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INTEGRAL

TV Cycling Test of the JEM-X FM 1

Facility report: TOS-MCV/2001/2676/ln/BL

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Thermal Balance and Thermal Vacuum Cycling Test of the JEM-X Flight Model 1

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References

1. Thermal Vacuum Test Procedure for the JEM-X FM1 Instrument, IN-TP-JEM-0008, issue 1, rev. 1
2. JEM-X QM TB/TV Test Report, TOS-MCV/2001/2608/ln/BL
3. Minutes of the Test Readiness Review, 31-08-2001, INT-MN-39872
4. Minutes of the Post Test Review, 7-09-2001, INT-MN-39908

1. Introduction

JEM-X is a scientific payload to be flown on the INTEGRAL spacecraft. JEM-X will measure the X-ray radiation levels. The Integral spacecraft will carry two identical JEM-X units mounted inside the payload module. The up coming test is dedicated to the flight model (FM) #1, consisting of thermal balance phases and thermal cycling in vacuum.
The scope of the test is to verify the thermal design during TB phases and to check the integrity of the instrument during TV cycling. The objectives of the TV test are further to identify any workmanship deficiencies and to perform thorough functional check out of the FM #1.
The JEM-X instrument requires different temperature levels for the conductive and radiative environment. The applicable temperature ranges are (ref. 1):
- non-operating range from -45ºC to +55ºC at the mounting interface (I/F),
- operating range from -30ºC to +40ºC at the mounting interface (I/F),
- non-operating range from -70ºC to +55ºC for the shroud,
- operating range from -70ºC to +25ºC.

These temperature levels correspond to qualification levels imposed by the fact, that the qualification model underwent only 4 cycles during the TB/TV test in January 2001 at ESTEC (ref. 2). The test shall consist of one cycle in the non-operational temperature range including switch-on verification at T_{max} and T_{min} and 3 cycles in the operational qualification temperature range.

2. Test facility

2.1. Description

The Large Vacuum Facility (LAVAF) of the Mechanical Systems Laboratory consists of a horizontal stainless steel cylinder. A shroud - horizontal cylinder, back and door - is mounted internally.
Pumping system:
- 64 m^3/h forepump and 2200 l/s turbo molecular pump,
- pressure gauges covering the range from 10^{-8} mbar to 1000 mbar.

Shroud:
- black painted copper (Chemglaze Z300),
- diameter of 850 mm,
- length of 1750 mm.

The temperature of the shroud is controlled with an Eurotherm temperature controller, type 822. A master unit and two slaves are implemented. The regulation units use a mixture of heated compressed air and liquid nitrogen.The shroud can be set to any temperature between -185ºC and +110ºC.
Cold plate:
- standard plate of 500 mm x 390 mm.

The cold plate is controlled with a similar gas mixing unit working with an

Eurotherm controller 900.
Standard feed troughs are DEUTSCH connectors (37 pins for electrical purposes and 18 pairs of selected thermocouple (TC) wires. Voltage and current signals can be acquired in addition to the temperature sensors by the data acquisition system.

2.2. Preparation

The special cold plate for JEM-X, which was manufactured by VACUTECH BV, Rijswijk, consists of the layers, electrically isolated from each other, an aluminium plate of 8 mm thickness and a copper plate of 5 mm thickness carrying the heat exchanger pipes.
A pre-test of the cold plate and shroud was agreed not to be necessary, because the cold plate is dedicated to JEM-X only and was not used in the mean time. The shroud verification is based on the bake-out run of the facility to be performed prior to the test (ref. 3).
A bundle of 18 TC, type T, i.e. copper/constantan was prepared and checked. They are used to monitor the temperature on JEM-X, the shroud and cold plate. The locations of the TC are defined in ref. 1 and are identical to the QM TB/TV test. The following tables summarises the TC location. The TC's were installed using as a guidance the photographs of the QM test.

MCPS Channel Nº	Location	TC Nº	Connector
1	DFEE -X face, centre	01	1A
2	DFEE -X face, -Z edge	02	2A
3	DFEE +Y face, centre, **reference**	03	3A
4	DFEE Support Bracket +Y/+Z	04	4A
5	DFEE Support Bracket +Y/-Z	05	5A
6	DFEE Top Plate, +Y	06	6A
7	Detector Dome, +Y	07	7A
8	Detector Dome, -Z	08	8A
9	Collimator Ring Support, +Y/+Z, **reference**	09	9A
10	Collimator Ring Support, -Y/+Z	10	10A
11	Detector Support Strut +Y/+Z, mid section	11	11A

Table 1: Thermocouple location

MCPS Channel Nº	Location	TC Nº	Connector
12	Detector Support Strut +Y/+Z, near DFEE	12	12A
13	Collimator	13	13A
14	Mounting I/F, opposite TC04	14	14A
15	Mounting I/F, opposite TC05	15	14A
16	Shroud	16	16A
17	Shroud	17	17A
18	Cold plate	18	18A

Table 1: Thermocouple location

The location of TC09 and TC10 is slightly different compared to the QM test, placing them on the bracket side instead on the taped area in order to avoid a damage of the FEP thermal control tape.
The functionality of 50% of the mounted TC's was verified after installation of the test specimen in the LAVF using a heat gun. Those TC's were 1-3, 7, 9, 11-13, 15, 18, performing without any problem.

Photo 1: TC01 and TC02

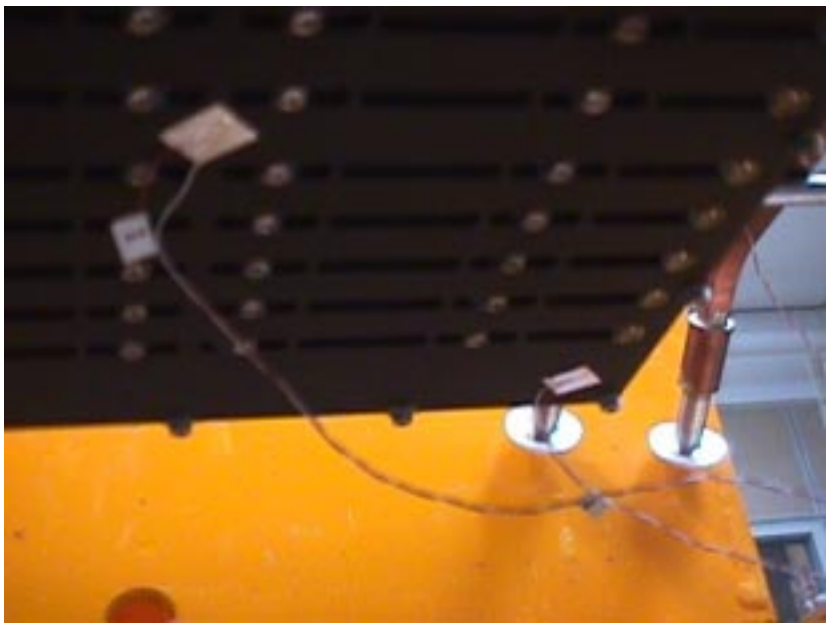


Photo 2: TC 03 and TC 06

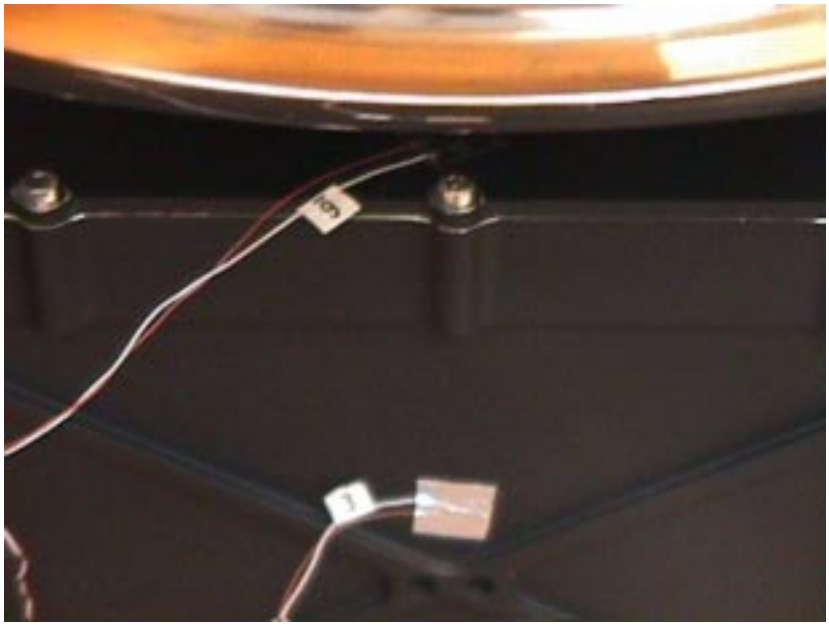


Photo 3: TC 04

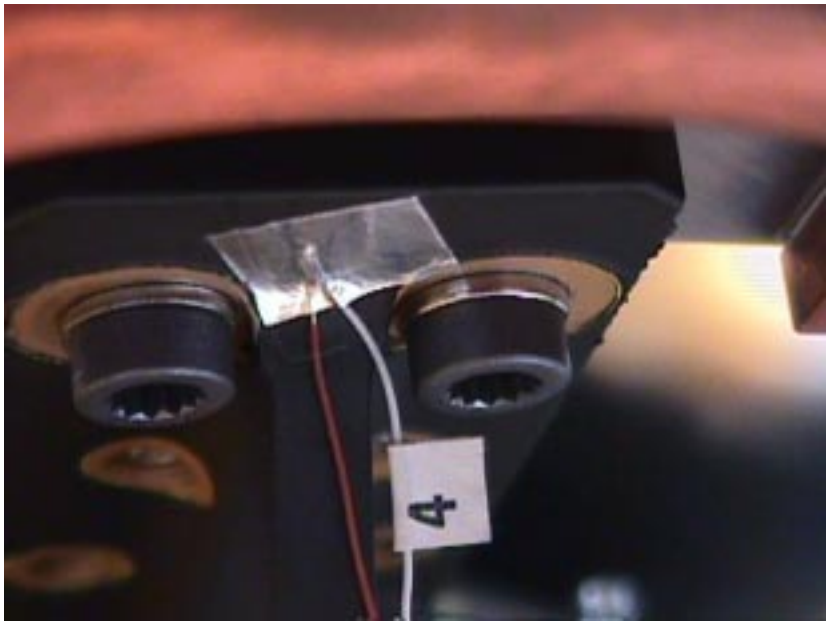


Photo 4: TC 05

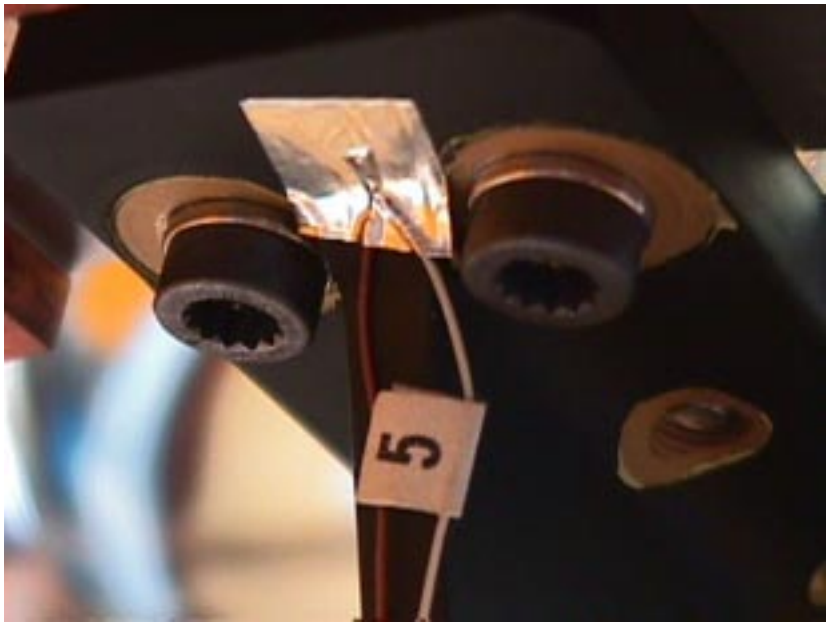


Photo 5: TC 07

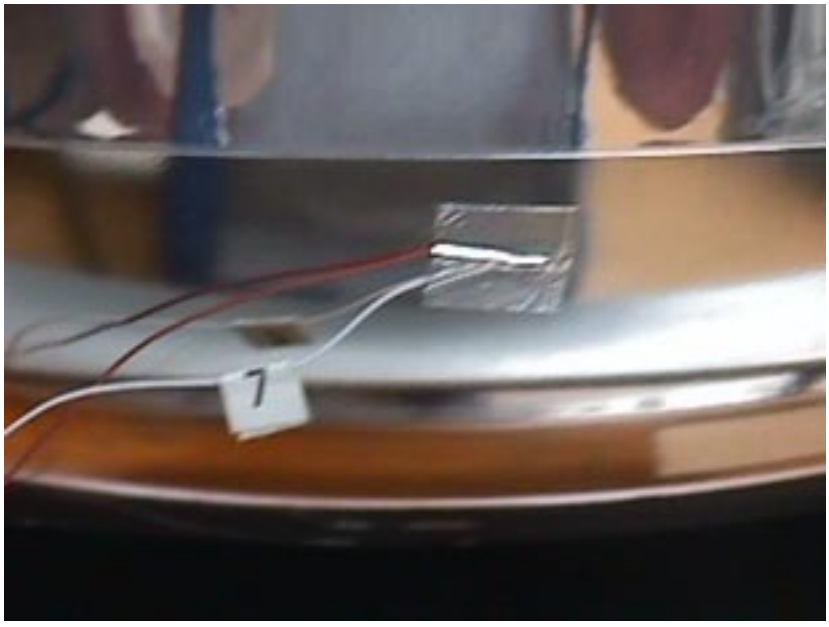


Photo 6: TC 08

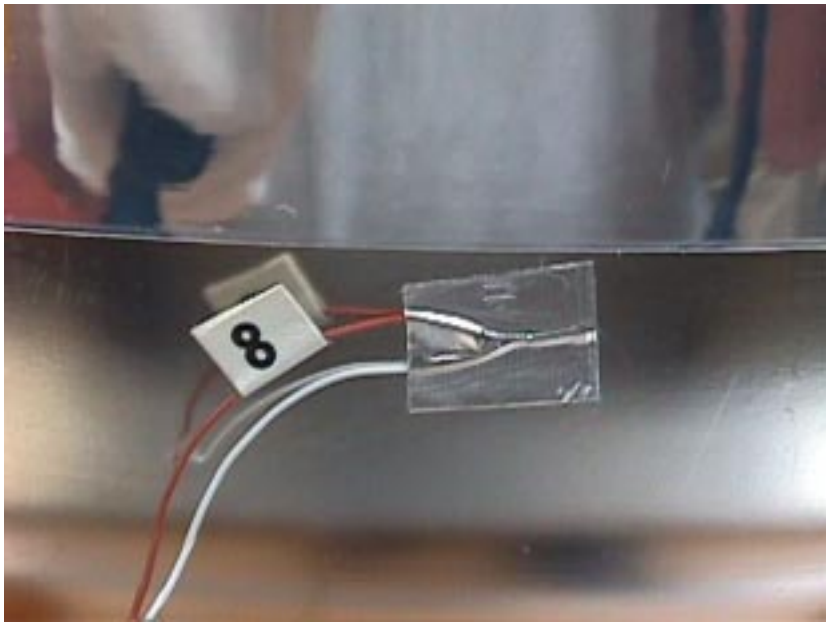


Photo 7: TC 09

Photo 8: TC 10

Photo 9: TC 11 and TC 12

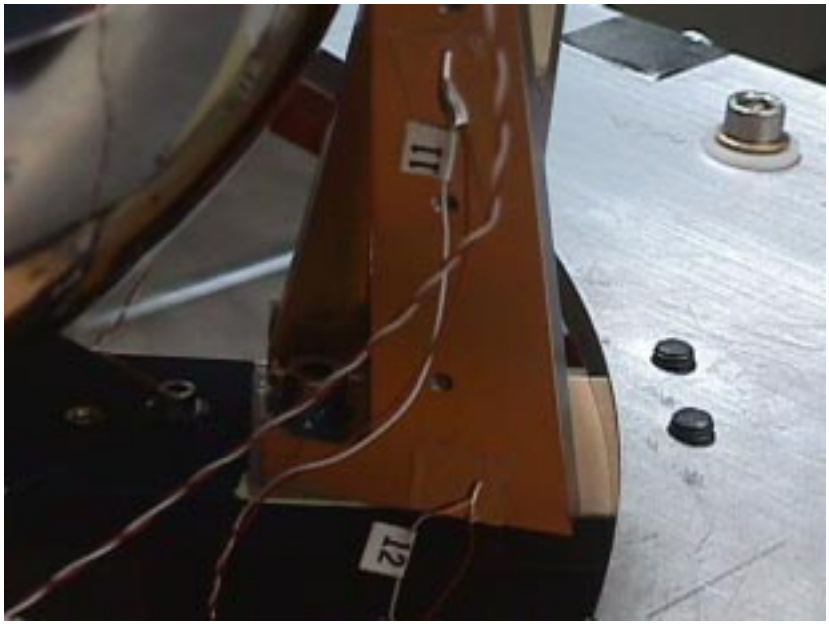


Photo 10: TC 13

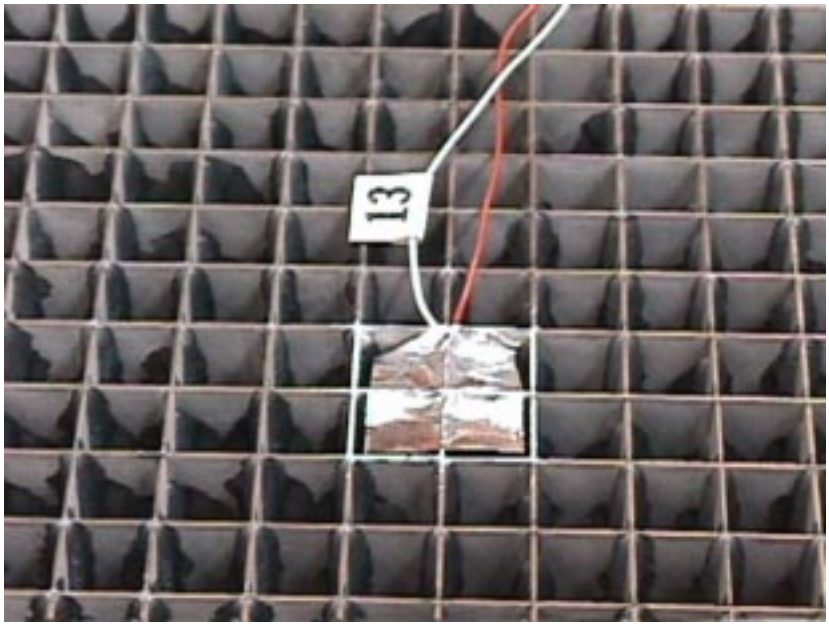


Photo 11: TC 14

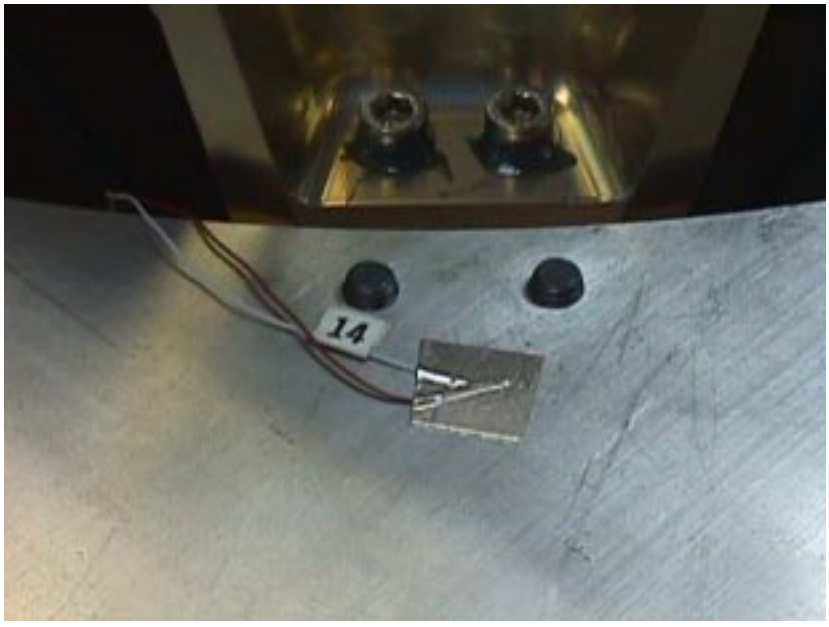


Photo 12: TC 15

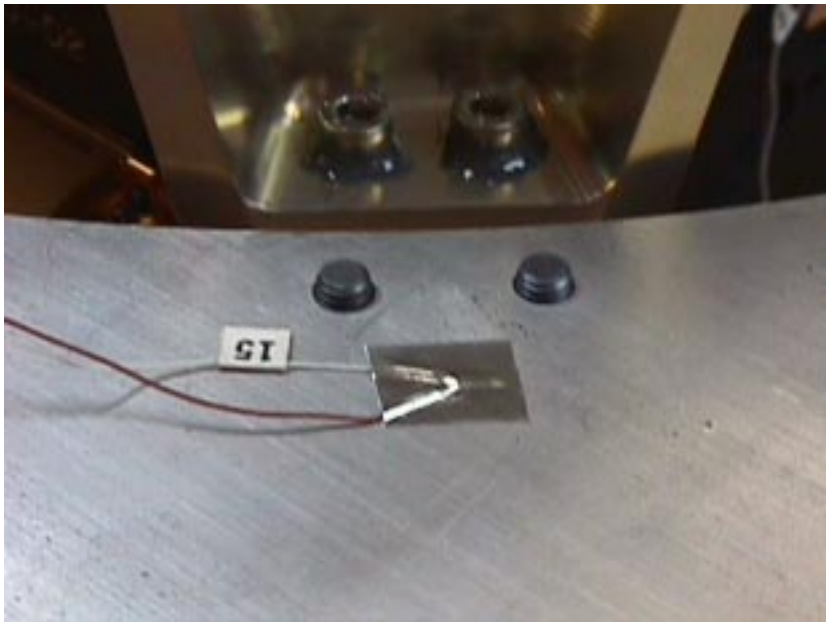
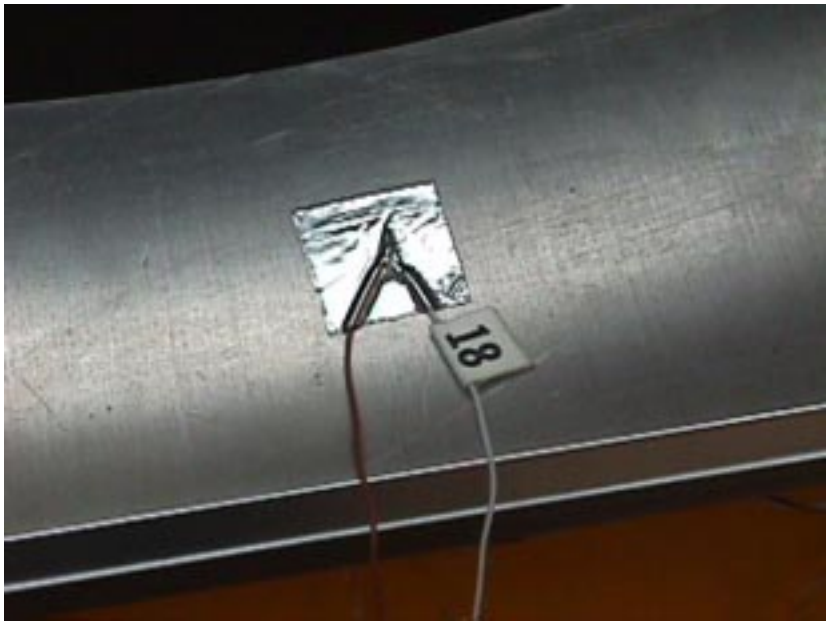


Photo 13: TC 18



2.3. Data acquisition system

The temperatures are recorded on a chart recorder, YOKOGAWA DR230, connected to a PC. The measurement accuracy is ±(0.05% of rdg +0.5ºC). The error of the compensation of the reference junction is ±1ºC. The channel numbers are identical to the TC numbers.
The high vacuum pressure is measured with a Penning gauge. The voltage output is recorded on channel nº 55. The pressure has to be re-calculated using the formula in the range from 10^{-8} mbar to 10^{-4} mbar:

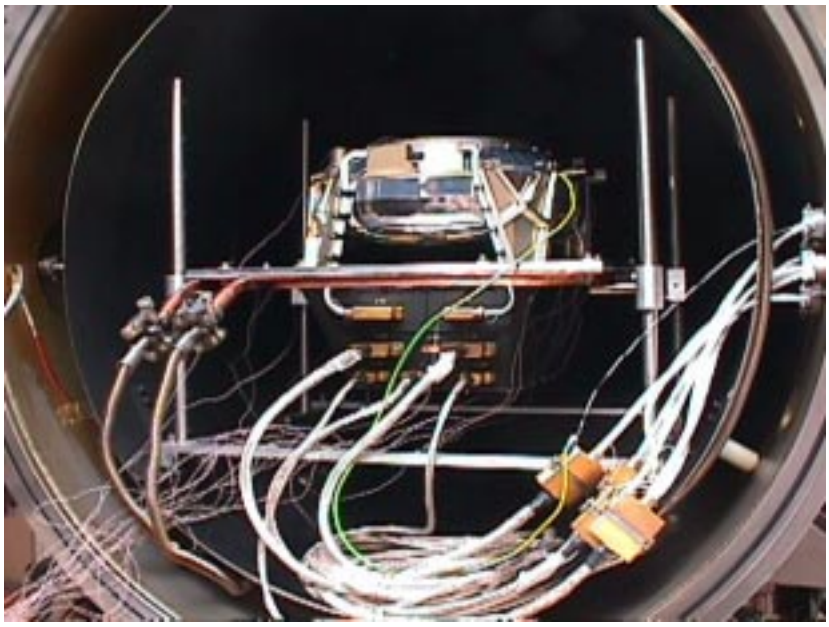
$$\log p = 0.652\ U - 9.48,$$

p - pressure, U - voltage

3. Test specimen

The test specimen is the flight model #1 of the JEM-X instrument.
It was mounted on the cold plate using 8 M6 titanium bolts applying a torque of 6.2 Nm.
The test specimen installed in the LAVAF is shown on the next photo.

Photo 14: JEM-X FM #1 inside LAVAF



4. Test execution

During the Test Readiness Review the requirement for the test tolerances w.r.t. the temperature was waived (ref. 3). The requirements shall be ±5K on the cold plate and ±10K on the shroud.
The test was executed in shared responsibilities. ESTEC/TOS-MCV was in charge of providing the environmental conditions as defined in the test procedure and to register the temperatures and high vacuum pressure. The Danish Space Research Institute (DSRI) was responsible for the performance and functional tests of JEM-X using own equipment.
The TV/TB was started August, 31th 14:30 and finished September, 7th 9:00.

4.1. Test personnel

DRSI: P. A. Jensen (test director),
S. Laursen
S. Brandt

Alenia Spazio: M. Goria

ESTEC: B. Lehmann
S. Roure

4.2. Sequence of events

1. Specimen installation in the LAVAF and functional check
2. Chamber closure and de-pressurisation
3. Execution of non-operational hot dwell followed by the switch on verification
4. Execution of non-operational cold dwell followed by the switch on verification
5. Cold TB phase
6. Start of first TV cycle in the operating temperature range
7. Extension of the fist hot operational dwell to perform the hot TB phase
8. Execution of cycle nº 2 to 4.
9. Chamber re-pressurisation

10. Functional check at ambient and dismounting

4.3. Test procedure deviations

The deviations from the test procedure are provided below.

1. The hot TB phase was shifted to the 2nd hot dwell in order to optimize the test time.

4.4. Facility operation

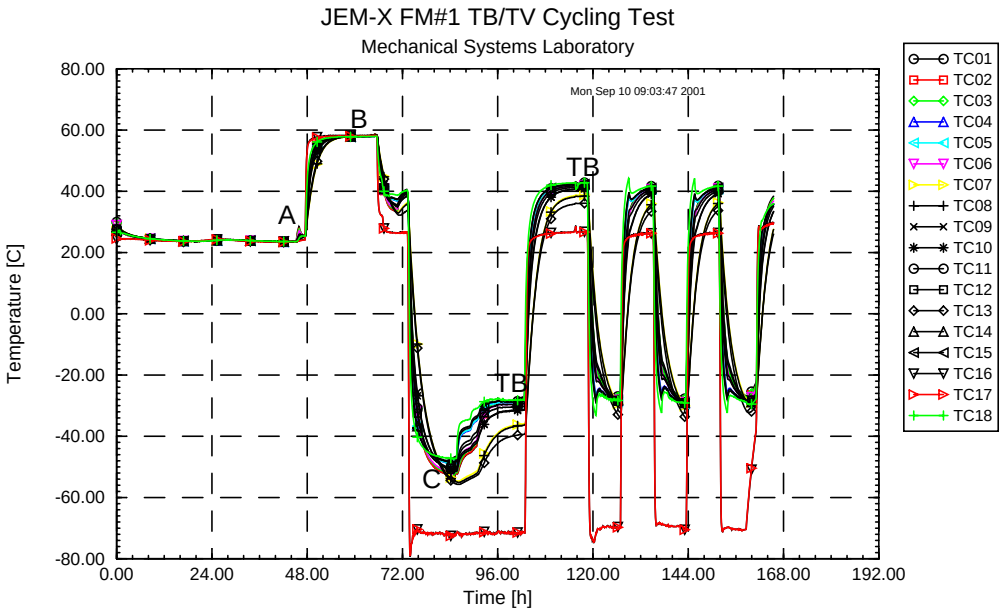
The facility performance was as expected. The pressure stayed below to 10^{-5} mbar during the whole test duration. The threshold for actuating the high voltage supply of the instrument of 10^{-5} mbar was therefore always guaranteed. The actual value was taken from the pressure gauge display prior to unit operation.
The temperature regulation units were programmed with a ramp of 5K/min. and dwell times of 8 hours. The upper and lower limits of the cold plate were increased by 3K and 5K w.r.t. the nominal ones to counteract the influence of the shroud. The controllers of the shrouds were set to 25ºC and -65ºC. To reach a better stabilising of the temperatures during the TV part, the cold plate was boosted for a duration of 2 hours to 55ºC (hot case) and -35ºC (cold case).

5. Results

5.1. Test summary

The temperatures of the test are provided in figure 1. The long exposure at room temperature is a result of the initial conditions during the weekend. A verification (calibration) of the thermister readings of the instrument was performed at the end of the following dwells at room temperature (A), hot non-operational (B) and cold non-operational (C). The thermal balance phases are marked on the plot with TB.

Fig. 1: Test summary



The temperatures imposed by the shroud and cold plate during the test together with the reference TC's, i.e. TC03 and TC09, are provide below. The temperature requirements were realised with a good accuracy.

Fig. 2: Temperatures of cycle #1

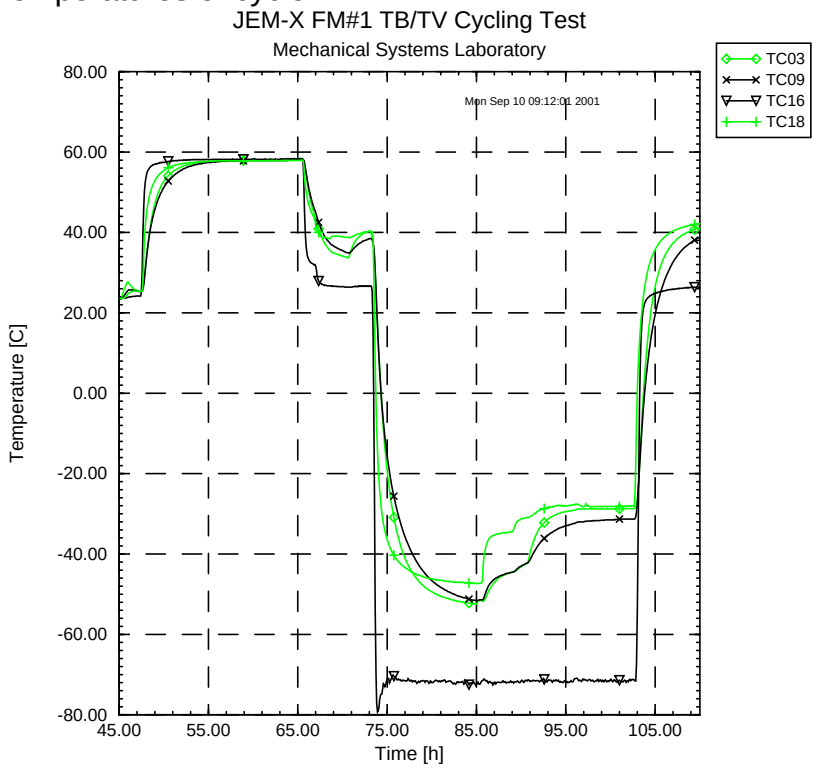
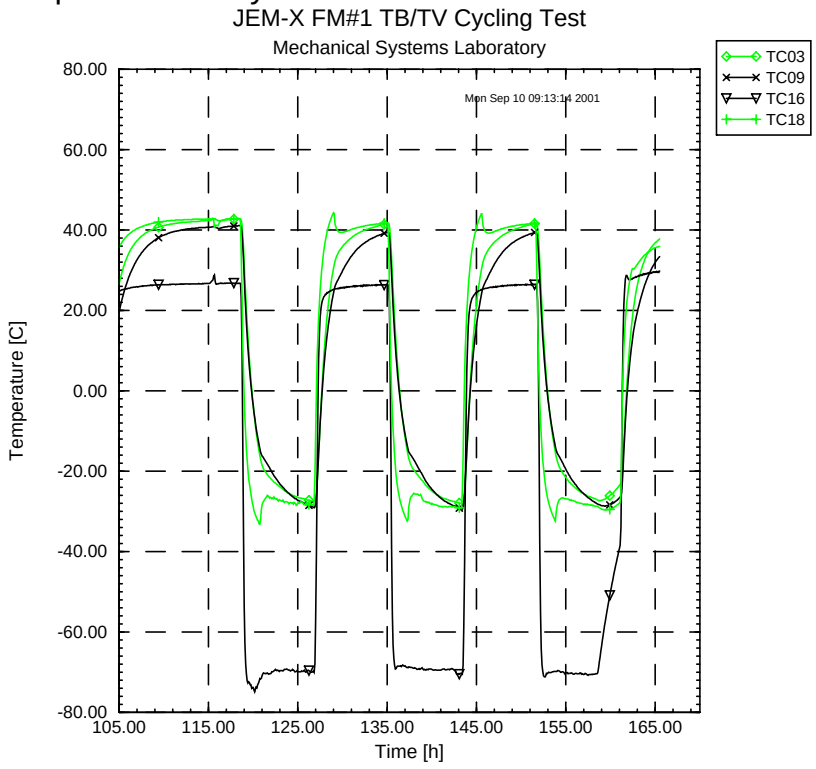


Fig. 3: Temperatures of cycles #2 - #4



5.2. Temperature stabilising during the TV test

The test procedure aimed for a change rate of less than 1K/h during the dwell at the minimum and maximum temperatures. It can be concluded, that the DFEE temperature was in line with the imposed conditions. Whereas, the collimator did not react as fast as the DFEE. It is a results of the relative good de coupling of the sensor unit by conductance (bracket) and radiation (low emissivity). Typical plots are provided below.

Fig. 4: Details of cold dwell (cycle #2)

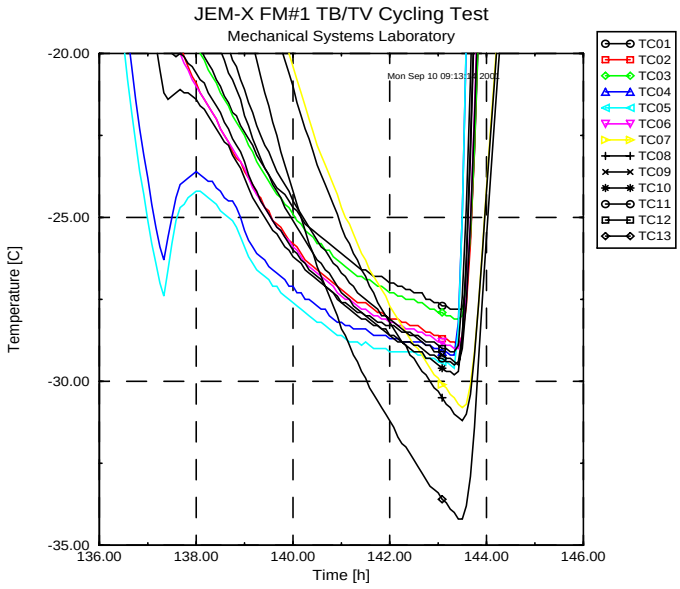
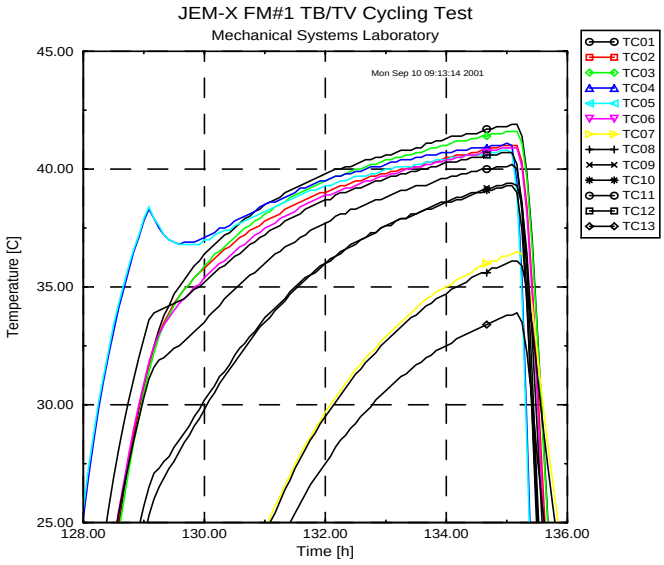


Fig. 5: Details of hot dwell



5.3. TB phases

The results of the cold and hot TB phase are provided in the table. The table contains all temperature sensors at t_{end} and t_{end-4h} in order to assess the stabilising. The data are taken from 4-Sep-2001 at 21:56 for the cold TB and from 5-Sep-2001 at 13:55 for the hot TB.

TC nº	T_{end} [ºC]	T_{end-4h} [ºC]	ΔT/4h	T_{end} [ºC]	T_{end-4h} [ºC]	ΔT/4h
TC01	-28.50	-28.40	-0.1	42.50	43.00	-0.5
TC02	-29.50	-29.40	-0.1	41.70	42.10	-0.4
TC03	-28.80	-28.70	-0.1	42.30	42.80	-0.5
TC04	-28.90	-28.80	-0.1	42.00	42.30	-0.3
TC05	-29.30	-29.20	-0.1	41.70	42.00	-0.3
TC06	-29.60	-29.50	-0.1	41.70	42.10	-0.4
TC07	-36.30	-35.90	-0.4	38.40	38.90	-0.5
TC08	-36.70	-36.30	-0.4	38.00	38.50	-0.5
TC09	-31.40	-31.20	-0.2	40.60	41.10	-0.5
TC10	-31.70	-31.40	-0.3	40.50	40.90	-0.4
TC11	-30.40	-30.30	-0.1	41.20	41.50	-0.3
TC12	-29.60	-29.40	-0.2	41.70	42.00	-0.3
TC13	-39.70	-39.30	-0.4	35.60	36.10	-0.5
TC14	-28.60	-28.50	-0.1	42.30	42.50	-0.2
TC15	-28.70	-28.60	-0.1	42.10	42.30	-0.2
TC16	-71.70	-71.20	-0.5	26.60	26.80	-0.2
TC17	-71.70	-71.20	-0.5	26.50	26.70	-0.2
TC18	-28.10	-28.10	0.0	42.70	42.80	-0.1

Table 2: TB phases

The stabilising is clearly within the requirement of <1K/4h. The results of the thermal mathematical model runs indicated a good correspondence between predictions and measurements in the range of a few degrees (ref. 4). Therefore it was concluded, that the TB phases can be deleted for the MF #2 test.

6. Conclusion

The TB/TV test of the JEM-X FM #1 was performed during September 2001 in the Mechanical Systems Laboratory (TOS-MCV) at ESTEC.
The test phases were performed in accordance with the requirements of the test procedure. The total number of TV cycles was four, executed within the qualification temperature range The selected ramp rate of 5ºC/min guaranteed the desired change rate of ≤1ºC/min on the instrument. The dwell time of 8 hours is sufficient to satisfy the stabilising requirement of ≤1ºC/h, if the cold plate is boosted by 10 degrees above the limit for 2 hour during the transition.
The TB phase temperatures confirmed the adequacy of the thermal mathematical model as demonstrated by the results.
The bake out of the facility at 80ºC in preparation of the test improved the initial vacuum level during the non-operational hot soak back significantly.
In general, it was concluded, that the imposed environment was adequate to achieve the objectives of the TB/TV test for the JEM-X FM #1.