MAJIS Shutter QM and FM Thermo-vacuum Test Report

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Acronyms

ABCL	As Built Configuration List
AD	Applicable Document
AO	Announcement of Opportunity
API	Application Programming Interface
AIT	Assembly Integration &Test
AIV	Assembly Integration &Verification
BOL	Begin Of Life
CC	Configuration Control
CCS	Central Checkout System
CIDL	Configuration Item Data List
Co-I	Co-Investigator
COTS	Commercial Off The Shelf
Co-PI	Co-Principal Investigator
CPCU	Command and Process Control Unit
CU	Compression Unit
DCDC	Direct Current Direct Current
DPU	Data Processing Unit
DSP	Digital Signal Processing
EGSE	Electric Ground Support Equipment
EOL	End Of Life
EM	Engineering Model
EMC	Electro-Magnetic Compatibility
EMI	Electro-Magnetic Interference
EP	Entrance Pupil
ESA	European Space Agency
ESOC	European Space Operations Centre
ESTEC	European Space Technology and Research Centre
EVL	Event Logger
FM	Flight Model
FOV	Field-Of-View
FPA	Focal Plane Assembly
FS	Flight Spares
HK	House-Keeping
HTML	Hyper Text Mark-up Language
HTTP	Hyper Text Transport Protocol
H/W	Hardware
IAPS	Istituto di Astrofisica e Planetologia Spaziali
ICD	Interface Control Document
IFE	Instrument Front-End Electronics
LAN	Local Area Network
LEOP	Launch & Early Orbit Phase
LM	Local Manager
LOS	Line Of Sight
MCS	Mission Control System
ME	Main Electronics
MIB	Mission Information base
MGSE	Mechanic Ground Support Equipment
MLI	Multi Layer Insulation
MOC	Mission Operations Centre
MOS	Margin Of Safety
MRB	Material Review Board
N/A	Not Applicable
NCR	Non Conformance Report
OBCP	On-Board Control Procedure
OBSW	On Board Software
OIRD	Operations Interface Requirement Document
OGS	Operational Ground Segment
OGSE	Optics Ground Support Equipment
OOL	Out Of Limit
PA	Product Assurance
PDF	Portable Document Format (Adobe Acrobat)
PE	Proximity Electronics
PFM	Proto-Flight Model
PI	Principal Investigator
PLM	Payload Module
PM	Project Manager
PPL	Preference Part List
PS	Project Scientist
PSF	Point-Spread-Function
QA	Quality Assurance
QLA	Quick Look Analysis
QM	Qualification Model
QPL	Qualified Part List
RD	Reference Document
RFW	Request For Waiver
RH	Relative Humidity
RMS	Root Mean Square
RTA	Real Time Analysis
RTK	Real Time Kernel
S/C	Spacecraft
SCMP	Software Configuration Management Plan
SE	System Engineer
SIP	Science Implementation Plan
SPMP	Software Project Management Plan
SQAP	Software Quality Assurance Plan
SRR	Software Requirements Review
SSS	Software System Specification
SVM	Service Module
S/W	Software
TBC	To Be Confirmed
TBD	To Be Determined
TBN	To Be Nominated
TBW	To Be Written
TC	Tele-Command
TM	TeleMetry
TRB	Test Review Board
URD	User Requirements Document
WP	Work Package

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1. INTRODUCTION

1.1 Purpose and scope

This test report provides a summary of the Thermo-Vacuum Test results on the QM and FM shutter units, a mechanical part of the spectrometer MAJIS (Moon And Jupiter Imaging Spectrometer), a payload instrument on board of the JUCE (JUpiter ICy moons Explorer) mission. The shutter actuator is composed by an electromagnetic brushless actuator mounted with an aluminium blade. The aims of the actuator are to maintain the blade in two stable positions (open and closed), to rotate the blade from one position to other in a time less than 300ms and a low power consumption. These tests have been conducted to demonstrate the capability of the shutter to operate according to requirements in vacuum at predefined temperature conditions. The target temperatures for the QM model are Top-Min = 100K and Top-Max = 165K and pressures less than 1 mbar. A total number of thermo-vacuum cycles of 42 are requested, including an extra hot point at 337K but only for the first cycle at the beginning. A slope of 2.7K/min has been agreed and planned for all the cycles. For the life test, performed only on the QM1, selected as reference, a total number of 1500 cycles at the same conditions of T and P are requested.
For what concerns the test performed on the FM model, the target temperature is Top-Min = 105K and Top-Max = 160K.
A total number of thermo-vacuum cycles of 4 are requested, including an extra hot point at 337K but only for the first cycle at the beginning. A slope of 2.7K/min has been agreed and planned for all the cycles.

2. REQUIREMENTS

The shutter shall be capable to operate and meet all the specific requirements when subjected to environmental conditions. In table 1, all ground operations, ground testing and flight operations are summarized.

On ground Testing Environment			
Operating Temperature	No-Operating Temperature	Nominal Operating Pressure	No-Operating Pressure
110-155 K	110-333K	Vacuum (<1 mbar)	Vacuum (<1 mbar)
293-300 K			
Ground Operations and Handling			
273-308 (K)		$7*10^4$ N/m^2 (10.1 psi) – $1*10^5$ N/m^2 (14.7 psi)	
In orbit Thermal and pressure Environment			
Operating Temperature	No-Operating Temperature	Nominal Operating Pressure	No-Operating Pressure
110-155 K	110-333 K	Vacuum (< 1 mbar)	Vacuum (<1 mbar)

Table 1: Requirements for the shutter

3. TEST SETUP FACILITY DESCRIPTION

The baseline of the IAPS PLAB Thermo Vacuum facility used for this test is an SRDK Series Cryocooler, which consists of an SRDK-408D2 Cold Head, Compressor Unit, Flex Lines, and Cold Head Power Cable A sketch of the test set up is shown in figure 1.
The SRDK series Cold Head is a GM cycle cryo-refrigerator. The function of the Cold Head is to produce continuous closed-cycle refrigeration at temperatures, depending upon the heat load imposed.
The Cold Head has three major components:

- Drive unit;
- Cylinder;
- Displacer-regenerator assembly, which is located inside the cylinder.

On the SRDK-408D2 Cold Heads is applied rare earth material for the second stage displacer to produce 6.5K temperature. The second stage cooling capacity is approximately 1.0W at 6.5K. The Compressor Unit is required to operate the Cold Head.
The Compressor Unit provides the power and the high-pressure helium gas for the Cold Head, and it is composed of a compressor capsule, a cooling system and lubricating oil mist Absorber.

Functionally, the high-pressure helium gas from the Compressor Unit is supplied to the Cold Head through the helium gas supply connector. The supply gas is passed into the displacer-regenerator assembly, comes out through the displacer-regenerator assembly to the crankcase through the motor housing, and finally it returns to the Compressor Unit through the helium gas return connector. The helium gas expansion in the displacer-regenerator assembly provides cooling condition for the first and second-stage cold stations.
The temperature range is from 6.5 to 353K while the temperature slope can be set from a minimum of 0.1K/min to a maximum of 3.6K/min.

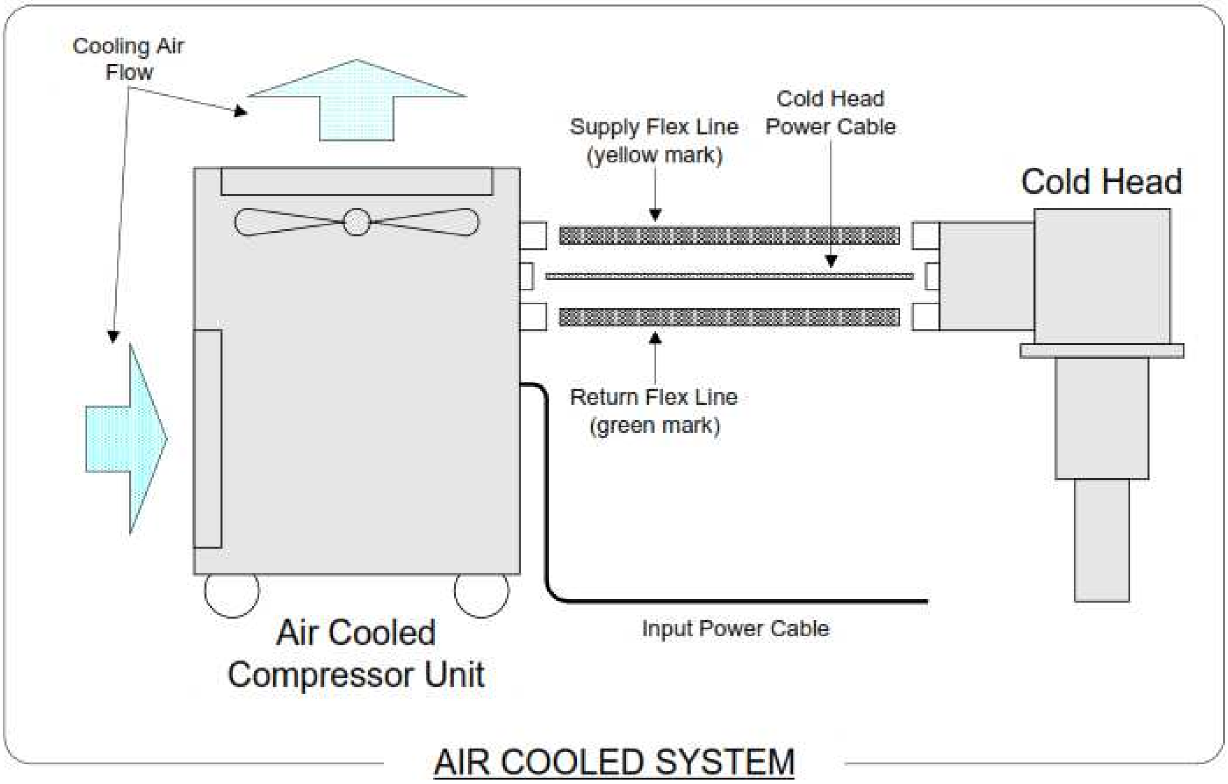

Figure 1 : overall sketch of the test setup used

3.1 THERMAL CONTROL SYSTEM

The thermal profile execution, the time base, the ramp rate, and the stabilization time is managed by the IAPS LabVIEW software connected to a temperature controller (LAKE SHORE 335) by an IE488 protocol. The control panel of the software is shown in figure 2.

The temperature of the cold head is read by a Silicon Diode (DT-670B-CU) sensor, while the unit temperature is read by 4 PT100 sensors properly placed.

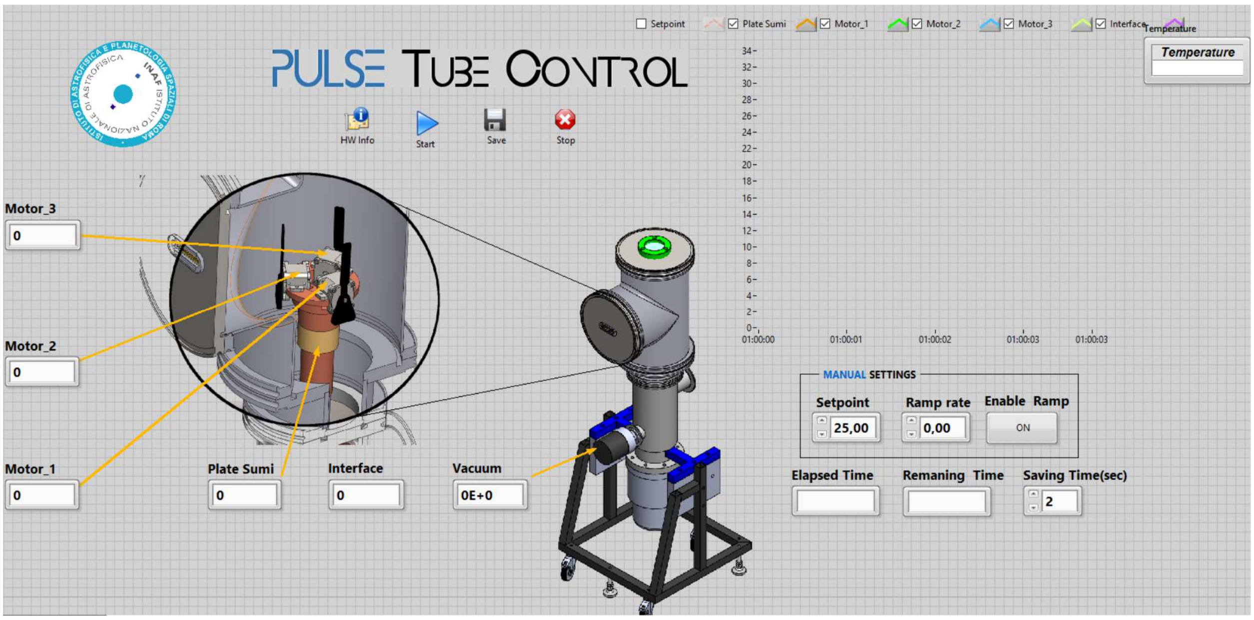

Figure 2: The Labview panel of the control system

3.2 DATA ACQUISITION SYSTEM (DAS)

The temperature is acquired by two different system:

- Lake Shore 335 for the cold head (DT-670B-CU)
- CompactDAQ for the unit tested (RTD 4 wire)

A sketch of the acquisition system is shown in figure 3.

A dedicated LabVIEW software, developed by IAPS team, oversees temperature control and data storage, through a GPIB communication protocol.

Figure 3: the acquisition system

Mains features of CompactDAQ are:

- Possibility of housing 8 modules for the measurement of PT 100 4-wire (24-bit resolution).
- Excellent flexibility and future expandability of the measuring system.
- N° 4 temperature sensors (PT100 4-wire), positioned on the unit
- N °1 Silicon Diode.
- N° 1 full-range pressure transducer.

4. TEST SET-UP INTERFACE

To interface the QM and FM models with the cold head, a dedicated copper interface has been designed and produced according to the project reported in Figure 4.

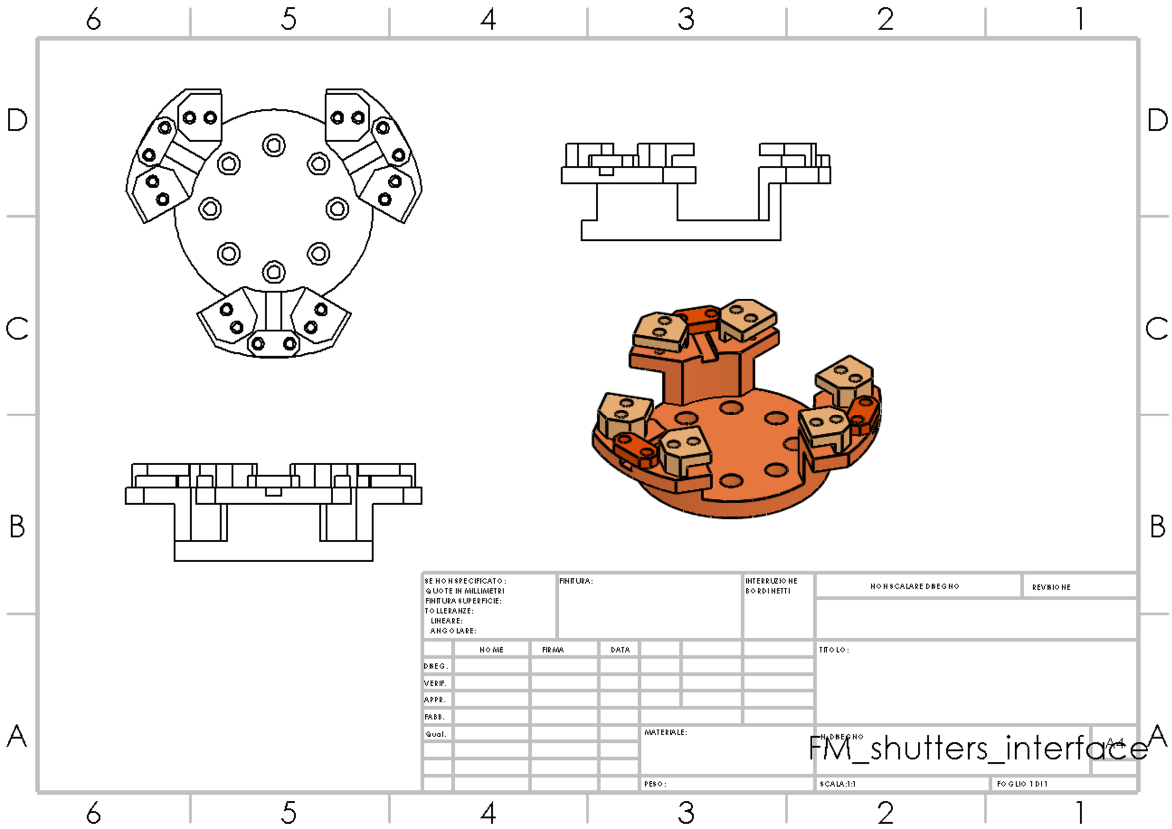

Figure 4: test setup adaptation interface

5. PRE-TEST ACTIVITY

The QM shutters models have been received at the PLab and the delivery included the 2 QM models and their electronics.

The shutters have been tested immediately after the visual inspection and no problem has been found.

The mechanical interface was already tested during shutter dummy test executed in advance prior the QM tests. All the screws have been thighten at 3.5 N cm. The cable's length has been modified compared to the dummy test and it is now too short to allow the "cold stop" to be applied on both shutters, so the cold stop has been applied only on QM1, selected as reference. For the FMs the length shall be not shorter than the QMs.

6. QM TEST DESCRIPTION

6.1 QM RTD PLACEMENT

The reading points placement of the temperature probes (PT100) used for the QM test are shown in Figure 5.

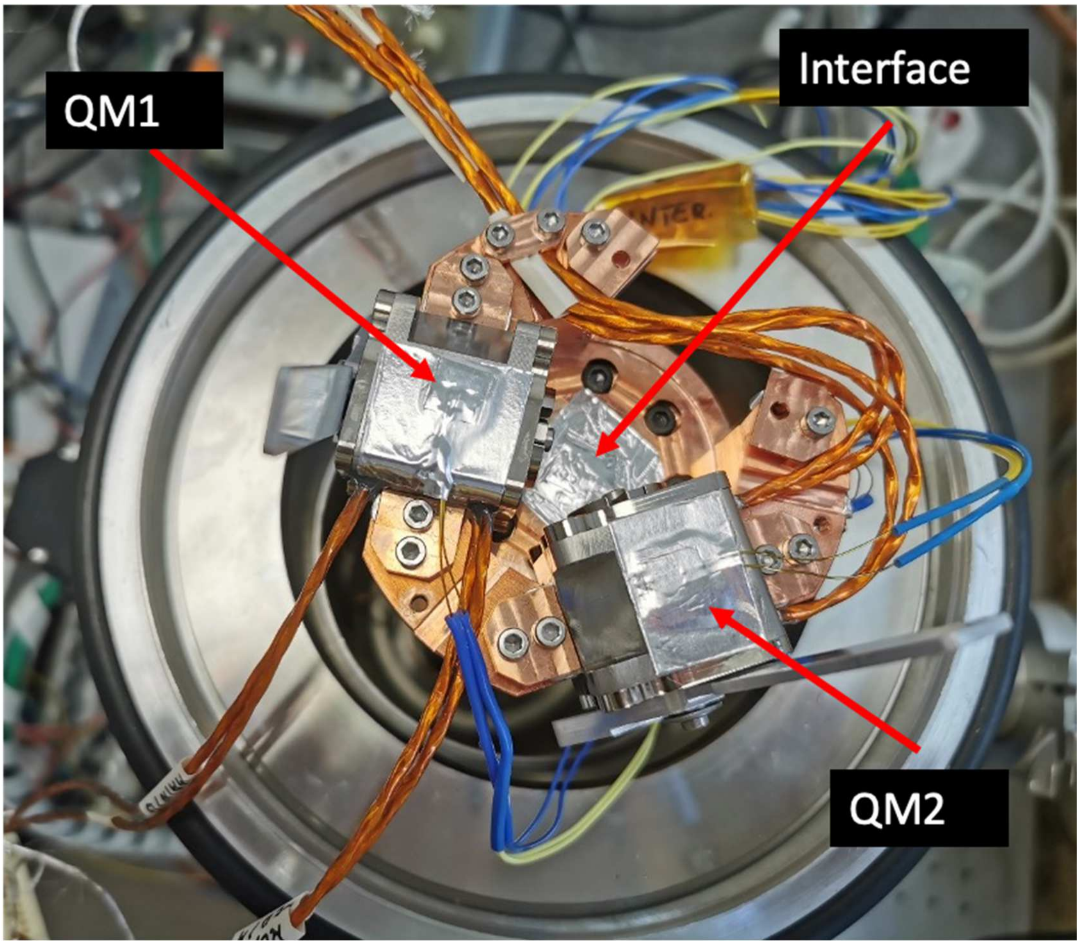

Figure 5: RTDs placement for QM

6.2 QM TEST CYCLES

In Figure 6 a single thermal cycles plot is shown along the key points.

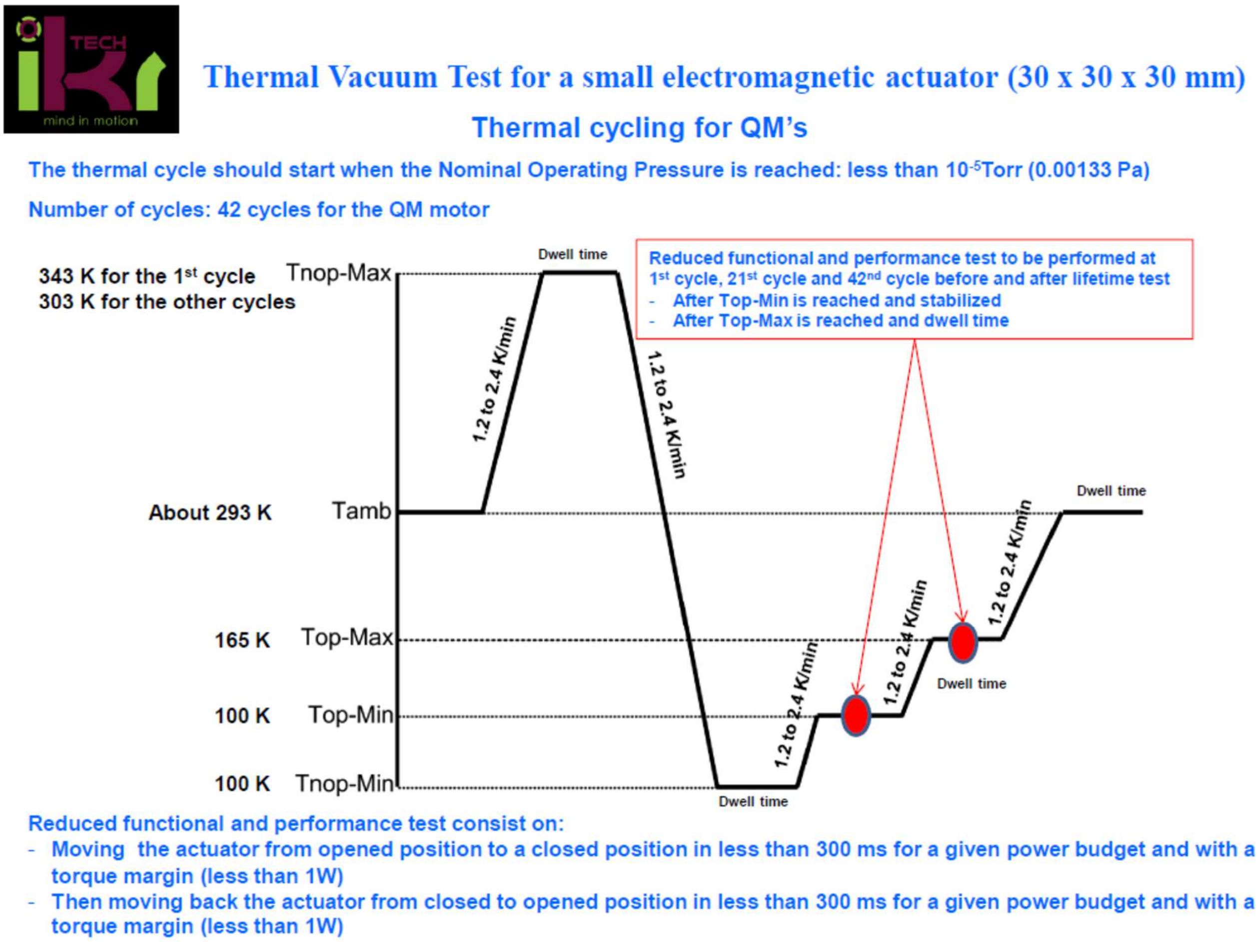

Figure 6: cycles and key points of the QM test

The key points (in red) show the motor temperatures where the shutter is activated for testing. The target temperatures for QM1, used as reference point, are **Top-Min = 100K** and **Top-Max = 165K**.
A total number of **42 cycles are performed**, including an extra hot point at **337K** (for QM1 as reference) but only for the first cycle at the beginning. A slope of **2.7K/min** has been agreed and planned for all the cycles.
To comply with these motor temperatures, the temperature set point of the controller has been set at 61K, 151K for the above key points and 343K for the hot point. The overall cycles for the temperature set points are shown in Figure 7 where there are also indicated the points (yellow dots) where the shutters shall be activated. Notice that not all the activations are performed for all the cycles due to the exclusion of the night-time working hours and sometime only a single test for a cycle has been executed for the same reason.
The temperature difference between the motors and the set point temperatures is mainly due to the thermal flux from the ambient to the motor coils.

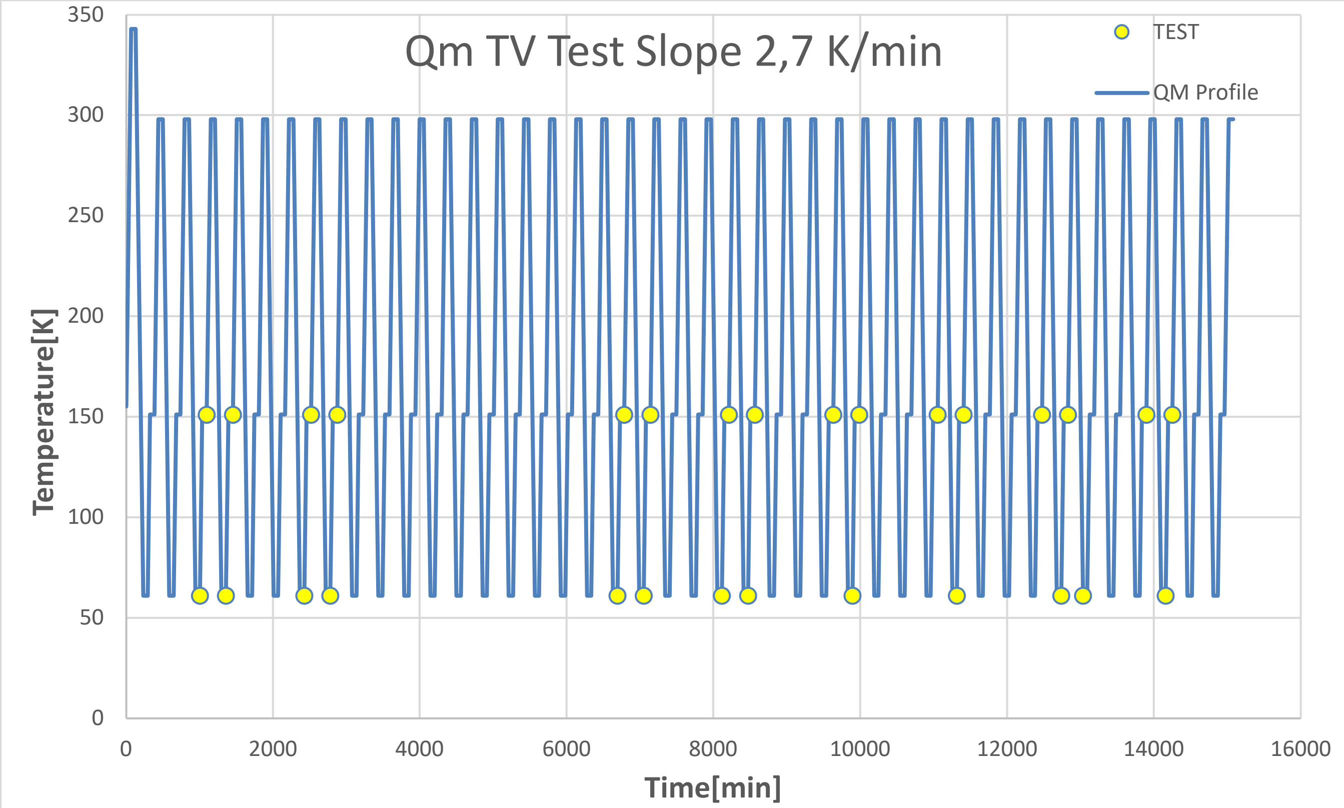

Figure 7: Temperature set point plot for the overall cycles of the QM

6.3 QM TEST results

In Figure 8 a plot of the temperatures and vacuum data acquired during the thermo-vacuum cycles is shown. For the performance test 42 thermo-vacuum cycles have been performed but only data of 40 cycles have been saved due to a software problem of the setup.

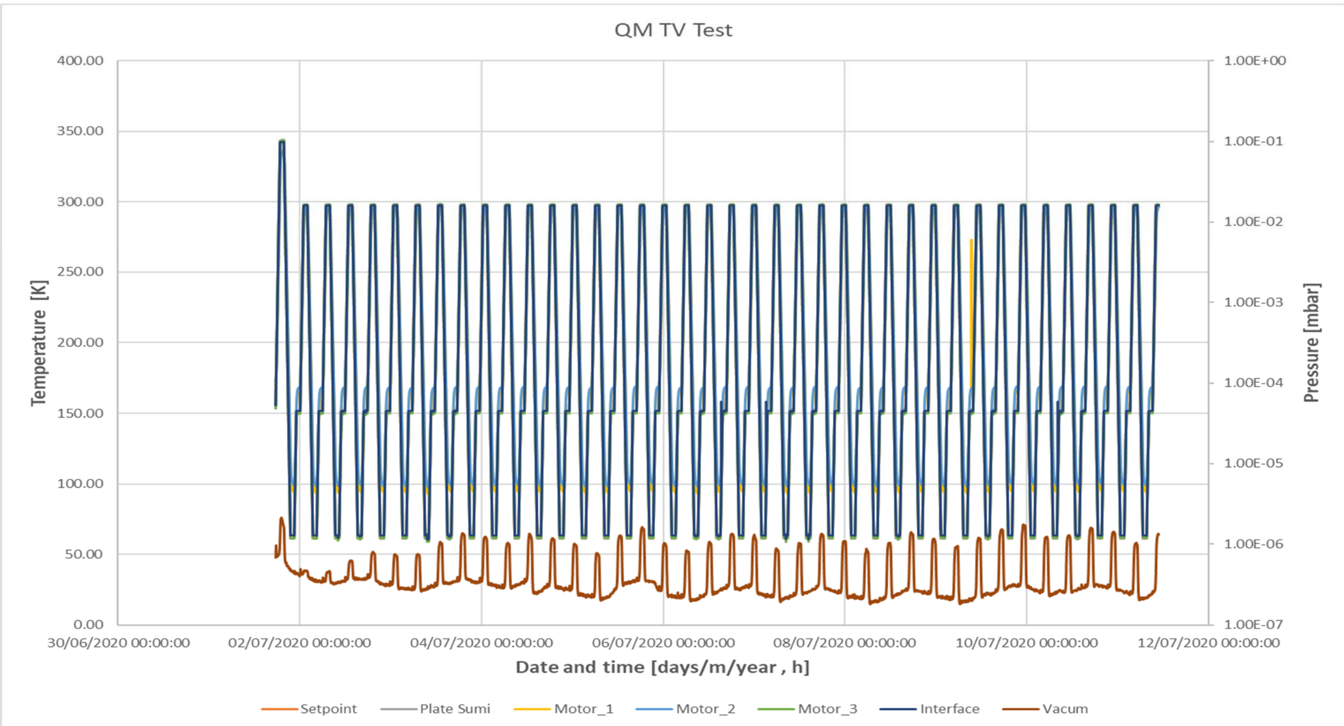

Figure 8: Temperature and vacuum plots for the QM test

In Table 2 a list of all the performed test has been summarized. The first column represents the file name of the video recorded during each performance test while the second one the motor temperature conditions at which the test has been done. The two red box correspond to the test where the QM2 didn't work.

VIDEO NAME	Conditions	QM 1	QM 2	Data, time
Performance Test_100K_1	100K	✓	✓	02/07/2020, 10:20
Performance Test_165K_1	165K	✓	✓	02/07/2020, 11:38
Performance Test_100K_2	100 K	✓	✓	02/07/2020, 15:10
Performance Test_165K_2	165K	✓	✓	02/07/2020, 17:30
Performance Test_100K_3	100K	✓	✓	03/07/2020, 09:44
Performance Test_165K_3	165 K	✓	✓	03/07/2020, 11:19
Performance only on Shutter2 298K	294 K	✓	✓	03/07/2020, 13:12
Performance Test_100K_4	100 K	✓	✓	03/07/2020, 15:38
Performance Test_165K_4	165 K	✓	✓	03/07/2020, 17:12
Performance Test_100K_5	100 K	✓	✓	06/07/2020, 08:50
Performance Test_165K_5	165 K	✓	✓	06/07/2020, 10:24
Performance Test_100K_6	100 K	✓	✓	06/07/2020, 14:46
Performance Test_165K_6	165 K	✓	✓	06/07/2020, 16:19
Performance Test_100K_7	100 K	✓	✓	07/07/2020, 08:32 *First the motor 2 and then the motor 1
Performance Test_165K_7	165 K	✓	✓	07/07/2020, 10:05
Performance Test_100K_8	100 K	✓	✓	07/07/2020, 14:28
Performance Test_165K_8	165 K	✓	✓	07/07/2020, 16:01
Performance Test_165K_9	165 K	✓	✓	08/07/2020, 09:50
Performance Test_100K_9	100 K	✓	✓	08/07/2020, 14:12
Performance Test_165K_10	165 K	✓	✓	08/07/2020, 15:44
Performance Test_165K_11	165 K	✓	✓	09/07/2020, 09:30
Performance Test_100K_12	100 K	✓	✓	09/07/2020, 13:44
Performance Test_165K_12	165 K	✓	✓	09/07/2020, 15:17
Performance Test_165K_13	165 K	✓	✓	10/07/2020, 09:04
Performance Test_100K_14	100 K	✓	✓	10/07/2020, 13:26
Performance Test_165K_14	165 K	✓	✓	10/07/2020, 14:59
Performance Test_135K	135 K	✓	✓	13/07/2020, 08:06

Table 2: summary of the test performed on the QM

6.3.1 RESOLVED TEST FAILURE EVENT

The first failure on the QM2 occurred on the fifth performance test (see red box in Table 2). This problem has been resolved by IKR team allowing the successive tests execution on the QM2.

6.3.2 UNRESOLVED TEST FAILURE EVENT

The second failure occurred on the sixteenth performance test (see red dox in Table 2) has not been resolved due to the absence in situ of the IKRtech team, while the QM2 restarted to work on the successive switch on.
The data of the last two cycles have been lost due to a setup software problem.

6.4 LIFE TEST DDESCRIPTION

After the QM performance test a life test has been performed on the QM1 selected as reference.
The requirement for the life test is:

- 1500 open/close cycles in vacuum at operating temperature range.

To satisfy this request, a QM1 motor temperature of **136 K** has been agreed and planned. To reach this temperature for QM1, the set-point was set at 115.5 K.

6.4.1 LIFE TEST RESULTS

In Figure 9 a plot of the temperature and vacuum data acquired during the life test is shown.

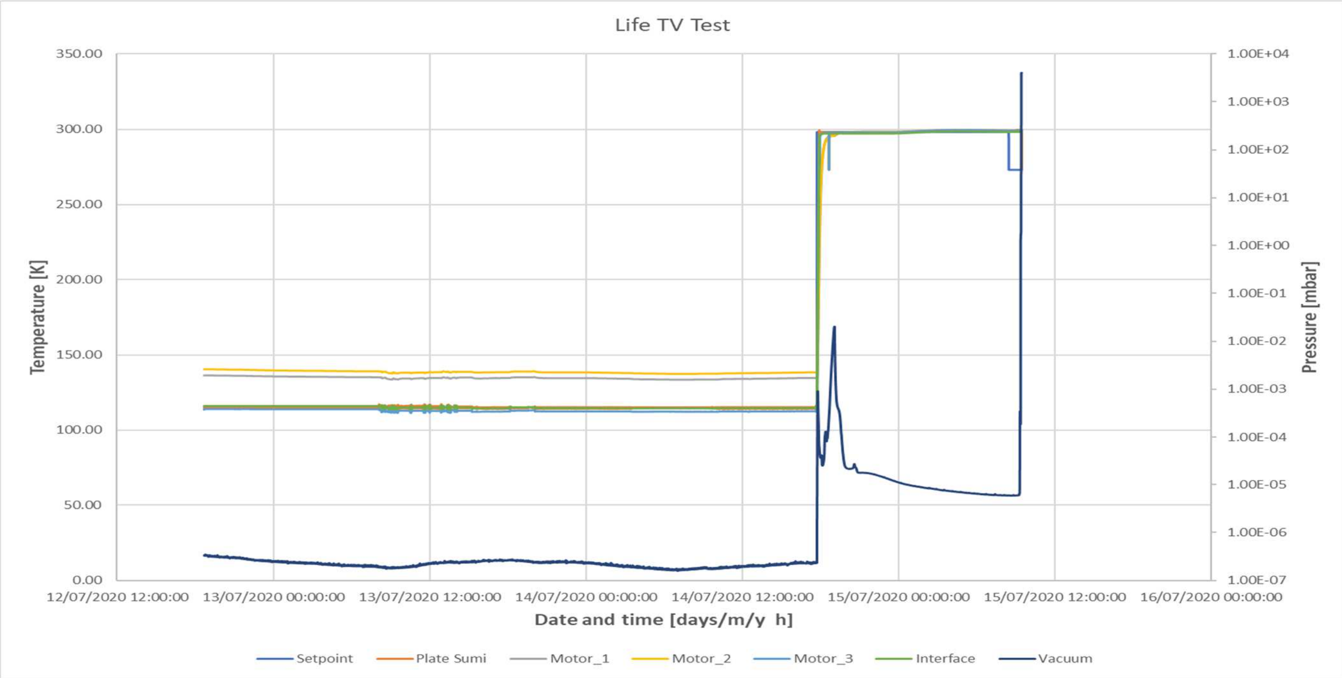

Figure 9: temperature and vacuum data plot for the QM1 life test

In Table 3 the list and results on all life test performed are summarized. The first column represents the file name of the video recorded during the operations of the shutters, the second one the conditions at which the test has been done (temperature and current), the third one the number of the cycles performed in that session.
The red boxes refer to the problems with the shutter activations while the yellow boxes refer to a change of the conditions (ramp, current and number of cycles).

VIDEO FILE NAME	T & Current	Nr cycles	Data, time	Note	Duration of a full cycle (open and close of the shutter)
Before Life test new electronics	135 K & 150 mA		13/07/2020, 08:30	The electronic has been change	
I 5000 life test	134.2 K & 150 mA	5000	13/07/2020, 10:29	Current check 80 mA	2*(0.3+0.025)= 0.65s
II 5000 life test	134.2 & 150 mA	5000	13/07/2020, 11:32	Current check 80 mA	2*(0.3+0.025)= 0.65s
III 1400 life test	134.2 K & 150 mA	1400 (losing step)	13/07/2020, 11:56	Current check 80 mA	2*(0.3+0.025)= 0.65s
IV 3600 life test	134.2 K & 150 mA	3600 (losing step)	13/07/2020, 12:52	Current check 80 mA	2*(0.3+0.100)= 0.80s
V 200 life test	134.9 K & 150 mA	5000 (losing step)	13/07/2020, 13:19	Current check 160mA	2*(0.3+0.100)= 0.80s
VI 5000 life test	134.9 K & 150 mA		13/07/2020, 14:05		
Test friction several current	134.2-134.4 K		13/07/2020, 15:33	No check on the current	

i160e100 mA	134.2-134.4 K & 160 mA and 100 mA	Don't works	13/07/2020, 15:47	160 mA from Open to Close and 100 mA from Close to Open	100ms-100ms-100ms ramps and 3s plateau
i200e200 mA	134.2-134.4 K & 200 mA	OK	13/07/2020, 15:51	2000 mA both directions	
Life test 6&6s and 4 s	134.2-134.4 K & 200 mA	• 100 x 4= 400 @ 6.6 s • 100 x 6=600 @ 4s • 200 x 2= 400 @ 4s • 500 x 2= 1000 @ 4s	13/07/2020, 15:57 @ 16:49 @ 17:26 @ 17:50	160 mA	• 2*(0.3+3) = 6.65 s • 2*(0.3+ 1.75) =4s • 2*(0.3+ 1.75) =4s • 2*(0.3+ 1.75)=4s
Life Test_200 cycles	135 K & 200 mA	200 x 2 =400	13/07/2020, 18:56		2*(0.3 + 1.75) = 4s
Life Test 200_200mA_1	134.5 K & 200 mA		13/07/2020, 20:20	Lost communication with the PC @ about 3:10	2*(0.3 + 1.75) = 4s
Life Test 200_200mA_2	134.5 K & 200 mA		13/07/2020, 23:23		2*(0.3 + 1.75) = 4s
2000 Cycle 4 sec 200mA Life Test	133.5 K & 200 mA	• 5 cycles 150mA (OK) • 5 cycles 100 mA Close OK Open no • 5 cycles 100mA (Close) and 150 mA (Open) • 2000	14/07/2020, 10:01 @10:03 @10:11		2*(0.3 + 1.75) = 4s
Life test 2000 150mA	133.9 K & 150mA	Only check	14/07/2020, 12:32	Check on the motor 1@ 150 mA after 2000 cycles	2*(0.3 + 1.75) = 4s
Life Test 200mA 4000 Cycle_1	133.9 K & 150mA	4000	14/07/2020, 12:33	150 mA	2*(0.3 + 1.75) = 4s
Life Test 200mA 4000 Cycle_2	133.9 K & 150mA	4000	14/07/2020, 15:29	150 mA	2*(0.3 + 1.75) = 4s
Test on QM1 & QM2 before open	294 K & 150 mA	Check on the motor 2 and 1	15/07/2020, 09:02	• 150 mA Ok • 100 mA (Close ok Open no) • 130 mA OK • Check on the motor 2 with 150 mA/100 mA/ 80 mA (OK)	2*(0.3 + 1.75) = 4s
Opening Cryostat			09/07/2020, 09:20		

Table 3: list of life time test performed on QM1

The total number of performed activation cycles was at least **28,400**.

A visual inspection by a microscope was recommended and done before the FM performance test. Results are not presented here.

6.4.2 RESOLVED TEST FAILURE EVENTS

In all the failure events indicated in Table 3, the cause of the problems has been attributed by the IKRtech team to the too fast operations of the shutter with consequence excessive heating of the ball bearings. After cooling down indeed the motors started to work again correctly. This problem is addressed in more details in a specific formal and separated document issued by IKRtech.

6.4.3 UNRESOLVED TEST FAILURE EVENTS

Nothing to report.

7. DEVIATIONS

The temperatures of the motors have been discussed and agreed in order to have the value as much as possible close to the inner part of the motor shutter and not on the interface. This is more stressing for the motor, but the test is considered safe and more representative of the real situation experienced by the shutter in flight by the IKRtech team. The slope of the transient regions of the cycles has been discussed and agreed to be higher than the AD1 in order to speed up the testing procedure. The higher slope has not been considered risky for the mechanism.

8. FM TEST DESCRIPTION

8.1 FM RTD PLACEMENT

The reading points of the temperature probes (PT100) used for the FM test are shown in Figure 12.

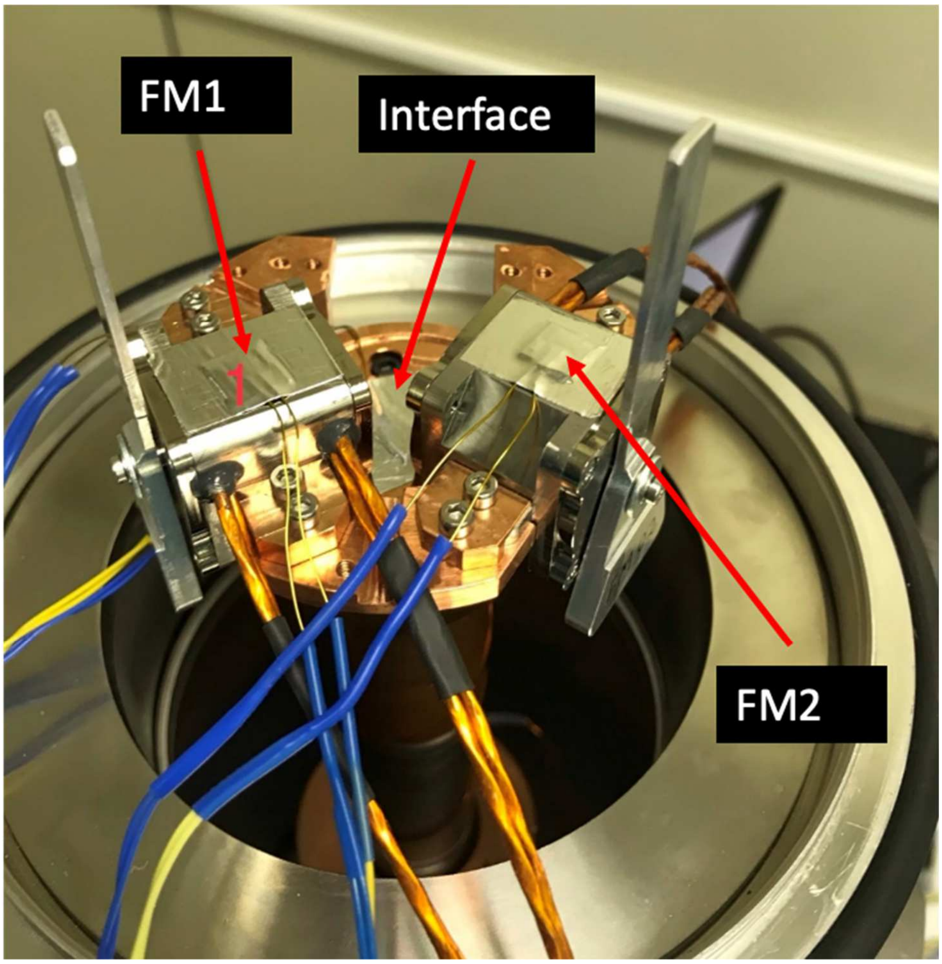

Figure 10: RTDs placement for FM

8.2 FM TEST CYCLES

In Figure 11 a single thermal cycle plot is shown along the key points.

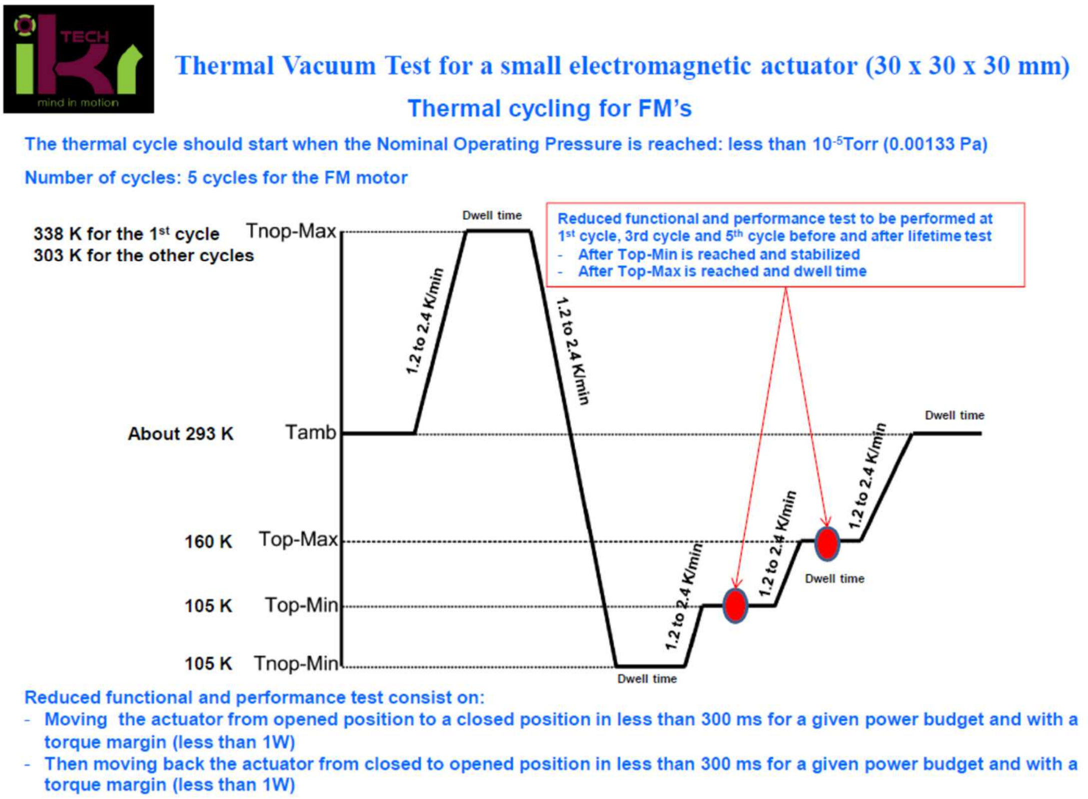

Figure 11: cycles and key points of the FM test

The key points (in red) show the motor temperatures where the shutter is activated for testing. The **Top-Min is 105K**, while the **Top-Max is 160K**.

A total number of **4 cycles are performed**, including an extra hot point for the motor FM1 (used as reference) at **337K** but only for the first cycle at the beginning. A slope of **2.7K/min** has been agreed and planned for all the cycles.

To comply with these motor temperatures, the temperature set point of the controller has been set at 61K, 151K for the above key points and 343K for the hot point. The temperature difference between the motors and the set point temperatures is mainly due to the thermal flux from the ambient to the motor coils. The overall cycles for the temperature set points are shown in Figure 12 where there are also indicated the points (yellow dots) where the shutters shall be activated. Notice that not all the activations are performed for all the cycles due to the exclusion of the night time working hours and sometime only a single test for a cycle has been executed for the same reason.

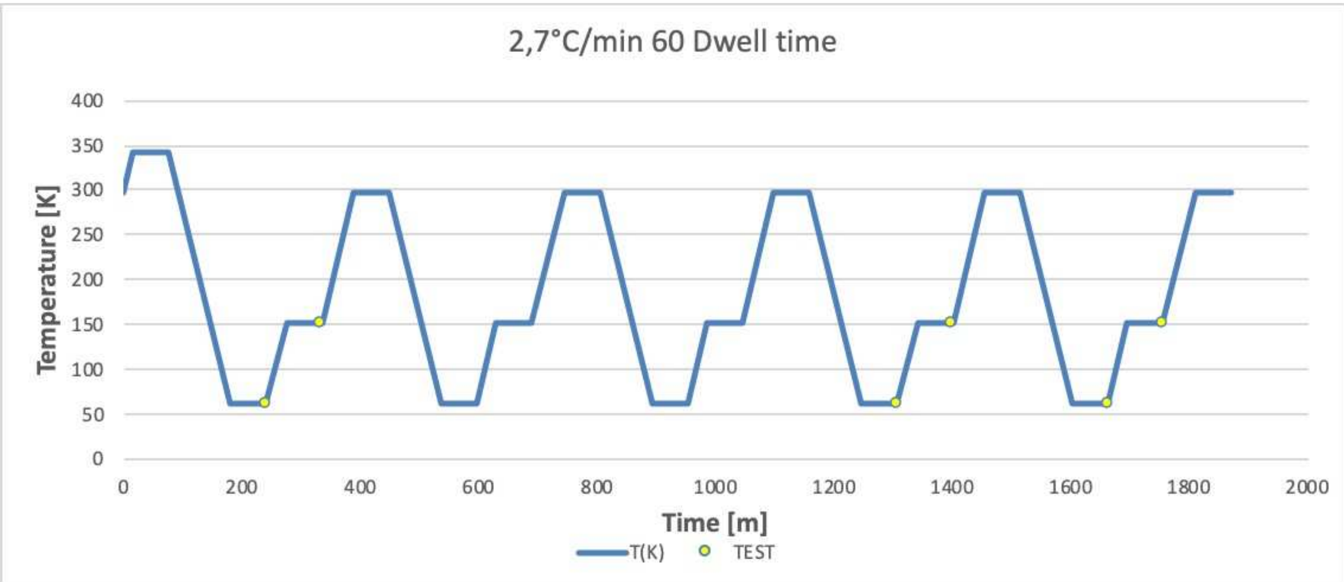

Figure 12: Temperature set point plot for the overall cycles of the FM

8.3 FM TEST RESULTS

The data acquired during the heating are shown in Figure 13 and these are the only available acquired data due to a software problem. Nonetheless all the cycles have been performed regularly. The only data available are in an excel file named IAPS-PLAB-TV-RP-001_Iss1_rev0_FM-data.xlsx.The temperature values recorded by hands during the activations are instead reported in Table 4.

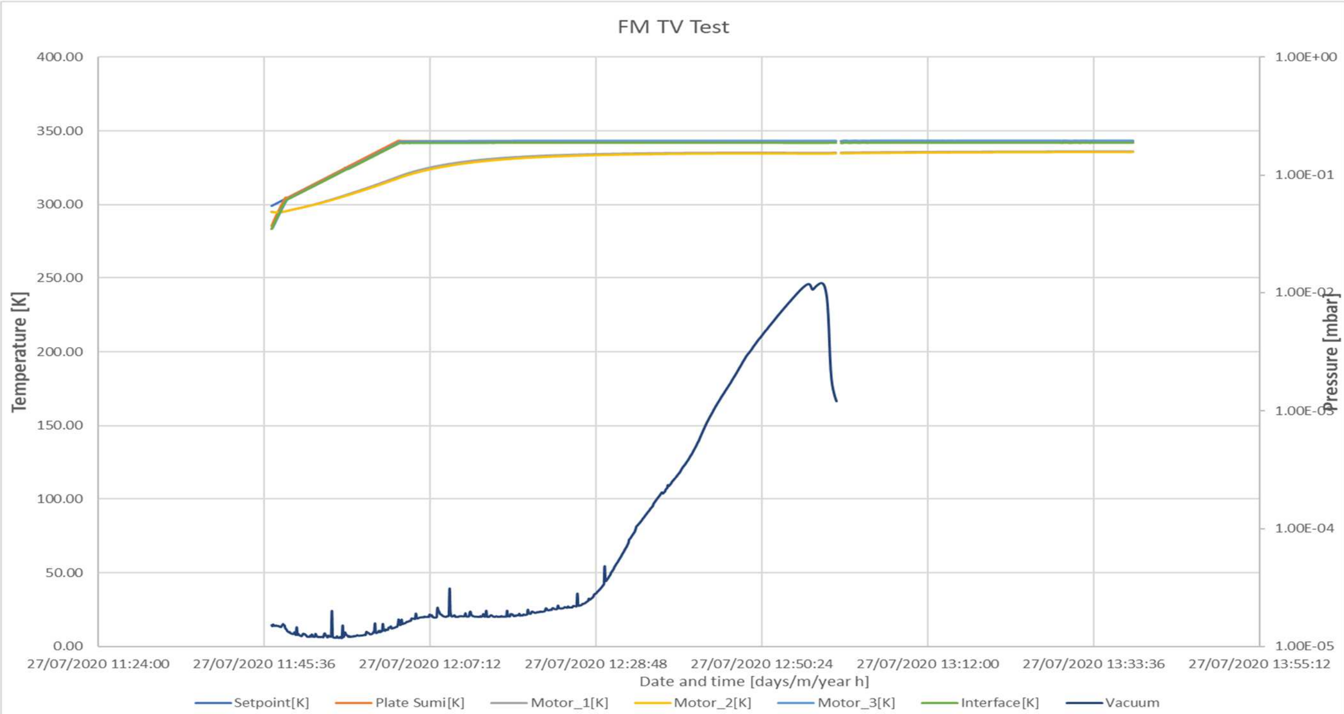

Figure 13: temperature and vacuum data plot for the FM test

In Table 4 the results on all performance tests have been summarized. The first column represents the file name of the video recorded during each performance test, the second the conditions at which the test has been done. The temperatures values were manually recorded. The recording files are available separately and are not referenced here.

VIDEO NAME	Conditions	Motor 1	Motor 2	Data, time
Performance Test_100K_1	T_1= 106.4 K T_2= 105.1 K	✓	✓	27/07/2020, 16:16
Performance Test_165K_1	T_1= 173.1 K T_2= 173.4 K	✓	✓	27/07/2020, 17:46
Performance Test_100K_2	T_1= 105.6 K T_2= 105.5 K	✓	✓	28/07/2020, 09:59
Performance Test_165K_2	T_1= 172.9 K T_2= 172.5 K	✓	✓	28/07/2020, 11:32
Performance Test_100K_3	T_1= 105.8 K T_2= 105.9 K	✓	✓	28/07/2020, 15:54
Performance Test_165K_3	T_1= 172.8 K T_2= 173.2 K	✓	✓	28/07/2020, 17:28
End of test	T_1= 298.2 K T_2= 297.8 K	✓	✓	29/07/2020, 09:01

Table 4: list of shutter activations for FM

8.3.1 RESOLVED TEST FAILURE EVENTS

During the cooling test, the cryo-cooler was blocked due to an overheating. After about 1 hour this inconvenient has been resolved.

8.3.2 UNRESOLVED TEST FAILURE EVENTS

The temperature and vacuum data acquired during the tests were lost due to a software bug and they have not been recovered. Only the temperatures manually recorded are available in the table.

9. DEVIATIONS

The temperatures of the motors have been discussed and agreed in order to have the value has much as possible close to the inner part of the motor shutter and not on the interface. This is more stressing for the motor but the test is considered safe and more representative of the real situation experienced by the shutter in flight by the IKRtech team. The slope of the transient regions of the cycles has been discussed and agreed to be higher than the AD1 in order to speed up the testing procedure. The higher slope has not been considered risky for the mechanism.

10. SUMMARY AND CONCLUSIONS

A thermal qualification test has been successfully performed on two qualification models of the shutters, named QM1 and QM2. The results after the qualification procedure have been considered successfully for the qualification of the shutter.
A life test has also been performed on QM1, with a total cumulative number of cycles of at least 28,400.

Another campaign on the FM shutters has been successfully performed for the acceptance thermal test and the results are declared successfully.