OPERATION OF THE BEAM POSITION MONITOR FOR THE SPIRAL 2 LINAC ON THE TEST BENCH OF THE RFQ

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Abstract

SPIRAL2 project is based on a multi-beam superconducting LINAC designed to accelerate 5 mA deuteron beams up to 40 MeV, proton beams up to 33 MeV and 1 mA light and heavy ions (Q/A = 1/3) up to 14.5 MeV/A. The accurate tuning of the LINAC is essential for the operation of SPIRAL2 and requires measurement of the beam transverse position, the phase of the beam with respect to the radiofrequency voltage, the ellipticity of the beam and the beam energy with the help of Beam Position Monitor (BPM) system. The commissioning of the RFQ gave us the opportunity to install a BPM sensor, associated with its electronics, mounted on a test bench. The test bench is a D-plate fully equipped with a complete set of beam diagnostic equipment in order to characterize as completely as possible the beam delivered by the RFQ and to gain experience with the behavior of these diagnostics under beam operation. This paper addresses the first measurements carried with the BPM on the D-plate: intensity, phase, transverse position and ellipticity under 750 KeV proton beam operation

GENERAL DESCRIPTION OF SPIRAL2

SPIRAL2 facility is being installed in Caen, France. It includes a multi-beam driver accelerator (5mA/40Mev deuterons, 5mA/14.5MeV/A heavy ions). The injector is constituted by an ECR ion source (Q/A= 1/3), an ECR deuteron/proton source, a low energy beam transfer line (LEBT) followed by a room temperature RFQ which accelerates beam up to an energy of 0,75MeV/u. A medium energy transfer line (MEBT) transfers the beam to the superconducting Linac.

The Linac is composed of 19 cryomodules: 12 contain one β = 0.07 cavity and 7 contain two β = 0.12 cavities. All cavities in the cryomodules operate at F = 88.0525MHz.

The superconducting Linac is designed to accelerate deuterons, protons, heavy ions Q/A= 1/3 and Q/A = 1/6 for a future injector. (Table 1)

Table 1: SPIRAL 2 Main Beam Parameters

Particle	Current Max (mA)	Energy (MeV/u)
Proton	5	2 - 33
Deuteron	5	2 - 20
Q/A = 1/3	1	2 - 14.5
Q/A= 1/6	1	2 - 8

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SPIRAL2 nominal mode of operation is planned to be C.W. mode. The considerations on commissioning and tuning periods of the LINAC lead to consider also pulsed mode operation in order to minimize the mean power of the beam. The shortest duration of a macro-pulse will be 100 µs. The repetition rate may be as low as 1Hz and as high as 1 kHz. The intermediate configurations have to be taken in account in order to reach the C.W. operation. The step to increase or decrease either the macro pulse duration or the repetition rate will be 1µs.

SPIRAL2 BEAM POSITION MONITORS

General Description

A doublet of magnetic quadrupoles is placed between the cryomodules for the horizontal and vertical transverse focusing of the beam. Beam Position Monitors (BPM), of the electrostatic type, is inserted in the vacuum pipe located inside the quadrupoles of the LINAC.

Each BPM sensor contains four probes on which beam image currents induce bunched-beam electrical signals. The electronics board associated with each BPM sensor processes the electrical signals and enables the measurement of beam transverse position, phase, energy and transverse beam ellipticity $\sigma_x^2 - \sigma_y^2$, where σ_x and σ_y are the standard deviations of the transverse size of the beam.

BPM Acquisition Modes

The BPMs data and measures are acquired under CW or pulsed mode operation in three modes: Normal, post mortem and electrode signal reconstruction.

A synchronizing signal "SF" is distributed simultaneously to the SPIRAL2 diagnostics, including the BPM to indicate that the beam is present during its high level.

Normal mode: the electronics module acquires the data on the SF rising edge after a delay and during a given integration time. The integration time must be less than the time where the SF signal is high. Both the delay and the integration times are selected by the operator.

Data: beam centroid transverse position and beam ellipticity, electrode received signal amplitude and vector sum in phase and magnitude of the four electrodes are transferred to the VME local memory on the fall of "SF" signal. EPICS driver reads the data every 200ms from the local VME memory.

BPM Specifications

The main specifications for the BPM system are summarized in Table 2.

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Table 2: Main SPIRAL2 BPM Specifications

Parameter	Measurement resolution	Measurement range
Position	± 50µm ± 150µm	± 10 mm ± 20 mm
Phase	± 0.5deg	±180 deg
Ellipticity	± 20%	
Beam current		0.15 – 5 mA

BPM Sensor Mechanical Design

Capacitive sensors have been selected (Electrodes aperture diameter: 48 mm, length in the direction of the beam: 39 mm, subtended lobe-angle: 62°) (Figure 1).

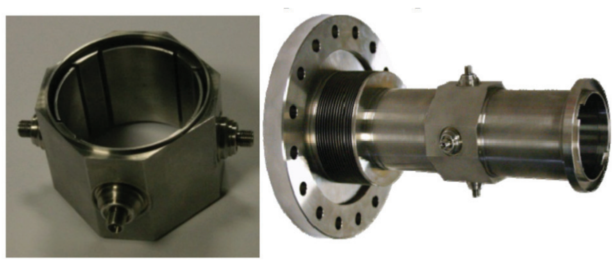

Figure 1: Left: SPIRAL2 BPM central block with the capacitive electrodes. Right: BPM with its flanges.

A dedicated test bench based on a coaxial transmission line has been designed and built in order to characterize each BPM: electrical center coordinates, position and ellipticity sensitivities at β=1[1].

BPM Sensor Readout Electronics Module

Each BPM sensor feeds an electronic module through eighty meter long coaxial cables. The 20 BPM electronics modules are located in three VME 64x crates. Each module contains an analog and a digital board. The design of the analog module of the card is based on the scheme of auto-gain equalization using offset tone having frequency slightly offset from the RF reference [2]. The electronic module is able to work either at 88.0525 MHz or at 176.1050 MHz to deliver the required information.

The Accelerator Control Division of Bhabha Atomic Research Centre realized the BPM Electronics modules.

Two prototypes of the BPM readout electronics module were qualified in IPN leading to several upgrades in order to meet specifications. The prototypes results are in a good agreement with results obtained with the measurement setup used to characterize the BPMs. [3].

BPM TESTS ON THE SPIRAL2 INTERMEDIATE TEST BENCH (ITB)

General Description of the ITB

An "Intermediate Tests Bench" (ITB) has been assembled as part of the injector commissioning plan [4]. The ITB is positioned after the focusing quadrupole following the first re-buncher of the M.E.B.T. Two other focusing quadrupoles are placed between the re-buncher, and the RFQ. A beam stopper able to withstand nearly the full power of the beam terminates the ITB which includes 18 beam diagnostics identical to the SPIRAL2 driver ones. The aim of the ITB is to fully characterize the properties of the beam accelerated by the RFQ and also to study the behaviour of these diagnostics. All kinds of measurements may be carried: beam intensity, transverse beam position, profiles and emittance, phase and longitudinal emittance with a beam energy equal to 750KeV/A.

Control command operation gathers the measurements performed by all these diagnostics almost on real time (every 200ms). Figure 3 shows the ITB.

BPM Current Dynamic Range

The first tests of the BPM and its associated electronics was to check the beam current dynamic range over which the BPM electronics are working properly. The beam current is given by the Faraday cup (CF) of the ITB on one side and by the magnitude of the four vector sum of the four electrodes given by the BPM electronics at F = 88.0525 MHz and 2.F on the other side. Horizontal and vertical slits located in the LEBT vary the beam intensity.

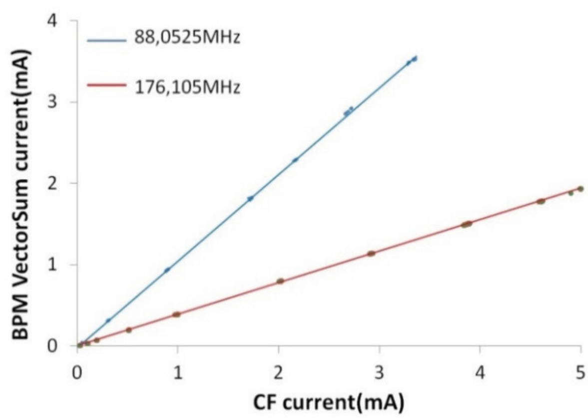

Figure 2: BPM beam current dynamic range.

Measurements were performed on fall January 2016. They showed an upper limitation of the measurement range (CF current = 3.5mA) at F due to the saturation of the front end of the BPM electronics (see Figure 2) where as it is fully operational at 2.F. This saturation is assigned to a difference in signal magnitude obtained during the beam operation compared to that obtained by the beam dynamics simulation.

Further tests were performed on this issue on June 2016 where 10dB attenuations were added at the analogue inputs of the readout electronics analogue inputs, this leaded to the following dynamic range: 75 µA - 5.5 mA at F and 60 µA – 5.5 mA at 2.F.

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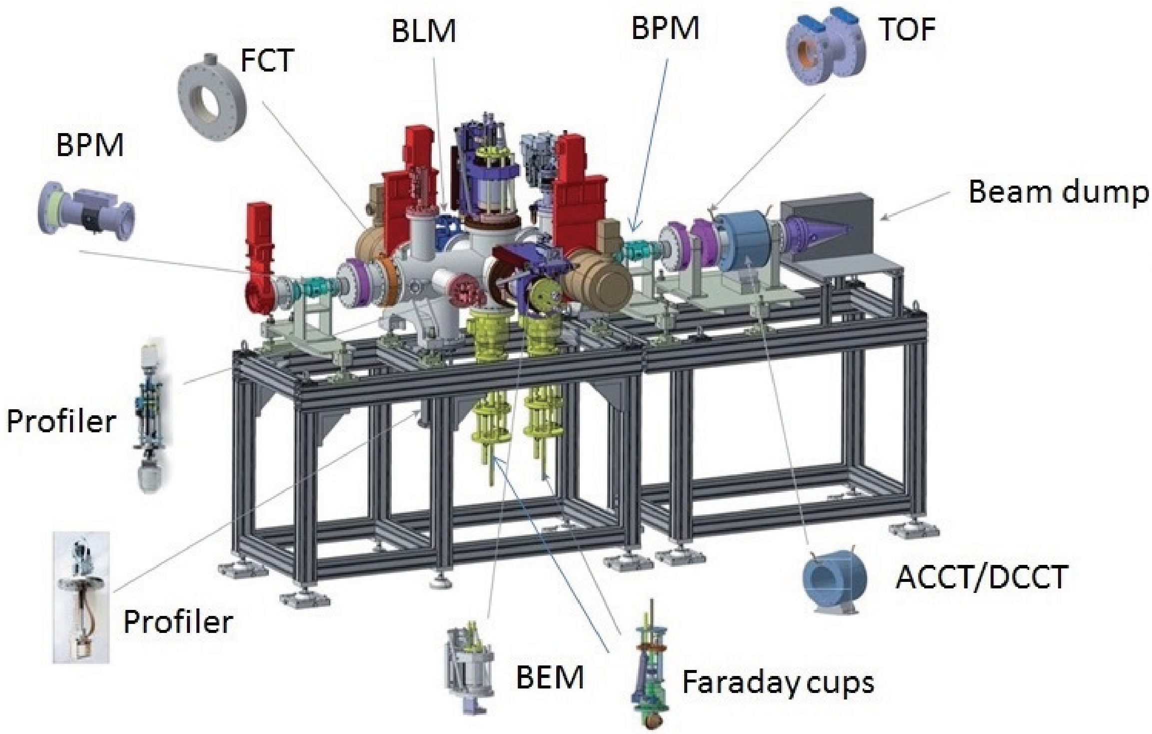

Figure 3: View of the Intermediate Test Bunch equipped with a full set of beam diagnostics.

BPM Phase Measurement

The phase relative to the accelerating RF signal has been measured simultaneously by the BPM and by one of the three electrostatic P.U. electrodes of the time of flight (TOF) energy measurement system mounted on the ITB. The BPM is measuring the phase at F and 2.F whereas the TOF is only measuring it at F. The RFQ phase was swept over 360° with a 10° step over different beam currents. The results of the BPM and TOF measurements were gathered in order to show the mean value of the measured phase and the range over which the phase is fluctuating.

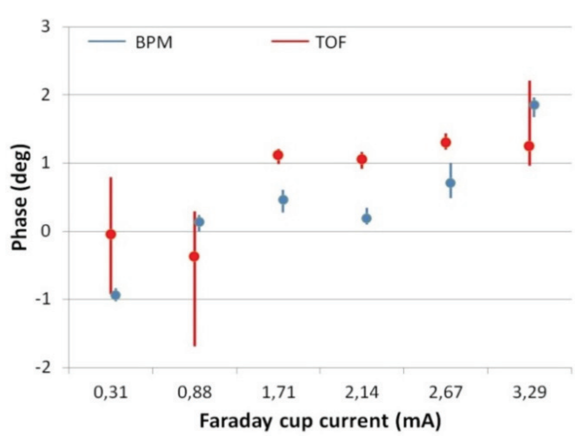

Figure 4: Beam phase measurement with BPM and a PU –TOF electrode at 88.0525MHz.

The results (Fig. 4) show a proper behaviour and a good agreement with the electrode of the TOF system over the measured beam current dynamic range: the fluctuation is within 1° for medium and high current where as it is less precise for the TOF at low beam currents.

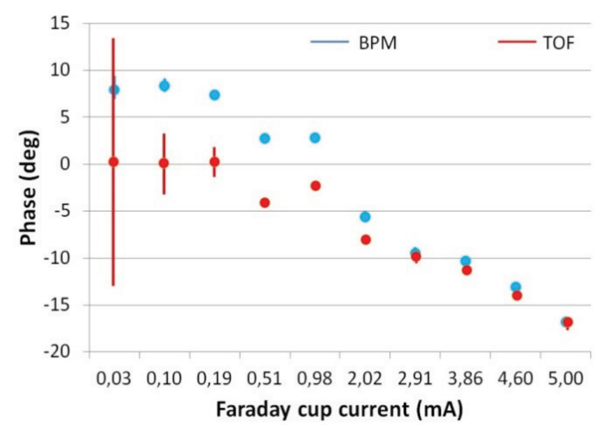

Figure 5: Beam phase measurement by a BPM at 176.105MHz and a TOF PU electrode at 88.0525MHz.

BPM phase measurements were also simultaneously performed at 2.F. with the TOF electrode (same manner as previously) however the beam conditions were different. TOF measurements at F were performed. The results are sketched in fig. 5. The same comments reported at F apply for 2.F.

Beam Position Measurements

The beam position measurements were simultaneously performed by the BPM and the secondary emission monitor (SEM) profiler (pulsed mode operation) located after a drift space downstream in the ITB. The results obtained with the BPM measurements at F and 2.F have been com-

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pared to the profiler measurements (frequency independent). The BPM position sensitivity was set to 25.7 mm for all the measurements. The beam position was changed by varying the current of a steerer DC13 located in the quadrupole Q13 located just before the BPM. It was swept over the range [-5A; 4A] with a 1.5A step. An example is given in Figure 6

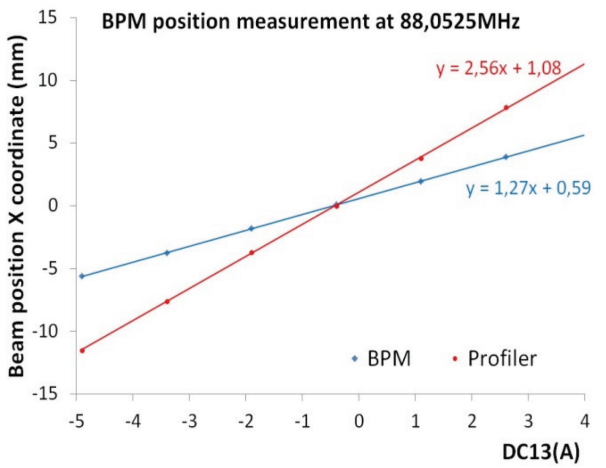

Figure 6 : Beam position measurement at 88.0525MHz.

The expected linear response of the BPM is confirmed. The results are gathered in the table 3 for F and 2.F. The BPM position sensitivity remains roughly constant over the current dynamic range. Considering the low value of the velocity (β ~ 0.04) of the beam accelerated by the RFQ, we took in account Shafer study [5] which states that the beam position sensitivity at a frequency f for a beam travelling in a cylindrical chamber of radius r should be multiplied by (1+G) where G is:

$$G = 0.139.\left(\frac{2.\pi.f.r}{\beta.\gamma.c}\right)^2 - 0.0145\left(\frac{2.\pi.f.r}{\beta.\gamma.c}\right)^3$$

With the help of the measured positions of the SEM profiler, we were able to calculate easily the expected position on the BPM. Therefore we applied the adequate correction to the sensitivities at 88.0525MHz and 176.105MHz drawn from our measurements on our laboratory test bench (S= 25.7 mm at β ~ 1). It came out in good agreement with the estimations of Shafer.

Table 3: Beam Position Sensitivity

Beam Current	Measured Sensitivity		Theoretical Sensitivity	
	F	*2*F*	*F*	*2*F*
4mA	21.9mm	16.7mm	22.3mm	15.9mm
1.5mA	21.6mm	16.3mm	22.3mm	15.9mm
0.25mA	21.6mm	16mm	22.3mm	15.9mm

BPM Ellipticity Measurement

The quantity $\sigma_x^2 - \sigma_y^2$ is delivered by the BPM electronics and as well drawn from the SEM profiler measurements. The BPM ellipticity sensitivity was set to 354 mm² for all measurements. The beam 2D shape was modified by changing the current in the quadrupole Q13 located before the BPM (beam current equal to 1.2mA). The current of Q13 was swept over a range [2.5A - 30A] with a 2.5A step leading to significant changes of the ellipticity.

The linear behaviour of the BPM ellipticity towards Q13 current is confirmed by the measurements (fig. 7). The same behaviour is confirmed by the BPM measurements at 176.105MHz. Further investigations should be run to explain the discrepancies between beam dynamics simulations and measurements.

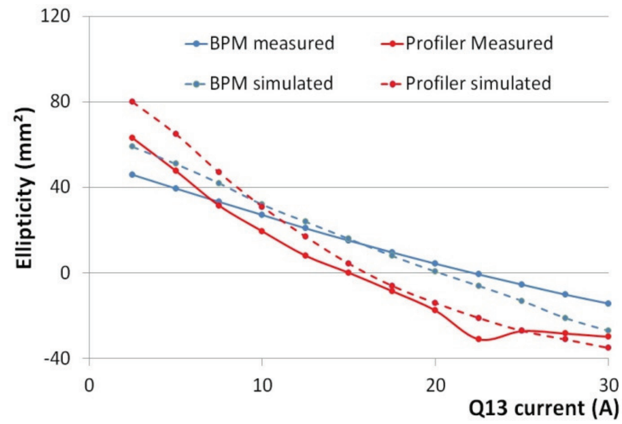

Figure 7: Beam ellipticity measurement at 88.0525MHz.

CONCLUSION

The BPM sensors realized with its associated electronics for the Linac of SPIRAL 2 have been put on operation on the ITB of SPIRAL2. We will be able to measure the transverse position of the beam and the phase of the beam with respect to the RF signal. However further investigations have to be made concerning the ellipticity measurement. A second BPM sensor with its electronics module will be mounted very soon on the ITB in order to check the energy measurement by means of the BPM.

ACKNOWLEDGMENTS

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REFERENCES

[1] M. Ben Abdillah and P.Ausset, "Development of Beam Position Monitors for the SPIRAL2 LINAC", in *Proc. 1st Int. Beam Instrumentation Conf. (IBIC'12)*, Tsukuba, Japan, October 2012, paper TUPA18, pp. 374-377.

[2] G. Joshi *et al.*, "An offset tone based gain stabilization technique for mixed-signal RF measurement systems", *Nucl. Instr. Meth.*, vol. A 795, 2015, pp. 399-408.

[3] P. Ausset and M. Ben Abdillah, "Development of the Beam Position Monitors system for the LINAC of SPIRAL2", in *Proc. 2nd Int. Beam Instrumentation Conf. (IBIC'13)*, Oxford, UK, September 2013, paper WEPC15, pp. 702-705.

[4] P. Ausset *et al*, "SPIRAL2 injector diagnostics", in *Proc. DIPAC 09*, Basel, Switzerland, pp. 110-112.

[5] R.E. Shafer, "Beam Position Monitor Sensitivity for Low-β Beams", in *Proc. 17th Linac Conf. (LINAC'94)*, Tsukuba, Japan, August 1994, paper THPA84, pp. 905-907.

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