SPIRE PFM4/PFM5

THERMAL BALANCE TEST REPORT

PREPARED BY:	A.S. GOIZEL	RAL	13/03/07	? Signature Not Verified Digitally signed by Anne-Sophie Goizel Date: 2007.03.13 11:10:21 Z
CHECKED BY:	B. SHAUGHNESSY	RAL		? Signature Not Verified Digitally signed by Bryan Shaughnessy Date: 2007.03.13 12:24:41 Z
APPROVED BY:	E. SAWYER	RAL		

“Page left intentionally blank”

CHANGE RECORD

Issue	Date	Section	Change
Draft A	01/03/07	-	New Document.
Issue 1	13/03/07	-	First Issue.

ACRONYMS

Acronym	***Definition***
AD	Applicable Document
BDA	Bolometer Detector Arrays
BSM	Beam Steering Mechanism
CBB	Cold Black Body
CQM	Cryogenic Qualification Model
DRCU	Digital Readout Control Unit
DTMM	Detailed Thermal Mathematical Model
EGSE	Electronic Ground Support Equipment
FM	Flight Model
FPU	Focal Plane Unit
FS	Flight Spare
HCSS	Herschel Common Science System
HeI	Helium I
HeII	Helium II
HOB	Herschel Optical Bench
I/F	Interface
IIDB	Instrument Interface Document Part B
IRD	Instrument Requirement Document
ILT	Instrument Level Testing
JFET	Junction Field Effect Transistor
L0	Level-0
L1	Level-1
L2	Level-2
L3	Level-3
LN2	Liquid Nitrogen
MGSE	Mechanical Ground Support Equipment
PFM	Proto Flight Model
RD	Reference Document
SMEC	Spectrometer Mechanism
SCU	Subsystem Control Unit
SOB	SPIRE Optical Bench
SPIRE	Spectral and Photometric Imaging Receiver
SVR	Science Verification Review
TBT	Thermal Balance Test
VM	Virtual Machine

CONTENTS

LIST OF TABLES

LIST OF FIGURES

1 INTRODUCTION

This document summarises the thermal performance of the SPIRE Proto-Flight Model (PFM) measured during the fourth and fifth instrument test campaigns which took place at RAL in November/December 2006 and February/March 2007 respectively.

2 DOCUMENTS

2.1 Reference Documents

ID	Title	Number
RD1	PFM4 Thermometers 0-5.xls	D. Smith 12/10/06
RD2	PFM4 Thermometer C2T Issue 1.1.xls	D. Smith 28/02/07
RD3	PFM As Built Configuration List	SPIRE-RAL-DOC-002326 Issue 2.8
RD4	SPIRE PFM4 Thermal Balance Test Specification	SPIRE-RAL-MEM-002722 Issue 1
RD5	Cooler Recycle Command List Specification	SPIRE-RAL-NOT-002771 Issue 4.10
RD6	SPIRE Science Verification Review Thermal Performance	SPIRE-RAL-REP-002557 Issue 2
RD7	PFM4 Thermometers 1-0.xls	D. Smith 18/10/06
RD8	PFM4 Sensor Characterisation Post-Processing.xls	A. Goizel 11/12/06

Table 2-1 - Reference Documents

2.2 Applicable Documents

ID	Title	Number
AD1	Instrument Interface Document Part A	SCI-PT-IIDA-04624 3.3
AD2	Instrument Interface Document Part B - SPIRE Instrument	SCI-PT-IIDB/SPIRE-02124 Issue 3.2
AD3	SPIRE Instrument Requirement Document	SPIRE-RAL-PRJ-000034 Issue 1.3
AD4	SPIRE Cryogenic Thermal Design Requirements	SPIRE-RAL-PJR-002075 Issue 1

Table 2-2 – Applicable Documents

3 PFM4 TEST CAMPAIGN OVERVIEW

3.1 PFM4 Thermal Balance Test Campaign Objectives

The following objectives were defined for this test campaign:

- Verify the cooler performance during recycling has returned to normal following the change of MGSE L0 straps (HR-SP-RAL-NCR-150),
- Complete the fine tuning of the cooler recycling VM control parameters,
- Perform a “hot” recycling (with both heat switches opened) and confirm whether this process could be used to decontaminate the detector should an helium leak take place in the flight cryostat,
- Complete the flight temperature sensors calibration with the AC bridge (HR-SP-RAL-NCR-155),
- Verify the Photometer JFET temperature gradient during operation (HR-SP-RAL-NCR-158),
- Check PFM SMEC operation and power dissipation profiles,
- Perform a cooler hold time test with a 1.7K, 5K thermal environment.

3.2 Changes to the Cryostat/instrument Built Standard

The following changes have been implemented between the PFM3 and the PFM4 test campaigns:

- New L0 MGSE straps have been fitted to the cooler and spectrometer L0 enclosure. These new straps now include a flight representative bolted interface to the cooler and spectrometer enclosure (including light baffle).
- Some of the EGSE sensors have been upgraded and/or repaired since PFM3. The PJFET was fitted with three sensors (versus two during PFM3) to provide a better idea of where the temperature gradients are taking place. Please refer to [RD1] for additional information about the sensors configuration.
- The PFM SMEC has been fitted to the instrument for the first time. Further details about the instrument standard build can be found in [RD3].

3.3 Summary of Cryostat Operations

Table 3-1 gives an overview of the cryostat operation timeline which took place during the PFM4 test campaign.

Cryostat Warm-up	**Start Date**	**Completed**
Cryostat Cooldown to 4K	01/11/06	07/11/06
Cryostat at 1.7K-4K	08/11/06	08/11/06
L0 warmed up to 4K to investigate issue with L0 stage instabilities	11/11/06	12/11/06
Cryostat L0 manostat left indefinitely opened to avoid instabilities in L0 temperature stage. L0 running at ~1.55K as a result (instead of 1.7K)	13/11/06	Until end of test campaign
Cryostat left over week-end with no top-up of the L0 He tank as part of continuation of L0 stage instabilities investigation.	18/11/06	19/11/06
Note: telemetry stopped working properly during this period	18/11/06 ~04:00	20/11/06 ~16:00
Start of instrument warm-up	15/12/06	-

Table 3-1 – Summary of Cryostat Operations

Important Note: A leaking needle valve has been found to be the cause for the instabilities experienced with the cryostat L0 temperature stage. As a result, the test campaign has been run with the manostat fully opened at all times from the 13/11/06 to ensure a stable L0 stage. This also means that the cryostat L0 temperature has been running at ~1.55K instead of the nominal 1.7K, thus affecting the thermal tests.

3.4 Overview of Thermal Tests Performed

All tests from the PFM4 Thermal Test Specification [RD4] were completed successfully with the exception of the nominal thermal balance test which could not be completed due to issues with the temperature control of the cryostat L0 stage.

Test Name	**Start Date**	**Completed**	**Issues / Test Limitations**	**Report Section**
First Recycling	08/11/06	08/11/06	The cooler performance during recycling have returned to normal following the change in MGSE L0 straps	4.1.1
Automated Cooler Recycling and Fine Tuning	17/11/06	11/12/06	The automated cooler recycling is working fine.	4.1.2
Hot Recycling	13/11/06	13/11/06	Encouraging results were obtained on prime side.	4.1.4
	04/12/06	04/12/06	Hot recycling doesn't work on redundant side.	
Flight Temperature Sensors Calibration	21/11/06	21/11/06	Completed on prime side.	4.2
	11/12/06	11/12/06	Completed on redundant side.	
	11/12/06	11/12/06	Completed on mechanism prime.	
Thermal Balance Test Nominal Case	02/12/06	04/12/06	A cooler autonomy test case was run instead with the L0 stable at 1.55K.	**Error! Reference source not found.**
	08/11/06	12/11/06		

Table 3-2 –Thermal Balance Tests Performed During PFM4

The results and conclusions from each test will be described in more details in the following sections.

4 PFM4 THERMAL TEST RESULT

4.1 Cooler Recycling Test Results

4.1.1 First Cooler Recycling – Performance Check

During the PFM3 test campaign, some issues were encountered with the cooler performance during recycling i.e. the shunt and evaporator were running at warmer temperatures than before and a degradation of the bolted interface conductance between the cooler heat switches and the L0 GSE straps seemed at the time to be the most likely cause (see HR-SP-RAL-NCR-150 for more details). A new set of L0 MGSE straps (with non-degraded interfaces) was therefore implemented before the PFM4 test campaign in order to validate this statement. The first cooler recycling of the FPM4 test campaign took place on the 8th November and was completed manually (without automated script) with the L0 temperature stage maintained at 1.7K. Figure 4-1 below compares the temperature profiles for the shunt and evaporator during the start of condensation phases for recyclings performed during the last three PFM test campaigns. The figure shows that the cooler temperature profiles during PFM4 match those from PFM2, whereas the PFM3 profiles are warmer (i.e. degraded performance).

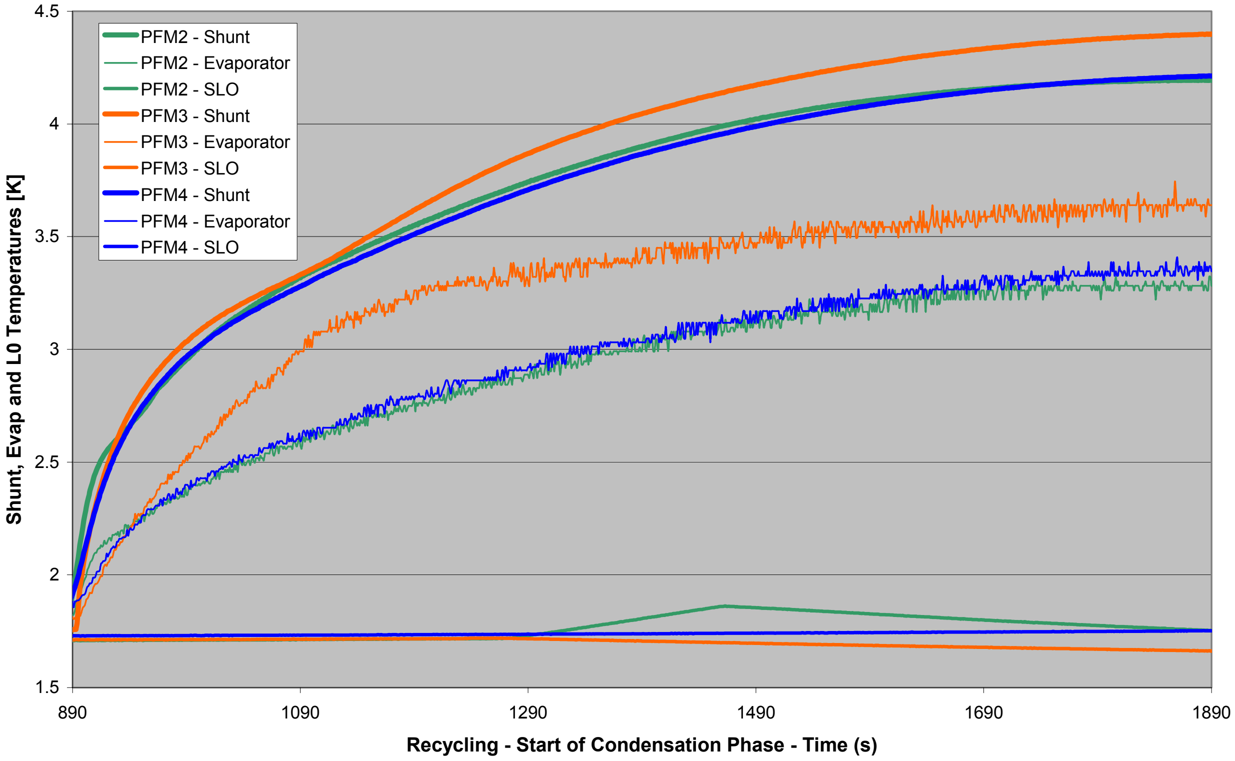


Figure 4-1 – Cooler Temperature Profiles during Recycling in PFM2, PFM3 and PFM4 test campaigns

Note: the SLO temperatures are just there to provide an indication of the L0 stage temperature at the time of recycling. It shows that although the PFM3 cooler temperatures were warmer, the L0 stage was similar or slightly cooler.

Figure 4-2 on the following page compares the temperature gradients measured between both the evaporator (square marker) and the shunt (triangular markers) with the top of the L0 MGSE evaporator strap at the peak of condensation phase for recyclings performed during PFM2 (orange and red markers), PFM3 (blue and pink markers) and PFM4 (green markers). Again, the data show that the cooler PFM4 performance is back to the original PFM2 performance (if not slightly better).

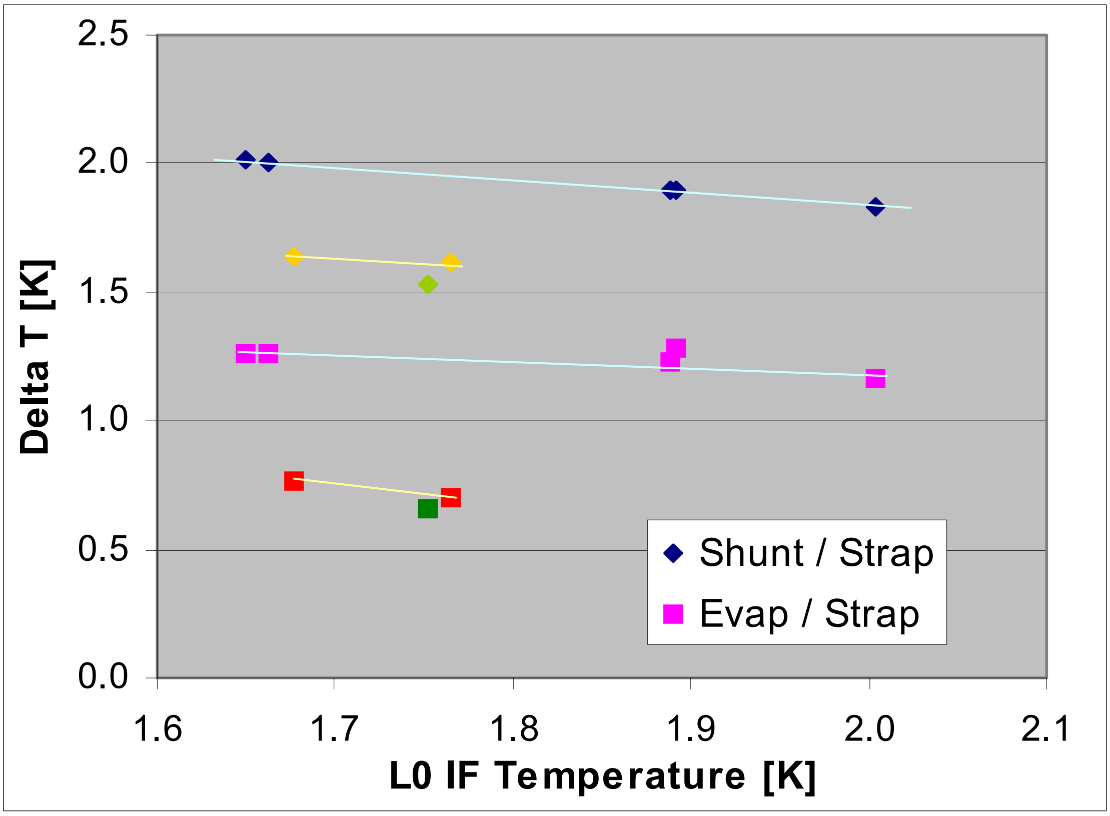


Figure 4-2- Shunt/Evaporator to L0 strap Gradients During Condensation Phase Peak

These test data have allowed to confirm that when presented to “non-degraded” thermal strap, the cooler performance have returned to normal and therefore that this degraded behaviour should not be present in flight (as the flight straps will only have been subjected to a few integration cycles).

4.1.2 *Automated Recycling Performance*

Figure 4-3 and Figure 4-4 show the temperature profile of the cooler sorption during the condensation phase, with a manual and controlled recycling. One can see that the bang-bang approach allows a better control the pump temperature around the 45K point. Additional fine tuning (as part of the PFM5 test campaign) could further improve the pump profile by ensuring it remains above 45K at all time.

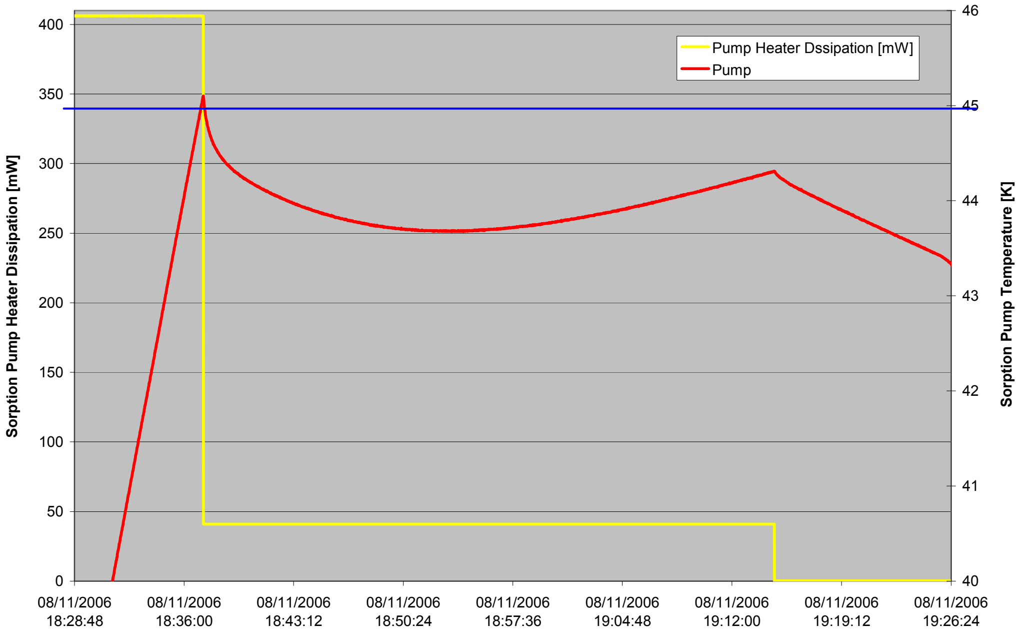


Figure 4-3 – Pump Temperature Profile during Manual Recycling

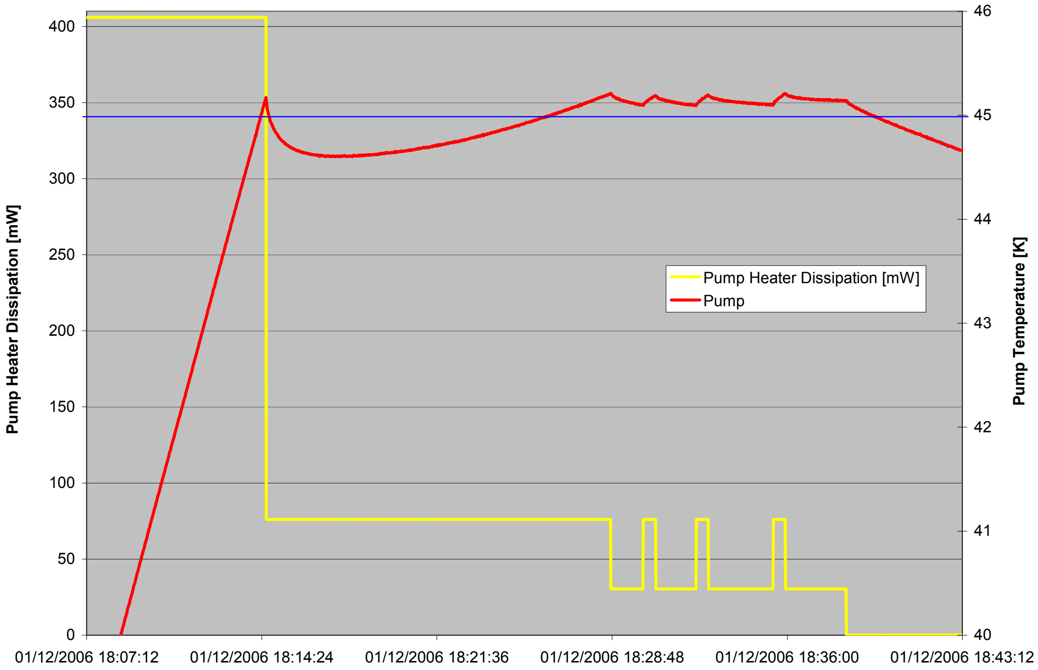


Figure 4-4 - Pump Temperature Profile during Controlled Recycling [RD10]

4.1.3 Prime versus Redundant Recycling Performance

The cooler recycling was performed for the first time using both the prime and the redundant side of the instrument (i.e. prime or redundant sensors and heaters on cooler). This allowed to check that the cooler performance was the same on either side. Some differences were observed however for the evaporator heat switch temperature profile. The following Figure 4-5 and Figure 4-6 describe the temperatures recorded during cooler recyclings performed on the Prime and Redundant sides of the instrument as part of the PFM4 test campaign.

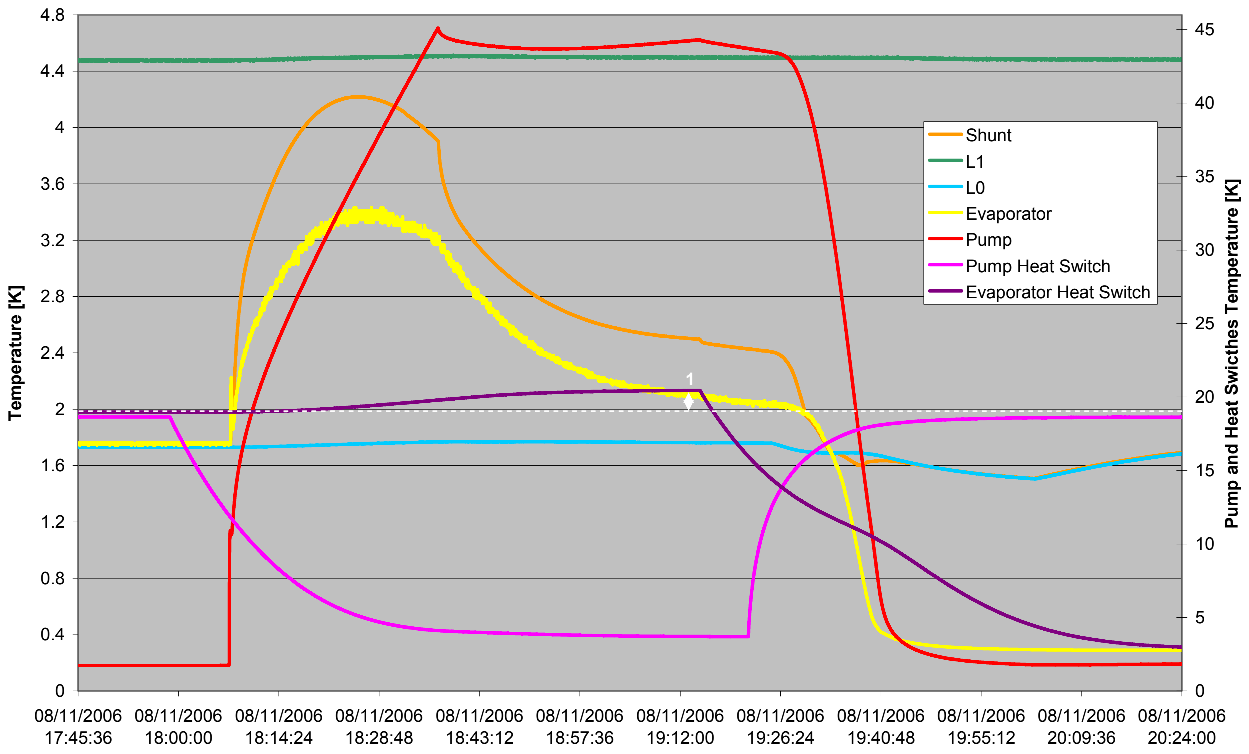


Figure 4-5 – Cooler Recycling on Prime Side with Level 0 at 1.7K

Observations:
The evaporator heat switch was already ON at the start of the recycling as indicated by its sorption pump temperature at 19K. Its temperature increased from a nominal 19K (with 0.8mW applied on the switch and the pump temperature at 1.7K) up to 20.1K at the end of the condensation phase during which the pump is maintained to 45K (as indicated by the marker 1).

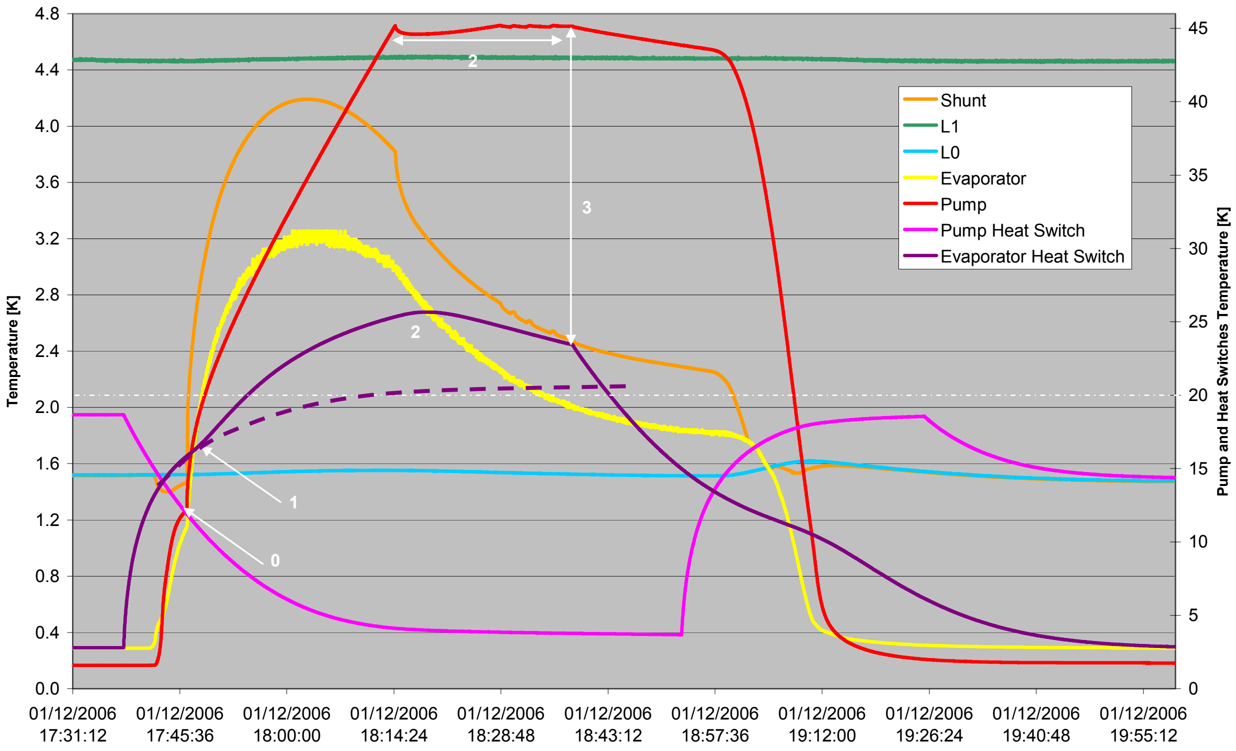


Figure 4-6 – Cooler Recycling on Redundant Side with Level 0 at 1.55K

Observations:

In this case, the evaporator heat switch was OFF at the beginning of the recycling and appeared to be warming up nominally when subjected to 0.8mW. A sudden change in the heat switch temperature profile was detected however shortly after the start of the pump warm-up (as indicated by marker 1). The evaporator heat switch sorption pump temperature increased up to 25.7K (as indicated by marker 2) during the condensation phase during which the pump is maintained at ~45K (with 0.8mW still applied on evaporator heat switch). After reaching a peak at 25.7K, the switch appears to start cooling down again, despite that fact that the pump is still at 45K. This seems to suggest that the evaporator heat switch temperature is driven by the voltage applied to the pump heater rather than the pump temperature itself i.e. shortly after 2, the voltage to the pump heater was reduced as part of the bang-bang control.

Conclusions:

The evaporator heat switch sorption pump appears to be warming up when the pump heater is being powered up during recycling. This behaviour is even more pronounced when the recycling is performed on the redundant side of the instrument. This suggests that pump heaters (prime and redundant) wires are somehow in contact with the evaporator heat switch sorption pump which then warms up from joule dissipation from the wires when the pump heaters are used. The redundant pump heater wires are in better contact with the evaporator heat switch sorption pump than the prime ones, thus explaining the difference in heat switch temperature profile during recyclings performed on the prime or redundant side of the instrument. The evaporator heat switch behaviour is not nominal and an NCR has been raised to keep track of this behaviour (HR-SP-RAL-NCR-166). It does not however prevent the cooler from being recycled nor does it degrade the recycling performance in any way i.e. the evaporator heat switch needs to be ON (with its sorption pump temperature above 15K) when the cooler pump is warmed to 45K, the final evaporator heat switch temperature doesn’t affect the switch ‘ON performance’ as long as it is above 15K (if anything, warmer temperature mean a more efficient heat switch conductance and/or that the switch heater dissipation could be reduced).

4.1.4 Hot Recycling for 300mK System Decontamination

"Hot recyclings" (with both the pump and evaporator heat switches "OFF" i.e. opened) were attempted for the first time during the PFM4 test campaign, both on the prime and redundant sides of the instrument. This "hot" recycling aims at maintaining the evaporator (hence the 300mK detectors) at a temperature above 4K for a certain period of time in the hope that any potential helium contamination could be removed from the detector. The following Figure 4-7 and Figure 4-8 describe the cooler temperature profiles recorded during these "hot" recyclings.

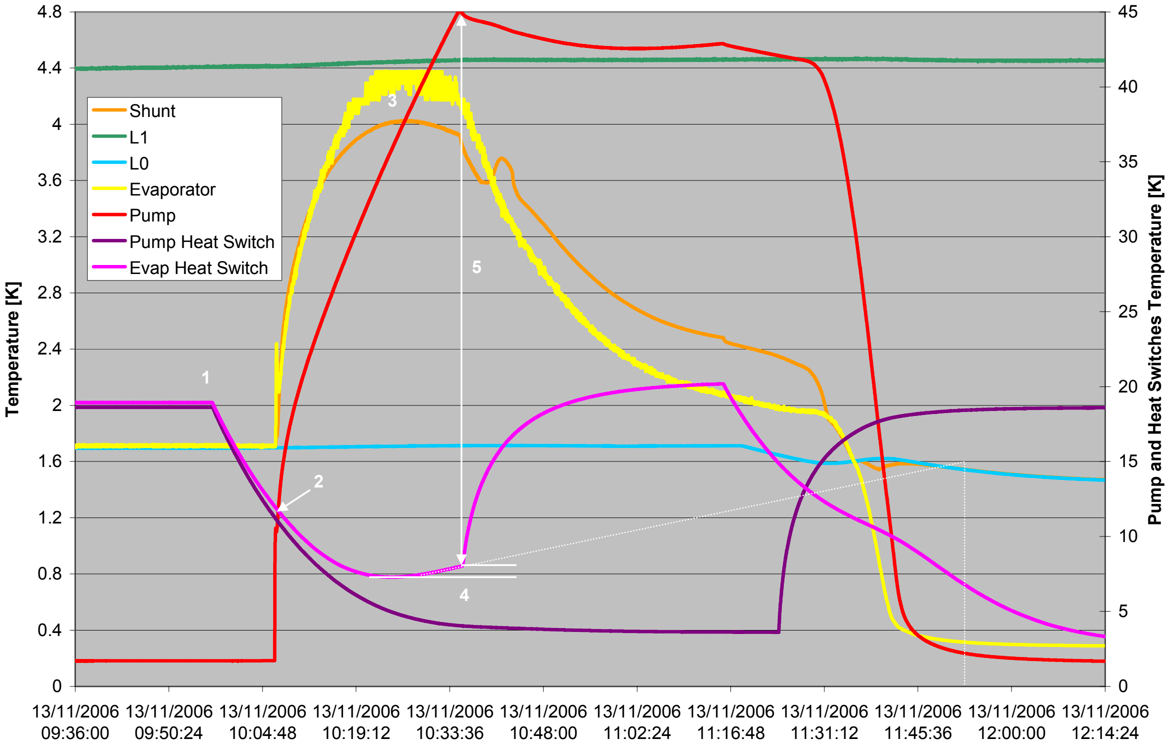


Figure 4-7 - Decontamination case on Prime Side with Level 0 at 1.7K

Observations:

1 – Both heat switches are being turned OFF in preparation for the hot recycling.

2 – When both heat switch sorption pump temperatures have reached below 12K, the hot recycling is initiated.

3 – While the pump is being heated up to 45K, the evaporator warms up and peaks at 4.3K (versus 3.4K during a normal recycling with the evaporator heat switch closed).

4 – As the pump is being warmed up, one can see that the evaporator heat switch sorption pump also starts warming up even so its heater is OFF (switch temperature increased by ~1K in 13 minutes). This confirms the observations and conclusion from section 4.1.3 that the evaporator heat switch sorption pump tends to warm up when the pump heater are in used.

5 – End of hot recycling test and return to normal operating conditions for nominal recycling.

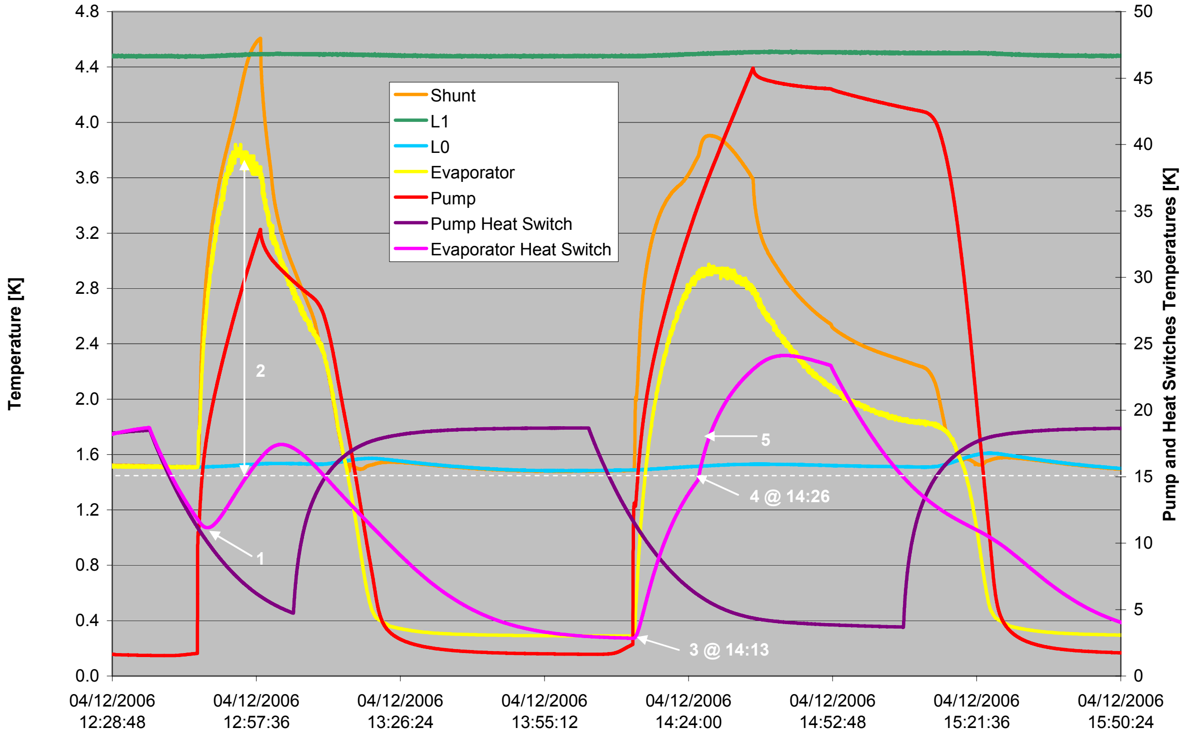


Figure 4-8 - Decontamination on Redundant Side with Level 0 at 1.55K

Observations:

0 – Both heat switches are being turned OFF in preparation for the hot recycling.

1 – When both heat switch sorption pump temperatures have reached below 12K, the hot recycling is initiated.

2 – While the pump is being heated up to 45K, the evaporator warms up and peaks at 3.8K (versus 4.3K during previous warm recycling completed on prime side). Here again, one can see that the evaporator heat switch sorption pump is being warmed up by the joule dissipation from the pump heater wires. This behaviour is more pronounced when operating on the redundant side however as already observed in section 4.1.3, which means that in this case, the switch quickly reaches its 15K actuating temperature (i.e. +4K in 7 minutes) thus compromising the hot recycling test.

3 – A second attempt at recycling warm was carried out, starting this time only when the evaporator heat switch sorption pump temperature had reached its nominal OFF temperature (~3K). As soon as the pump heat switch reached below 12K, the power on the pump heater was applied and instantly the evaporator heat switch sorption pump started warming up.

4 - It reached its 15K actuation temperature in less than 13min (with heater OFF), compromising again the hot recycling.

5 – End of hot recycling test and return to normal operating conditions for nominal recycling.

Conclusions:

These tests confirmed that the evaporator switch behaves differently when used on the prime and redundant side of the instrument. While this behaviour does not have any degrading impact on the cooler performance during normal recyclings, it prevents the possible use of a “hot” recycling on the redundant side as the switch reaches its actuation temperature too quickly. It is also noted that when a hot recycling is performed on the prime side, it is probably advantageous to reduce the power to the pump heater once the evaporator temperature has peaked, to limit any further warm-up of the evaporator heat switch sorption pump and thus optimise performance.

4.2 Flight Temperature Sensors Calibration

4.2.1 Prime Temperature Sensors

The prime flight temperature sensors were calibrated with a Lakeshore AC bridge on the 21rst November 2006. It is important to note that:

- These measurements could only be done as the instrument was being powered down,
- A screen shot the DRCU data (temperature as well as raw) has been taken at the start of the test,
- The cooler was in a recycled state at the start of the test with cold tip at 285mK,
- Powering down the instrument means that the cooler pump heat switch could not be maintained in its ON position and therefore that the pump, shunt, pump heat switch and evaporator temperatures started to drift ~10 minutes after shutting the instrument down,
- The evaporator heat switch sensor, SMEC, SMEC IF and BSM could not be checked out at the time as there were no available harnesses to allow the connection of the sensors to the bridge.

		Temp K	**Raw**	**R, ohms**	**R, ohms**	**R, ohms**
Sensors	**#**	**DRCU**	**DRCU**	**DRCU**	**1uA**	**10uA**
-	1	-	-	-	-	-
SLO	2	1.566	-4513	1869.1	1860	1842
-	3	-	-	-	-	-
PLO	4	1.575	-4194	2062.5	2061	2037
BSM IF	5	4.438	-4610	625.6	621	620.9
SCAL2	6	4.593	-4003	406.1	411.3	411.07
SCAL4	7	4.519	-3970	422.0	422.6	422.35
SCAL Flange	8	4.441	-4002	919.4	908.7	908.4
HK Filter	9	4.472	-2864	442.3	438.4	438.3
-	10	-	-	-	-	-
-	11	-	-	-	-	-
Pump HS	12	18.59	-21440	255.5	394.5 (***)	397 (***)
Evaporator (*)	13	0.285	3574	170332.1	195,590	169,160
Pump	14	1.666	-3471	1053.7	830 (***)	813 (***)
Shunt	15	1.568	-4487	1926.1	1933	1912
-	16	-	-	-	-	-
SUB (**)	13	4.501	-4222	504.0	499.6	499.46
Baffle (**)	14	4.487	-3231	659.1	655.3	655.4

Table 4-1 – Resistance Measurements of the Prime Flight Temperature Sensors with the AC bridge (21/11/06)

(*) – 3.16nA and 31.6nA have been used for the evaporator temperature sensor to reflect excitation current that will be used in flight (constant 40nA for evaporator versus constant 10mV for other sensors)
(**) – Repeat test with different harness connected to the channels 13 to 16.
(***) – Unstable at the time the measurement was taken.

Observations:

- This test confirmed that the temperature sensors fitted on the L1 do not have any self-heating but that they are subjected to DC offsets errors of about 5 ohms (consistent with data measurement from the PFM2 test campaign).

- The sensors fitted to the L0 spectrometer and photometer enclosures (SLO and PLO) have some self-heating errors (in the order of 5mK) combined some DC offsets errors up to 15 ohms for SLO.

- The evaporator prime temperature sensor reading has been verified for the first time on the AC bridge (as it was still stable) and predicted that an 11mK self-heating error was present on the cold tip at 285mK when monitored on the DRCU. This suggests that the cold tip is actually running at a base temperature of 274mK. This is consistent with the error which had been predicted with the correlated thermal model as described in section 4.2 of [RD6].

The prime SMEC and SMECIF sensors were reading inconsistent data, 1.2K and 3.6K respectively (please refer to HR-SP-RAL-NCR-167 for more details). Measurements of the BSM, SMEC and SMEC_IF temperature sensors on the AC bridge were subsequently completed on the 11th December 2006.

		Temp K	**Raw**	**R, ohms**	**R, ohms**	**R, ohms**
Sensors	**#**	**DRCU**	**DRCU**	**DRCU**	**1uA**	**10uA**
BSM	1	**-**	**-**	**-**	342.9	342.75
SMEC	2	**1.216**	-11439	579.03	577.1	576.9
SMEC IF	3	**3.619**	-5015	426.92	423.9	423.75

Table 4-2 – Resistance Measurements of the Prime Flight Temperature Sensors with the AC bridge (11/12/06)

These measurements demonstrated that little self-heating is taking place but also that the resistances measured by the DRCU for the SMEC and SMEC_IF sensors are consistent with the AC bridge measurements within 3 ohms (which is within range of known DC offset error for L1 sensors). This therefore suggests that the SMEC temperature sensors inconsistencies are related to the calibration curves used to convert from resistance into temperatures.

Details of the test data post-processing can be found in [RD8].

4.2.2 Redundant Temperature Sensors

The redundant flight temperature sensors were calibrated with a Lakeshore AC bridge on the 11th December 2006. It is important to note that:

- These measurements could be done while the instrument was ON (on prime side) with the AC bridge connected to the FPU redundant side,
- This means that the pump, shunt, pump heat switch and evaporator temperatures were stable at the time the measurements were completed,
- The cooler was in a recycled state at the start of the test with cold tip at 285mK,
- The telemetry was inadvertently turned OFF during this test which means that the data is not directly available to be downloaded from QLA but it can still be recovered,
- The evaporator heat switch sensor could not be checked out at the time as there was no available harness to allow the connection of the sensor to the bridge.

		R, ohms	**R, ohms**
Sensors	#	**1uA**	**10uA**
-	1	-	-
SLO	2	2010.0	1979.1
-	3	-	-
PLO	4	2342.4	2304.2
BSM IF	5	616.5	616.36
SCAL2	6	379.6	379.3
SCAL4	7	316.3	316.1
SCAL Flange	8	364.9	364.8
HK Filter	9	451.8	451.65
-	10	-	-
-	11	-	-
Pump HS	12	251.3	251.2
Evaporator (*)	13	200,400	173,590
Pump	14	972.3	968.8
Shunt	15	1930.8	1902.0
-	16	-	-
SUB (**)	13	505.8	505.64
Baffle (**)	14	658.2	657.9
Evaporator (*) Repeat	*13*	*200,650*	*173,712*
-	-	-	-
BSM	1	351.3	351.2
SMEC	2	582.7	583.0
SMEC IF	3	412.72	412.56

Table 4-3 – Resistance Measurements of the Redundant Flight Temperature Sensors with the AC bridge (11/12/06)

(*) – 3.16nA and 31.6nA have been used for the evaporator temperature sensor to reflect excitation current that will be used in flight (constant 40nA for evaporator versus constant 10mV for other sensors)
(**) – Repeat test with different harness connected to the channels 13 to 16.

Observations:

- The redundant evaporator temperature sensor reading has been verified for the first time on the AC bridge and predicted that an 13mK self-heating error was present on the cold tip at 288.1mK when monitored on the DRCU. This suggests that the cold tip is actually running at a base temperature of 275mK. This is consistent with the data from the prime sensor and the error which had been predicted with the correlated thermal model as described in section 4.2 of [RD6].

Details of the test data post-processing can be found in [RD8].

4.3 Photometer JFET Temperature Gradients

During PFM3, an important temperature gradient (1.4K) was observed between the far end of the photometer JFET chassis (see maker 1 in Figure 4-9 below) and its L3 interface (see maker 2 in Figure 4-9 below). An NCR (HR-SP-RAL-NCR-158) was raised to keep track of the issue and several possible causes were considered:

- Temperature measurement error as the sensors are accurate to +/-0.25K only (Silicon Diode),
- Under-performing contact conductance between the L3 GSE strap and the PJFET chassis,
- Under-performing isolating joint on the PJFET chassis,
- Higher gradient along the PJFET chassis than expected,
- A combination of all the above.

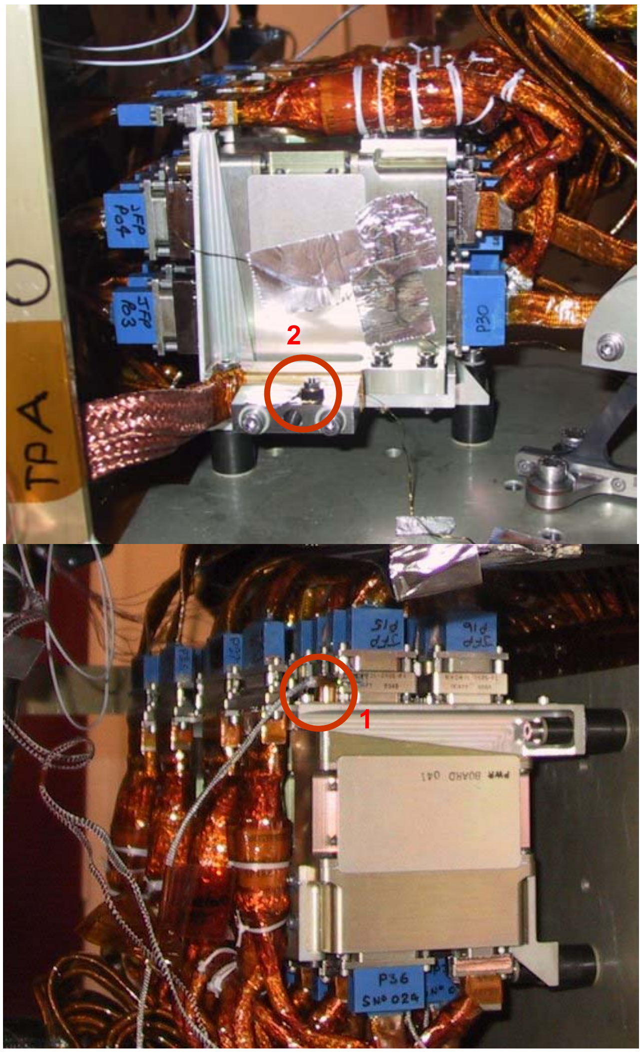


Figure 4-9 – Picture of Photometer JFET before PFM3 test campaign

For the PFM4 test campaign, the two sensors were replaced with more accurate ones (TVO sensors, accurate to +/- 0.01K). One was placed on the previous L3 interface (see maker 1 in Figure 4-10 below) and the second one was place on the PJFET chassis near the L3 interface (see maker 2 in Figure 4-10 below). Additionally, a third sensor was fitted to the PJFET chassis far end to help the characterisation of the gradients (see maker 3 in Figure 4-10 below).

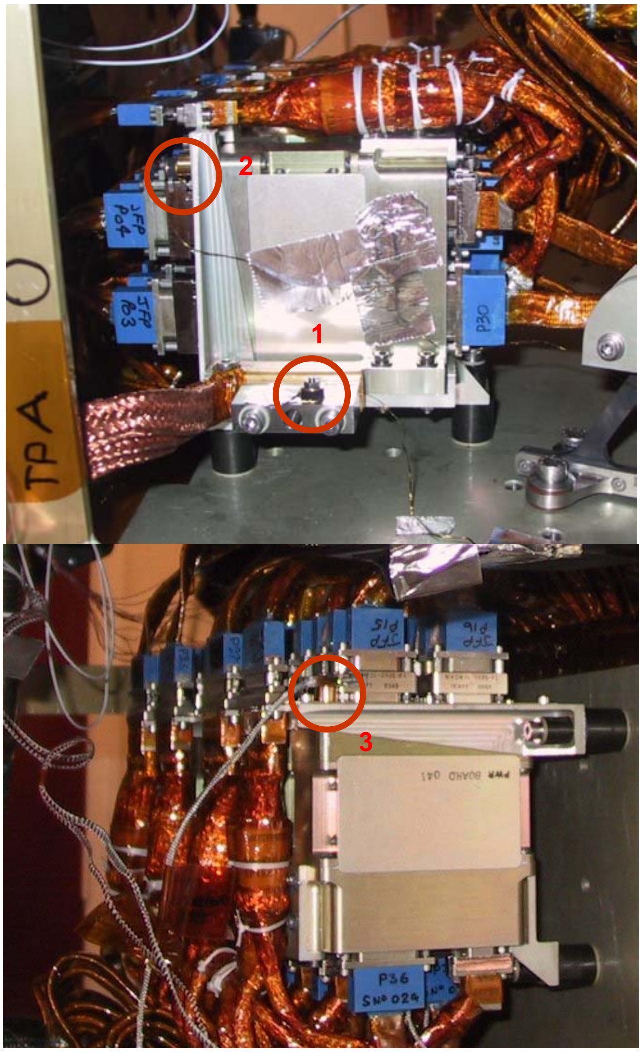


Figure 4-10 – Picture of Photometer JFET before PFM4 test campaign

Figure 4-11 on the following page describes the gradients recorded along the photometer JFET while operating during the PFM4 test campaign. One can see that the 1.5 K overall gradient is still present and that the following breakdown is applicable:

- A 0.33K temperature gradient has been measured across the PJFET chassis,
- A 1.18K temperature gradient has been measured across the PJFET L3 interface.

It is still impossible however to define how much of the temperature drop across the L3 interface can be allocated to the bolted or glued interface. The bolted interface is expected to be better in the flight cryostat as GSE straps were used here.

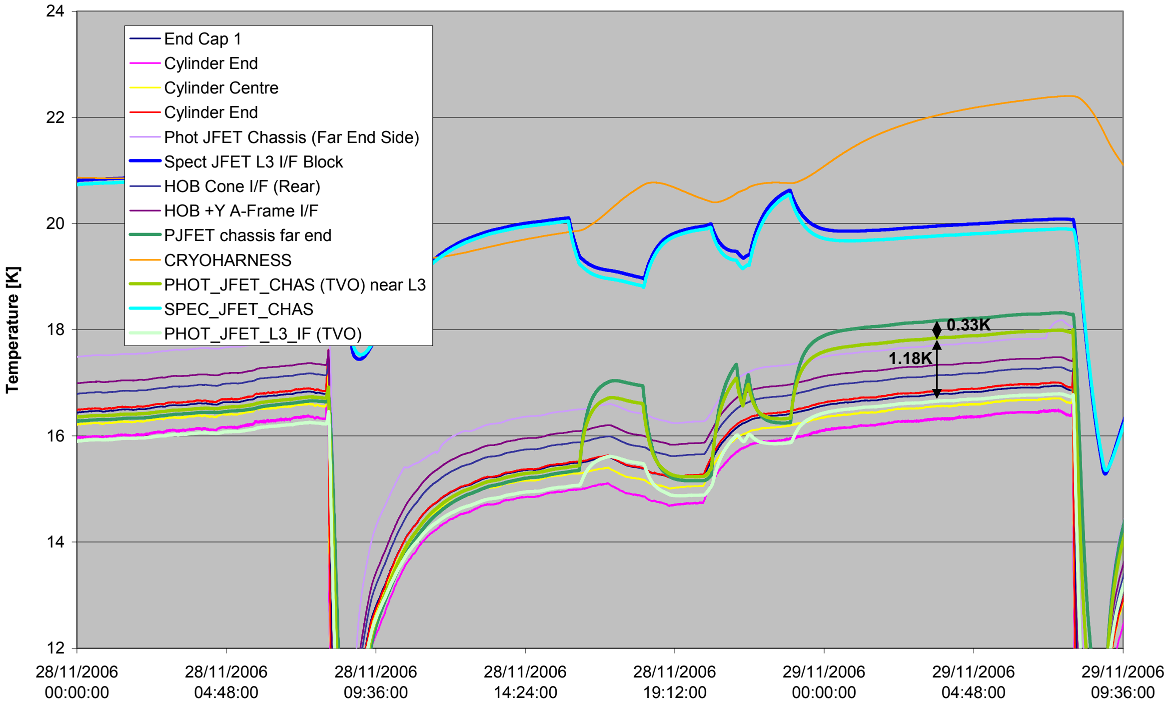


Figure 4-11 – PJFET Thermal Gradients during Photometer Mode during PFM4 Test Campaign

4.4 SMEC PFM Operation

4.4.1 Definition of SMEC Operating Modes

Resolution	**Low**	**Medium**	**High**
Range wrt ZPD	+/- 1mm	+/- 3.4mm	-7/+31.5
Range	7mm to 9 mm	4.76mm to 11.4mm	1mm to 39.5mm
Scan type	Triangular	Triangular	Triangular
Scan speed	0.5 mm/s	0.5 mm/s	0.5 mm/s

Figure 4-12 – Overview of SMEC Operation Modes

Note: ZPD is at 8mm

4.4.2 Verification of SMEC PFM Coil Resistance

The resistance of PFM SMEC coils could be verified while the SMEC was operated in a High Resolution mode (where the peak current and voltage measurements are the most accurate). A plot of the PFM SMEC current, voltage and power dissipation is presented in the graph below and shows that for an average FPU temperature of 5.4K, the SMEC coil resistance is closed to ~4 ohms (i.e. 3.7 ohms has been measured at unit level on CQM SMEC for a similar hardware, ref LAM.ELE.SPI.PRV.040731_01, edition 1 rev 0).

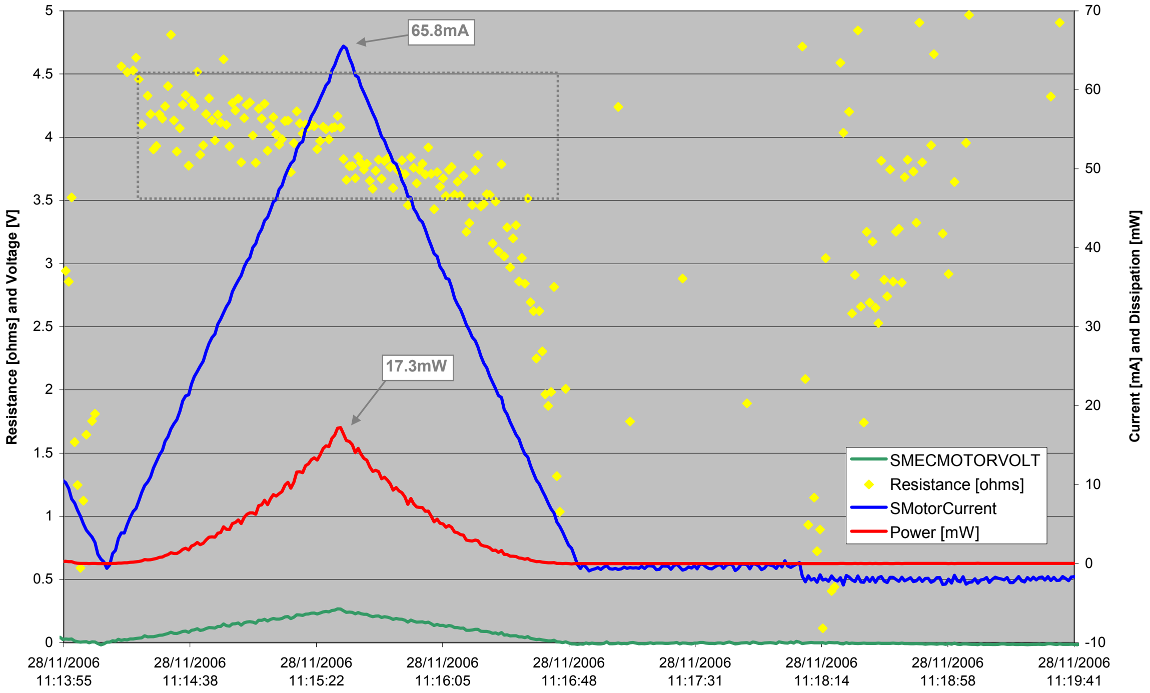


Figure 4-13 – SMEC Current, Voltage and Power Dissipation Profiles in HI Resolution Mode

Note: The power dissipation profile is non linear and needs to be integrated over full scanning range.

4.4.3 Verifications of SMEC PFM Power Dissipation

The SMEC linear law is calculated based on the SMEC maximum displacement (39.5mm) in HI resolution mode and the measured high peak current, as described in the table below.

Mode	**Max Range Displacement**	**Measured Peak Current**	**Linear Law**
-	**mm**	**mA**	**-**
HI	39.5	65.8	1.6658

Table 4-4 – SMEC PFM Linear Law

This linear law can then be used to predict the peak currents for the lower resolution modes based on their maximum range displacement. Note: 4 ohms has been assumed for the calculations as the voltage/current signals become too noisy to allow this calculation.

Mode	**Max Range Displacement**	**Estimated Peak Current**
-	**mm**	**mA**
MED	11.4	19
LO	9	15

Table 4-5 – SMEC Peak Current For Lower Resolution Modes

The figure below describes the SMEC current and position profiles during low and medium resolution scans, one can see that the peak current are really close to the one predicted (within noise).

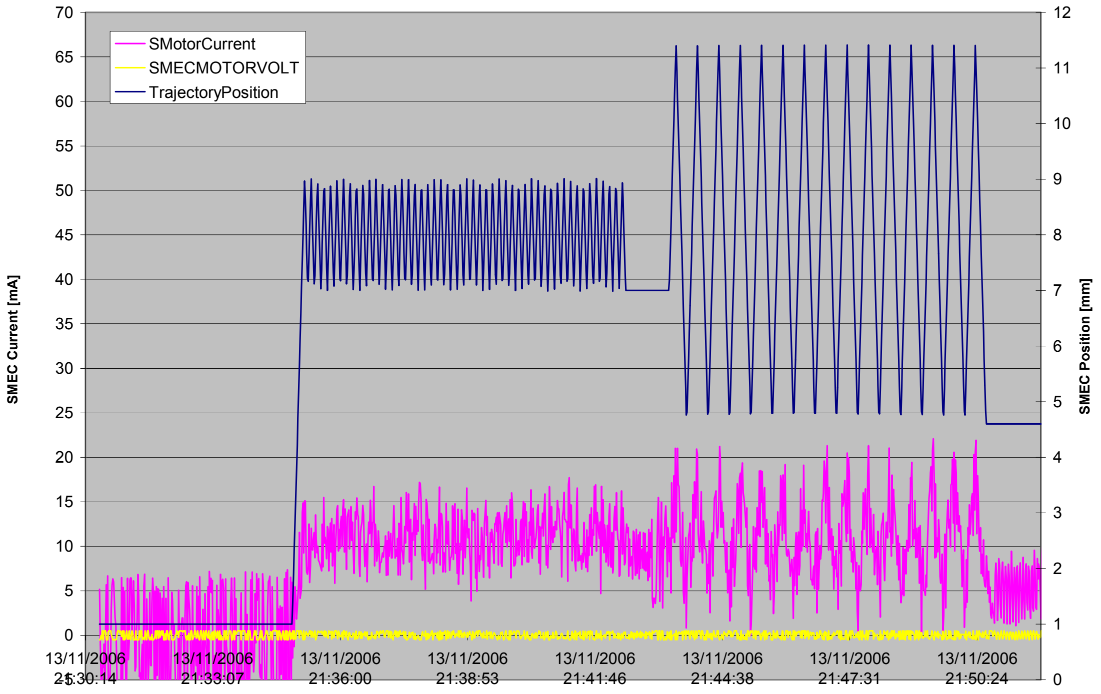


Figure 4-14 - SMEC Current and Position Profiles in LO and MED Resolution Modes

The table below summarises the predicted peak and average power dissipations for all three SMEC scanning modes.

Mode	Peak Current	Peak Power	Average Power [*]	Duty Cycle in Spectrometer Mode
-	**mA**	**mW**	**mW**	**%**
LO	15.0	0.90	0.43	33.3
MED	19.0	1.44	0.46	33.3
HI	65.8	17.3	3.56	33.3

Table 4-6 – Summary of SMEC Power Dissipations

[*] Integrated over full displacement range for a single scan.

4.5 Thermal Balance Test Case/Cooler Autonomy Check

Some difficulties were experienced when operating the calibration cryostat during the PFM4 test campaign – the L0 temperature stage which temperature is controlled with a manostat appeared to be very instable, especially during the cooler recyclings. Further investigations showed that a leaking needle valve (between the L0 and the L1 Helium pots) prevented proper operation of the L0 stage with the manostat fully closed. In order to get a stable L0 stage, the cryostat therefore had to be operated with the manostat fully opened. This affected the base temperature of the L0 stage which as a result has been running at 1.5K instead of 1.7K. The thermal balance test case which was supposed to be a test in a flight representative environment was therefore replaced with a cooler autonomy test case. This test allowed to confirm that the cooler is still operating as expected and that no degradation of performance has taken place. Table 4-7 summarises the result of this test.

Parameters	**Value**	**Comments**
Recycling Start Date Time (UTC)	At 17:38 on 01/12/06	Start of Cooler Recycle on Redundant side
Recycling End Date Time (UTC)	At 19:36 on 01/12/06	Cooler recycle script completed.
L0 Temperature	1.55K	During Recycling.
Recycling Duration	~ 2hr	-
Pump Temperature	Regulated	@ 45K with bag-bang control
Evaporator Condensation Temperature	2K	
L0 Temperature	1.55K	During Operation.
L1 Temperature	4.275K	During Operation.
Hold Time Start	At 19:36 on 01/12/06	-
Hold Time End	At 11:30 on 04/12/06	-
Cooler Hold Time	~64hr	
Evaporator Cold Base Temperature	285.1 mK	Versus 288.5mK for a 1.7K L0 interface temperature.

Table 4-7 –Thermal Balance Test Case – Instrument Performance Summary

5 PFM4 TEST SUMMARY AND CONCLUSIONS

All tests were completed successfully and all objectives were met with the exception of the thermal balance test in a flight representative environment (1.7K, 5K) due to some issues with the cryostat L0 temperature stage. A cooler autonomy test was carried out instead to confirm the cooler hold time was still as expected.

Several cooler recyclings have been carried out during the PFM4 test campaign which allowed to confirm that the cooler performance has been fully recovered following the change in MGSE L0 straps. The cooler performance did match these from the previous PFM2 test campaign thus confirming everything was nominal again.

The fine tuning of the cooler recycling VM control parameters has been progressing well and additional fine tuning should be considered as part of the PFM5 test campaign (more details in the following section 6).

The “hot” recycling (with both cooler heat switches opened) has been attempted for the first time on the prime and redundant sides of instrument. It was demonstrated that the evaporator can be warmed up to 4.3K when operated on the prime side but also that this “hot” recycling cannot be carried out on the redundant side because of an unexpected warm-up of the evaporator heat switch sorption pump (see section 4.1.4 and HR-SP-RAL-NCR-166 for more details). This hot recycling will be attempted again as part of the PFM5 test campaign in order to check how long the evaporator could be held at 4.3K for.

The prime and redundant flight temperature sensors have been calibrated with an AC bridge and a procedure will be issued that will allow to confirm the calibrations of the sensors once in flight.

The Photometer JFET temperature gradients during operation have been verified and this information has been incorporated in the thermal model.

The PFM SMEC has been operated for the first time as part of the PFM4 test campaign and its power dissipation profiles could be checked for all operation modes.

6 PFM5 TEST SUMMARY AND CONCLUSIONS

Only a limited set of thermal tests were carried out as part of the PFM5 test campaign:

- The fine tuning of the cooler recycling VM control parameters has been successfully completed, allowing the pump to be held slightly above 45K during the whole condensation period of the cooler recycling. The temperature and power profile of the pump during recycling are presented in Figure 6-1. More details about the control parameters used for this automated recycling can be found in Appendix (see section 7).

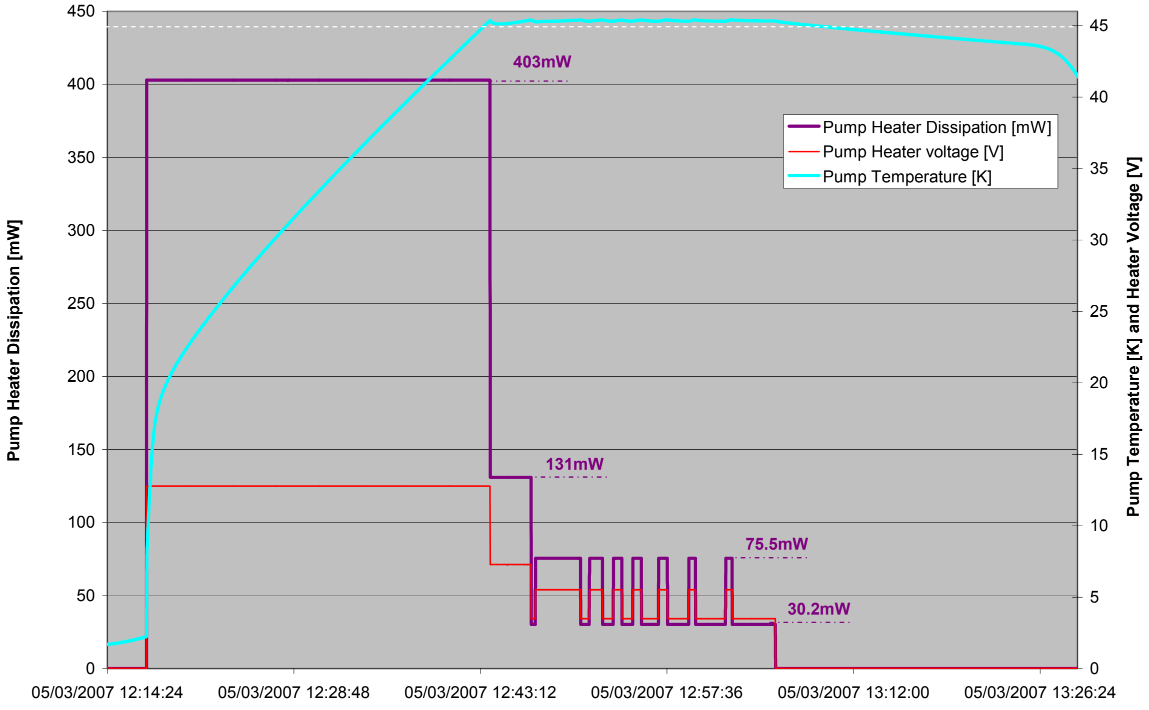
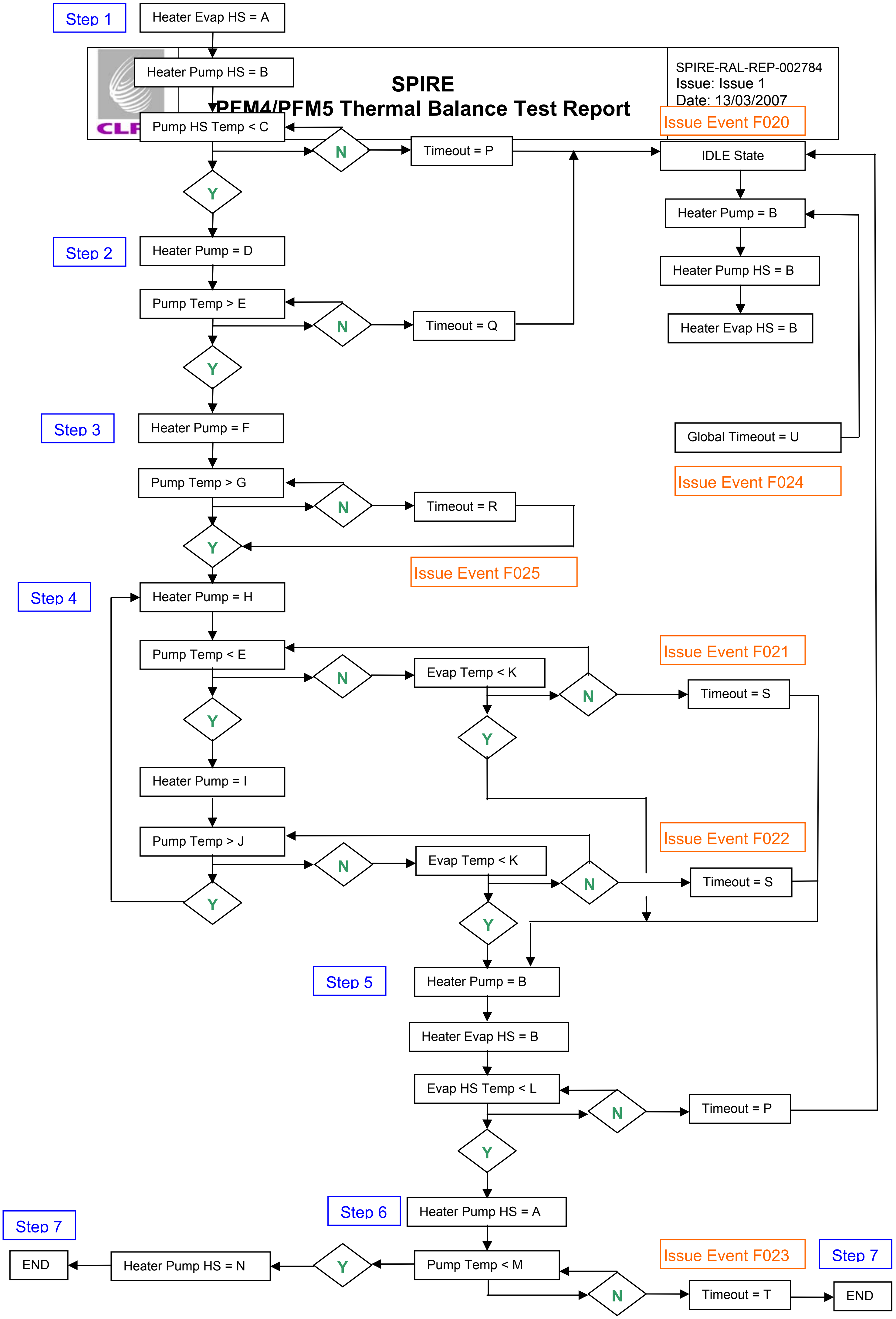


Figure 6-1 – Pump Temperature and Power Dissipation Profile during Automated Recycling

- The cooler “Hot” recycling was attempted once again on the prime side. This test confirmed that the evaporator cannot be maintained at 4.3K for a long period of time (<10 min). This is due to various heat leaks (to the shunt via the He^3 gas and possibly through the evaporator heat switch which passively warms up to 10K after a certain period of time).

7 APPENDIX – FM COOLER AUTOMATED RECYCLING CONTROL PARAMETERS

This section gives a summary of the algorithm and parameters used for the automatic cooler recycling. It corresponds to version 4.11 of the procedure described in SPIRE-RAL-NOT-002771 and has been used during the PFM5 test campaign.


Step 1
Heater Evap HS = A
Heater Pump HS = B
Pump HS Temp < C
N
Timeout = P
Issue Event F020
IDLE State
Y
Heater Pump = B
Step 2
Heater Pump = D
Heater Pump HS = B
Pump Temp > E
N
Timeout = Q
Heater Evap HS = B
Y
Step 3
Heater Pump = F
Global Timeout = U
Pump Temp > G
Issue Event F024
N
Timeout = R
Y
Issue Event F025
Step 4
Heater Pump = H
Pump Temp < E
Issue Event F021
N
Evap Temp < K
N
Timeout = S
Y
Y
Heater Pump = I
Pump Temp > J
Issue Event F022
N
Evap Temp < K
N
Timeout = S
Y
Y
Step 5
Heater Pump = B
Heater Evap HS = B
Evap HS Temp < L
N
Timeout = P
Y
Step 6
Heater Pump HS = A
Step 7
END
Heater Pump HS = N
Y
Pump Temp < M
Issue Event F023
Step 7
N
Timeout = T
END

Parameters for Cooler Recycling Using the PRIME Instrument Side

Param	Description	Setting	Current	Voltage	Hex	Dec
A	Heater Heat Switch ON (during Recycling)	0.8 mW	1.4 mA	0.56V	0x0DEB	3563
B	Heaters OFF	0 mW	0.0 mA	0V	0x0000	0
C	Pump Heat Switch – Actuation Temperature	11.98 K	-	-	0xBFBE	49086 -16450
D	Heater Pump Dissipation 1	400 mW	31.54 mA	12.7V	0x0A25	2597
E	**Pump Temperature Condensation 1**	**45.3K**	**-**	**-**	**0x8CA6**	**36005** **-29531**
F	**Heater Pump Dissipation 2**	**130mW**	**17.98mA**	**7.23V**	**0x05C9**	**1482**
G	**Pump Temperature Condensation 2**	**45.4K**	**-**	**-**	**0x8C7E**	**35965** **-29571**
H	Heater Pump Dissipation 3	30mW	8.639mA	3.47V	0x02C8	712
I	Heater Pump Dissipation 4	75mW	13.659mA	5.49 V	0x0465	1125
J	**Pump Temperature Condensation Threshold**	**45.4K**	**-**	**-**	**0x8C7E**	**35965** **-29571**
K	Evap Temperature Condensation	2 K	-	-	0x7ECB	32459
L	Evaporator Heat Switch Actuation Temperature	14.96K	-	-	0xB5A8	46504 -19032
M	Pump Temperature Threshold	2 K	-	-	0xEFCC	61388 -4148
N	Heater Heat Switch ON (during Recycling)	0.42 mW	1.022 mA	0.41V	0x0A2A	2602
O	Loop Sampling (sec)	10 sec	-	-	10	10
P	Heat Switch Timeout^2 (min)	½ hr	-	-	30	30
Q	Pump Heating Timeout 1^2 (min)	1hr	-	-	60	60
R	Pump Heating Timeout 2^2 (min)	1/2hr	-	-	30	30
S	Evaporator Timeout^2 (min)	1 hr	-	-	60	60
T	Pump Cooling Timeout^2 (min)	1hr	-	-	60	60
U	Global Timeout^{12} (min)	2.5 hr	-	-	150	150

Parameters for Cooler Recycling Using the REDUNDANT Instrument Side

Param	Description	Setting	Current	Voltage	Hex	Dec
A	Heater Heat Switch ON (during Recycling)	0.8 mW	1.4 mA	0.56V	0x0DEB	3563
B	Heaters OFF	0 mW	0.0 mA	0V	0x0000	0
C	Pump Heat Switch – Actuation Temperature	12 K	-	-	0xBEA8	48808 -16728
D	Heater Pump Dissipation 1	400 mW	31.54 mA	12.7V	0x0A25	2597
E	**Pump Temperature Condensation 1**	**45.3K**	**-**	**-**	**0x873D**	**34621** **-30915**
F	**Heater Pump Dissipation 2**	**130mW**	**17.98mA**	**7.23V**	**0x05C9**	**1482**
G	**Pump Temperature Condensation 2**	**45.4K**	**-**	**-**	**0x8717**	**34582** **-30954**
H	Heater Pump Dissipation 3	30mW	8.639mA	3.47V	0x02C8	712
I	Heater Pump Dissipation 4	75mW	13.659mA	5.49 V	0x0465	1125
J	**Pump Temperature Condensation Threshold**	**45.4K**	**-**	**-**	**0x8717**	**34582** **-30954**
K	Evap Temperature Condensation	2 K	-	-	0x7EED	32493
L	Evaporator Heat Switch Actuation Temperature	15K	-	-	0xB771	46961 -18575
M	Pump Temperature Threshold	2 K	-	-	0xEE1F	60959 -4577
N	Heater Heat Switch ON (during Recycling)	0.42 mW	1.022 mA	0.41V	0x0A2A	2602
O	Loop Sampling (sec)	10 sec	-	-	10	10
P	Heat Switch Timeout[2] (min)	½ hr	-	-	30	30
Q	Pump Heating Timeout 1[2] (min)	1hr	-	-	60	60
R	Pump Heating Timeout 2[2] (min)	1/2hr	-	-	30	30
S	Evaporator Timeout[2] (min)	1 hr	-	-	60	60
T	Pump Cooling Timeout[2] (min)	1hr	-	-	60	60
U	Global Timeout[12] (min)	2.5 hr	-	-	150	150

Note 1: A global timeout variable should be implemented – it should stop the script U minutes after the first command has been sent should the script still be running.

Note 2: All timeouts are now specified in time rather than number of sample loops

Note 3: The minimum “Loop Sampling” resolution is 1 sec.

Note 4: When using temperature as a condition, remember that all sensors temperature varies inversely with resistance (except for the evaporator sensor ‘SUBKTEMP’ which temperature decreases as its resistance decreases). As the resistance is the value being checked by the VM, the < and > conditions must be set to account for these features.

Note 5: Note that when the recycling is performed on the redundant side, the STEP numbers don’t come up.