IFO Basis ISI Motion

B. Lantz, J. Kissel, R. DeRosa, J. McIver and the Seismic Team
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1 Summary

To better understand the behavior of the interferometers, we propose a set of channels to record the ISI-derived suspension-point motion in the IFO basis. We think this would be useful to help evaluate the ways in which large motions at the microseism and below are coupling to noise in the detectors. Better understanding of the noise coupling from table motion may help set design guidelines for improved controllers.

A similar calculation is done in the OAF model at LLO. The OAF calculation uses only the translation DOFs of the ISI tables, and the results are not stored in the science frames. Also, I think that the OAF model calculated the motion at the optic, not at the table, so this is not the calculation we currently desire for ISI performance evaluations. The calculation we desire includes the relevant rotational motion of the ISIs. This is an important distinction because the motion of the suspension point is often dominated by the rotations of the ISI optical tables. The projections of the ISI motion from the ISI cartesian basis to motion at the mirror suspension points is done in the various SUS models and is described in T1100617. The suspension point signals are AC coupled at about 30 mHz and are calibrated at 1 nm/count above this frequency.

The names for the new channels should be
{IFO}:ISI-SUSPOINT_{DOF}
where DOF is one of {DARM, CARM, MICH, PRCL, SRCL, or IMC}. For example, the channel might be
H1:ISI-SUSPOINT_DARM, or
L1:ISI-SUSPOINT_PRCL.
We also considered H1:ISI-IFOBASIS_DARM, but decided the name SUSPOINT better conveyed the message that this includes the rotational DOFs. For reference, the suspension point signals have names like H1:SUS-ETMX_M0_ISIWIT_L_DQ, H1:SUS-BS_M1_ISIWIT_L_DQ, L1:SUS-MC3_M1_ISIWIT_L_DQ, and L1:SUS-PRM_M1_ISIWIT_L_DQ.

2 IFO basis Suspension point motion

The Longitudinal degree of freedom for the individual optics is defined as normal to the HR face of the optic. Thus, for example $ITMX_L$ is aligned with +x in the global coordinate system, but $ETMX_L$ is along the -x direction. Thus, it is usually true that moving an optic in the +Longitudinal direction makes the cavity shorter. A bit of algebra gives the transforms from individual optics to IFO basis motion as:

$$\begin{aligned}
DARM &= (-ITMX_L - ETMX_L) - (-ITMY_L - ETMY_L) \\
CARM &= (-ITMX_L - ETMX_L) + (-ITMY_L - ETMY_L) \\
MICH &= \sqrt{2} \cdot BS_L + ITMX_L - ITMY_L \\
PRCL &= -PRM_L - 2 \cdot PR2_L - 2 \cdot PR3_L - \frac{\sqrt{2}}{2} \cdot BS_L + \frac{1}{2} ITMX_L + \frac{1}{2} ITMY_L \\
SRCL &= -SRM_L - 2 \cdot SR2_L - 2 \cdot SR3_L + \frac{\sqrt{2}}{2} \cdot BS_L + \frac{1}{2} ITMX_L + \frac{1}{2} ITMY_L \\
IMC &= \frac{1}{2} \Big[-\sqrt{2} \cdot MC1_L - 2 \cdot MC2_L - \sqrt{2} \cdot MC3_L \Big] \ \textit{(this is } {}^{1}\!/_{2} \times \textit{ the round trip length)}
\end{aligned} \tag{1}$$

Channel Names

The channels for the various optics are listed below. I have picked the L1 channels because Jess is in Louisiana. Naturally, we want this info for both sites.

$ETMX_L$	L1:SUS-ETMX_M0_ISIWIT_L_DQ
$ITMX_L$	L1:SUS-ITMX_M0_ISIWIT_L_DQ
$ETMY_L$	L1:SUS-ETMY_M0_ISIWIT_L_DQ
$ITMX_L$	L1:SUS-ITMY_M0_ISIWIT_L_DQ
BS_L	L1:SUS-BS_M1_ISIWIT_L_DQ
$MC1_L$	L1:SUS-MC1_M1_ISIWIT_L_DQ
$MC2_L$	L1:SUS-MC2_M1_ISIWIT_L_DQ
$MC3_L$	L1:SUS-MC3_M1_ISIWIT_L_DQ
PRM_L	L1:SUS-PRM_M1_ISIWIT_L_DQ
$PR2_L$	L1:SUS-PR2_M1_ISIWIT_L_DQ
$PR3_L$	L1:SUS-PR3_M1_ISIWIT_L_DQ
SRM_L	L1:SUS-SRM_M1_ISIWIT_L_DQ
$SR2_L$	L1:SUS-SR2_M1_ISIWIT_L_DQ
$SR3_L$	L1:SUS-SR3_M1_ISIWIT_L_DQ

Table 1: Names of the channels to be used to create the ISI-SUSPOINT IFObasis channels

3 What are we Looking For?

A look at figure 1 prompts several questions, for example,
Why is the windy SUSPOINT_DARM so big?
Are we really pushing the test mass around by 70 microns pk-pk?

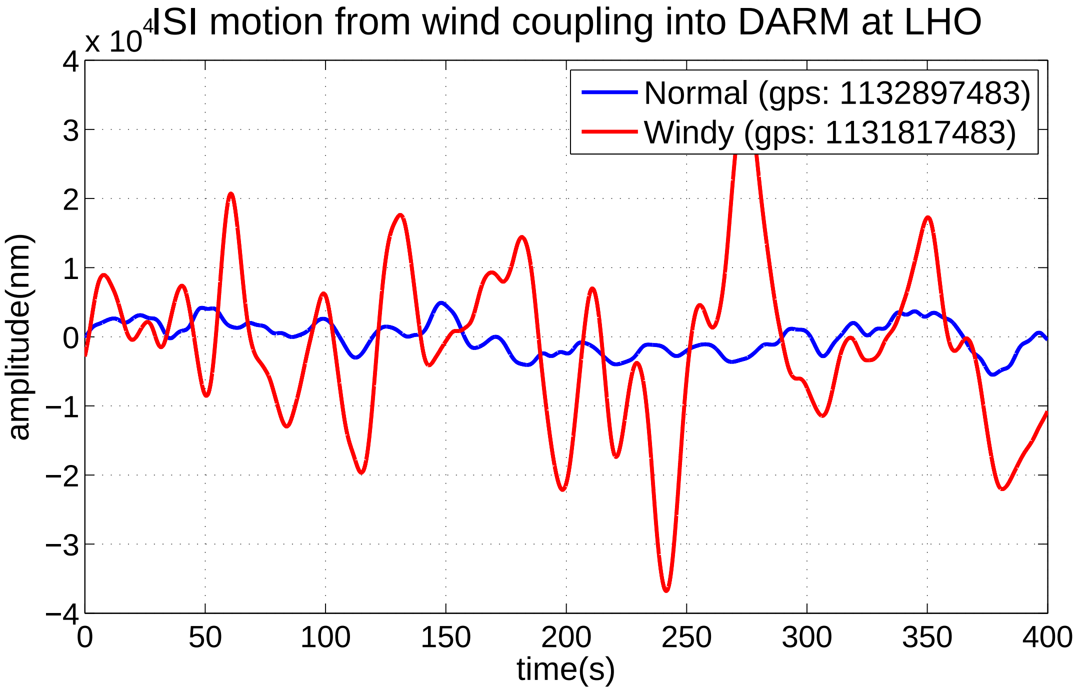

Figure 1: Sample of the Suspension point motion in the DARM basis at LHO. The red curve is for a windy time and the blue curve is for a quieter time. While the wind was blowing, the Suspension points were moving by 40 to 70 microns pk-pk over 20-30 second time intervals. This raises many questions.

Is there a correlation between the noise in DARM and the peak amplitudes or peak velocities of SUSPOINT_DARM?
What do these big length errors do to the angular loops?
What do the other SUSPOINT DOFs look like?
Which is the best blend filter to use to cut the pk-pk motion?
Is there any sort of threshold we should try to keep SUSPOINT_DARM below?
How do these motions correlate with the scattering arches?
etc.

4 Computation in the OAF model

The OAF (which once stood for Online Adaptive Filter) model at LLO is saved at
/opt/rtcds/userapps/trunk/isc/l1/models/l1oaf.mdl
The calculated lengths are:
L1:OAF-SEISCAV_$\{DOF\}$_LENGTH_DQ (test point at 256 samples/sec), and
L1:OAF-SEISCAV_$\{DOF\}$_LENGTHMON (the associated EPICS variable),
where *DOF* is one of (MC, PRCL, SRCL, MICH, CARM, DARM, XARM, or YARM).

These are calculated as:

$$\begin{aligned}
DARM &= (ETMX_X - ITMX_X) - (ETMY_Y - ITMY_Y)\\
CARM &= (ETMX_X - ITMX_X) + (ETMY_Y - ITMY_Y)\\
MICH &= -(BS_X - BS_Y) + ITMX_X - ITMY_Y\\
PRCL &= 2 * HAM3_{X,S} - HAM2_{X,S} - 2 * HAM2_{X,L} + \tfrac{1}{2}(BS_X - BS_Y) + \tfrac{1}{2}ITMX_X + \tfrac{1}{2}ITMY_Y\\
SRCL &= 2 * HAM4_{Y,S} - HAM5_{Y,S} - 2 * HAM5_{Y,L} - \tfrac{1}{2}(BS_X - BS_Y) + \tfrac{1}{2}ITMX_X + \tfrac{1}{2}ITMY_Y\\
MC &= HAM3_{X,S} - HAM2_{X,S}\\
XARM &= (ETMX_X - ITMX_X)\\
YARM &= (ETMY_Y - ITMY_Y)
\end{aligned} \tag{2}$$

The HAM tables are set up to use two different transfer functions, one for the Large and a one for the Small optic suspensions. The OAF model provides an excellent reference for the calculation of the ISI table motion at the suspension points. There are several points of note: the beamsplitter motion is in the X-Y direction, i.e. the direction of the face of beamsplitter, the Mode Cleaner is the motion of 2 tables rather than 3 optics, and all the lengths are the single-pass lengths.

5 Discussion

5.1 Non-normal incidence

Many of the mirrors are not normal to the optical beam, i.e. BS, PR2, PR3, SR2, SR3, and all the input mode cleaner mirrors. It is convenient to approximate these as either 45 or 90 degrees. In general, for mirrors inside a cavity (e.g. SR2, PR2, etc) the optical path change of the cavity, dP is related to the suspension point Longitudinal motion, dL, as

$$\begin{aligned}
dP &= 2 * \cos\theta * dL\\
&\approx 2 * dL \text{ for MC2, SR2, SR3, PR2, and PR3, or}\\
&\approx \sqrt{2} * dL \text{ for MC1 and MC3.}
\end{aligned} \tag{3}$$

where θ is the angle between the incoming beam and the normal to the optic face. In the OAF calculations, it is clear that θ is approximated to be either 45 degrees (e.g. for the beamsplitter) or 0 degrees (e.g. for SR2 on HAM4). We will also make this approximation.

5.2 ISI table translation to SUS longitudinal motion

The correct transforms from optical table motion to suspension point motion are described in T1100617. The components which are used in the OAF calculation, i.e. just the translation components, are approximated below. These can be used to check that the transforms in equations 1 and 2 are internally consistent. The MC1 and MC3 relations in OAF do not include the HAM2

Y motion, because it cancels out.

$$\begin{aligned}
ITMX_L &= ITMX_X \\
ITMY_L &= ITMY_Y \\
ETMX_L &= -ETMX_X \\
ETMY_L &= -ETMY_Y \\
BS_L &= {}^1\!/\!\sqrt{2}(-BS_X + BS_Y) \\
MC1_L &= {}^1\!/\!\sqrt{2}\,HAM2_X \\
MC2_L &= -HAM3_X \\
MC3_L &= {}^1\!/\!\sqrt{2}\,HAM2_X \\
PRM_L &= HAM2_X \\
PR2_L &= -HAM3_X \\
PR3_L &= HAM2_X \\
SRM_L &= HAM5_Y \\
SR2_L &= -HAM4_Y \\
SR3_L &= HAM5_Y
\end{aligned} \tag{4}$$

5.3 Round Trip or Not?

Not round trip. The definitions for the various cavity lengths in aLIGO are typically given as 1/2 of the round trip cavity length, e.g. DARM is defined as the 4 km length of the X arm - the 4 km length of the Y arm. The signal recycling cavity is the distance from SRM to the average location of the two input mirrors. Thus, for the input mode cleaner, which is a triangular cavity, we calculate the round trip length, and then divide by two.

5.4 Angular motion of the optics

At this time, we completely ignore the inconvenient fact that angular motion of the optics changes the paths and path lengths. We choose to ignore it for the moment because it is a much harder problem. This should bother you. What sloth! What outrage! But ask yourself this question - are you the one who can set this right? Remember, “its got to be done very careful; I reckon there aint one boy in a thousand, maybe two thousand, that can do it the way its got to be done.” [1]

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[1] said Tom Sawyer to Ben Rodgers, on the occasion of whitewashing a fence.