DEIMOS Service Mission, March 2016

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Figure 1: Part of the service mission team getting ready to start working on DEIMOS.

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2. Summary

This document reports on the service mission performed on the DEIMOS grating system between March 13 and March 28, 2016. The main work done on the system consisted of the following tasks:

- Installed new arcs with that were modified with a 2-degree tilt on one edge to prevent the arcs wearing out a large wheel shaft (see Figure 2 for an overview of the grating slider assembly).
- Installed rounder and more concentric flywheels. Wheels have beveled edges to prevent wearing of the belt pulley shaft.
- Optimized the concentricity of the flywheel-shaft assembly.
- Glued with Loctite 620 bearings holding the flywheel shaft.
- Replaced damaged screws.
- Replaced tension springs in the grating cells.
- Cleaned and polished parts in the clamping system.
- Installed new pulleys in the grating tilt mechanism that are thicker and have a flange to prevent belts from falling off (see Figure 3 for a general view of the grating tilt mechanism).
- Installed new wider (3/16") and stronger (no joint point) belts in the grating tilt mechanism.
- Modified the belt covers to accommodate the new pulleys and belts.
- Replaced leaking pneumatic pressure regulator for clamp #4 in slider 3.

As a result:

- The grating tilt system is more robust to belts breaks.
- Belts are extremely unlikely to slip off the pulleys.
- The clamping performance and flexure properties of the grating system improved considerably (see Section 9).
- No time was lost to the grating sub system for 15 nights (2 months).

For the reasons above, we consider the service mission a success and expect that for the foreseeable future, the grating subsystem will continue to operate more reliably. There are still a few minor issues we will continue to pursue. There is now one minor issue and that is clamping slider 3 in the range between 45 and 90 degrees is

intermittent, and at least once required rotating to acquire calibrations. There is an easy work around and that is to simply clamp at a rotator angle where we know it will clamp.

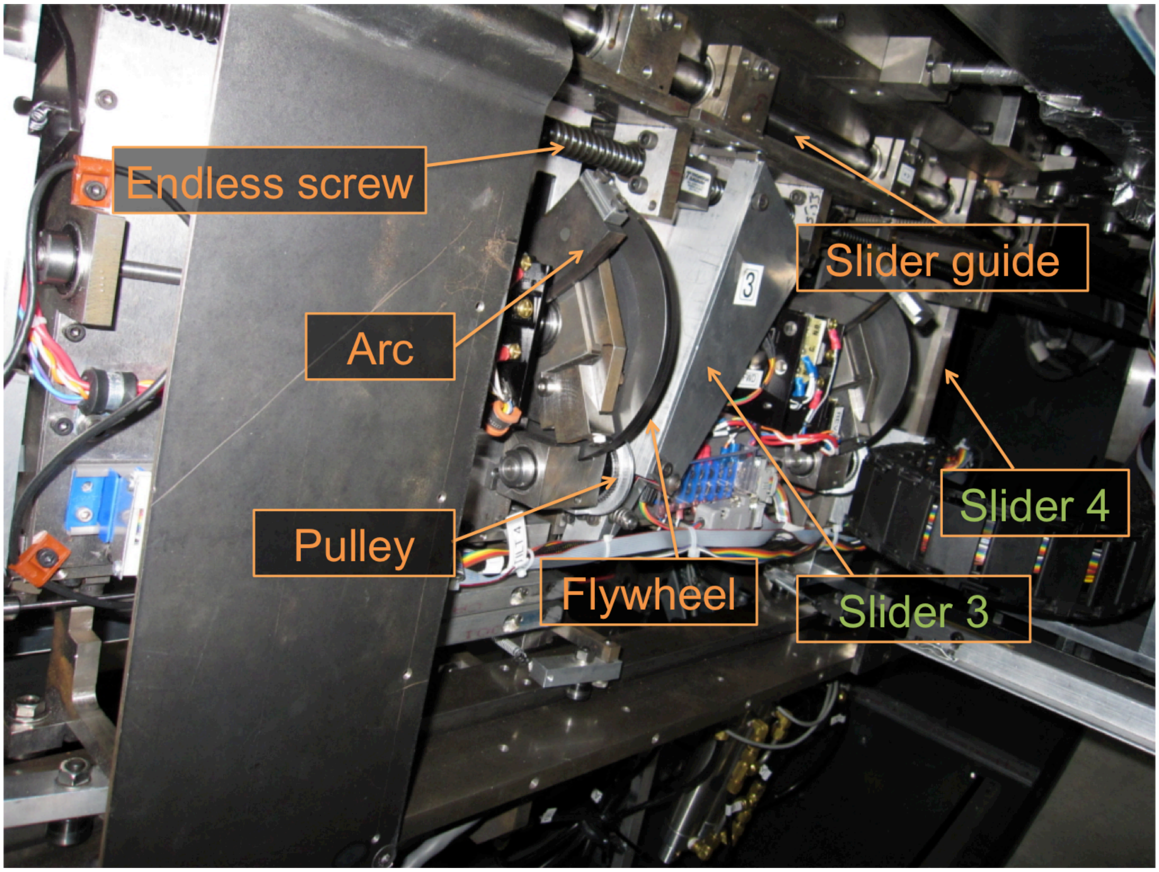

Figure 2: Grating slider assembly inside DEIMOS enclosure with some of the main components referred in the text labeled.

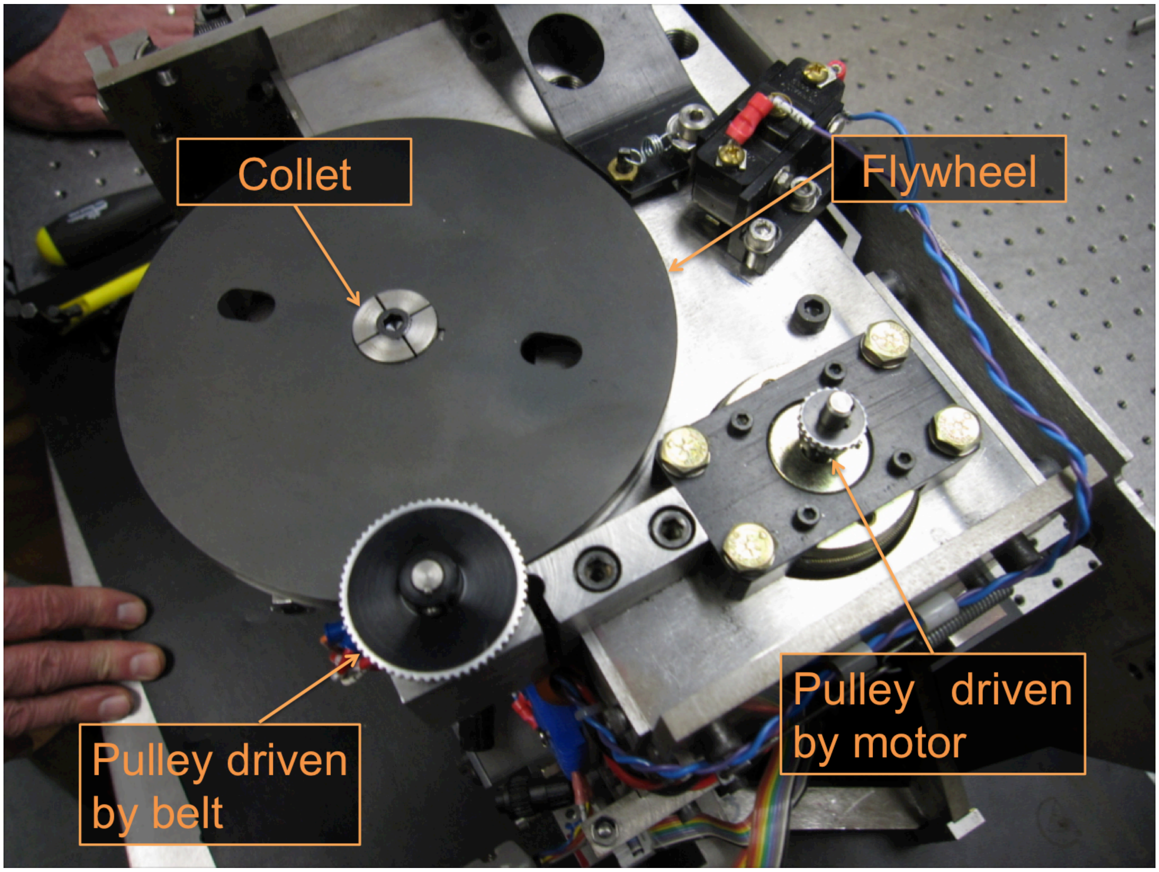

Figure 3: Some of the main components of the grating tilt mechanisms replaced during the service mission.

In the following sections we describe in detail the different tasks performed during the mission, the achieved improvements, and some thoughts on future work to further improve the reliability of the system.

3. Slider disassembly in the lab

This section describes the step-by-step procedure to disassemble slider 3 in the lab. The procedure for slider 4 is similar, with some small modifications due to slightly different design.

1. Remove hard stop for edge arc
2. Remove belt cover and belt
3. Remove large gear assembly
4. Remove spring tensions near small gear
5. Remove front L plate
6. Release screw that maintains encoder rotation

7. Remove the grating tilt arc
8. Install new arc, which has a 20 degree tilt on edge to prevent the arc cutting into the shaft.
9. Check concentricity of arc. Dial indicator measures ±3/10 of a thousandth inch.
10. Remove ramp from old arc
11. Install ramp on new arc
12. Reattach screw that maintains encoder rotation
13. Pull slider on blocks
14. Remove keeper for axil of large wheel. A special wrench for micro-rotors is required.
15. Axil position with respect to the large wheel was modified to prevent the arc from putting tension on the thicker part of the axil. This operation required the axil to be disassembled from the big wheel, to allow the axil sliding through the wheel.
16. Remove flexure support
17. Release tension on springs
18. Remove slide rail with bearing slider guide
19. Reinstall arc hard stop for safety
20. Remove ball screw mount
21. Remove side plate (we noticed later on this is not necessary).
    21.1. Tilt up to access screws on bottom
    21.2. Tilt back and remove
22. Tapped shaft of flywheel to remove.

In the whole process, it is critical to make sure that the reference tab (see Figure 4) in the grating mechanism is not bent, otherwise the homing reference will be lost.

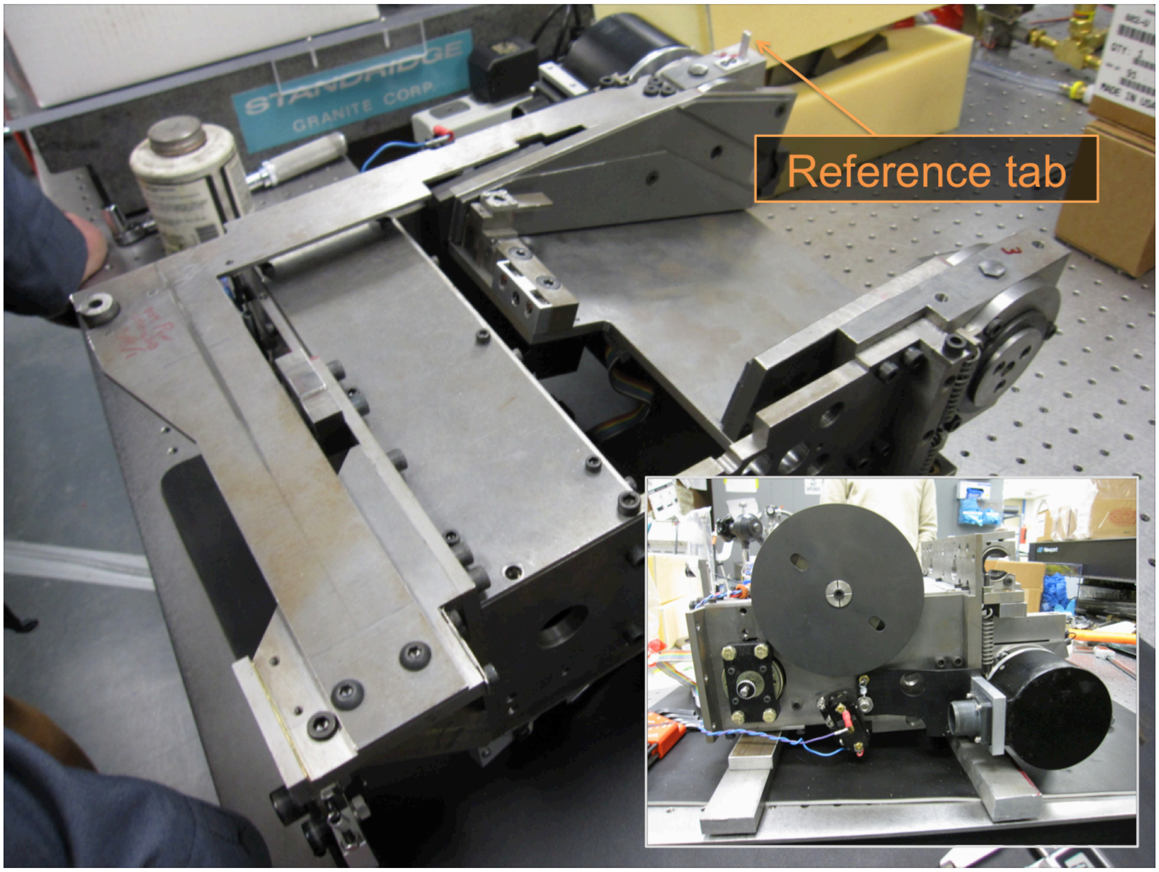

Figure 4: Grating cell showing the reference tab. The inset shows how we lifted the cell to prevent the tab from bending.

To re-assemble the slider, reverse the order of the above procedure. Once the cell has been assembled, the grating tilt motor should be exercised to verify if the current is smooth. A low and steady current indicates that there are not strong friction variations between the flywheel axis and the arc.

6. Findings

State of some components

Some of the components in the grating tilt mechanism were in poor condition despite being recently installed in January 2015 during the first service mission. Two things that stand out were:

- In both grating cells, there was a lot of wear and tear in the flywheel shaft at the contact point with the arc.
- The old flywheel assembly on slider 3 was not round to 0.005” – 0.006”.

Figure 5 and Figure 6 are images of the wear on some of the components.

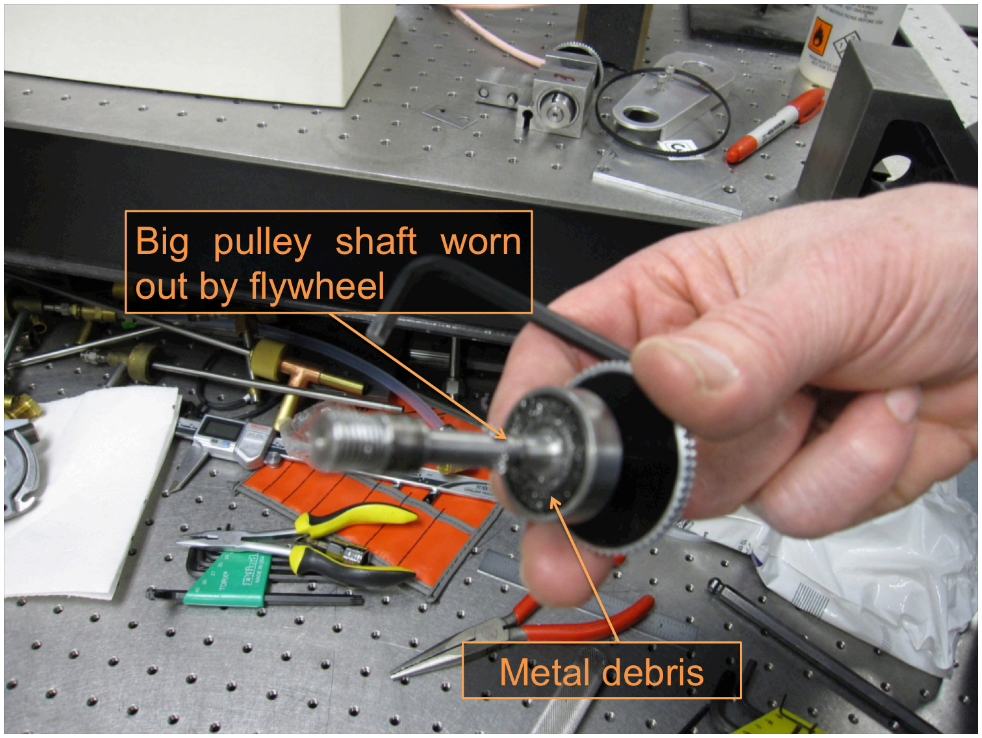

Figure 5: Pulley axis and metal debris caused by friction between the flywheel and the pulley axis. New machined flywheels have a 2 deg bevel to prevent wearing the pulley axis.

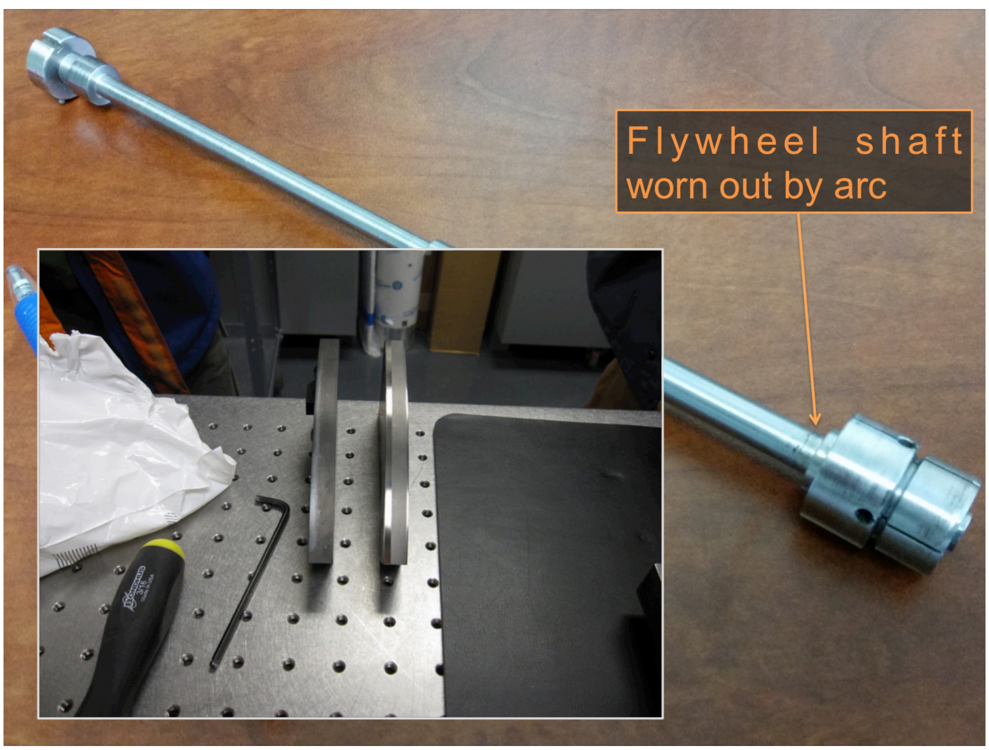

Figure 6: Flywheel shaft worn out by contact with arc. Inset shows the old arc (left) and the replacement arc (right), which has been machined with a beveled surface to prevent wearing the flywheel shaft.

Flywheel-shaft assembly roundness

- The new flywheel assembly on slider 3 was not round to at least 0.002”. This was true for the two spares as well.
- The pressure of the arc on the flywheel shaft did not make any difference in the roundness of the flywheel measurement for either of the grating cells.

Figure 7: Jim and Marc measuring the roundness on the flywheel.

Run out in the flywheel-shaft assembly

We think that run out in the flywheel-shaft assembly was one the major causes of the problems with the grating tilt system before the service mission. Large run outs meant differential friction between contact surfaces (arc and flywheel axis, or flywheel and pulley axis), and this would cause tension variations in the belts. Fatigue in the belts caused by the variations in tension would end up breaking them.

During the service mission, we spent a significant amount of time accurately measuring and minimizing the run out in the different components. Below are some of the run out measurements we obtained in the new flywheel-shaft assembly:

- Run out in the flywheel was less than 0.0002”.

- Run out at the end bearing surface was ~0.0002".
- Run out at the collet bearing surface was ~0.002".
- Collet was not well centered in the flywheel.
- Replacing the bearings holding the flywheel shaft in the cell structure did not improve the run out.

One line of work to try to reduce the total run out was to apply Loctite 620 on bearings holding the flywheel shaft on the wheel side (see Figure 8). The procedure to apply the Loctite was:

1. To clean the bearing hole
2. To apply Loctite
3. To let Loctite sit for long enough (at least 1.5 hours, overnight if possible)

The run out in slider 3 flywheel-shaft assembly (see Figure 9) when the bearings were not attached with Loctite, was 0.004". Once the bearings were glued to the grating cell attachment hole with Loctite and the Loctite dried out for 1.5 hours, the run out was 0.0032". Since the improvement was very modest, we decided to clean the bearing and to apply Loctite on both, the inner surface of the bearing hole and the outer surface of the bearing. As an additional precaution, we let the Loctite to dry out overnight. However, the following day we still measured a run out of 0.003" – 0.004". The contribution to the run out was measured to be:

- In the flywheel axel: ~0.0001"
- In the bearing: ~0.0002"
- At the flywheel: ~0.0027"

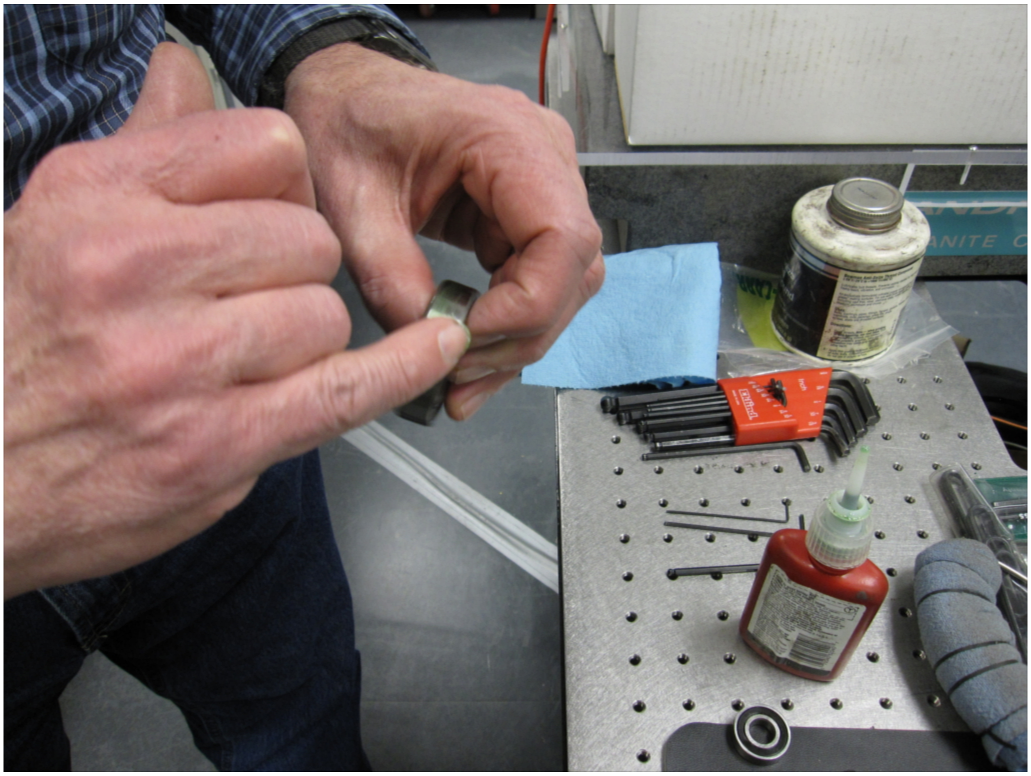

Figure 8: Applying Loctite 620 to the bearings holding the flywheel shaft in position.

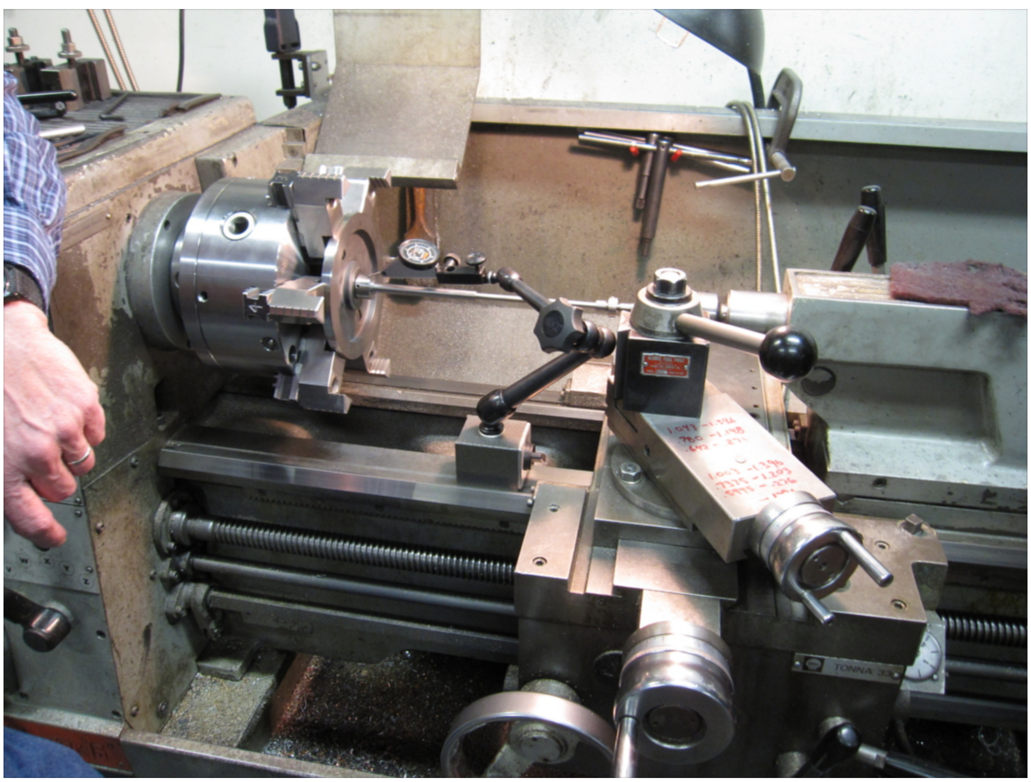

Figure 9: Measuring the run out on the different parts of the flywheel-shaft assembly.

Finally we decided that 0.0027" run out in slider 3 was acceptable. In fact, when the arc was reinstalled and turned the flywheel with the motor powered up, we measured a run out of 0.0011".

The final run out measured in slider 3 with the arc and bearings installed with Loctite was 0.0011".

Run out in the slider 4 arc

The run out measured on the arc was 0.0006". One of the corner screws was degrading the run out, so we modified the screw (*chicago it*).

Replacing the pulley system

One of the major improvements made during this service mission was the replacement of the old pulleys and drive belt in the grating tilt system. The new pulleys are thicker and have a double flange to prevent belts from slipping off. The new belts are wider and have no joint point (see Figure 10) that makes them more robust to breaks.

Initial tests of the new parts were done on cell #5, which is available for testing in the summit's instrument lab. New big pulleys had a hub with a tightening bolt (Figure 11). The hub was too thick for clearance to the belt cover. The hub was machined out and the tightening bolt was fitted to the pulley's grooved surface.

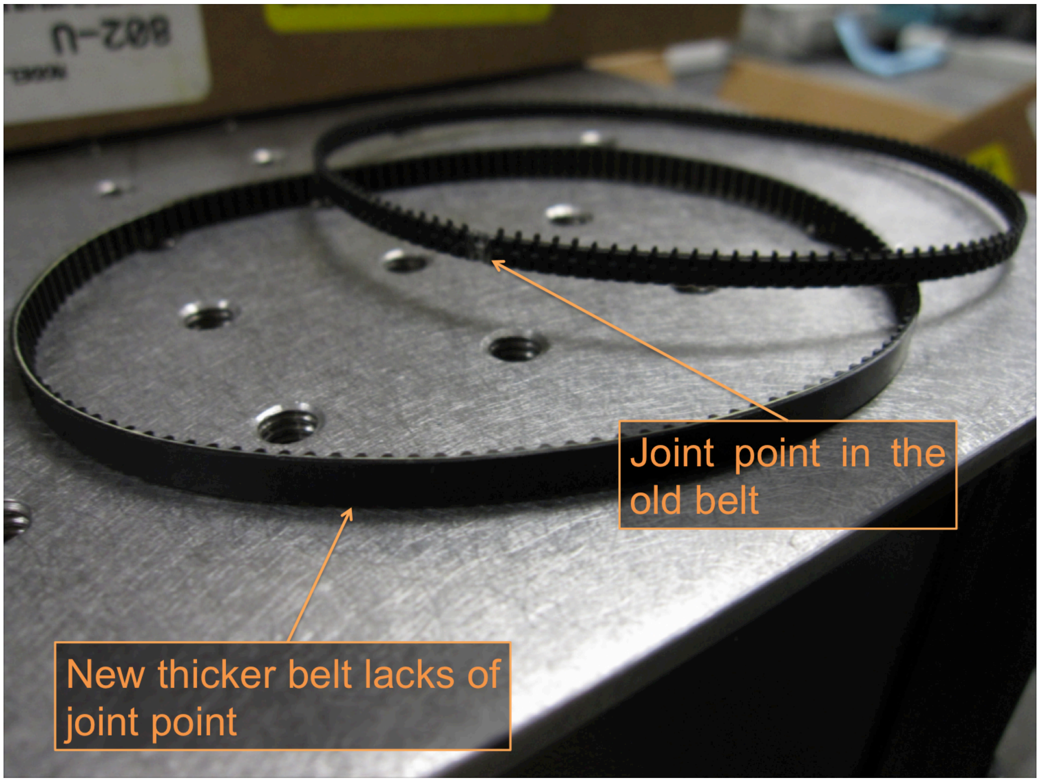

Figure 10: Comparison between the old and new drive belt. The new drive belt is thicker and does not have a joint point, which makes it stronger. Old belts tended to break at the joint point.

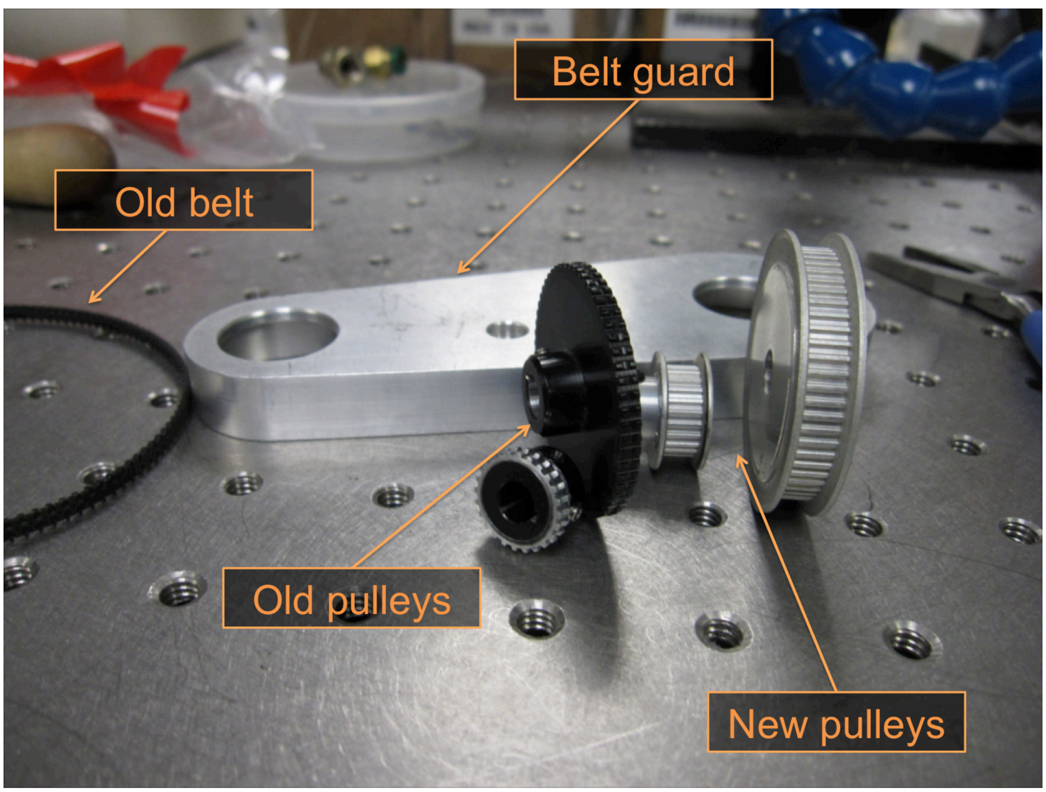

Figure 11: Comparison between the old and new pulleys for the grating tilt system. The new pulley are wider than the old ones and feature a double flange to prevent belts from falling off.

7. Adjusting the grating tilt limits

Once the grating cells were re-assembled and installed in DEIMOS, it was necessary to re-define the grating tilt forward and reverse limits. This is an iterative process where the limits had to be adjusted manually. In slider 3, the limit switch had to be adjusted to prevent the arc running into it when sent to Zeroth Order.

The following table shows the primary and secondary grating tilt limits, in terms of the keywords G3TLTNAM and G4TLTNAM, before and after the service mission.

	Grating 3 tilt		Grating 4 tilt	
	New value	**Old value**	**New value**	**Old value**
Reverse Primary	-78203	-79370	-91600	-91619
Reverse Secondary	-79847	-80537	-92529	-92579
Forward Primary	16212	16107	2600	2499
Forward Secondary	17079	17113	2900	2868

8. Adjusting the clamping

Once the grating cells were assembled they were re-installed in the instrument. During the motion tests after installing the cells, we noticed that the bottom part of grating cell #3 hit one of the kinematic points at the bottom of the slider guide. We concluded this was caused by tension springs (see Figure 12) in the grating cell being too loose. These springs are designed to hold the grating cell in position. However at a rotator angle of -90 degrees at which the grating cell is hanging off the slide guide, the springs would allow a gap between the ball screw enclosure and the rest of the cell. This gap was large enough for the bottom part of the cell to hit the kinematic point.

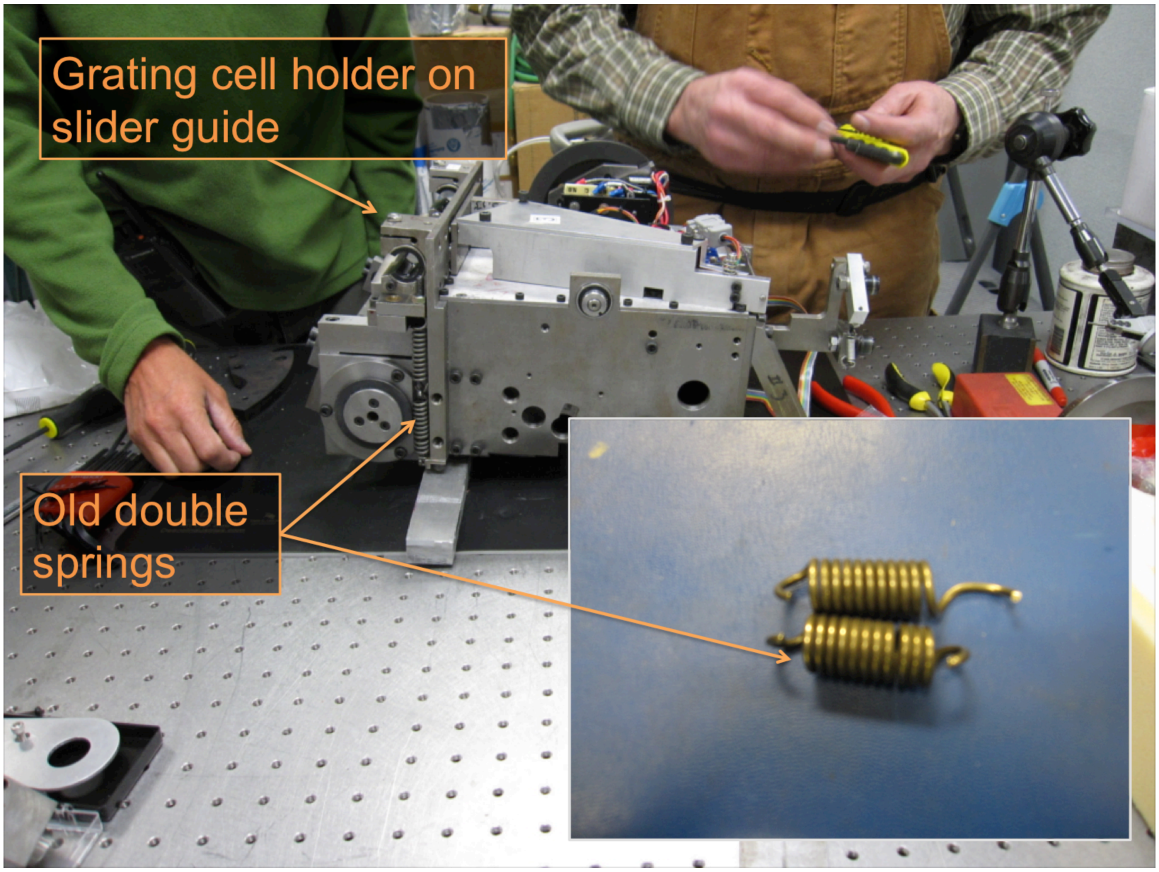

Figure 12: Tension springs are required to hold the grating cell in position when the grating is unclamped. During the service mission we replaced the old double springs (in the figure) with new single springs because the old ones had gone beyond their elastic limit (see inset).

The best rotator orientation to adjust the spring tension was -120 degrees. Spring tension was adjusted by turning the spring tension screw. The outer length of the tension screw was used as a proxy to the tension measurement. The following table shows the different tension adjustments (screw length) we performed.

	Slider 3		**Slider 4**		**Comment**
	Left	**Right**	**Left**	**Right**	
Adjustment 1	0.365"	0.345"	0.384"	0.382"	Slider 3 hit kinematic point
Adjustment 2	0.455"	0.454"	0.472"	0.467"	Very small clearance to kinematic point.
Adjustment 3	All the way	All the way	All the way	All the way	Clearance to the kinematic point ok, but slider 3 does not clamp up at -180 deg.

Tightening the springs such that the tension was maximized cleared the condition for the cell #3 to hit the kinematic point. However, even with the maximum tension in the springs, the gap between the ball screw holder and the rest of the cell did not seem to become smaller and, additionally, slider 3 would not clamp at a rotator angle of -180 deg (gravity vector perpendicular to spring tension).

In view of the previous problems, we decided to remove the cells from the instrument and pursue two objectives to improve cell's clamping performance:

- To reduce the friction associated to the moving parts in the clamping mechanism. This would require disassembling the moving parts in the clamping mechanism to sand and lubricate them.
- To increase the tension on the cell springs. This would require replacing the double springs, which had likely lost their elastic properties, by new single stronger springs.

The following tasks were performed (see Figure **13**) to achieve the previous two goals:

- Cleaned and sanded defining cones.
- Polished contact surfaces of moving parts.
- Lubricated cone surfaces and other surfaces that come in contact when the clamp is released. Two different types of lubricants were tested; Mobile 1 and vacuum grease. We finally used Mobile 1 because it seemed to give better results.
- Installed new and stronger springs. These new springs were slightly oversized but this was not a problem.

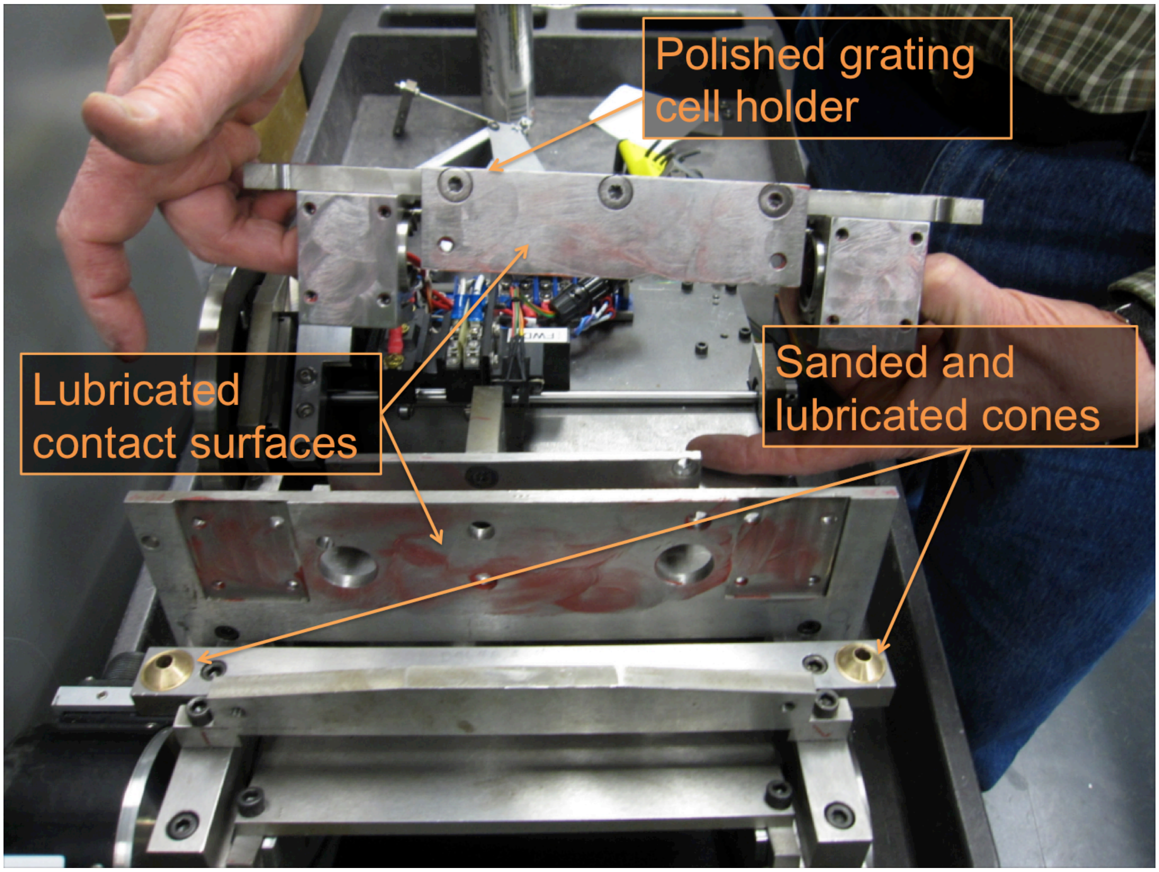

Figure 13: Contact surfaces and guide cones were lubricated to facilitate the cell repositioning after unclamping. Cones were sanded and flat metallic contact surfaces where polished before lubrication.

These modifications improved our clamping ability. Therefore we proceeded to perform extensive clamping and flexure testing at different rotator angles with the gratings loaded in the cells.

9. Clamping and flexure tests

Several modifications were required in the grating clamping mechanism to ensure gratings clamped up correctly. Modifications in the clamping mechanism were followed by clamping and flexure tests (see Figure 14). The objectives of these tests were:

1. To make sure that both gratings clamp up at any orientation of the rotator angle.
2. To ensure the flexure compensation system could correct for flexure at all rotation angles and for all clamp orientations.

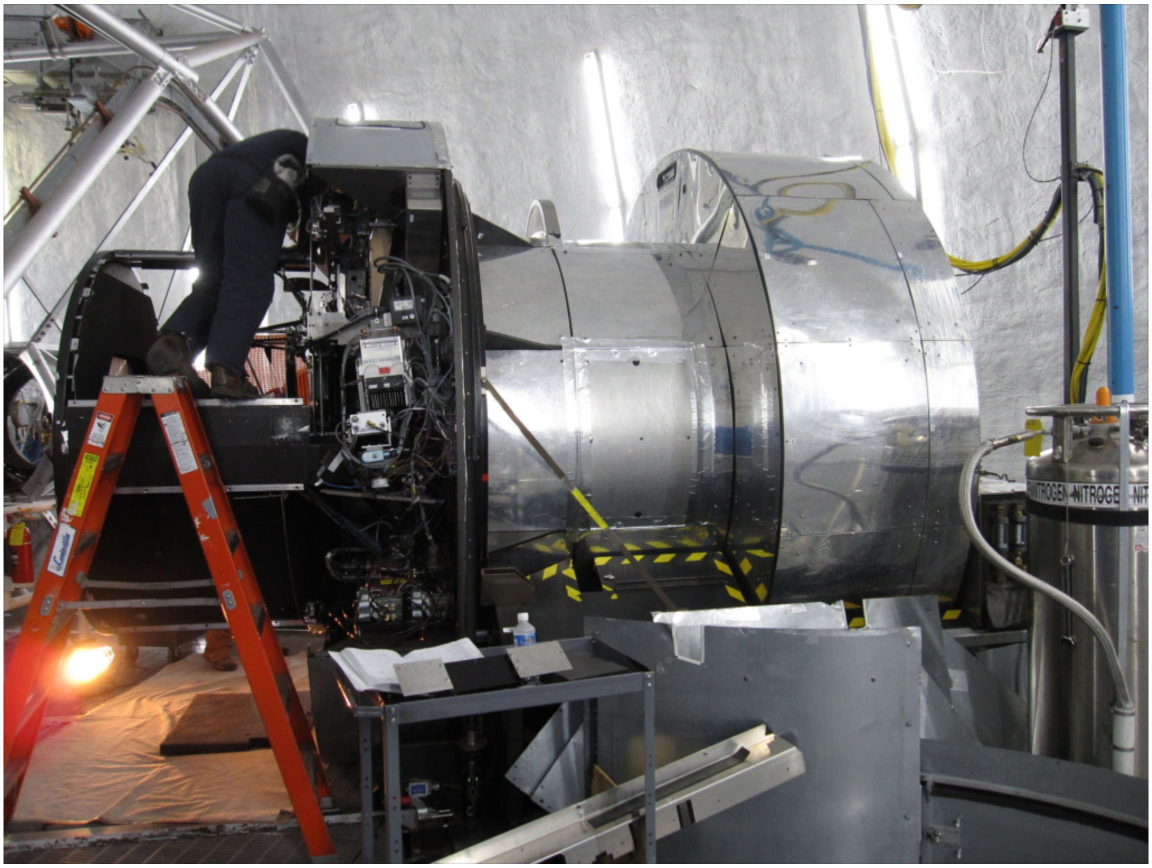

Figure 14: Steve adjusting and inspecting the clamps during initial clamping tests with the instrument still open.

Slider 3 clamping mechanism

We found that clamp #4 in slider 3 was not clamping properly. Different combinations of shims in the clamp were used to make sure the clamp's foot made tight contact with the clamping surface. Shims combinations went all the way from no shims at all to up to 0.0057" total thickness. New thicker shims where machined to facilitate the addition and removal of thickness to the clamping surface. We noticed that when clamp #4 went in position the first time there was no gap between the foot and the clamping surface. However, when clamp #5 was tightened and #4 went back in, there was a gap between clamp #4 foot and the clamping surface.

Clamping tests

The DEIMOS gratings must be able to clamp up at all DEIMOS rotator position angles, a task made difficult by the varying gravity and subsequent flexure of the grating select mechanism. To achieve the accurate positioning required for each grating slider's cone to insert properly into the "pin", the system employs a two-stage alignment process. First, the slider is moved into approximate position based on the absolute encoder, then it makes a slow move until a flag on the stage interrupts an optical switch. With the exact position now determined, the select stage makes a relative move of the number of encoder steps given by the keyword GRATOFFn. This should put the stage into position where it can clamp up.

This section shows a series of clamping tests as a function of the rotator angle to determine the optimal value of the GRATOFFn keyword. Figure 15 shows the first clamping tests with the instrument closed after the service mission. The previous figure shows that clamping was not possible at all angles for slider 3. Clamping was successful at all rotator angles for slider 4, although the pin did not insert first in many cases (e.g. rotator angles 45 to 135).

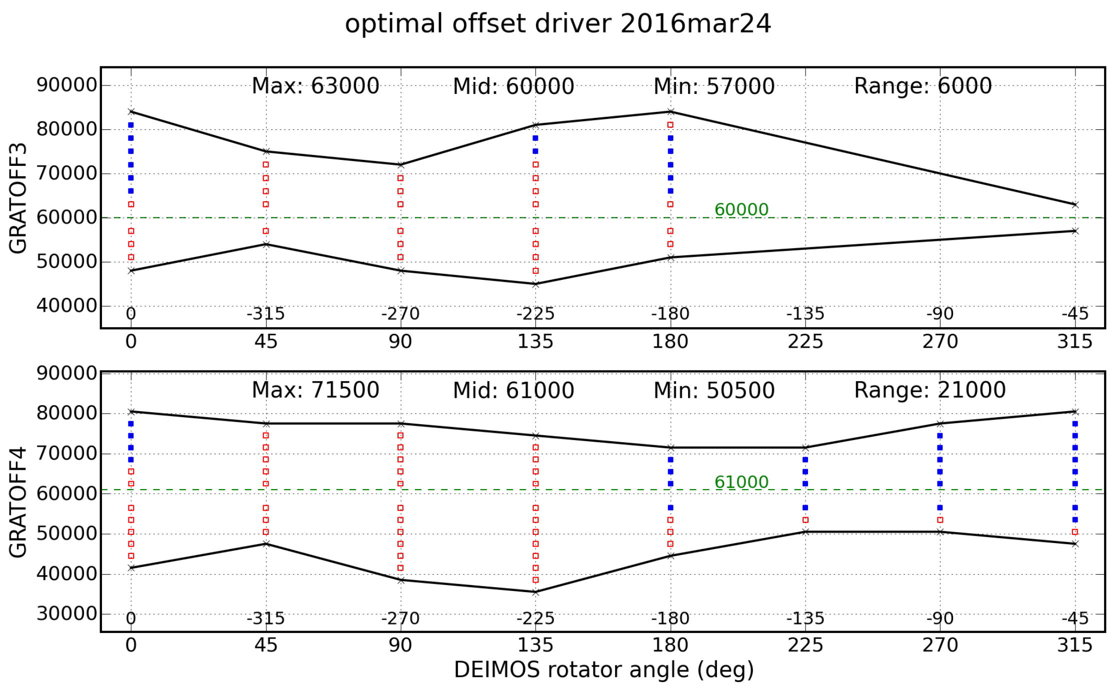

Figure 15: Clamping curves for sliders 3 (top panel) and 4 (bottom panel). Blue filled squares represent successful clamp ups where the pin went in first. Red open squares represent successful clamp ups where the pin did not go in first. Black crosses represent offset values at which clamping was not successful. Those angles for which there are no symbols (e.g. slider 3 at rotator angles 225, 270 and 315) correspond to unsuccessful clamp ups in the whole offset range. The green dashed line shows the optimal clamping value. The maximum offset value at which the grating could be clamped at any rotation angle is shown as the 'Max:' plot annotation. In the same way, the minimum offset value, mid (optimal) value and range are shown as annotations.

Manual adjustments were done to try to improve the clamping performance in slider 3 and a new battery of tests was run on April 1, 2016. The results are displayed in Figure 16.

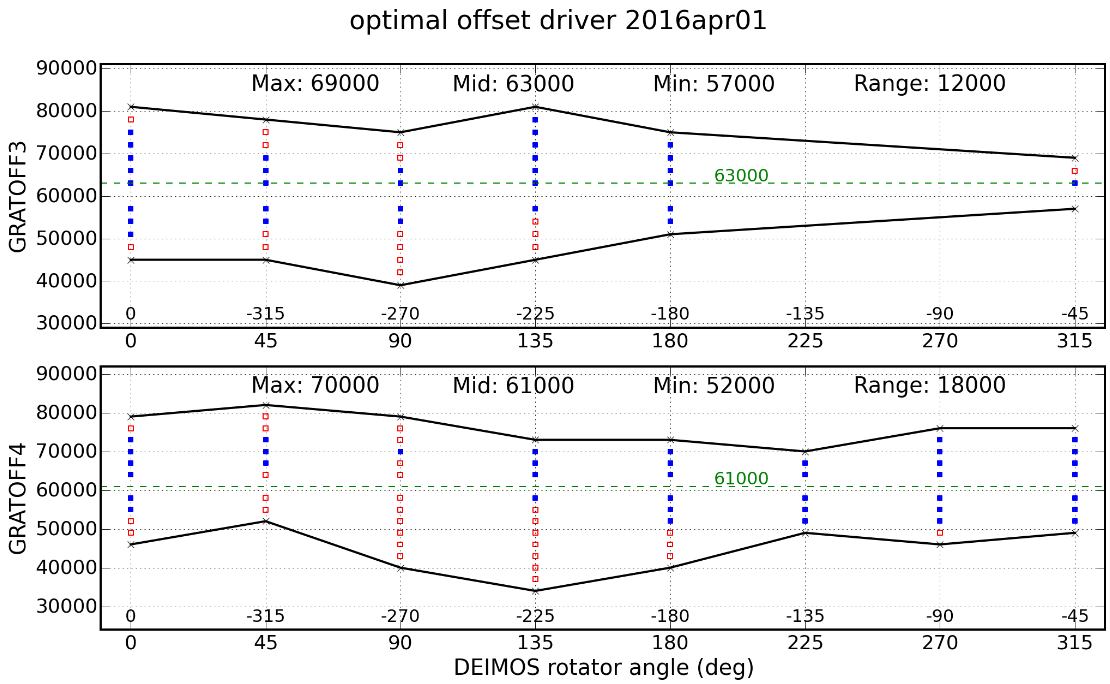

Figure 16: Clamping curves for sliders 3 (top panel) and 4 (bottom panel) obtained on April 1. See Figure 15 for an explanation of the symbols.

The clamping tests performed on April 1 (Figure 16) show a slightly general improvement with respect to March 16 (Figure 17). Clamping with the ping going in first occurs more often on April 1 than on March 16 for both sliders. However, the region of the rotator where slider 3 cannot clamp up is the same in both dates.

Figure 17 shows the clamping performance in slider 4 on April 23. There was a clear improvement in clamping performance, since the range of offsets at which slider 4 clamps successfully with the pin getting in first is larger than in previous dates.

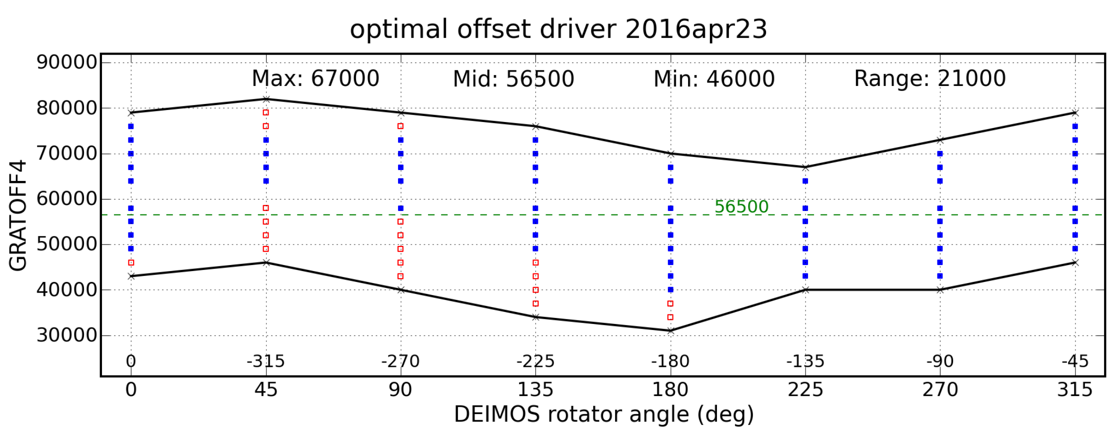

Figure 17: Clamping curve for slider 4 obtained on April 1. See Figure 15 for an explanation of the symbols.

Two more sets of adjustments and tests were performed during May. Figure 18 shows the latest clamping curves for sliders 3 and 4.

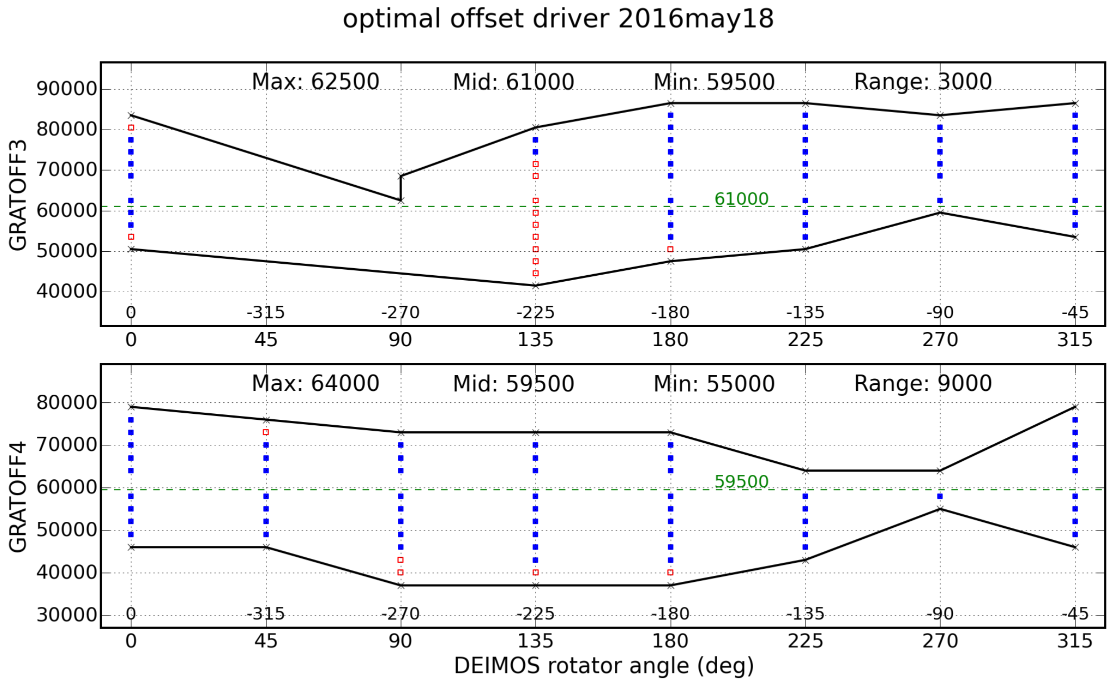

Figure 18: Clamping curves for sliders 3 (top panel) and 4 (bottom panel) obtained on May 18. See Figure 15 for an explanation of the symbols.

The latest situation regarding clamping performance after the service mission is that slider 4 can be clamped at any rotator angle, but there is a range of rotator angles (-315 to -270 deg) where clamping is unsuccessful for slider 3.

Flexure tests

Several flexure tests were made once the service mission was over. In this section, we show the test results in different dates.

As a reference, the following flexure curves for slider 3 (Figure 19) and 4 (Figure 20) show the state of the system before this service mission.

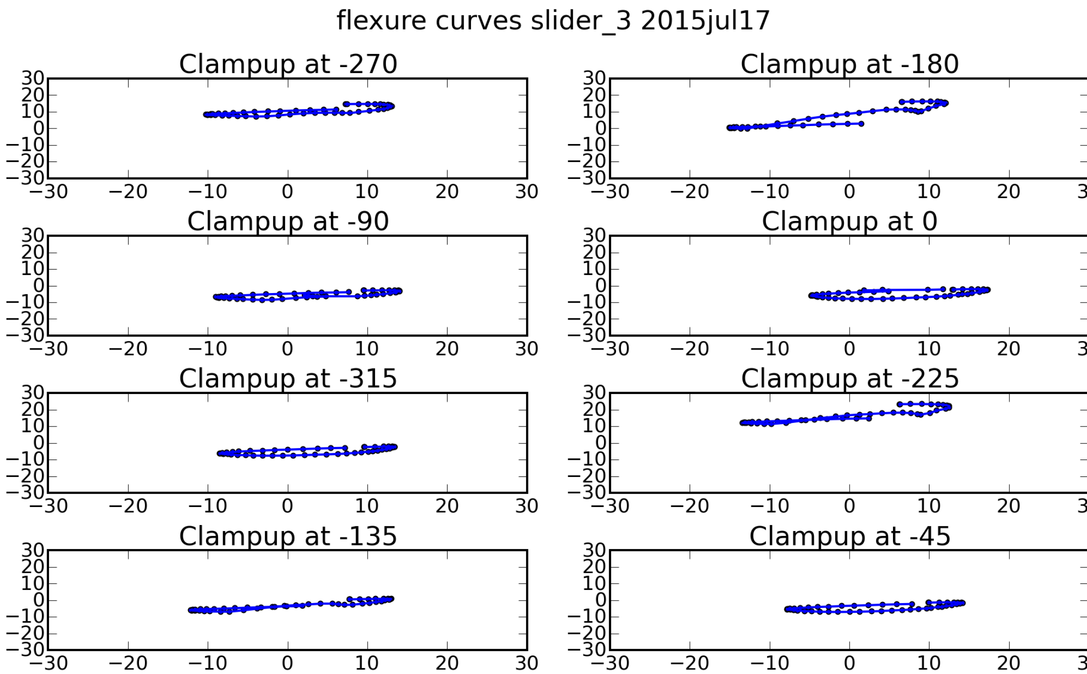

Figure 19: Flexure curves for slider 3 before the current service mission. The X and Y axes in each panel represent the FCS cross-correlation offset with respect to the initial position. In each curve, the rotator was jogging from -180 to 180 degrees once the grating was clamped up at the rotator angle indicated in each plot title. Each axis range covers the correction range of the FCS.

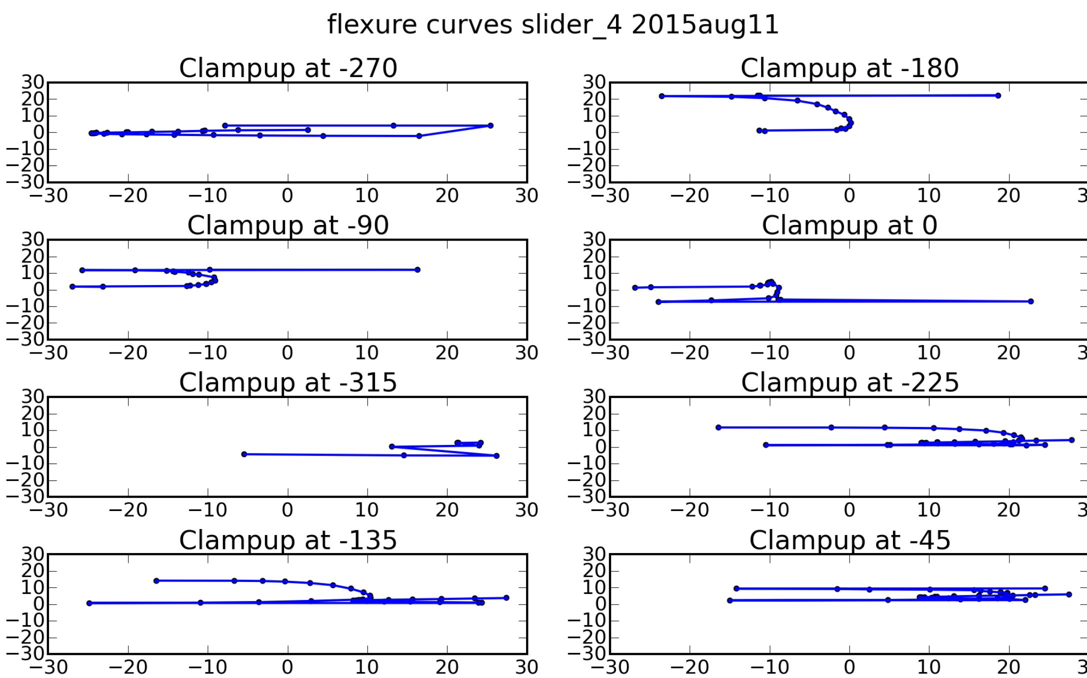

Figure 20: Flexure curves for slider 4 before the current service mission. See Figure 19 for a description of the plots.

Before the second service mission, slider 3's flexure range was within the FCS correction range, however, slider 4 was off range for several clamping angles. Based on the curves in Figure 19 and Figure 20, we decided to always clamp slider 3 at a rotator angle of -30 degrees and slider 4 at an angle -180 deg. This was the work around for all observing with DEIMOS prior to the second service mission.

The initial flexure curves we obtained as soon as the instrument was closed after the second service mission are shown in Figure 21 and **Error! Reference source not found.**Figure 22.

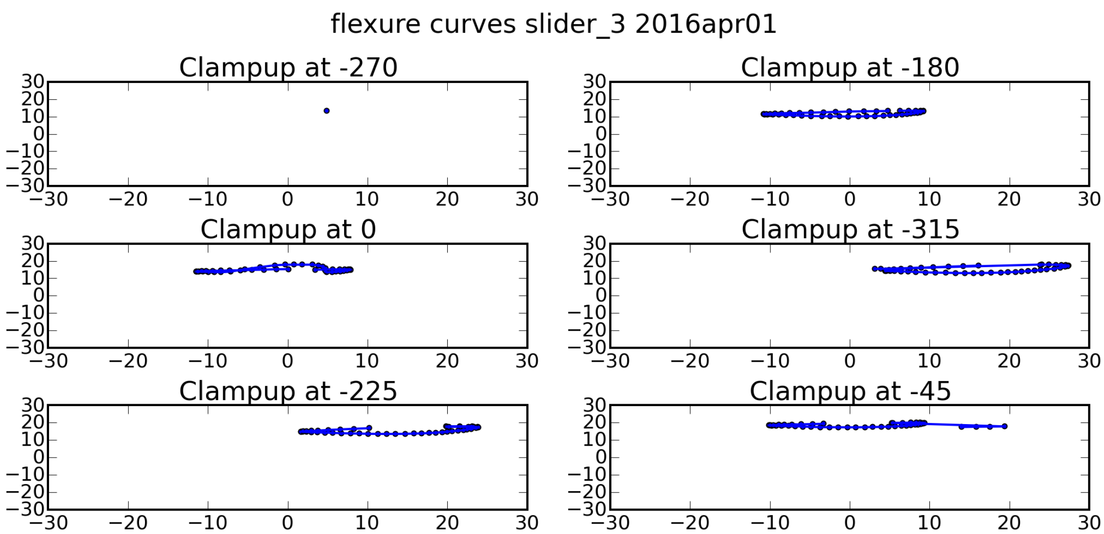

Figure 21: First flexure curves for slider 3 obtained after the current service mission. See Figure 19 for a description of the plots.

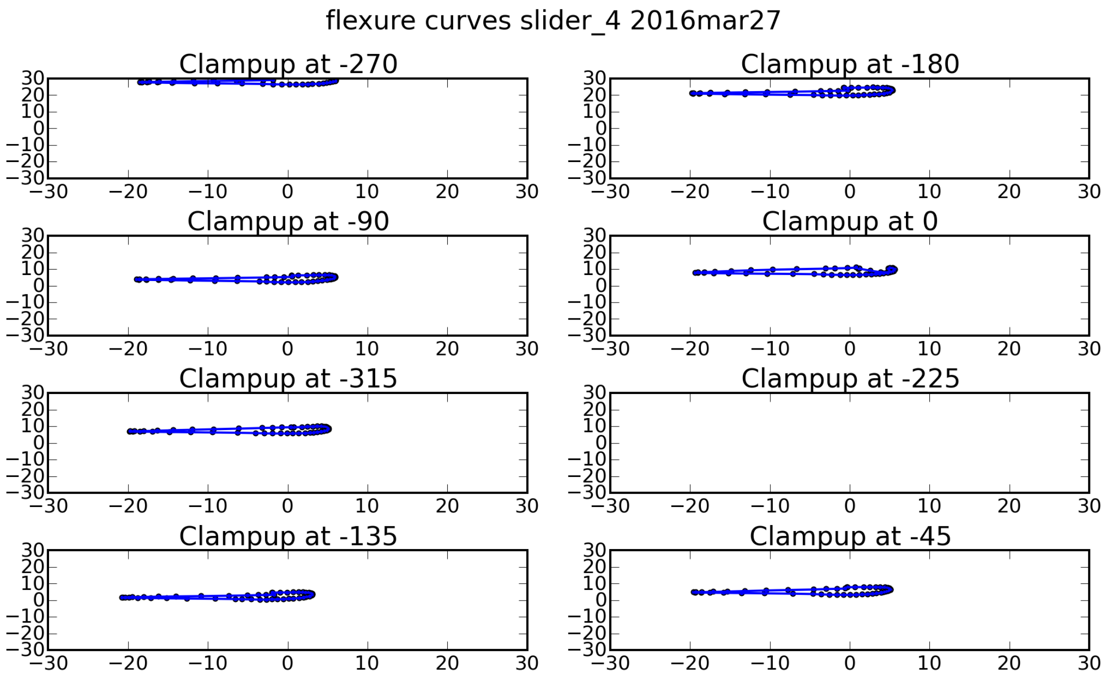

Figure 22: First flexure curves for slider 4 obtained after the current service mission. See Figure 19 for a description of the plots.

Slider 3 looked worse than before the service mission, because after the mission it was not possible to clamp it at some of the rotator angles (-90 and -135 deg). Besides, the curves looked irregular and broken. This means that the FCS may struggle to perform the appropriate flexure corrections. However, slider 4 improved considerable after the mission. Slider 4 would not only clamp at any rotator angle, but the flexure curves looked fairly uniform as compared to the situation previous to the service mission (compare Figure 20 and Figure 22).

Several attempts were made to fix the problem with slider 3 and to try to improve slightly the behavior of slider 4. One of these attempts was very fruitful for slider 3, which improved enormously (see Figure 23). However, the modifications led to a situation with slider 4 flexure increasing.

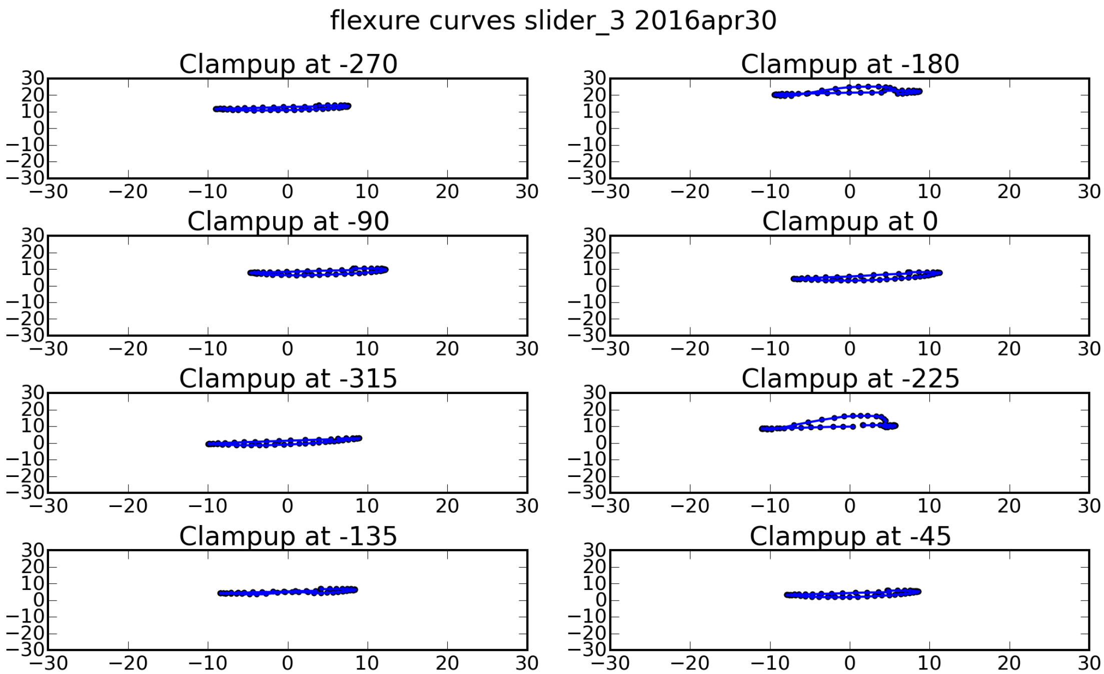

Figure 23: Latest flexure curves for slider 3 obtained after the current service mission. See Figure 19 for a description of the plots.

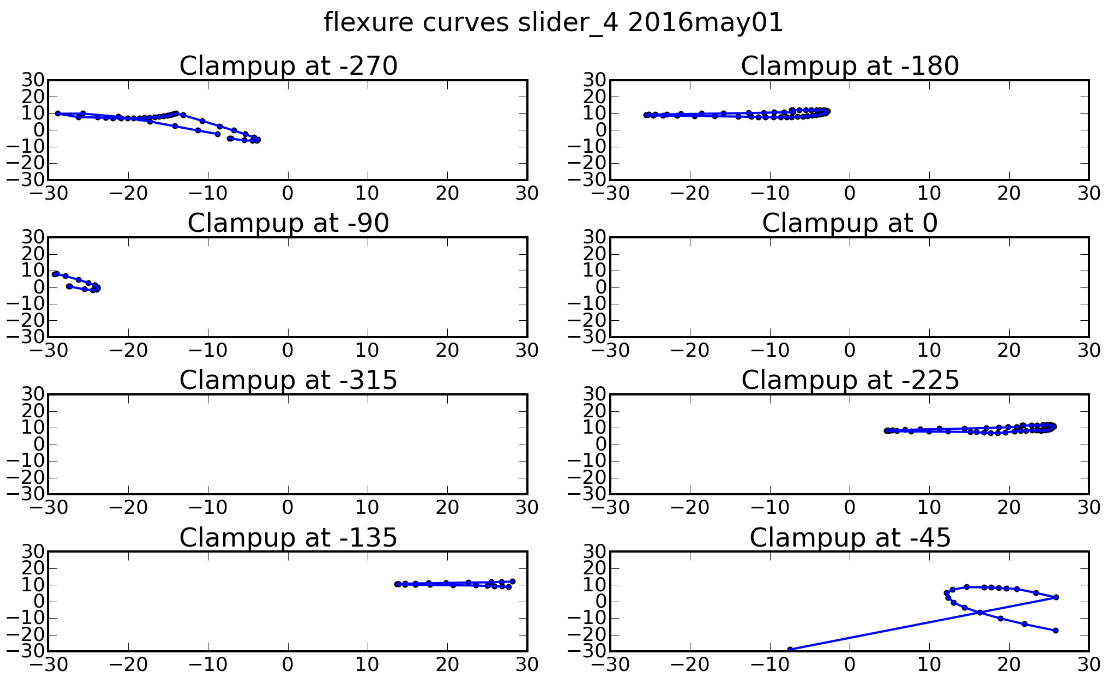

Figure 24: Latest flexure curves for slider 4 obtained after the current service mission. See Figure 19 for a description of the plots.

Additional fine-tuning in the clamps and in the clamping pin was performed during May. These latest modifications have resulted in flexure curves for both gratings that are considerably better than before the service mission (see Figures 25 and 26).

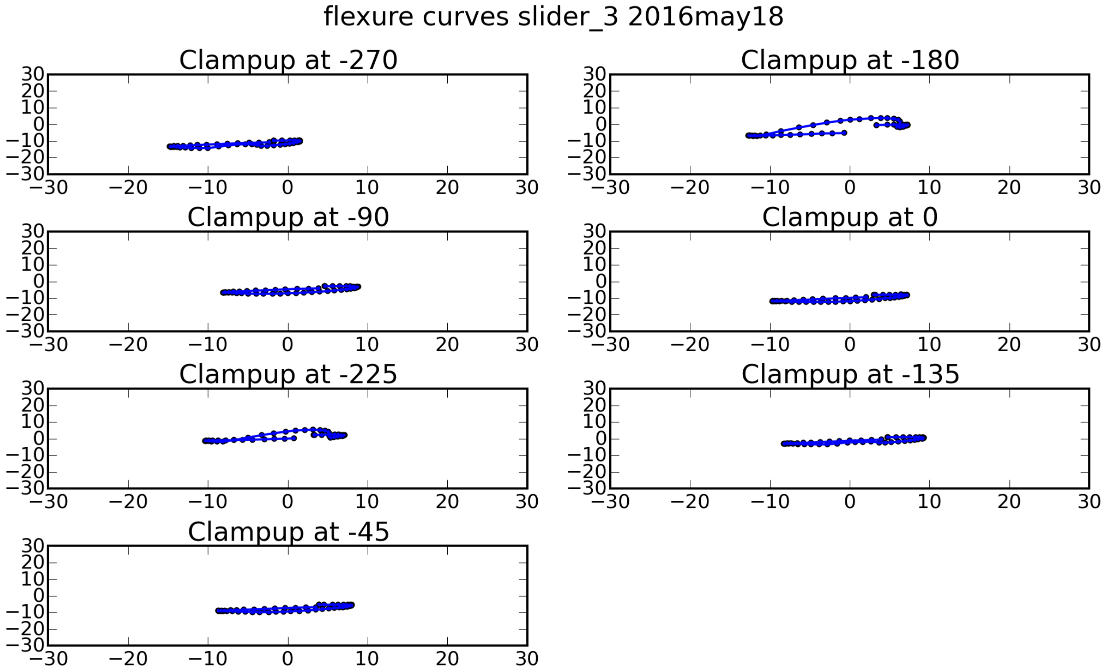

Figure 25: Latest flexure curves for slider 3 obtained after the current service mission. See Figure 19 for a description of the plots.

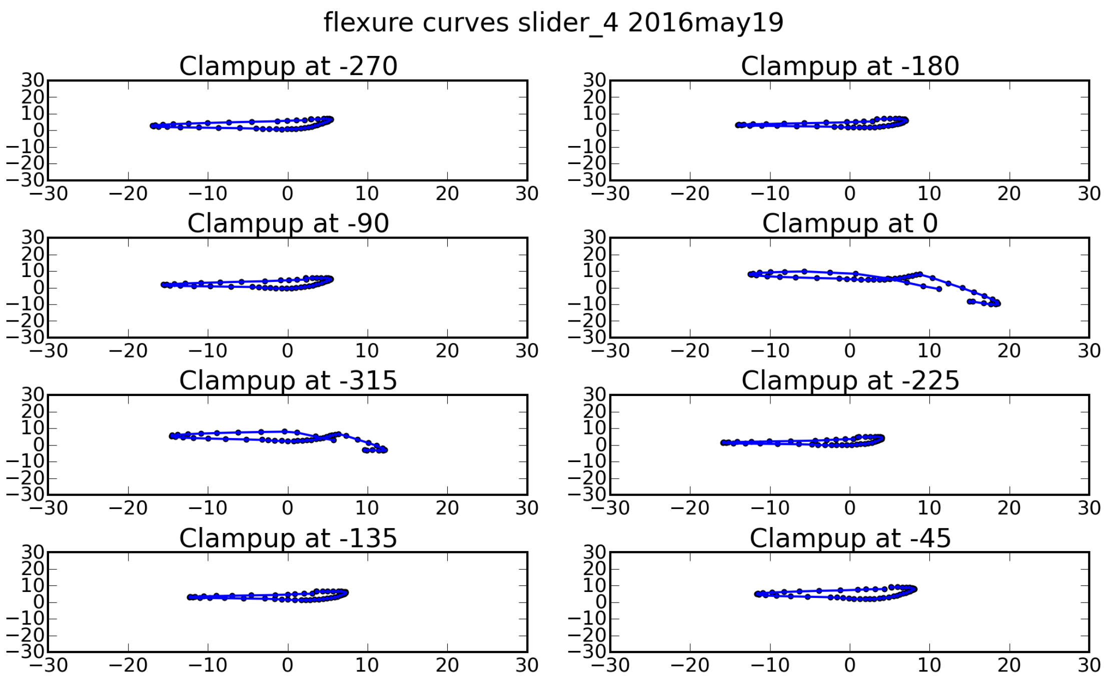

Figure 26: Latest flexure curves for slider 4 obtained after the current service mission. See Figure 19 for a description of the plots.

As it can be inferred from the two previous figures, the flexure curves for both sliders are uniform and within the FCS correction range at all clamping angles. This represents a considerable improvement with respect to the situation we had before the service mission.

In view of the latest clamping and flexure curves, slider 4 can be clamped at any rotator angle. Slider 3 can be clamped at any rotator angle except for -315 to -270 degrees, where clamping success has shown to be intermittent.

12. Spares available after the service mission

These are the spares available specific to this service mission:

- Flywheel and shaft arrangement.
- Shaft for the grating tilt drive pulley.
- A small and large pulley for the grating tilt mechanism.
- One 3/16" wide belt. Six additional 1/4" belts with Kevlar reinforcement were bought, but they do not fit in the pulley.

13. Conclusions

This service mission has made DEIMOS more robust and we believe this will have a positive impact in the amount of technical downtime caused by this instrument. The main goal of the mission was to improve the grating tilt mechanism performance, which was the cause of large amounts of time lost before the mission. Even though our post-mission statistics is still low, be believe we have achieved this goal. Also important to the mission was to improve the flexure properties of the instrument. The mission has proven to be successful in this area too. The flexure amplitude of slider 3 is within the FCS correction range for all rotator angles, although there is still some issue when clamping at a rotator angles between 45 and 90 degrees. Slider 4 can be clamped up at any rotator angle and its flexure amplitude is within the FCS correction range for all rotator angles.

Future work will be focused on:

- Improving the clamping performance on slider 3.
- Reprogramming the FCS software to increase its robustness.

We are currently working on the first item and work on the second item is planned as a Continuous Improvement project for FY17. A suggestion that we are not pursuing at this time is to machine the flywheel and shaft of one solid piece. This will ensure concentricity between the wheel and the shaft.