Vacuum and Cryogenic Sytem for the MUSE detectors

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ABSTRACT

MUSE with its 24 detectors distributed over an eight square meter vertical area was requiring a well engineered and extremely reliable cryogenic system. The solution should also use a technology proven to be compatible with the very high sensitivity of the VLT interferometer.

A short introduction reviews the various available technologies to cool these 24 chips down to 160 K. The first part of the paper presents the selected concept insisting on the various advantages offered by LN2. In addition to the purely vacuum and cryogenic aspects we highlight some of the most interesting features given by the control system based on a PLC.

Keywords: Cryostat, liquid nitrogen, Vacuum system, CCD detector

1. INTRODUCTION

MUSE, the Multi Unit Spectrograph Explorer instrument is one of the next instruments to be installed in the coming months onto the VLT. MUSE combines 24 spectrographs in order to be able to probe a field of view as large as possible. Each spectrograph is equipped with 4000 x 4000 pixel detectors. Right at the start of the project various alternatives have been envisaged to cool this battery of detectors. After careful comparison with a few other solutions, the LN2 continuous flow cryostat appears to be the safest option for this instrument. Despite the complexity of the "tubing" and the somehow high operational cost this system can guarantee a very smooth and reliable operation.

2. CRYOGENIC SYSTEM, DESIGN, DESCRIPTION

Figure 1 shows the schematic of the cryogenic system of MUSE, this schematic shows only 3 cryostats (Continuous Flow Cryostats, CFC) from the 24 of the complete system.

Every CFC includes 3 heat exchangers: i) the cold plate, ii) the radiation shield, iii) the warm heat exchanger. The over pressure produced by the natural evaporation inside the liquid nitrogen tank (**1**) is used to circulate the coolant to the cryostat via a vacuum insulated line (Blue line). The coolant is then circulating in the cooling finger, which directly cools the chip carrier. The coolant continues via a second annular heat exchanger, which surrounds the first one, acts as radiation shield and cools the radiation shield of the head. Before leaving the cryostat, the gas flows in a third heat exchanger (**9**) where it is warmed up close to ambient temperature in order to avoid any risk of condensation along the exhaust pipe. A certain amount of Nitrogen can escape through the by-pass valve (**7**). The valve is adjusted such that LN2 flow keeps the detector a few degrees above the operating temperature. The additional cooling is obtained from the complement of flow allowed from the regulation valve (**6**). A PID (Proportional, Integral and Differential) loop is used to control the "on/off' regulation valve. The use of the by-pass valve has the double advantage of guaranteeing a minimum cooling even during a power failure and avoiding any large temperature variation caused by the "on/off operation.

In addition to the previous description we can mention that the storage tank is fitted with an overpressure safety valve, which guarantees an operating pressure of 0.6 bars. The gas which leaves the cryostats is collected in the exhaust container (**11**). An over pressure valve (**10**) is used to stabilize the pressure (**P2** = 0.1 bar) in this container. When the instrument is used in a small laboratory, it is very important to direct the gas leaving the safety valve to the outside of the laboratory to prevent any dangerous decrease of oxygen in the room.

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The gas from the container has a second way to escape: it can leave to a second container which is fitted with thermal exchange plate in order to be permanently at room temperature. This temperature stabilization container (**12**) will supply clean nitrogen gas at room temperature to the optical area in order to avoid any contamination or degradation of the optics.

A temperature sensor (**T2**) is installed in every gas exchange container. It will measure the temperature of the gas and in case the temperature departs from the ambient by more than 5 K it will not allow the gas anymore to circulate in the IFU. The valve (**13**) will be closed. This valve will also be normally closed valve such that in case of power failure (CFC gas heating not operational) they will close automatically.

A temperature sensor (**T1**) is used to monitor the temperature of the outer skin of the LN2 transfer line. In case this temperature shows a large gradient compare to the ambient temperature, the system will give a warning which will be used to plan a vacuum regeneration of the line.

An additional temperature **(TA)** sensor mounted on a small black radiator is used to measure the ambient temperature for comparison with **(T1)** an **(T2)**

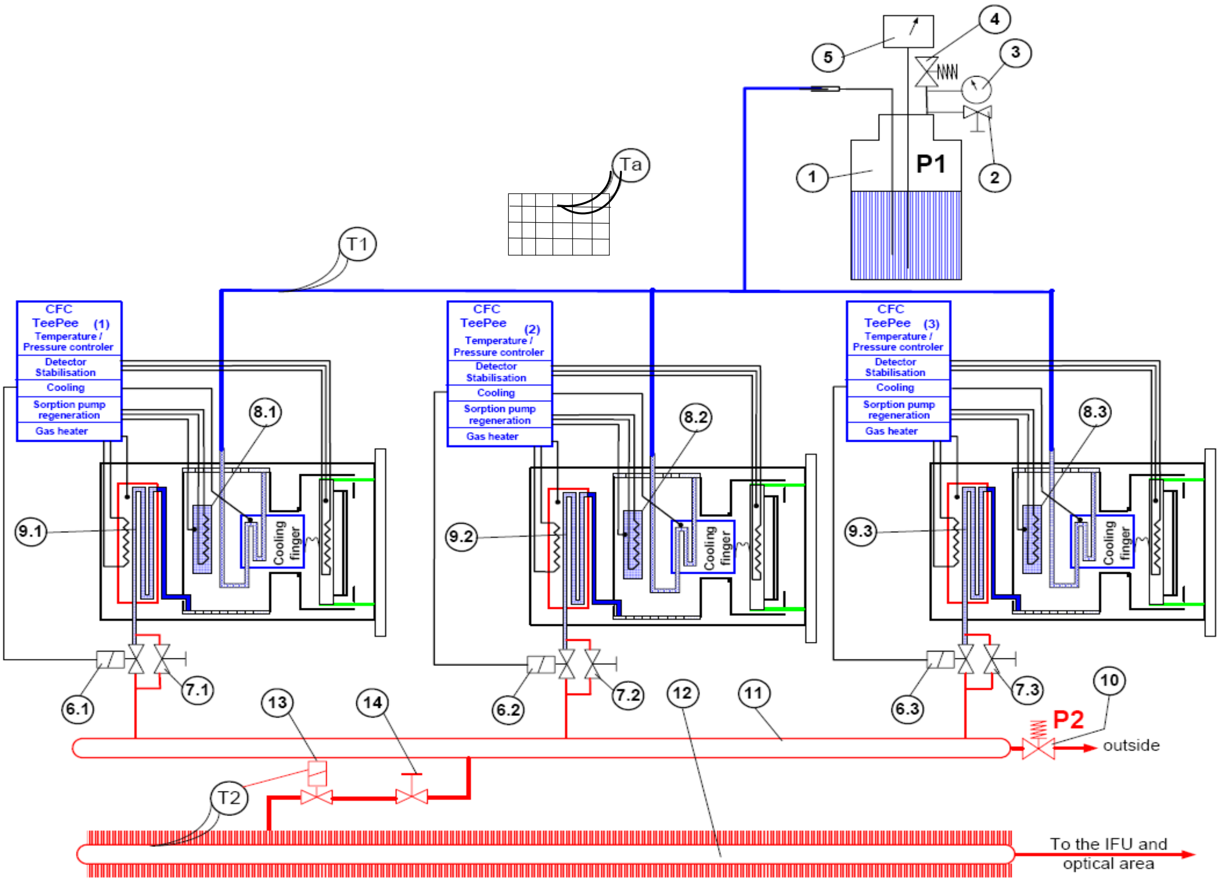


Figure 1: MUSE cryogenic system

1.LN2 storage tank, 2. De-pressurization valve, 3. Manometer, 4. Over-pressure valve, 5. Liquid nitrogen level gauge, $6_{(i)}$. Regulation valve, $7_{(i)}$. Bypass valve, $8_{(i)}$. Sorption pump, $9_{(i)}$. Gas heater, 10. Gas buffer over-pressure valve, 11. Gas buffer, 12. Gas thermal conditioner, 13. Gas flushing safety valve

For the LN2 distribution and supply the facility is divided in two halves mirrored around the vertical axis of the instrument. Every half is supplied from one single nitrogen storage tank. The distribution lines are divided in a lower arm and an upper arm (fig 2 left). Every arm supplies the nitrogen to two rows of cryostats. The lines are connected to the cryostats using vacuum insulated bayonet connection known also under the name of Johnston fitting. We re-discovered at a larger scale the well known problem of the poor performance of the Johnston fitting (especially when the connection is done with the male part looking up). All connections exhibit very cold spot, temperatures between -8°C to -25°C have been recorded on some of the connection where a large amount of ice can also build in with time. This is absolutely not acceptable and do not conform with the very tight thermal requirement of the VLT (no part should have temperature gradient more than -4°C and +2°C compare to the ambient).

A cold sealing has been implemented in order to improve the thermal performance of the connection. This sealing is based on a PTFE insert on the side of the cryostat and a stainless steel knife seal on the side of the line. Figure 2 (right) shows the connection of the DV 13 before and after the modification. Actually after the modification, a number of cool-down have been carried out. No degradation of the performance can be seen. The temperature is now only 3°C below the ambient without any condensation or ice.

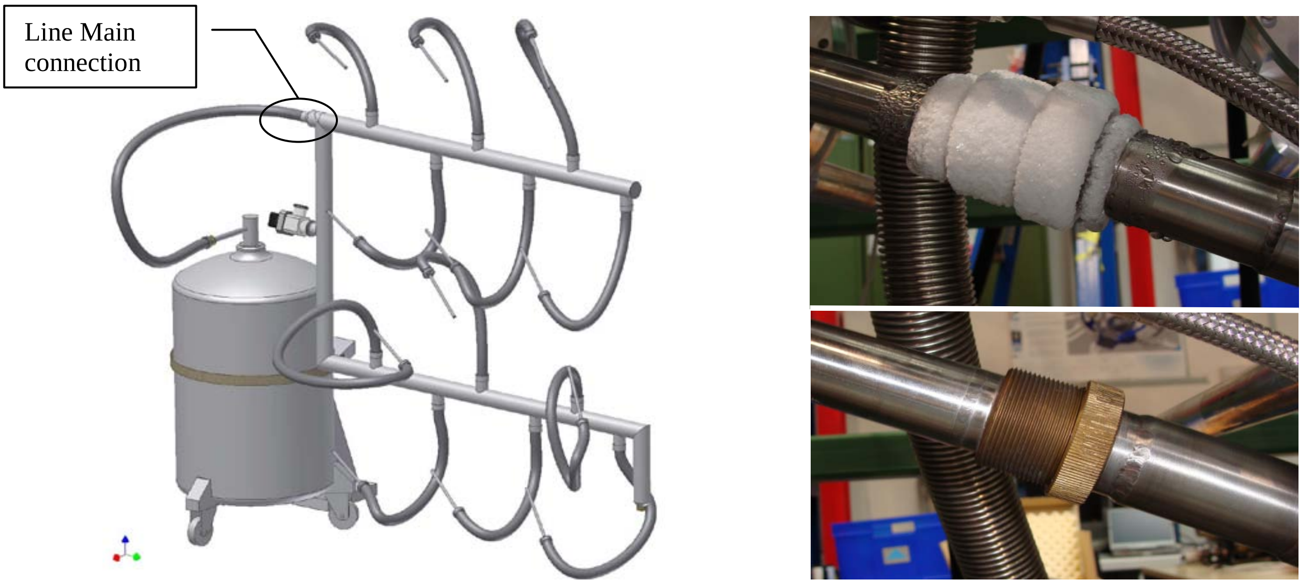


Figure 2: Half instrument nitrogen supply system (left), Johnston fitting, original design (right up) after cold sealing implementation (right)

Figure 3: Main connection valve system

Figure 3 (right) shows the actuator of the valve system which equips the line main connection. A small in-line valve is installed inside the Johnston fitting (fig.3 left). This valve is open when the male connector is fully inserted and is closed as soon the male connector is retracted by 5 mm. A handle with a came system is used to activate the valve. This guarantees a fully safe tank exchange operation. Before changing the tank, the operator first closes the valve. The system continues operating for approximately 10 minutes with the LN2 remaining in the line. During this time the operator can disconnect the tank without getting the complete LN2 contained of the line flowing back.

3. VACUUM SYSTEM

Figure 4 shows a schematic of the vacuum system on the instrument. It is not intended to pump permanently the cryostats. During normal operation, the vacuum is kept via a small cryogenic sorption pump (**11**). Nevertheless the experience has shown that vacuum problems might happen and in such case there is always an enormous advantage to have a pumping system available. The next step was to implement a complete vacuum system on board permanently operational. The tubes being permanently connected are remaining very clean, this allows the system to recover very rapidly high vacuum quality. Every cryostat is insulated from the vacuum system by a system of two valves. A remotely controlled electro-magnetic valve (**5**) allows normal or emergency evacuation of the cryostat. A manual valve (**6**) is closed when one cryostat has to be removed from the instrument. A full range vacuum gauge (**2**) is used to monitor the pressure inside the cryostats.

A number of valves and vacuum sensors is used in order to guarantee the safety of the system and protect the detectors against any contamination in case of malfunctioning of one of the pump.

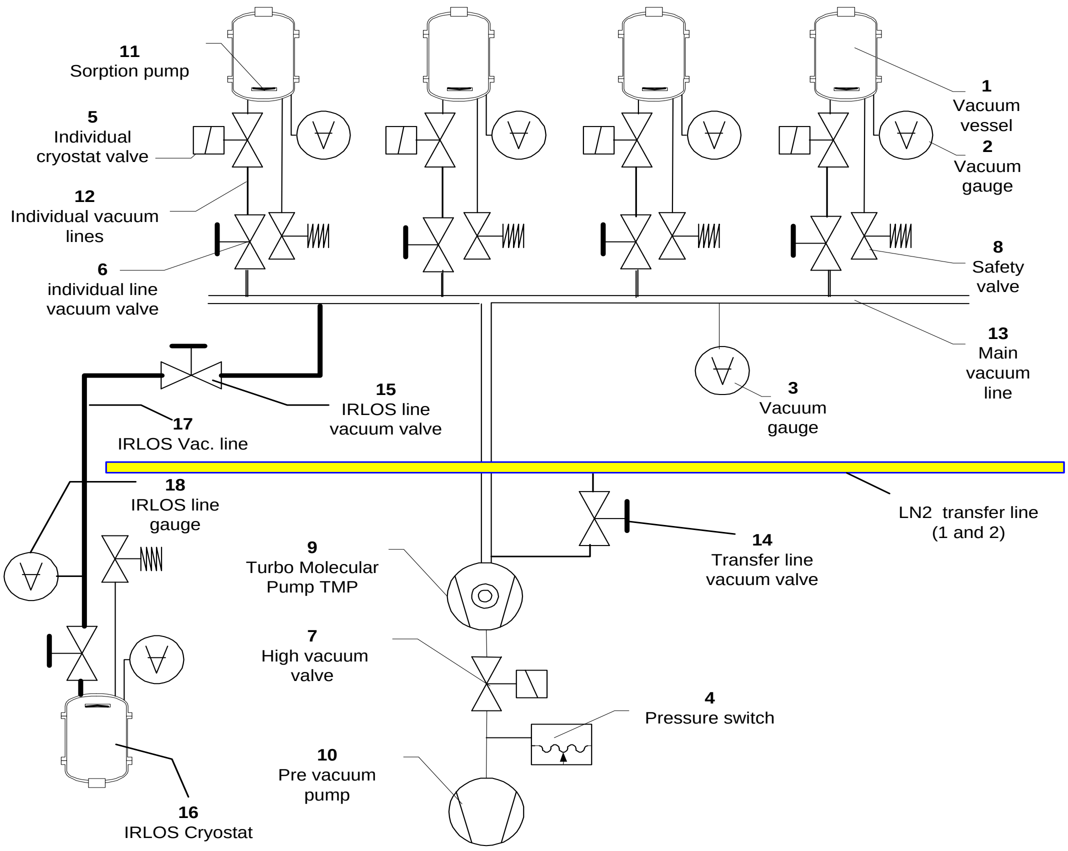


Figure 4: MUSE Vacuum system

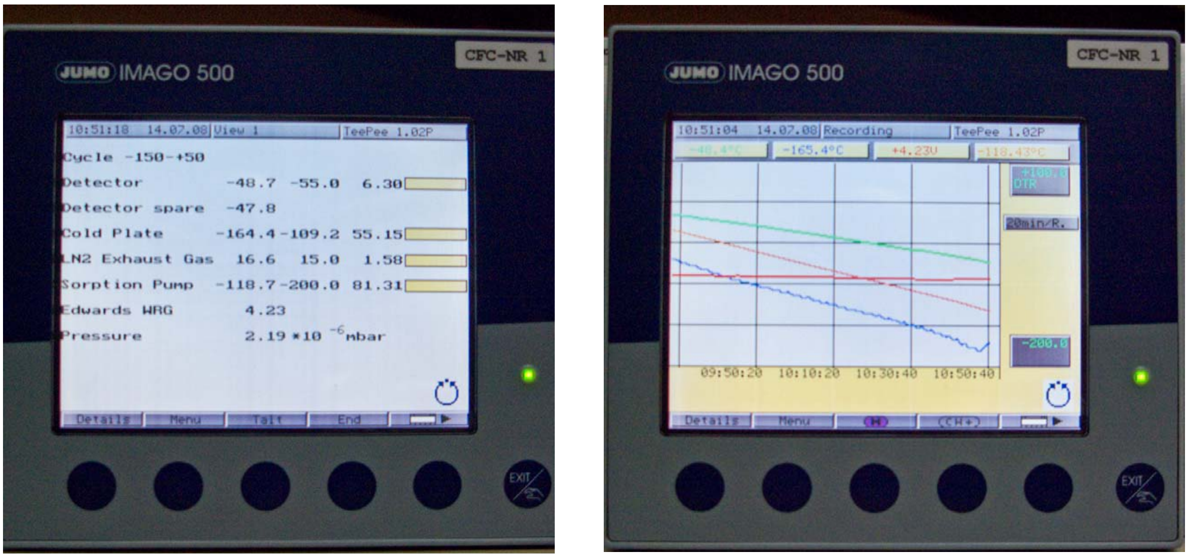
1. Cryostat vacuum vessel, 2. Cryostat vacuum gauge, 3. Vacuum line vacuum gauge, 4. Pressure switch, 5. Individual cryostat valve, 6.Individual line valve, 7. High vacuum valve, 8. Safety over-pressure valve, 9. Turbo-molecular pump, 10. Pre-vacuum pump, 11. Sorption pump, 12. Individual vacuum lines, 13. Main pumping line, 14. LN2 transfer line evacuation valve, 15. IRLOS vacuum line, 16. IRLOS cryostat, 17. IRLOS vacuum line, 18. IRLOS vacuum gauge.

In addition to the 24 detectors from MUSE the complete associated adaptive optic facility needs an additional detector: IRLOS, the Infra-Red Low Order Sensor. This infrared detector which is also cooled with a CFC cryostat is integrated in the MUSE system.

The vacuum system is also used for the periodic re-generation of the insulating vacuum of the LN2 transfer lines.

4. CRYO-VACUUM CONTROL

The cryogenic control system is basically split in two main levels. The cryostats are controlled by individual controllers based on Jumo Imago 500. The controller has three permanently active loops (Cryostat cold plate, Gas exhaust heating and Detector temperature stabilization) and a forth loop which can be activated on demand to regenerate the sorption pump. In addition this controller (named “Teepee”, for Temperature and Pressure) monitors the pressure inside the cryostat.



```
10:51:18  14.07.08 View 1              TeePee 1.02P
Cycle -150-+50
Detector              -48.7  -55.0   6.30
Detector spare        -47.8
Cold Plate           -164.4-109.2  55.15
LN2 Exhaust Gas        16.6   15.0   1.58
Sorption Pump        -118.7-200.0  81.31
Edwards WRG             4.23
Pressure                2.19 *10 -6mbar
```

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10:51:04  14.07.08 Recording           TeePee 1.02P
-48.4°C   -165.4°C   +4.23V   -118.43°C
```

Figure 5: Views of the CFC controller (Teepee) screen

The Jumo controller is also used to ramp the temperature of the detector during cool-down and warming-up, it also initiates an alarm in case one of the temperatures or the pressures are out of range. In addition it can be used to display easily the behavior of the system during a certain laps of time.

Figure 6 shows the architecture of the top level cryo-vacuum controller based on a Siemens S7-300 PLC.

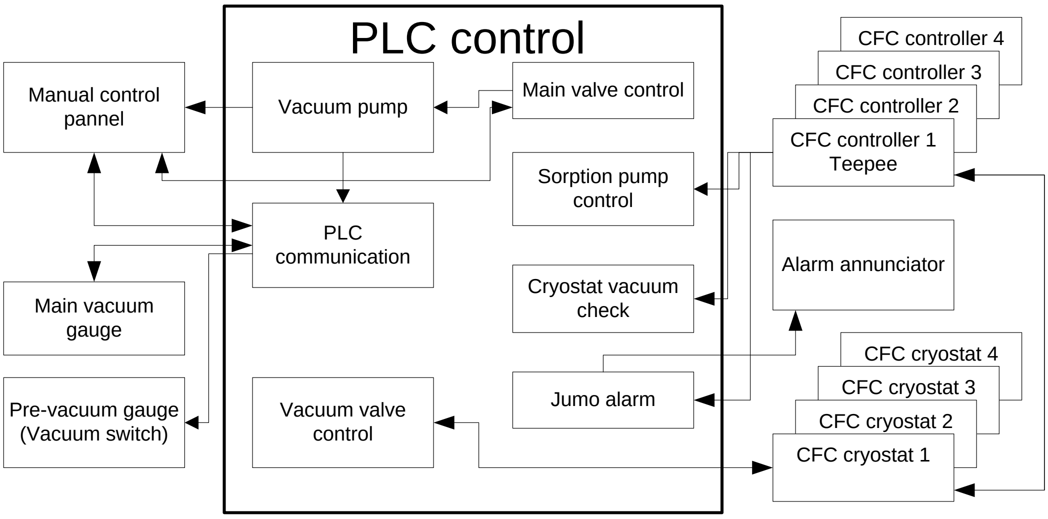
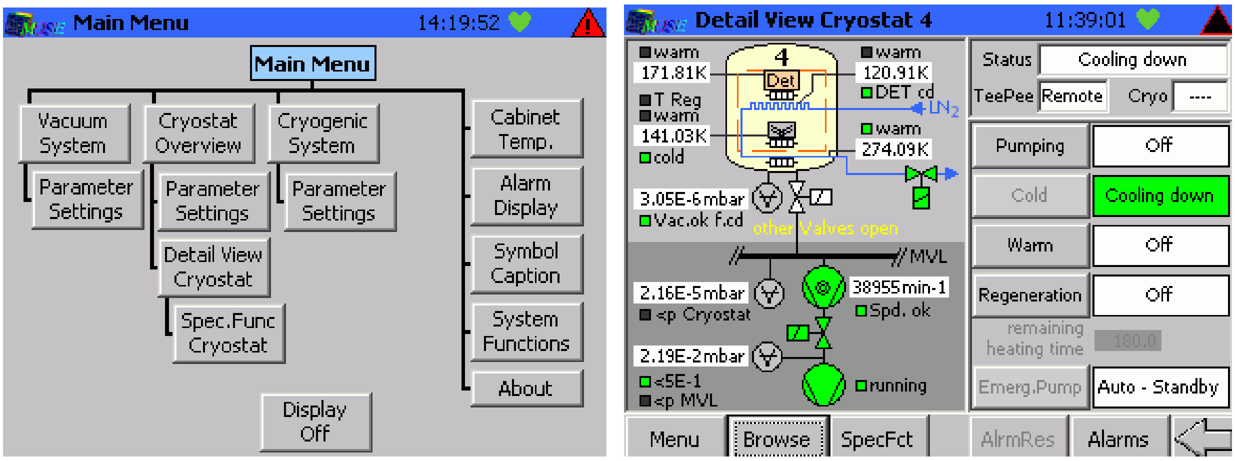


Figure 6: Architecture of the top level cryo-vacuum controller

This top level controller manages the various process either through the Teepee controllers for what is directly related to the cryostats or through additional interfaces for the general activities (Pumping, gas flushing…). It also monitors and handles all the functional interlocks and alarms. The PLC is associated to a Simatic touch panel which gives a very convivial working interface and allows also having a very clear view of the on-going processes.



warm 171.81K
T Reg warm 141.03K
cold
warm 120.91K
DET cd
warm 274.09K
3.05E-6mbar
Vac.ok f.cd
2.16E-5mbar
<p Cryostat
38955min-1
Spd. ok
2.19E-2mbar
<5E-1
<p MVL
running

Status: Cooling down
TeePee: Remote
Cryo: ----
Pumping: Off
Cold: Cooling down
Warm: Off
Regeneration: Off
remaining heating time: 180.0
Emerg.Pump: Auto - Standby

Figure 7: Two views of the touch panel screen

Figure 7 shows on the left side a view of the main menu offered by the touch panel. The right picture shows directly the display of the status of cryostat number 4 as selected from the cryostat overview menu. As already mentioned as it is an active panel, operations (pumping, warm-up…) can be directly started from screen by touching the relevant field.

5. TESTING, PERFORMANCE

The VCS has the very high responsibility of guaranteeing a safe and healthy operation of the 24 detectors. Before the delivery to the MUSE project, it has been submitted to very hard and extensive testing. During this phase, using the system with cryostats fitted with un-sensitive dummy detectors, the performance has been assessed and all aspects relative to safety have been verified.

It would be far too long and inappropriate to the scope of this document to describe the full testing of this complex cryo-vacuum system. We will concentrate on some of the critical and specific most challenging aspects. Originally the main role of the vacuum system was mainly to offer permanent safe operation. The test has shown that the 24 cryostats connected together can be evacuated down to a pressure of 10-5 mbar within less than 5 hours.

5.1 Vacuum system performance

The main specification and goal of the vacuum system is to guarantee a safe operation of the detectors at any time during the all life of the instrument.

The system is not originally designed to allow the full evacuation of the cryostats. In a normal sequence, the cryostat arrives on the instrument after having undergone a series of functional and performance test first in stand-alone and also together with the dedicated IFU. Later, in case of problem, most probably the faulty cryostat will be dismounted in order to allow an intervention in a safe and clean environment. Then the repaired detector cryostat can be re-installed after being tested and evacuated.

The vacuum system is based on a central powerful magnetic bearing turbo-molecular pump (400 l/s) which is a standard for VLT instrumentation. In order to make the best use of this very high pumping capacity, the vacuum distribution line has been designed as a large cross section tube in form of a large 90 degrees rotated “H” having the turbo pump at the centre. This guaranties a very efficient conductance even in the molecular flow regime.

Finally the system is extremely efficient and allows an evacuation of one single cryostat to a pressure of 10^{-4} mbar within less than 2.5 hours, even in the case of a full evacuation of up to 12 cryostats the system can lower the internal pressure in the individual cryostat within a reasonable time of less than 3 hours. This big H volume offers also a sort of vacuum buffer which allows to absorb without any risk of contamination the arrival of a cryostat with rather poor vacuum level even when other one are already cold and still on pumping with a very good vacuum. Figure 6 shows what can be qualified as the “robustness” of the vacuum system. We see that the arrival of cryostat 15 even at a pressure of 10^{-1} mbar did not cause an increase of pressure larger than 10^{-4} mbar on the cryostat 09, 17 and 19 which were at a pressure of 10^{-6} mbar. In order to get the best pumping efficiency at any time the vacuum in the line is regularly automatically regenerated. The PLC is used to carry this task automatically during day time, when the instrument is in stand-by.

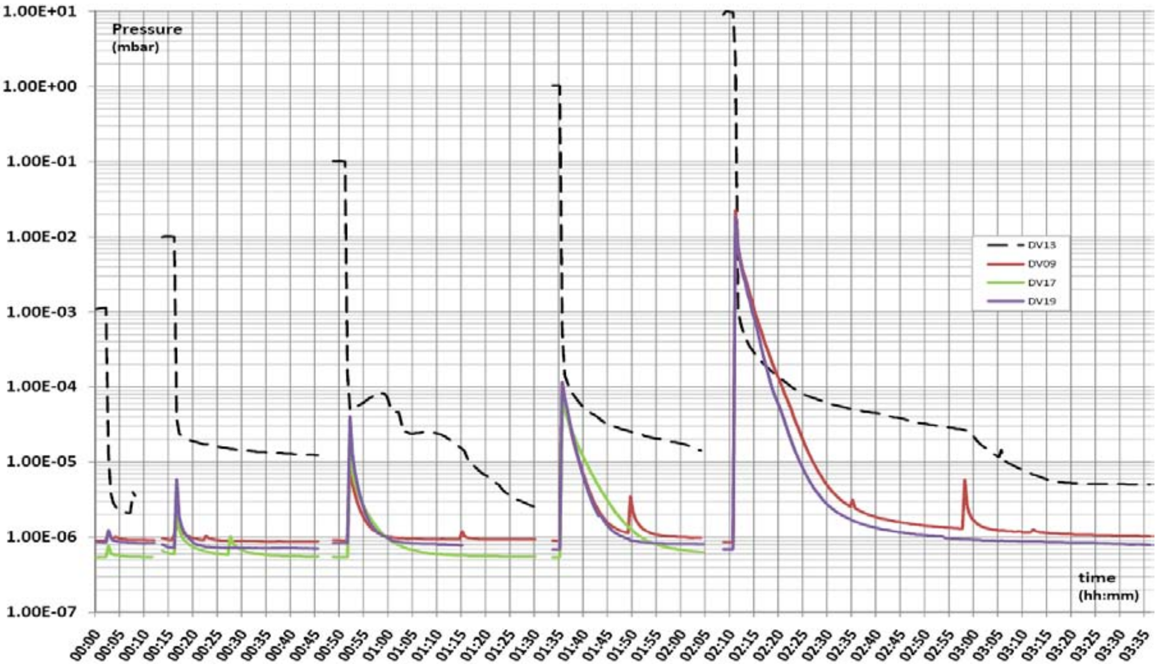


Figure 8: “Robustness” of the vacuum system

5.2 Cryogenic system performance

The cryogenic system should guarantee the safe and reliable operation of the 24 detectors at the specified cryogenic temperature of 163 K. The challenge of the cryogenic system is to ensure a reliable operation of each cryostat independently of its position on the instrument. The split of the instrument in two halves supplied by two separate 120 litres LN 2 tanks allows reaching largely the specified 30 hours holding time. Some special design features were introduced in order to have the upper raw of cryostats receiving the same supply than the lower raw.

Figure 9 shows the evolution of the 3 main temperatures (Detector chip, Cold plate and sorption pump) during the cool-down of one half of the instrument. The system is able to cool down the complete battery of cryostat within 3 hours. This time is not limited by the cryogenic system it-self but by the control system which ramps the cool-down of the detector chip. The holding time depends on the setting temperature of the cryostat cold plate and varies between 36 hours for a setting at 110 K to 44 hours for a setting at 130 K. This is largely over the 30 hours specified in order to have a smooth operation at the observatory.

Figure 10 illustrates the robustness of the cryogenic system. The cryostats are built with a significant thermal inertia which ensures the detector to be somehow un-sensitive to variation or even to some failure of the cryogenic supply.

- The left part of the figure shows the behaviour of the system in the case where the cryostat over cool the cold plate. The temperature of the detector is not affected even after more than 30 minutes running 15K bellow the setting temperature.
- The right part shows the behaviour of the system when the cryostat fails to cool the cold plate (LN2 supply tank empty...). In this situation also the temperature can be kept at operating temperature even after a one hour without LN2 and a cold plate temperature rising 20K above its operating temperature.

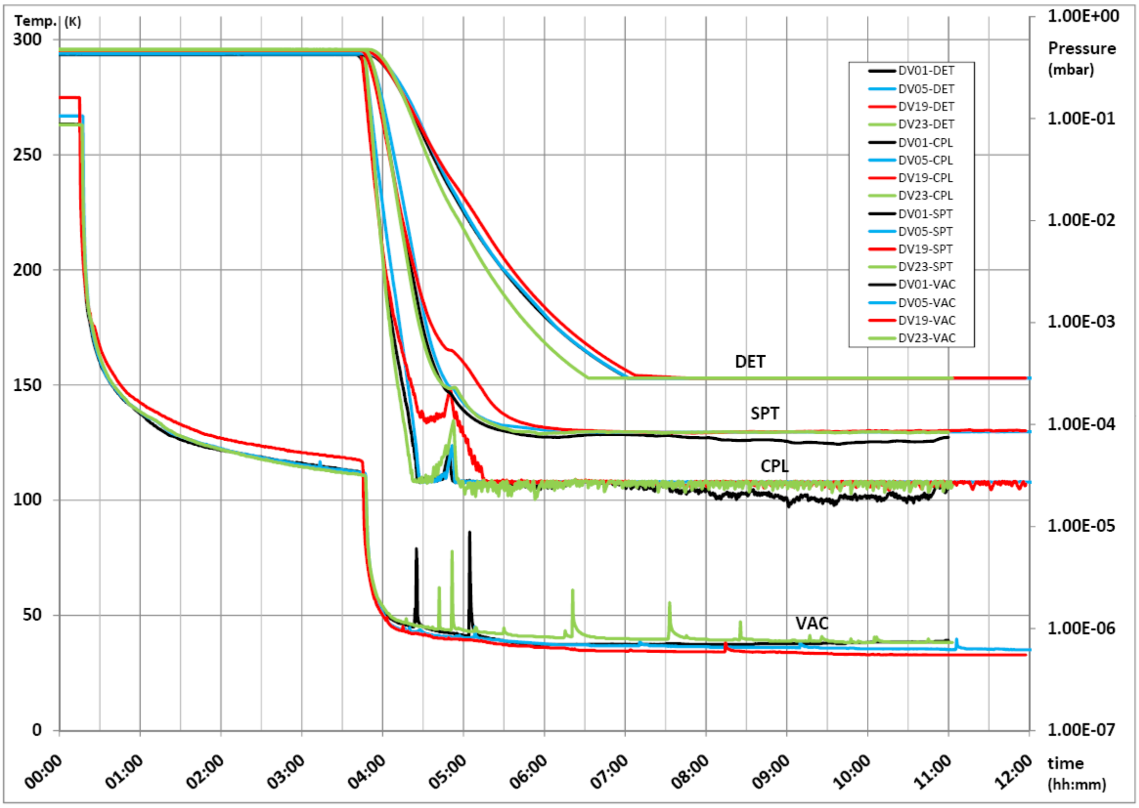


Figure 9: Cooling of 12 cryostats

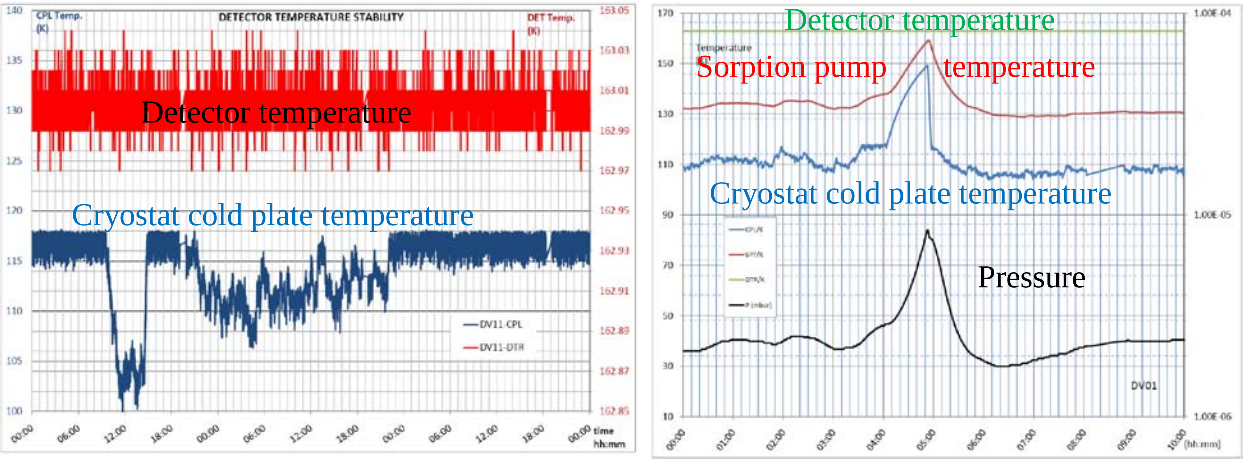


Figure 4: Robustness of the cryogenic system

6. STATUS

Actually the system is installed on the MUSE main structure. A first test with two cryostats has been carried out in order to verify the operation and give the necessary training to the MUSE team. In order to keep the LN2 tanks outside the clean environment where the instrument is integrated, the system is operated with 10 meters long LN2 transfer lines. The system in this final configuration is actually ready to be used for the system AIT and the system testing. Figure 11 shows a picture of the Vacuum and Cryogenic System installed on the instrument in the integration hall of the CRAL in Lyon.

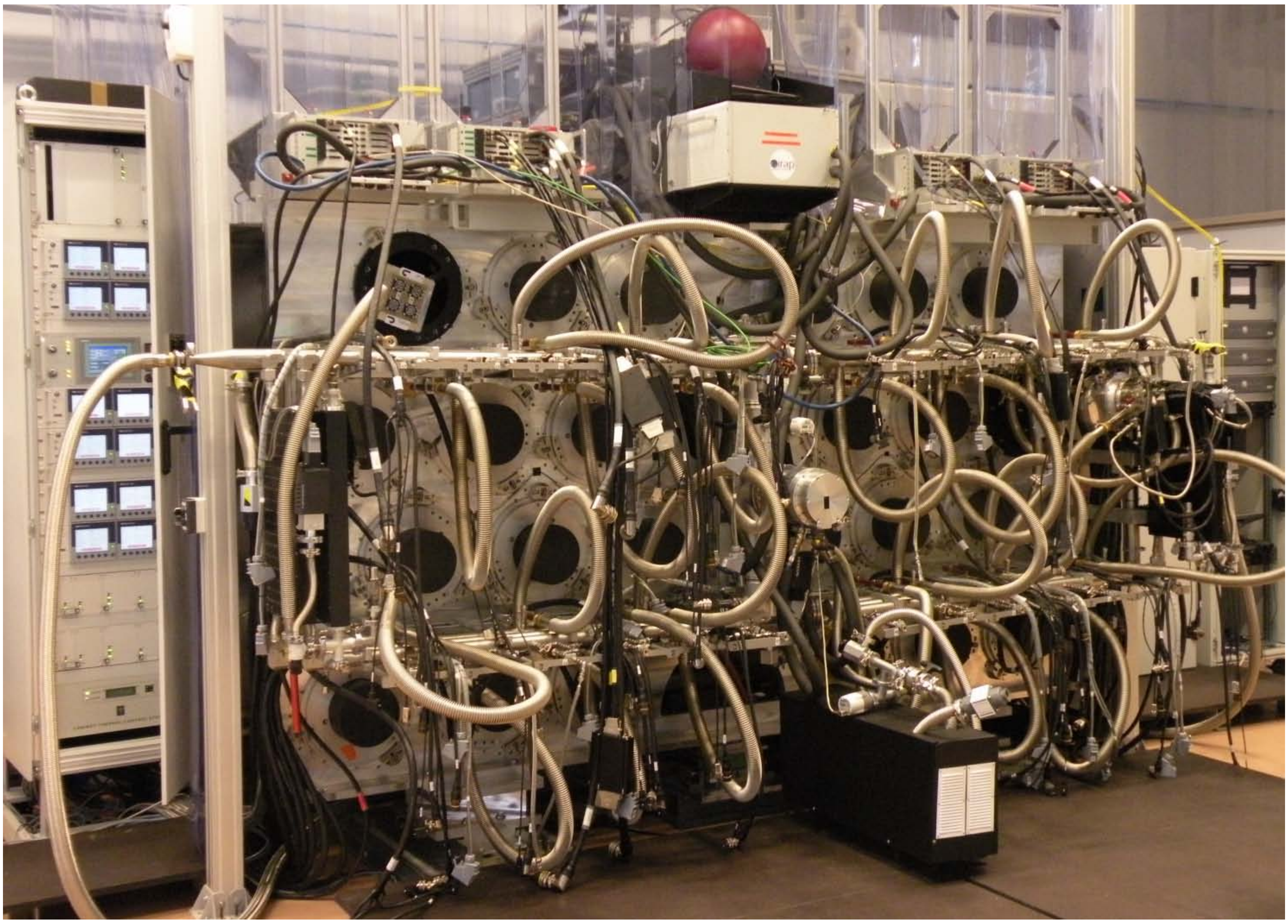


Figure 5: MUSE Vacuum Cryogenic System (with one IFU in position)

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