Remote refilling of LN2 cryostats for high sensitivity astronomical applications

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Abstract. The most sensitive observation mode of the ESO VLT (European Southern Observatory Very Large Telescope) is the interferometric mode, where the 4 Units Telescopes are directed to the same stellar object in order to operate as a gigantic interferometer. The beam is then re-combined in the main interferometry laboratory and fed into the analyzing instruments. In order not to disturb the performance of the Interferometer, this room is considered as a sanctuary where one enters only in case of extreme need. A simple opening of the door would create air turbulences affecting the stability for hours. Any cold spot in the room could also cause convection which might change the optical path by fraction of a micron. Most of the instruments are operating at cryogenic temperatures using passive cooling based on LN2 bath cryostat. For this reason, dedicated strategy has been developed for the transfer of LN2 to the various instruments. The present document describes the various aspects and care taken in order to guarantee the very high thermal and mechanical environmental stability.

1. Introduction

Most of the instruments operated for astronomical observations require the use of cryogenics. The optical detections are done using opto-electrical sensors, mainly well selected and optimized Charge Coupled Devices (CCDs). In order to get the best out of these detectors and in particular to reduce the electron noise, they need to be operated at cryogenic temperature (~ 140 K). Infrared observation makes sense only if the emissivity of all components in the optical path, or close to it, can be kept as low as possible. For this reason the largest part of the IR instruments is cryogenically cooled between 220 K and 70 K depending of the wavelength range of operation.

After a short introduction to the European Very Large Telescope and its interferometer the paper presents and justifies the strategy selected for the distribution and supply of liquid nitrogen to the various instruments and sub-systems through the complete observatory. Finally the core of the paper addresses the remote refilling of the instruments dedicated to the interferometric observations.

2. The VLT and its interferometer

At 2635 metres above sea level in the Atacama Desert of Chile, ESO’s Paranal Observatory is one of the best astronomical observing sites in the world and is the flagship facility for European ground-based astronomy. Figure 1 shows the VLT on top of Cerro Parana while figure 2 and 3 shows detail of the VLT facility. It hosts several world-class telescopes; among them are the Very Large Telescope, the Visible and Infrared Survey Telescope for Astronomy, and the VLT Survey Telescope. The Very Large Telescope array (VLT) is the flagship facility for European ground-based astronomy at the beginning of the third Millennium. It is the world’s most advanced optical instrument, consisting of four Unit Telescopes with main mirrors of 8.2 m diameter and four movable 1.8 m diameter Auxiliary Telescopes.
The telescopes can work together, to form a giant ‘interferometer’, the ESO Very Large Telescope Interferometer (VLT-I), allowing astronomers to see details up to 25 times finer than with the individual telescopes. The light beams are combined in the VLTI using a complex system of mirrors in underground tunnels where the light paths must be kept equal to distances less than 1/1000 mm over a hundred metres. With this kind of precision the VLTI can reconstruct images with an angular resolution of milliarcseconds, equivalent to distinguishing the two headlights of a car at the distance of the Moon.

![Image](https://example.com/image1.jpg)

**Figure 1.** The VLT on top of the Cerro Paranal (Chile).

![Image](https://example.com/image2.jpg)

**Figure 2.** The VLT interferometer with various optical paths (Schematic)

![Image](https://example.com/image3.jpg)

**Figure 3.** Top view of the VLT interferometer platform.

3. **General strategy for the distribution of liquid nitrogen**

Together with the very sensitive instruments and systems in operation on the VLT-I, the VLT complex has a suite of 20 Instruments with a total of 60 cryogenic systems. Even if some of these systems are kept at cryogenic operating temperature by mechanical cryocooler all 60 system need LN2 at some stage. From the beginning all service, preparation and maintenance activities have been kept in the basecamp in order to have the minimum of energy dissipation and movements inducing vibrations close to the telescope. The basecamp which also includes the boarding facilities for the staff sits 3 km away from the VLT platform at an elevation of 2300 metres.

The instruments are located at various places distributed over the complete Telescope platform and even spread over 3 different elevation levels. A central supply with a fixed pipeline distribution had been considered at the beginning of the project. The idea was rapidly discarded due to the complexity of such an installation to distribute LN2 toward places which are rotating. A central distribution system
would not be really efficient considering the very low power requirement of instruments. In a number of cases the consumption would be clearly dominated by the thermal heat losses of the lines.

Based on all these consideration the following strategy has been selected:
The LN2 is stored at the base camp (where a fraction of it is also produced by our own liquefier). Laboratory tanks are used for the distribution towards the individual posts. A 120 liter tank, which is still easy to handle by a single person, has been selected as standard. Figure 4 and 5 show the specific vehicle used for the transport of the LN2 supply tanks from the base camp ut to the telescope platform.

![Figure 4. The refilling of the supply tanks at the base camp](image1)

![Figure 5. The unloading of the supply tanks at the telescope platform](image2)

4. Specific case of the VLT-I instruments

Figure 6 below shows the schematic used for the remote refilling of one of the VLT-I instruments. The principle is the same for most of the systems. As explained in the previous section, the LN2 is provided from a 120 l LN2 tank which is equipped with the usual transfer head with the necessary safety equipment. The transfer in is ensured by vacuum insulated transfer lines. A nominal diameter of 6 mm has been selected for all the transfer lines. This guaranties an efficient transfer of up to 1 litre per minute using an overpressure of 0.45 bar. In order to minimize any thermal impact on the on the complete laboratory, the gas evacuation is also provided by vacuum insulated lines. The exhaust transfer line leads the cold gas to the outside of the laboratory. In the next room, which is not temperature or turbulence sensitive, the gas is warmed-up in heat exchangers close to room temperature. A small over pressure safety valve installed in the warm gas flow line prevents any moisture from entering the circuit in case the system runs out of nitrogen. The transfer lines (both for liquid or exhaust gas) are made from a combination of rigid and flexible sections in order to adapt the shape without impacting too much the thermal performance.

The N2 transfer flow rate is controlled by custom designed vacuum insulated electro-magnetic valves. These valves are based on commercial ASCO cryogenic valve specially prepared to operate under
vacuum. The most critical requirement is to heat sink the activation coil in order to avoid any damage due to overheating even if the system were to run out of LN2 during a transfer.

Various types of controllers have been developed over the time but generally the controller can also use a very simple temperature measuring system. There is no need to have a real PID controller. The aim is to detect the transition phase when the liquid nitrogen reaches the level sensor. Figure 7 shows the two different designs used for the level detection. In the case the LN2 tank is completely closed and without opening from the top, the level sensor system is directly implemented on the tank itself. A simple temperature sensor is mounted on a poorly thermal connected protrusion of the LN2 tank. The sensor is slightly heated in order to increase the temperature difference when it is in gas or immersed in liquid. When the LN2 tank offers an access port on the top, the level sensor is built as a plunger which senses directly the level of the liquid. An additional thermal sensor attached to the bottom of the LN2 tank is used as lower level sensor. The instruments are all kept permanently operational, this in order reduce thermal cycles and to be ready in case of a target of opportunity. For this reason they are all refilled systematically during the morning after the calibration of the data taken during the night. In case of an abnormal consumption the lower level sensor would initiate an alarm. The refilling operation takes in average between 20 minutes and 1 hours for the largest instrument tanks.

**Figure 6.** Typical schematic of the VLT-I cryostat refilling system 1: LN2 storage supply tank; 2: Main distribution line; 3: Cryogenic electro valves; 4: Instrument tank upper level sensors; 5: Instrument filling lines; 6: Gas exhaust lines; 7: Gas heaters; 8: Anti-return valves
Figure 7. Level sensor system to detect the top level of the LN2 tanks (left: tank without top access port, right: tank with top access port)

Figure 8 below shows the setup used for the Infrared Wave-Front Sensor (WFS) system of the VLT-I. Each telescope has one of these small cryostats which in addition to the IR detector hosts also a filter wheel and some re-imaging optic. This is an ESO standard 2-tanks cryostat which has been developed especially for VLT-I applications. The upper tank absorbs the highest heat load (radiation shielding) while the lower tank only has to keep cold the well shielded optical assembly and the detector itself. This concept guarantees a very low heat load and consequently extremely low boiling rate in the detector cooling tank. This means also extremely low vibration introduced on the sensitive optical system. The lower tank is refilled by over-spilling from the upper one. This has the advantage, during the original cooling, to prevent any too early and rapid cooling of the detector. A too early cooling of the detector might lead to contamination by cryo-trapping on the optical surfaces or on the sensitive surface of the detector.

This cryostat has a direct access port at the centre of the top of the two tank system. The plunger level system is installed vacuum sealed with a Viton O-ring on this port. It senses the liquid level in the lower tank.

The WFS is installed in the centre of the so-called “Coude room”, which is a 12 meter diameter circular room located inside the central pillar exactly below the telescope. This room is a sort of sanctuary where the beam of the telescope is focused and analysed. Due to the simultaneous operation of the visible Wave Front Sensor this room does not support any light. This imposes also a remote refilling for this specific cryostat. The schematic used is very like the standard one with the difference of the refilling line pre-cooling. The 8 m transfer line is rather long and pre-cooling it requires a significant amount of LN2 compare to the capacity of the cryostat tank itself. For this reason, the gas used for the pre-cooling of the line is exhausted separately via the pre-cooling gas exhaust line. This line is fitted at its second end with an electro-magnetic valve: the Transfer string valve. Only when the first drops of liquid are detected at the entrance of the cryostat, the controller closes this valve. The LN2 is then forced to enter the cryostat and this initiates the real re-filling operation. The upper tank is first refill and when it is full the LN2 continues to fill the lower tank up to its high level is reached. The refilling is stopped automatically when the level sensor detects the LN2 level.
Figure 8. Schematic used for the refilling of the WFS cryostat. 1: LN2 storage supply tank; 2: Cryogenic electro valves; 3: Main distribution line; 4: Instrument tank upper level sensors; 5: Liquid detection sensor; 6: Pre-cooling cooling gas exhaust lines; 7: Transfer starting valve; 8: Gas heater; 9: Anti-return valves; 11: Vacuum insulated gas line

5. Conclusion
Since the installation of the first instrument in 2005, the complete VLT-I instrument suite has been installed. The system, despite a rather high manpower demand, is a technical success which allows to meet the very high requirement to achieve the interferometric science.

6. References
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