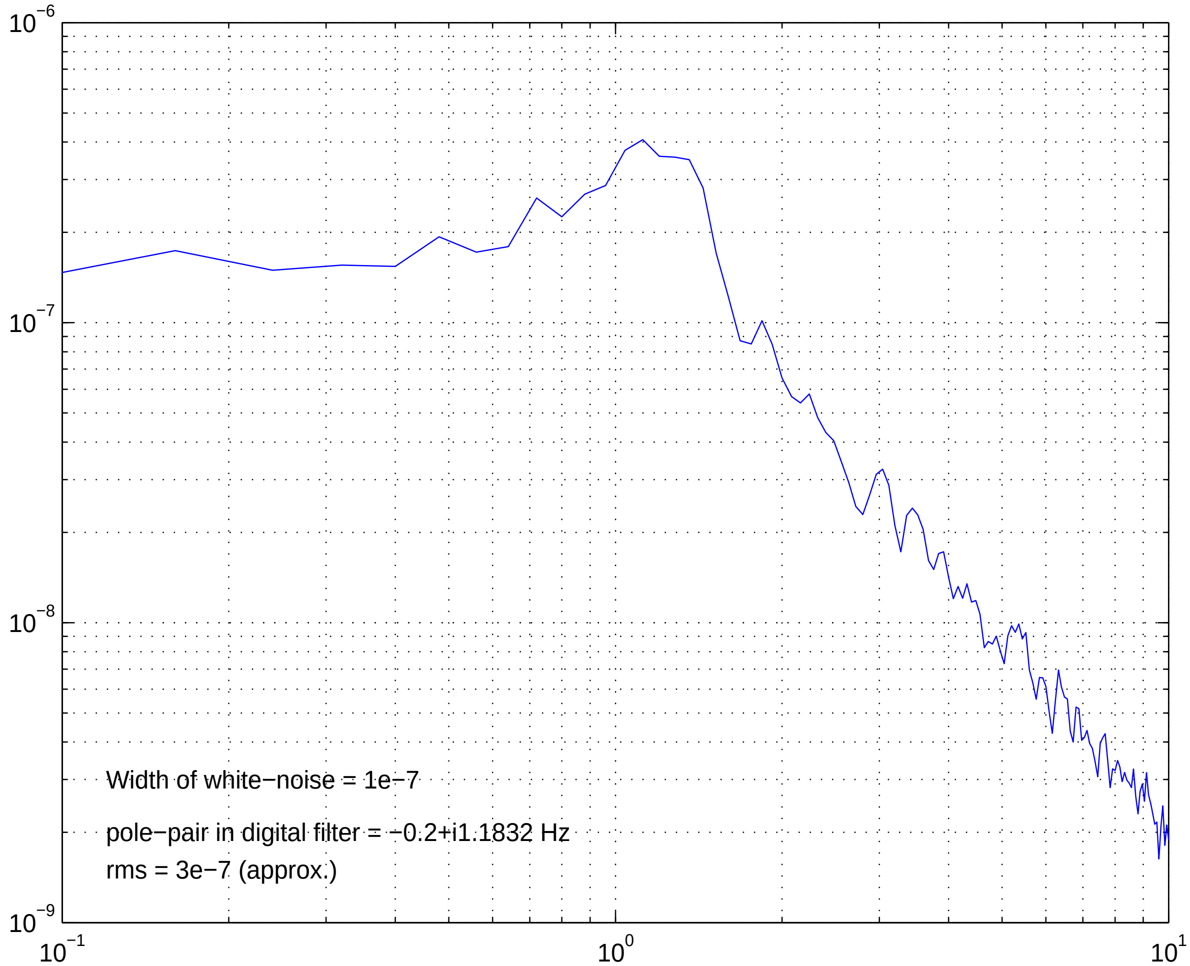
**(ii) Spectrum of misalignments :** We pass white-noise through a digital filter with a single pole-pair at 1.2 Hz and feed that as pitch or yaw to a mirror. The spectrum it generates is shown in Fig.1. This is close to (although a number of details are missing ) what was presented by Daniel Sigg in May, 2000 Director's review

(http://www.ligo-wa.caltech.edu/~sigg/DR_000401/dr_5_1_00.pdf).

According to Daniel,''The interpretation of these spectra is up to you. They have been obtained from the ASC control signals and were corrected for SUS tranfer functions but not loop gains. These are the angular motions at least in-band (servo BW between 1-5Hz); Whether they are due to ground motion or imposed by the length control system is everybody's guess".

The rms value (~3.4e-7 rad) that we get from this spectrum in Fig.1 is close to what one gets from spectra presented by Daniel. In this study we do not employ any alignment control system. Also note that we use the same spectrum for pitch and yaw of all mirrors, even though in reality they differ slightly from each other.

**Fig 1 :** Spectral density of misalignment (pitch/yaw) for all mirrors: rad/sqrt(Hz) vs. Hz



# Lock acquisition time

Table I shows lock-acquisition time for various cases of misalignments studied. It should be noted that lock-acquisition time is a statistical quantity and the locking probability depends, among many other factors, on the profile of the random sequence used for seismic noise (characterised by seed value) in any particular run.

These runs show that upto 3.4e-8 rad rms value of misalignments (pitch and yaw) in all mirrors, locking could be achieved in most cases within a reasonable time.

The average lock-acquisition time is found to be about 5 sec in scalar case and about 17 sec in misaligned case of 3.4e-8 rad rms as described in last paragraph.

**Table I :** Time at lock acquisition for scalar and misaligned cases. Procedure of lock-acquisitioon starts at 1.0 sec. Each seed represents a fixed stream of random numbers that generates seismic noise.

| seed | Scalar (no misalign) | pitch & yaw ~3.4e-8 rad (rms) all mirrors |
|---|---|---|
| 1 | 2.2 | 2.2 |
| 10 | 5.5 | 10.8 |
| 25 | 2.1 | 2.1 |
| 50 | 2.5 | 2.5 |
| 75 | 8.2 | 3.3 |
| 100 | 11.3 | 28 |
| 300 | 9.0 | 12 |
| 500 | 2.4 | 23.8 |
| 700 | 8.4 | 29.3 |
| 1000 | 9.5 | 67.5 |

# Lock-acquisition runs

The following four figures show results of typical lock-acquisition runs of Hanford 2Km interferometer in the presence of misalignments in all mirrors. The assumed spectrum of misalignment is shown in Figure 1. As such, the spectrum in Fig.1 corresponds to a rms value of about 3.4e-7 rad. White noise is passed through a digital filter representing this spectrum profile and the time-series of noise in misalignments is generated. We vary the width of this white-noise, however keeping the spectrum profile same, to vary the rms value of time-series of misalignments and quote that value in the corresponding figure below.

The preliminary results show that one can comfortably lock only at the level of 3e-8 to 4e-8 rad rms value of misalignments in all mirrors. Above that value some short spikes are seen but those, in absence of any alignment control, do not materialise into a locked state.

This rms level is one order lower than the corresponding spectrum presented by Daniel in March 2000 Director's Review.

# Description of following four plots :

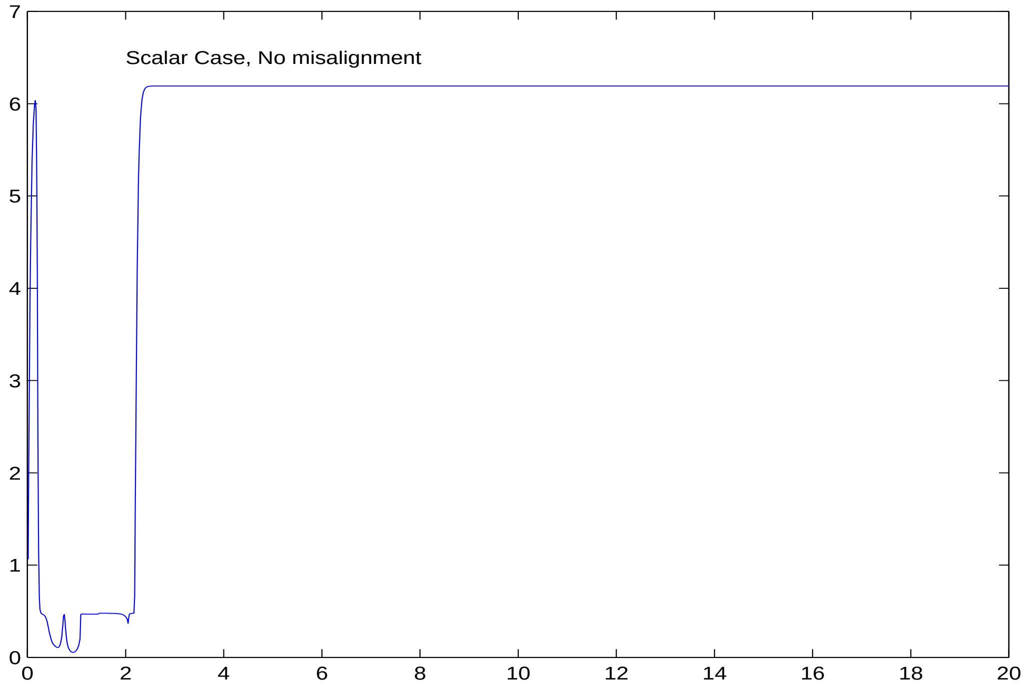
- Y-axis: Beam-splitter pick-off power (field going from beam-splitter to the

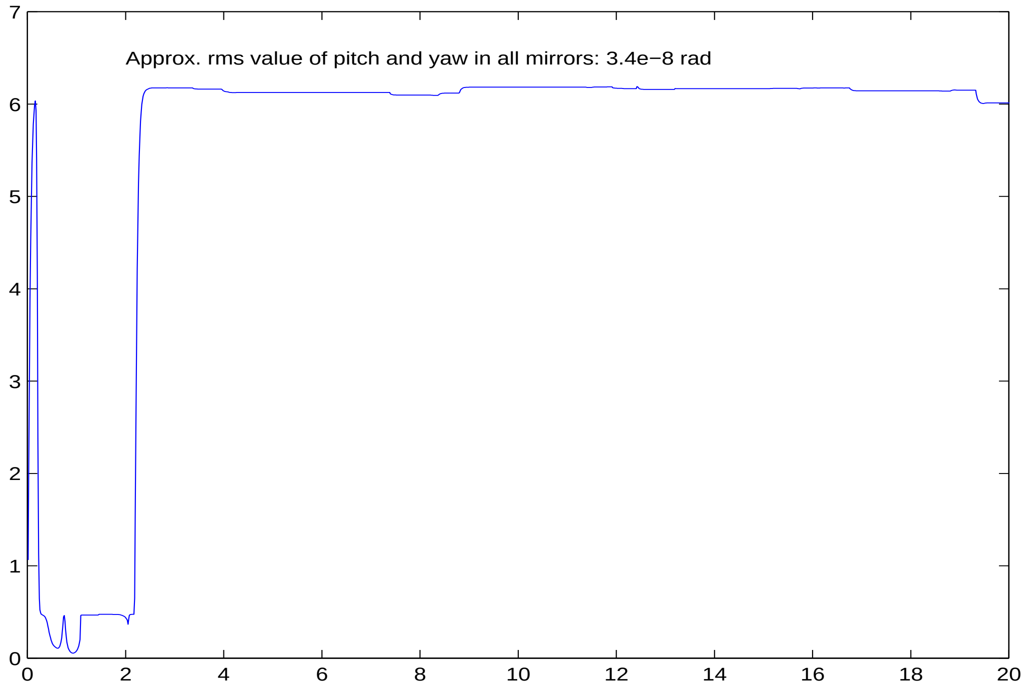
  X input mirror), X-axis: time in seconds

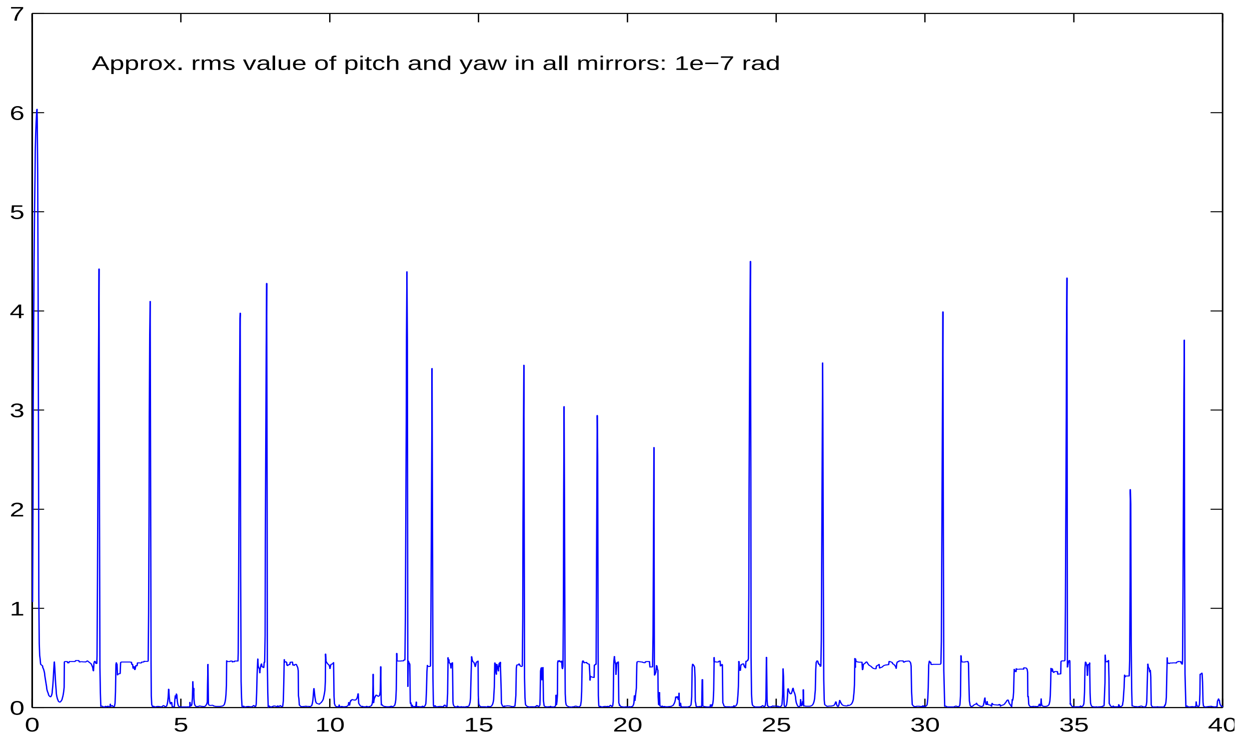
- All runs were actually made for 120 seconds but we show only the first 20 or 40 seconds of data.

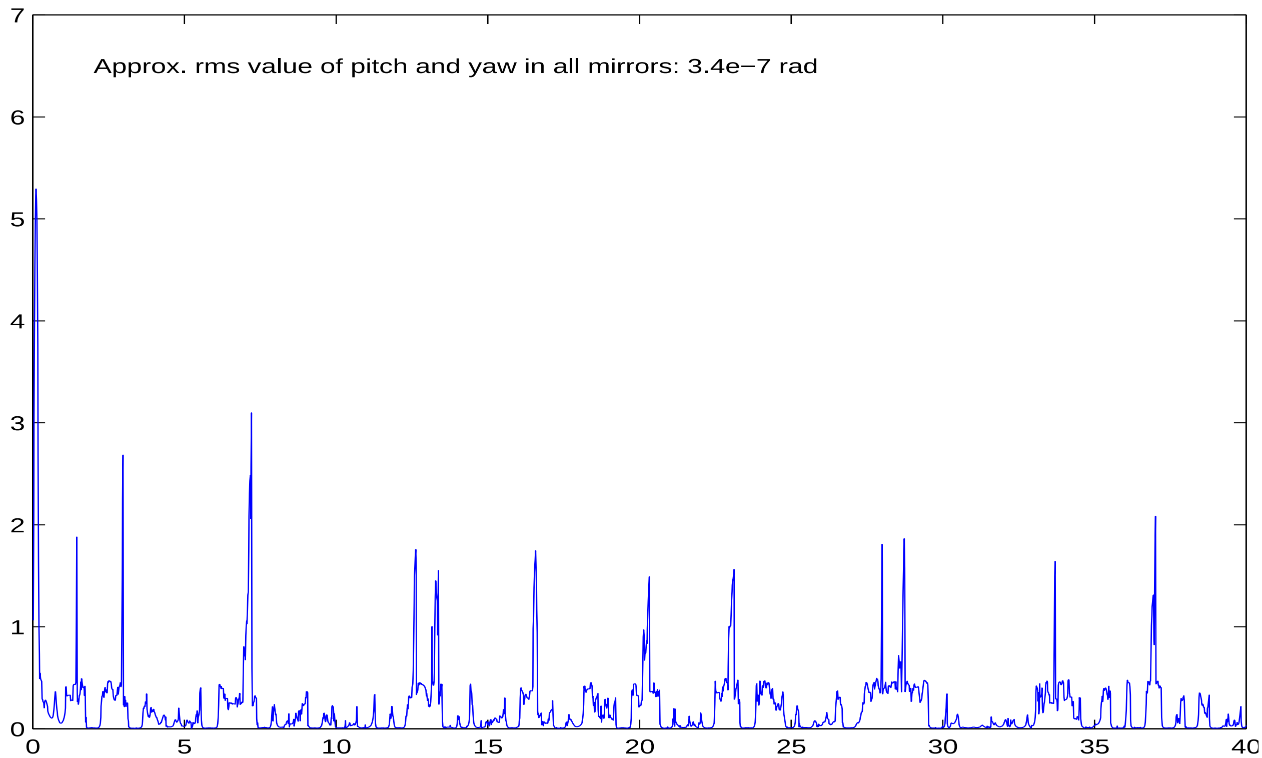
- Lock acquisition procedure starts at 1.0 sec.

- All four plots are for runs with a fixed stream of random numbers (characterised by seed =1) used for generating seismic noise.


Scalar Case, No misalignment
0
1
2
3
4
5
6
7
0
2
4
6
8
10
12
14
16
18
20


Approx. rms value of pitch and yaw in all mirrors: 3.4e−8 rad
0
1
2
3
4
5
6
7
0
2
4
6
8
10
12
14
16
18
20


Approx. rms value of pitch and yaw in all mirrors: 1e−7 rad
0
1
2
3
4
5
6
7
0
5
10
15
20
25
30
35
40


Approx. rms value of pitch and yaw in all mirrors: 3.4e−7 rad
0
1
2
3
4
5
6
7
0
5
10
15
20
25
30
35
40