New BSC Transfer Functions Model for E2E-SimLIGO (DRAFT)

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Introduction

A comparison of some transfer function measurements made by Hytec [1] showed that the current model implemented in SimLIGO is quite far from the real world. This new calculation is an attempt to fix this problem and improve the reality of the mechanical simulation in SimLIGO.

The new transfer function are essentially obtained fitting the experimental data and using some qualitative results obtained from the incomplete but available Hytec model1.

1 Model Description & Assumptions

The quasi-equivalent mechanical system response is obtained with a set of transfer functions represented with zeros, poles, conjugate zeros pairs, conjugate poles pairs and an overall gain factor.

Transfer function for the angular degrees of freedom are not implemented because no measurements are available. Anyway, it is believed that the effect of the crosstalk horizontal displacement to yaw is larger than that produced by the yaw to yaw transfer function.

The amount of angular seismic noise is believed be to not very relevant for the IFO because of the strong coupling between displacement and angles DOF. It can be indeed neglected in a first approximation.

These new transfer functions are obtained with the following assumptions:

- transfer function magnitude is obtained fitting measurements reported in [1].
- Below 100mHz and above ~20Hz, the magnitude is extrapolated using the complete Hytec model (we cannot have it) plotted together with the measurements.
- The phase qualitative behavior is checked from the incomplete and available Hytec model. This model if compared to the measurements provides a reasonable proper qualitative behavior of the transfer function magnitude measurement.
- Phase behavior at higher frequency (above ~20Hz) is considered not relevant for the type of simulation we need to run2.
- An empirically and very simple crosstalk between the horizontal degrees of freedom and yaw has been introduced. Essentially a percentage of the horizontal displacement divided by the radius of the BSC upside-down optical table goes into yaw.
- due to the strong symmetry of the system the two orthogonal horizontal to horizontal transfer function are considered identical.

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1This model does not account for the frequency dependent viscous damping of the damped coils springs and their viton seats.
Figure 1: Horizontal to horizontal BSC stack transfer function fit and experimental data.

- Same as above for horizontal to pitch transfer function and for horizontal to roll transfer function. Asymmetries or the real mechanical system are neglected.

2 Horizontal to Horizontal Transfer Function

Complex conjugate poles and zeros pairs are used to describe peaks and notches. Single zeros are used to fit the magnitude above about 10Hz and the asymptotic trend about 20Hz.

In the e2e func module syntax, the horizontal to horizontal transfer function in the poles zeros gain representation is:

```plaintext
PxPx(x) = digital_filter( 1.5544722e+09,
/* Poles */ { },
/* Complex conjugate zeros */ { ( -0.300, -24.944), ( -1.000, -56.549), ( -10.000, -79.168) },
/* Complex conjugate poles */ { ( -0.400, -7.540), ( -0.500, -13.823), ( -0.500, -35.186), ( -1.099,
```
Figure 2: Vertical to vertical BSC stack transfer function fit and experimental data.

(-41.469), (-1.493, -62.204), (-3.030, -68.487), (-4.000, -83.566), (-5.000, -94.248), (-5.000, -106.814));

3 Vertical to Vertical Transfer Function

In this case, the system behavior is very close to a chain 4 masses connected with ideal spring and a constant viscous damping. No extra zeros or poles are used to match the asymptotic slope.

In the e2e func module syntax the horizontal to horizontal transfer function in the poles zeros gain representation is:

```
PzPz(x) = digital_filter( 1.2373392e+13,
/* Zeros */ { },
/* Poles */ { },
/* Complex conjugate zeros */ { ( -0.333, -16.965), ( -0.667, -39.584), ( -1.111, -64.088),
/* Complex conjugate poles */ { ( -0.333, -16.965), ( -0.667, -39.584), ( -1.111, -64.088),
```


Figure 3: Horizontal to pitch/roll BSC stack transfer function fit and experimental data.

4 Horizontal to Pitch/Roll Transfer Function

Same comments made for the horizontal to horizontal BSC stack transfer function applies here. A zero in zero was added to fit the low frequency region.

In the e2e func box syntax the horizontal to horizontal transfer function in the poles zeros gain representation is:

```c
PxTy(x) = digital_filter(5.0311790e+13,
    /* Zeros */ { -0.001, -0.001, -31.416, -31.416 },
    /* Poles */ { },
    /* Complex conjugate zeros */ { ( -10.000, -79.168) },
    /* Complex conjugate poles */ { ( -0.400, -7.540), ( -0.500, -13.823), ( -1.099, -40.212),( -3.030, -71.000), ( -4.000, -89.850), ( -10.000, -94.248), ( -5.000, -108.699) } );
```
Figure 4: Horizontal to pitch/roll BSC stack transfer function fit and experimental data.

5 Pitch/Roll to Horizontal Transfer Function

This transfer function has been implemented considering the Hytec incomplete model which shows that it is proportional to the horizontal to horizontal transfer function. As expected the transfer function shows a DC gain greater than zero. In fact, the displacement induced by the angle should show up if the point where we are looking at is far from the rotation axis. (we are ‘on’ the upside-down optical table surface).

In the e2e func box syntax the horizontal to horizontal transfer function in the poles zeros gain representation is:

```c
TxPy(x) = digital_filter( 4.4069287e+09,
    /* Poles */ { },
    /* Complex conjugate zeros */ { ( -0.300, -24.944), ( -1.000, -56.549), ( -10.000, -79.168 ) },
    /* Complex conjugate poles */ { ( -0.400, -7.540), ( -0.500, -13.823), ( -0.500, -35.186), ( -1.099, -41.469), ( -1.493, -62.204), ( -3.030, -68.487), ( -4.000, -83.566), ( -5.000, -94.248), ( -5.000, -106.814) } );
```
6 Sources

Box sources and pdf plots are available from:

http://www.ligo.caltech.edu/~vsanni/e2e/SeismicNoise/BSCStackTF/

References