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MMT Observatory

Smithsonian Institution &
The University of Arizona®

Status of Adaptive Secondary Testing – Nov/Dec 2010

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1. Introduction

During the October NGS-AO run, numerous problems with the deformable secondary mirror were encounter which ultimately prevented the adaptive optics system from performing as designed, significant telescope observing time was lost, and collection of science data was compromised. As a result of this, a series of tests on the deformable mirror (DM) was conducted in November and early December 2010. This report reviews some of the issues seen during operation of the DM and discusses the various tests conducted, data collected, and preliminary conclusions. The status of the DM prior to the December AO run is then discussed along with tasks which still need to be performed in the January/February 2011 time period.

2. DM issues seen during the October 2010 NGS-AO observing run

2.1 High actuator currents

High actuator currents were observed during the October AO run. There appeared to be two distinct phenomena. The first is the so-called 'salt and pepper' current pattern seen on the mirror where there are actuators with high current and low currents side by side, distributed over the mirror surface. Often, but not always, these patterns have been seen near the mirror edge and center ring. This pattern of alternating high currents has been seen for some time and has appeared to come and go over time. During the October run, these currents were often quite high (figure 1).

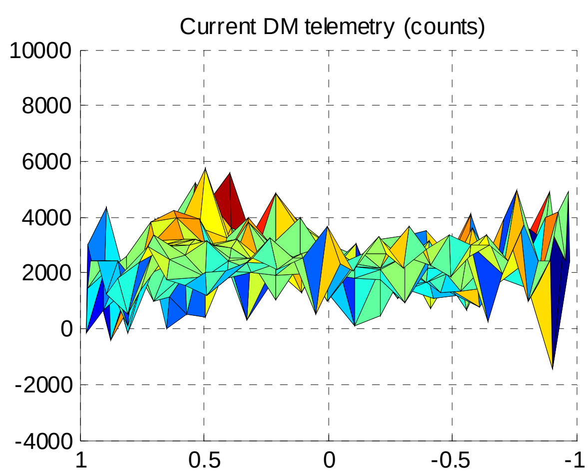


Figure 1: Shown is a side view of the surface plot of actuator currents. The typical 'salt and pepper' pattern of actuator currents can be seen on the mirror, particularly at the edges.

The second issue seen during the October run was a localized area of high actuator currents. This is shown in figure 2. This phenomenon of very high localized actuator currents had not been observed before. The high currents appeared to be correlated with tilt of the DM surface. Actuator currents as high as 32,768 counts (saturation) were observed during at least two nights on Oct. 27th and 28th.

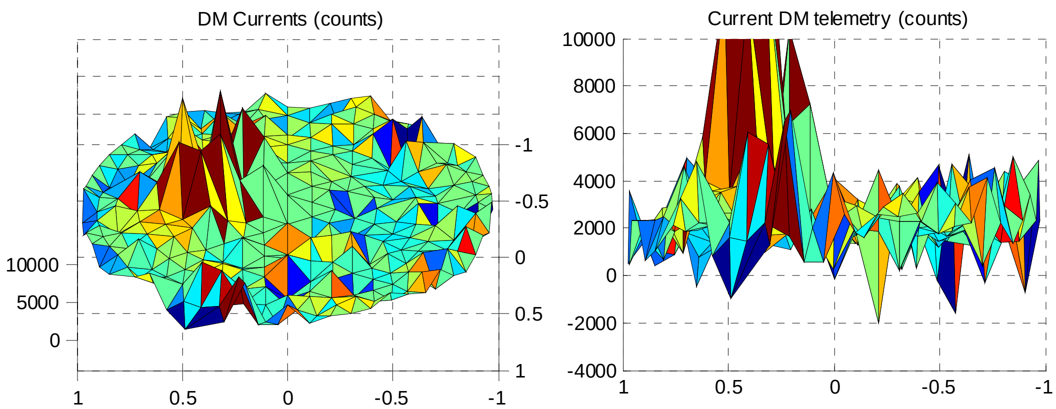


Figure 2: Surface plots of actuator currents. Very high currents were observed in a localized region of the mirror. The amplitude of the currents appeared to be correlated with DM tilt.

2.2 Difficulties in obtaining a proper mirror flat

Attempting to flatten the DM during the October run proved to be very difficult. Several symptoms were noted which included large current errors on numerous actuators and position errors on individual actuators. One particularly troublesome problem was the inability of the DM to flatten due to an average gap height error of 239 microns which is physically impossible. This error has occurred in the past but was particularly troublesome during the Oct. run. Since it prevents the mirror from obtaining a proper flat, the DM cannot operate in closed loop. In addition, since telemetry data is not being saved when the DM is not in closed loop operation, diagnosing the actual problem proved very difficult.

2.3 Large numbers of actuators in open loop

During the October run, large numbers of actuators were often placed on the 'open loop' list. When an actuator is placed on the 'open loop' list, a bias current is applied to the DM which allows the associated magnet to 'float' at the average flat position of the mirror. No control or feedforward currents are applied. This number varied throughout the run, as actuators were often placed on the list when high current errors were encountered. Figure 3 shows a map of the actuators during the night of Oct. 28th. Actuators on the open loop list are shown in red; actuators not on the open loop list are shown in green. The actuators marked in black are non-operational and no current is being applied. At this particular time, there were 76 actuators on the open loop list with 3 non-functioning actuators. However, there were times during the run where as many as 132 actuators had been placed on the open loop list.

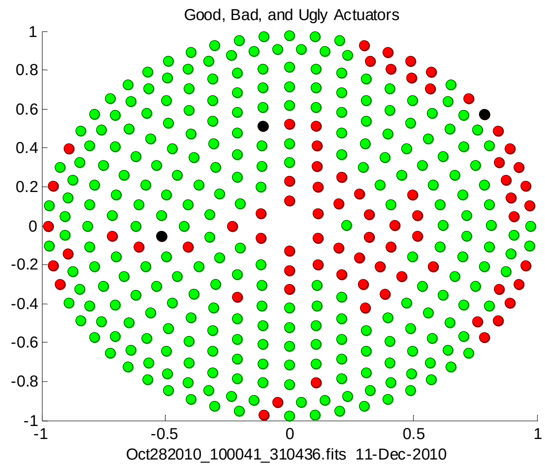


Figure 3: Map of actuators placed on the open loop list. Red marks actuators on the list, green marks actuators not on the list, black are non-functioning actuators. This data set shows 76 actuators (plus 3 non-functioning) on the open loop list.

2.4 Drifting and jumping seen in capacitive sensors and actuators

The position and currents for individual actuators were often seen to drift or jump. This seemed to affect many of the actuators, if not all, at various times. This phenomenon has been seen for quite some time. It often appeared to get significantly worse as the operating temperature of the crates and actuators changed rapidly. Figure 4 shows a time history plot of a typical jumping actuator. The difficulty in assessing poor response is that it appears to be extremely random. Actuators which show the drift at some time can then go back to responding normally within a few minutes, while different actuators then begin to have issues. The number of drifting and jumping actuators has been highly correlated with temperature changes in the electronics and, to a lesser extent, relative humidity.

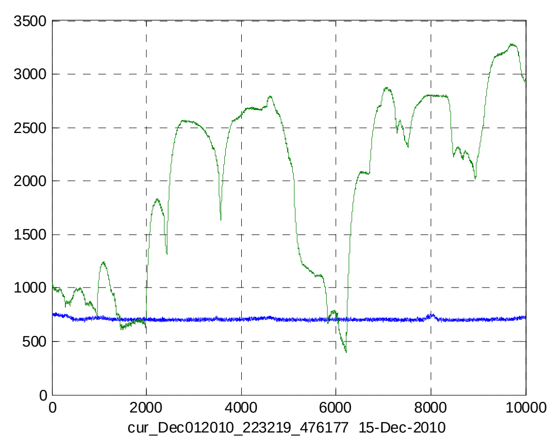


Figure 4: Time history of actuator current for a typical 'jumping' actuator (green) and normal (blue). Data was taken during the Dec tests while attempting to hold the mirror flat. Changes in temperature can make a significant difference in how many actuators display this type of response. The *x*-axis displays the number of frames (at 275 Hz)

2.5 Temperature sensitivity of capacitive sensors and actuators

As discussed in the previous section, temperature changes can significantly affect the number of actuators which drift and jump. Figure 5 shows the time history response for all 336 actuators when the temperature setpoint was intentionally varied during DM testing. The vast majority of actuators exhibit problems when the crate temperature varies rapidly.

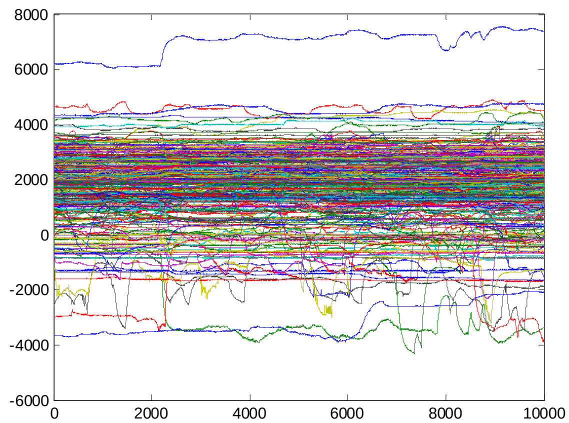
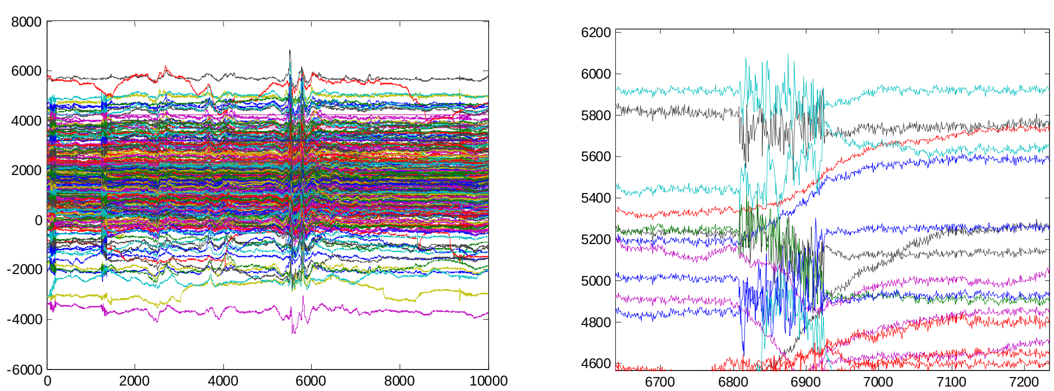


Figure 5: Time history plot of all 336 DM actuator currents. Many actuators are affected when rapid temperature setpoint changes to the electronics are introduced. *x*-axis is number of frames (at 275 Hz)

2.6 Noise issues due to bad actuator and possible grounding issues

During the October run, instances were seen where bursts of noise would affect all 336 actuator currents and positions simultaneously. The noise bursts would last from approximately 0.5 seconds to 1.5 seconds. Figure 6 shows a small noise burst in currents during the October run. This has also been seen on prior telemetry dating back to at least 2008.



(a) (b)

Figure 6: (a) Time history of actuator currents shown multiple noise bursts over 18 second time frame. (b) Close up of noise. This phenomenon has been present in the data since at least 2008.

3. Initial DM testing performed in November 2010

3.1 Removal of aspheric shell and inspection

An initial set of tests were conducted on the DM in early November to determine if any obvious mechanical or electronic issues were apparent with the mirror that could quickly be solved. To this end, the aspheric shell was removed on November 1, 2010 and a quick physical inspection of the shell and electronic components of the deformable mirror were conducted. There was no apparent damage to any of the electronic components, either the actuators or the DSP boards. Due to the previous damage on the back side of the aspheric shell, it was difficult to determine if any additional damage had occurred. However, after a quick visual inspection of the shell, we saw nothing that seemed obviously worse than was previously there. Four actuators and two DSP boards were removed and visually inspected. No physical damage was found. We then looked to see if there was any correlation between actuators placed in open loop and physical damage to the coating of the shell or to the capacitive sensors and magnets. There was virtually no correlation between visible damage on the shell or actuators and those actuators that had seen anomalous behavior during the October run.

3.2 Replacement of Aspheric shell and testing

On November 4, 2010 we re-installed the aspheric shell to run additional tests on the DM. At the time, the spherical shell was unavailable for transport up the mountain as it needed to be cleaned and a suitable storage container needed to be obtained.

During the time period the aspheric shell had been off, a thorough review of telemetry data from the Oct. run revealed that very high currents were seen in a localized region of the mirror surface. Before re-installing the shell, this area was inspected thoroughly for any anomalies. During the inspection of the reference body, areas where deposits of a hard substance were noted on the surface (figure 7).

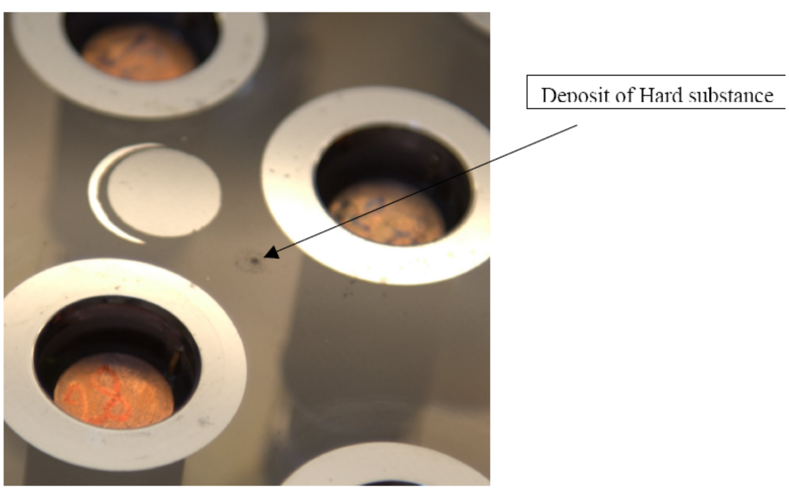


Figure 7: Deposits of hard substance were found on the reference body where high actuator currents were seen in telemetry data from the October run.

Attempts to remove this substance with alcohol or Q-tips did not work. Figure 8 shows multiple deposits of hard substance on the reference body. Figure 10 shows the corresponding position on the back of the aspheric shell.

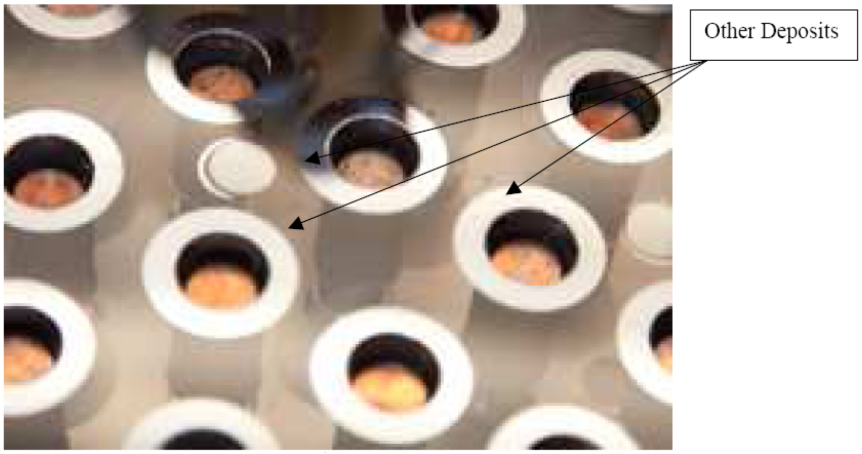


Figure 8: More deposits of hard substance on the reference body where high actuator currents had been seen.

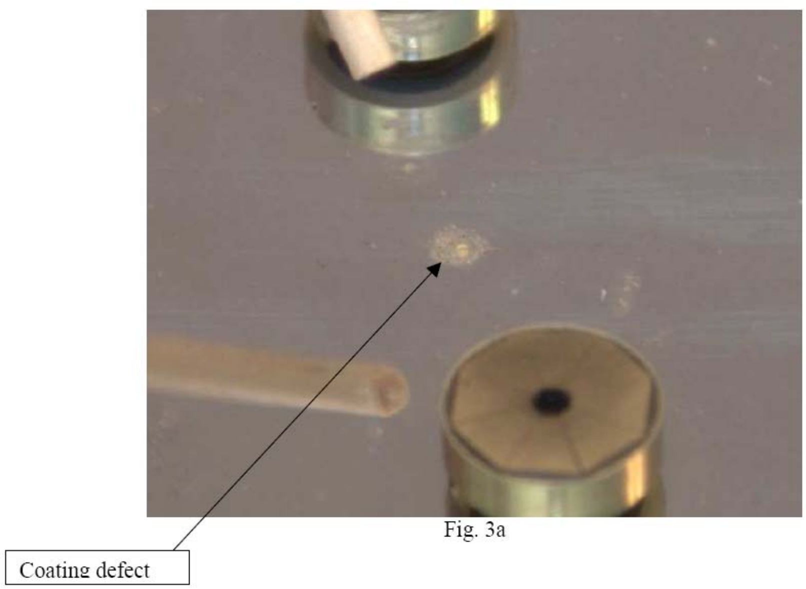


Figure 9: A defect in the coating of the aspheric shell corresponding to one of the deposits on the reference body.

The hard substance on the reference shell and the corresponding anomaly on the back of the shell seemed to indicate the two areas had been touching where the deposit of hard substance was found. The high actuator currents may have been the result of the two areas sticking together during operation, thus resulting in high actuator currents when the deformable mirror was commanded to tilt in a direction which increased the gap height in the contaminated area.

3.3 Grounding issues and actuator removal

Another issue that was discovered during testing was a high frequency noise present on the capacitive sensor reference signal. During testing it appeared that there was a high level of noise on the individual actuator positions and this was preventing us from flattening the mirror during the test. The reference signal should be a 10 Volt peak to peak square wave. However, when an oscilloscope was used to measure the reference signal, a much higher frequency oscillation was superimposed on the normal signal (figure10).

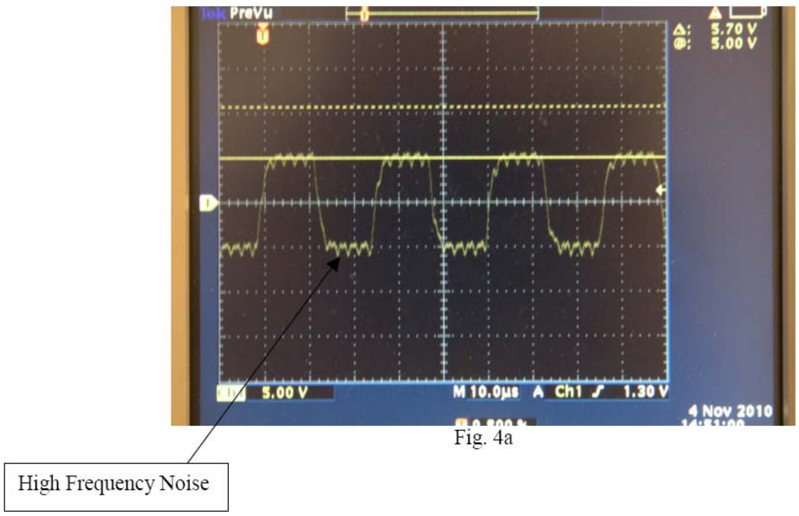


Figure 10: High frequency noise present on the capacitive sensor reference signal. When the oscilloscope signal was grounded to the telescope ground wire, the reference signal got significantly worse (figure 11).

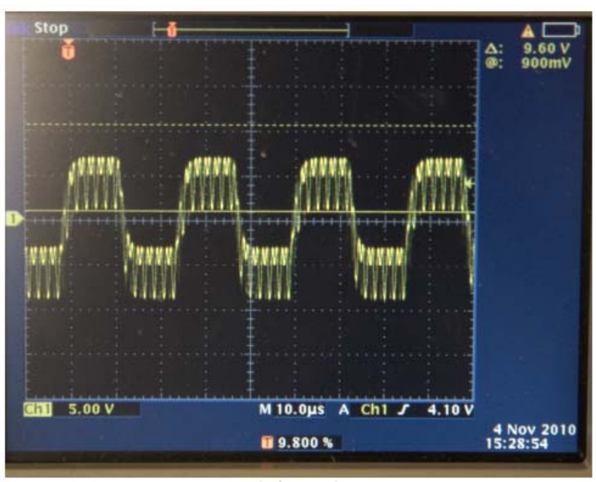


Figure 11: Capacitive sensor reference signal noise was much worse when connected to telescope ground wire.

The ground wire was then disconnected from the DM and the test was done again. This time there was virtually no noise on the reference signal. With the ground wire disconnected, we again attempted to flatten the DM and were instantly successful. It is not entirely clear if this is what was preventing the DM from being properly flattened during the October run since telemetry data is quite limited before the loop is closed. However, it could potentially explain some of the aberrant behavior seen at times during the run.

An additional noise problem was seen with actuator DSP number 106 which caused the shell to acoustically vibrate when it was put back in the loop before high currents shut the mirror down. This actuator was taken out in software but also physically disconnected from the DSP board to prevent it from accidentally being placed in line again.

3.4 Chirp signal tests

Tests were performed 15 December on the aspheric shell in which a varying frequency sine wave (chirp) signal was input to the DM. The telemetry data was analyzed to assess the performance of the mirror to see if high currents or anomalous behavior was seen on the actuators. Figure 12 shows the time histories for all 336 actuators currents. Although some drifting and jumping actuators were seen, nothing in the test was observed that was significantly different from prior to the October run. However, this test was run at constant setpoint temperature and after the shell had been removed, lightly cleaned, and replaced so it was not surprising that high currents or anomalous behavior were not seen.

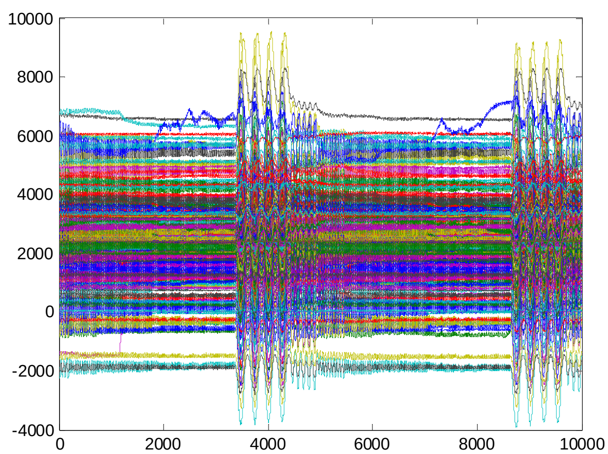


Figure 12: Chirp test performed on aspheric shell showed reasonable response of the mirror at constant set point temperature. Drifting and jumping actuators currents are still present. Frame number is show on the x-axis where the sample rate was 275 Hz.

The aspheric shell was then removed after the tests were completed. During the removal and test, it was noted that actuator DSP number 158 was shorted to case. This was not good for mirror safety and also created a large ground loop that caused noise on the reference signal. The actuator has been physically disconnected from the DSP board.

4. Additional DM testing with the Spherical shell conducted 16 Nov. to 9 Dec. 2010

4.1 Thorough inspection of the aspheric shell and cleaning

On Nov 16th the aspheric shell was again removed. A thorough inspection of the shell and shell coating was conducted by Gary Rosenbaum. Attempts were made to clean off the contaminants using isopropyl alcohol and then acetone with limited success. Finally, toward the end of the day, distilled water was applied to one of the contaminated areas which then quickly dissolved the contaminant. A thorough cleaning of the reference body and shell with distilled water was performed which removed a significant amount of contaminates from both reference body and shell.

It was noted that there was significant dust build up on the optical surface of the shell. Gary concluded that over most of the optical side of the shell, the reflectance of the mirror was down by at least 2-3% and with all the dust, the scatter was quite high (probably 4-5%). One area of the coating covering a few square inches was found to be seriously degraded on both sides of the mirror. Further inspection and test of the aspheric shell should be performed at some point.

4.2 Shipping and cleaning the spherical shell

It was decided to run a series of tests with the spherical shell in place of the aspheric shell in order to understand the effects of the degradation in the coating on the back side of the aspheric shell. There were serious concerns that damage to the coating was responsible for much of the anomalous behavior of the DM. By running tests with the spherical shell, whose coating was still quite good, a determination could be made as to whether the degraded coating was the root cause of the poor performance. The spherical shell was cleaned, boxed for shipment, and transported up the mountain on 17 November. Some additional cleaning was done to both the aspheric shell and the spherical shell prior to mounting the spherical shell to the reference body.

4.3 Flattening of spherical shell and chirp signal testing after initial cleaning of reference body

Once the spherical shell was mounted to the reference body, another series of tests were run to assess the behavior of the secondary mirror. These tests were run on 22 Nov. and 24 Nov. Before testing was able to start, an appropriate flat had to be found for the spherical shell. This proved to be somewhat difficult as the spherical shell had not been used in quite some time. Once the flat was found, telemetry data was taken with the DM loop closed at zero gain and at a constant setpoint temperature. Figure 13 shows a surface plot of the actuator currents with the spherical shell at flat.

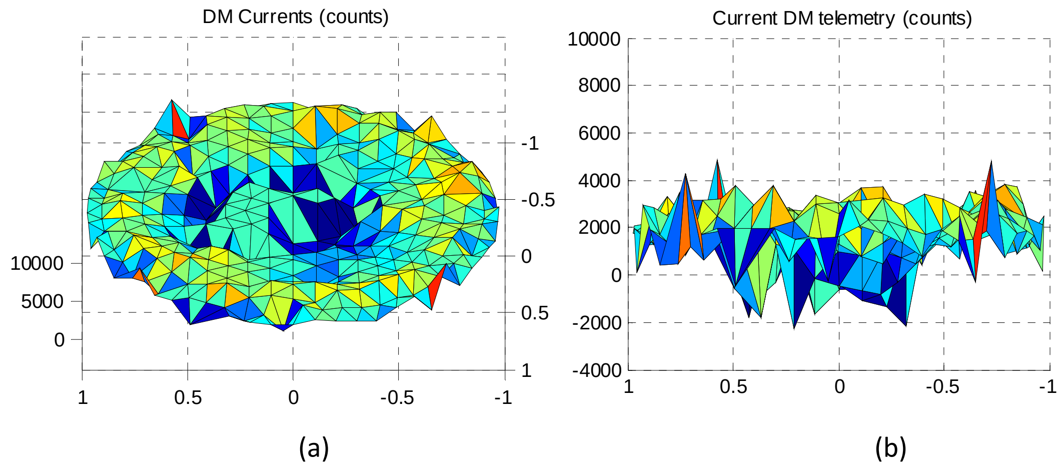


Figure 13: (a) Surface plot of actuator currents with the spherical shell holding flat. (b) Side view shows currents were quite low between -2000 and +5000 counts (typical is -2000 to 6000 counts)

4.4 Spherical shell temperature set point tests

During a number of AO observing runs, it was anecdotally noted that anomalous actuator performance became worse when the set-point temperature of the chiller was changing. In order to understand this effect, a test was run on 24 Nov, 2010 with the spherical shell where the chiller set-point temperature was varied rapidly from approximately 8 deg C (22 deg C crate) to 24 deg C (30 deg C crate) to see what affect this had on actuator performance. Figure 14(a) shows the initial response of the DM actuator currents with constant chiller set-point temperature at 8 deg C. The actuator currents are generally well behaved and drifting and jumping actuators are kept at a minimum.

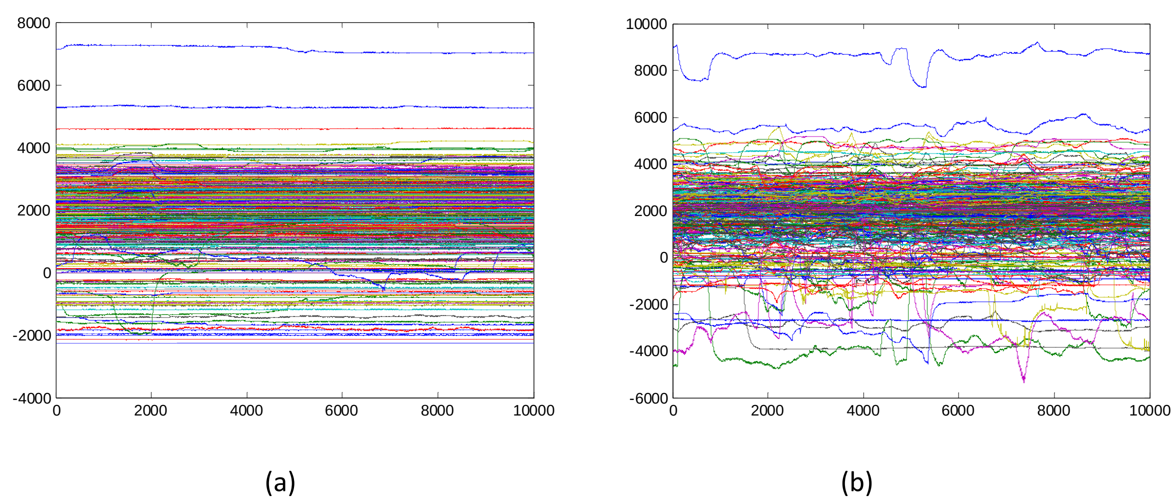


Figure 14: (a) Actuator currents during a constant set-point temperature of 8C (chiller). Anomalous actuator behavior is minimal. (b) During temperature set-point change. Anomalous actuator behavior is the same for both the spherical and aspheric shells despite differences in the coating.

Figure 14(b) shows the actuator currents during a set-point change when the temperature was varying rapidly. This type of jumping and drifting actuator current is quite similar to what has been seen with the aspheric shell during observing runs. Other data sets from the test show current jumps of up to +32768 counts and -32768 counts (saturation). The extremely poor response of the spherical shell, where the coating is essentially undamaged, indicated that the degraded coating on the aspheric shell is not the primary factor in the anomalous behavior of the mirror.

4.5 Tests performed after final cleaning of aspheric shell and reference body

On 1 Dec. two DSP boards with known numerous bad actuators were replaced by spare DSP boards. The board from crate #0 DSP channels 104-111 all showed improved performance after the board was replaced. However, the DSP board from crate #1 DSP channels 216-223 showed no improvement. On 6 Dec. the reference signal board was replaced with a spare board to see if this had any effect on the noise seen on all actuators in the system. Data collected while holding a flat position showed that there was no change in the noise characteristics due to the reference board change. At this time, there was significantly more cleaning done to the aspheric shell prior to its reinstallation. The reference body was already quite clean at this time. On 8 Dec. the spherical shell was removed and the aspheric shell was replaced on the reference body. An additional series of tests showed reasonable current responses of the actuators could be maintained as long as there were no dramatic changes in the temperature set-point. Flats and chirp signal tests were performed with relatively good resulting performance.

4.6 Position correlation of bad actuators and putting more actuators back online

One very significant discovery was that many misbehaving actuators were correlated by position on the mirror surface, rather than by the DSP boards. The typical indication was one bad actuator which would have a large negative value. The actuators surrounding the one misbehaving actuator would then react and apply high currents to attempt to restore the flat. This resulted in one actuator with large negative current values, and 5-6 actuators surrounding the bad actuator with large positive current values.

The typical response was to remove all the actuators with high currents from operation, thus placing large numbers of actuators in open loop that were not actually malfunctioning. As a result, more burden was placed on the fewer remaining actuators to bend the surface to the commanded position. This resulted in even higher currents where many in-loop and open-loop actuators were interfacing, compounding the problem, and resulting in even more actuators being put into overcurrent. Once this was discovered, and a method was in place for analyzing the data to find the truly misbehaving actuators, many more actuators were able to be placed back in the loop. This resulted in a significant improvement in the overall mirror response and lowered the currents dramatically.

Figure 16 shows a surface plot of the actuators off-line after re-evaluating which actuators were actually bad. As of 9 Dec., only 14 actuators were listed as open loop, the fewest number since at least 2007. An additional 6 were physically disconnected.

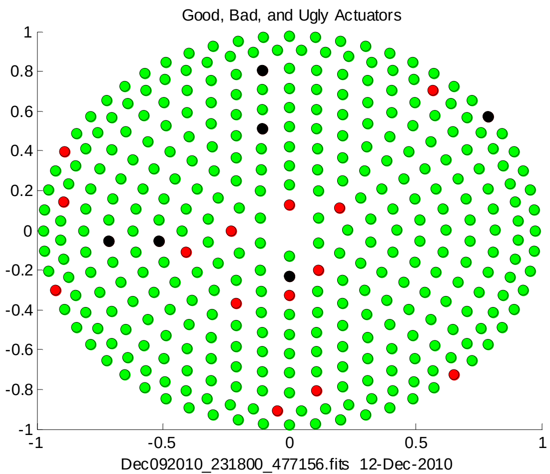


Figure 16: Significant numbers of actuators were placed back into service resulting in much lower actuator currents applied by the DM. Only 14 actuators are currently in open loop.

Figure 17 shows the currents during a flat with the aspheric shell mounted to the reference body. The currents are the lowest seen since prior to 2007 with a maximum actuator current of approximately 6000 counts and minimum of approximately 0 counts. The chiller set-point temperature was set constant for these tests.

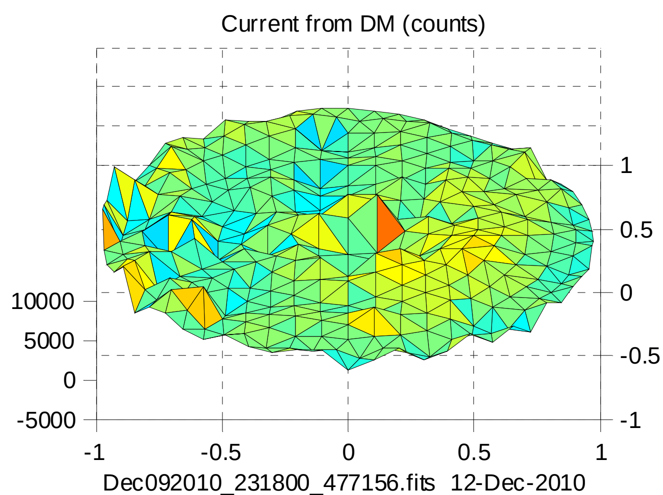


Figure 17: Surface plot of actuator currents. The currents seen after cleaning the reference body and shell, along with returning numerous actuators to service, resulting in very low currents across the shell.

5. Current state of the DM prior to the December 2010 NGS-AO observing run

Although the response of the DM has been improved since the October 2010 observing run, significant work on the adaptive secondary still needs to be performed. This is particularly true for the electronic components of the actuator controller and the capacitive sensor as there are still considerable issues with the DM response when the temperature changes rapidly. This seems to affect the actuators randomly and is very difficult to track down and correct while at the telescope.

Despite this, significant improvement in the mirror performance was obtained. Cleaning of the shell and reference body seems to have eliminated the high localized currents seen during the October 2010 run. Replacing the aspheric shell with the spherical shell eliminated the coating as a primary cause of the misbehaving actuators and seems to have narrowed the possible causes to electronic components of the DSP boards, actuators, or capacitive sensors. Several noise issues were detected and resolved. The issue of the bogus 239 micron gap while flatten the mirror was resolved which often caused significant loss of observing time at the telescope. Understanding the effects of the actual misbehaving actuators enabled us to put large numbers of actuators previously in open loop back into service and made an enormous difference in the large currents previously seen in the system performance.

The tests performed during Nov./Dec. not only saw significant progress in improving the DM performance but also allowed a better understanding of the overall system and its components by both CAAO and MMT personnel. This should in turn be beneficial for future maintenance, reliability, and improvement of the adaptive secondary system.