FAILURE MODE AND EFFECTS ANALYSIS OF THE BEAM INTENSITY CONTROL FOR THE SPIRAL2 ACCELERATOR

C. Jamet, S. Leloir, T. André, B. Ducoudret,, G. Ledu, C. Potier de Courcy – GANIL – FRANCE email:jamet@ganil.fr

International Beam Instrumentation Conference
Monterey, California, USA September 14–18, 2014

The first phase of the SPIRAL2 project includes a driver and its associated new experimental areas (S3 and NFS caves). The accelerator, located in Caen (France), is based on a linear solution composed of a normal conducting RFQ and a superconducting linac. Intense primary stable beams (deuterons, protons, light and heavy ions) will be accelerated at various energies for nuclear physics

The beam intensity monitoring is a part of the control of the operating range. A high level of requirements is imposed on the intensity control system. In 2013, a Failure Mode and Effects Analysis (FMEA) was performed by a specialized company helped by the GANIL's Electronic Group. This paper presents the analysis and evolutions of the electronic chain of measurement and control.

INTRODUCTION

In the first phase, the SPIRAL2 driver will be able to accelerate and deliver beams of protons, deuterons and ions with q/A=1/3 to NFS (Neutron for Science) and S3 (Super Separator Spectrometer) experimental rooms.

Beam	P	D+	Ions (1/3)
Max. Intensity	5 mA	5mA	1 mA
Max. Energy	33 MeV	20 MeV/A	14.5 MeV/A
Max. Power	165 kW	200 kW	43.5 kW

Beam specification

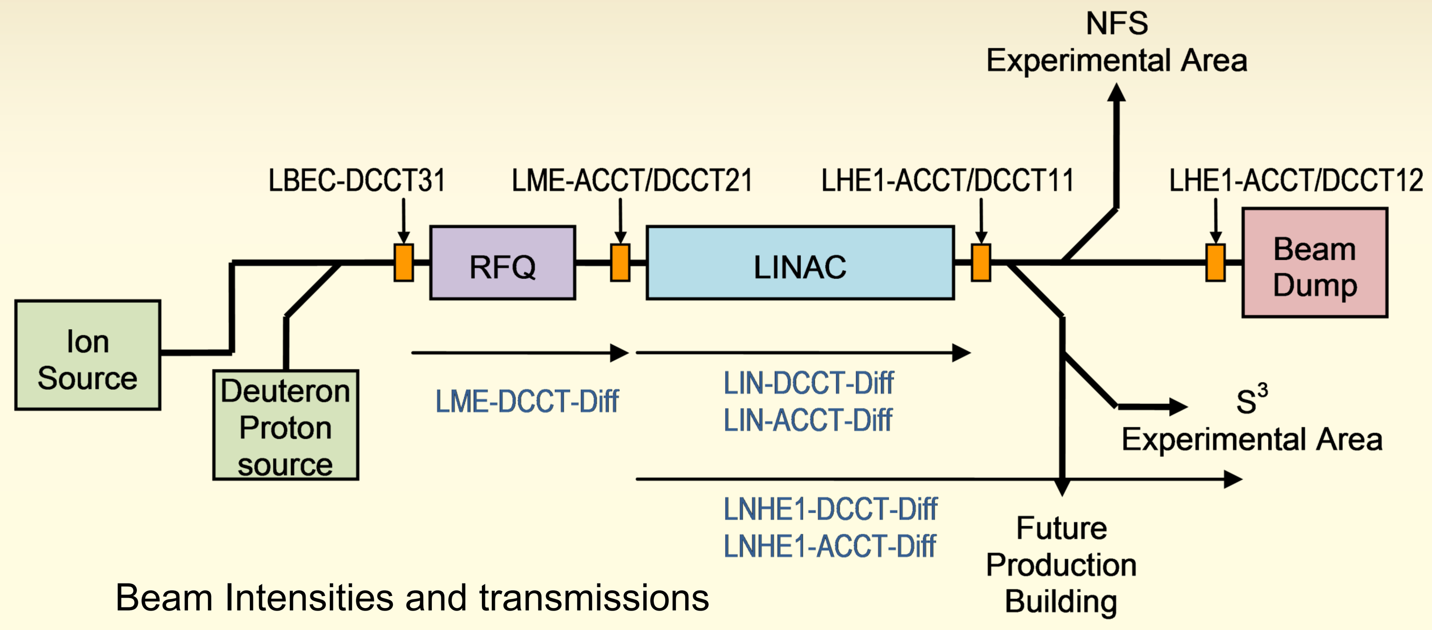
To obtain the commissioning authorization, the SPIRAL 2 project has to demonstrate and prove to the French Safety Authority that these devices which monitor the operating range of the facility are built in respect of the quality assurance rules.

To respond to this request, a FMEA (Failure Mode and Effects Analysis) of the intensity and transmission monitors was performed in 2013 by a French company, Ligeron®, specialized in the safety system developments.

BEAM INTENSITY AND TRANSMISSION CONTROLS

A DCCT and three ACCT-DCCT blocs will be installed along the accelerator to measures the intensity in the LEBT, MEBT, and in the HEBT.

The transmissions of the MEBT, Linac and Linac plus HEBT will be also monitored.



Beam Intensities and transmissions

ACCT and DCCT diagnostics are complementary.

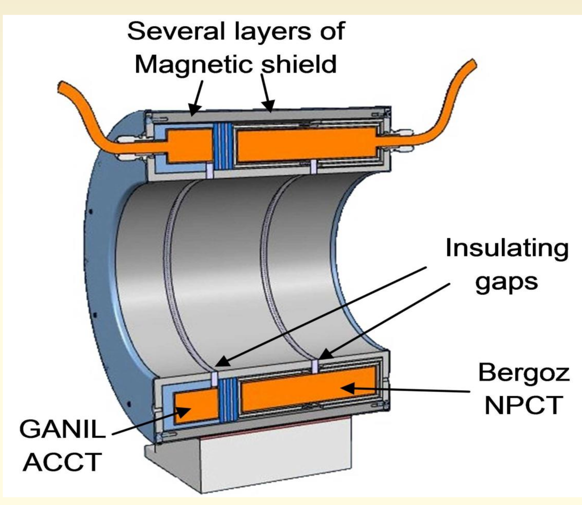
The DCCT, a commercial device, measures the intensity of continuous and chopped beams (response time around 50 µs for a bandwidth of 10 kHz), the minimum intensity is around a few dozens of µA without offset compensation.

The ACCT chain is faster with a response time less than 1 µs (bandwidth more than 300 kHz) and an intensity accuracy better than 10 µA with a chopped beam.

MEASURING CHAIN DESCRIPTION

ACCT-DCCT bloc

Two kinds of transformers are used to measure the beam intensity by a non-interceptive method, DCCT (NPCT) and ACCT. A Bergoz NPCT and a homemade ACCT inside a magnetic shield, compose an ACCT-DCCT bloc.



Transformer descriptions:
DCCT: NPCT-175-C030-HR
ACCT: Torus: Nanocristaline, Turn ratio: 300:1
Internal diameter: 184 mm, External diameter: 220 mm

Three shielding layers (Armco, Mu-metal and copper) protect the sensors from external electromagnetic fields.

A vertical shield plate between AC and DC sensors is installed to minimize the disturbance produced by the DCCT magnetic modulator on the ACCT.

ACCT measuring chain

The preamplifier was developed to reduce the ACCT low frequency cut-off up to few 10 mHz and decrease the low drop.

The amplitude detection electronic is synchronized to a signal "Clamp synchronization" which memorizes the voltage level when the beam is not present and subtracting the memorized value.

DCCT measuring chain

A thermal regulation maintains the temperature at 40 °C ±1°C in order to decrease the effect of the temperature variation on the offset value.

An electronic offset compensation is planned to reset the offset at each start of a new beam tuning. The command is done manually.

INTENSITY SURVEILLANCE BOARD

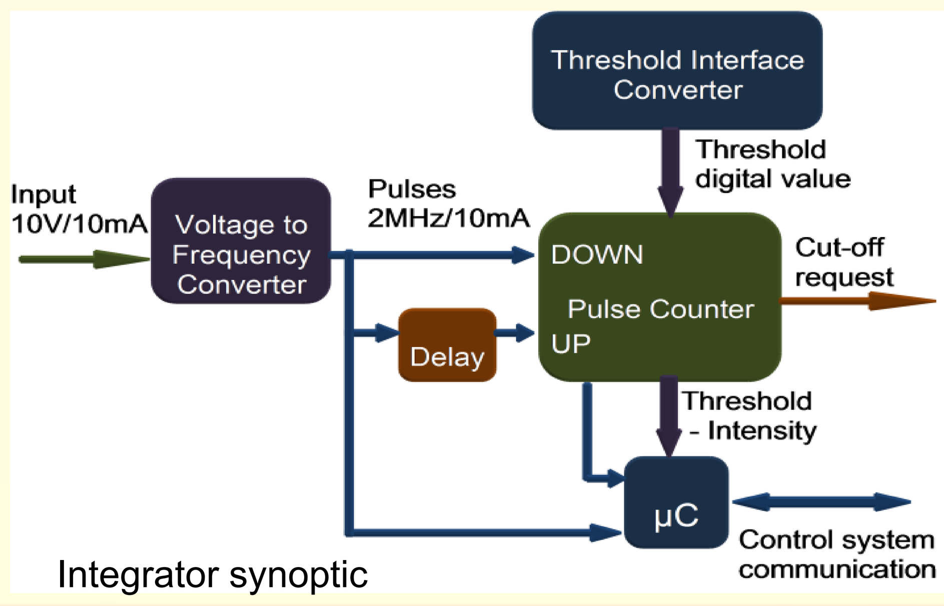
Requirements

The main board requirements are the following:

- ✓ The surveillance of the average current independently of the duty cycle of the beam chopper (duty cycle period of 200 ms or 1s)
- ✓ A response time of 35 µs with an input level of 5mA

The electronic board realizes a moving integration by using a VFC, a delay of 200ms or 1s and a pulse down/up counter [5].

The ACCT or DCCT signal is converted into a pulse frequency. Continually, a counter adds up the pulses and removes the delayed pulses. The delay corresponds to the time interval of integration. This time is equal to a multiple of the chopper period, the counter value is then representative of the input average signal.



Integrator synoptic

A microcontroller is used to perform the counting function and monitor the other thresholds with less reliability but more flexibility. The microcontroller manages the other functions like the communication between the electronics and the control system.

MEASUREMENT RESULTS

The MPS controls require knowing the absolute value of the beam intensities. These uncertainties will be taking account in the threshold level.

Sources of uncertainty	ACCT	DCCT
Linearity*	0.1%	0.6%
Offset vs. Temperature* $\Delta T = 1°C$	-	10 µA
Integrator Offset	0.5 µA	0.5 µA
External magnetic field max. **	1,5 µA	-
Noise	3nA/√Hz	200nA/√Hz
Low drop ***	-	-
Slew rate	5µs	50µs

* measured by the GANIL test bench ** Measured with the I surveillance board
*** Low drop effect removes by an optimised sample & hold

FAILURE MODE AND EFFECTS ANALYSIS RESULTS

The Aim of the FMEA consists to verify that the intensity and transmission control respond to the requirements of the Enlarged Protection System (EPS). The risks are to underestimate the beam intensities and beam transmissions.

The determinist analysis consisted to study the effects of failure modes on the safety functions. The failure mode identification was realized from functional and physical descriptions of the control chains.

The FMEA results show dangerous failures and give three categories of recommendations:

- ✓ Technical recommendations
- ✓ Recommendations to establish periodical controls
- ✓ Recommendations to establish operating procedures

Technical recommendations

The main technical recommendations are to add surveillances of the hardware functions (saturation detections, timing controls, power supply and temperature regulation control) and add verifications by the microcontroller of the correct writing of the thresholds in the surveillance boards. All these surveillances are added and set off the cut-off request in case of activation. All these recommendations were taking account in the new design of the electronic devices. An authorisation is now necessary to send a test, to enter a threshold and to deduct the DCCT offset. This authorisation is given when the beam is stopped in the LEBT.

Periodical controls

The control of the measurement chain consists in injecting test currents in the test coil. The measured values and the threshold overrun have to be controlled.

Each hardware control has to be tested. In the new electronic design of the surveillance boards, a connection between each board and a test box is planned.

A control of the thermal regulation is also asked.

Operating procedures

After each intervention on the beam pipe near ACCT-DCCT blocs, a verification of the beam intensity measurement is intended with the beam presence.

After each threshold modification, a remote verification of the threshold value is done by an operator.

CONCLUSION

The FMEA performed in 2013, the conception review organised in the beginning of 2014, validated the final design of the intensity and transmission controls. The last prototypes are currently under test. The definitive manufacturing of the overall chain is planned for the end of this year.

The experience of FMEA is quite positive. The analysis has helped to define precisely the requirements, to develop an electronic more robust and to adapt this design to the recommended controls.