

DM Flexure Testing

Purpose: To see how well the DM follows the tip-tilt stage motion as a function of driving frequency, and to find resonant frequencies of the tip-tilt stage

Overview: Initially, the setup for the experiment was very simple. A single laser was reflected off of the center of the DM and the spot on the wall was observed to determine the slope of the DM as a function of time. At frequencies above about 30Hz it is impossible to follow the spot and one only sees a streak. All 3 actuators of the tip-tilt stage were exercised, and the results were recorded. A function generator was used to drive the tip-tilt stage with a sine wave. A 50 ohm terminator was used on the input from the function generator.

Interesting and unexpected things were observed, and the experiment evolved to investigate what was observed. It was suspected that the DM's tip-tilt was not following the motion of the stage. Thus, a small flat mirror was glued to the DM cell, and this was illuminated with a laser to monitor its motion. To sample the slope across the surface of the DM, we wanted to illuminate the DM with multiple parallel lasers. This was effectively accomplished by illuminating the DM with the Zygo. A pinhole mask was placed in front of the Zygo to break its beam into 21 individual beams.

Experiment #1: Nov 25, 2004: First test for DM resonances

Procedure: The total path length from the DM to the wall is 14.9m. The laser (at one end of the bench) illuminates the DM (at the other end of the bench) through a pinhole near the DM. The beam reflecting off of the DM reflects off of 4 other mirrors (at opposite ends of the bench to fold the light path) before hitting the wall. Channel #1 was exercised which moves the beam horizontally. We scanned through frequencies from 350Hz to 1000Hz in increments of 50Hz driving the DM at 1V peak-to-peak. The iris in front of the DM was removed to reduce weight and because of the rattling noise it made. A DC offset of 50V was applied to all 3 channels since the amplifier cannot output negative voltages.

Results: The length and tilt of the spot on the wall was noted at each frequency. The text results (including an IDL script to plot the data) are presented in `nov25.Dmresonance.idl.txt`, and the plot at `nov25.DMtest.ps`, at irtfweb.ifa.hawaii.edu/~msc/DMtests. We observe a strong resonance near 400Hz, and the amplitude of the spot motion increases from 700Hz through 1000Hz (when the noise from the DM was so bad we stopped the experiment!). Along with the resonance, we observed that the spot tilt increased from 0 degrees at low frequency to 90 degrees by 500Hz, despite the fact that only the #1 actuator was being exercised.

Experiment #2: Nov 26, 2004: Scanning more frequencies with larger amplitude

Procedure: The setup is the same as on Nov 26, 2004. We scanned from 120Hz to 975Hz, noting the length and tilt of the spot on the wall. In order to drive the DM at the

largest stroke without causing damage to the DM, we drove the DM at 5Vpp from 120Hz to 200Hz, 3Vpp from 200Hz to 360Hz, and 1Vpp from 360Hz to 975Hz.

Results: The text results (including IDL scripts for plotting) for this experiment can be found on the above web page at nov26.DMresonance.idl.txt.

A plot of the amplitude and tilt of the spot motion is given in DMscaled.ch1.ps on the web site. The data taken with the DM being driven at 5Vpp and 3Vpp are divided by the voltage to scale the data down to the amplitude that would be observed if the DM were driven at 1Vpp. In addition to the 400Hz resonance and the post-700Hz rise, we also note a small increase in amplitude at 150Hz. The increase in tilt of the spot closely follows the increase in amplitude near the 400Hz resonance feature. After this, the tilt slowly increases but does drop below 90 degrees.

The amplitude and tilt information were used to plot the x and y components of the spot motion, which is given in DMxyscaled.ch1.ps. As usual, the DM was being moved in the x direction only. The peak of the x amplitude is near 375Hz, and drops before rising again near 700Hz. The y amplitude is initially zero, but starts to increase near 200Hz. It exceeds the x amplitude near 375Hz to peak near 425Hz. After 375Hz, the y amplitude is always greater than the x amplitude. At high frequencies, the amplitudes in the x and y directions are similar.

Experiment #3: Dec 3-4, 2004: Testing channels #2 and #3

Procedure: Experiment #2 was repeated, exercising actuators #2 (to move the DM cell diagonally) and #3 (to move it vertically).

Results: The results for actuator #3 are given in dec03.DMresonance.idl.txt. Plots showing amplitude and tilt, and x and y amplitude are DMscaled.ch3.ps and DMxyscaled.ch3.ps, respectively. The results for actuator #2 are given in dec04.DMresonance.idl.txt. Plots showing amplitude and tilt, and x and y amplitude are DMscaled.ch2.ps and DMxyscaled.ch2.ps, respectively.

When exercising actuator #2, the 400Hz resonance feature is seen, as well as another increase in the spot motion at 650Hz. The increase in the spot motion near 650Hz is in the x direction only, whereas the 400Hz resonance has similar amplitude in both the x and y directions.

When exercising actuator #3, the 400Hz resonance feature is very pronounced. The y amplitude rises sharply near 400Hz, drops equally sharply, and never rises again at higher frequencies. The x amplitude, on the other hand, steadily rises from about 300Hz through 1000Hz.

Comparing these results leads to a few interesting conclusions. When exercising all three channels, there is a strong resonance in the y direction near 400Hz. There is a smaller increase in the x motion near 400Hz when exercising actuators #1 and #2. For all three channels, there is a small and similarly size increase in spot motion near 150Hz. The high frequency rise in spot motion is different for the three channels. For channel #1, the x and y amplitudes are similar. For channel #2 and #3, all of the energy is in the x direction. We conclude that the 400Hz resonance put energy primarily in the y direction

for all actuators, whereas energy tends to be put into the x direction for all actuators at high frequencies.

Experiment #4: Dec 11, 2004: DM vs. DM cell motion

Procedure: Given the above results, we became suspicious that the DM was not accurately following the motion of the DM cell. To investigate this, we devised the following experiment. A small mirror was glued to the DM cell, and was illuminated with its own laser shining through a pinhole placed just before the mirror. A separate laser illuminated the center of the DM itself, also shining through a similarly placed pinhole. As before, the beam was folded across the bench several times. In this case the path length from the DM to the wall is 480". For this experiment we observed the amplitude and tilt of the mount's spot as well as the spot reflecting off of the center of the DM. For this experiment, only actuator #3 was used.

Result: The results are presented in a text file (with IDL plotting scripts) in `dec11.DMresonance.idl.txt`. Plots have been prepared showing the motion of the spots (`DM_mount.size.ps`), tilt of the spots (`DM_mount.tilt.ps`), x motion (`DM_mount.Xstroke.ps`), and the y motion (`DM_mount.Ystroke.ps`).

Generally speaking, the DM motion follows its cell's motion up to about 500Hz, after which they decouple. Beyond this frequency, we see practically no motion of the spot from the DM cell, whereas there is still considerable motion from the DM, especially at high frequencies. At low frequencies, the motions of the two spots have similar amplitude and tilt. At the 400Hz resonance, the DM spot motion is nearly twice the motion of the DM cell's spot's motion. The tilt of the DM's spot is also greater than the tilt of the DM cell spot starting at 400Hz, and the tilt of the DM's spot continues to increase through 600Hz. The x component of the DM cell's motion is greatest at 400Hz, whereas the x component of the DM's motion is greatest near 550Hz (where there is a small increase in the cell's motion). Beyond 600Hz we see no motion from the DM cell, but there is a strong peak in the DM's motion at 800Hz. As noted previously, the 400Hz resonance is primarily in the y direction. We see this in the DM cell's motion and the DM's motion, but the DM's y motion is nearly twice the DM cell's y motion (this is reflected in the total amplitude of the motions). We also note that the DM's y motion does not drop as quickly as the cell's motion, with a "shoulder" in the plot near 500Hz. As with the x motions, we see no motion from the DM cell but we do see a steady rise in the y motion from 650Hz through 1000Hz.

Experiment #5: Jan 24, 2004: DM flexure test

Procedure: Since the above experiment showed that the DM was moving independently of the DM cell, we felt that either the DM itself must be warping in its cell or that the compressibility of the O-rings was allowing the DM to move independently of the DM cell. To investigate this, we sought to illuminate multiple areas of the DM with parallel laser beams. This was accomplished by placing a pinhole mask with 21 holes in front of the Zygo interferometer, equipped to project a collimated beam. Due to the size of the Zygo beam, we could not fold the beam across the table; rather the beam from the Zygo

was reflected off of the DM and directly onto the far wall. As in the previous experiment, a laser shone through a pinhole and off of the mirror glued to the DM cell. The distance from the DM to the wall was 216". The pinhole mask has holes 0.1" in diameter (given the distance to the wall, this is nearly optimized to give the smallest spot size), 0.5" apart, making a pattern 2" across. The pattern has 5 rows, the first and fifth row having 3 holes, and the other rows having 5 holes. We scanned from 100Hz to 1000Hz in steps of 25Hz up to 500Hz and in steps of 50Hz beyond. The driving voltage was selected to give the maximum amplitude of the spot motion without (hopefully) causing damage to the DM or the DM cell. For each frequency, a digital camera was used to photograph the spot patterns on the wall, along with labels. The labels note the driving frequency, driving amplitude (sine wave, in volts peak-to-peak), and also include a bubble level line and a 3" scale bar. These images are available on the web site as .jpg files. Images ending with hz1.jpg have been contrast enhanced in order to make it easier to read the label and see the DM spots. Non-enhanced images have been included since it is easier to see the DM cell's spot motion in these images.

Results: The images speak for themselves, and we only note general trends here by commenting on specific images. Using these images it is possible to do a more complete, quantitative analysis of the spot motion and phase.

At low frequency, the DM motion makes the spots look like linear streaks. As the frequency increases, the tilt of the spot increases, and the spot pattern has become a loop rather than a line.

The 0Hz image shows the spot pattern with everything at rest. The spots from the DM are not evenly spaced due to the fact that the DM is not perfectly flat.

The 150Hz image generally shows what it looks like when the system is running at low frequency, with one difference. The spots on the lower half are straight lines whereas the spots on the top half are 'S' shaped. In order for this to happen, the top of the DM must be warping in the y direction at twice the frequency that the mirror is being driven in the x direction, because in the amount of time it takes for the DM to move half of a cycle in x (i.e. from the left extreme to the right extreme) the top of the DM has warped through a full cycle.

At 300Hz, the spots still look like lines, but the length of the lines is no longer uniform, with the lines to the top left being significantly longer than the lines at the opposite corner. Also, the slope of the lines also not uniform. Relative to the central spot, the lines are strongly diverging from the center, showing that tip-tilting the DM at these frequencies can impart a considerable curvature to it.

At 350Hz, the spot pattern is clearly loop shaped, and the slope of the spot pattern has continued to increase. Relative to the central spot, each spot pattern is generally a straight line that points away from the center, i.e. the curvature noted above. The only new thing is that in addition to the overall tip-tilt of the DM, there is also a small x or y motion that is roughly $\pi/2$ out of phase with the larger motion that produced the loop shape.

At 450Hz, the slope of the spot pattern has rotated enough that the central spot/loop is elongated vertically. The fact that the loops are more pointed at the bottom may mean that the x or y motion that is making the loop (in this case, x) is not exactly $\pi/2$ out of phase. As the frequency increases, the amplitude of the DM motion decreases. At higher

frequencies the spots are once again linear. At 1000Hz, the curvature of the DM is the most noticeable deviation from the tip-tilt motion of the DM (which is considerably greater than the motion of the mount).

Conclusions:

We found a weak resonance at 150Hz, a strong resonance at 400Hz that is primarily in the y direction (regardless of the driving actuator), and a rise in the amplitude of the DM motion from 700Hz through 1000Hz although the DM cell was not significantly moving. At low frequencies the DM followed the motion of the DM cell, but the motions decouple at high frequencies. We also found that at frequencies as low as 150Hz there is noticeable warping of the DM due to the tip-tilt motion, and from 350Hz this motion imparts noticeable curvature to the DM. The difference in the motion of the DM and its cell is due to the warping of the DM itself.