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Output matrix tuning for large and small optics controllers

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ABSTRACT

This document describes a procedure for tuning the output matrices of the controller for a suspended optic. The procedure uses an optical lever to bypass the sensor constants and obtain an accurate measure of the angular motion of the optic. This provides enough information for us to minimize cross couplings between position, pitch, and yaw by tuning the controller's force constants.

INTRODUCTION

We would like to be able to excite individual modes of our suspended optics without disturbing the other modes. There are a variety of mechanisms by which motion in one mode may be transmitted to another, including (but not limited to) intrinsic mechanical coupling, non-orthogonal drive signals arising from mismatched force constants, and local-damping mediated cross couplings arising from mismatched sensor constants [1]. We can compensate for a lot of these by tuning the force constants, provided we have an accurate measure of the cross couplings. Using the sensor constants to measure these cross couplings is only a viable option if the sensor constants have been tuned, but as of this writing, tuning the sensor constants requires tuned force constants.

We can get around this dilemma by using an optical lever to measure the angular motion of the optic instead of the shadow sensors. This measurement gives us enough information to minimize all of the cross couplings between position, pitch, and yaw.

The basic procedure is as follows:

1. Drive position. Measure pitch and yaw with the optical lever, tuning the position force constants to independently minimize the optic's motion in each angular mode.
2. Drive pitch. Measure yaw with the optical lever, tuning the pitch force constants in such a way that the coupling to both yaw and position is minimized. We do this by acting on one side of the optic at a time. With only two actuators active, say the two on the left side of the optic, minimizing the yaw motion of the optic also minimizes its "position" motion.
3. Drive yaw. Measure pitch with the optical lever, tuning the yaw force constants in such a way that the coupling to both pitch and position is minimized. This is an analogous procedure to tuning the pitch force constants.

This procedure doesn't address the side mode, because there is not a lot you can do about it by just tuning the force constants. At this writing there is preliminary evidence that setting the side damping gain to some low value, much less than critical damping, helps reduce cross couplings between side and other modes.

The procedure, as described in this document, is still under development. As of this writing, hardware is being developed for the final version, and questions remain about how much of the cross couplings you can tune away and how well we need to do. We are distributing this document at this time to aid in the development of the subject.

SETTING UP

A schematic of the tuning setup is shown in Figure 1.

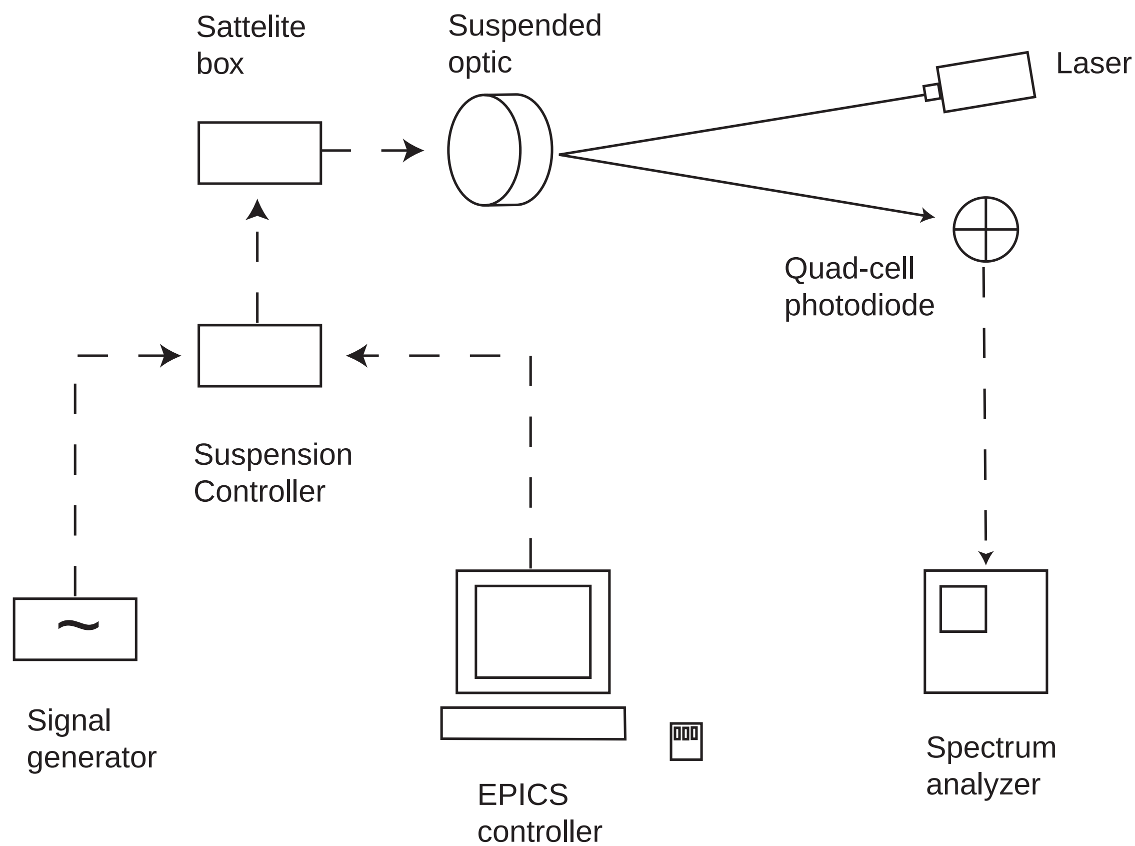

Figure 1 Basic setup for measuring angular motion of an optic and for tuning its controller's output matrix. The signal generator provides the excitation signal, for position, pitch, yaw, or side motion, and the spectrum analyzer reads the mirror's angular motion from an optical lever. Output matrices are tuned in software using the EPICS controller.

Optical levers for large optics

Most large optics have ISC optical levers already installed, and you can tap the outputs of those to measure the angular motion of the mirror. As of this writing, the procedure for tapping these signals has not yet been finalized, so we will not include instructions in this document. (It is straightforward to improvise a signal tap, if you need to. See the optical lever wiring diagram, for example [2], for details.) Once this procedure is finalized, dedicated hardware for tapping the optical lever outputs should be available at the sites.

Calibration of an optical lever has been described by Mike Zucker [3].

Optical levers for small optics

Small optics typically do not have optical levers in place, so you will have to improvise.

Appropriate excitation signals

The appropriate amplitude of excitation signal going into the controller depends on the frequency you are operating at and whether you are tuning a large optic or a small optic. You can safely start with $50mV$ at any frequency on any optic and increase from there to suit your needs. The drive signal you end up using should produce a peak on the spectrum analyzer (in the signal you intend to measure) at least an order of magnitude above the background noise.

Force constants are typically frequency dependent. We have typically tuned the controllers at either $2.0Hz$, near one of the stack resonances, or $0.16Hz$, near the microseismic peak. It is not known at this time at what frequency the cross couplings are most critical.

Appropriate damping gains

Damping gains should be set to their final values, *i.e.* the values expected for normal operation. Peter Fritschel has shown that this corresponds to somewhat less than critical damping, and he has given quantitative guidelines for optimal gain [4].

MEASURE THE UNTUNED CROSS COUPLINGS

Before you start tuning the force constants to reduce the cross couplings, it is a good idea to measure and record the cross couplings with untuned force constants.

Measure position to angle coupling

Drive POS TEST IN, measure POS MON to get a rough idea of the motion of the optic, then measure both the pitch and yaw motions of the mirror with the optical lever and record your observations. Even without the sensor constants tuned, you may apply the approximate rule of thumb that $1.0V$ on POS MON corresponds to roughly $1.0mm$ of travel in the optic, provided each of the sensor constants is 25 (or at least close to 25).

Cross couplings between position and angle are usually expressed in terms of meters per radian or radians per meter, depending on the direction of the coupling.

Measure the pitch to yaw and pitch to position coupling

Drive PIT TEST IN. Measure both the pitch and yaw signals with the optical lever, and take the ratio of yaw/pitch, which we may take to be the baseline pitch to yaw coupling.

Still driving PIT TEST IN, measure the POS MON signal from the front of the controller to get the pitch to position coupling.

Measure the yaw to pitch and yaw to position coupling

Drive YAW TEST IN, and measure both yaw and pitch with the optical lever, taking the ratio pitch/yaw as the baseline cross coupling. As before, measure the position motion using POS MON, and record an approximate value for the yaw to position coupling.

Now that you have an idea of what you are starting with, it's time to try and improve things.

TUNE THE FORCE CONSTANTS

In the following discussion, I will assume that the force constant gains all start out at 50.

Tune the POS force constants

First, we want to minimize position to angle coupling. Send a test signal into the controller's POS TEST IN port, and observe the yaw signal as measured by the quad-cell photodiode. Adjust the POS->UR and POS->LR output matrix elements each by the same amount until the yaw signal at your test frequency is minimized.

Now measure the pitch with the quad-cell. Drive the POS TEST IN, same as before, and adjust the POS->LL and POS->LR output matrix elements to minimize the quad-cell's yaw signal. Note that you must change each matrix element by the same total amount (*e.g.* lowered by 2), rather than the same relative amount (*e.g.* each reduced by 4% of its original value), so that you do not undo the position to yaw coupling minimization you did just before this step.

You have now tuned the POS output matrix. The minimized yaw motion, as measured with the quad-cell, should not change when you minimize the pitch motion.

Tune the PIT force constants

Now we want to be able to drive pitch without exciting either yaw or position. Send a test signal into the controller's PIT TEST IN port, and measure yaw with the optical lever. Set the PIT->UR and PIT->LR output matrix elements to zero, so that no force is applied to those two magnets. Now adjust the PIT->LL output matrix element to minimize the mirror's yaw motion.

Record the optimal values for PIT->UL and PIT->LL output matrix elements. Set PIT->UR and PIT->LR back to 50, and then set PIT->UL and PIT->LL to zero, so that no forces are applied to the left side of the mirror. Now adjust the PIT->LR output matrix element to minimize the mirror's yaw motion.

Bring the PIT->UL and PIT->LL elements back up to their optimal values. You should see little or no change in the yaw signal. You have now minimized the coupling from pitch to yaw and at the same time, the coupling from pitch to position.

Tune the YAW force constants

This procedure is in principle the same as that for tuning the pitch force constants, only with pitch and yaw reversed.

Send a test signal into the controller's YAW TEST IN port, and measure pitch with the optical lever. Set the YAW->LL and YAW->LR output matrix elements to zero, so that no force is applied to those two magnets. Now adjust the YAW->UR output matrix element to minimize the mirror's pitch motion.

Record the optimal values for YAW->UL and YAW->UR output matrix elements. Set YAW->LL and YAW->LR back to 50, and then set YAW->UL and YAW->UR to zero, so that no forces are applied to the upper half of the mirror. Now adjust the YAW->LR output matrix element to minimize the mirror's yaw motion.

Bring the YAW->UL and YAW->UR elements back up to their optimal values. You should see little or no change in the pitch signal. You have now minimized the coupling from yaw to pitch and at the same time, the coupling from yaw to position.

MEASURE HOW WELL YOU'VE DONE

Now, with all of the force constants set to their optimal values, measure the residual cross couplings between each of the modes, and compare those with the untuned cross couplings you measured above.

Drive PIT TEST IN. Measure both the pitch and yaw signals with the optical lever, and take the ratio of yaw/pitch. If everything has worked properly, this ratio should be on the order of 1% or less. Still driving PIT TEST IN, measure the POS MON signal from the front of the controller.

Now measure the yaw to pitch cross coupling. Drive YAW TEST IN, and measure both yaw and pitch with the optical lever. Again, the ratio of pitch/yaw is a measure of the yaw to pitch cross coupling and should be on the order of 1% or less. As before, measure the position motion using POS MON, and record an approximate value for the yaw to position coupling.

Finally, measure the position to angle coupling. Drive POS TEST IN, measure POS MON to get a rough idea of the motion of the optic, then measure both the pitch and yaw motions of the mirror with the optical lever. Record your observations, and compare with the untuned cross couplings.

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