Royal Netherlands
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Ministry of Transport,
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Folding Mirror Mechanism Anomaly Report

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1 Anomaly Description

1.1 Summary

On Feb 28th 2006 at 00:23:18 GMT OMI stopped generating science data due to FMM anomaly. Till February 19th the FMM always bounced against the calibration end-stop when moving to the calibration position. Between February 19th and February 28th the FMM only bounced in 66% of the cases.
On February 28th, when moving the FMM into calibration position for a LED calibration measurement by means of executing the LED SIS, the opto-coupler status remained "dark" even after the four additional steps to correct for bouncing. As a result the LED SIS was automatically aborted with a non nominal exit code 54. Due to this non-nominal exit code TMON 35 tripped, which started the execution of the FM SCS IN3 ("Safe SCS") resulting in a transition to Idle mode which effectively stopped the generation of science data. As part of the FM procedure, the FMM is supposed to move to nadir position.
Analysis of the telemetry data showed that the FMM, as part of the FM procedure, had indeed moved to nadir position. This was confirmed when, after March 3rd, earth images became available again which showed that the optical path was not blocked by the FMM.

The investigation started immediately after the occurrence of the anomaly. Involved with the investigation were the Instrument Operations Team (IOT), industry (Dutch Space and TNO-TPD), NASA and the AURA Flight Operations Team (FOT). Decisions were formalized by means of Non-Conformance Review Boards. OMI resumed generating science data on March 3rd (only earth and dark measurements, no calibration and irradiance measurements for which the FMM has to be moved).
As part of the anomaly investigation 13 FMM tests were carried out in the period March 8th – May 17th. Although the FMM tests provided detailed information on the in-flight FMM behaviour, the FMM behaved nominally during all tests and no root cause could be found for the anomaly.
On June 12th OMI resumed full nominal operations generating earth science data as well as calibration and irradiance data.

1.2 Background

The FMM is a stepper motor. It is used during calibration measurements and is positioned in the optical path of the telescope between the primary and secondary mirror (see ***Figure 1***). The radiation of the sun (solar calibration) or WLS is reflected by the FMM towards the secondary mirror and from that point on follows the same optical path as the radiation from earth. Degradation of the detector can be monitored by combining the results from the Solar-, WLS- and LED- calibration measurements. The FMM, therefore, forms a crucial part of OMI.

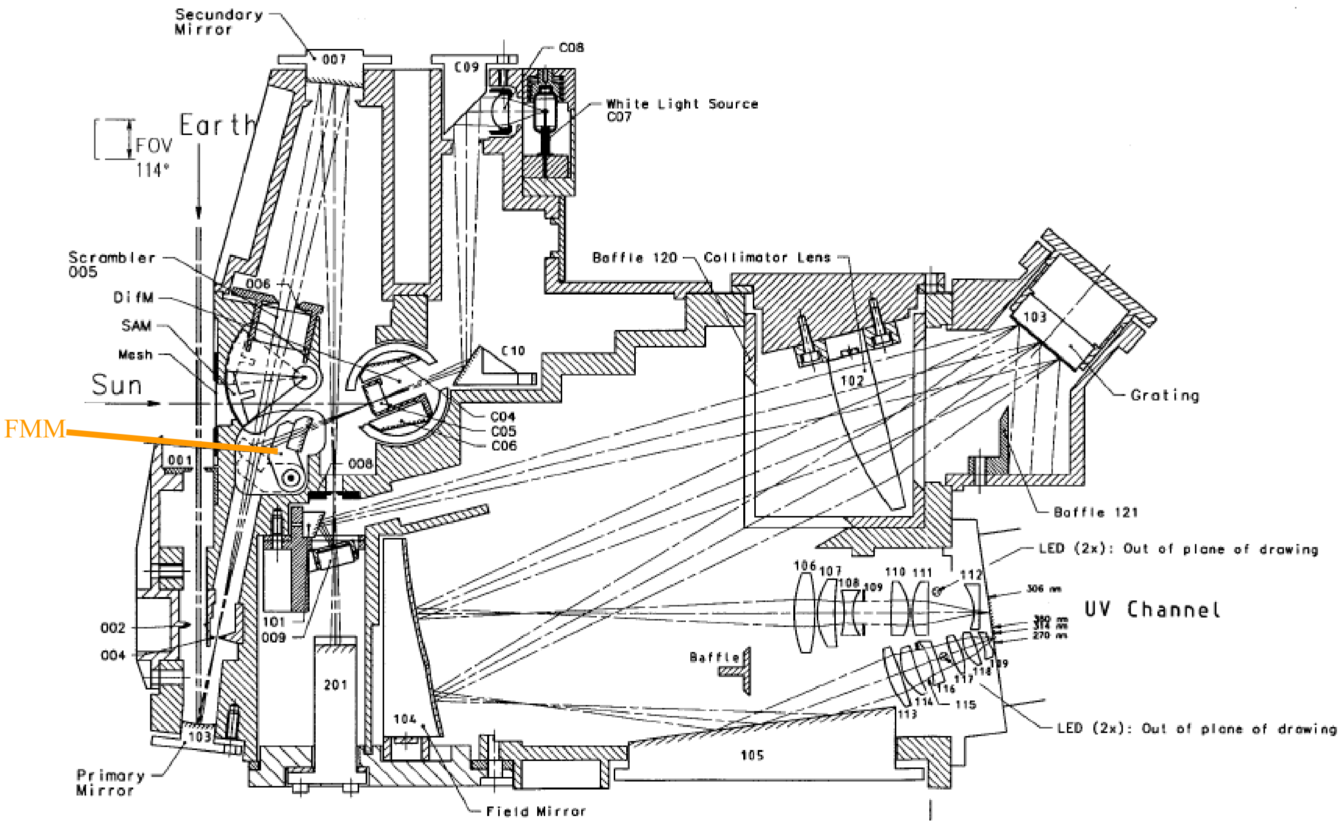

Figure 1 Design drawing of the OMI optical bench

For nadir (earth) measurements there is no need to move the FMM because the default position is the nadir position.

Figure 2 shows the relation between mechanism position, motor phase and opto-coupler status. For calibration measurements the initial FMM position is assumed to be unknown. After resetting the motor phase to STATE1 the FMM is moved from this unknown position to calibration position zero (STATE4) by commanding 85 steps (multiple of 4 plus 1) counter clock wise. In case the FMM bounces against the end-stop (with an assumed number of 4 steps), indicated by a dark status of the opto-coupler, the FMM is moved four additional steps counter clock wise from position four to position zero. Since the end-stop is located between positions zero and one, the FMM is assumed to push against the end-stop during calibration measurements. When the calibration measurement is finished, the FMM is moved to nadir position 79 by commanding 79 steps clock wise.

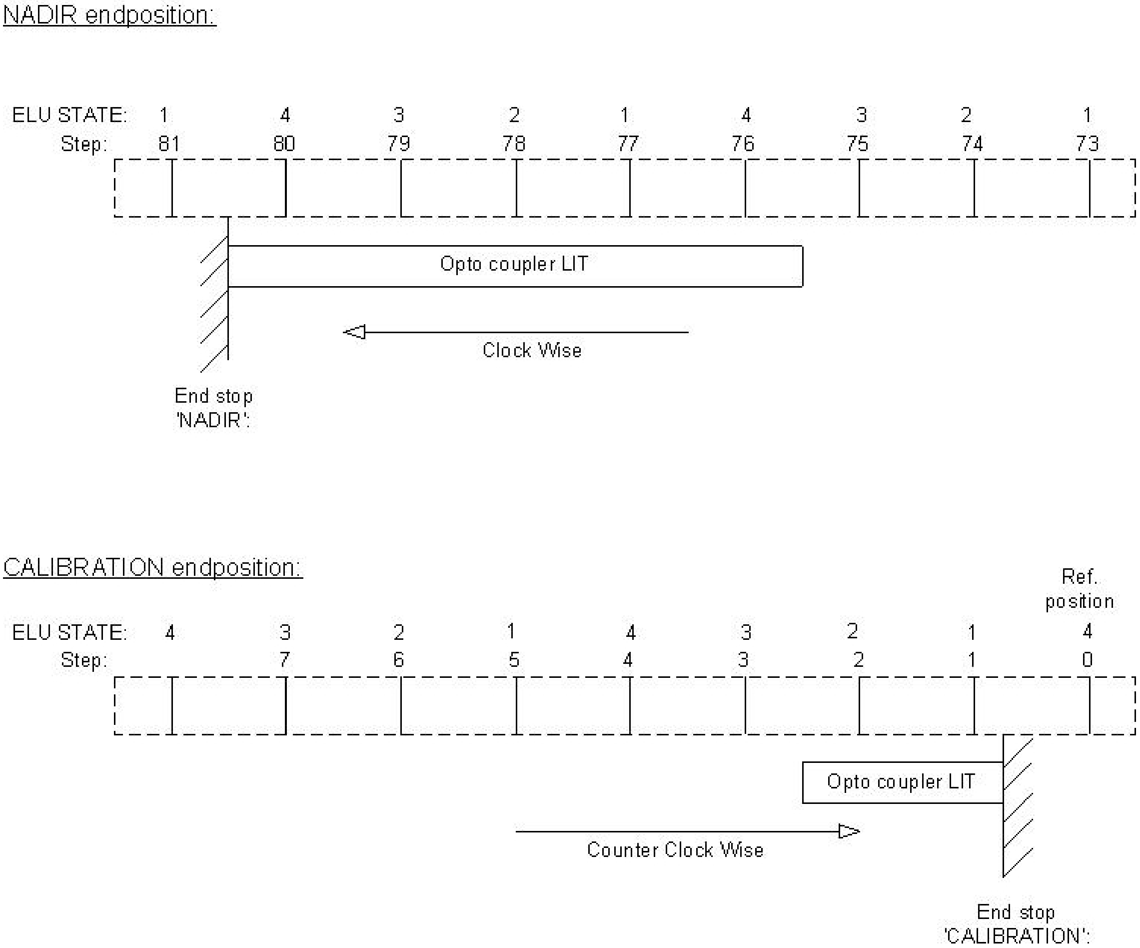

Figure 2 The motor phase and opto-coupler status as a function of mechanism position

1.3 Investigation

After the FMM anomaly had occurred it was not clear if the FMM could still be moved, although telemetry indicated that the FMM moved to nominal position as part of the FM procedure. Tests 1-3 (see Appendix A) were designed to find out if the FMM could still be moved around its nadir position. The tests showed that the FMM was still able to move. The next step in the investigation would be to bring the FMM to calibration position. There was, however, a possibility for the FMM to get stuck between the nadir- and the calibration- end-stop. In that case an attempt would have to be made to get the FMM moving again using both the nominal and the redundant coils at the same time, thereby applying double torque. Since the FMM had never been commanded using double torque, this way of driving the FMM needed to be tested first. In test 4 the FMM was moved around its nadir position using redundant coils. In test 5 the FMM was moved using both the nominal and the redundant coils. After these tests were completed successfully the first careful test towards calibration position could be attempted. The 6th test served to find out if the FMM could be moved from position 79 to position 2 without loosing steps in between due to mechanical or electrical wear. Tests 7 and 8 were a repeat of test 6.
Test 9 served to find out if there was mechanical or electrical wear or an opto-coupler problem at position 1. Test 10 was a repeat of test 9.
Test 11 served to find out if there was electrical or mechanical wear or an opto-coupler problem at position 0. Furthermore it could be checked if bouncing would take place when the FMM was moved to position 0 in a careful step-by-step approach. Test 12 was a repeat of test 11, but with the WLS switched on. The WLS was

used in this test to see whether the FMM actually moved from position 1 (in front of the end-stop) to position 0 (behind the end-stop).
To find out what the precise position of the calibration end-stop was and when the FMM jumps back against the end-stop the last test 13 was devised in which the FMM was moved to virtual position -4, i.e. 5 positions behind the end-stop.
For an overview of all the tests, dates, purposes and results see Appendix A.

1.4 Investigation results

All tests were successful. During all tests the FMM showed nominal behaviour. There is no loss of steps observed when moving the FMM from nadir position to calibration position and vice versa. There is no indication for an opto-coupler problem. No bouncing against the calibration end-stop takes place when commanding the FMM step-by-step instead of 85 steps at once. When using the WLS, the WLS signal is highest at FMM position 1 whereas position 0 (the calibration position) was expected (see ***Figure 3*** and for more details see reference 12).

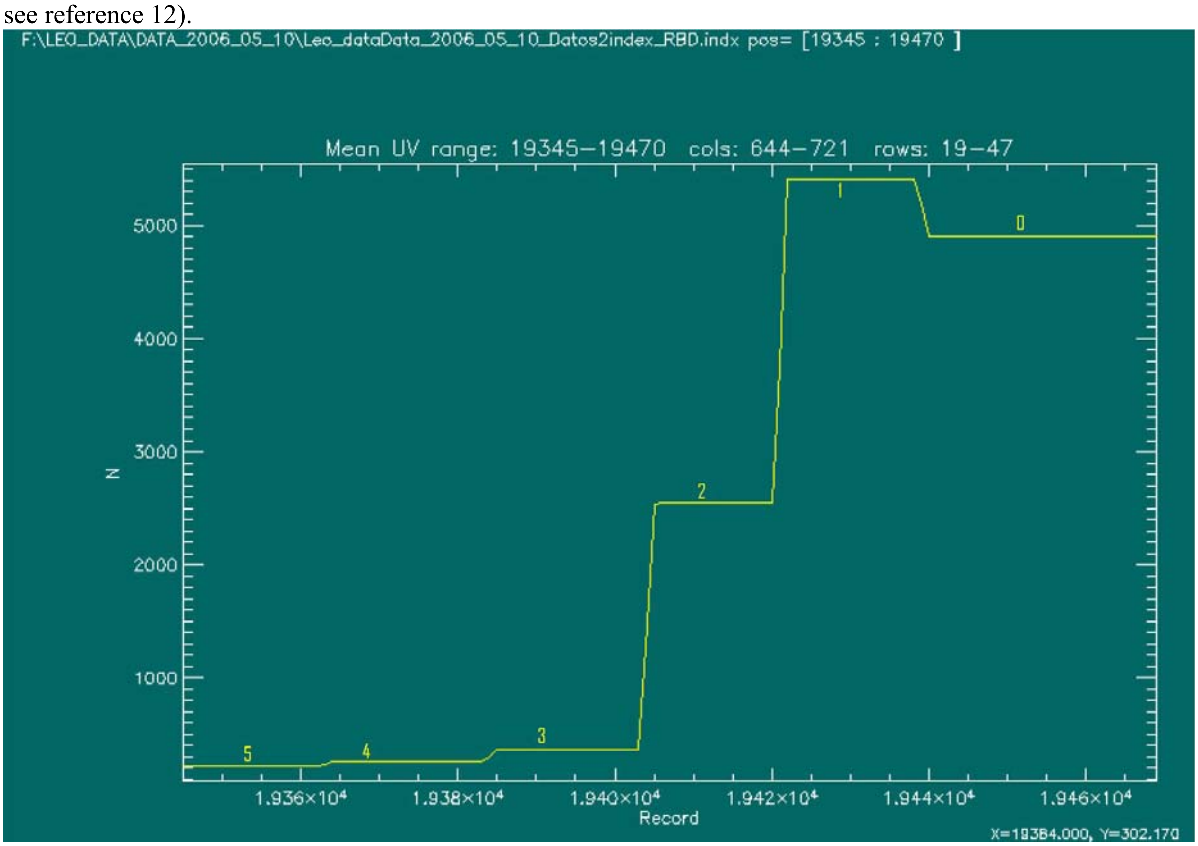

Figure 3 UV1 average WLS signal from 17:45:34 (#19345) – 17:49:44 (#19470). The FMM position goes from 5 →4 → 3 → 2 → 1 → 0. The signal in position 0 is obviously lower than at position 1. The signal change from position 1 → 0 is about 20% from the signal change from position 2 → 1. The signal change from position 1 →0 is about 25% the signal change from position 3 →2.

It turns out that the FMM position during a calibration measurement is just in front of the calibration end-stop and not at the calibration end-stop (see ***Figure 4*** and for more details reference 9).
Another conclusion from the FMM tests is that, when starting to use the FMM, position 79 can be assumed to be the initial (known) position.

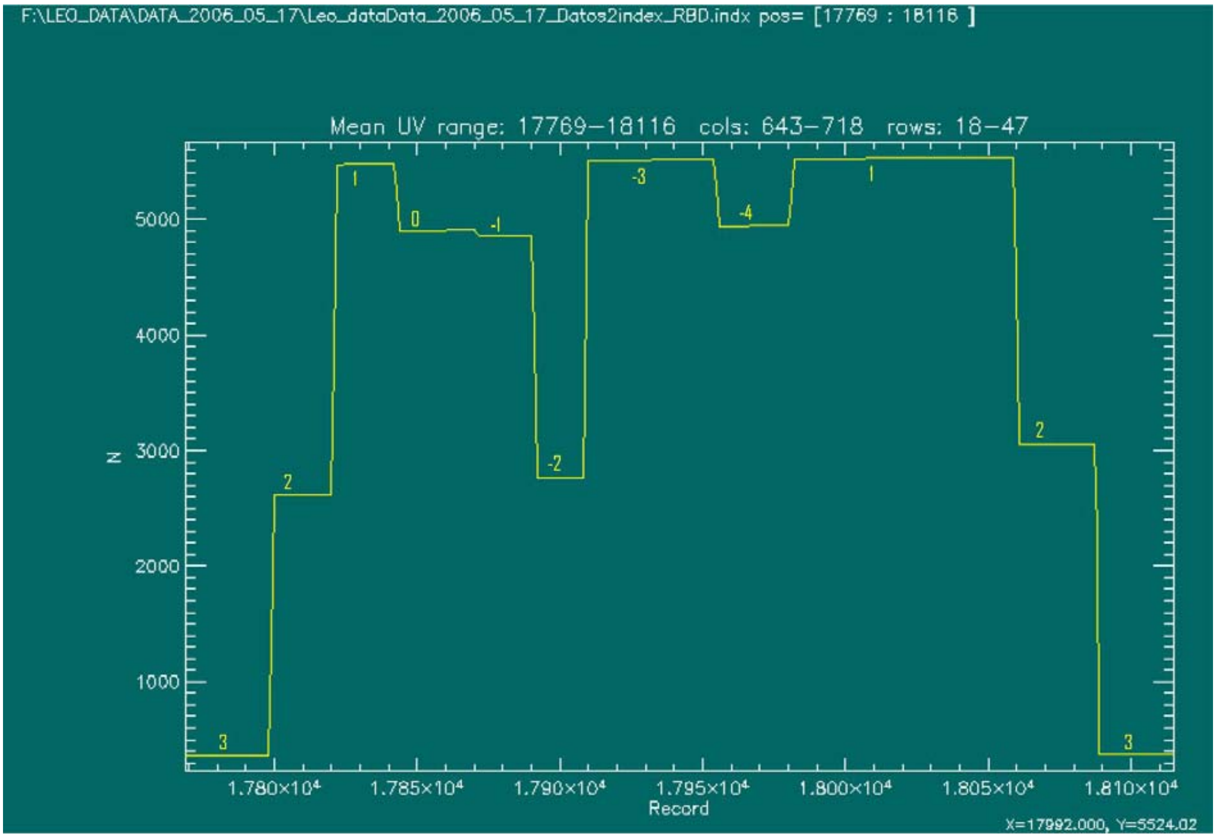

Figure 4 UV1 average WLS signal from 16:16:42 (#17769) – 16:28:18 (#18117). The FMM position goes from 3 → 2 → 1 → 0 → -1 (actually 0) → -2 (actually 2) → -3 (actually 1) → -4 (actually 0) → 1 → 2 → 3. A small signal change can also be observed when going from position 0 → -1, which is unexpected, because the FMM was assumed to be pushing against the calibration end-stop at position 0. The signal change between positions 0 and -1 is about 1.5%. Which leads to the conclusion that during calibration measurements the FMM is positioned just before the calibration end-stop. This figure also confirms that the FMM jumps back when FMM position commanded from position -1 to position -2. Obviously at commanded position -2 (ELU state 2) the preferred energetic mechanical state is at FMM position 2, which also has ELU state 2.

2 Causes and Contributing Factors

2.1 Preliminary root cause discussion Non-Conformance Review Board

Proposed possibilities that could have caused the FMM anomaly:

1. loss of steps when moving the FMM to the calibration end-stop
2. opto-coupler problem
3. 8-step bounce instead of 4-step bounce

2.2 Root cause conclusion by Non-Conformance Review Board

Despite all the successful tests, the root cause for the FMM anomaly has not been found.

One possible cause (although it cannot be proven) is that, instead with the usual four steps, the FMM bounced eight steps when moving to the calibration position. This has occurred only once during an on-ground test.

3 Impact

From February 28 00:23:13 until March 3 00:00:00 2006 OMI was in idle mode and no science data was taken.
OMI resumed taking science data on March 3, but no calibrations and irradiance measurements for which the FMM has to be moved were performed. On June 12th OMI resumed full nominal operations generating earth science data as well as calibration and irradiance data. The lack of calibrations and irradiance measurements had no significant impact on the science data.

4 Proposed anomaly solutions

A relation is assumed between the changing bouncing behaviour as observed between February 19th and February 28th and the FMM anomaly on February 28th.
By operating the FMM in a different way, bouncing against the calibration end-stop can be avoided.
In the new way of moving the FMM the initial position is assumed to be always 79. First 78 steps counter clock wise are commanded to move the FMM to position one. This is followed by one step counter clock wise to position zero. If the FMM happens to bounce anyway, four additional steps counter clock wise are given. Although the measurement will not be aborted in case of bouncing, this occurrence will be regarded as another anomaly.
All calibration measurements are performed by means of SISs. All SISs that use the FMM will be modified to avoid bouncing.
Replacing the old SISs by the new SISs will have no impact on the measurement schedule.

5 Resolution

In 2 years time all SIS' have been updated to avoid bouncing of the FMM against the end-stop. Since all SIS's have been updated no more FMM bouncing has occurred.

6 References

1. TN-OMIE-KNMI-831, "Analysis results FMM test of 17 May 2006 with White Light Source (WLS)".
2. TN-OMIE-KNMI-795, "FMM Anomaly".
3. MN-OMIE-KNMI-801, "Minutes NRB meeting #1 FMM anomaly (2 March 2006)".
4. MN-OMIE-KNMI-804, "Minutes NRB meeting #2 on FMM anomaly (xx March 2006)".
5. MN-OMIE-KNMI-805, "Minutes NRB meeting #3 on FMM anomaly (17 March 2006)".
6. MN-OMIE-KNMI-811, "Minutes NRB meeting #4 on FMM anomaly (xx March 2006)".
7. MN-OMIE-KNMI-821, "Minutes NRB meeting #5 on FMM anomaly (10 April 2006)".
8. MN-OMIE-KNMI-822, "Minutes NRB meeting #6 on FMM anomaly (21 April 2006)".
9. TN-OMIE-KNMI-828, "Analysis results FMM test of 10 May 2006 with White Light Source (WLS)".
10. MN-OMIE-KNMI-829, "Minutes NRB meeting #7 on FMM anomaly (27 April 2006)".
11. MN-OMIE-KNMI-830, "Minutes NRB meeting #8 on FMM anomaly (15 May 2006)".
12. TN-OMIE-KNMI-831, "Analysis results FMM test of 17 May 2006 with White Light Source (WLS)".
13. MN-OMIE-KNMI-836, "Minutes NRB meeting #9 on FMM anomaly (18 May 2006)".
14. Long_Term_Trending_13mar06
15. Notes from W. van Werkhoven.
16. SE-OMIE-0726-FS/06, "FMM anomaly in-orbit diagnostic".

Appendix A: FMM test overview

Test	Date	TDRSS Time	Orbit(s)	Purpose	Positions	Result(s)
1	08/03/2006	17:22:29 – 17:47:00	**8758**	Find out if FMM can still be moved.	79, 78, 77, 76	• Unexpected lit at position 76. Test aborted. • At end of test FMM at position 76
2	16/03/2006	17:34:00 – 17:54:00	**8875**	Find out if a) drawing SER 0610 is wrong or b) initial position previous test was 80 instead of 79.	76, 75, 76, 77, 78, 79	• Dark at position 75. • At end of test FMM at position 79.
3	20/03/2006	17:09:42 – 17:29:42 18:50:06 – 19:05:00	**8933** **8934**	Find out if results from previous test are reproducible. The test is repeated 5x.	79, 78, 77, 76, 75, 76, 77, 78, 79	• Always dark at position 75. • Test reproducible.
4	23/03/2006	16:02:00 – 16:22:00	**8976**	Find out if the redundant coils can be used and if a test with redundant coils produces the same results as the previous tests with nominal coils. This test is repeated 3x.	79, 78, 77, 76, 75, 76, 77, 78, 79	• Always dark at position 75. • Test reproducible.
5	06/04/2006	19:33:56 – 19:55:01	**9182**	Find out if the redundant coils in combination with the nominal coils can be used and if a test with both coils produces the same results as the previous tests 3 and 4. This test is repeated 3x.	79, 78, 77, 76, 75, 76, 77, 78, 79	• Always dark at position 75. • Test reproducible.
6	12/04/2006	17:16:22 – 17:36:05	**9268**	Can the FMM be moved to the calibration position (without hitting the end-stop) and back to nominal position (without hitting the end-stop) without loosing more than 8 steps due to mechanical or electrical wear.?	79, 5, 4, 3, 2, 75, 76, 77, 78, 79	• No mechanical wear at position 2. • No loss of steps from N→C. • No loss of steps from C→N • Test reproducible. • Drawing of calibration end-stop (SER 0610) (motot phase and opto-coupler position) correct.
7	13/04/2006	18:01:22 – 18:18:34	**9283**	Repeat of test 6		
8	18/04/2006	16:39:30 – 16:59:30	**9355**	Repeat of test 6		
9	24/04/2006	14:27:44 – 14:32:22	**9441**	Is there wear or opto-coupler problem at position 1?	79, 3, 2, 1, 75, 76, 77, 78, 79	• No mechanical wear at position 1. • No opto-coupler problem at this position. • No loss of steps from N→C • No loss of steps from C→N • Test reproducible

Test	Date	TDRSS Time	Orbit(s)	Purpose	Positions	Result(s)
10	24/04/2006	16:02:54 – 16:25:00	**9442**	Repeat of test 9		
11	27/04/2006	15:02:12 – 15:22:12	**9485**	Is there wear at position 0 and does bouncing or an opto-coupler problem occur?	79, 5, 4, 3, 2, 1, 0, 75, 76, 77, 78, 79	• No mechanical wear at position 0. • No opto-coupler problem at this position. • No loss of steps from N→C • No loss of steps from C→N • No bouncing took place during this test.
12	10/05/2006	17:42:48 – 18:00:08	**9676**	Repeat of test 11 with WLS to distinguish between bouncing of the FMM and a possible opto-coupler problem.		• Differences in WLS images for different positions of the FMM can be detected. • Signal is highest at position 1. • Signal changes as function of FMM position are wavelength dependent. • No loss of steps from N→C • No loss of steps from C→N • No bouncing took place during this test. • Physical position calibration end-stop below position 1.
13	17/05/2006	16:13:53 – 16:33:53	**9777**	Where is the calibration end-stop situated and when does the FMM jump back?	79,3,2,1,0,-1(0),-2(2),-3(1),-4(0),1,2,3,75,76,77,78,79	• The WLS signal at position -1 is slightly (but significantly) lower than at position 0 (suggesting the calibration end-stop is between position 0 and -1 • The FMM jumps back from position –1 to position 2 (suggesting the calibration end-stop is between position 1 and 0) • The two previous conclusions seem to be in disagreement with one another. There is no explanation at the moment. • The signal is highest at position 1. • Looking at the uniformity as function of row (viewing direction) a significant difference can be observed for positions 0 and -1. From the illumination uniformity over the rows as well as from the signal levels it can be concluded that the FMM has moved slightly from position 0 to position -1. • The optimal FMM position for WLS measurements seems to be position 1.

Table 1 The FMM test overview lists when a test takes place (date, time, orbit), the test purpose, the FMM steps taken and the test results. For the orbits indicated in bold the L1 and L2 products are affected.

7 Abbreviations

- FM Fault Management
- TMON Telemetry Monitor
- FMM Folding Mirror Mechanism
- WLS White Light Source
- LED Light Emitting Diode
- SIS Stored Instruction Sequence