LN2 auto-filling investigation

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Introduction or Purpose	

Recently the Liquid Nitrogen auto filling (LN2 auto filling) system has been installed in GRACE.
Different problems have been detected in operating this system in ensuring a correct filling of the three cryostats in GRACE. It became necessary to study the problems and think of possible ways forward aimed to satisfy the initial requirements for this system.

Note:
In this document a distinction will be made between liquid nitrogen and gaseous nitrogen. Since at ING nitrogen in general is indicated by LN2 we will stick to this terminology. The difference in phase will be mentioned separately. That explains the term liquid LN2 or gaseous LN2, which strictly speaking is not correct.

Scope	

This document covers how the system has evolved from the initial installation as designed by Kevin Dee into the current system. It will high light the problems encountered and flag possible safety implications of having this system.

Exceptions	

This document will not provide the final solution to the problems reported. It will summarize on the existing problems and suggest on possible ways forward.
The exact initial requirements will not be mentioned in here as they will need to be retrieved from different people that were involved initially.

The adaptive optics suite is housed in GRACE. This special room should provide a stable environment for correct functioning of the AO system. Environmental stability in respect to humidity, temperature, airflow is critical for adaptive optics systems. Especially the Deformable Mirror (DM) is very sensitive to any fluctuations in the above parameters. During the existing LN2 filling procedure of the three cryostats in Grace this environment is disturbed. A dewar has to brought into GRACE to fill the cryostats. To ensure sufficient Oxygen levels inside GRACE the double doors need to be opened to allow for proper ventilation. This affects the environmental stability and can result in the need to repeat the calibration and setup of the Adaptive Optics system and the DM in particular, which can be very time consuming.

Investigations were started to determine whether an auto-filling system could be implemented. This would enable the operator to be outside GRACE and eliminate the need to open the double doors for extended periods of time.

Initially a system with static sealed vacuum pipes was designed. This consists of a pipe that is contained inside another pipe that contains a vacuum. The vacuum acts as a thermal insulation and reduces the thermal losses when the line is cooled. Unfortunately the bore of the pipe that will conduct the LN2 was specified to big and therefore the time required to cool and fill the whole pipe was far too long to make the system effective.

This initial design was then taken to investigate if a simplified version could be manufactured on site with the available materials. A test line was build from copper pipe that was insulated with foam tubing. This was connected to a LN2 dewar to do testing. Approximately 8 metres of copper pipe was connected and tested and controlled by a single manual valve. The filling times were acceptable.

During the further completion of this system it became apparent that the control over each fill line (for each cryostat) needed to be mounted outside GRACE. This was addressed by fitting three separate valves on a control panel that would be fitted on the GRACE outside wall. From each valve an individual copper pipe would be run to each cryostat. This resulted in increasing the total pipe length to almost three times the initial value. The thermal inertia grew accordingly and thus the time required for cooling and filling all three pipes increased dramatically.

In an attempt to reduce the filling times the pressure on the LN2 dewar was raised to 2 bar instead of 1 bar. Result of this action is that gaseous LN2 is blown into the cryostat with more pressure that causes more spillage of the LN2 that is already inside the cryostat. Basically LN2 is blown out off the cryostat. Another added risk of this action is the increased risk of the silicon tubing breaking that causes a serious safety hazard.

A test was done to fill the OASIS cryostat. It took 25 minutes to cool the line up to the cryostat (that means it was frozen) and then another 25 minutes to fill the cryostat. During all this time gaseous LN2 was blowing into the cryostat and into the GRACE room. One can imagine what effects that will have on the thermal stability… It was perfectly visible how the LN2 inside the cryostat was blown out quite violently. The levels of gaseous LN2 put into GRACE raises the question whether no Oxygen depletion is occurring.

In summary: The current system probably misses its initial purpose to maintain environmental stability.

- Large amounts of (cold) gaseous LN2 will be conducted into GRACE that will affect thermal stability and possibly airflow above the optical bench.
- The required fill times are far too long to be reasonably practical. People will loose patience that could result in improper filling and cryostats warming up.
- The amount of gaseous LN2 raises concerns of possible Oxygen depletion although sensors are present to detect this.
- After filling the cryostats the system needs to be properly vented to ensure that no LN2 in liquid or gaseous form is left in a contained volume (between two valves)
- After this the silicon tubes need to be removed from the cryostat to reduce LN2 boil off due to a thermal conductor formed by the filler tube.

The first question to be answered is to assess whether the current system can be modified or upgraded in such a way that it will satisfy the initial requirements. Obviously these requirements need to be written down again. If it is not realistic to expect that the system will satisfy the requirements, no more effort should be spend on this system as it is now.

As an alternative two other possible ways off attack can be defined:

1. Improve on the traditional manual filling and ventilation to reduce the risk of Oxygen depletion in order to maintain the double doors closed and reduce the disturbance on the environmental stability.
2. Fully automate the system for remote filling for each individual cryostat.

1. Main problem on the manual filling used at ING currently is the need to ventilate the gaseous LN2 to exclude Oxygen depletion. In order to achieve this, ventilation is required by opening the double doors. This then causes the environmental disturbance. If the ventilation of the gaseous LN2 to the outside of GRACE can be improved, the requirement to open the double doors could be eliminated. Carrying a portable Oxygen depletion sensor could alert people about risk of Oxygen depletion. A dewar still needs to be brought into GRACE through the small door, which causes a risk of the bench being knocked.

2. For a fully automated LN2 filling system, the technique for filling needs to be changed significantly. Instead of filling by pressurizing LN2 to push the LN2 to the cryostats a system is needed that provides liquid LN2 available instantaneously at low pressures. In order to achieve this several special components are required.

System description:
A completely ‘wetted’ system needs be implemented (this is what was originally envisaged with the special vacuum filling tubes). This means that the LN2 pipes will be permanently filled with LN2 right up to the cryostat that will be separated by an electro-magnetic valve. When the electro-magnetic valve is opened Liquid LN2 is available immediately to fill the cryostat. Requirement for this system is to keep the pipes filled with liquid LN2. The common way to conduct LN2 at ING through pressurization is not suitable since this will produce considerable amounts of gaseous LN2 that can not be connected to pipe work that is sealed off by an electro-magnetic valve. Pressure build up will lead to destruction of the enclosed volume, unless a safety relief valve is implemented.
To address this a so called ‘phase separator’ can be used. This unit enables delivery of low pressure liquid LN2 to each point on demand.
An example of such a device can be found here:
http://www.vacuumbarrier.com/Semi/mops.html

The LN2 can then be filled by gravity. The liquid LN2 will simply flow to each cryostat without all the pressure build up and related gas insertion to GRACE.
A system lay-out can be found here:
http://www.vacuumbarrier.com/Semi/MBE.pdf
Practical problem is that the phase separator needs to be placed higher than the cryostats.

Summary	

The current system as installed in GRACE is not ready for operation as it stands now.
Serious concerns can be raised related to the efficiency and safety implications of this system.

Revision of the initial requirements is needed. The current system can then be measured against these to determine whether there will be a possibility that this system can be upgraded in such a way that it will satisfy these requirements. If this is not realistic to expect no more effort should be spend on improving the current system. Instead of that it should be investigated which of the two proposed alternative ways forward is most effective.

One very important thing to bear in mind is the safety regulations that are in place to regulate the safe use and transportation of LN2. It is significantly different to plumb a system for a water distribution circuit than it is for LN2. Another fact to remember is that one litre of LN2 expands into 700 litres of gaseous LN2…!!

In my opinion if it will be decided that we adopt option no.2 we will need to seek some professional support for guidance. There are specialist companies who do nothing else than this kind of business. They are capable of delivering very well defined quantities of LN2 in very high duty cycles for the food industry, so providing a system for filling the cryostats in GRACE should not be a problem. Obviously the cost involved in doing this will be higher.

References

http://www.asscientific.co.uk/

http://www.vbs.peco-europe.co.uk/mbe.pdf

http://www.vacuumbarrier.com/

Kevin Dee, Engineering & Project Solutions