A PROGRAMMABLE LOGIC CONTROLLER-BASED SYSTEM FOR THE RECIRCULATION OF LIQUID C_6F_{14} IN THE ALICE HIGH MOMENTUM PARTICLE IDENTIFICATION DETECTOR AT THE LARGE HADRON COLLIDER

I. Sgura *, G. De Cataldo, A. Franco, C. Pastore, G.Volpe,
INFN sez. Bari and Dep. of Physics Via G. Amendola 173, 70126 Bari Italy

Abstract

The aim of this paper is to present the design and the implementation of the Control System (CS) for the recirculation of liquid Perfluorohexane (C_6F_{14}) for the ALICE High Momentum Particle IDentification detector (HMPID).

The HMPID is a detector of the ALICE experiment at the CERN Large Hadron Collider (LHC). It uses liquid C_6F_{14} as Cherenkov *radiator* medium in twenty-one quartz vessels for the measurement of the charged particles velocity.

The primary task of the Liquid Circulation System (LCS) is to ensure the highest transparency of C_6F_{14} to the ultraviolet light. In order to provide safe long term operation a Programmable Logic Controller-based CS has been implemented.

CS provides both automatic and manual operating modes, remotely or locally. Its finite state machine design minimizes the possible operator errors and provides a hierarchical control structure allowing the operation and monitoring down to a single *radiator* vessel. LCS is protected against unsafe working conditions by both active and passive measures. The passive ones are intrinsically guaranteed whereas the active ones are ensured via the control software running in the PLC. The human interface and data archiving are provided via PVSS, the Supervisory Control And Data Acquisition (SCADA) framework which integrates the full detector control.

LCS under CS control proved to meet all designed requirements thus enabling HMPID detector to successfully collect data since the very beginning of LHC operation.

INTRODUCTION

The ALICE-High Momentum Particle IDentification detector (HMPID) is a proximity focusing Ring Imaging CHerenkov (RICH), for the identification of charged pions and kaons in the range of $1 < pt < 3$ GeV/c and protons in the range $2 < pt < 5$GeV/c [1]. It consists of seven identical RICH modules exploiting large area CsI photocathodes for Cherenkov light imaging [2]. HMPID uses liquid C_6F_{14} as Cherenkov *radiator* medium in the twenty-one quartz vessels coupled to Multi-Wire Chambers (MWPC) equipped with pad segmented CsI photo cathodes.

LCS [3,4] is a closed, pressure-regulated apparatus which purifies, fills, re-circulates and empties the *radiator* vessels (Fig. 1). The Intrinsically safe working conditions are ensured by a gravity flow circuit preventing any accidental over-pressure.

Due to LCS complexity and its inaccessible location during the LHC operation, its safe long term operation is ensured then by a dedicated Control System (CS). This latter is integrated in the HMPID Detector Control System (DCS) [5, 6].

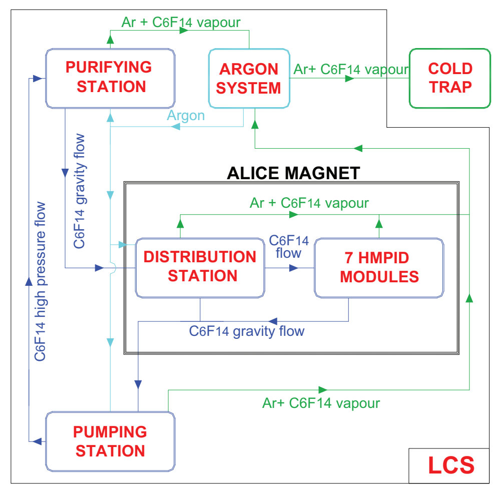

Figure 1: Block diagram of LCS: it consists of distinct stations interconnected and located in ALICE experimental area. The liquid is continuously pumped from the pumping station to the purifying station from where the liquid flows by gravity into the distribution station. This latter controls the flow rate in the *radiator* vessels from which the liquid returns in the pumping station where the cycle restarts.

THE C_6F_{14} CONTROL SYSTEM

Since 2003 C_6F_{14} CS has been conceived and implemented to fulfil the following requirements:

- to be highly reliable and scalable, as well as simple and robust;
- to be coherent and homogeneous with all detector control sub-systems;
- to be operable permanently and independently of the state of the other HMPID subsystems;
- to be able to take immediate actions for protecting all sensitive system components.

*corresponding author: irene.sgura@ba.infn.it

To fulfil these requirements a control system based on Siemens S7-300 Programmable Logic Controller (PLC) has been then chosen.

Architecture

According to the industrial automation standards ANSI/ISA 95, in C_6F_{14} CS architecture can be recognised three hierarchical levels: field level, control level and supervisory level (Figure 2).

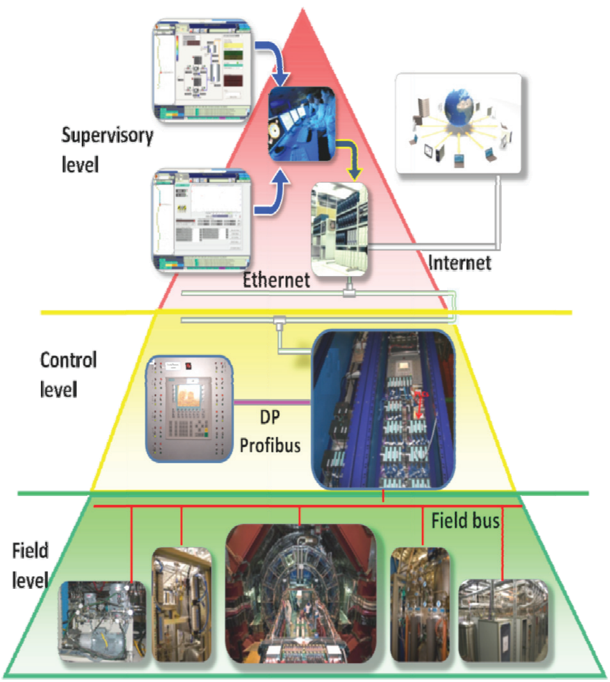

Figure 2: C_6F_{14} CS hardware architecture.

LCS represents the first level with all used sensors and actuators that work with industrial standard current and voltage ranges.

Control Level

The control level is the core where the control software processes run. It controls the underlying sensors/actuators by receiving and sending information through field buses.

Its design has been oriented towards the definition of elementary units (RICH $_{ith}$ $1 < i < 7$, purifying and pumping stations) which can be controlled and monitored singularly in LCS. Figure 3 shows a schematic of the Rich unit which corresponds to one HMPID module.

The hardware of the control level consists of a network of Siemens S7-300 PLCs, one per control unit, reflecting the traditional Master-Slave requirements. They are interconnected using the PROFIBUS DP [7] communication protocol.

The Master PLC acts as gateway between the supervisory and control level (Figure 4).

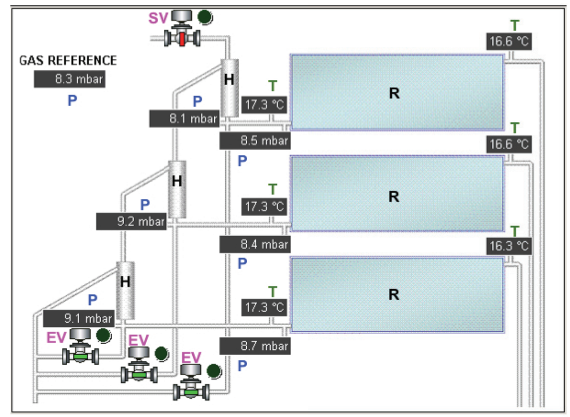

Figure 3: $RICH_i$ elementary unit: it consists of the i.th HMPID module's three *Radiator* vessels (R), the Header tubes (H) for supplying the matching *radiators*, the Pressure transducers (P), the Temperature sensors (T), the Supply and Emptying Valves (SV/EV) needed for module's operations.

This hardware architecture ensures:

- insulation of the control structure by the gateway to the external environment;
- remote implementation of the system's semantic verification procedure. Even if the operator commands are correct, the gateway verifies their compatibility with LCS state;
- local access via PROFIBUS DP by the Panel Operator LP (Figure 4), located in an accessible area during LHC operations. LCS can continue to work even if the supervisory level does not work. Both the local and remote control can be blocked by an hardware switch on LP, still ensuring monitoring.

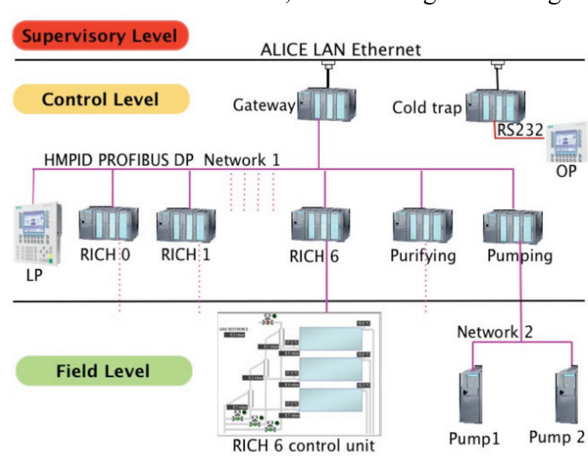

Figure 4: Hardware architecture of the control level.

The control system was developed in the environment Siemens STEP 7 [8] through the software tool Simatic Manager.

FSM Modelling

In order to automate LCS operation, the behaviour of each elementary unit has been modelled as a Finite State Machine (FSM), using Simatic S7 Graph language [9].

The unit behaves according to a state diagram and can move between defined states by means of executing actions. These actions are triggered either by the operator or by other events such as state changes of defined control-process.

According to the Cern JCOP prescriptions [10] three increasing severity alarm levels have been identified: WARNING, ERROR and FATAL.

Both the WARNING and ERROR allow the system to continue the normal operation. The FATAL level alarm is active when harmful conditions happen. In this case the CS has been designed to react automatically preventing permanent damages. In order to provide some flexibility during the commissioning phase, the automatic and manual operational modes are defined. In MANUAL state, the operator can directly check all the actuators, under its own responsibility, while the safety checks are always active.

In Figure 5 the state diagram of the $RICH_i$ FSM is shown.

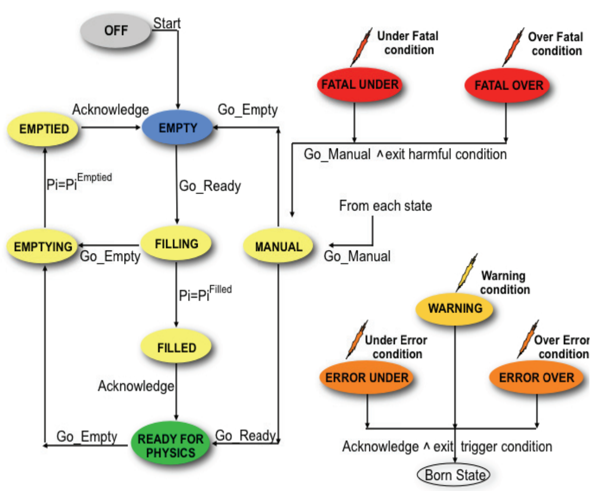

Figure 5: State diagram of the $RICH_i$ FSM. In "Ready for Physics" the *radiator* vessels are filled, the recirculation is active. A "FATAL OVER" condition rises when *radiator* vessel's pressure reaches 140 mbar. The control program reacts involving the entire module, closing the supply valve and opening the emptying valves. As the harmful condition has been recovered the Go_Manual command can be issued.

For each elementary unit, the FSM communicates to the field devices through a software interface implemented in Instruction List language (IEC 61131-3 standard). This latter reads the raw values from the sensors, it verifies the correct operation and converts the acquired data in engineering appropriate values according to the specific calibration curve. Furthermore, this interface receives the actions from the FSM block and converts them into the appropriate state value of the actuators. This approach guarantees the insulation of the FSM to the physical characteristics of the field devices and it eases the maintenance operations.

Supervisory Level

The supervisory level is the CS upper level. It supervises, via ALICE LAN Ethernet, the control process through a PVSS II as Supervisory Control And Data Acquisition (SCADA) system [11]. This level enables the interfacing and the integration in HMPID DCS. It provides the human-machine interfaces, alarm message handling and allows the data recording. The database is implemented as the ORACLE Real Application Cluster (RAC) [12]. All data stored in the archive are available for display and analysis using a graphical User Interfaces (UI).

The communication between the PLCs and PVSS has been established via the Siemens S7 driver [13] which is able to poll and write data to a Siemens S7 PLC.

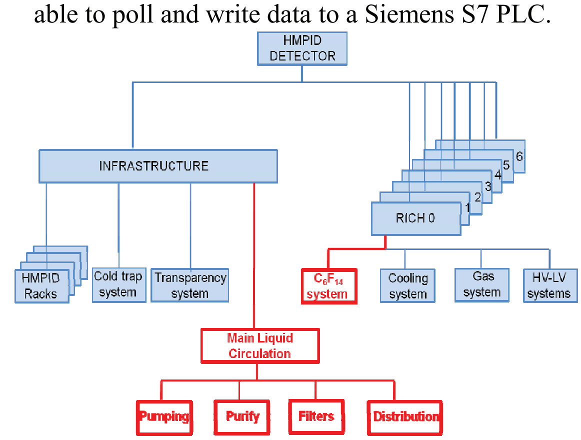

Figure 6: HMPID DCS control hierarchical structure.

Figure 6 shows the control hierarchical tree structure of HMPID DCS. It is type detector oriented hierarchy where HMPID is the top-node and 8 branches exist at the first level:

- seven for controlling the 7 HMPID modules. Each one hosts the control of the HMPID ancillary systems;
- one, called "infrastructure", dedicated to control all the other subsystem

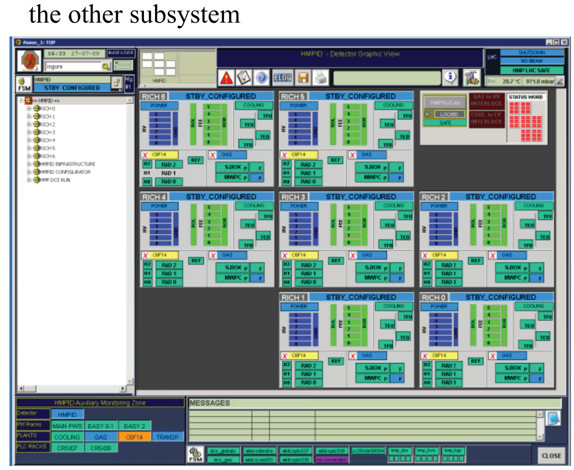

Figure 7: HMPID DCS UI.

Except for LCS, the FSMs of the other nodes are implemented in PVSS using the toolkit provided by the JCOP Framework and based on State management interface (SMI++)[14, 15]. The FSM browsing tree to navigate through the detector logic structure, relevant monitoring panels, and control elements is integrated in the standard UI developed for HMPID (Figure 7).

Figure 8 shows the UI RICH 0 liquid system (as seen in the FSM browser on the left side). As soon, CS registered a R_2 pressure value lower than the predefined threshold (red square in box 1), went immediately into a "FATAL UNDER" state, being the dominant alarm condition (as seen in box 1).

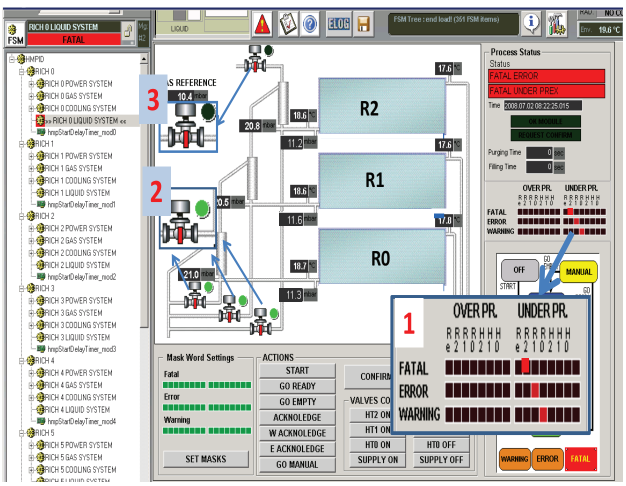

Figure 8: $RICH_0$ liquid system UI when in FATAL state.

It operated closing the emptying valves which are "normally open" (box 2) and the supply valve which is "normally closed" (box 3). At the same time HMPID DCS SMS system tool was enabled to send an alarm message to the expert operator via the GSM network mobile. When the harmful condition has been recovered the Go_Manual command can be issued.

CONCLUSIONS

C_6F_{14} CS was conceived and implemented according to the industrial standards using the Siemens S7 300 PLC as control devices, FSM structure for modular and automatic command execution and PVSS as SCADA environment.

CS allows LCS to run for 24 hours a day, correctly and safely. It is flexible, user friendly both for expert and no expert operator, coherent and homogenous with all the detector control sub-systems and it represents a cost-effective solution.

Moreover, CS showed an excellent capability to cope with harmful conditions that were not foreseen in the original LCS design.

Since the first LHC operation in 2008, LCS under CS control has enabled HMPID detector to successfully collect data.

Acknowledgements

We would like to thank A. Dell'Olio, M. Dell'Olio, Y. Leseneschal, J. Van Beelen and V. Rizzi for their fundamental contributions to the installation and cabling of the C_6F_{14} recirculation system and Control System. We would like also to thank Bosteels for the technical support.

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