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 specifications

<table>
<thead>
<tr>
<th>Beam</th>
<th>$P$</th>
<th>$I_0$ (1/3)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Max. Intensity</td>
<td>5 mA</td>
<td>5 mA</td>
</tr>
<tr>
<td>Max. Energy</td>
<td>33 MeV</td>
<td>20 MeV/µA</td>
</tr>
<tr>
<td>Max. Power</td>
<td>165 kW</td>
<td>200 kW</td>
</tr>
</tbody>
</table>

To obtain the commissioning authorization, the SPIRAL 2 project has to demonstrate and prove to the CEA Nuclear 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 measure the intensity in the LEBT, MEBT, and in the HEBT. The transmissions of the MEBT, Linac and Linac plus HEBT will also be monitored.

**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.

**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.

**MEASUREMENT RESULTS**

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

<table>
<thead>
<tr>
<th>Sources of uncertainty</th>
<th>ACCT</th>
<th>DCCT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Linearity*</td>
<td>0.1%</td>
<td>0.6%</td>
</tr>
<tr>
<td>Offset vs. Temperature</td>
<td>–1°C</td>
<td>–1°C</td>
</tr>
<tr>
<td>Integrated Offset</td>
<td>0.5 µA</td>
<td>0.5 µA</td>
</tr>
<tr>
<td>External magnetic field</td>
<td>1.5 µA</td>
<td>1.5 µA</td>
</tr>
<tr>
<td>Noise</td>
<td>500 nA/Hz</td>
<td>500 nA/Hz</td>
</tr>
<tr>
<td>Low drop ***</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>Slow rate</td>
<td>5 µs</td>
<td>50 µs</td>
</tr>
</tbody>
</table>

* measured by the GANIL test bench ** Measured with the I surveillance board

**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 (saturations 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 by 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 current signals 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.