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SPIRAL2 MACHINE PROTECTION SYSTEM STATUS REPORT

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Abstract

The phase 1 of the SPIRAL2 (Second Generation of Ions Radioactive Production System in Line) facility, the extension project of the GANIL (Big Heavy Ions National Accelerator) laboratory in Caen, France, is to be commissioned. The accelerator, is composed of a normal conducting RFQ (Radio Frequency Quadrupole) and a superconducting Linac (Linear Accelerator). It is designed to accelerate high power deuteron and heavy ion beams up to 200kW. A Machine Protection System (MPS) has been implemented to protect the accelerator from thermal damages for this very large range of beam intensities. This paper presents the solutions chosen for this system, composed of three subsystems: one dedicated to thermal protection which requires a PLC and a fast electronic system, a second one dedicated to enlarged safety protection, and a third safety subsystem dedicated to fast vacuum valve protection. Both of those subsystems work associated with a global EPICS-based (Experimental Physics and Industrial Control System) control and HMI system, which gives the operation team global supervision of the accelerator and allows controlling sensor trigger thresholds, interlock system, beam initialization and power increase through the beam time structure. The MPS has been developed and is currently tested to be ready for the incoming SPIRAL2 commissioning.

INTRODUCTION

The SPIRAL2 facility has been constructed and is now in its commissioning phase.

The accelerator is based on an injector composed of a deuteron source and a heavy ions source, with the first step of pre-acceleration through an RFQ (see Fig. 1). The beam is then accelerated through a superconducting Linac, and then carried to one of the Linac Experiment Area (AEL), Neutron For Science (NFS) or S^3 (Super Spectrometer Separator). The Linac has been designed to accelerate particles ranging from deuterons to heavy ions at high power, up to 200kW for deuterons. Beam time structure may vary from continuous beam (88MHz) to chopped beams (1Hz to 1kHz) and single bunch mode beams.

A Machine Protection System (MPS), associated to an EPICS based control and HMI system, has been developed to protect the accelerator from thermal damages and control this very large range of beam power and various types of beam time structure.

MAIN FUNCTIONS

The main functions of the Spiral2 MPS are [1]:

- Protect the beam pipes and moving devices (slits, faraday cups, beam profile monitors, targets…) from thermal damages.
- Control the operating range of the facility.
- In case of beam losses, identify accelerator device activation.
- Ensure a reinforced safety protection of the beam dumps and target, which all have their own protection system addressing "beam off" requests to the MPS.
- Secure a high class protection of the fast vacuum valves.
- Providing an overview and an interface of the system's availability from the control rooms. The MPS transfers state-feedback of accelerator equipment and alarms to the EPICS interface, and receives instructions in return: handling insertion devices, acknowledgments, threshold management.

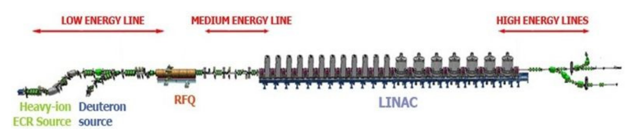

Figure 1: View of the SPIRAL2 accelerator.

Beam Cuts and Response Time

The MPS ensures those functions by receiving beam stop requests from diagnostics systems, or from ancillary systems (cryogenics, vacuum, radiofrequency…). Those beam cuts are of two types, fast and slow.

- The fast thermal protection system protects the accelerator chambers in case of 200kW instantaneous beam losses: it is designed for a response time of a few tens of µs. This fast cut is operated by activating chopper high voltage device in the low energy beam line. A second fast beam cut made is the safety classified fast cut. Its response time is determined by the time of insertion of the fast vacuum valves, and by the thermal resistance of the target that receives the beam. The beam must be cut fast enough to preserve the accelerator and the target in case of dysfunction of the thermal MPS control. This time is estimated to a few ms. This safety class fast beam cut is made by shutting down the RFQ because it is estimated simpler and safer than the activation of chopper high tension device.
- The slow cut is operated through the insertion of a beam stop or a faraday cup, some of them being safety classified to be used as a safety slow beam cut. Whenever a fast cut is operated, a slow beam cut is requested simultaneously, the fast beam cut devices maintaining their action until the permanent slow beam cut is achieved.

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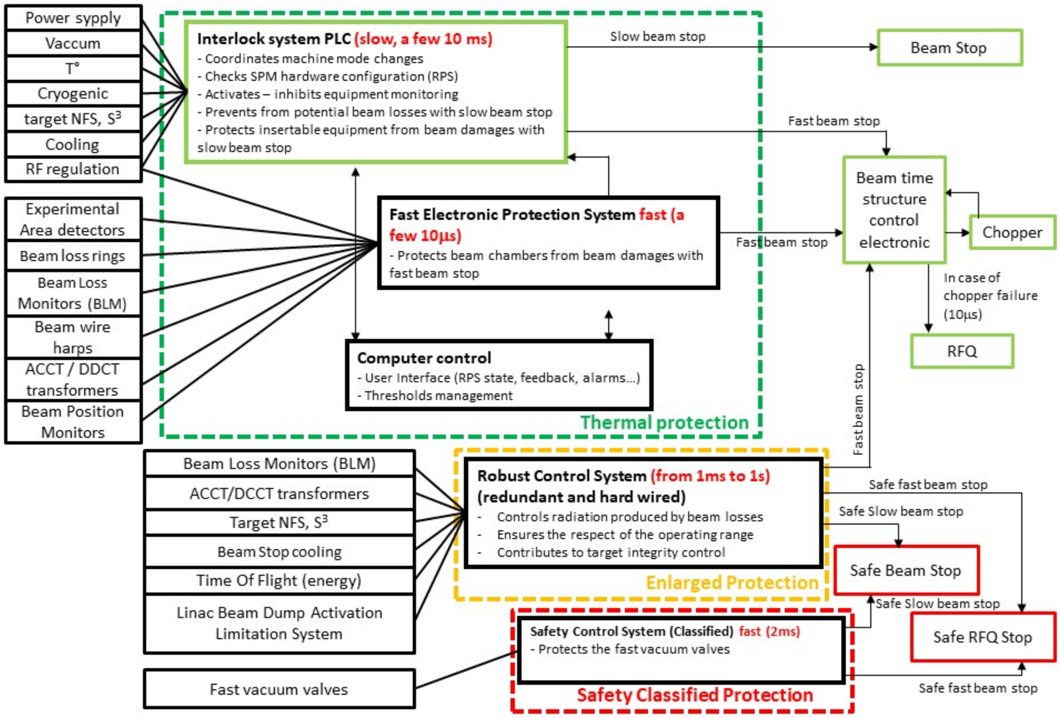

Figure 2: Functional diagram of the SPIRAL2 Machine Protection System, with its three sub-systems: Thermal Protection, Enlarged Protection, Classified protection for fast vacuum valves.

Threshold Management

Different types of diagnostics systems are distributed along the accelerator. Most of them are non-interceptive, in order to control continuously the beam characteristics and the beam losses. When the monitored parameters exceed a threshold, an alarm is emitted to the MPS, thus requesting a beam cut. Those thresholds ensure the beam to stay within its limits and protect the accelerator from thermal damages. They have to be recalculated by the general control system for each beam, due to the specificity of the SPIRAL2 facility which accelerates a large range of beam with various intensities and energies.

In the case of safety classified diagnostics, those thresholds are set through hard-wired electronic systems, and can only be modified manually directly on the electronic box.

In the case of the other diagnostics, the thresholds can be set through the EPICs control system, by an operator from the control center, or automatically according to the accelerated beam and the aimed experiment.

ARCHITECTURE

The MPS is composed of three sub-systems (see Fig. 2)

Protection System of the Safety Class Fast Vacuum Valves

This safety classified protection system is based on the association of a PLC and its panel, with two redundant subsystems respecting a technological dissimilarity principle: one is based on safety relays and opto-isolators, the second one on 7400-series integrated circuits. Each of those two subsystems is itself composed of two redundant and ambivalent hard-wired sub-systems (see Fig. 3). To respect the requirement of IEC 61508 standard and make this system reliable, a Failure Mode and Effects Analysis (FMEA) was conducted to consider and eliminate dangerous failure. The redundancy principle allows respecting the single failure criterion.

This safety system receives alarm from a safety classified vacuum monitoring system, which inserts fast safety valves in case of pressure rise in the high energy beam line which could indicate a loss of confinement and radioactive element dissemination. The MPS monitors the insertion of those fast safety valves and protects them from the beam with the fast safety classified beam cut (RFQ), as well as a slow cut through the insertion of safety classified beam stops.

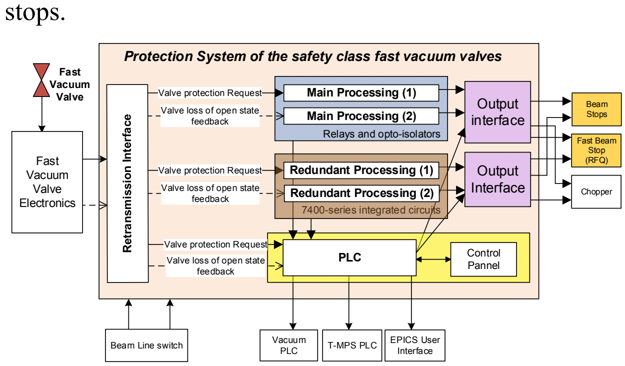

Figure 3: Redundancy architecture of the protection system of the fast vacuum valves.

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Enlarged Machine Protection System (E-MPS)

This system is a simple and secured one, based on the association of a PLC and its panel, with two redundant and ambivalent hard-wired sub-systems using safety relays and opto-isolators. This system relies on the following diagnostics based subsystems:

- The monitoring of radiation produced by beam losses
- The operating range control of the facility
- The Linac beam dump and target integrity controlling set.

The E-MPS receives alarms from beam losses monitors, beam intensity and energy diagnostics, beam dump and target control parameters. Those alarms are filtered according to the beam tracks, and a fast beam cut is operated through the RFQ, as well as a slow cut through the insertion of safety classified beam stops.

The beam track is defined through a secure control panel based on hard-wired keys, as shown in Fig. 4. It ensures the insertion of slow beam stops, and the powering off of the specific dipoles switching the beam source and the beam target (Linac beam dump or one of the experimental area)

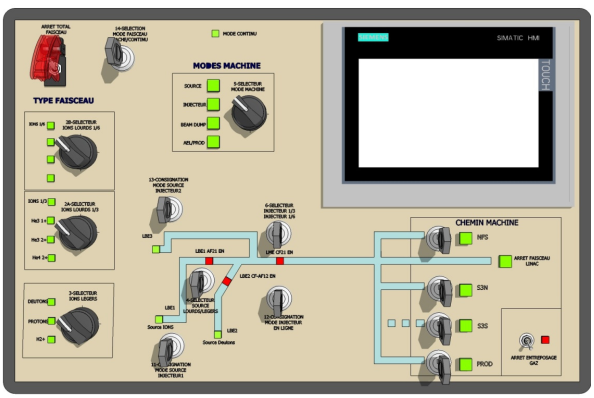

Figure 4: Drawing of the control panel based on hard-wired keys.

Thermal Machine Protection System (T-MPS)

A fast electronic protection system

- Protects the beam chambers from direct beam damages.
- Activates a fast beam cut through the low energy beam line slow chopper, and simultaneously send a slow beam cut request to the interlock PLC.

It receives the alarms from all the beam diagnostics, like losses rings and slits, beam losses monitors, beam profile monitors, intensity measurements with AC and DC Current Transformers (ACCT and DCCT), beam position monitors, time of flight monitors for energy measurements [2].

An Interlock PLC With about 1300 inputs/outputs, it is associated to three control panels distributed along the facility [3], allowing a first interface independently of the EPICs control system. This PLC:

- Manages slow beam cuts, through a fast beam cut with the chopper, and simultaneously inserting a slow beam stop.
- Controls the beam power by managing the Beam Time Structure Electronic.
- Activates or inhibits the monitoring of the beam cut requests from the equipment.
- Prevents from potential beam losses with slow beam cuts, by controlling ancillary systems: cryogenics, vacuum, radiofrequency.
- Protects insertion devices from beam damages by controlling slow beam stop and beam power.
- Transfers reset and acknowledgments signals from the Epics user interface to the fast electronic protection system and the beam diagnostics electronics.
- Verifies the MPS configuration through the Run Permit System (RPS). The Run Permit System enables to securely define the Machine Mode (see Table 1) and coordinates the machine mode changes. One Machine Mode corresponds to the choice of one beam type, one beam path along the accelerator and one beam power. Beam parameters (intensity, energy, source voltage, charge and mass of the accelerated ion), as well as the machine mode instruction, are defined through the Epics interface, coherently with the secure beam track control panel associated to the E-MPS.

Table 1: Machine Modes

Beam Type	Beam Path	Beam Power
deuterium	Deuterium source	0,03 kW
Proton	Heavy ions source	0,4 kW
Heavy ions	Injector	2 kW
	Linac Beam Dump	3 kW
	S^3	6 kW
	NFS	10 kW
		50 kW
		200kW

MPS CONTROL AND COMMAND

The CC (Control and Command) of the MPS is based on real time architecture coupled with HMI dedicated programs. The core role of MPS CC is to help operators and engineers during adjustment and monitoring of the beam. Main functions of control and command are:

- states and alarms display
- beam losses handling
- threshold management
- defects/trigs management.

As shown in the following figure (Fig. 5), MPS CC is composed of 3 layers. In subsections bellow every components of the system are described.

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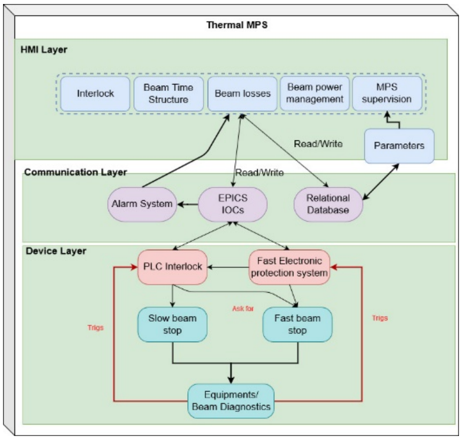

Figure 5: MPS control command.

MPS Layers

The first layer consists of all HMIs that users need to supervise MPS. The second one is the communication layer which makes the link between HMI layer and devices layer which compose the MPS. It operates in a real time system. The device layer includes PLCs and electronic systems which interface the equipment and diagnostics as for example Beam Lost Monitors (BLM), Slot, Magnets and others.

IOCs

To implement the communication between MPS device layer and HMI layer many IOCs were created.

- A soft IOC is interfaced with the Interlock PLC. The Interlock, Beam Time Structure, Beam power management and MPS Supervision software are using these IOCs in order to control or display information.
- VME IOCs are used to communicate with the Electronic protection system. Beam losses and MPS supervision keep information from those IOCs.

Relational Database

For Spiral2 facility, a database managing beam parameters was created. Parameters include all accelerator component values for a given beam (beam value sets). Each time that a new set of parameters is calculated, they are stored in database.

Concerning the MPS, power max thresholds and diagnostics thresholds are written in database as part of this set of parameters. Thresholds are written to the electronic system throughout EPICS IOCs by "Parameters software" application.

Parameters Software

"Parameters software" is in charge to apply beam value sets on accelerator components. In a second time, this application backups parameters to database.

For MPS system this software compares power thresholds with those currently taken into account by the interlock PLC. On the other hand, it writes the diagnostics thresholds in electronic system.

Alarm and Trig Management

When any accelerator diagnostic or component encounter a problem a trig is activated. As for example the problems with component shutdown, threshold overtaking etc.

Once trigs are detected they are transmitted to interlock PLC or the Fast Electronic protection system. The Alarm system monitors EPICS PVs and records trigs inside its database. Then MPS supervision is getting trigs from alarm system database.

HUMAN MACHINE INTERFACES

In order to cover all the needs for monitoring and control MPS, five software's have been designed and developed. Each of them has a role of assistance of users in getting information from the system. All software are based on Java programming language. Either by programming directly or by CS-Studio.

Main Supervision

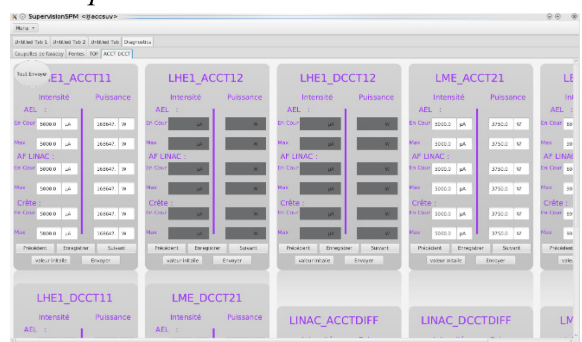

Figure 6: Main supervision.

Main Supervision (Fig. 6) have two following functions:

- MPS state control

A synoptic view displays the accelerator diagram by trigs zones and components that are used by MPS. When a trig occurs the trigged zone is clearly identified. The user has an access to trigs history and can clear the MPS.

All trigs are handled by alarm system. Those trigs come from PLC Interlock or Electronic protection depending of the kind of the Accelerator component.

- Thresholds management

For each diagnostic that is used in the MPS context a threshold management subsystem is implemented within an Electronic protection system. When the threshold is exceeding the limit, an alarm is sent to the fast electronic protection system. The protection system sends a signal to cut off the beam.

The thresholds are written to the Fast Electronic Protection System during beam initialization step. This is done by Parameters application software.

Most of the thresholds are calculated from the beam characteristics during the calculation parameter phase in order to determine the value of every accelerator component. For example, a faraday cup threshold is given in intensity and the corresponding power is calculated. All of them are stored in parameters database.

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Operators can modify and adjust the thresholds as needed. The corresponding power or intensity is automatically recalculated.

This application is pure Java software and use JavaFx graphic layer.

Interlock

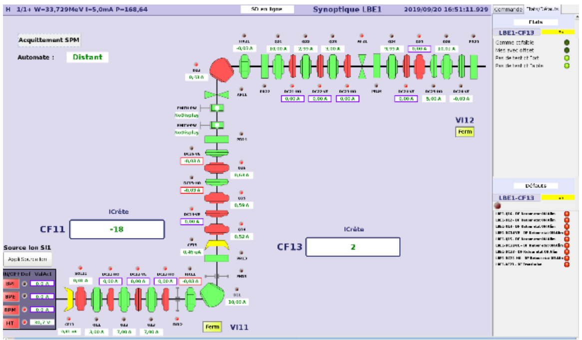

Figure 7: Interlock HMI.

As shown in (Fig. 7), the Interlock application is based on synoptics that displays all components linked to the « Slow Beam Stops ». These can be beam stops or faraday cages.

Users can view the current state of each component.

Five states are defined for a beam stop:

- Interlock (Red)
- Radiologic and Access Restriction (Orange)
- In (Yellow)
- Out (Green)
- Not In Not Out (Grey)

Interlock is a priority state. It means that one or more defect/trig prevents to move out the beam stop. Operators can see the defect/trig list and understand why a faraday cage or a beam stop is in Interlock state.

Once a beam stop isn't in Interlock or in Radiologic and Access Restriction, operators can remotly move the beam stop.

All the application communicate with Interlock PLC. HMI was developed with CS-Studio BOY tool and the spiral2 accelerator widget library.

Power Raise Handler

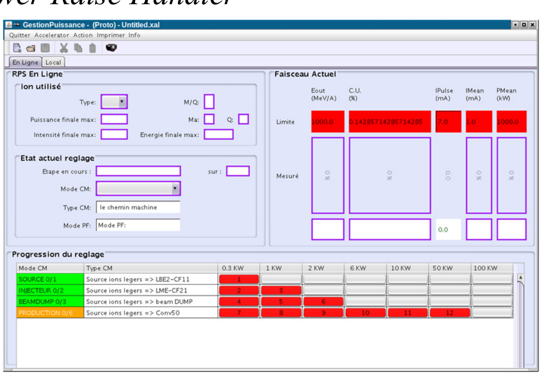

Figure 8: Power rise handler application.

Figure (Fig. 8) shows the HMI that permits to users to level up beam power during tuning phase. A setup matrix called « 3D matrix » is displayed to the application. It contains all the power steps by « Machine path ».

« Machine path » defines the path of the beam from source to experimental area. Actually more than 60 paths are available.

Each power raise change sends a demand to the PLC Interlock. According to the machine condition the PLC makes a decision to level up power. Only the PLC has an ability to validate the step.

Power raise handler application coding will be made by Java coding.

Beam Losses

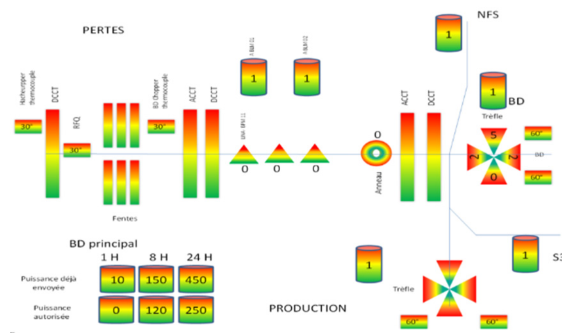

Figure 9: Beam losses HMI.

Beam losses application will represent a synoptic in order to display each diagnostic losses. Those are represented by gauges with a color in function of delta between current value and threshold. Figure (Fig. 9) overhead shows the GUI interface.

The coding of the beam losses will made by CS-Studio BOY. The history of losses is recorded and stored in "Archive system". A description of "Archive system" and CS Studio BOY is given in the TOOLS section.

Beam Structure

Figure 10: Beam structure application.

The "Beam structure application" interfaces the Interlock PLC for controlling the beam structure by defining the beam pulse duration and period.

All interactions are gathered together while using this application and have an effect on the beam time structure including - choppers, RFQ and sources.

The following specifications are included:

- Providing the chart of the duty cycle and individual pulsations of each device composing the final signal.

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- Managing of lists of duty cycle configurations based on the pulsations of the source, chopper and RFQ.
- Offline preparation of duty cycle: For each beam raise step of the 3D matrix, the objective is to determine the duty cycle configuration to apply with which elements.
- Backing-up duty cycle applied after each beam power raise - automatically and when a backup of the accelerator parameters is applied.
- Controlling PLC interlock controls and validating all actions on the duty cycle.
- Identifying which duty cycle have to be applied in case of MPS's beam cut.

The figure (Fig. 10) show user interface. More information about MPS can be found in [4].

TOOLS

This section describes the tools used to design and develop MPS software.

GenIOC

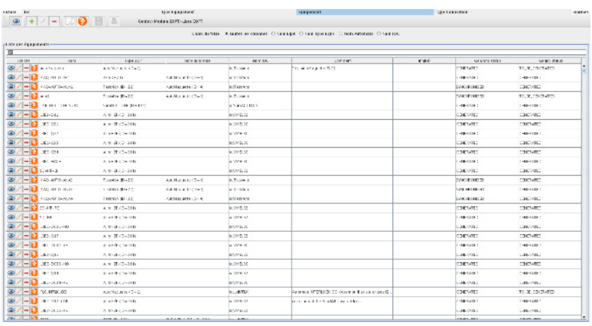

Figure 11: GenIOC interface.

GenIOC is a specific software developed for Spiral2 to manage an equipment database and therefore generates Epics databases for IOCS.

As shown in (Fig. 11), among its functionalities, this software permits to create soft IOCs which have to communicate with a PLC. The Modbus protocol makes possible the exchanges between PLCs and IOCs. The list of named functions and addresses are extracted as a spreadsheet from the PLC data bloc and then it is integrated to GenIOC as input data.

Before generating an IOC, a substantial work is necessary to design the « Equipment type » and « Equipment ». The definitions of these terms are as follows:

- Equipment type: template that define equipment functions. Once generated by GenIOC it's corresponding to EPICS records and database.
- Equipment: extends and inherit an equipment type functions. One or many equipment can extend an equipment type. The equipment are defined as macros in IOCs.

Let's take an example with the dipole LBE-D11. This dipole has several signals functions like actual current value (IAct) or setup value (ICons). These functions are defined within the diploe corresponding to Equipment type and the dipole name to the Equipment. Finally, the PV name is "LBE1-D11:IAct".

CS-Studio

This EPICS toolbox makes it easier to create HMI. It is a widely used tool in Spiral2 control and command. CS-Studio is also used as a applications starter. Java software, BOY HMIs and Matlab are launched this way.

Another tool is provided by this toolbox:

- Archive system and Data browser

Data browser permits to display PV values that are recorded by the archive system consisting of archivers and database. Archivers are programs that monitor EPICS PVs and integrate it to the database. Some of MPS values are stored in Archive system.

CS-Studio is presented with more accuracy in [5].

VP-UML

It is a java tool, which is useful to design software. Functionalities and system interactions are described by the well known UML (Unified Modeling Language) diagrams (Use case diagram, Sequence diagram, Activity diagram…)

Another feature that VP-UML provides is ORM (Object Relational Mapping) that was used to generate database and java code for parameters.

For more details about VP-UML see [6]. All of the MPS applications are designed using this tool which turns out to be very efficient and reliable for development, maintenance and evolutions.

CONCLUSION

Hardware architecture, including hard-wired sub-systems, was installed and has been or is currently tested. Time response of the whole MPS processing chain meets the specification with substantial margin. The validation of the classified safety systems, including MPS, being necessary for the authorization from the Nuclear Safety Authority, the Linac can now enter its commissioning phase [7 ,8]. All software have been developed except Beam losses display and trigs display in MPS Supervision. At the end of the year MPS will be totally operational.

With regard to real time infrastructure everything is operational and the global control architecture proved to be efficient to answer MPS requirements and specifications.

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