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# Cryogenic control system migration and developments towards the UNICOS CERN standard at INFN

Paolo Modanese[a] *, Andrea Calore[a, d], Tiziano Contran[a], Alessandro Friso[a], Marco Pengo[a], Stefania Canella[a], Sergio Burioli[b], Benedetto Gallese[c], Vitaliano Inglese[d], Marco Pezzetti[d] and Ruggero Pengo[a]

*[a]INFN Laboratori Nazinali di Legnaro, viale dell'università 2, Legnaro 35020 (PD), Italyb*
*[b]INFN Laboratori Nazinali del Gran Sasso, via G. Acitelli, 22,Assergi L'Aquila 67100, Italy*
*[c]INFN Sezione di Genova, via Dodecanese, 33Genova 1614, Italy*
*[d]CERN, CH-1211 Geneva 23, Switzerland*

**Abstract**

The cryogenic control systems at Laboratori Nazionali di Legnaro (LNL) are undergoing an important and radical modernization, allowing all the plants controls and supervision systems to be renewed in a homogeneous way towards the CERN-UNICOS standard. Before the UNICOS migration project started there were as many as 7 different types of PLC and 7 different types of SCADA, each one requiring its own particular programming language. In these conditions, even a simple modification and/or integration on the program or on the supervision, required the intervention of a system integrator company, specialized in its specific control system. Furthermore it implied that the operators have to be trained to learn the different types of control systems. The CERN-UNICOS invented for LHC [1] has been chosen due to its reliability and planned to run and be maintained for decades on. The complete migration is part of an agreement between CERN and INFN.


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* Corresponding author. Tel.: + 390498068679.
*E-mail address:* paolo.modanese@lnl.infn.it


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## 1. Overview of the LNL Cryogenic Systems

At LNL the helium cryogenic installation is the largest in Italy: it includes two helium refrigeration systems, 22 cryostats for superconducting resonant Quarter Wave Resonators (QWR) cavities and one cryostat for two Superconducting Radio Frequency Quadrupoles (SRFQ) cavities, one helium liquefaction plant, one helium purification system and a quite large gas helium recovery and storage systems. In order to renew their relevant control systems three possibilities were taken into account: the "turnkey" solution done by each manufacturer was estimated very expensive and did not allow to standardize the control systems leaving a situation of heterogeneity. The reverse engineering solution was considered very laborious and would have needed human resources not available and not obtainable at INFN. The choice of CERN-UNICOS offers instead the possibility to access directly to highly specialized resources available at CERN by sending LNL staff there to learn the tools and then apply them to the local cryogenic systems. The project officially started in 2013, first with the successful revamping of the Linde TCF20 liquefier control system followed by the new cryo-control of two out of 22 cryostats of the ALPI superconducting accelerator. A new unified control room (T.1) was set-up dedicated to all the cryogenic plants and their subsystems.

| Cryogenic System | Subsystem | CPU | OP | AI | AO | DI | DO | ETH |
|---|---|---|---|---|---|---|---|---|
| ALPI | Cold Box ALPI (actual inst.) | 1 | 0 | 101 | 20 | 28 | 96 | 1 |
| | Cold Box ALPI (future inst.) | 1 | 0 | 140 | 30 | 72 | 150 | 2 |
| | Auxiliary Cold Box (ACB) | 1 | 1 | 12 | 2 | 32 | 16 | 1 |
| | Cycle compressors | 4 | 4 | 32 | 4 | 120 | 112 | 3 |
| | LINAC cryostats (for 24 units) | 6 | 0 | 390 | 200 | 770 | 770 | 12 |
| PIAVE Injector | Linde TCF50 + 3 cryostats | 1 | 1 | 110 | 55 | 64 | 60 | 1 |
| Liquefier | Linde TCF20 | 1 | 1 | 24 | 11 | 32 | 60 | 1 |
| Helium Storage and Purification Systems | Recovery System (future inst.) | 1 | 0 | 26 | 0 | 84 | 60 | 1 |
| | LN2 purification unit (. actual inst) | 1 | 1 | 16 | 0 | 32 | 64 | 1 |
| | LN2 purification unit (fut inst) | 1 | 1 | 36 | 0 | 70 | 134 | 1 |

Tab. 1. Cryogenic Control Systems Signals

Fig. 1. Cold Box ALPI. In front is the supercritical Turbine

Fig. 2. ACB cryostat top flange. In front are the circulators

In there, 6 Operator Workstations OWS are present, through which it is possible to access directly as client the server where the UNICOS standard SCADA (WinCC-OA) software is installed. Three servers have been set up: 2 for the control of all cryogenic plants while one is used for the development and upgrading of all new control systems. All servers use Scientific Linux as operating system. In the future it will possible to use up to 11 clients for the simultaneous monitoring of all plants, for a total of about 60,000 data point elements.

### *1.1. ALPI*

#### *1.1.1. ALPI Refrigerator*

The ALPI refrigerator was built in the early 90s by Air Liquide on the basis of a Helial refrigerator: it was the first horizontal cold box (Fig. 1) manufactured by Air Liquide.

. Fig. 3. Cryostats and transfer lines of LINAC (photo by F. Mangiaracina)

The cycle was originally obtained with two turbines in series plus a reciprocating wet expander or, as an alternative, a Joule Thomson (JT) valve. This plant, thanks also to the recent up-grade with the installation of a third supercritical turbine, has a refrigeration capacity of 3900 W @ 60-75K and 1200 W@4.2K. The recent installation of the third turbine and the addition of a second Joule Thomson have allowed obtaining a net improvement of refrigeration efficiency, maintaining the original mass flow. The plant is able to process up to 150 g/s of helium supplied from a compressor station which consists of 4 units (two redundant): one Mycom 65 g/s (Fig.3), one Mycom 95 g/s, two Howden 55 g/s each. The turbine T1 can process up to 73 g/s at the input pressure of 15.8 bar abs and exhaust pressure at 6.4 bar abs. The turbine T2 can process also the same mass flow rate, at inlet pressure of 6.2 bar abs exhaust pressure of 1.2 bar abs. The supercritical turbine T3 has been sized for 70 g/s with an inlet pressure of 15.8 bar and it is able to provide an additional refrigeration power up to 400 W @ 4.5 K.The control system has been upgraded the first time in year 2000, from the old Syclope Z80 PLC to a more modern industrial PLC, the Eurotherm PC3000. Today this PLC is obsolete and no replacement parts are available: also the program needs to be totally revised because of the many “patches” added during the past years. The PC3000, consists of 4 racks and a single CPU, which are connected to the all I/O signals (Tab. 1). Considering the imminent migration to UNICOS, the local control of some other subsystems and the I/O signals (Fig. 1) will be integrated into the new control system The vacuum system of the Cold Box, and the purging and vacuum system of the transfer cryogenic lines will be integrated, in the new control architecture, to the Cold Box, internal purifier and the transfer lines. At the moment each compressor has its dedicated control system (Tab. 1) and their logic will be integrated in the cold Box PLC.

In parallel to the Main Box Cold box, connected to the helium gas cryogenic transfer lines an “Auxiliary Cold Box” (ACB) is also installed to keep cold (around 80 K) the thermal shields of the cryostats in case of stop of the refrigerator. One has to prevent that the thermal shields, warming up, would outgas the trapped impurities towards the superconducting cavities. The ACB consists of a cryostat (Fig.2) containing liquid nitrogen in which a heat exchanger is immersed: the gas helium is cooled flowing through the heat exchanger by two circulators and pumped to the shields and back by two helium gas circulators in series. The mass flow in each pump is up to 100 g/s @ 6.5 bar with a $\Delta p$ of 0.54 bar each. The electric motors of each circulator, which is water cooled, absorbs a power of 7.1 horsepower (3 phase and 2 pole motor). Its speed is adjusted by a variable frequency drive (VFD Magnetek) up to 200 Hz. The actual control system (Tab. 1) is done by a Schneider M340 PLC with a touch panel (Magelis Schneider). The only two analog output are used to keep the liquid nitrogen level and to control the bypass valve which regulates the discharge pressure of circulators.

*1.1.2. ALPI – LINAC*

The ALPI LINAC Helium refrigerator, commissioned in 1991, is dedicated to maintain the superconducting linear accelerator, which consists of superconducting quarter wave resonators. The LINAC (Fig.3) currently consists of 20 cryostats housing a total of 73 superconducting cavities (16 Nb bulk and 57 Nb sputtered on bulk Cupper). The liquid helium is distributed as a two phase fluid towards the cryostats in parallel. Each cryostat is connected to a valve box which is placed in the main cryogenic distribution line. The valves that put in communication the cryostat to the line are controlled by a complex and an old control system. Each cryostat is locally controlled by a logic unit/CPU that is connected to the field I/O signals (Tab. 1). These units are connected via RS485 serial signal to a concentrator which in turn is connected to two PC via ISA BUS, where is running a QNX v.2.2 operating system. This old system has been working for 20 years and has proven to be very reliable and functional. However today is obsolete and must be replaced with a new one. It is no longer possible to find other spare parts or repair.

The project of UNICOS migration the cryostat control system has then the highest priority and the first prototype with UNICOS for the first group of cryostats has already been realized. The new project follows the line marked by the old system, maintaining almost the same architecture. A single PLC will control up to 5 cryostats, and the same configuration of electrical panels is maintained and it will be completely replaced by new ones. The Schneider Premium PLC and the panels of the supervisor with WinCC_OA is used with UNICOS CPC 6.

*1.2. PIAVE Injector*

*1.2.1. PIAVE refrigerator*

The refrigerator for the Piave injector is a Linde TCF50. (Fig.4) .It was commissioned in 2004 and it provides the refrigeration for the three cryostats used to pre-accelerate the heavy ions produced by a ECR ion source, located on a 350 kV voltage platform. The helium compressor system is a Kaeser FB360 that processes up to 63.5 g/s at a discharge pressure of 13 bar abs and a suction pressure of 1.05 bar abs. The refrigeration capacity of the TCF50 is 406 W @ 4.5 K with the aid of liquid nitrogen (LN2) precooling, while it is 334 W without LN2. The two Linde turbines in series can process up to 39 g/s @ 13 bar abs.

The plant is relatively recent and the control system has not ever been particularly modified. The PLC is a Siemens S7-400 connected via Profibus to remote islands (ET200S) linked to the field I/O signals (Tab.1). The SCADA is the Siemens WinCC. Locally, on the main cabinet, it is also possible to work with a small operator panel OP (Corso OP27), which is not used because frequently situated in the accelerator area which is not accessible during the operation. Although smaller, even this system consists of several subsystems that are controlled by the same PLC: the main Cold Box, the Valve Box, the vacuum system, and 2 Linde Cryogenic Turbo-expander.

Also the control of the 2 cryostats for QWRs cavities and the cryostat for the SRFQs cavities is implemented into the main program. The migration of this control system to UNICOS is scheduled after the completion of new the ALPI Cryogenic Control Systems.


Fig. 4. PIAVE TCF50 Cold Box

Fig. 5. TCF20 Cold Box

*1.2.2. PIAVE – SRFQ*

The necessary energy to inject the ions into LINAC is achieved by 2 cryostats housing QWR cavities, identical to those installed on the branch of the low energy of the LINAC, and by a cryostat for superconducting radio frequency quadrupoles (SRFQ [2]) built for the acceleration of slow and relatively low current heavy ion species. The control of these cryostats is integrated into the PLC with the control of the refrigerator.

*1.3. Liquefier Linde TFC20*

The Linde TCF20 liquefier (fig. 5) has been purchased in 1996 and it control system is the first cryogenic control system that has been upgraded with the standard UNICOS. The liquefier has been used to produce liquid helium to cooldown the "gravitational antenna Auriga" (to detect gravitational waves), the PVLAS experiment (for a vacuum polarization experiment) and to serve the numerous tests and experiments at LNL on superconductivity. The production capacity can reach 100,000 liter/year and the storage capacity is up to 5000 liters. The old control system was a Satcom PLC and the supervision was running on old MS-DOS operating system, consisting in some pages on DOS which could show a list the value of the main parameters of the machine.

Given that the entire control system has been completely replaced and renovated, changing the entire electrical panel and keeping only the electronic instrumentation strictly necessary: the new electrical panel was installed near the Cold Box and all I/O signals (Tab. 1) were disconnected from the old control system and connected to the new one. The new Supervisor used with UNICOS has been done with PVSS II (today WinCC_OA) with which have been realized the panels of the supervision.

The migration was completed in early 2013 in collaboration with CERN and INFN – Sezione di Genova.

*1.4. Helium Storage (LHe, MP, HP)*

The total amount of helium at LNL is about 2 tons and it is stored in three forms: liquid helium, pure gas helium and impure gas helium.

Liquid helium is mainly produced by Linde TCF20 liquefier and stored in its 5000 liters Dewar. It is also possible to produce liquid helium with the refrigerators, when the power required by the superconducting accelerators is appreciably lower than the cryogenic power available. To storage liquid helium are available three dewars of 3500 liters each one, two dewars of 1000 liters each and some other smaller dewars of 250-100 liters used into laboratory experiments.

Fig. 6. Gas Helium Storage

Fig. 7. LN2 purification unit

The pure gas helium is stored in the buffers (fig. 6) directly connected to the cryogenic plants which have a nominal pressure of 20 bar and maximum working pressure of 14 bar. The total volume available is about 70 $m^3$ and it is mainly used for the startup operations or the cryogenic plants. There is also a small storage of pure gas for emergencies, in packages of 200 bar cylinders which are provided, when needed, directly by the gas provider company.

The prevalent helium storage is the impure gas, mainly when the cryogenic plants are turned off. The vaporized helium is conveyed to three gasometers through a wide network of pipelines, approximately 900 meters of lines that serve approximately 4000 $m^2$ of laboratories. The helium is collected and stored in high pressure cylinders (fig. 6) (up to 200 bar) by 3 piston compressors (Burkhardt Compression) with a capacity of 200 $Nm^3/h$.

The relevant control system is currently based on an electromechanical and manual valves. Every day it is necessary to operate more than 60 manual valves. In the future these valves will be automatic and replaced by pneumatic actuated valves. The monitoring of the impurities on the recovery lines is also a local control.

As soon as possible, we need to create a new helium recovery control system (Tab 1), in order to put together all these subsystems and to remote and automate all the recovery system operations reducing the possibility of human error that could be cause of helium loss in the atmosphere or of heavy pollution of the helium gas.

### *1.5. Helium Purification System*

There exists at LNL internal purifiers located each inside or close to each refrigerator/liquefier. There exists also a standalone helium purifier. The purification unit (fig. 7) for helium gas, cooled by liquid nitrogen and built in 1992 by Air Liquide – DTA is a very precious system. The helium to be purified is precooled in a counter-flow heat exchanger against the pure helium and the cold nitrogen gas produced in the absorption stage. This equipment is a double coiled pipe exchanger located into 2 dewars. The adsorption phase is done flowing helium gas through the activated coconut charcoal cooled into a liquid nitrogen bath. The liquid nitrogen tank consists of a double-walled cryostat with high vacuum and superinsulation (MLI). This plant can process up to 50 Nm3/h @ 30 bar of helium gas with the following levels of inlet impurities: air volume less than 0.1%, water less than 1 ppm. In these operating conditions the outlet gas quality is He N50 (He 99.9990%).

The control system of the purification unit has been upgraded in 2006 with the replacement of the old Operating Panel Schneider Magelis XBTC8251 with a new one, a Schneider Magelis Touch Screen. The program has been rewritten and a new graphic page for supervision of the operator panel has been realized. In the near future the purification capacity of this plant will be doubled with the addition of a new line of purification and 2 new purification columns. In this occasion, the control system (Tab. 1) will be upgraded with UNICOS and the supervision, now only local, will be remote.

A new monitoring station for pure helium will be realized that will be integrated into the new control system. Currently two measuring units are installed into the two refrigerators to constantly monitor the incoming gas. The analyzers are two Linde Helium Gas Analyzer (model WE-34M) with an additional pirolyzer unit (model SM38) able to measure the impurities of $H_2O$, $N_2$ and $C_xH_y$ and oil aerosol. These gas analyzers will be installed in the compressor room, in a single analyzer station, to monitor both the level of impurities of the cycle compressors and the impurities of the outlet of the cryogenic purifier unit to the cryogenic cycle.

## 2. Conclusion

The different cryogenic control systems at LNL will be refurbished and upgraded towards a CERN UNICOS standard. The migration to UNICOS, already started and partially completed, offers the possibility to face a very important and necessary renewal work with a relative modest investments in terms of economical and human resources.. The result will be a single control system with a single supervision, following codification and nomenclature standards.

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