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Local damping gain in the SOS & LOS Suspensions

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1 OVERVIEW

This note looks at the effect of the magnitude of the gain in the local damping loop (POS loop only, to date) in the SOS & LOS suspensions. Typically, this gain is set to achieve critical, or near-critical, damping, by applying a square wave force excitation to the optic and looking at the POS sensor output. This nicely suppresses the response at the pendulum frequency, but it also means that for frequencies just above this, the optic is more strongly 'tied' to its suspension tower. Since there is strong excitation at the first stack resonance of 1.5 Hz, it is not clear that critical damping is in any way 'optimal'.

I have looked at this question by modeling the response of the SOS & LOS suspensions to the expected motion of the suspension point, as a function of the damping gain. Of interest is the gain value(s) at which the displacement and velocity of the mirror is minimized. The conclusion is that in order to minimize one or both of these quantities, the system should be under-damped (Q of roughly 8).

2 SYSTEM MODEL

The system is modeled with Simulink, using a block diagram (shown in Figure 1) similar to that found in '*Response of Pendulum to Motion of Suspension Point'*, T960040-00-D. I have left out the coupling between the displacement and the pitch angle of the mass; as shown in T960040, the pitch angle makes a negligible contribution to the displacement of the mass.

The input for the 'suspension point position' is the same as that used for the LSC Final Design (T980068); it is a displacement spectrum that is generated by propagating measured ground noise at the LA site through a model of the stack. It would be more realistic to use new ground motion data, measured in the LVEA at either/both site/s. However, the results presented below depend mostly on what is happening at the pendulum frequency and the first stack frequency; only differences in the relative ground noise at these two frequencies would tend to change the results. The input spectrum is cut-off on the low frequency end at 0.5 Hz; this is done to avoid including the microseismic peak in the calculation.

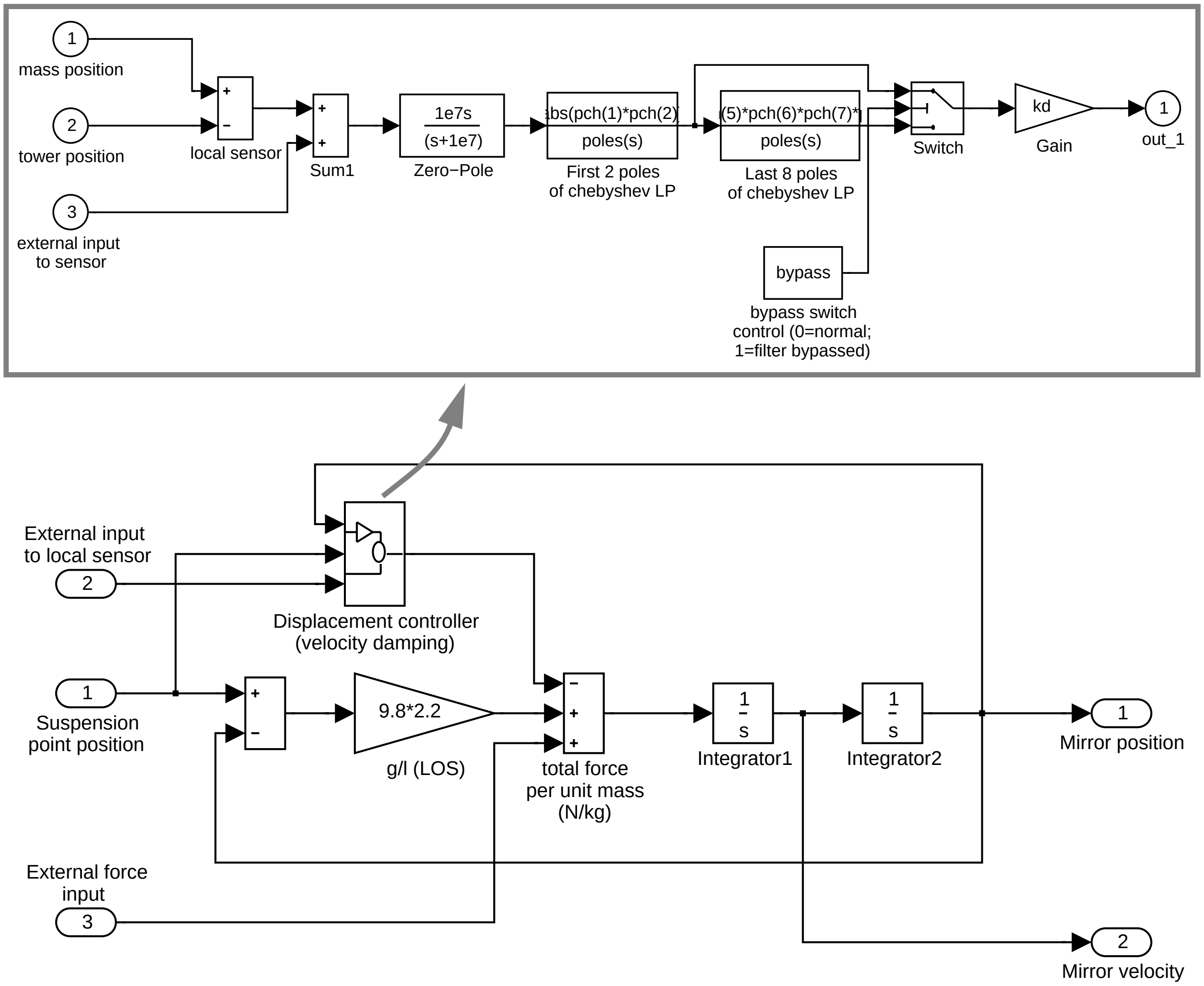

Figure 1: Block diagrams (Simulink) of the locally damped suspension model. Velocity damping is achieved with a zero at DC, and a high frequency pole for stability. This is followed by a 10th order, 1 dB ripple, Chebyshev low-pass filter; the two most-real poles of this filter are separated from the last 8, the latter of which can be switched in or out to emulate the bypass mode of the suspension controller.

3 Results

For maintaining servo lock, it may be desired to minimize mirror displacement of the locally damped mirror, whereas for lock acquisition it may be more desirable to minimize velocity. Fortuneately, these two minima occur at roughly the same value of the local damping gain. Figure 2 shows the residual displacement and velocity of the suspended optic as a function of the damping gain.

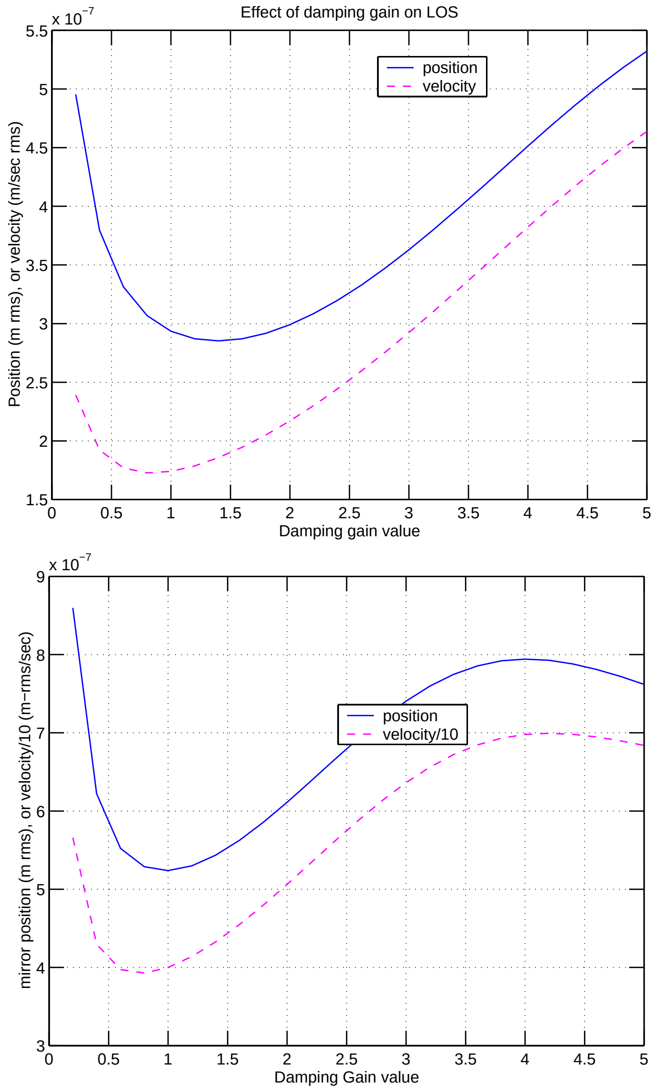

Figure 2: Residual displacement and velocity as a function of the damping gain for a LOS (top) and a SOS (bottom). The true velocity is 10x the value on the curve. In both cases the full 10th order Chebyshev filter is engaged.

More of the effects of the damping gain as shown in Figure 3 (SOS) & Figure 4 (LOS), where the response to suspension point motion, the step response to an external force, the residual displacement and the residual velocity are all shown for several values of gain. Since the damping gain is set by driving the POS (eg) test input with a square wave, and looking at the POS sensor response, I have shown in Figure 5 the step response for the near-optimal gain of 1; to aid in setting the appropriate gain, the values of the first several extrema are given, relative to the final step value. All of the results shown were generated with the full Chebyshev filter engaged. Bypassing the last 8 stages of the filter mainly changes the response around 10 Hz, has a small effect on the rms displacement and velocity (~10% lower with filter bypassed), and makes an insignificant change to the step response.

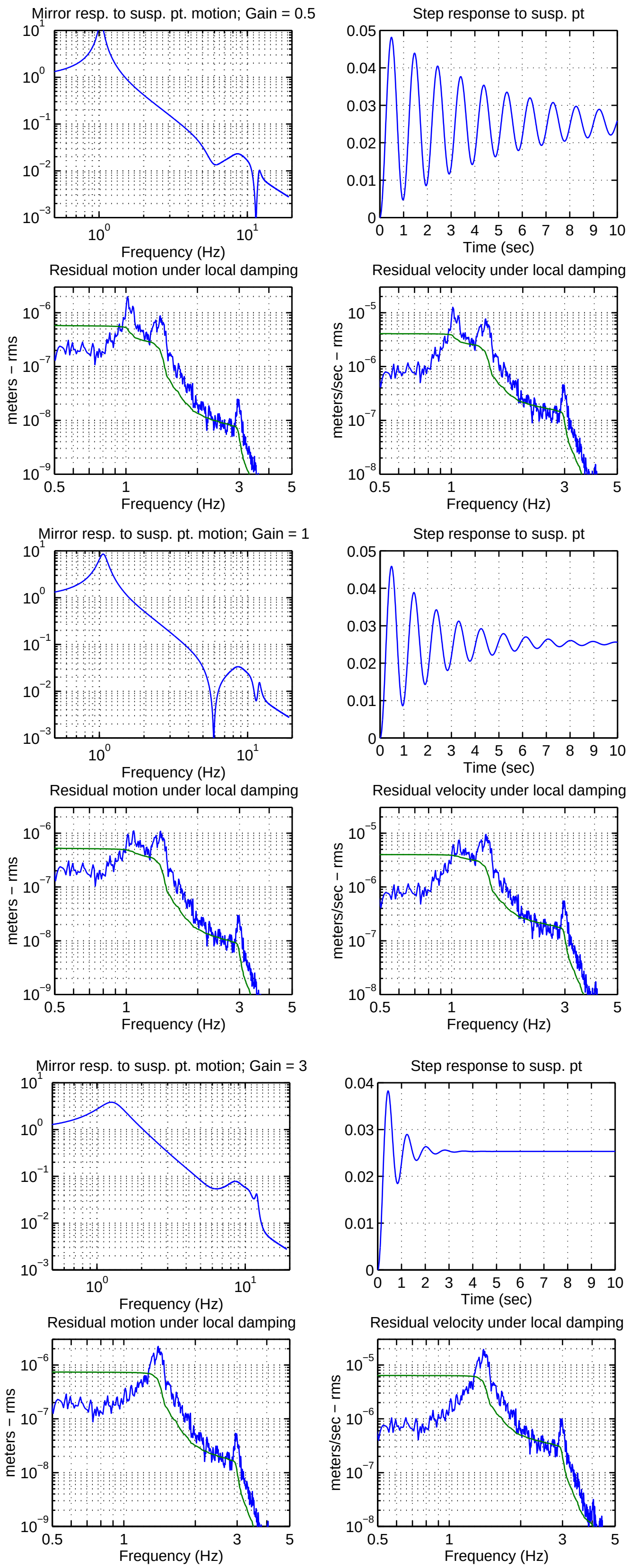

Figure 3: Response of SOS suspension to various damping gains (gain goes from 0.5, to 1, to 3, from top to bottom). A damping gain of 1 is near-optimum (see Figure 2).

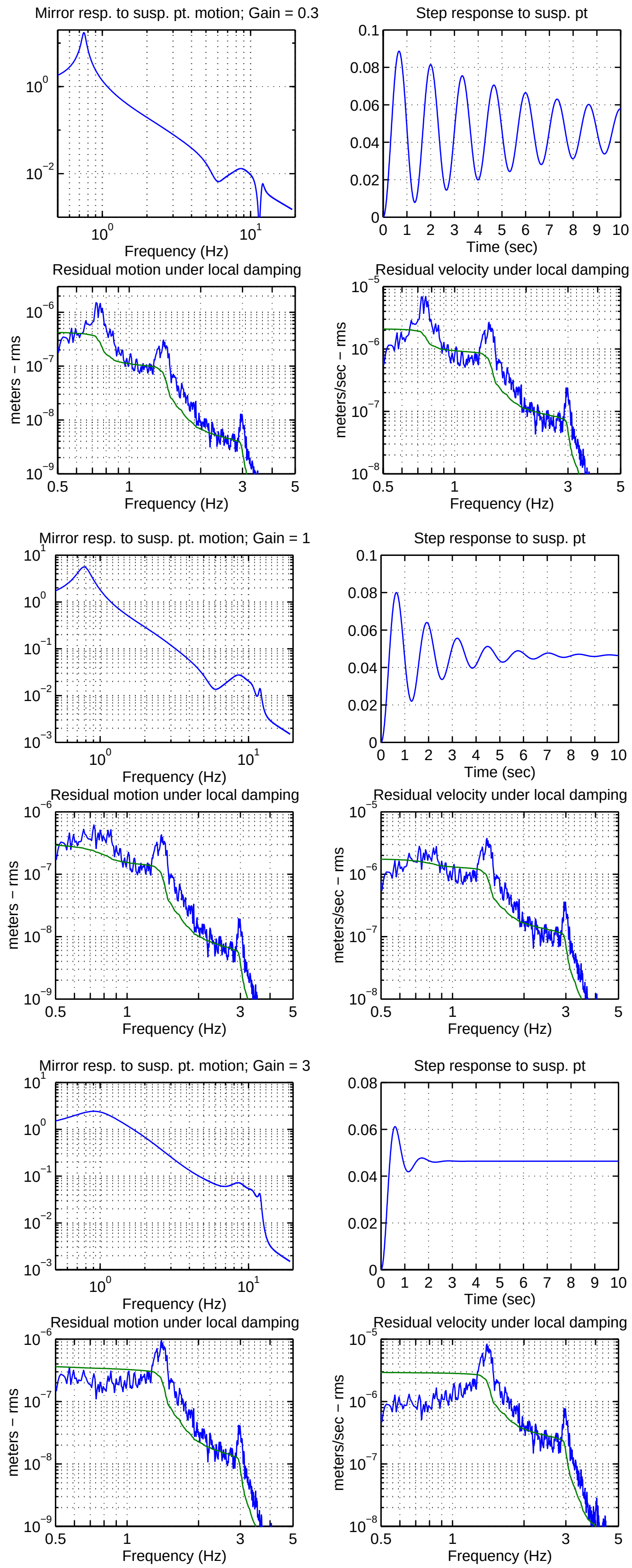

Figure 4: Response of LOS suspension to various damping gains (gain goes from 0.3, to 1, to 3, from top to bottom). A damping gain of 1 is near-optimum (see Figure 2).

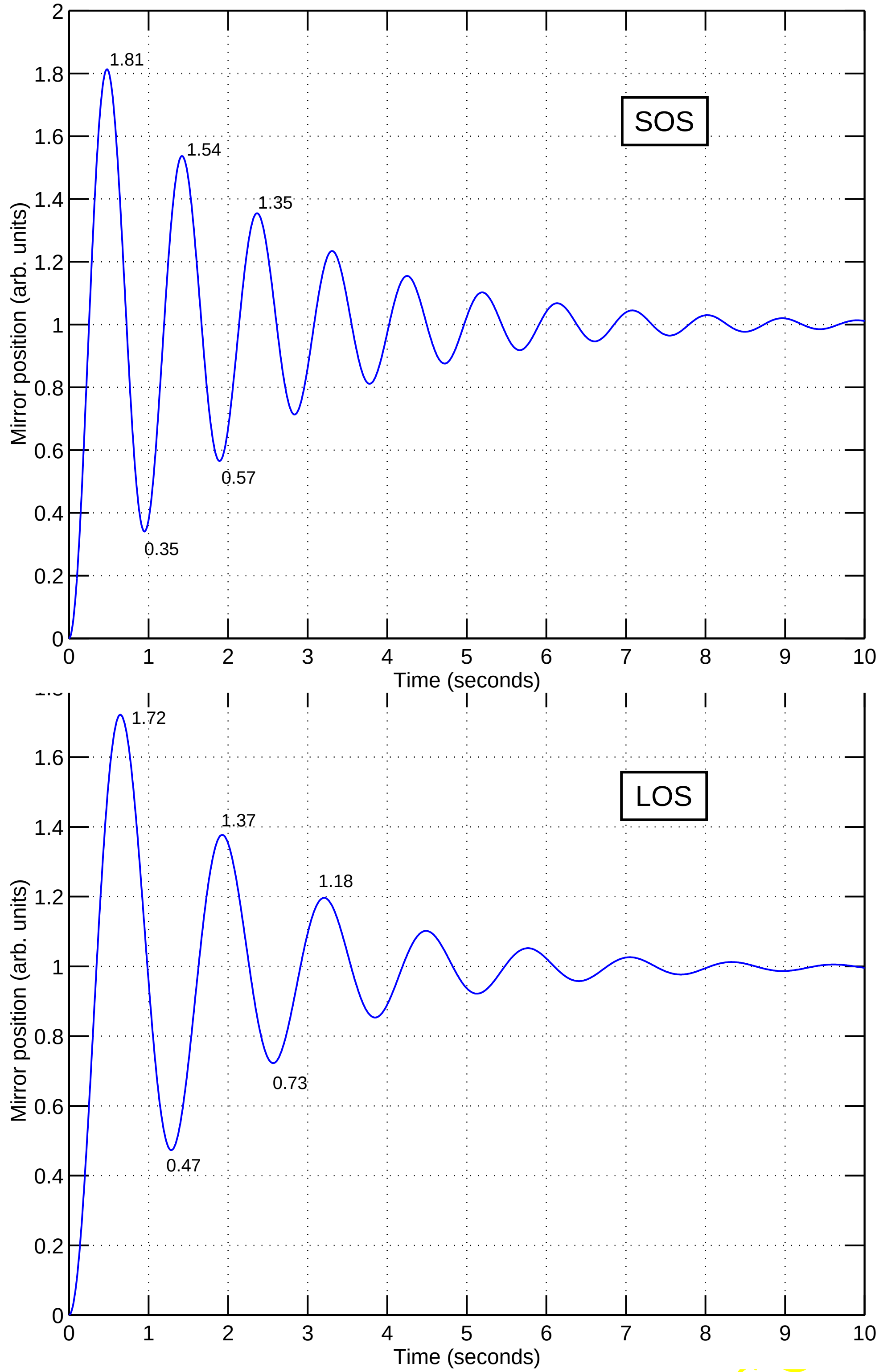

Figure 5: Step response of mirror position to external force for SOS (top) and LOS (bottom), both for damping gain of *kd* = 1. The plots are intended to aid in setting the damping gain at the optimal value (*kd* = 1); the values of the extrema, relative to the settled step value, are thus indicated next to the first few extrema.

A damping gain of *kd* = 1 is close to the optimum for both displacement and velocity minimization, for both the LOS & SOS. This can be compared to a 'pseudo-critical' gain of *kd* = 4[1], which has typically been used, and for which the displacement and velocity is nearly a factor of 2 higher than for *kd* = 1.

These results thus argue that the local damping gain should be set for relatively light damping, giving a *Q* of about 8, at least for the position degree-of-freedom. The two angular modes are not so straightforward to model, since we do not have a good estimate for the input excitations. Nonetheless, it seems like there would be a major contribution at the first stack resonance, and so the above results should hold fairly well for the pitch and yaw modes as well. So I would suggest that these modes also be lightly damped (*Q* = 8); similarly for the sideways pendulation mode. Light damping should also reduce cross-coupling in the suspension-suspension controller system between the various modes.

1. as used in T960040