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# The upgrade of the control system for the CERN/NA62 liquid krypton detector

Moraux A.[1], Bremer J.[2], Falaleev V.[1], Gonidec A.[1], Passardi G.[2], Pezzetti M.[2]

[1]Physics Department, CERN, 1211 Geneva 23, Switzerland
[2]Accelerator Technologies Department, CERN, 1211 Geneva 23, Switzerland

The NA62 experiment is a continuation of the CERN kaon research program and particularly of the NA48 experiment which was designed in the early 90's to measure the direct CP violation with a very high precision. An important component of the experimental setup is an electromagnetic calorimeter filled with 9000 liters of high-purity liquid krypton at 120 K. Its associated cryogenic system aims at providing a very high reliability and stable thermal conditions with temperature stabilization better than 0.1 K. The upgrade of the cryogenic control system was motivated by the need of ensuring its durability and standardization for the long term fixed-target physics program at the CERN Super Proton Synchrotron (SPS).

This paper describes the adopted technical solutions to minimize the control shut-down and emphasizes the related safety issues.

## BACKGROUND

### Cryogenic setup

At the creation of the NA48 experiment, the purpose of the electromagnetic calorimeter was to reconstruct kaons neutral decays using a quasi homogeneous liquid krypton (LKr) ionization chamber to combine good energy, position, and time resolution [1]. The cryogenic system consists basically of a vacuum insulated calorimeter cryostat, a krypton storage dewar to ensure loss-free storage for long idle period, and two nitrogen dewars (see Figure 1). Purifying and specific cooling devices have been integrated to maintain the liquid krypton at a relevant impurity level and to guarantee high-grade thermal stability [2]. Liquid transfer is generally achieved with a centrifugal pump passing the liquid through several filters dedicated to krypton purification in liquid phase. In normal operation, the vaporized krypton passes continuously through a filter before being recondensed.

To compensate static and dynamic heat loads produced by cold electronics, solid conduction, and power cables entering the liquid, a krypton condenser using liquid argon as intermediate coolant has been installed. Argon is further cooled by liquid nitrogen vaporization. Nitrogen heat exchangers, located in the gas space of the calorimeter and the storage dewar, provide emergency solutions in cases of unforeseen pressure rise. To prevent any critical situation which, in the worst case, could lead to a krypton loss, several redundancies have been implemented on the apparatus and on its dedicated control. Consequently, both cold water and compressed air supply systems can be switched to external sources, and inlet valves for emergency coolers are duplicated. Concerning the control system, most of important temperature and pressure sensors are duplicated, and the low voltage supply is backed up by an UPS giving autonomy of six hours, and by a diesel generator.

The first commissioning took place in 1996, and the cryogenic system has since operated to provide optimal conditions inside the calorimeter for 12 years of physics exploitation.

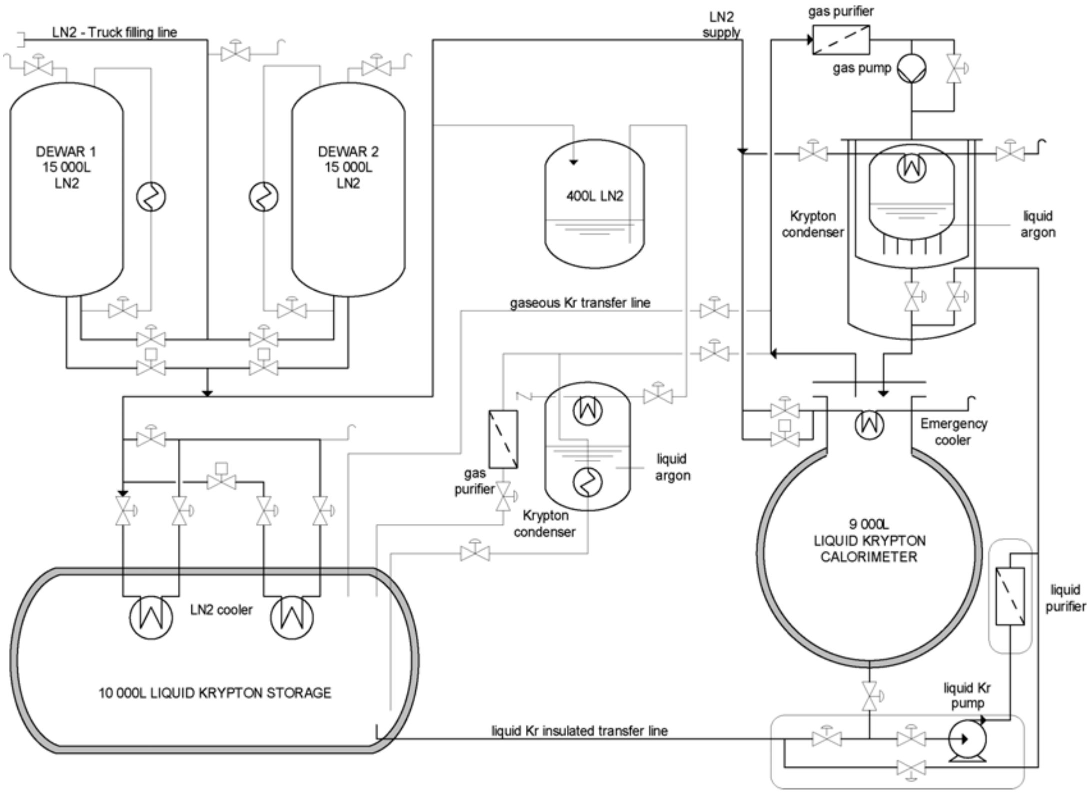

Figure 1 Simplified cryogenic flow scheme

Control system

Due to the specific requirement for uninterrupted operation in fail-safe mode, the slow control for the cryogenic system has been originally based on Programmable Logic Controllers (PLC). Siemens S5 were selected, after a circumstantial comprehensive study. The SCADA platform consisted of a FactoryLink® interface connected to the PLC by a coaxial cable using the SINEC H1 protocol. The hardware layout was primarily split into 4 different systems, each controlled by its own PLC: cryostat control, krypton storage control, nitrogen storage control, and calorimeter temperature measurements. The hardware was designed to allow fully independent operation of each subsystem and to fit the geographical repartition. An additional complexity of the conception came from the restricted access to the underground experimental area, entailing remote control system and a high level of automation. It has run now since the first commissioning without interruption and trouble.

## PROJECT: MOTIVATIONS, APPROACH AND CHOICES

The upgrade project took its origin in a lack of support, of spare parts and expertise on the FactoryLink® supervision which has critically risen in the last years of operation. The PLC source code remained singular, reducing intervention possibilities, even considering the associated consequential documentation. In parallel, for the LHC (Large Hadron Collider) project, and particularly concerning its cryogenics, CERN control teams have developed and implemented standardized tools and approach. This UNICOS (UNified Industrial COntrol System) framework systematizes production methodology and interface, of PLC-based control system production methodology and interface [3]. According to this new development, the original NA48 system represented an inadequate for long-term operation. In addition, future physics campaign perspectives using the NA62 detector have been presented, demanding a sustainable solution for the coming fifteen years for the control of the LKr cryogenics.

After analyzing the state of the original control system, a complete study of the different possibilities has been undertaken, which, considering costs, development time and mainly standardization possibilities, demonstrated the necessity of an upgrade of the entire control system instead of just a new supervision layer implementation. This also implied a review of the low voltage supply, electrical protection, distribution, drawings, instrumentation status, I/O cabling interface, PLC hardware devices, and operator interface. Consequently, some sensors and valve actuators were also modified to support a new control strategy.

Project overview

The overall project rest on a generic approach, which can be applied to all kinds of control system upgrade or development project. The project was divided into five phases (entire review of the original control system and survey of needs, technical study and solution proposal, time schedule and risks analysis, preparation and tests, field work and commissioning). A thorough analysis, from the instrumentation layer to the operation layer, has been carried out at the beginning of the project, in order to determine available technical solutions, taking into account budget, planning and risk factors. To warrant a smooth and secure transition, the integration part was organized into three sequential steps: nitrogen storage and vacuum control, liquid krypton control, and cryostat measurements. Each step has been studied and prepared altogether in advance to ensure a good correlation between the different cryogenic subsystems and to outweigh their inter-dependency.

Technical choices

Based on standard tools, the new system had for objectives to improve operational conditions, diagnostics capability, ease of intervention, and maintenance (See Table 1). Using modern control system technologies combined with the CERN/UNICOS framework, it was possible to overcome many of the limitations and complexities of the original control system. A part of the effort was dedicated to the upgrade of the system to the actual CERN standards and safety regulations. Current UNICOS implementation employs Siemens S7 and Schneider PLCs at the control level and PVSS® II at the supervision level. To enhance support and maintenance, the hardware equipment selection was based on the same solution chosen for the control of the LHC cryogenic accelerator sector [4]. Therefore, as shown in Figure 2, the four original systems were turned into a unique CPU, since this type, a Siemens S7-416, can handle the entire cryogenic plant control. Known as a possible delicate point, redundant power supplies and cards providing self-diagnosis information have been employed.

Table 1 Plant control modification plan

| System | Choice |
|---|---|
| Sensors | - Wiring update of platinum resistor<br>- Galvanic isolation improvement |
| Actuators | - Normalization into 24 VDC powered actuators |
| Low voltage production | - Replacement by new generation Siemens SITOP<br>- DC rack implementation |
| I/O cabling | - Upgrade to standard cabling interface |
| I/O cards | - Control purpose: Turned into S7 standard I/O cards<br>- Calorimeter sensors: acquisition from S5 modules through S7 communication card<br>- Deported cards: Profibus network and ET200M module |
| PLC hardware devices | - Siemens S7 416-2DP, Redundant power supplies, Ethernet card |
| Framework | - S7-UNICOS and object-oriented programming |
| Network | - CERN Ethernet technical network |
| Supervision | - PVSS® II: Simultaneous monitoring, real-time, historical trending, alarm management |
| Data archiving facilities | - CERN Timber / LHClogging |

Discrete control signals were changed to 24 V DC, eliminating electrical safety hazards during troubleshooting. Analogue control signals, except for temperature sensors, were standardized to 4 to 20 mA or to 0 to 10 V. Temperature sensors outside the liquid krypton cryostat, used for control purposes, were moved to Siemens S7 16 bits cards devoted to temperature metrology. Deported I/O cards, in charge of the control of the centrifugal liquid krypton pump, were originally placed in the cavern housing the experiment, due to the variable frequency drive limitations in accepted cable length for command signals. To provide as much reliability as possible, this extension was substituted by an ET200M module, interfaced to Profibus DP (Decentralized Periphery) with the CPU.

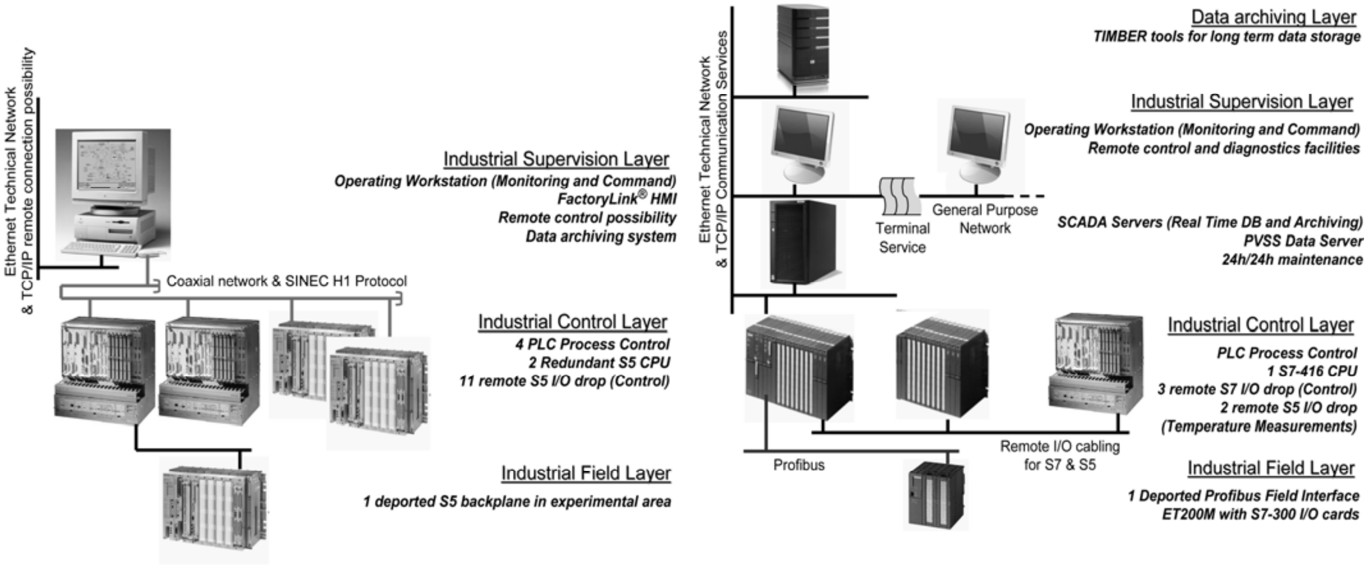

Figure 2 Original and new control architecture

Part of the risk analysis emphasises the possibility of a network failure scenario. Any troubles affecting the PLC-SCADA communication do not disturb the control, which keeps on running by itself. In case of necessity, a hardware alarm transmission frame will ensure on-call cryogenic operator intervention in the following hour. Thanks to the complete transition, the cryogenic operator is backed up by a 24/24h support, to cover eventual trouble within the control system.

## UNICOS PRINCIPLES AND SOURCE CODE TRANSLATION

A significant effort of this upgrade was the reliability adaptation, and the process logic transformation from the S5 source code in instruction list (LIST), close to the assembly language, to an object-oriented programming language. This task was partially compensated by the UNICOS development facilities, which minimize hand-code activities. Application generation tools have clearly relieved the production of an error-free application basis, whereas rapid prototyping, and a high level of automation, gave the possibility to focus on the process logic itself.

UNICOS is an industrial framework developed at CERN to produce control applications in the PLC and in its SCADA level counterpart [5]. It took its origin from several years of experience in cryogenics operation at LEP (Large Electron Positron) time. Its portability and resulting ease of use generated an important interest, and UNICOS-based applications have been extended to various activities such as magnet control, vacuum, or gas installation for experiments.

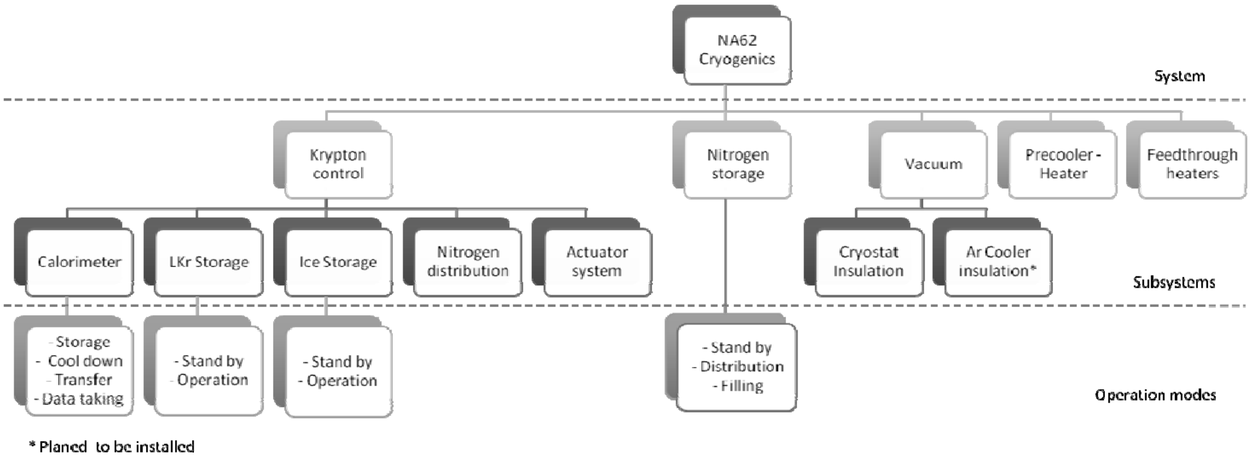

Figure 3 UNICOS process control objects breakdown

UNICOS objects philosophy follows a pyramidal organization through a 3-layer structure (I/O objects, Field objects, Process Control objects). The new source code had as objective to fill the different requirements in terms of reliability, alarm detection, automatic functions, and self-operation. Particular attention was paid to the process cut-out and to the relationship between the different control objects to have a structure as flexible as possible to compensate the previous hardware physical separation (see Figure 3). Fast restart of the process, in case of PLC damage, has been worked out and automatic controlled stops or subsystem shut downs, without disturbing remaining active parts, are now operational.

## UPGRADE STRATEGY AND SAFETY

The requirement to maintain the system operational while avoiding, during the upgrade of the control, any loss of liquid krypton made this operation a challenging task. A detailed analysis of human and process risks was performed, in order to guarantee related safety. Since the installation could not be shut down completely and given the limited time window for each individual subsystem upgrade, fieldwork activities were split into several steps (Table 2), with intermediate preparation and partial commissioning periods.

Table 2 Metrics of the plant control upgrade

| **Upgrade step** | 1. Nitrogen Storage/Vacuum | 2. LKr Control | 3. Temperature Meas. |
|---|---|---|---|
| **Physical I/O points** | 224 | 816 | 336 |
| **24 V Power supplies** | 5 | 11 | 3 |
| **Operator synoptic** | 10 | 24 | 19 |
| **Work packages** | 7 | 11 | 4 |

The first identified step targets the installation of a temporary PLC to manage the two vital subsystems, i.e. the nitrogen storage, and the calorimeter vacuum system. Throughout this period, key values such as nitrogen levels in both dewars, and the insulation vacuum gauges were still monitored. Work packages concerned intensive mechanical intervention on nitrogen pipes, new valve integration, valve actuator replacements, I/O cabling, and power supply maintenance.

In order to achieve the best safety scenario for the upgrade of the control for the liquid krypton calorimeter, the argon cooler unit was warmed up to stop gas circulation, minimizing control fulfilment. In this span, the krypton was kept in liquid phase inside the calorimeter safeguarded by a redundant hardware crate, controlling the pressure on the inlet valves of the emergency cooler.

The last phase was done after the calorimeter control restart to avoid the combination of several unexpected process behaviour, and to focus on feedthrough heaters system. Pulsed hot air has been supplied to the feedthrough flanges to substitute the PLC control during the upgrade. At the same time, the integration of the 26 Siemens S5 analogue cards into the final system has been realized to add all internal cryostat temperature measurements.

## PROCESS ISSUES AND PERSPECTIVES

The final commissioning of the upgraded NA62 control system has been successfully accomplished, in agreement with the results of the technical specification. During field work, the installation was never exposed to a lack of liquid nitrogen and vacuum shut downs have never led to difficult situation. The hardware security equipment has allowed the minimal vital condition during the upgrade field work as planned. The new control system was successfully integrated without generating unexpected problems. The operational stability was reach in a few hours and is now running under nominal operation for two months. Control loops tuning was expected to maintain the cryostat pressure into a range of ± 1 KPa around $1.15*10^{-1}$ MPa (See Figure 4). Performance and efficiency of the different PID controllers were studied through a data taking campaign and off-line analysis, to compensate process time-delay and nonlinearity obstacles.

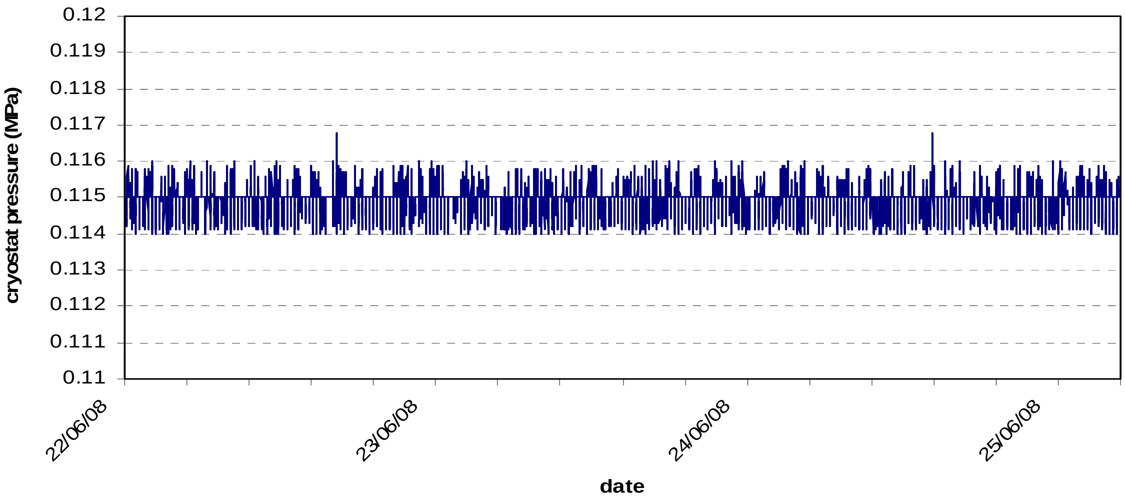

Figure 4 Krypton pressure over a period of four days

The working principle, based on our experience about cryogenic detector commissioning [6], strongly indicate that the UNICOS framework is a consequent factor to obtain suitable control system of a large and singular cryogenic plant. The encouraging results obtained have clearly shown an important degree of confidence for the future control system upgrades related to the luminosity increase of the LHC in particular the ATLAS Argon calorimeter detector upgrade.

## ACNKNOWLEDGMETS

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