THE SPIRAL2 CONTROL SYSTEM STATUS JUST BEFORE THE FIRST BEAM

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Abstract

The SPIRAL2 Facility at GANIL is based on the construction of a superconducting 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 [1, 2]. At the end of this year, we will reach an important milestone with the first beam accelerated by the superconducting LINAC. The control system of the new facility relies on EPICS and PLC technologies. This paper will focus on the latest validated systems: machine protection system, the LINAC cryogenic system and the radio frequency system of the superconducting cavities. The validation requested a huge effort from all the teams but allow the project to be ready for this important moment.

INTRODUCTION

The SPIRAL2 facility will produce different beams (protons, deuterons and heavy ions) at very high intensity and will use actinide targets. Refer to Table 1 for beams specifications.

Table 1: Beam Specifications

Beam	Proton	Deuteron	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

SPIRAL2 is controlled by the French Nuclear Safety Authority (ASN) which means that the accelerator cannot be started without ASN authorization.

However, SPIRAL2 had a partial authorization allowing to produce protons to pre accelerate them with the Radio Frequency Quadrupole (RFQ) and study the beam in the medium energy beam line, refer to Fig. 1 for a view of the accelerator.

To obtain the authorization to start the whole accelerator (LINAC cavities and high energy beam lines), specific dispositions were taken to demonstrate the safety of the facility. Consequently, the validation of all the systems taking part in the safety was a prerequisite to obtain the authorization and start the commissioning of the ensemble.

MACHINE PROTECTION SYSTEM

Amongst the several systems involved in the safety surveillance, the machine protection system (MPS) [3, 4], a wide and central system in which the control system group was deeply involved, is responsible for the following functionality:

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

The MPS is made of the following subsystems.

The Thermal Protection Subsystem

This system consists in an interlock PLC communicating with fast electronics on one side and a GUI on the other side. It collects “beam off” requests from the beam diagnostics and, according to the machine state, gives a slow and a faster “beam stop” to reach the expected response time (< 10 ms). Slow beam stop is issued to insert beam dumps; faster beam stop order is issued to the Beam Time Structure Control Electronic. Though this system is not in the scope of the safety systems controlled by ASN, it can forbid the beam production, consequently it was validated progressively with the ions sources RFQ and the low and medium energy beam line commissioning.

Figure 1: View of the SPIRAL2 accelerator and beam lines.

Enlarged Protection Subsystem

This system is in the scope of the safety systems controlled by ASN, consequently it was one of the system that shall be validated to obtain ASN authorization. To comply the safety requirements, it was designed with robust technology using safety relays, hardwired connections and ambivalent redundancy concept. From safety point of view, the system must guarantee that the accelerator is in its nominal operation domain. In other words, it must ensure that the beam intensity and eventual losses remain below a certain threshold and also that the radio frequency system is working properly. For this purpose, it collects "beam off" requests from safety classified diagnostics and command the insertion of the safe but slow beam dumps in the low energy beam lines and the fast but temporary stop on the RF system of the RFQ.

The safety tests took place at the beginning of July 2019, all the combination that should lead to a safe beam stop in the expected response time were successfully tested. The worst case for response time is 2 ms, the system demonstrated that it reacts in less than 1 ms. The validation of the MPS was one of the last file to be completed. SPIRAL2 obtained the authorisation to start the whole machine on 8th of July 2019.

LINAC CRYOGENIC TESTS

The superconducting LINAC is composed of 12 cryo modules with one RF cavity in each and 7 cryo modules with two RF cavities in each, the first cavities have a $\beta = 0.07$, the second ones with $\beta = 0.12$.

The cool down process of the LINAC is quite challenging because it has to be reliable in order to avoid to damage the cryo modules and RF cavities but it also has to reach a high level of performance to fulfil the performance requirements in terms of pressure and level of Helium.

Architecture

The control system for the cryogenic needs of the LINAC relies on PLCs, each cryo module has its dedicated PLC plus one used has a hub between the supervision stations and the PLCs. For the helium temperature, pressure and level regulation and monitoring, each PLC drives a set of valves, temperature, pressure and level sensors. It also drives a heater to compensate the RF load of the cavity and a motor for its frequency tuning.

Functionality

Cool down mode
- Cavity temperature regulation

Nominal mode
- Helium pressure and level regulation
- Heater regulation to maintain constant the calorific load

Service modes
- Warmup, Standby, safety

Cool Down Process

The cool down process is done in two phases, see Fig. 2, the first one is the controlled cool down. This is a long process (one day for first type of cryo modules, two to three days for second type of cryo modules) in which the helium is slowly injected in the cryo module in order to reach 150 K. During this, the level of helium remains close to zero since it goes in the gas state as soon as it is injected. The PLC generate a descending ramp for the temperature consign and a PID regulation control the valves for helium injection according to the consign. Each cryo module have its own slope, it can be adjusted by the operator. The second phase is the fast cool down. In order to avoid the so called "100 K effect" [5] and obtain the best performance of the RF cavity, the transition from 150 K to 50 K has to be as fast as possible. Hence, as soon as 150 K are reached, the helium valves are fully opened for the fastest cool down as possible. As soon as the helium level reaches 5% of the cryo module volume, a level PID regulation is triggered with a consign equal to 85 %. When the cryo module is considered well thermalized by the operator, the nominal mode is entered.

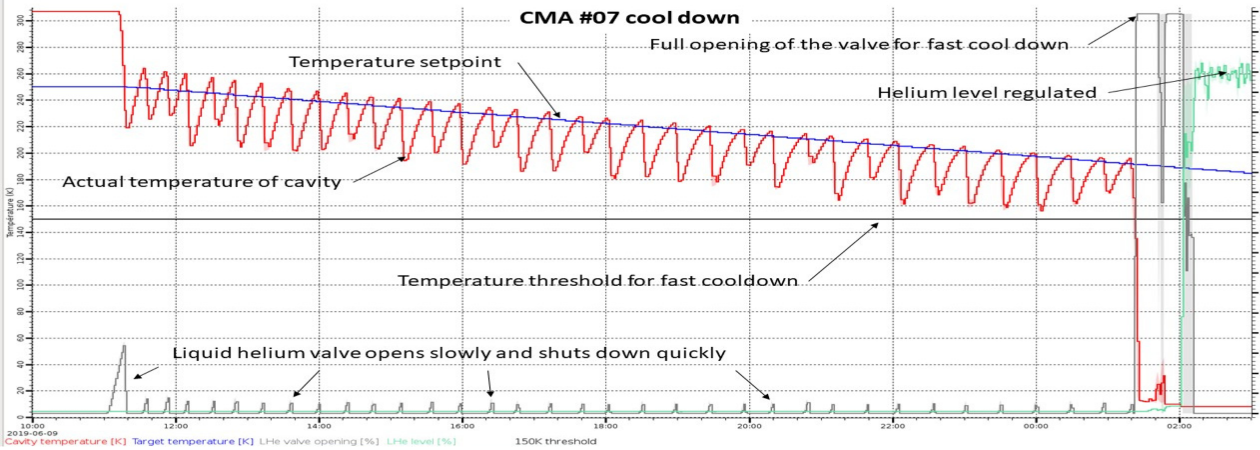

Figure 2: Description of the CMA 07 cryo module cool down.

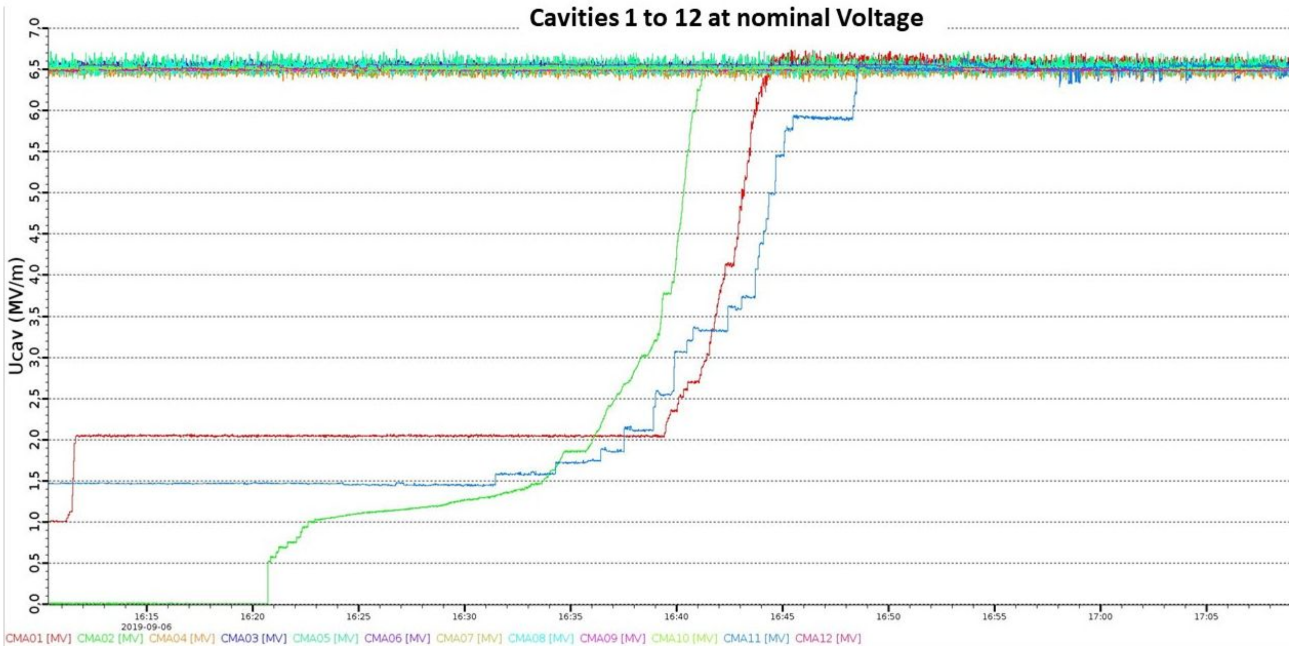

Figure 3: Graph showing the 12 cavities in the first cryo modules at their nominal field 6.5 MV/m all at the same time.

Nominal Mode

The nominal mode is the mode in which the RF cavities are started to accelerate the beam, the requirements is to regulate both the helium and the pressure level. The helium level must be sufficient for the cavity to be constantly immerged to remain in the supra conductor state. Helium level is regulated at 87% +/- 3%. The pressure must be regulated at 1200 mbar +/- 5 mbar.

By default, two PID regulations are used to control the level and pressure of helium, but such algorithms are not able to sustain the expected performance on a long period, for example, pressure variation above the 5 mbar tolerance occur several time in a night. When a quench occurs on a cavity, the PID algorithm is not able to remain in the +/- 5 mbar specification because it reacts too slowly and can oscillate. Such variations must be avoided because pressure variations directly modify the frequency tuning of the cavity which degrades the accelerator performance. To improve the regulation performance a LQ algorithm has been implemented. The advantages of this algorithm is that it relies on a model of the system which takes into account the interdependency of the parameters and it drives both level and pressure. Currently the operator can choose between PID or LQ regulation but, the results obtained with the LQ algorithm are so promising that it will most likely become the default algorithm soon.

In the nominal mode, the cryo module and its associated RF cavity are expected to be at constant calorific load, for this purpose, a heater was introduced in the cryo module. The heater is used to dissipate the calories that are not dissipated by the cavity when it's below it maximum power level. A PID regulation is used to control the level of the heater according to the power of the RF cavity.

HF CAVITY TESTS

The low level control system of the cavity and amplifier rely on robust technology like PLCs and FPGA, the higher level control applications use the EPICS framework. EPICS natively provide the possibility to develop state machine oriented programs. A set of applications was developed using this feature [6], it turned out to be very efficient for the HF cavity control see Fig. 3 and allowed the project to achieve the coupler and cavity conditioning very shortly. The cavities had been stored for several years, consequently there was a relative uncertainty about their cleanliness and how they would react. The state machine approach allowed to keep the conditioning under control, it allowed to save a lot of time.

CONCLUSION

Since 2016, the deuteron and heavy ions sources had been tested, the beam characterized with a dedicated test bench and most of the diagnostics validated in the medium energy beam line. This year, important milestones just has been taken for The SPIRAL2 facility and now everybody is excited and motivated to accelerate the first beam and make the first experiment in Neutron for Science experimental room by the end of the year.

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