LASER INTERFEROMETER GRAVITATIONAL WAVE OBSERVATORY
- LIGO -
CALIFORNIA INSTITUTE OF TECHNOLOGY
MASSACHUSETTS INSTITUTE OF TECHNOLOGY

Document Type **LIGO-T000003-A - D00** 09/12/00

Suspension Controller Tuning Procedure

Mark Barton, Gabriela Gonzalez, Steve Penn

Distribution of this draft:

DCC

This is an internal working note
of the LIGO Project..

California Institute of Technology
LIGO Project - MS 51-33
Pasadena CA 91125
Phone (626) 395-2129
Fax (626) 304-9834
E-mail: info@ligo.caltech.edu

Massachusetts Institute of Technology
LIGO Project - MS 20B-145
Cambridge, MA 01239
Phone (617) 253-4824
Fax (617) 253-7014
E-mail: info@ligo.mit.edu

WWW: http://www.ligo.caltech.edu/

1 ABSTRACT

The procedure for setting the input and output matrices in a suspension controller is given.

2 KEYWORDS

SUS, suspension controller, LOS, SOS

3 DOCUMENTS

`http://blue.ligo-wa.caltech.edu` : LHO CDS Web server, with many useful links to documentation of the CDS network and the DAQ system at Hanford.

`http://london.ligo-la.caltech.edu` : LLO CDS Web server, with many useful links to documentation of the CDS network and the DAQ system at Livingston.

`http://www.ligo.caltech.edu/~jay` : Jay Heefner's web page, with schematics of the suspension controllers, and the rack wiring at both LHO and LLO.

`http://www.ligo.caltech.edu/~rolf` : Rolf Bork's web page, with assorted CDS documentation including the equipment lists for the racks.

4 VERSION HISTORY

2/18/00: Version used at initial training session at LHO.

3/8/00: More screenshots.

3/16/00: Update of LLO-specific parts, expanded software section.

3/22/00: Rev 00. More screenshots, corrections to section on `SensMatrix2.m` routine (formerly `PendMatrix1.m`).

6/30/00 Major revisions to reflect simplifications made to software. New screenshots from current LHO screens.

8/30/00 Extensions to include new pitch and yaw actuation tuning

9/1/00 Fleshing out of sections on pitch and yaw actuation tuning

9/12/00 Rev A - final tidy-up of new stuff

5 OVERVIEW

5.1. Aim

The suspension controller electronics convert the OSEM sensor outputs into mirror monitor signals in a position-pitch-yaw basis, using a sensing (a.k.a. input) matrix of 12 weights. After position, pitch and yaw control signals have been generated, they are converted to coil drive signals for the magnet/coil actuators using an actuation (a.k.a output) matrix of 12 weights. The tuning procedure described here tries to compensate for differences in the sensors and actuators so that the monitor signals are as pure measures of position, pitch and yaw as possible, and that the control signals produce as pure displacements in position, pitch and yaw as possible. At the same time it tries to reduce unwanted couplings to the side sensors and actuators.

There are two distinct parts for the tuning procedure: the tuning of the sensing matrix and the tuning of the actuation matrix. There are different versions of the procedure for tuning the position component of the output matrix. One uses optical levers and the other assumes that the input matrix is already tuned and so giving reliable estimates of pitch and yaw.

6 TOOLS

6.1. Hardware

6.2. Software

Apart from occasional trips to the LVEA or mid- or end-stations to set up cables, the entire procedure can be done from the control room using software available on the CDS workstations.

6.2.1. Directory Structure

At LHO, the directory for files relevant to this procedure is

`/opt/CDS/d/ops/sustune/`

in the CDS filesystem. The equivalent directory for LLO is

`/opt/LLO/c/ops/sustune/`

All files in these directories should be owned by the user `ops`.

The `matlab` subdirectory of the above contains Matlab software that is common to all optics. As far as possible, new Matlab routines should be written to avoid hard coded paths. At each observatory there is a custom version of a routine `whereami.m` which defines variables for all currently relevant observatory-specific paths, and this should be invoked wherever relevant so that all other files are observatory-independent.

Files specific to a particular optic should be in a subdirectory with an appropriate name, e.g., `itmx2k`. Each optic subdirectory should have a `burt` subdirectory (e.g., `itmx2k/burt`) containing request files (`.req`) and snapshot files (`.snap`) for the backup and restore utility.

The `template` subdirectory contains software that is intended to be copied and modified for particular optics. This includes saved states for the Data Viewer and GDS tools as well as Matlab command files. Modified versions of the template files should be placed in the appropriate optic subdirectory.

6.2.2. Remote login and file transfer

The material in this section should not be relevant to the eventual final version of the procedure but is included for the convenience of people working on improving it, especially the custom software that has been written. Improved versions of the custom software will commonly need to be copied from one observatory to the other.

Observatory computers are divided into two classes: GC (general computing) and CDS. GC computers have full internet access. CDS computers are on a private network local to the observatory. Communication between the CDS network at an observatory and the outside world is via a gateway machine which is also on the GC network. These are `blue.ligo-wa.caltech.edu` at LHO and `london.ligo-la.caltech.edu` at LLO.

The CDS machines have an account `ops` which should be used for the procedures in this document. The passwords for ops at LHO and LLO are an open secret and can be found out by asking anyone at the observatories. For GC machines, you will need a personal account and password, obtainable from Christine Patton at LHO or Tom Evans at LLO.

Remote logins can be made to GC computers running Unix using `ssh` (`telnet` is disabled for security reasons). Good computers for remote logins (i.e., fast, full complement of software) include `spokane.ligo-wa.caltech.edu` and `decatur.ligo-la.caltech.edu`. Some computers (especially at LLO) also have `rlogin` enabled, but this should not be used from outside the observatories because it is a security risk. Note that if you have logged in to a GC machine under your personal username using `ssh`, you can type `rlogin -l ops gateway-name` to `rlogin` to the gateway as user `ops`.

The gateway machines support `ssh` but access doesn't seem to work from some machines, probably due to differing versions of `ssh`. The GC machines seem to be more tolerant, so if you experience problems, first use `ssh` to a GC computer at the same observatory as the gateway and then `rlogin` to the gateway.

Files can be transferred to or from most GC computers with `ftp`, but this is a security risk and `sftp` (secure ftp) should be used whenever it's available on the computer you're connecting from.

The gateway at LHO, `blue`, has both the GC and CDS filesystems mounted, so files can be copied between the two using `cp`. It also recognises LHO GC usernames. It has an `sftp` server but no plain `ftp` server. There is a secondary gateway machine `gold` with a plain ftp server which can be accessed from within LHO GC. The gateway at LLO, `london`, has only the CDS filesystem and allows logins only to CDS accounts. At the time of writing it had an `sftp` server but it didn't work, and although it has an `ftp` server, this should not be used from outside LLO if possible because of the security risk. Therefore the easiest safe way to transfer files between the two CDS systems is to log on to `london` and use `sftp` to `blue`.Whatever method you are using, be sure to be logged on as `ops` before adding files to the CDS side, to ensure that they have the correct ownership.

6.2.3. EPICS

EPICS is the interface software to much of the data acquisition hardware. It underlies much of the other software, including MEDM and BURT. If software that relies on EPICS is to be run from a terminal window, EPICS must be initialised first. However it should not be initialised more than once in the same terminal window.

6.2.4. MEDM

The status of the mirror controllers and the optical levers is monitored and changed using control screens specified by `.adl` files and displayed by MEDM. If the full site display (`sitemap.adl`, see Figure 1) is not already running, right click on the workstation desktop and choose “LHO Site

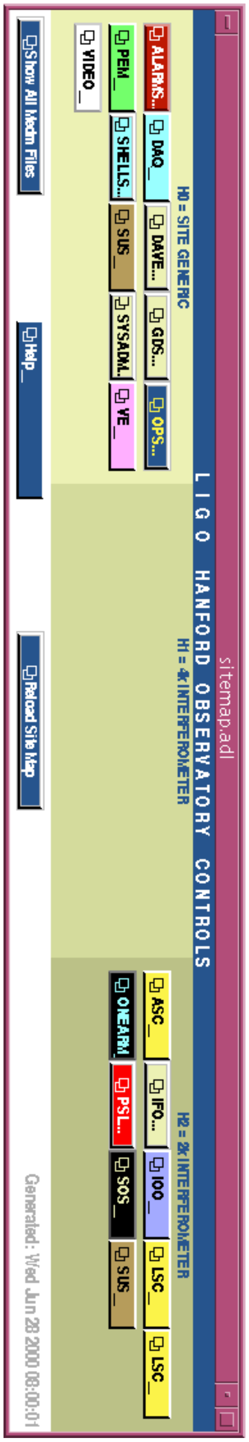


Figure 1: MEDM main site display

Map” (or TBD for LLO) from the popup menu. The suspension controller and optical lever displays can be found in popup menus on the site display.

Each suspension controller display (see Figure 2) is organized as a block diagram. The sensing matrix is viewed and adjusted in three subdisplays, one for each monitor (position, pitch and yaw). Each subdisplay is accessed through an icon on the left of the position, pitch or yaw path in the diagram. Click once on the appropriate icon to examine or adjust the weights (see Figure 3). Each subdisplay has four weights, one for each sensor (UL=upper left, LL=lower left, UR=upper right, LR=lower right). The default value for these weights is 25.

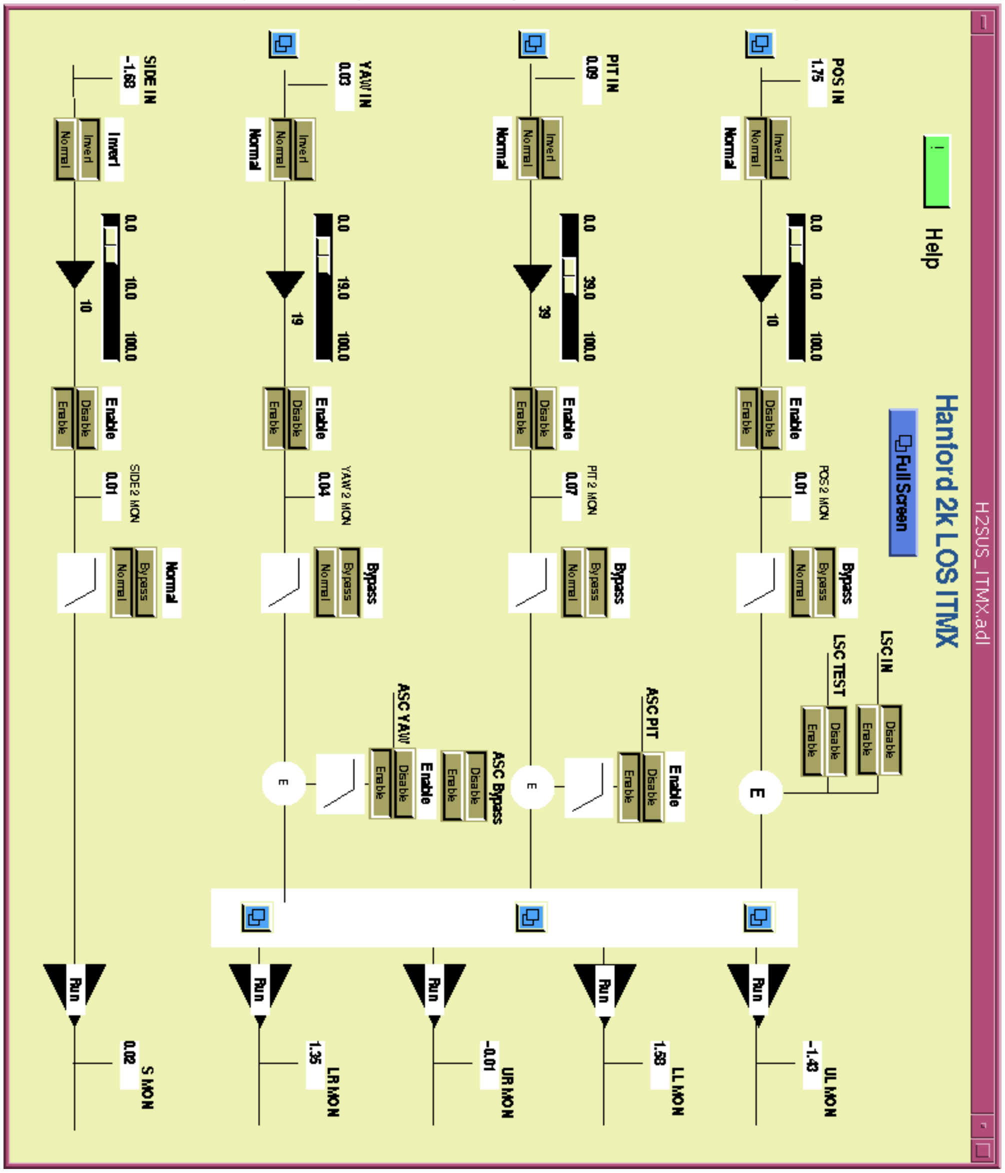


Figure 2: Suspension controller display for ITMx2K

The original version of the actuation matrix (see Figure 4) consists of four subdisplays, one for each of the UL, LL, UR, and LR coils. In each subdisplay, there are three weights corresponding to position, pitch and yaw. The four subdisplays are accessed through the icons after the LSC and ASC inputs and before the coil test inputs in the controller diagram.

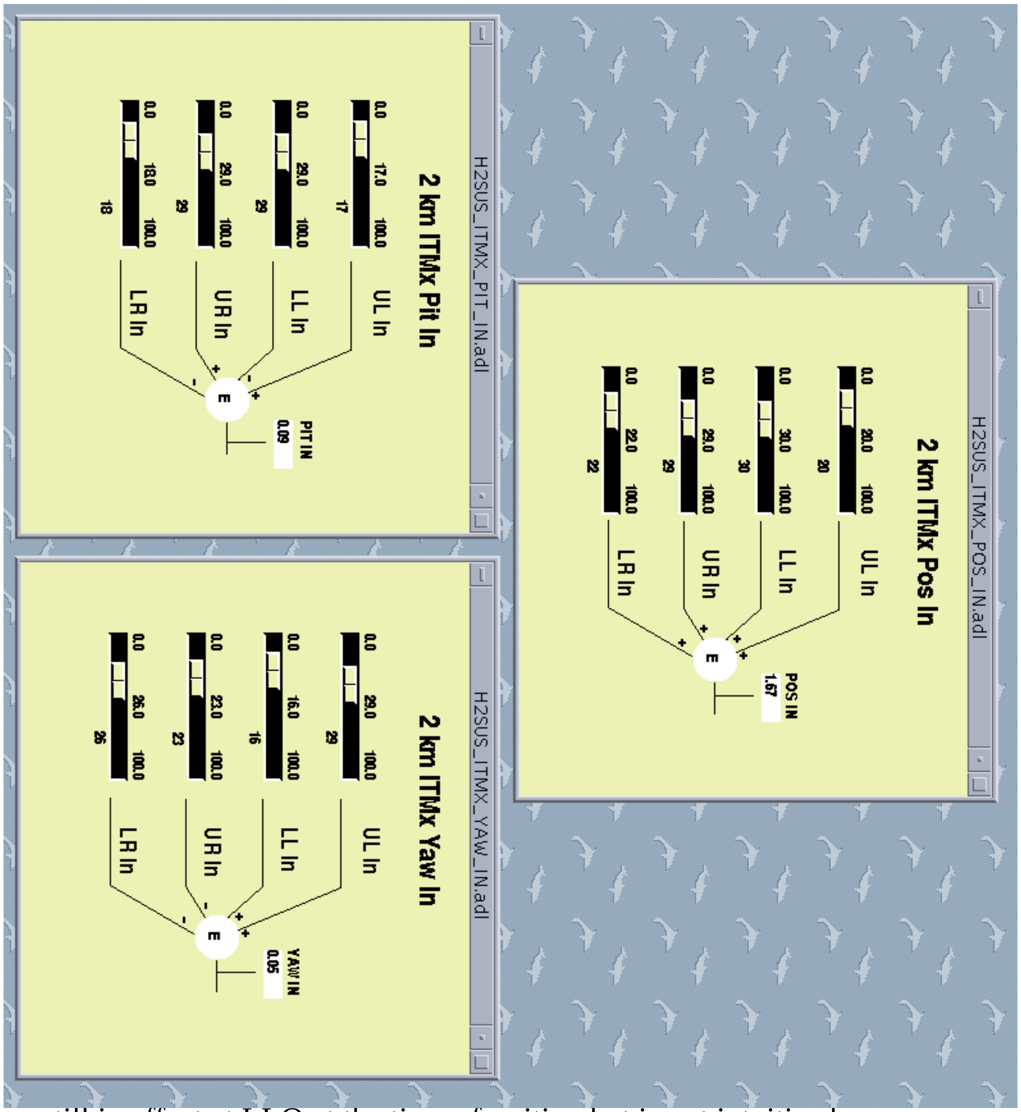


Figure 3: Sensing (input) matrix displays for ITMx2K

This version was still in effect at LLO at the time of writing but is not intuitive because one commonly needs to set all the weights for a single channel such as position, and this involves one control on each of four subdisplays. At LHO the 12 controls had been reorganised into three subdisplays, one for each of the position, pitch and yaw channels.

The nominal default value for the output gains is 100 (although the controllers are commonly initialized to 50 after a hardware reset).

6.2.5. The Data Viewer

The DAQS Data Viewer is used to monitor the OSEM sensor and optical lever signals for plausibility. To start it, bring up a terminal window and type “`dv`”, then “`start`” or “`start1`” depending on whether you want the output to appear on the left or the right screen of the workstation. (At LLO, right-click in the desktop and choose the appropriate command from the pop-up menu.) Master lists of the signal names available within DAQS are given in

<`http://gateway/daq/conf.fast`> (or from outside, <`http://blue.ligo-wa.caltech.edu/daq/conf.fast`> - not yet available at LLO.)

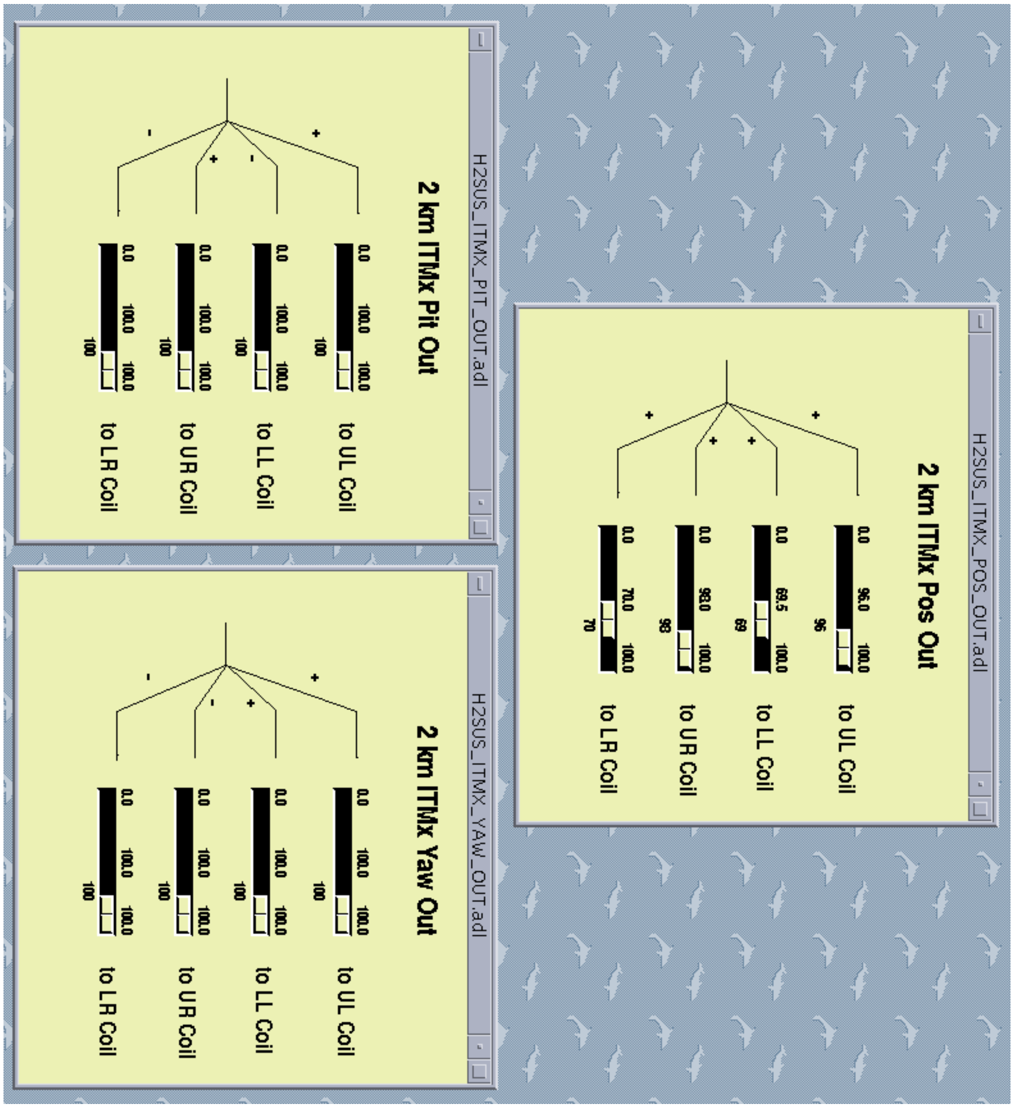


Figure 4: Actuation (output) matrix displays for ITMx2K

and

<http://gateway/daq/conf.slow> from the CDS network or <http://blue.ligo-wa.caltech.edu/daq/conf.slow> (TBD at LLO) from the GC network.

The example signal names in this procedure are given for ITMx of the 2K interferometer at Hanford. Signal names for other optics can be obtained by substituting appropriate values for “H2” and “ITMX”.

Version 3.1 of the DataViewer (only at LHO at the time of writing) would hang if certain message queues had unpurged entries. If you experience this, find out the contents of the queues with the command

```
ipcs -b
```

Then kill off all the messages corresponding to your username (`ops`) with commands of the form

```
ipcrm -q message-number
```

6.2.6. GDS Diagnostic Tools

The GDS Diagnostic Tools are used for many of the actual measurements in this procedure. To start the GDS tools, right click in the workstation desktop and choose GDS Diagnostics Tools from the popup menu. Signal names are as for DAQS.

6.2.7. Matlab

Much of the data analysis is done by programs running under Matlab. This is available on all control room machines at LLO. Just type `matlab` to start it. However as of 9/1/00 it is only on the machine `control0` at LHO. To use it on any other machine, e.g., `control7`, proceed as follows:

1. Bring up a terminal window.
2. Do an `rlogin` to `control0`.
3. Type either "`setenv DISPLAY control7:0.0`" or "setenv `DISPLAY control7:0.1`" depending on whether you want to have Matlab graphical output appear in the left or right screen of your workstation.
4. Type "`matlab`". Note that this does not run Matlab, it only sets up directory stuff.
5. Type "`start`".

When Matlab starts, set the working directory to the appropriate optic directory with a command like

```
>> pwd /opt/CDS/d/ops/sustune/itmx2k % for LHO
```

Also, add the `matlab` subdirectory to the path with a command like

```
>> addpath /opt/CDS/d/ops/sustune/matlab % for LHO
```

6.2.8. DataGet and other .mexsol routines

`DataGet.mexsol` is a Matlab extension that connects to the data server and downloads data into a `Matlab` format file. The up to date copy for LHO is at `/opt/CDS/e/matlab/appl`. As of 9/8/00 it was not officially installed at LLO. Therefore, to enable the routine to be used at LLO and to keep things as similar as possible between the observatories, a local copy has been placed in each `matlab` subdirectory, and the other routines are written to look for it there. `DataGet.mexsol` depends on a library called `frameMat` which has also been copied. The local copies need to be kept in sync with the version of the data server. As of 9/8/00, the version at LLO (for protocol version 9) was older than the version at LHO (v11).

6.2.9. XML Utilities

The command `/opt/CDS/a/gds/bin/xmldir` (`/opt/LLO/a/gds/bin/xmldir` at LLO) gives a directory of the information contained in an XML file.

The command `/opt/CDS/a/gds/bin/xmlconv` (`/opt/LLO/a/gds/bin/xmlconv` at LLO) converts an XML file to ASCII.

These utilities are invoked by some of the Matlab routines, especially the output matrix tuning ones.

6.2.10. BURT

BURT is the backup and restore tool for use with Epics. It is useful for saving particular states of the sensing and actuation matrices and restoring them quickly when desired. It is run by giving the commands

```
> setup epics # if this has not been done before for this terminal
> burtgooey &
```

in a terminal window. Full documentation can be found at <`http://www.aps.anl.gov/asd/controls/epics/EpicsDocumentation/ExtensionsManuals/Burt/BurtManual.book.html`>. Briefly, a BURT request (`.req`) file consists of a set of control names to be backed up (plus optional C-style comments). The control name for a control in a MEDM display can be found by pressing the middle mouse button over the control. The name can also be conveniently entered into the request file by dragging with the middle mouse button from the control to a text editor window showing the file. BURT processes the request file, producing a snapshot (.snap) file with the current values of those controls. Later, BURT can read the snapshot file and restore the saved values.

Each optic directory should have a `burt` subdirectory for `.req` and `.snap` files. The `templates` subdirectory has a number of `.req` files for common combinations of controls for ITMx2k. Rather than recreate them from scratch for other optics it may be convenient to copy these and edit the optic-specific part of each control name (the numeric part is consistent across controllers).

7 GENERAL SETUP

1. Make sure that all the servos are in RUN or ACQUIRE mode, whatever is the appropriate mode for that suspension. This is particularly important with the initial version of the controller electronics because (i) the coil readback circuits are commonly blown by transients when ACQUIRE mode is selected, and (ii) the bias voltages change between modes, putting the optical lever out of range.
2. If an optical lever is available, bring up the appropriate optical lever display. Check that the optical lever is mechanically zeroed, or at least within range (+/- 1), with a significant sum (>0.5). Get the aid of the appropriate person (Richard McCarthy at LHO or Rusyl Wooley at LLO) and ensure that there are available four fast (2048 S/s) optical lever DAQ channels from the IOO group of channels. The slow 1 S/s optical lever channels in the ASC group won’t do. Some optics such as ITMx have dedicated ones (H2:IOO-ITMX_OPTLEV_1, etc). For optics that don’t have them (e.g., RM) you will have to commandeer some temporarily from another optic.
3. If the GDS test outputs for the LSC test input (H2:LSC-ITMX_EXC) and the ASC pitch and yaw test inputs (H2:ASC-ITMX_P_EXC) are available, they should be used for excitation. Otherwise, wire up general-purpose GDS outputs (e.g., H2:LSC_MOD_1_EXC) to the appropriate test inputs of the controller.
4. Bring up the Data Viewer, and restore the saved state

```
/opt/CDS/d/ops/sustune/templates/allchannels.dvsave
```

. (or a saved state specific to the optic if it is available from an earlier round of tuning). Do a Save As and save it for future use in the subdirectory for the optic.

5. The signal names in the template are the sensor channels, optical lever channels and the excitation channel for the 2k ITMx: H2:SUS-ITMX_SENSOR_UL, H2:SUS-ITMX_SENSOR_LL, H2:SUS-ITMX_SENSOR_UR, H2:SUS-ITMX_SENSOR_LR, H2:SUS-ITMX_SENSOR_SIDE, H2:IOO-ITMX_OPTLEV_1, H2:IOO-ITMX_OPTLEV_2, H2:IOO-ITMX_OPTLEV_3, H2:IOO-ITMX_OPTLEV_4, H2:DAQ-GPS_RAMP3. Change them to the analogous signals for the optic being tuned. (If you have commandeered channels, remember to allow for this when entering the signal names. If there are no optical lever signals at all, you should move the excitation signal to Channel 6 in the signal selection dialog and reduce the number of active channels to 6.) Set all the y-axis limits appropriately so that the traces are centred and fully visible. Ensure that the ranges for related channels are the same, e.g., 0/-32000 counts for the optical lever channels (~full range) and ~4000 counts around the mean for the sensors (a safe range for the mirror motion). Save the changes. See Figure 3 for a typical output display.
6. Make a note of the optical lever position and the offsets of the sensors. This is particularly important - these positions need to be restored later. The sensor offsets should all be between -10,000 and -25,000. Anything outside this range indicates trouble for this sensor: the magnet is too far from its correct position, and the mirror may need a specialized tuning.
7. Make a note of the initial values of all biases, all gains, and the input and output matrices for all degrees of freedom, manually or with BURT.
8. Do a quick test drive of the optic by reversing each of the servos briefly one at a time.You should see all the sensors in the Data Viewer oscillate.

NOTE: Depending on the main servo gains this could take only a second or so to reach large amplitudes. Keep your eye on the Data Viewer display and your mouse on the INVERT switch.

7.1. Debugging Hints

- If none of the digital controls such as the enable and invert switches work, there may be a problem with the ribbon cable connecting the controller card in the VME crate to the suspension controller proper.
- If none of the analogue controls such as the gains work (in particular, if the readbacks do not correspond to the values the controls are set to), then there may be something wrong with the RS232 cable from the controller card in the VME crate to the suspension controller proper, or with the daughterboard on the suspension controller board which processes the RS232 data.
- If all the controls are dead then the controller card may need to be rebooted.

8 TUNING THE SENSING (INPUT) MATRIX

1. Using a text editor, open the Matlab command file template

```
/opt/CDS/d/ops/sustune/templates/getimatdataLHO.m
```

or

```
/opt/LLO/d/ops/sustune/templates/getimatdataLLO.m
```

as appropriate for the observatory.

2. Save a copy of the file as `getimatdata.m` in the optic subdirectory and edit it as explained in the comments in the template. (The signal names in the template are for ITMx2k and need to

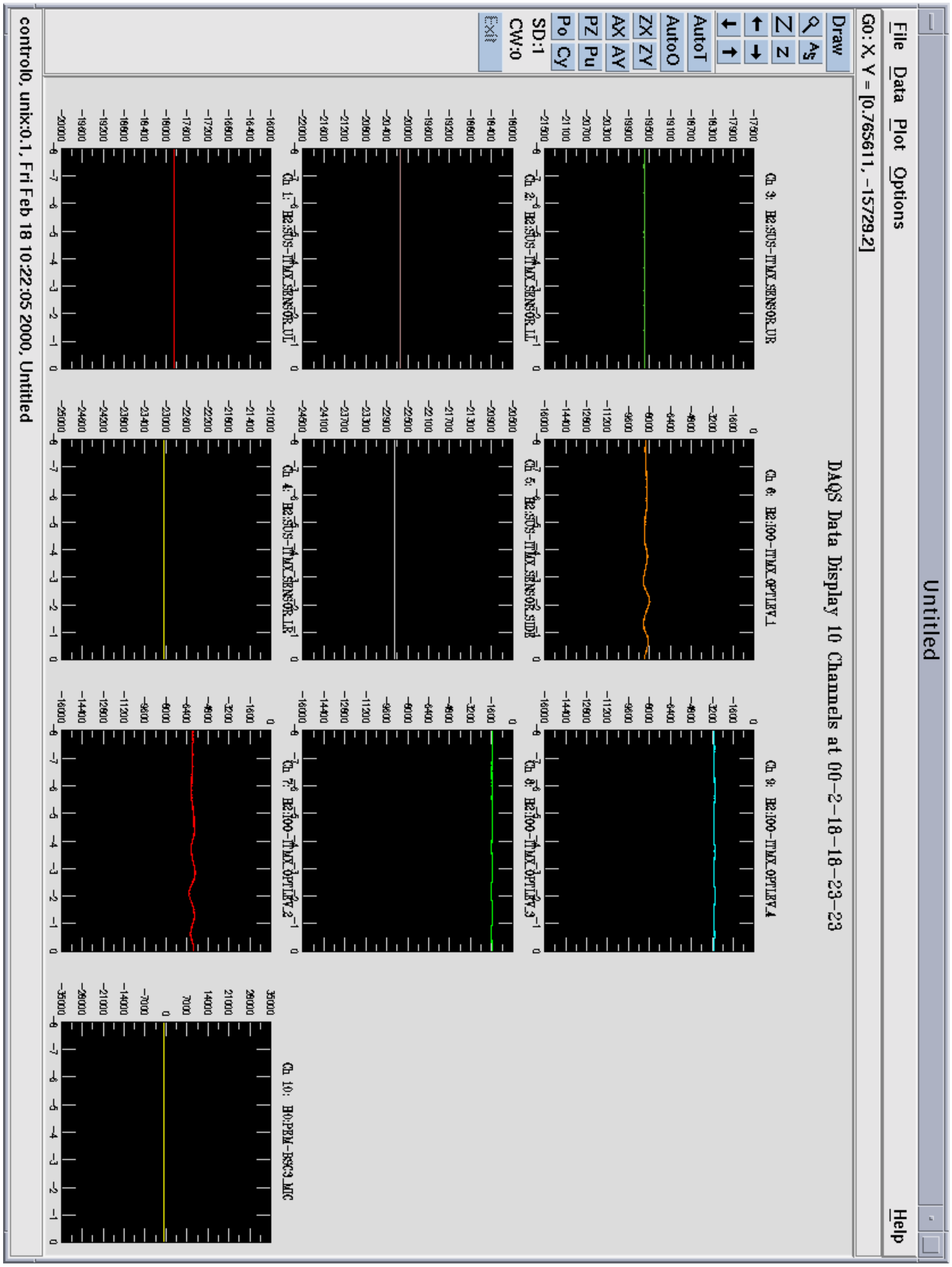

Untitled
File Data Plot Options Help
G0: X, Y = [0.765611, -15729.2]
Draw
Ag
Z z
AutoT
AutoO
ZX ZY
AX AY
PZ Pu
Po Cy
SD:1
CW:0
Exit
DAQS Data Display 10 Channels at 00-2-18-18-23-23
Ch 3: H2:SUS-ITMX_SENSOR_UR
Ch 6: H2:IOO-ITMX_OPTLEV_1
Ch 9: H2:IOO-ITMX_OPTLEV_4
Ch 2: H2:SUS-ITMX_SENSOR_LL
Ch 5: H2:SUS-ITMX_SENSOR_SIDE
Ch 8: H2:IOO-ITMX_OPTLEV_3
Ch 1: H2:SUS-ITMX_SENSOR_UL
Ch 4: H2:SUS-ITMX_SENSOR_LR
Ch 7: H2:IOO-ITMX_OPTLEV_2
Ch 10: H0:PEM-BSC3_MIC
control0, unix:0.1, Fri Feb 18 10:22:05 2000, Untitled

Figure 5: Typical Data Viewer output screen with no excitation

be changed as appropriate for the optic being tuned.)

3. In the MEDM window for the optic, perturb the optic by reversing servos for a few seconds and then turning the servos off. The following order is good:

- Disable all servos.
- Invert all servos (but don’t enable them yet).
- Enable the side servo.
- Watch the side sensor in data view display until a reasonable amplitude (e.g., 500 DAQ counts

p-p) builds up.

- Disable the side servo.
- Enable the position, pitch and yaw servos.
- Watch the optical lever channels in the data viewer display until the peak to peak amplitude is about half the mean value. (If there is no optical lever, watch the UL, UR, LL and LR sensors and wait for around 1000 DAQ counts p-p.)

NOTE 1: Amplitude will typically build up much more quickly in position, pitch and yaw than for side because there are four actuators in parallel. If it happens too quickly to be manageable, damp the optic, reduce the position, pitch and yaw gains and try again.

NOTE 2: The optical lever channels typically overload long before the sensor channels. If any clipping is visible, damp the optic and start again.

NOTE 3: Ensure that the graphs of the UL, UR, LL and LR sensor outputs have complicated envelopes with the occasional relatively narrow waist, indicating beating between sine waves of comparable magnitude and several different frequencies. If only a pure sinusoid is visible you have probably not excited all modes. Damp the optic and try again.

4. Make sure Matlab is running. Set the working directory to the appropriate optic subdirectory, and add the `matlab` directory to the path:

```
>> cd /opt/CDS/d/ops/sustune/itmx2k

>> addpath /opt/CDS/d/ops/sustune/matlab
```

5. Run the data collecting script created previously:

```
>>getimatdata
```

6. This will create a datafile `imatdata` in the optic directory. Run the Matlab command `imat` (for LOS) or `imatSOS` (for SOS) on the data file:

```
>> igains = imat('imatdata'); % for LOS, or

>> igains = imatSOS('imatdata'); % for SOS
```

The two routines are identical except for the frequency ranges in which they search for the peaks. Typical output from `imat` or `imatSOS` looks like the following:

```
The best fit pitch distance (nominally 7.2 mm) is  8.06 mm


 Set the Sensor Gains to the following values


          UL      LL      UR      LR

 Pos      29.4    30.6    19.4    20.6

 Pit      32.3    -22.4   29.3    -25.5

 Yaw      24.6    22.7    -27.4   -29.4
```

7. Check to make sure that the nominal and best fit pitch distances are close.
8. Make sure that the sensor gain values appear reasonable (i.e., approximately 25±10).

9. Make sure that the signs are the same as above. You don’t actually enter these signs when entering the gains into the controller, just the magnitudes. The signs are hardwired as indicated by the wiring diagram in the input matrix displays. Thus unless they’re the same as above they’re unimplementable.
10. Check that the graphs you get are similar to Figures 6-9 below. Most importantly check:

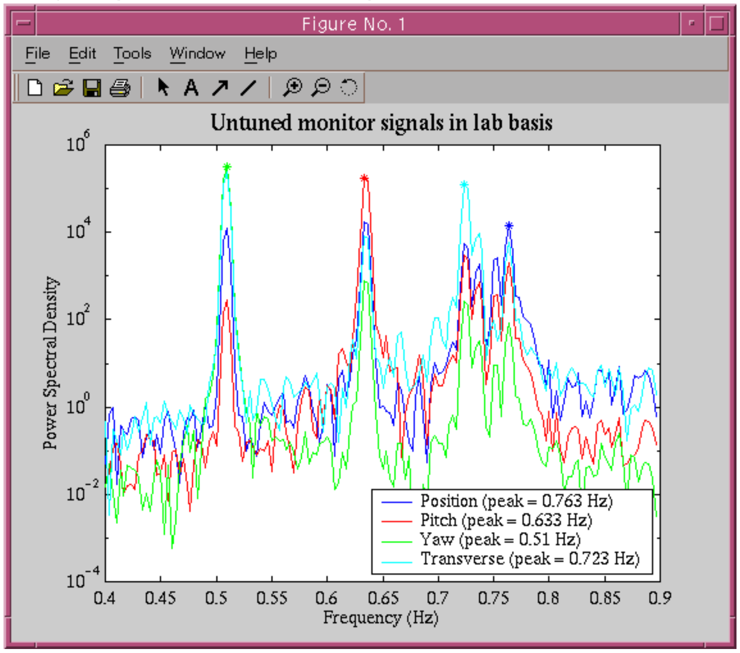


Figure 6: Typical output from `imat.m` - I: Power spectra of the monitor signals derived from the untuned sensors. Note that, for example, at the pitch frequency (0.61 Hz) there is energy in not only the pitch monitor signal but also in the position, yaw and side signals. That is, the tuning is poor.

- that the peaks for the signals (indicated by *) have been correctly identified,
- that graph 3 (“Tuned Monitor Signals in Normal Mode Basis”) shows each signal with one dominant peak and that that peak has no strength above background from any other signal
- that the listed frequencies are typical (position ≈ 0.76 Hz, pitch ≈ 0.61 Hz, yaw ≈ 0.49 Hz, transverse ≈ 0.73 Hz)

11. If everything looks good then bring up the three displays for the position, pitch and yaw components of the sensing matrix and enter the suggested sensor gains. Use BURT to snapshot these values for easy restoring later.

9 TUNING THE ACTUATION MATRICES

9.1. General Setup

9.1.1. Excitation setup

1. Find a GDS excitation output reasonably close to the controller for the optic and identify the channel name, e.g., H2:LSC-MOD_1_EXC.

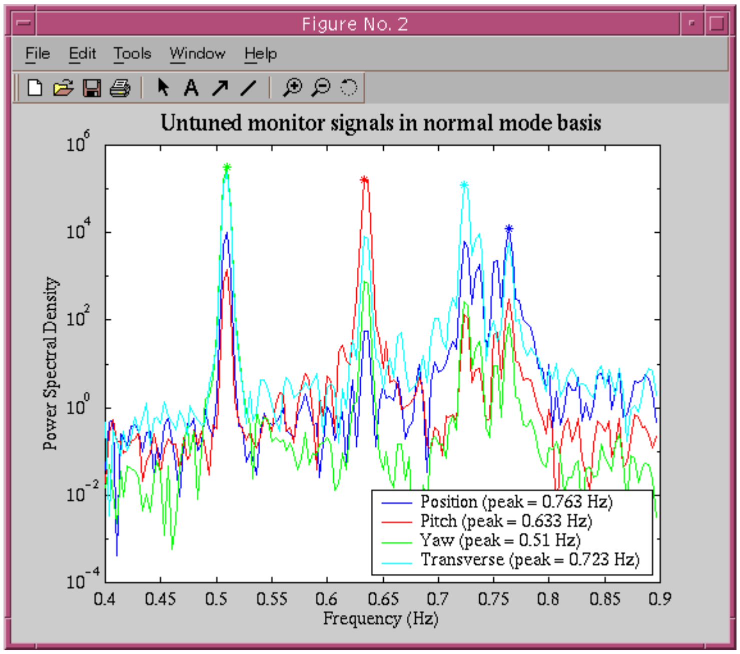


Figure 7: Typical output from `imat.m` - II: As for Figure 6 but in terms of modified “position” and “pitch” coordinates which allow for position-pitch cross-coupling. The pendulum mode is a pure displacement in the new “position” coordinate, which is mostly a the original (purely horizontal) displacement, but with a small admixture of pitch. Similarly, the pitch mode, is a pure “pitch” displacement.

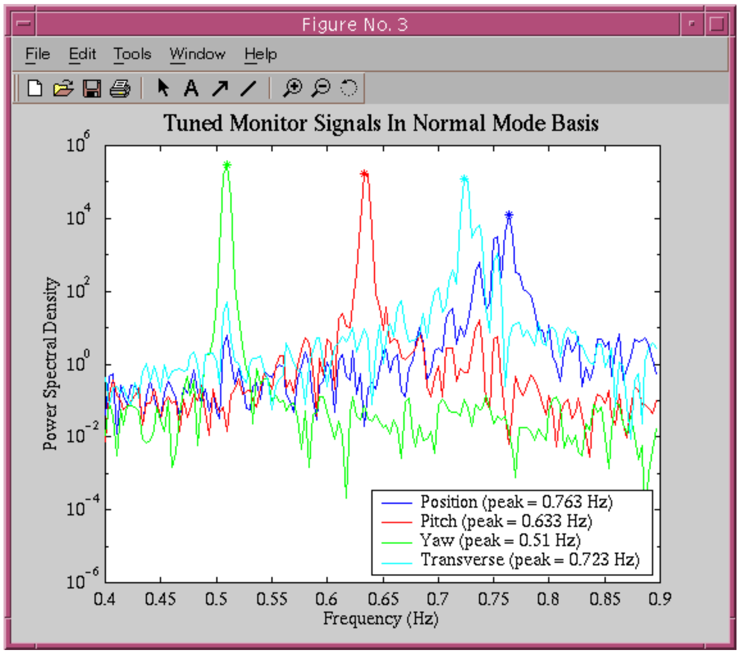


Figure 8: Typical output from `imat.m` - III: As for Figure 7, with differences in the gains of the sensors corrected for. Note that, in contrast to Figure 6, each mode frequency has energy in only one coordinate, as desired.

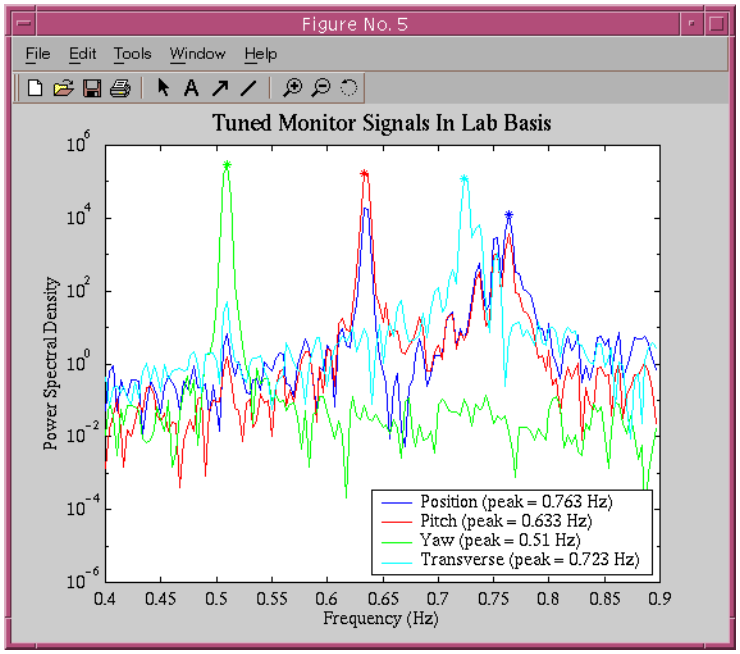


Figure 9: Typical output from `imat.m` - IV: As for Figure 8, with the position-pitch coupling correction removed. This is what the normal modes look like in the original lab-frame position and pitch coordinates.

2. Find a spare input for use as a excitation readback channel and identify the channel name, e.g., H2:DAQ-GPS_RAMP3.
3. Connect the excitation output to the input of an SRS560 amplifier (or similar) and select a gain of 5 and a 3 kHz 12-pole low-pass filter.
4. Put a BNC T adapter on the output of the SRS560.
5. Connect one side of the T to the appropriate test input (LSC TEST IN, PIT TEST IN or YAW TEST IN) of the controller as called for in the following sections. A BNC to LEMO adapter will be required.
6. Connect the other side of the T to the readback input.

9.1.2. Choice of measurement frequency

The optimum tuning for the position component of the output matrix varies considerably depending on the frequency used for actuation, due to the position-pitch coupling. At high frequencies (above the pitch and pendumlum modes at around 0.7 Hz), the optic acts like a free mass and the gains are approximately equal because they are compensating mostly for differences in strength of the magnet-coil pairs. At low frequencies the compliance of the pitch and pendulum modes dominates and it is necessary to push substantially harder (of order 25%) on the upper magnets to keep the optic upright as it moves in pitch. The decision as to which optics should be tuned at which frequencies has not yet been made at the time of writing. In the interim, all optics should be tuned at both high and low frequencies. Whichever of the resulting two sets of gains is finally chosen can then be entered into the controller at any time.

For tuning at “low frequency”, use 0.2 Hz. This is enough below the pendulum mode frequencies to count as low frequency, but not so low as to make the measurement time too onerous.

For tuning at “high frequency” the optimum frequency should be chosen somewhere around 2 Hz, preferably at a notch between seismic stack resonances. There is no point in going very much above 2 Hz because the response for a given level of actuation drops as f^-2, whereas the noise floor drops more slowly. Unless there are special circumstances, just use 1.8 Hz for a BSC stack and 1.85 Hz for a HAM stack. If it is necessary to revisit the choice, proceed as follows:

1. Run GDS tools and choose a power spectrum measurement (“Fourier Tools”).
2. Select the five OSEM sensor signals and measure the noise floor from approximately 0 to 4 Hz with a resolution (“BW”) of about 0.01 Hz.
3. Examine the noise spectra and choose somewhere around 2 Hz where there is a sharp dip for most or all of the sensors.

Whatever frequencies are chosen, create subdirectories for them in the optic directory, e.g.,

```
 /opt/CDS/d/ops/sustune/itmx2k/0.2Hz
```

and

```
 /opt/CDS/d/ops/sustune/itmx2k/1.8Hz
```

9.2. Position Component of Output Matrix

9.2.1. Method I, using optical levers only

9.2.1.1 Applicability

The optical levers give more accurate pitch and yaw information than the OSEM sensors and so this procedure should be used when they are available. Most large optics have optical levers permanently installed. Otherwise use the OSEM sensor procedure in the next section

9.2.1.2 Overview

The first stage of this procedure involves making five measurements of the response of the optic in pitch and yaw when it is pushed in what is nominally position by the actuators: one with all the gains set at 100, and one each with perturbations to the gains of the top, bottom, left and right pairs, according to Table 1. The Matlab command `omatposOL1` processes the data and suggests a set of gains, which should be substantially better in pitch. If it is generally satisfactory, the procedure can be halted. However due to the relatively large position-pitch cross-coupling (of order 25% at 0.2 Hz) which needs to be corrected for, the improvement in yaw is usually inadequate (or even negative) at first and another round of optimization is required. Therefore omatposOL1 suggests four more measurements which can be performed if necessary. The results should be saved to files according to Table 2. The second stage data is processed by the Matlab command file `omatposOL2` which does an almost identical calculation except that it uses the gain settings from `omatposOL1`.

9.2.1.3 Optical lever signal ordering

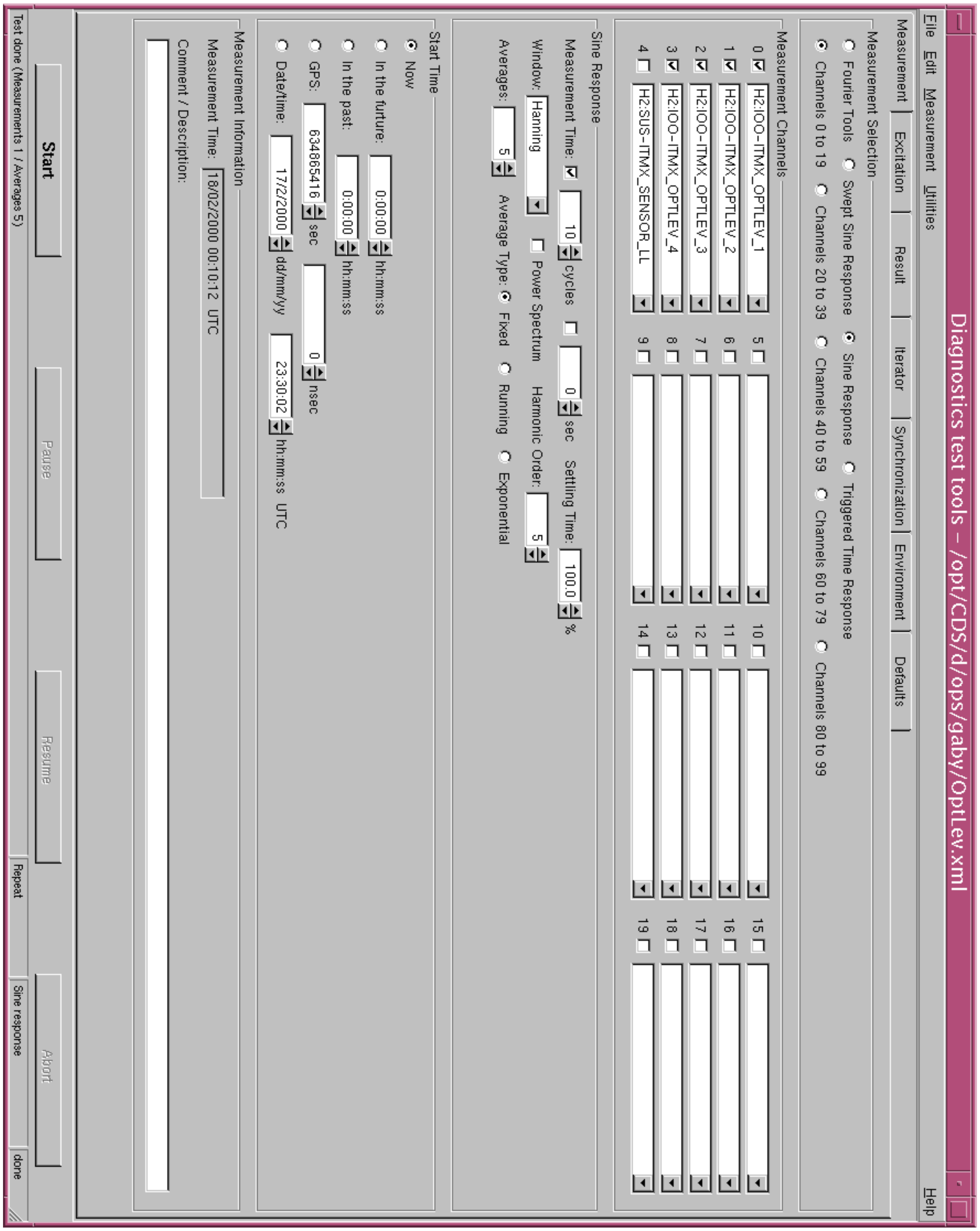
This procedure assumes that the four signals from the quadrants of the optical lever photodiode are numbered in order around the circumference, and that the the photodiode is mounted at either

0 or 90 degrees to the vertical. The algorithm used by the analysis software will be oblivious to left-right and/or up-down flips of all four quadrants, and will notice and correct for a 90 degree rotation, but may give nonsensical results if there is a flip of just two quadrants.

9.2.1.4 Detailed procedure

The following procedure should be repeated for each different measurement frequency.

1. Ensure that the excitation channel is active and connected to the LSC TEST IN input on the front panel of the mirror controller.
2. Make sure that Matlab is running and that the `matlab` directory has been added to the path. Use `cd` to go to the appropriate measurement frequency directory.
3. In GDS tools, open the file `OptLev.xml` in the directory `/opt/CDS/d/ops/sustune/templates`. Most of the settings will be as described below, but check them individually to be sure.
4. In channels 0 through 3 in the measurement pane (see Figure 10) select the optical lever signals (e.g., H2:IOO-ITMX-OPTLEV1, H2:IOO-ITMX-OPTLEV2, H2:IOO-ITMX-OPTLEV3 and H2:IOO-ITMX-OPTLEV4). Do not include other channels - the analysis software assumes that there will be exactly four channels in the output file. In particular, do not choose the readback channel on this screen. If the readback channel selected on the Excitation pane (in the next step) is also selected on the Measurement pane, then when the Start button is pressed, GDS complains that it is unable to apply excitation. Choose a sine response with 5 averages of 10 cycles each, and 100% settling time.
5. In the excitation pane (see Figure 11), choose the appropriate channel for excitation (e.g., H2:LSC-MOD_1_EXC), and for readback (e.g., H2:DAQ-GPS_RAMP3), a sine wave with the desired measurement frequency and an amplitude of 1 V.
6. Bring up the mirror controller display, and click on the control to enable the LSC test input. Set the servo gains to a value of 1 (very low). Make sure the mirror stays lightly damped and within the optical lever range.
7. In the controller screen, click on the three icons for the position, pitch and yaw components of the output matrix. (If using the old-style display, click on the four icons for the UL, UR, LL and LL components, and position the resulting windows on the screen as their name indicates: UR in the upper right, LR, in the lower right, etc.) If the pitch and/or yaw gains have not been tuned previously or the tuning has been invalidated by some major change, set them to 100; otherwise leave them alone. Set all the position gains to 100. If using the new style display, you may wish to dismiss the pitch and yaw windows for now.
8. Make sure you have all the mirror sensors, the optical lever channels, and the readback in DataViewer. Press “Start” in the GDS window. You should see the readback signal showing a sine wave. (It may be clipped at the maxima and minima: no need to worry about that.) The optical lever channels should also show some kind of oscillation at the same frequency. Make sure the optical lever signals do not clip. If they do, press Abort, reduce the amplitude (on the Excitation pane) and press Start again.
9. Wait till the oscillation in the readback channel is gone (~1 minute), indicating the first measurement is done.
10. In the Result pane select the transfer coefficients in the upper graph and the coherences in the lower graph (see Figure 13). Check that the coherences are reasonable (i.e., near 1.0 unless the corresponding magnitude is very small).



Diagnostics test tools – /opt/CDS/d/ops/gaby/OptLev.xml
File Edit Measurement Utilities Help
Measurement Excitation Result Iterator Synchronization Environment Defaults

Measurement Selection

○ Fourier Tools ○ Swept Sine Response ● Sine Response ○ Triggered Time Response

● Channels 0 to 19 ○ Channels 20 to 39 ○ Channels 40 to 59 ○ Channels 60 to 79 ○ Channels 80 to 99

Measurement Channels

0 ☑ H2:IOO-ITMX_OPTLEV_1
1 ☑ H2:IOO-ITMX_OPTLEV_2
2 ☑ H2:IOO-ITMX_OPTLEV_3
3 ☑ H2:IOO-ITMX_OPTLEV_4
4 □ H2:SUS-ITMX_SENSOR_LL
5 □ 6 □ 7 □ 8 □ 9 □
10 □ 11 □ 12 □ 13 □ 14 □
15 □ 16 □ 17 □ 18 □ 19 □

Sine Response

Measurement Time: ☑ 10 cycles □ 0 sec Settling Time: 100.0 %
Window: Hanning □ Power Spectrum Harmonic Order: 5
Averages: 5 Average Type: ● Fixed ○ Running ○ Exponential

Start Time

● Now
○ In the furture: 0:00:00 hh:mm:ss
○ In the past: 0:00:00 hh:mm:ss
○ GPS: 634865416 sec 0 nsec
○ Date/time: 17/2/2000 dd/mm/yy 23:30:02 hh:mm:ss UTC

Measurement Information

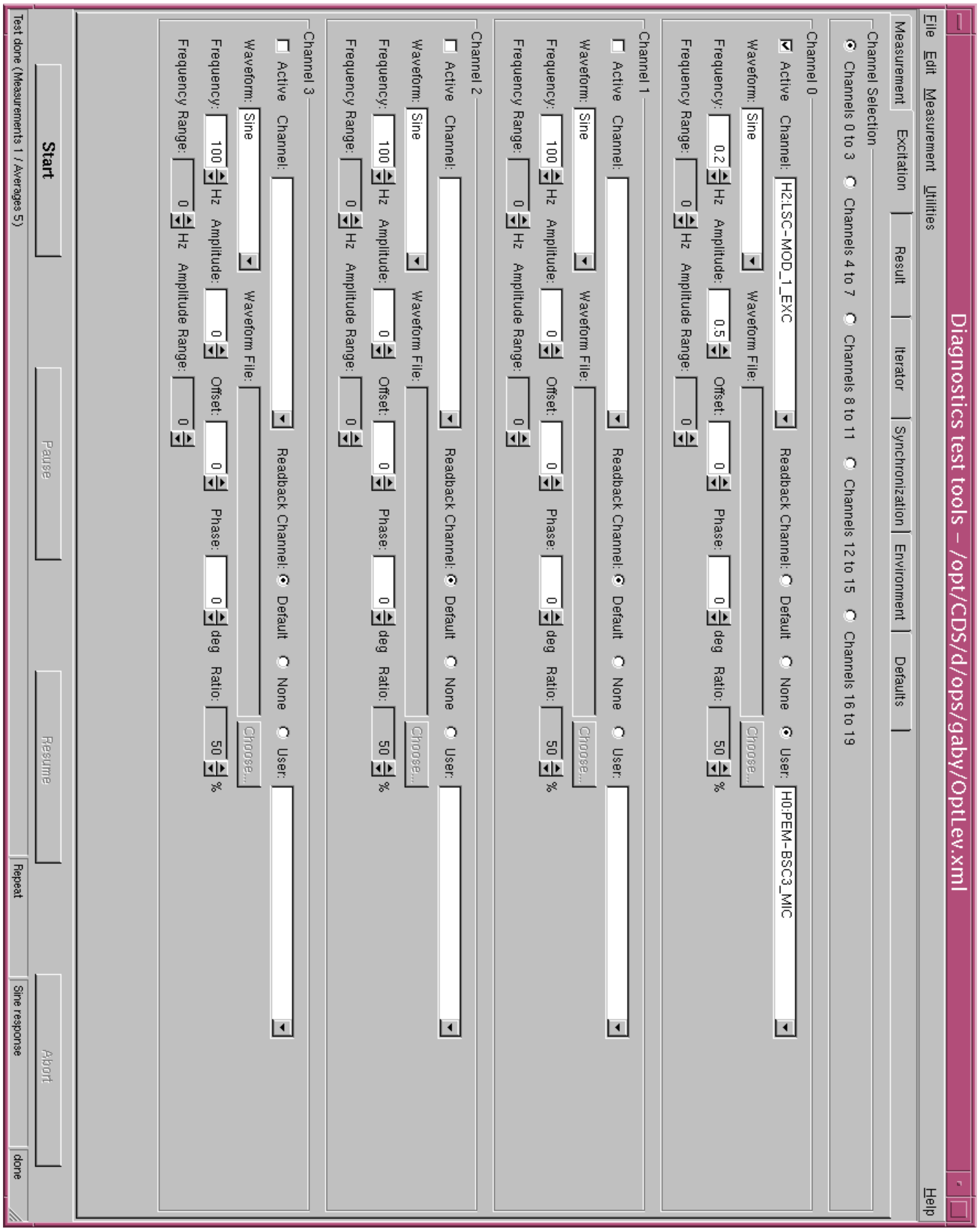
Measurement Time: 18/02/2000 00:10:12 UTC
Comment / Description:

Test done (Measurements 1 / Averages 5) Repeat Sine response done

Figure 10: Typical Measurement pane settings in GDS for a measurement in the output matrix tuning procedure.

NOTE: Due to a bug in GDS, you may not see any results at first. If so, click on the Range tab next to the graph and decrement the lower limit on the X axis by a small amount. For version x.x of GDS (LHO only at the time of writing), click the up-arrow button next to the graph to ring up the settings floater, adjust the range as described above and also click Update.

11. In the GDS window, go the “File” menu and use “Save As” to save the results in a file called `OptLevInit.xml` in the measurement frequency directory.
12. Repeat the measurement using different settings of the position gains in the actuation matrix



Channel Selection
● Channels 0 to 3 ○ Channels 4 to 7 ○ Channels 8 to 11 ○ Channels 12 to 15 ○ Channels 16 to 19

Channel 0
☑ Active Channel: H2:LSC-MOD_1_EXC Readback Channel: ○ Default ○ None ● User: H0:PEM-BSC3_MIC
Waveform: Sine Waveform File: Choose...
Frequency: 0.2 Hz Amplitude: 0.5 Offset: 0 Phase: 0 deg Ratio: 50 %
Frequency Range: 0 Hz Amplitude Range: 0

Channel 1
□ Active Channel: Readback Channel: ● Default ○ None ○ User:
Waveform: Sine Waveform File: Choose...
Frequency: 100 Hz Amplitude: 0 Offset: 0 Phase: 0 deg Ratio: 50 %
Frequency Range: 0 Hz Amplitude Range: 0

Channel 2
□ Active Channel: Readback Channel: ● Default ○ None ○ User:
Waveform: Sine Waveform File: Choose...
Frequency: 100 Hz Amplitude: 0 Offset: 0 Phase: 0 deg Ratio: 50 %
Frequency Range: 0 Hz Amplitude Range: 0

Channel 3
□ Active Channel: Readback Channel: ● Default ○ None ○ User:
Waveform: Sine Waveform File: Choose...
Frequency: 100 Hz Amplitude: 0 Offset: 0 Phase: 0 deg Ratio: 50 %
Frequency Range: 0 Hz Amplitude Range: 0

Test done (Measurements 1 / Averages 5)

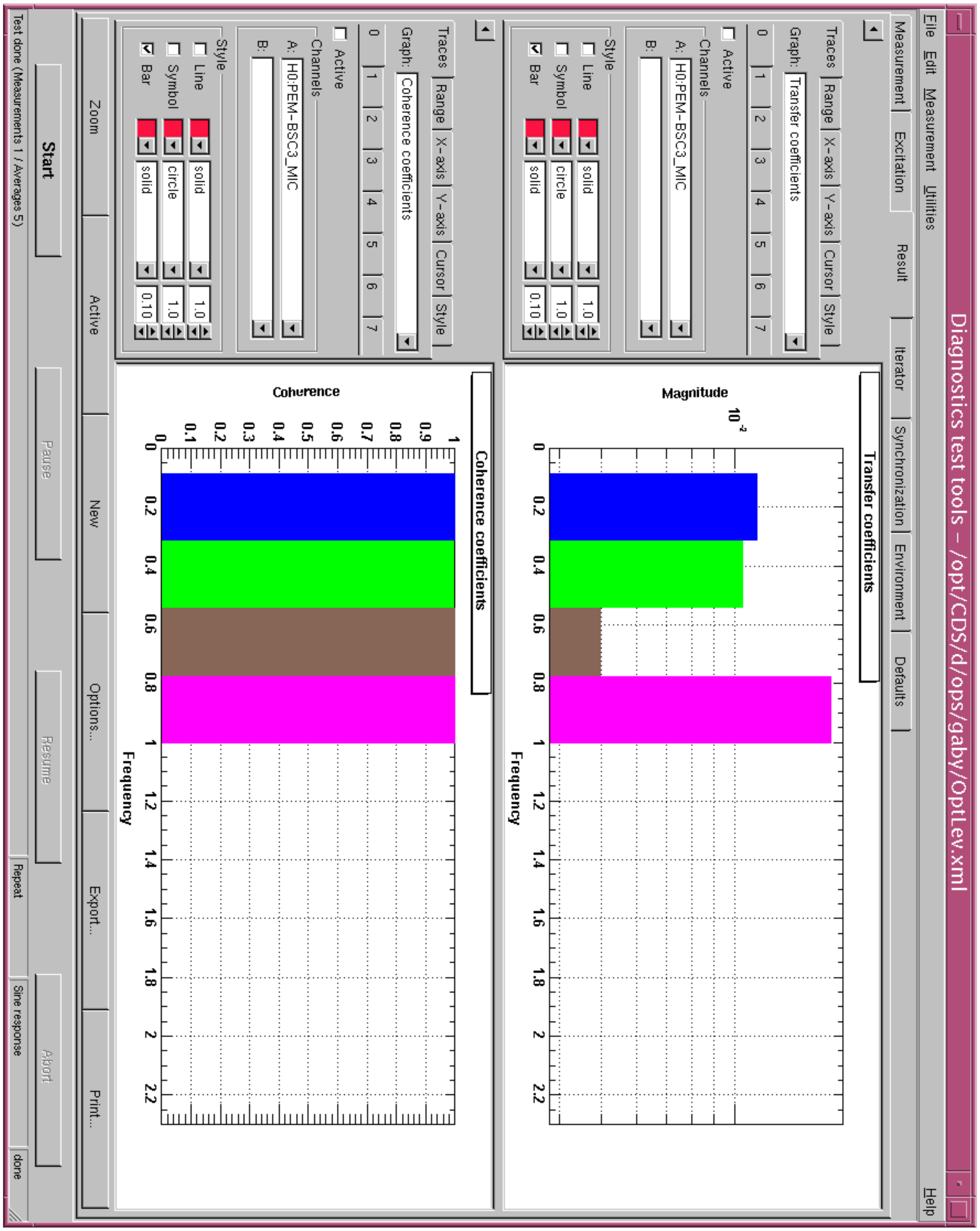
Figure 11: Typical Excitation pane settings in GDS for a measurement in the output matrix tuning procedure.

and saving the results to different files as described in Table 1. Apart from the different gains, all the measurements should be done with the same settings for excitation amplitude etc.

13. In the Matlab window, give the command

```
>> omatposOL1;
```

14. An optimised set of gains is printed together with a suggested set of four more configurations to be measured. Copy the information to a text editor and save it in the measurement frequency directory with a name such as `20000831tunedomatposOL.txt`.



Diagnostics test tools – /opt/CDS/d/ops/gaby/OptLev.xml

Graph: Transfer coefficients

A: H0:PEM-BSC3_MIC

Graph: Coherence coefficients

A: H0:PEM-BSC3_MIC

Test done (Measurements 1 / Averages 5)

Figure 12: Typical Results pane display in GDS for a measurement in the actuation gains tuning procedure.

15. Make a measurement with the optimised gains and save it as `OptLevInit2.xml`.
16. In the Matlab window give the following commands to compare the pitch and yaw couplings before and after Round 1 of optimisation:

```
>> [Pit0,Yaw0] = pityawOL('OptLevInit.xml');

>> [Pit1, Yaw1] = pityawOL('OptLevInit2.xml');

>> [Pit0, Yaw0; Pit1, Yaw1]
```

Table 1: Measurement program for Round 1 of tuning for the position component of the output matrix using the optical levers as reference - gain settings for which measurements are to be made, and the files to which the data should be saved

Measurement Number	*Position Output Gains* *UL UR* *LL LR*	*Filename*
1	100 100 100 100	`OptLevInit.xml`
2	90 90 100 100	`OptLevUp.xml`
3	100 100 90 90	`OptLevDown.xml`
4	90 100 90 100	`OptLevLeft.xml`
5	100 90 100 90	`OptLevRight.xml`

17. There should at least be an improvement between the two pitch couplings (in the left column). (At 0.2 Hz this ought to be substantial, e.g., an order of magnitude.) If the yaw (in the right column) is greatly improved as well there may no need to go on to Round 2.
18. If the yaw is about the same or worse, or if any the suggested gains are less than 90, a second round will probably yield further improvements. Make the four suggested additional measurements using the same procedure as above, saving the results to files `OptLevUp2.xml`, `OptLevDown2.xml`, `OptLevLeft2.xml` and `OptLevRight2.xml` as in Table 2.

Table 2: Measurement program for Round 2 of tuning for the position component of the output matrix using the optical levers as reference

Measurement Number	*Position Output Gains* *UL UR* *LL LR*	*Filename*
1	As suggested in the output `from omatposOL1`	`OptLevInit2.xml`
2		`OptLevUp2.xml`
3		`OptLevDown2.xml`
4		`OptLevLeft2.xml`
5		`OptLevRight2.xml`

19. In the Matlab window, give the command `omatposOL2`. This prints an even more optimised set of gains. Copy the output and append it to the text file from step 14.
20. Do a measurement with the optimised set of gains from `omatposOL2` and save it in the measurement frequency directory as `OptLevInit3.xml`.
21. In the Matlab window give the following commands to compare the effectiveness of the diffrent settings:

```
>> [Pit2, Yaw2] = pos2pityawccOL('OptLevInit3.xml');
```

```
>> [Pit0,Yaw0;Pit1,Yaw1;Pit2,Yaw2]
```

22. Copy the output of the above command and append it to the text file from step 14.
23. Probably the optimised gains from Round 2 give better results. If so, create a BURT snapshot of the settings with a name reflecting the measurement frequency, e.g.,

```
/opt/CDS/d/ops/sustune/itmx2k/burt/20000630tunedomatposOL0.2Hz.snap
```

Otherwise revert to the Round 1 values and snapshot them instead.

9.2.2. Method II , using OSEM sensors only

9.2.2.1 Overview

This procedure is very similar to the one using the optical levers except that the OSEM sensor signals are logged instead, and the pitch and yaw cross-couplings are computed assuming the optimised input matrix from above. The Matlab routines are `omatposOSEM1(igains)` and `omatposOSEM2(igains)` where `igains` is the output of `imat.m`. The following detailed procedure shouldbe repeated for each measurement frequency of interest.

At the time of writing, the input matrix tuning procedure on which this procedure depends was not reliable enough. Tuning using the input matrix as a reference gave cross-couplings equivalent to about a 5-10% perturbation of the gains as measured by comparison with the optical lever version. Therefore until such time as the input matrix procedure is improved, at least for high frequencies it is probably better to leave well enough alone rather than apply this procedure! For low frequencies, the position-pitch coupling is sufficiently large that it

9.2.2.2 Detailed Procedure

1. Ensure that the excitation channel is active and connected to the LSC TEST IN input on the front panel of the mirror controller.
2. Make sure that Matlab is running and that the `matlab` directory has been added to the path. Use `cd` to go to the appropriate measurement frequency directory.
3. In GDS tools, open the file `Sensor.xml` in the directory `/opt/CDS/d/ops/sustune/templates`. Most of the settings will be as described below, but check them individually to be sure.
4. In channels 0 through 3 in the measurement pane select the four face OSEM sensor signals in UL-LL-UR-LR order (e.g., H2:SUS-ITMX_SENSOR_UL, H2:SUS-ITMX_SENSOR_LL, H2:SUS-ITMX_SENSOR_UR and H2:SUS-ITMX_SENSOR_LR). Do not include other channels - the analysis software assumes that there will be exactly four channels in the output file. Choose a sine response with 5 averages of 10 cycles each, and 100% settling time.
5. In the excitation pane (see Figure 11, choose the appropriate channel for excitation (e.g.,

H2:LSC-MOD_1_EXC), and for readback (e.g., H2:DAQ-GPS_RAMP3), a sine wave with the desired measurement frequency and an amplitude of 1 V for high frequency or 0.5 V for low frequency.

6. Bring up the mirror controller display, and click on the control to enable the LSC test input. Set the servo gains to a value of 1 (very low).
7. In the controller screen, click on the three icons for the position, pitch and yaw components of the output matrix. (If using the old-style display, click on the four icons for the UL, UR, LL and LL components, and position the resulting windows on the screen as their name indicates: UR in the upper right, LR, in the lower right, etc.) If the pitch and/or yaw gains have not been tuned previously or the tuning has been invalidated by some major change, set them to 100; otherwise leave them alone. Set all the position gains to 100. If using the new style display, you may wish to dismiss the pitch and yaw windows for now.
8. Make sure you have all the mirror sensors and the readback in DataViewer. Press “Start” in the GDS window. You should see the readback signal showing a sine wave. (It may be clipped at the maxima and minima: no need to worry about that.) The sensor channels should also show some kind of oscillation at the same frequency. Make sure they do not clip. If they do, press Abort, reduce the amplitude (on the Excitation pane) and press Start again.
9. Wait till the oscillation in the readback channel is gone (~1 minute), indicating the first measurement is done.
10. In the Result pane select the transfer coefficients in the upper graph and the coherences in the lower graph (see Figure 13). Check that the coherences are reasonable (i.e., near 1.0 unless the corresponding magnitude is very small).

NOTE: Due to a bug in GDS, you may not see any results at first. If so, click on the Range tab next to the graph and decrement the lower limit on the X axis by a small amount. For version x.x of GDS (LHO only at the time of writing), click the up-arrow button next to the graph to ring up the settings floater, adjust the range as described above and also click Update.

11. In the GDS window, go the “File” menu and use “Save As” to save the results in a file called `SensorPosInit.xml` in the measurement frequency directory.
12. Repeat the measurement using different settings of the position gains in the actuation matrix and saving the results to different files as described in Table 3.

Table 3: Measurement program for Round 1 of tuning for the position component of the output matrix using the sensors as reference

Measurement Number	*Position Output Gains* *UL UR* *LL LR*	*Filename*
1	100 100 100 100	`SensorPosInit.xml`
2	90 90 100 100	`SensorPosUp.xml`

Table 3: Measurement program for Round 1 of tuning for the position component of the output matrix using the sensors as reference

Measure ment Number	*Position Output Gains* *UL UR* *LL LR*	*Filename*
3	100 100 90 90	`SensorPosDown.xml`
4	90 100 90 100	`SensorPosLeft.xml`
5	100 90 100 90	`SensorPosRight.xml`

13. In the Matlab window, give the command

```
>> omatposOSEM1(igains);
```

14. An optimised set of gains is printed together with a suggested set of four more configurations to be measured. Copy the information to a text editor and save it in the measurement frequency directory with a name such as `20000831tunedomatposOSEM.txt`.
15. Make a measurement with the optimised gains and save it as `SensorPosInit2.xml`.
16. In the Matlab window give the following commands to compare the pitch and yaw couplings before and after Round 1 of optimisation:

```
>> [Pit0, Yaw0] = pityawOSEM('SensorPosInit.xml',igains);
>> [Pit1, Yaw1] = pityawOSEM('SensorPosInit2.xml',igains);
>> [Pit0, Yaw0; Pit1, Yaw1]
```

17. There should at least be an improvement between the two pitch couplings (in the left column). (At 0.2 Hz this ought to be substantial, e.g., an order of magnitude.) If the yaw (in the right column) is greatly improved as well there may be no need to go on to Round 2.
18. If the yaw is about the same or worse, or if any the suggested gains are less than 90, a second round will probably yield further improvements. Make the four suggested additional measurements using the same procedure as above, saving the results to files as in Table 4.
19. In the Matlab window, give the command

```
>> omatposOSEM2(igains);
```

20. This prints an even more optimised set of gains. Copy the output and append it to the text file from step 14.
21. Do a measurement with the optimised set of gains from `omatposOSEM2` and save it in the measurement frequency directory as `SensorPosInit3.xml`.
22. In the Matlab window give the following commands to compare the effectiveness of the diffrent settings:

```
>> [Pit2, Yaw2] = pityawOSEM('SensorPosInit3.xml',igains);
>> [Pit0, Yaw0; Pit1, Yaw1; Pit2, Yaw2]
```

Table 4: Measurement program for Round 2 of tuning for the position component of the output matrix using the optical levers as reference

Measurement Number	*Position Output Gains* *UL UR* *LL LR*	*Filename*
1	As suggested in the output from omatposOSEM1	SensorPosInit2.xml
2		SensorPosUp2.xml
3		SensorPosDown2.xml
4		SensorPosLeft2.xml
5		SensorPosRight2.xml

23. Copy the output of the above command and append it to the text file from step 14.
24. Probably the optimised gains from Round 2 give better results. If so, create a BURT snapshot of the settings with a name reflecting the measurement frequency, e.g.,

```
/opt/CDS/d/ops/sustune/itmx2k/burt/20000630tunedomatposOSEM0.2Hz.snap
```

Otherwise revert to the Round 1 values and snapshot them instead.

9.3. Pitch Component of Output Matrix

9.3.1. Overview

This procedure is very similar to the OSEM sensor version of the position component tuning except that the excitation is applied to the PIT TEST IN input and a slightly different set of perturbations is used. (Instead of the gains on the Left and Right sides, those on the Main diagonal and Off diagonal are perturbed.)

At the time of writing, the input matrix tuning procedure on which this procedure depends was not reliable enough. Tuning using the input matrix as a reference gave cross-couplings equivalent to about a 5-10% perturbation of the gains, at least for position. Therefore until such time as the input matrix procedure is improved, it is probably better to leave well enough alone rather than apply this procedure!

1. Ensure that the excitation channel is active and connected to the PIT TEST IN input on the front panel of the mirror controller.
2. Make sure that Matlab is running and that the `matlab` directory has been added to the path. Use `cd` to go to the appropriate measurement frequency directory.
3. In GDS tools, open the file `Sensor.xml` in the directory `/opt/CDS/d/ops/sustune/templates`. Most of the settings will be as described below, but check them individually to be sure.
4. In channels 0 through 3 in the measurement pane select the four face OSEM sensor signals in UL-LL-UR-LR order (e.g., H2:SUS-ITMX_SENSOR_UL, H2:SUS-ITMX_SENSOR_LL, H2:SUS-ITMX_SENSOR_UR and H2:SUS-ITMX_SENSOR_LR). Do not include other

channels - the analysis software assumes that there will be exactly four channels in the output file. Choose a sine response with 5 averages of 10 cycles each, and 100% settling time.

5. In the excitation pane (see Figure 11, choose the appropriate channel for excitation (e.g., H2:LSC-MOD_1_EXC), and for readback (e.g., H2:DAQ-GPS_RAMP3), a sine wave with the desired measurement frequency and an amplitude of 1 V for high frequency or 0.5 V for low frequency.
6. Bring up the mirror controller display. If the LSC test input is enabled from the previous procedure, click to disable it. If using the new-style "Basic Screen" display (LHO only as of this writing), click on the Full Screen button to display the less commonly used controls. Click to enable the pitch test input. Open the window for the pitch input gains and set all the gains to 0. Set the main servo gains for position and yaw to a value of 1 (very low). Set the main servo gain for pitch to 100.
7. Click Start in GDS to apply some excitation. Check that the sensor signals show motion at the excitation frequency but do not clip. If necessary, adjust the excitation amplitude.
8. In the controller screen, click on the three icons for the position, pitch and yaw components of the output matrix. (If using the old-style display, click on the four icons for the UL, UR, LL and LL components, and position the resulting windows on the screen as their name indicates: UR in the upper right, LR, in the lower right, etc.) If the position and/or yaw gains have not been tuned previously or the tuning has been invalidated by some major change, set them to 100; otherwise leave them alone. Set all the pitch gains in these panels to 100. If using the new style displays, you may wish to dismiss the position and yaw windows for now.
9. Make sure you have all the mirror sensors and the readback in DataViewer. Press "Start" in the GDS window. You should see the readback signal showing a sine wave. The sensor lever channels should also show some kind of oscillation at the same frequency. Make sure they do not clip. If they do, press Abort, reduce the amplitude (on the Excitation pane) and press Start again.
10. Wait till the oscillation in the readback channel is gone (~1 minute), indicating the first measurement is done.
11. In the Result pane select the transfer coefficients in the upper graph and the coherences in the lower graph (see Figure 13). Check that the coherences are reasonable (i.e., near 1.0 unless the corresponding magnitude is very small).

NOTE: Due to a bug in GDS, you may not see any results at first. If so, click on the Range tab next to the graph and decrement the lower limit on the X axis by a small amount. For version x.x of GDS (LHO only at the time of writing), click the up-arrow button next to the graph to ring up the settings floater, adjust the range as described above and also click Update.

12. In the GDS window, go the "File" menu and use "Save As" to save the results in a file called `SensorPitInit.xml` in the measurement frequency directory.
13. Repeat the measurement using different settings of the position gains in the actuation matrix and saving the results to different files as described in Table 5.
14. In the Matlab window, give the command

```
>> omatpitOSEM1(igains);
```

15. An optimised set of gains is printed together with a suggested set of four more configurations to be measured. Copy the information to a text editor and save it in the measurement frequency directory with a name such as `20000831tunedomatpitOSEM.txt`.
16. Make a measurement with the optimised gains and save it as `SensorPitInit2.xml`.

Table 5: Measurement program for Round 1 of tuning for the pitch component of the output matrix using the sensors as reference

Measure ment Number	*Pitch Output Gains* *UL UR* *LL LR*	*Filename*
1	100 100 100 100	`SensorPitInit.xml`
2	90 90 100 100	`SensorPitUp.xml`
3	100 100 90 90	`SensorPitDown.xml`
4	90 100 100 90	`SensorPitMain.xml`
5	100 90 90 100	`SensorPitOff.xml`

17. In the Matlab window give the following commands to compare the position and yaw couplings before and after Round 1 of optimisation:

```
>> [Pos0,Yaw0] = posyawOSEM('SensorPitInit.xml',igains);
>> [Pos1, Yaw1] = posyawOSEM('SensorPitInit2.xml',igains);
>> [Pos0, Yaw0; Pos1, Yaw1]
```

18. If any of the optimised gains are less than 90, a second round will probably yield further improvements. Make the four suggested additional measurements using the same procedure as above, saving the results to files as in Table 6.

Table 6: Measurement program for Round 2 of tuning for the pitch component of the output matrix using the optical levers as reference

Measure ment Number	*Pitch Output Gains* *UL UR* *LL LR*	*Filename*
1	As suggested in the output from `omatpitOSEM1`	`SensorPitInit2.xml`
2		`SensorPitUp2.xml`
3		`SensorPitDown2.xml`
4		`SensorPitMain2.xml`
5		`SensorPitOff2.xml`

19. In the Matlab window, give the command

```
>> omatpitOSEM2(igains);
```

20. This prints an even more optimised set of gains. Copy the output and append it to the text file from step 15.
21. Do a measurement with the optimised set of gains from `omatposOSEM2` and save it in the measurement frequency directory as `SensorPitInit3.xml`.
22. In the Matlab window give the following commands to compare the effectiveness of the diffrent settings:

```
>> [Pos2, Yaw2] = posyawOSEM(‘SensorPitInit3.xml’,igains);
```

```
>> [Pos0, Yaw0; Pos1, Yaw1; Pos2, Yaw2]
```

23. Copy the output of the above command and append it to the text file from step 15.
24. Probably the optimised gains from Round 2 give better results. If so, create a BURT snapshot of the settings with a name reflecting the measurement frequency, e.g.,

```
/opt/CDS/d/ops/sustune/itmx2k/burt/20000630tunedomatpitOSEM0.2Hz.snap
```

Otherwise revert to the Round 1 values and snapshot them instead.

9.4. Yaw Component of Output Matrix

This procedure is very similar to the pitch component tuning except that the excitation is applied to the PIT TEST IN input and yet another a slightly different set of perturbations is used. (Instead of the gains on the Up and Down sides, those on the Main diagonal and Off diagonal are perturbed.)

At the time of writing, the input matrix tuning procedure on which this procedure depends was not reliable enough. Tuning using the input matrix as a reference gave cross-couplings equivalent to about a 5-10% perturbation of the gains, at least for position. Therefore until such time as the input matrix procedure is improved, it is probably better to leave well enough alone rather than apply this procedure!

1. Ensure that the excitation channel is active and connected to the YAW TEST IN input on the front panel of the mirror controller.
2. Make sure that Matlab is running and that the `matlab` directory has been added to the path. Use `cd` to go to the appropriate measurement frequency directory.
3. In GDS tools, open the file `Sensor.xml` in the directory `/opt/CDS/d/ops/sustune/templates`. Most of the settings will be as described below, but check them individually to be sure.
4. In channels 0 through 3 in the measurement pane select the four face OSEM sensor signals in UL-LL-UR-LR order (e.g., H2:SUS-ITMX_SENSOR_UL, H2:SUS-ITMX_SENSOR_LL, H2:SUS-ITMX_SENSOR_UR and H2:SUS-ITMX_SENSOR_LR). Do not include other channels - the analysis software assumes that there will be exactly four channels in the output file. Choose a sine response with 5 averages of 10 cycles each, and 100% settling time.
5. In the excitation pane (see Figure 11, choose the appropriate channel for excitation (e.g., H2:LSC-MOD_1_EXC), and for readback (e.g., H2:DAQ-GPS_RAMP3), a sine wave with the desired measurement frequency and an amplitude of 1 V for high frequency or 0.5 V for low frequency.

6. Bring up the mirror controller display. If the LSC test input is enabled from the previous procedure, click to disable it. If using the new-style “Basic Screen” display (LHO only as of this writing), click on the Full Screen button to display the less commonly used controls. If the pitch test input is enabled from the previous procedure, click to disable it. Click to enable the pitch test input. Open the window for the yaw input gains and set all the gains to 0. Open the windows for the position and pitch input gains and set them to the tuned values from Section 8 if available or 25 otherwise. Set the main servo gains for position and yaw to a value of 1 (very low). Set the main servo gain for pitch to 100.
7. Click Start in GDS to apply some excitation. Check that the sensor signals show motion at the excitation frequency but do not clip. If necessary, adjust the excitation amplitude.
8. In the controller screen, click on the three icons for the position, pitch and yaw components of the output matrix. (If using the old-style display, click on the four icons for the UL, UR, LL and LL components, and position the resulting windows on the screen as their name indicates: UR in the upper right, LR, in the lower right, etc.) If the position and/or yaw gains have not been tuned previously or the tuning has been invalidated by some major change, set them to 100; otherwise leave them alone. Set all the pitch gains in these panels to 100. If using the new style displays, you may wish to dismiss the position and yaw windows for now.
9. Make sure you have all the mirror sensors and the readback in DataViewer. Press “Start” in the GDS window. You should see the readback signal showing a sine wave. The sensor lever channels should also show some kind of oscillation at the same frequency. Make sure they do not clip. If they do, press Abort, reduce the amplitude (on the Excitation pane) and press Start again.
10. Wait till the oscillation in the readback channel is gone (~1 minute), indicating the first measurement is done.
11. In the Result pane select the transfer coefficients in the upper graph and the coherences in the lower graph (see Figure 13). Check that the coherences are reasonable (i.e., near 1.0 unless the corresponding magnitude is very small).

NOTE: Due to a bug in GDS, you may not see any results at first. If so, click on the Range tab next to the graph and decrement the lower limit on the X axis by a small amount. For version x.x of GDS (LHO only at the time of writing), click the up-arrow button next to the graph to ring up the settings floater, adjust the range as described above and also click Update.

12. In the GDS window, go the “File” menu and use “Save As” to save the results in a file called `SensorPitInit.xml` in the measurement frequency directory.
13. Repeat the measurement using different settings of the position gains in the actuation matrix and saving the results to different files as described in Table 7.
14. In the Matlab window, give the command

```
>> omatyawOSEM1(igains);
```

15. An optimised set of gains is printed together with a suggested set of four more configurations to be measured. Copy the information to a text editor and save it in the measurement frequency directory with a name such as `20000831tunedomatyawOSEM.txt`.
16. Make a measurement with the optimised gains and save it as `SensorYawInit2.xml`.
17. In the Matlab window give the following commands to compare the position and yaw couplings before and after Round 1 of optimisation:

```
>> [Pos0, Pit0] = posyawOSEM(‘SensorYawInit.xml’,igains);
```

Table 7: Measurement program for Round 1 of tuning for the yaw component of the output matrix using the sensors as reference

Measurement Number	*Yaw Output Gains* *UL UR* *LL LR*	*Filename*
1	100 100 100 100	`SensorYawInit.xml`
2	90 100 100 90	`SensorYawMain.xml`
3	100 90 90 100	`SensorYawOff.xml`
4	90 100 90 100	`SensorYawLeft.xml`
5	100 90 100 90	`SensorYawRight.xml`

```
>> [Pos1, Pit1] = posyawOSEM(‘SensorYawInit2.xml’,igains);
>> [Pos0, Pit0; Pos1, Pit1]
```

18. If any of the optimised gains are less than 90, a second round will probably yield further improvements. Make the four suggested additional measurements using the same procedure as above, saving the results to files as in Table 8.

Table 8: Measurement program for Round 2 of tuning for the yaw component of the output matrix using the optical levers as reference

Measurement Number	*Yaw Output Gains* *UL UR* *LL LR*	*Filename*
1	As suggested in the output from `omatyawOSEM1`	`SensorYawInit2.xml`
2		`SensorYawMain2.xml`
3		`SensorYawOff2.xml`
4		`SensorYawLeft2.xml`
5		`SensorYawRight2.xml`

19. In the Matlab window, give the command

```
>> omatyawOSEM2(igains);
```

20. This prints an even more optimised set of gains. Copy the output and append it to the text file

from step 15.

21. Do a measurement with the optimised set of gains from `omatyawOSEM2` and save it in the measurement frequency directory as `SensorYawInit3.xml`.
22. In the Matlab window give the following commands to compare the effectiveness of the diffrent settings:

```
>> [Pos2, Pit2] = pityawOSEM(‘SensorYawInit3.xml’,igains);
```

```
>> [Pos0, Pit0; Pos1, Pit1; Pos2, Pit2]
```

23. Copy the output of the above command and append it to the text file from step 15.
24. Probably the optimised gains from Round 2 give better results. If so, create a BURT snapshot of the settings with a name reflecting the measurement frequency, e.g.,

```
/opt/CDS/d/ops/sustune/itmx2k/burt/20000630tunedomatyawOSEM0.2Hz.snap
```

Otherwise revert to the Round 1 values and snapshot them instead.

10 DAMPING GAINS

1. TBD.