INTENSITY CONTROL IN GANIL'S EXPERIMENTAL ROOMS

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Abstract

The safety re-examination of existing GANIL facilities requires the implementation of a safety system which makes a control of the beam intensity sent to the experimental rooms possible. The aim is to demonstrate that beam intensities stay below the authorized limits defined by the safety GANIL group. The challenge is to be able to measure by a non-interceptive method a wide range of beam intensities from 5nA to 5µA with a maximum uncertainty of 5%, independently of the frequency (from 7 to 14.5MHz) and the beam energy (from 1.2 to 95MeV.A). After a comparative study, two types of high frequency diagnostics were selected, the capacitive pick-up and the fast current transformer. This paper presents the signal simulations from diagnostics with different beam energies, the uncertainty calculations and the results of the first tests with beam.

INTRODUCTION

A safety review has been required to The National Large Heavy Ion Accelerator (GANIL, Caen, France) by the Nuclear Safety Authority (ASN, France). The beam intensity monitoring has to be upgraded to protect personnel from radiation hazards. A system that controls the beam intensity delivered in experimental rooms in the energy and frequency ranges used at GANIL has to be developed. This project is called CIA for "Control of the Intensity in experimental Areas". At the end of the project, seven equipments will be installed in beam lines and experimental rooms. All of them will be classified as EIS (Element Important to Safety). Hence they have to meet a number of requirements in terms of safety, in particular, an insurance of well-functioning stronger as possible.

REQUIREMENTS

The system has to provide a high reliable measure of the beam intensity with a relative precision better than 5% in the range 5nA to 5µA. The detector response should be independent of temperature, beam position, energy, frequency and phase extension. The reliability is enhanced through general care and periodic maintenance.

Uncertainty Calculation

One of the fundamental safety requirements is to check if the beam intensity limit is not exceeded. In order to avoid exceeding the limit, the threshold has to take into account the global measurement uncertainty. As an example, we consider a maximum beam intensity allowed of 5nA and a global uncertainty of 1nA. The threshold must be set at 4nA and the maximum beam intensity that could be delivered without triggering the alarm is 3nA. Thus the uncertainty has to be as low as possible. The uncertainty has to be characterized as regards its influence quantities:

- beam energy
- beam phase extension
- beam lateral position
- temperature
- frequency
- extern magnetic fields

All these influence quantities generate systematic errors. Stochastic errors as electronic noise and RF disturbance have also to be taken into account. When the standard uncertainties of every uncertainty component have been estimated, the combined standard uncertainty attributable to all of these components may be estimated.

Quality Assurance Process

In addition to specifications, a Quality Assurance Process has to be followed. That involves:

- characterization of the measurement chain in laboratory and with beam,
- verification and validation that the system meets specifications,
- test procedure guides,
- certified reports,
- traceability of instruments,
- Follow-up study, periodic tests...

FEASABILITY STUDY OF TECHNICAL SOLUTIONS

Two high frequency diagnostics have been selected: the capacitive Pick-Up (PU) and the Fast Current Transformer (FCT). The features of the FCT are its large bandwidth (up to 2GHz) and its high sensitivity (5V/A). A PU was developed at GANIL and a FCT was bought at Bergoz Instrumentation [1].

The signal processing consists in measuring the second harmonic of the signal receiving from the diagnostic. A relative simple relation exists between the average value of the outgoing signal and its second harmonic. The mean value of the beam intensity can be then calculated by taking account of the diagnostic transmittance. The principal disadvantage of this method is the dependence on beam energy and phase extension. This method is already used in another GANIL project named CICS for "Irradiation Control of the SPIRAL Target" and detailed in a DIPAC'05 paper [5]. Compared to CICS, CIA has to deal with two difficulties: the large range of beam

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intensity (from 5nA to 5µA) requiring sensitivity modifications and the large range of beam energy (from 1.2 to 95MeV.A).

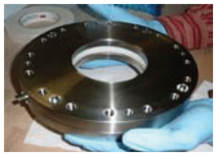

Figure 1: FCT developed by Bergoz Instrumentation.

SIGNAL SIMULATIONS

The FCT achieves its measurement via the beam magnetic field while the PU measures the intensity via the beam electric field. The electric and magnetic field-line distributions depend on the beam energy. A high energy leads to a significant Lorentz contraction of the electromagnetic field. Hence a study on the energy sensitivity of the electromagnetic field was conducted. A simulation of FCT and PU signals was done. Its primary goal is to model closely the physical interactions involved, the detectors performance and the beam parameters. There are few, if any, articles in scientific literature about magnetic field generated by beam while articles about beam electric field abound. Thus, we had to start again from equations of the classical electrodynamics [2][3][4]. First electric and magnetic fields generated by a single particle e, with velocity v, are modeled. The transverse electric field at a point a perpendicular distance b from the straight line path of the charge was found to be:

$$E_{\perp} = \frac{e\gamma b}{\left(b^2 + \gamma^2 v^2 t^2\right)^{3/2}} \quad (1)$$

The origin of the time t is chosen so that the charge is closest to the observation point at $t = 0$. γ is the Lorentz factor. The magnetic induction is related simply to the electric field by the relation:

$$\vec{B} = \frac{\vec{v} \wedge \vec{E}}{c^2} \quad (2)$$

These fields are then convolved with the charge distribution of bunches. This model produces coherent and reliable results with a previous study conducted with beam. Consequently its use is considered relevant. On table 1, is presented the second harmonic variation in the range of energy for CSS1, CSS2 and CIME cyclotrons.

Table 1: Simulation Results

cyclotron	energy range (MeV.A)	frequency range (MHz)	second harmonic variation	
			FCT	**PU**
CSS1	[4; 13]	[7; 14]	0.007%	0.07%
CSS2	[24; 95]	[7; 14]	0.01%	0.1%
CIME	[1.2; 25]	[9.6; 14.5]	0.9%	8%

The FCT is ten time less sensitive to energy variations than the PU. However its sensitivity to energy must be taken into account to avoid measurement error.

CHARACTERIZATION TESTS OF THE FCT IN LABORATORY

Two series of laboratory tests were performed at Bergoz Instrumentation and GANIL. The first purpose of these tests was to ensure that the FCT meets its specifications. The uncertainty with temperature and frequency has to be at most equal to 1%. The cutoff frequency has to be at least equal to 200MHz.

Tests carried out in GANIL aimed at a more detailed characterization. The electronic setup is composed of an amplifier and a Lock-In Amplifier (Stanford Research Systems SR844). It has a frequency range of 25kHz to 200MHz. Its function of interest is the harmonic detection (*F* and 2*F*). Tests were realized in laboratory with a coaxial line (figure 2) developed at GANIL which simulates the bunch beam. The table 2 presents simulation results.

Figure 2: Coaxial line.

Table 2: Results

	specifications	**measurements**
lower cutoff frequency	< 200kHz	6.485kHz
upper cutoff frequency	> 200MHz	267.575MHz
cumulative uncertainty	< 1% on 5-45ºC and 14-29MHz	0.76% on 25-45ºC and 14-29MHz

The uncertainty associated to frequency is the dominant term. The FCT is relatively stable with respect to temperature. As the FCT response in function of temperature is linear and the relative uncertainty (normalized by the mean value) associated to temperature on the range 25 to 45°C equals 0.06%, it is a reasonable assumption to say that the relative uncertainty on the range 5 to 45°C would not exceed 0.6%. Moreover a measurement on 6-41°C gave a relative uncertainty of 0.15%. This assumption involves a cumulative uncertainty on 5-45°C and 14-29MHz lower to 1%.

The aim of the linearity test is to check that the relation between the delivered intensity and the measured intensity is truly linear. The measurement has been performed with a signal of constant frequency (20MHz) and decreasing the intensity from 50µA to 5nA. The least squares method is used to find the best fit straight line. The non-linearity error is the maximum deviation from the best fit straight line. The percentage is quoted using the normal full scale. The non-linearity error of FCT does not exceed 1%FS on [1nA; 5µA] and equals 6.5%FS on [50pA; 1nA] which is in good agreement with the desired specifications.

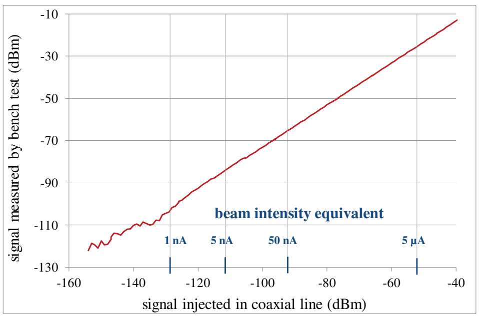

Figure 3: Measurement chain linearity with coaxial line.

TESTS WITH BEAM

A prototype of each diagnostics, FCT and PU, has been set on beam line. The figure 4 presents measurement chains. In the PU measurement chain, the high input impedance of the amplifier is used. The amplifier is as close as possible to the PU in order not to distort the signal.

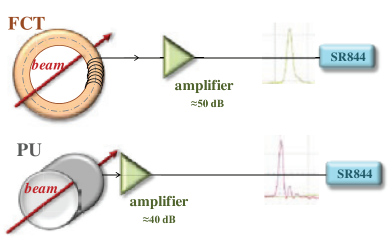

Figure 4: Measurement chains with beam.

The aim is to reduce the beam intensity to 1nA and evaluate linearity, sensitivity and resolution of the measurement chain.

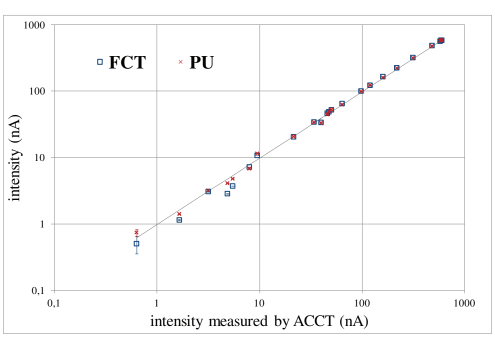

Figure 5: Measurement chain linearity with beam.

The non-linearity error equals 1.54%FS (Full Scale) for FCT and 1.15%FS for PU. The major disadvantage of these beam tests is the reference diagnostic, an AC Current Transformer used in routine at GANIL. This ACCT is worse in terms of linearity and sensitivity than diagnostics to be characterized. Figure 6 shows the stochastic uncertainty (standard deviation of measurements) of FCT, PU and ACCT.

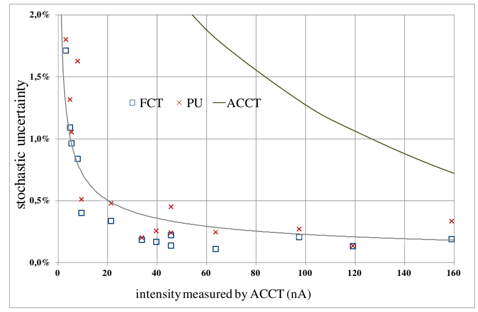

Figure 6: Stochastic uncertainty of measurement.

The maximum stochastic uncertainty of FCT is 1.7% and of PU is 1.8% on [1nA; 500nA]. These stochastic uncertainties are composed of diagnostic uncertainty and beam uncertainty.

One important purpose of beam tests is to characterize the energy sensitivity of FCT and PU. A decrease of beam energy leads to a rise of the bunch length which leads to a second harmonic level decrease. A correction, *a posteriori,* of the second harmonic is thus possible. An energy correction of FCT measurements has been done. First beam tests agree with this correction. Concerning PU, beam tests have shown that the necessary correction is more significant. As beam tests do not agree with model, correction factors have to be adjusted. For now, only three energy values have been tested. More beam tests are required to realize this adjustment. Beam tests are scheduled for the end of 2013.

CONCLUSIONS

A safety system based on a beam diagnostic involves a Quality Assurance Process. A feasibility study has already been done; simulations and tests in laboratory have also been performed. It remains the characterization with beam. Some beam tests have been realized in July and other are scheduled for the end of the year 2013. The choice of the equipment will depend on the intensity range required and which should be decided soon.

REFERENCES

[1] http://www.bergoz.com

[2] J. D. Jackson, "Classical Electrodynamics", John Wiley & Sons, Inc., (1975)

[3] M. Reiser, "Theory and Design of Charged Particle Beams", John Wiley & Sons, June 2008

[4] J. C. Denard, "Beam Current Monitors", CERN Accelerator School on Beam Diagnostics, June 2008, Dourdan, France

[5] P. Anger, *et al.*, "Irradiation Control of the "SPIRAL" Target by Measuring the Ion Beam Intensity via a Fast Current Transformer", DIPAC'05, POT028