Impact of offsetting the CG of stage 1 BSC-ISI

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1 Summary

Having the CG of stage 1 of the BSC ISI 3.99 inches (10.13 cm) above the LZMP does not seem to have a significant impact on performance. This is an excellent thing to do. This offset is smaller than the offset of the system tested at LASTI, and it allows us to increase the frequencies of the vibration modes. These vibration modes cause all sorts of trouble, and the vibration mode frequency can increased by removing some of the stage 1 keel, which moves the stage 1 CG up.

By moving the CG above the LZMP, we couple the stage 1 horizontal modes to the stage 1 tip and tilt modes (ie X and RY become coupled). This does not make much difference at low frequencies, where the alignment of the LZMP and the actuators are important, but it does make a difference at and above the fundamental modes.

This coupling could cause trouble for two reasons. First, as the modes become coupled, the plant which the X (or RY) controller sees changes as the other controller is turned on. If this changes the plant around the upper unity gain frequency, it could have an impact on robustness. The plots below show that this should not be a problem.

The other reason for concern is that by coupling the modes together, one can allow other types of ground motion to couple to the translation mode of the optics table (the 'money' direction). For a single stage system, this coupling is clear, but for multistage system, the coupling is not obvious, because the offset in the attach points of the stage 1 to 2 flexures make the system more complicated. Changing the vertical offset from 0 cm to 10.1 cm makes only a small difference to the transmission of motion from the input ry direction to the x motion of stage 2.

2 Model

The model used is the same as the one used to evaluate the changes suggested to ASI in 2005, with the exception of the location of the stage 1 CG. This, obviously, means that it is slightly different that the system for the FDR, but since the impacts are all really small, I don't think this is a problem. However, the mode frequencies for the final Advanced LIGO design will be slightly different than the modes you see here.

The parameters used for this are (standard SI units):

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ASI =
        param_set : 'FDR, Nov 2009'
            mass1 : 850.7260 kg
    stg1_cgoffset : 0.1013 m
           stage1.Rxx:  0.5306 m
           stage1.Ixx:  239.5157 kg m^2
           stage1.Iyy:  244.3060 kg m^2
           stage1.Rzz:  0.7099 m
           stage1.Izz:  428.7664 kg m^2
            mass2 : 2.4510e+03 kg
     dynamic_mass : 350.2722 kg
             cg_z : -0.0064 m
              Ixx : 965.5081 kg m^2
              Iyy : 984.8182 kg m^2
              Izz : 942.2063 kg m^2
              Ixy : -105 kg m^2
              Ixz : -272 kg m^2
              Iyz : -159 kg m^2
          rod_k01 : 9.4038e+04 N/m
          rod_k12 : 2.0594e+05 N/m
        blade_k01 : 2.2783e+05 N/m
        blade_k12 : 2.7371e+05 N/m
     tip_radius01 : 0.7206 m
     tip_radius12 : 0.7239 m
     rod_length01 : 0.1269 m
     rod_length12 : 0.0444 m
           spring.E:        1.8961e+11 N/m^2
           spring.St:       744660000 N/m^2
           spring.wol:      0.5000 (m/m width/length)
           spring.a:        0.0300 (poison ratio)
           spring.thick01:  0.0139 m
           spring.thick12:  0.0121 m
           spring.length01: 0.4300 m
           spring.length12: 0.3215 m
```

I ran the model with 2 setting, first with the stage 1 CG offset at 0 cm, i.e. the CG is aligned with the LZMP of the stage 0-1 flexures. Then I ran with the model with a 3.99

inch offset, so that the CG is now above the LZMP. In figure 1, we can see the transfer function of horizontal motion at the H1 geophone location when you drive the H1 actuator. In the aligned case, one can see the four modes associated with the translation and the RZ rotation. When we apply the offset, several new modes associated with the tip/tilt motion appear.

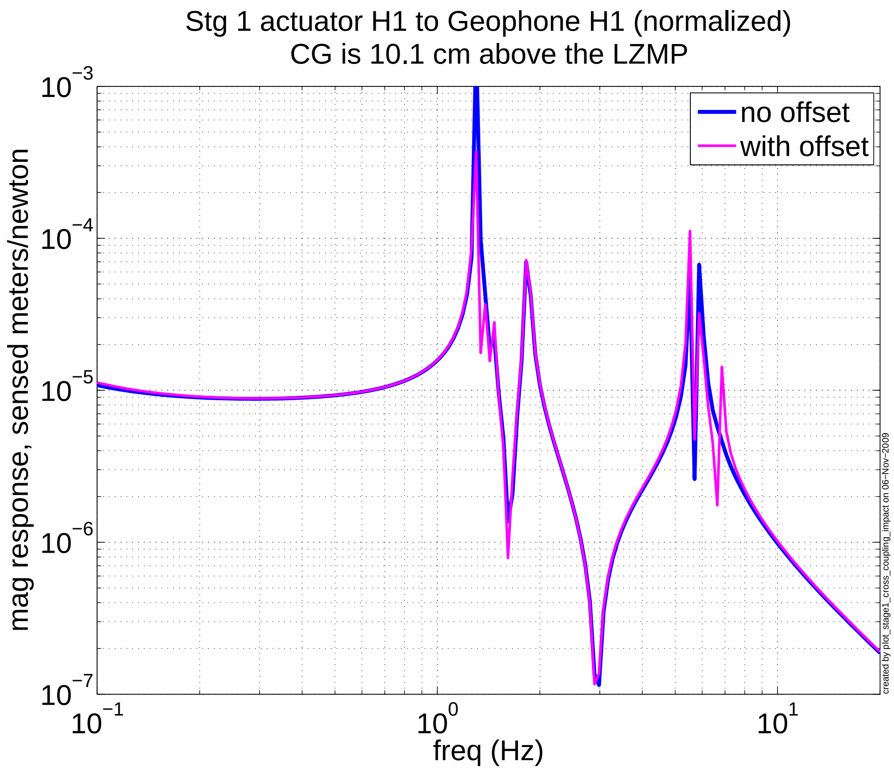

Figure 1: Impact on the undamped plant dynamics, as seen by sensor/ actuator pair H1

The system is designed to run with successive loop closures. First, one closes a set of 12 collocated damping loops which reduce the Q of the 12 body modes. The isolation loops are then designed from this damped plant. In figure 2, we can examine how the damped plant changes when the (old) ry loop is closed on stage 1. What we want is for the X plant to not change very much around the upper unity gain frequency, ie in the 10-50 Hz range. We design the loops for each stage as 6 independent SISO loops, and if turning on one loop has a large impact on the other loops, especially near the upper unity gain frequencies, then MIMO design tools will be needed, which will make commissioning more difficult.

The other issue is performance. In figure 3 we plot the transmission from RY motion

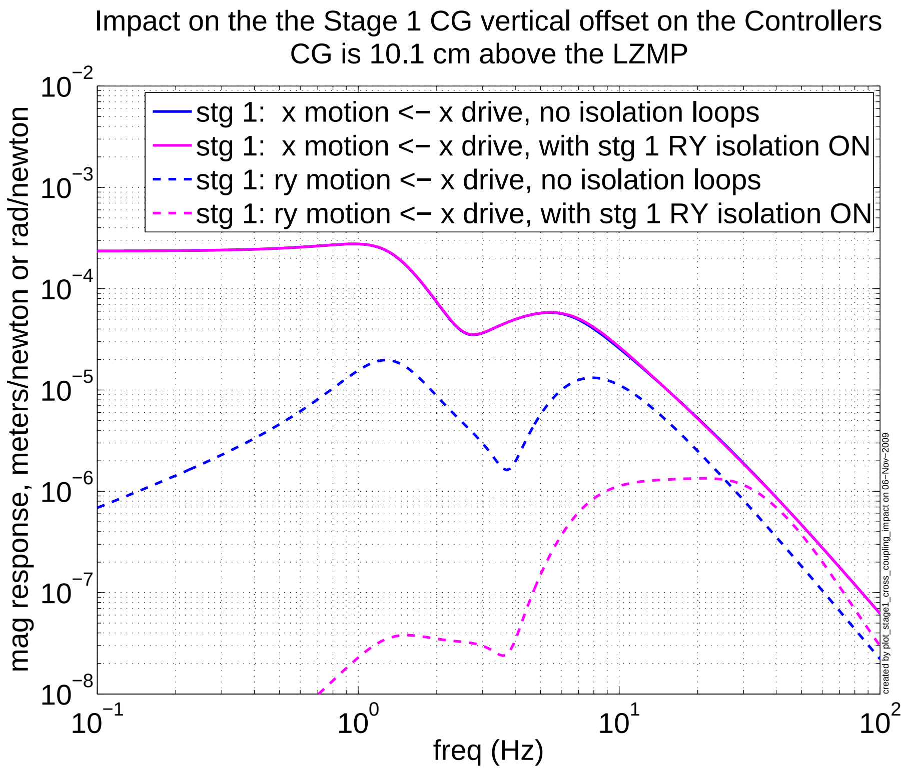

Figure 2: Change in the X plant for stage 1, when the RY loop controller is turned on. The solid blue curve (almost completely obscured by the solid magenta curve) is the transfer function from the stage 0-1 coordinate X drive to the stage 1 X motion, when all 12 damping loops are on and all 12 isolation loops are off. The dashed blue curve shows the coupling from the X drive to RY motion. The solid magenta curve shows the X plant when the stage 1 RX and RY isolation loops are engaged. The X plant has changed, because the X and RY modes are coupled by the CD offset. We are pleased to note that the change in the X plant is so small that it is difficult to see. The change in the X to RY coupling (shown as the dashed magenta curve) is quite obvious.

of the support table to X motion of stage 2. Again we compare the case with no offset at with a 3.99 inch offset. This plot is surprising, in that the performance above 10 Hz is improved by adding the offset. The coupling of the modes results in another pair of poles and zeros, the zeros are at about 90 Hz. The low frequency motion comes from the tilt-translation coupling between stage 1 and stage 2. Combined with the experimental results from LASTI which show that the horizontal performance is good enough, even though the tilt motion there is bad, and the CG offset is larger, we conclude that the 3.99 inch offset is fine.

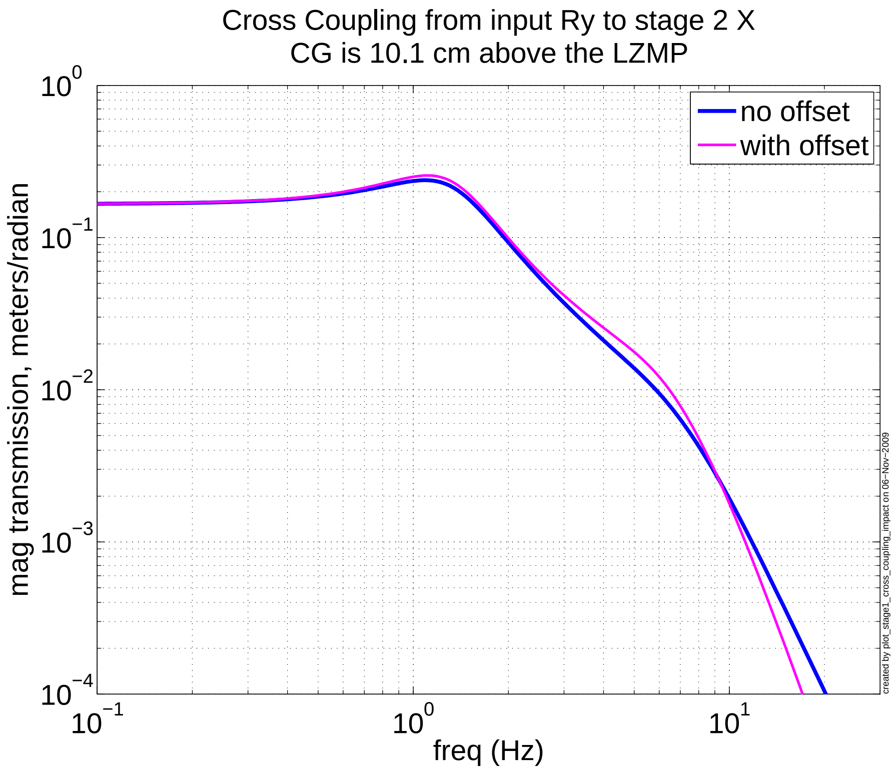

Figure 3: Comparison of the transmission