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SAFETY CLASSIFIED SYSTEM USING BEAM INTENSITY MONITORING FOR THE RESPECT OF NUCLEAR REQUIREMENTS OF SPIRAL2 FACILITY

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Abstract

The SPIRAL2 Facility at GANIL is based on the construction of a superconducting ion CW LINAC (up to 5 mA - 40 MeV deuteron beams and up to 1 mA - 14.5 MeV/u heavy ion beams) with two experimental areas called S3 and NFS.

The building, the accelerator and experimental equipment studies started in 2009. For safety-classified system using beam intensity monitoring, SPIRAL2 project system engineering sets up a specific reinforced process, based on V-Model, to validate, at each step, all the requirements (technical, nuclear safety, quality, reliability, interfaces...) from the functional specifications to the final validation.

Since 2016, the main part of the safety devices is installed and is currently under testing. These tests which are pre-requisites to deliver the first beam will demonstrate that both functional and safety requirements are fulfilled.

This contribution will describe the requirements (operation field, limitation of equipment activation…), the technical studies, the failure mode and effects analysis, the tests, the status and results of the SPIRAL2 Machine Protection System using AC and DC current transformers to measure and control the beam intensity.

INTRODUCTION

Officially approved in May 2005, the GANIL SPIRAL2 radioactive ion beam facility (Fig. 1) was launched in July 2005, with the participation of French laboratories (CEA, CNRS) and international partners. In 2008, the decision was taken to build the SPIRAL2 complex in two phases: A first one including the accelerator, the Neutron-based research area (NFS) and the Super Separator Spectrometer (S3), and a second one including the RIB production process and building, and the low energy RIB experimental hall called DESIR [1][2][3].

In October 2013, due to budget restrictions, the RIB production part was postponed, and DESIR was planned as a continuation of the first phase.

The first phase SPIRAL2 facility is now built, the accelerator is installed [4]. The French safety authority agreement is now validated and the accelerator is under testing with the aim of obtaining the first beam for physics (NFS) in 2019 [3].

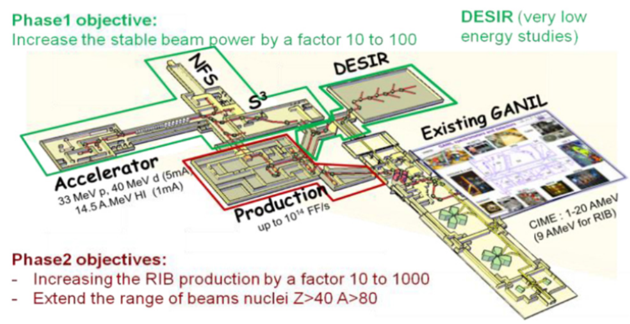

Figure 1: SPIRAL2 project layout, with experimental areas and connexion to the existing GANIL.

PROBLEMATIC

The GANIL/SPIRAL2 facility is considered as an "INSTALLATION NUCLEAIRE DE BASE" (INB), administrative denomination. According to the French law (law n°2006-66, decree 63-1228 and 2007-1557). The GANIL is under the control of the French Nuclear Safety Authority. The classification of the SPIRAL2/GANIL facility in the INB field is due to the characteristics of the beams at the last acceleration state and the use of actinide target.

SPIRAL2 will produce different beams (protons, deuterons and heavy ions) at very high intensity. Table 1 recalls the main beam characteristics.

Table 1: Beam Specifications

Beam	P	D^+	Heavy Ions
Max. Intensity	5 mA	5 mA	1 mA
Max. Energy	33 MeV	20 MeV/A	14.5 MeV/A
Max. Power	165 kW	200 kW	45 kW

The goals are to protect workers, public and environment against all risks identified and to reduce as low as possible frequencies and consequences of incidents and accidents.

Concrete building (14.000 m3) and an 8 meters underground beam axis, without beam power control is not sufficient for protection against external exposure to ionizing radiation. Controlling the accelerator device activation due to beam losses (beam losses limited to 1 W/m for D+ beams), along with the target and Beam dump activation as well as the operating range is then required.

To control the beam power for this goal, a dedicated and Safety Machine Protection System (MPS) is required.

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METHODOLOGY

Systems engineering is a very structuring approach for a complex project

The Systems engineering focuses on the needs definition for the customer and for the functional requirements, from the beginning of the cycle (V Model Fig. 2), by documenting the requirements, then with the synthesis of the conception (design), realization and the validation of the system.

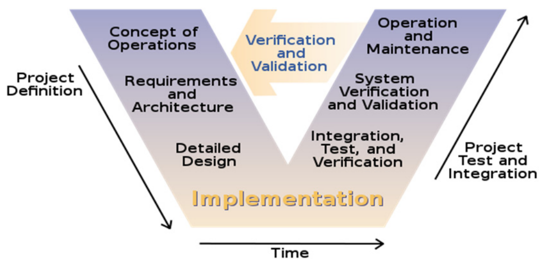

Figure 2: V cycle.

For Safety devices and notably for Safety Machine Protection System device, SPIRAL2 Project use a specific Quality Management Plan for the Safety (PMQS). This plan is naturally based on the Deming cycle (Plan, Do, Check and Act) but relies on the establishment of a particular task force managed to reach the set of the requirements. This task force contribute to validate the conformity (Fig. 3) at each breakpoint or reviews of the V cycle. This checking chain is composed of an independent technical validation, a nuclear safety control, an independent dependability checking, a validation of the integration in the building and the interface conformity with the other processes, a quality and documentation checking. All of those links are required to obtain the safety level for SPIRAL2 (with compliance of French decree for nuclear facility)

Figure 3: Chain for Safety Quality Management Plan.

Concerning the dependability checking, in order to respect the requirements of IEC 61508 standard, a Failure Mode and Effects Analysis (FMEA) was realized to eliminate dangerous failures. The single failure criterion was selected as dependability criterion.

SYSTEM DEFINITION

Beam Intensity Monitoring Subsystem

In order to control continuously the intensities and the losses, non-destructive beam intensity measurements are set up along the accelerator (Fig. 4). The use of two kinds of non-destructive measurement chains DCCT (Bergoz NPCT-175-C030-HR) and homemade ACCT is justified by the difference of detection principles and by their complementarities (Fig. 5).

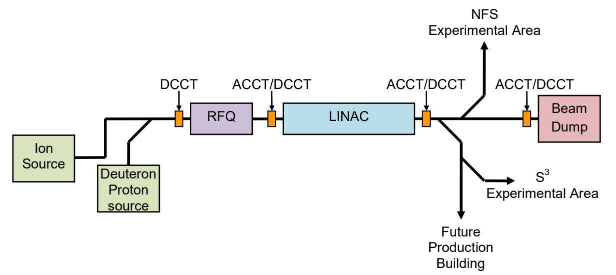

Figure 4: Intensity measurement locations.

The DCCTs measure the intensity of continuous and chopped beams with a slow response time (about 50 µs for a bandwidth of 10 kHz). The minimum intensity that can be measured is few 10 µA due to the offset level.

The ACCTs are faster with rise times about 1µs and with minimum levels less than 5 µA [5] [6].

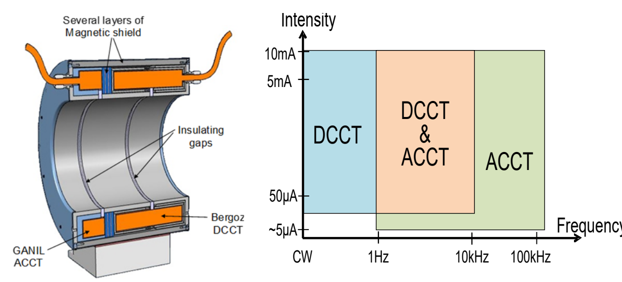

Figure 5: ACCT/DCCT bloc section and operating range

The ACCT or DCCT signal is converted into a pulse frequency. Continually, a counter adds up the pulses and removes the delayed pulses. To generate the beam cut alarm signal, the counter starts at the threshold value and its inputs are inverted (count down the pulses and count up the delayed pulses). Therefore, the counter value is equal to the threshold value minus the integrator value. The threshold values must take into account the qualified uncertainty measurement. The thresholds for beam loss detection have to be recalculated for each beam, due to the specificity of SPIRAL2, which accelerates a large range of beams, with various intensities and energies. The general control system calculates these thresholds.

Control Subsystem of the Beam Dump Activation

Operation requires the possibility of human intervention on the Linac Beam Dump and its surrounding. Hence this subsystem guarantee that the Beam Dump activation remain under an acceptable threshold (expressed in number of particles that can be dropped into the Beam Dump during a 24 hours time frame). The Table 2 specify the shortest times according the beam power after which the threshold is reached.

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Table 2: Worst Cases (20 MeV/A Deuton Beam)

Beam Power	Time to reach the threshold
200 kW	3 minutes
10 kW	1 hour
417 W	Always below threshold

The subsystem integrate the number of particles over a 24 h period from the beam intensity monitoring (ACCT/DCCT) taking into account the ion charge. As soon as 95 % of the threshold is reached, a beam cut-off request is sent to the beam cut treatment subsystem.

Taking into account the safety and reliability requirements, the LabVIEW technology using the cRIO (Compact Reconfigurable Input Output) solution with FPGA (Field-Programmable Gate Array) in its backplane was selected for the subsystem and proved its reliability. The LabVIEW-EPICS gateway and EPICS-CSS (Control System Studio) tool for HMI (Human Machine Interface) were used. Redundancy and auto-test were implemented. To ensure that the system is alive, a watchdog is monitored by an external cycle monitor able to request a beam cut off if the system is out of order [7].

Beam Cuts Treatment Subsystem

This safety-classified subsystem is the core part of the SPIRAL2 Machine Protection System (MPS); it is a simple and secured one, based on the association of a PLC with a hard-wired system. This system relies in particular on the following diagnostics based subsystems:

- The monitoring of radiation produced by beam losses (ACCT/ DCCT monitor and scintillation monitor)
- The operating range control of the facility (ACCT/ DCCT monitor),
- The Linac beam dump integrity controlling set (Control subsystem of the beam dump activation and cooling subsystem)

It receives alarms from beam losses monitors, beam intensity, beam dump and targets control parameters. Therefore, it activates the beam cut through commands sent to safe and slow beam stops in the low energy beam line (response time: 1.5 s) in association with a temporary RF stop on the RFQ (response time: 1 µs). It based on a redundant hard-wired system as show in Fig. 6.

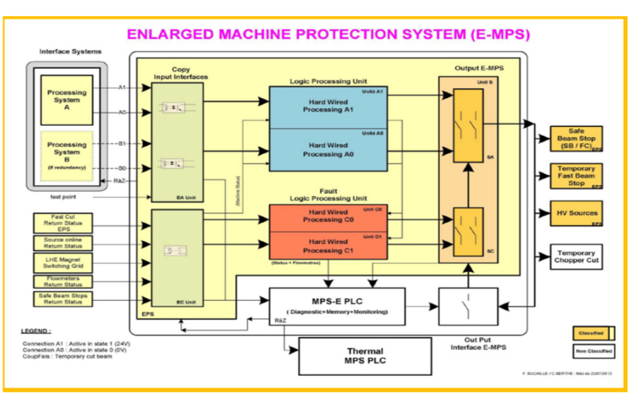

Figure 6: Redundant hard-wired system.

The response time was determined by the thermal and activation calculations with safety margin. The expected response times are for the fastest 15 ms (10 ms for the detection, 4 ms for the treatment and 1 ms for the beam cut) to a few seconds for slower ones [8] [9].

TESTS AND SAFETY VALIDATIONS

Every subsystems and electrical connections have been realized, integrated and installed since 2018. For each subsystem, the second phase of the V-cycle has been respected. It concerns the followings: unit tests, subsystems tests and global tests, functional tests and tests in a degraded situation according to the Failure Mode and Effects Analysis (FMEA) during the design phase.

Each deviation from the validated design reference requires analysis, processing and validation by the six links of the chain for Safety Quality Management Plan (PMQS). After iteration and complete agreement of the six links, the modifications are carried out with an updating of the different documents (diagrams, technical design files, FMEA ...). A safety-specific quality summary file is completed to prepare the operation phase and to be potentially audited during inspections of the nuclear safety authority.

To complete the validation of each subsystem, a final global testing of the Machine Protection System (MPS), without beam, is scheduled in September 2019 before allowing the Linac beam acceleration in October 2019.

During the Linac commissioning, as the beam ramps up, additional validations with beam will be conducted in 2019 and 2020.

CONCLUSION

The classified safety Machine Protection System with all subsystems is now installed, tested and individually validated. Final and global validation is in progress to allow the Linac beam commissioning next month.

For the safety-classified system using beam intensity monitoring in order to respect the nuclear requirements of SPIRAL2 facility, our main feedback concerns the followings:

- The required very low beam intensity level for the detection of ACCT/DCCT (in the order of a few µA) integrating the definition of global uncertainties [10] is brilliantly achieved through a specific development for SPIRAL2.
- The ACCT/DCCT monitor architecture, the control subsystem of the beam dump activation with CRIO and the beam cuts treatment subsystem (with optoelectronic relay and PLC) have progressed to be very reliable and have been hardened by Failure Mode and Effects Analysis (FMEA) through the use of principle like redundancy, dissimilarity, simplification, auto-testing and degraded mode studies
- The short subsystem response times (few ms) have been validated
- The V-cycle time is long between the start of the design in 2013 and the overall validation in 2019

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because time is the only adjustment variable. There has been no change in the technical, safety and cost requirements.

- Many human resources are needed to achieve safety and quality requirements

The goal is reached: Producing, with a multidisciplinary team, a complex instrumentation meeting the SPIRAL2 safety and quality requirements is a technical and human challenge that the SPIRAL2 project has raised.

Such as Needs = Such as designed = Such as installed

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