THRUSTER POINTING MECHANISM QUALIFICATION TEST RESULTS

Theodor Nitschko, Gerhard Traxler, Gerhard Mitterbauer, Josef Zemann, Manfred Falkner*, Jean-Michel Lautier*, Richard Rigollet**

RUAG Aerespace Austria (RAA), Stachegasse 16, A-1120 Vienna, Austria

Tel.: +43 1 80199 2740, Fax.: +43 1 80199 6950, Email:theodor.nitschko@ruag.com

**ESA-ESTEC/NL, **EADS Astrium TLS/F*

ABSTRACT

RUAG Aerospace Austria has developed the Thruster Pointing Mechanism (TPM) for the Alternative Thruster Module Assembly (ATMA) as part of the future extended versions of the commercial telecommunications satellite EUROSTAR-3000 made by the European Prime Contractor EADS Astrium.

The main function to be performed by the TPM is to provide the required pointing capability around two perpendicular axes for the Electric Thrusters for mainly North-South Station Keeping (NSSK), and for additional functional capabilities such as eccentricity control and repositioning. A Hold-Down and Release Mechanism (HDRM) is part of the TPM and supports the mobile thruster platform during launch.

RUAG Aerospace Austria was contracted by EADS Astrium and ESA to develop the TPM, which consists of a Tilting Mechanism with a Mobile Platform and the Hold Down and Release Mechanism.

The primary functions of the TPM are to:

- support the thrusters during launch and in orbit
- provide pointing of the thrusters via tilting of the platform
- reduce thermal conductance between thrusters and the S/C.

The TPM is compatible with the ROS-2000, the PPS 1350-G, and the SPT-100 Hall Effect Thrusters.

For verification of the TPM design a Qualification Life Time Model (QLTM) was manufactured and tested.

The scope of this presentation is to present briefly the design of the TPM, and to highlight the qualification test results.

1. MAIN DESIGN FEATURES

The Platform with the Main Plate (***1***) and the thrusters shims (***2***) (thrusters not shown) tilts around a Single Point Hinge (SPH) (***3***) with two controlled rotational degrees of freedom (DOF).

One Transverse Strut Unit (TSU) (***4***) connects the Platform directly to the S/C by means of two ball joints and restricts the movement of the platform to two degrees of freedom.

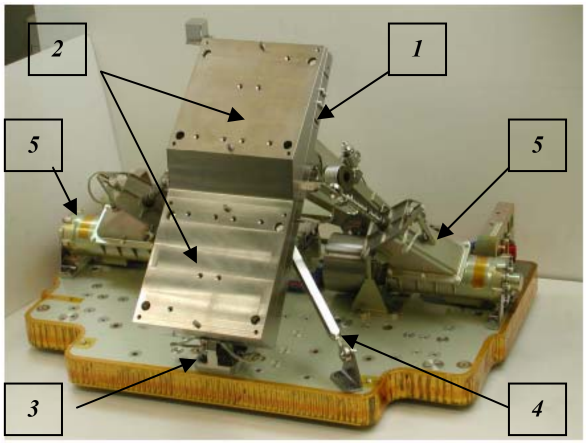


Figure 1 - TPM-QLTM, front view, stowed configuration, mounted on ATMA base plate.

Two linear Drive Units (DU) (***5***) move the pivot points of two Movable Strut Units (MSU), and provide the pointing of the TPM in two DOF. The other ends of the MSUs are connected to the platform by means of ball joints.

The Platform has a flat surface, and one thruster shim with two thruster I/F areas is mounted to it, which provides the necessary canting angle of the thrusters wrt. each other, and/or the required offset angle to the spacecraft.

The Strut Units feature self-lubricating spherical bearing assemblies (rod ends) at both ends. There are two types of Strut Units, two Movable Strut Units (MSU) and one Transverse Strut Unit (TSU).

The Drive Units are operated via stepper motors, which directly drive a preloaded recirculating roller screw (RRS). The spindle provides a linear motion for the Gimbal Joints, where the Movable Strut Units (MSU) are connected to.

Both spindle and Gimbal Joint are supported by preloaded angular contact ball bearings. Bearings and Spindle are coated with a grease lubricant to ensure low wear and friction over the required temperature

Proc. '13th European Space Mechanisms and Tribology Symposium – ESMATS 2009', Vienna, Austria 23–25 September 2009 (ESA SP-670, July 2009)

range and lifetime. A system consisting of redundant Hall sensors indicate the reference position of the 2 mechanical axes. Mechanical end stops (dog-stops) limit the motion at the end of the maximum travel.
A Hold Down and Release Mechanism (HDRM) (***6***) supports the platform during the launch phase and is used to sustain the launch loads. In orbit it will be released via a non-explosive actuator (*7*).

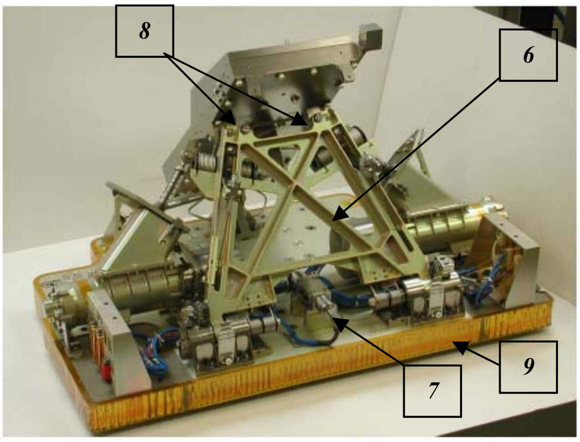


Figure 2 - TPM-QLTM, back view, stowed configuration, mounted on ATMA base plate.

The HDRM is an aluminum lightweight construction and has a Ball-Cup I/F (***8***) to the platform and a Hinge interface to the baseplate. Actuation of the non-explosive Cable Release Actuator (CRA) releases the clamping levers which preload the Ball-Cup I/F and the HDRM support structure tilts away from the Platform.
Redundant Micro Switches are indicating the stowed position as well as the successfully reached end position of the HDRM.
The platform and struts are free after that action and can be moved to any desired point within the pointing range of the TPM, via single or simultaneous actuation of the two Drive Units. Operation of one Drive Unit always operate both degrees of freedom, because the 2 DOF's are coupled with this special kinematics.

The TPM was mounted on the ATMA base plate (***9***) during Qualification Testing and upgraded with the following thruster equipment units. (ATMA base plate as well as the thruster equipment units are under Astrium responsibility.)

- two thruster dummies (on the TPM shim) (***10***)
- two HIB's (on the TPM platform) (***11***)
- two XFCU's (on the ATMA base plate)
- two connector brackets (on the ATMA base plate) (***12***)
- MLI fixation I/F (around the TPM platform) (***13***)
- Thruster piping (partly on ATMA base plate and on TPM platform)
- Thruster harness (partly on ATMA base plate and on TPM platform)

During ATMA thermal cycling test and during Vibration test the following units are upgraded too:

- MLI tent with support structure (partly on the TPM platform)
- two Filter Units

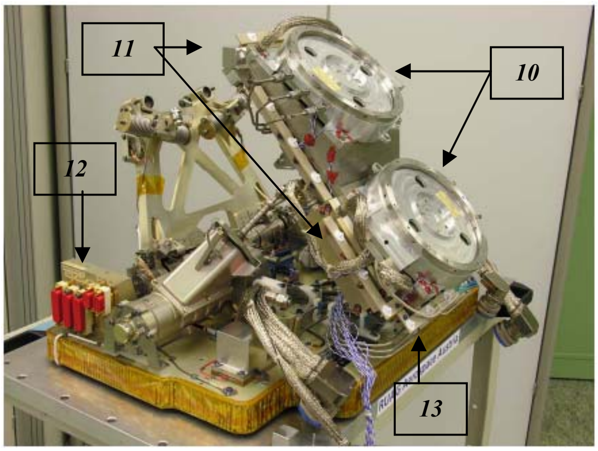


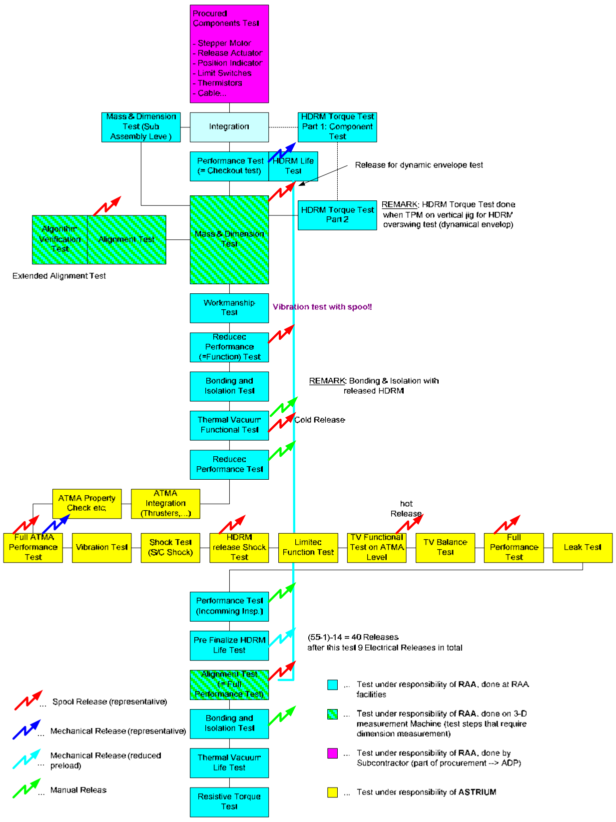
Figure 3 - TPM-QLTM, side view, deployed configuration, mounted on ATMA base plate assembled with two thruster dummies and the thruster equipments.

2. TPM / ATMA QUALIFICATION TEST

The qualification test program was designed to demonstrate the integrity and stability of the TPM /ATMA design during and after exposure to the specified environmental test conditions.
The complete qualification test program was carried out on the Qualification Model (QM=QLTM, one item). Vibration, shock and thermal vacuum tests on ATMA level are carried out by ASTRIUM.
The TPM can be equipped with:

SPT-100 (x2)
ROS 2000 (x1) and SPT-100 (x1)
PPS 1350G (x1) and SPT-100 (x1)
ROS 2000 (x2)
PPS 1350G (x2)

However if not explicitly stated the tests were performed at full qualification levels with ROS 2000 Thrusters (dummy), because they are assumed to cover the other ones. But other HET configurations will be tested to validate the notching philosophy.
Dummy Heaters to simulate HET firing have been used for the qualification level thermal vacuum functional test. The dummies have been fully representative of the flight equipment with respect to the thermal behavior.
The actual sequence of the qualification test program is shown below.



2.1 TPM Thermal Vacuum Life Test

The objective of the Thermal Vacuum Life Test was to demonstrate the ability of the equipment to maintain its actuation performance (motor, bearings, spindle and lubricants) for the number and magnitude of actuation during life time. The environment was a thermal vacuum environment which simulates the extreme in-orbit environment. The environmental conditions are intended to be more severe than those expected to occur during the lifetime of the TPM in order to provide better assurance of locating faults. For verification the actuation number was, compared to the S/C life time, exceeded by a factor of 1.5. Although the test was done in positions close to the nominal position and the loading was mainly done by gravitation (covering all in-orbit loads) and not by harness and piping resistive torques, hysteresis effects are considered by having harness and pipework mounted.
After certain number of actuation, performance tests including torque margin verification tests are done to demonstrate the health of the mechanism.

The qualification character of the life test was given by:

- Running 1.5 times the required number of cycles
- Having 1.5 times the strut loads compared to tested values caused by resistive harness & piping torques
- Full strut loads acting permanently in contradiction to in orbit conditions where close to nominal position zero load is expected
- Running the test 50% on maximum operational temperature and 50% on minimum operational temperature is assumed as worst case thermal environment

Success Criteria:
The TPM has after life cycling still a motorization margin of 3 (the TPM can be operated in the spindle regions of the life cycle test with 1/3 of the nominal motor current (= 1/3 of motor torque)).

2.1.1 Test Requirements

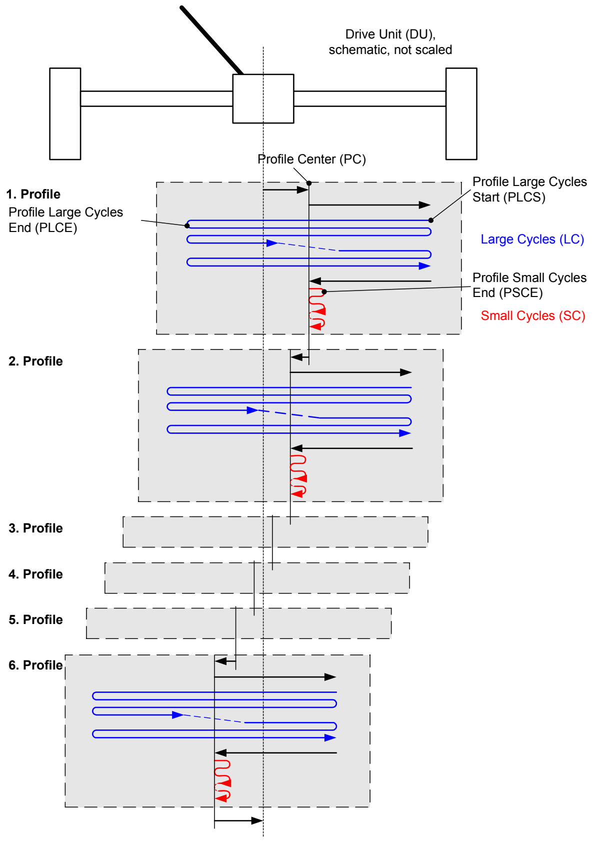
- Pressure of $\leq 10^{-5}$ torr
- Temperature
  The temperature values on Temperature Reference Point (TRP) of the two motor brackets were defined to be target temperatures (under motor operational conditions).

Case	Target Temperature TRP (Motorbracket) operational
Cold Case	-5°C
Hot Case	+83.3°C

- Cycles

  The main parameters were:

  - 1100 large cycle (α = ±2°) = 273-277 step (depending on start location) followed by 56000 small cycles (α = 0.118°) = 8 Step. This scenario (Profile) was run on 6 locations.
  - 50% of these cycles will be run at cold operational Temperature and 50% at hot operational temperature
  - The TPM was gravitationally loaded in such a way that the spindle force (mobile strut-force) was larger than 1.1 (SF) times the induced forced from pipe and harness bending at limit operational range.
  - Each phase differs from the previous one by a shift of the mean TPM position by 0,3 deg
  - The location of the starting point was defined 0,75° from the zero position and further points toward the zero position to achieve the 6th point at 0,75° in the other way.



Accumulated Numbers Life Time Profile:

Accumulation	Cycles	Alpha	Steps
Large Cycles	6.600	65.209	4.422.000
Small Cycles	336.000	97.278	6.608.000
Total Cycles	342.600	162.486	11.030.000
Requirement	200.000	88.000	
Req x SF 1.5	300.000	132.000	
	OK	OK	

2.1.2 Test Configuration

The TPM/ATMA was tested in following configuration:

- ATMA Baseplate: Fully equipped as used by ASTRIUM for mechanical and thermal tests.
  - ATMA/TPM HIB dummies mounted
  - ATMA Thruster base dummies mounted on shims (no thruster upper parts!).
  - Full ATMA piping and harness mounted
- No MLI mounted
- HDRM in released configuration, CRA mounted

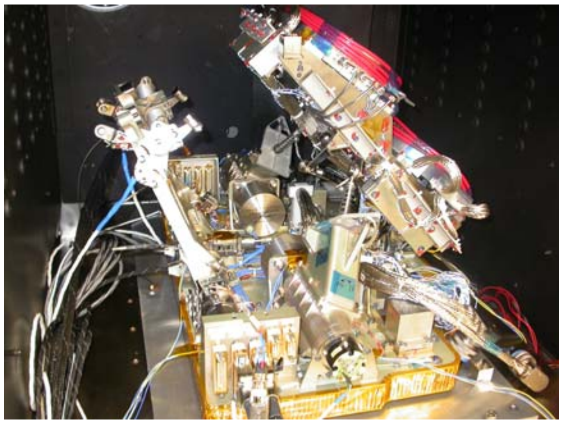


Figure 4 – TPM/ATMA in Test Configuration

2.1.3 Test Duration

Cumulating the individual step-times gives following test-duration:

- Test Time (operational time = cooling heating cycling, performance testing etc.): 5,7 weeks (test-equipment and operator available 24h/day and 7days/week)
- Test time including taking in consideration operator availability: 7,5 weeks (test-equipment all time available, operator regular working time)
- Test time including 20% margin: 9,1 weeks

Total operation [days]	**39,9**
Total operation [weeks]	**5,7**
Operator needs (number)	20
Average Waiting Time [h]	16,0
Operator wait delay [day]	**13,3**
Total Time (operation +wait) [day]	53,3
Total Time (operation +wait) [week]	**7,6**
Time with Margin 20% [week]	**9,1**

2.1.4 Test run

Following holding times to achieve equilibrium pressures and temperatures were derived:

- Duration to achieve 1.33E-5mbar: 3 days at 40°C
- Equilibrium temperature Base Plate Assy (ΔT <3°C): 10h
- Equilibrium temperature Mobile Plate Assy (ΔT <3°C): 16h

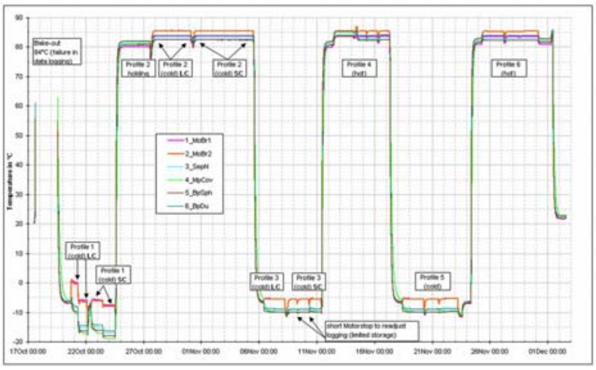


Figure 5 – Temperature of Main Sensors during life test

2.1.5 Test Results

The life test was performed without a significant resistive torque increase.

Following Inspections have been performed after removing the ATMA from TV chamber after TV life test:

- Careful visual inspection
- Check of the electrical function of Hall Sensors
- Limit current test

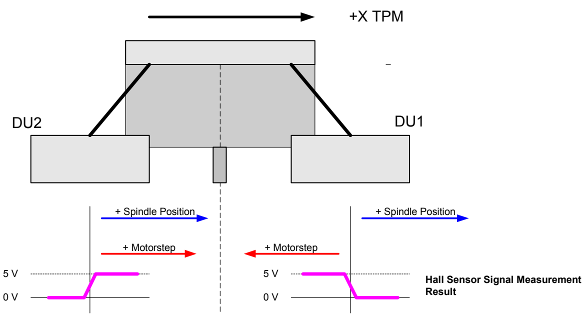
Visual Inspection:

The visual inspection (no strip down) was performed according the TPM hardware inspection plan.
The conclusion after its finalization was that there are no additional visual degradations on the hardware could be detected after the thermal vacuum life test.

Electrical function of Hall Sensors:

Note: Specifically developed for this program!

The specified accuracy of the hall sensors (HES) electrical function was tested after the environmental tests performed by Astrium and before the life test at RAA. The test was repeated after the life test and the maximum deviation from the results gained at the first test amounted to max. 2 motor steps which is equivalent to 0,0186 deg (platform position). The specified accuracy for the HES was ±0,5 deg.



	DU1 steps from Nominal Position	DU2 steps from Nominal Position
Nominal Position	0	0
Outer Dog Stop	-728	-705
Inner Dog Stop	+1003	+1020

		Before			After		
DU	Sensor	+ to -		- to +	+ to -		- to +
1	nom	-43	⇔	-34	-42 (1)	⇔	-36 (2)
1	red	-12	⇔	-5	-12 (0)	⇔	-6 (1)
2	nom	-32	⇔	-22	-31 (1)	⇔	-23 (1)
2	red	-13	⇔	-5	-12 (1)	⇔	-6 (1)

Based on these test results it can be stated that there was marginal shift which is within TPM/ATMA specification.

Limit current test:

A limit current test was performed to determine the absolute torque margin and compare it to the limit current test done before and after TV life test.
The definition for the limit current test was driven by following constraints

- Target was to cover a as large as possible range to pass all regions of at least the small cycles from TV life test. By this it was decided to **start at -65 steps** and have a **cycle range of ±130** steps. A larger range is limited by the fact that the minimum voltage reduction/step at the EGSE is $\Delta U_{min} = 0.01V$.
- Under nominal conditions the TPM will be operated at 2Hz with a pulse length of 110ms. (This is equivalent to setting the EGSE to 22% duty cycle). By reducing the voltage the impact of flattening of the ascending slope of the current (inductive effects,..). Therefore the torque-margin test will be done with a EGSE setting of 50%. It was decided to perform the test with 22% and 50% duty cycle EGSE setting.

At ambient temperature the nominal current is I_{nom} = 0.43A. For demonstrating sufficient torque margin (torque is directly proportional to current) it has to be demonstrated:
RF = $I_{nom}/I_{stic} > 3$, where I_{Stop} is the current when the movement stops (resistive torque > actuating torque).

So the main test parameter used are:

- Voltage at Start: $U_{start} = 10V$
- Voltage Reduction/Step $\Delta U = 0.01V$
- Frequency: f = 2Hz

Results of the Limit Current Test:
By decreasing the motor current the ascending part of the current (inductivity) dominates the pulse length. To compensate this the pulse-duration was increased to

have the required current-level for the required duration (leads to 50% instead 22% of step-duration.

Test	Spindle	Winding	Start DU1	Start DU2	Cycle Steps	EGSE Dutycyc. setting	U_{Stop}	I_{Stop}	I_{nom}/I_{STOP} >3?
						[%]	[V]	[A]	
post Ast	*DU1*	*nom*	*-65*	*0*	*±130*	*22%*	*7.29*	*0.120*	*3.6*
post Ast	*DU1*	*nom*	*-65*	*0*	*±130*	*50%*	*3.83*	*0.070*	*6.1*
post Ast	*DU2*	*nom*	*0*	*-65*	*±130*	*22%*	*6.87*	*0.097*	*4.4*
post Ast	*DU2*	*nom*	*0*	*-65*	*±130*	*50%*	*3.71*	*0.060*	*7.2*
post Ast	*DU1*	*red*	*-65*	*0*	*±130*	*22%*	*7.07*	*0.105*	*4.1*
post TV Life	DU1	nom	-65	0	±130	22%	7.63	0.124	3.5
post TV Life	DU1	nom	-65	0	±130	50%	3.99	0.069	6.3
post TV Life	DU2	nom	-65	0	±130	22%	6.94	0.112	3.8
post TV Life	DU2	nom	-65	0	±130	50%	3.74	0.065	6.6
post TV Life	DU2	red	-65	0	±130	22%	6.85	0.090	4.8

- the required factor of 3 is exceeded, under regular pulse length it is even significantly exceeded (factor >6 instead of 3)
- There was only marginal increase of limit current/limit Voltage pre/post TV life test.
  For 22% Dutycycle max 0.34V (related to 28V nominal Voltage → +1.2%)
  For 50%Duty Cycle max 0.16V (related to 28V nominal Voltage → +0.6%)

Based on these test results it can be stated that there was no mechanical degradation which having an impact on the resistive torque.

2.1.6 Conclusion

- The required temperatures were achieved.
- The required number of steps have been performed
- After all profiles a torque margin test was performed. It was verified that there is no step loss with I/3 current (equivalent to 1/3 torque).
- The life test was performed without remarkable resistive torque increase. This was verified by a additional limit current test.
- The limit current test shows that no mechanical degradation which having an impact on the resistive torque occurred during the life test.

The TPM QLTM Thermal Vacuum Life test was successfully concluded.

2.2 TPM HDRM Life Test

The objective of the HDRM Life Test was to demonstrate the life requirement of 55 actuation for the HDRM release. 10 representative electrical releases, hard preloaded (1151N) and 45 mechanical releases, soft preloaded (150N) of the mechanism were done.

Success Criteria:
The TPM HDRM has after life test still a motorization margin of 3.

2.2.1 Test Configuration

The TPM/ATMA was tested in following configuration:

- ATMA Baseplate: Fully equipped as used by ASTRIUM for mechanical and thermal tests.
  - ATMA/TPM HIB dummies mounted
  - ATMA Thruster base dummies mounted on shims (no thruster upper parts!).
  - Full ATMA piping and harness mounted
  - partly no MLI was mounted

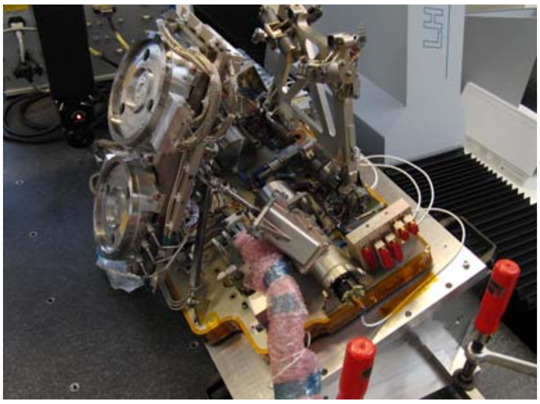


Figure 6 - TPM QLTM (at 3D Measurement) HDRM deployed

2.2.2 Test

During the TPM/ATMA qualification test sequence there were in total performed:

- 10 representative electrical releases, hard preloaded (1151N)
- 45 mechanical releases, soft preloaded (150N)
- Total 55 releases.
- as well as 7 manual releases, soft preloaded (150N)

Company	Nr	Type	Cumulated Number QLTM				Description	Date
			elec. Q	mech Q	m+e Q	total Q		
RAA	2	Mechanical		2	2	2	Overswing test	25.01.2008
RAA	1	Mechanical		3	3	3	3D measurement	28.01.2008
RAA	1	Mechanical		4	4	4	3D measurement	31.01.2008
RAA	1	Mechanical		5	5	5	Functional Test	01.02.2008
RAA	1	Electrical	1		6	6	After vibration test	06.02.2008
RAA	1	Electrical	2		7	7	TV Cold release	18.02.2008
RAA	1	Electrical	3		8	8	TV Hot release	28.02.2008
ASTRIUM	1	Manual				9	conduct rework	28.03.2008
ASTRIUM	1	Manual				10	(pointing test)	10.04.2008
ASTRIUM	1	Electrical	4		9	11	HDRM release after shock test	12.06.2008
ASTRIUM	1	Manual				12	(pointing test)	25.06.2008
ASTRIUM	1	Manual				13	munting of Thermo couples)	08.07.2008
ASTRIUM	1	Electrical	5		10	14	Release in TVAC @@@hot/cold	30.07.2008
ASTRIUM	1	Manual				15	(re-arm el. release mechanism	04.09.2008
ASTRIUM	1	Manual				16	(pointing test)	08.09.2008
ASTRIUM	1	Manual				17	(pointing test)	26.09.2008
RAA	1	Electrical	6		11	18	Alignment Test (ITM-NCR-0035-AAE	08.10.2008
RAA	40	Mechanical		45	51	58	HDRM Life Test Completion Mechanical	09.10.2008 13.10.2008
RAA	4	Electrical	10		55	62	HDRM Life Test Completion Electrical	13.10.2008 14.10.2008
Total	4		**10**	**45**	**55**	62		

Figure 7 - TPM QLTM HDRM Summary of Releases

Visual Inspection:

The visual inspection was performed according to the TPM HDRM inspection plan.

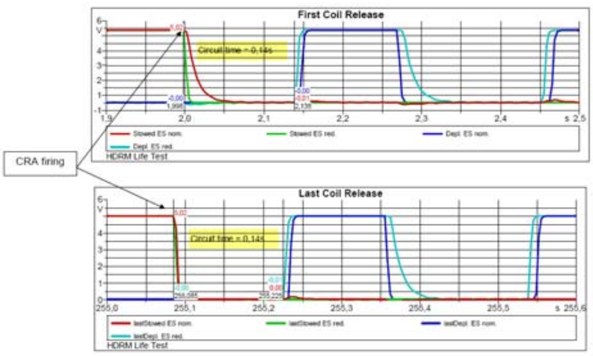
The conclusion after its finalization was that there some regions, rope catcher / rope deviator and deployment spring fixation brackets, that show indents coming from dynamic behavior of the release rope end-fittings during release but there are however no indents that give an indication of function loss during qualification tests or loss of function in the near future.

Figure 8 – TPM QLTM in deployed configuration .

Motorization margin / deployment time:

During the TPM QLTM HDRM Life Completion test, starting with test no. 11 (08.10.2008) and completed with test no. 55 (14.10.2008) the deployment time of the HDRM structure was recorded.

The time between cable release actuator (CRA) actuation and limit switch reaction (stowed and limit switch reaction (deployed) was recorded.



The first and the last test record shows that in both cases the time between the stowed and deployed limit switch reaction was 0,14 sec.

No degradation of the spring force and no change of the resistive torque occurred during the HDRM life test.

2.2.3 Conclusion

The HDRM Life test was finalized successfully. In the final QLTM configuration there were in total done:

- 10 representative electrical releases, hard preloaded (1151N)
- 45 mechanical releases, soft preloaded (150N)
- Total 55 releases.

The TPM QLTM HDRM Life test was successfully concluded.

2.3 Conclusion (TPM/ATMA qualification)

- Performance Testing
  - ATMA mass within specification.
  - Proof pressure and leak test, no anomaly.
  - Electrical (isolation, bonding, continuity, power consumption, indicator) performed successfully.
  - Reference position check, within their qualification range. Deviation locked versus un-locked platform position accuracy.
  - Sensor operation performed successfully.
- Mechanical Testing – Vibration & Shock
  - All results successful and conform to predictions except anomaly after random test in Y-axis (last tested axis) frequency drop in the second Y-axis mode by 13% compared to a max. requirement to 5%. This has been explained by a preload relaxation due to too long bolts wrt inserts. This doesn't jeopardise ATMA mechanical qualification status.
  - No pre-load tension evolution observed in the HDRM rope during all vibration testing campaign.
  - The ATMA / HDRM release induces a shock level at thruster/XFCU foot within their shock qualification envelope.
- Thermal Testing
  - Number of thermal cycles achieved successfully.
  - Reduced performance tests performed successfully.
  - After correction about TVac test boundary and MLI locations, good correlation between test results and Thermal Model
- Life Testing
  - HDRM life test performed successfully.
  - TPM life test performed successfully.

The Qualification review was held on the 9th and 10th of June 2009 at Astrium Toulouse with following conclusion. "The ATMA/TPM qualification wrt mechanical, thermal and life duration was declared successful versus E3000 specified requirements and applicable standards."

The TPM/ATMA qualification was successfully concluded and is compliant to Eurostar 3000 requirements.

3. LESSONS LEARNED

MAC oil based lubricants very well suited for high-duty applications; high contact pressure & high numbers of cycles.

Where practicable, always carry out life checks on individual tribo-components prior to sub-assembly level tests.

Check parts clearance in each configuration and as often as possible during integration and the test campaign.

Carefully check impact on speeding up life test by step-frequency increase on duty-cycle and thermal budget.

Trying to safe money on EGSE and test-sensors might in the end have the controversial effect.

4. ACKNOWLEDGEMENT

We gratefully acknowledge the support of the customer ASTRIUM in the performance of this demanding project.