THE NEW CONTROL SOFTWARE FOR THE CERN NA62 BEAM VACUUM

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Abstract

NA62 is a fixed target experiment to measure very rare decays of Kaons at CERN Super Proton Synchrotron accelerator. The NA62 experiment line comprises several large detectors installed inside a vacuum vessel with a length of 250 m and an internal diameter of up to 2.8 m.

The vacuum installation consists of 170 remote controlled pumps, valves and gauges. The operational specifications of NA62 require a complex vacuum control system: tight interaction between vacuum controllers and detector controllers, including pumping or venting vetoes, and detector start-stop interlocks; most of the valves are interlocked, including the large vacuum sector gate valves; the vacuum devices are driven by 20 logic processes.

The vacuum control system is based on commercial Programmable Logical Controllers (Siemens PLC: S7-300 series) and a Supervisory Control And Data Acquisition application (Siemens SCADA: WINCC OA). The control software is built upon the standard framework used in CERN accelerators vacuum, with some specific developments. We describe the control architecture, and report on the particular requirements and the solutions implemented.

INTRODUCTION

At CERN, the European Organization for Nuclear Research, the NA62 experiment analyses the outcomes of collisions of proton beams from the SPS (Super Proton Synchrotron) against a fixed target. The rare decays of Kaons are detected along a vacuum vessel of the 250 m. This large vacuum installation is broken down into 7 volumes, called vacuum sectors, separated either by sector valves or by windows. The use of sectors reduces mechanical intervention impact and sector valves, interlocked on pressure rise, avoid the propagation of leaks. The vacuum pressure specification for sectors 1 and 2 is lower than 10^{-2} mbar; it is achieved using 5 primary pumping groups. The vacuum pressure specification for sectors 3 to 7 is lower than 10^{-5} mbar; it is achieved using 8 turbo-molecular pumping groups and 7 large cryogenic pumping groups.

The control software for NA62 Beam Vacuum is based on the same framework as the vacuum control of the LHC (Large Hardon Collider) and its injectors [1].

The huge NA62 vacuum vessels require very large cryogenic pumping stations that offer very high pumping speed. In addition, usual turbo-molecular pumping is installed. The large detectors of NA62 are installed inside the beam vacuum vessels and require a complex hardware and software alarm system between vacuum and detector controls. Performant diagnostic tools are required to improve interventions and reduce costly beam interruptions.

New control device types and new control functionalities have been especially developed in 2014 for the NA62 Experiment. The software architecture is a two-layer system. The lower one, or automation layer, comprises a set of functions and data blocks, running in a Siemens Simatic S7™ PLC. The higher one, or supervisory layer (SCADA), was developed using the Siemens WINCC OA™ application; it consists of a set of routines and processes for monitoring, diagnostics and archiving, together with the graphical user interface.

DATABASE

The database structure, generically called Vac-DB, was developed in collaboration with IHEP for the vacuum control of the LHC and its injectors. This structure is also used for NA62.

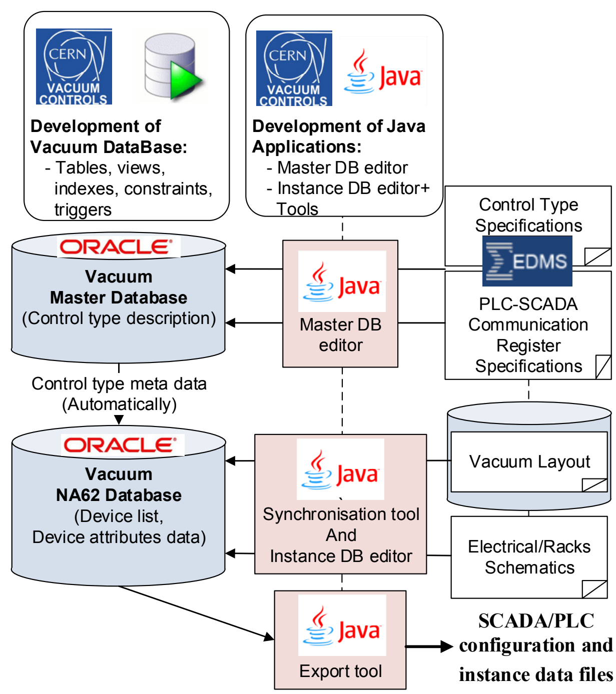

Figure 1: Vacuum database and applications.

Vacuum devices are classified into control types. The control type is identified by the family, type and sub-type of the device; it represents field devices (valves, mechanical pumps, active gauges, passive gauges, etc.) or virtual devices (pumping group process, gas injection process, software interlock, etc.).

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A first Oracle database called “Vacuum Master Database” contains the definitions of control types. The definitions include the Data-Point structures for the SCADA application, the description of SCADA-PLC communication registers, and the list of attributes for every control type.

A second Oracle database, the “Machine Instance Database”, contains all device instances and all attribute values. The “Vacuum Database Editor” is a Java application used to insert user’s inputs and to synchronise attribute values with the CERN central Layout Database. Then the Java application automatically produces SCADA/PLC configuration and instance data files, from database views of the NA62 Vacuum instance database.

PLC SOFTWARE

Simatic Step7 PLC functions have been developed by the vacuum control team. The Baseline of the software is composed of organisation blocks (OBs), diagnostic functions and control type functions. Both the baseline and the PLC hardware configuration of NA62 are archived in a versioning repository (SVN) and then deployed to PLC projects; the instance data is generated by the Java export tool from Vac-DB.

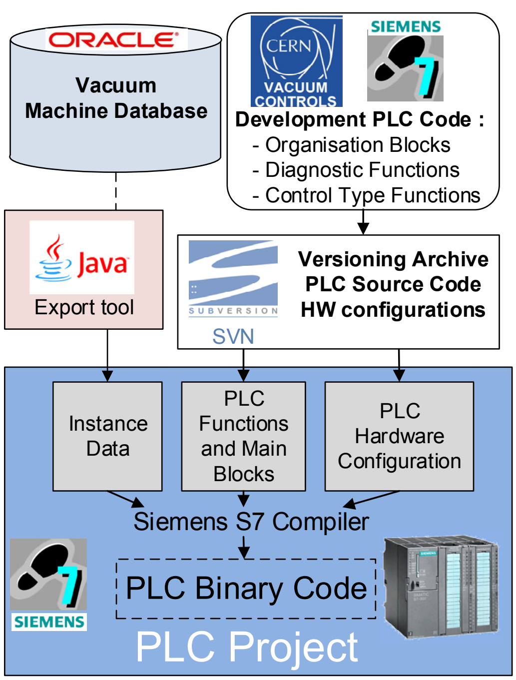

Figure 2: PLC software production.

The PLC binary code is generated by compiling the hardware configuration, the baseline and the instance data. The process of development, archiving and production of PLC code is illustrated by Fig. 2.

Two different software standards run in each PLC CPU. Before 2011, control types were developed using assembly language for PLC functions [2]. Since 2011, all new control types are developed in structured text language, within a novel standard.

Legacy control types that required new functionalities (primary and turbo-molecular pumps, valves and active gauges) were migrated to the new standard. Nevertheless, a significant number of legacy control types remained unchanged.

Legacy Assembly PLC Functions

A set of PLC functions and data blocks was created in 2001 for the vacuum controls of the SPS, then deployed in the LHC and later in PS-Complex and experimental areas. The functions were developed in Statement List Siemens (STL), similar to assembly language. The main organization block (OB) polls throughout a device list and handles one device per PLC cycle. The control type for a device is taken from device Data Block (DB) and the associated device type function (FC) is called with the device DB number as a parameter. Each control type has a dedicated FC; a complete set of FCs covers devices such as ion pumps, sector valves, passive gauges, etc.

Each device has its own device DB, containing all the variables needed by the function; the DB structure depends on device control type. Functions access and update DB variables, global variables and Write and Read Registers.

New Structured Text PLC Function Blocks

A set of new PLC Function Blocks (FB) were develop to incorporate new functionalities for existing control types, and to integrate new control. It has become the standard in vacuum controls PLC software, for all new developments since 2011. Not all of the previously created control types have been migrated to this standard yet; hence, both VACCIN and PSL system coexist in same PLC CPU.

The new standard has the following specifications:

- SIEMENS-SCL Language: textual high-level language; used for complex algorithms.
- FBs: functions with instance DBs.
- Process driven by a phase sequencer: sequence of actions with conditions and time dependencies.

There is one PLC FB per control type, who manages the behaviour of the device taking into account its sub-type. The typical structure of an FB is: get orders and parameters (from communication registers), read physical inputs, manage software interlocks, calculate and update maintenance variables, manage errors and warnings, manage behaviour according to the logic (which can be sub-type dependant), write outputs, update statuses (communication registers). Each device has a DB instantiated by the respective control type FB. This instance DB is composed of: header variables (name, control type, sub-type, machine…), common variables (auto request, manual request, interlock request, on status, off status, error status, object status, mode status…), control type specific variables (input/output addresses, valid range, unit conversion variables, maintenance variables…).

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PLC-SCADA Communications

Both PLC programming standards have the same PLC-SCADA communications schema. Devices statuses, orders and parameters are stored in a set of communication DBs. The SCADA application writes orders and parameters into the Write Register DB, from which the PLC function gets the data during initialisation phase. At the end of the PLC function, statuses are updated in the Read Register DB. Vacuum systems are slow processes, allowing 1s as polling period of the Registers by the SCADA. Orders and parameters are transmitted to the PLC Write Register immediately after operator request. The PLC time is synchronized with Network Time Protocol servers, and some device data are time stamped with the accuracy of the PLC cycle time.

SCADA SOFTWARE

The supervisory layer of the NA62 vacuum controls is based on Siemens WINCC OA™ application. The SCADA framework [3] developed in collaboration with IHEP, for the vacuum control of the LHC and its injectors, has been reused for NA62. The schema of development, archiving and production of SCADA code is illustrated by Fig. 3.

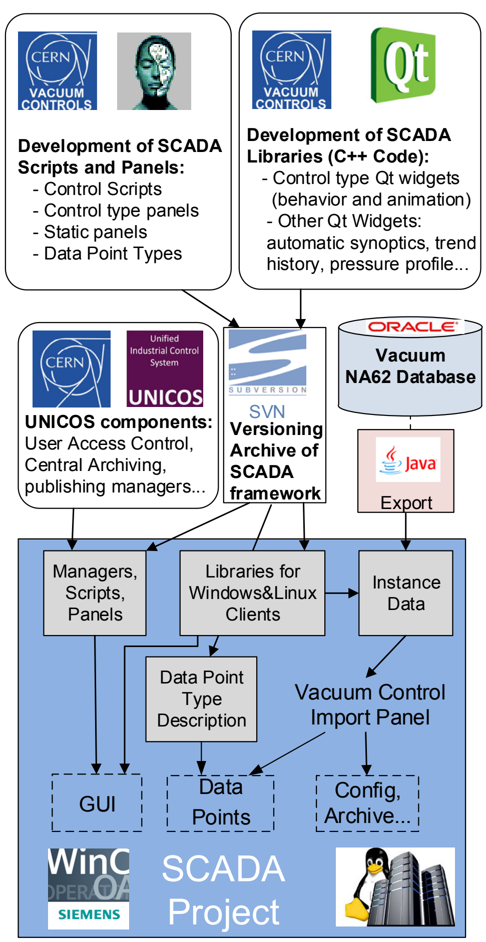

Figure 3: SCADA software production.

Graphical User Interface (GUI)

Devices are represented in the GUI using external widget objects. Symbols, animations and behaviours are defined by QT/C++ code and are control type dependant. Automatic synoptic, trend history and pressure profile are generated by QT/C++ libraries.

In the synoptic panel, main orders are directly accessible with a right click on the device symbol. A double click on this symbol opens the details panel of the corresponding control type. This details panel is graphically developed with the WinCC OA Graphical Editor.

Other functionalities, common to different panels, are developed in QT/C++ libraries.

NA62 NEW CONTROL TYPES AND FUNCTIONALITIES

Several control types and functionalities have been especially developed for NA62 and are currently only deployed in this experiment.

Pumping Group Logic

The high vacuum in sectors 3 to 7 is produced with turbo-molecular pumping groups. The control hardware for pumping groups has been improved [4] with an automatic venting in case of power cut, thus avoiding oil contamination from the primary pump to the turbo-molecular rotor. In addition, the logic disables the venting in case the valves to the vessels are not closed, to prevent accidental venting of the sector vessels.

The vacuum control system is linked to the NA62 detectors control system through several alarms.

Alarms to DCS

Three kinds of alarms are provided to the Detector Control System (DCS).

First, pressure level alarms: free potential relay contacts from the vacuum gauge controllers are hardwired to the DCS. The contact is triggered by the controller following a hysteresis comparison of the pressure measurement against pre-programmed thresholds. The pressure measurement can be low-pass filtered at 16, 160 or1 600 ms; the thresholds can be remotely setup from the SCADA, through the PLC and Profibus network.

Second, vacuum process alarms: PLC output relay modules are hardwired to the DCS. They deliver vetoes to the detectors, according the status of the vacuum sectors. These alarms are calculated by complex algorithms according to the vacuum process states. They are parameterized in the vacuum database, from which is defined the PLC instance data block, the type of logic and the reference to the source devices.

Finally, high level notification alarms: the SCADA application publishes the statuses of gauges and valves to

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CMW[1] for the NA62 experiment operators. These alarms are not critical and used for information only.

Alarms from DCS

In the opposite direction the DCS provides 2 types of hardwired alarms to the vacuum PLC.

First, pump enable alarms: if the detector is not ready for pumping, these alarms prevent any associated pumping valves to be opened. During operation, in the event of a detector window rupture, H2 would be released in the vacuum vessel; the pumping and so the compression of a large quantity of H2 being highly explosive. In case of window rupture detected, the process will automatically close pumping valves.

Second, vent veto alarms: the venting of some sectors may be required during a mechanical intervention. The venting is performed in-situ using a manual valve. Local notifications, using flashing LED, remind to the vacuum operator if venting is allowed or not.

PLC and SCADA developments for these new alarm types have been added to the vacuum control framework. These alarms allow a strong interaction between Detector and Vacuum Control Systems; they provide effective diagnostic information to both vacuum and detector operators.

Pulsed-command Valves and Pumps

In most of the accelerator vacuum systems, the fail-safe position of sector valves is closed, to avoid propagation of any unexpected leak. In the NA62 experiment, due to beam physics transparency requirement, very large valves have been installed with a specific mechanism. As any valve movement produces a leak, a new control type has been developed to cope with this behaviour. The same kind of control type for pumps has also been developed, to drive primary pumps with similar specifications. For both valves and pumps the last order requested is thus maintained in case of power failure.

Gauges with Profibus Interface

Gauges with embedded controller and Profibus interface have been installed in NA62 for the first time at CERN's accelerators vacuum. These gauges may reduce significantly the cost of controls. A new control type has been developed to integrate them in the vacuum controls framework. The new control type offers some extra functionalities as compared with standard one, like the possibility to act individually on each sensor of the full-range pair.

HSR™ Cryogenic Pumping Group

Seven very large cryogenic pumps have been installed in the Decay tubes vacuum sector (135 m long and 2.8 m diameter vessels with decay tubes detectors inside). These are the largest cryogenic pumps installed at CERN, if not counting the pumping effect of the superconducting magnets in the LHC. They are provided by HSR™ together with their dedicated controller.

For turbo-molecular pumping groups, the PLC manages the logic, which can be found in several control types (one per field device type, and another for the process).

For the HSR™ cryogenic pumping groups, it is slightly different: the group is controlled as a whole by the vacuum PLC, while the process is managed by the HSR™ controller. A first control type is dedicated to the cryogenics cold head, its sensors and the back valves. A second control type is dedicated to the large valve with same behaviour as standard vacuum valves. Both send global orders and get field device statuses from the HSR™ controller via a RS-232 interface. Some vacuum framework functionalities required upgrading; e.g. the trend history originally developed for one analogue value per device has been extended to integrate all the analogue values and bit statuses of the cryogenic pump control type: 2 pressure analogue values, 2 temperature analogue values, 4 bit statuses for the fore valve (V1) and purge valve (V5).

CONCLUSION

The vacuum control framework has shown a high level of flexibility, while being used to build the core of the NA62 vacuum control system. New device types and particular user specifications required custom developments. Thanks to the well-organized structure of the vacuum control framework, the new control types and functionalities have been easily developed and deployed. The result is a very effective control system well adapted to NA62 experiment layout and operational specifications.

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