DEVELOPMENT OF THE BEAM POSITION MONITORS FOR THE SPIRAL2 LINAC

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Abstract

The SPIRAL 2 facility will deliver stable heavy ion beams and deuteron beams at very high intensity, producing and accelerating light and heavy rare ion beams. The driver will accelerate between 0.15mA and 5 mA deuteron beam up to 20 MeV/u and also q/A=1/3 heavy ions up to 14.5 MeV/u.

The accurate tuning of the Linac is essential for the operation of SPIRAL2 and requires from the Beam Position Monitor (BPM) system the measurements of the beam transverse position, the phase of the beam with respect to the radiofrequency voltage and the beam energy.

This paper addresses all aspects of the design, realization, and calibration of these BPM, while emphasizing the determination of the beam position and shape. The measurements on the BPM are carried out on a test bench in the laboratory: the position mapping with a resolution of 50 µm is performed and the sensitivity to the beam displacement is about 1.36dB/mm at the centre of the BPM. The characterization of the beam shape is performed by means of a special test bench configuration.

An overview of the electronics under realization for the BPM of the SPIRAL2 Linac is given.

OVERVIEW

SPIRAL2 represents a major advance for research on exotic nuclei. It will provide better insight into the table of nuclides, thereby fostering the discovery of new properties of matter.

SPIRAL 2 Linac is installed in Caen, France. It is composed of 2 types of cryomodules A and B respectively for low (β= 0.04) and high (β=0.2) energy sections. Each of these cryomodules contains respectively one or two resonators superconducting radiofrequency cavities.According to beam dynamics calculations, all the cavities operate at 88.0525MHz.

A doublet of magnetic quadrupoles takes place between the cryomodules for the transverse horizontal and vertical focusing of the beam.

Measurement of the particle beam position in accelerators is an essential part of beam diagnostics, and the Beam Position Monitors (BPMs) provide the basic diagnostics tool for commissioning and operation of accelerators. One of the primary applications of the BPM**s** is the stabilization of the particle beam positions through feedback.

In order to save room, BPM will be inserted in the vacuum pipe inside the quadrupoles which will be buried at their turn in the quadrupole magnet.

Different beams are accelerated by SPIRAL2; Table 1 shows the main characteristics of some of these beams at the start and at the end of the linac.

Table 1: Beam Characteristics

	Linac start	Linac End
Beam relative velocity β	0.04	0.2
Beam energy (MeV)	1.46	40

The specifications of the required BPM resolution for beam position feedback in SPIRAL2 linac are listed in Table 2.

Table 2: BPM Specifications

Beam position resolution	50 um
Beam position range	±20 mm
Beam shape resolution	20%

This paper addresses the design, realization and calibration of these BPMs; it also shows the design adopted for the realization of the BPMs acquisition cards.

BPM DESIGN

SPIRAL2 BPMs have four electrodes mounted directly within the focusing magnets as shown in Figure 1 (A zoom of the BPM portion is shown on the right) . A BPM has four electrodes that couple to the beam through the image charge produced by the beam [1].

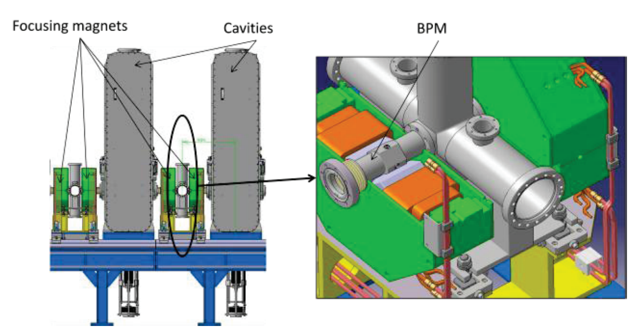

Figure 1: BPM position inside the linac.

The influence of the electrode dimensions on the signal level and harmonic content for different beams was calculated using the method described by Schulte [2]. The BPM electrodes are considered as capacitors that are

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charged by the beam and discharged through a resistor connected to ground.

BPM diameter and length are respectively equal 48mm and 39mm respectively. Each electrode has an angular coverage of 63 degrees.

BPM REALIZATION

SPIRAL2 will be equipped with 20 BPM. As consequence the equipment to be supplied consists of 23 BPMs: one prototype, two pre-series planned for a test bench to commission the RFQ and will be considered later as spares and 20 to be put on operation. Each BPM has four electrodes and each electrode is composed of a feed-through and capacitance as shown in Figure 2.

Figure 2: Feed-through (left), BPM block(right) and BPM.

BPM realization is divided into three steps:

Feed-Through Realization

Our industrial partner CoorsTek* is in charge of BPM fabrication, it delivered 110 feed-through that were tested.

The testing first verifies feed-through isolation then measures its capacitance and TDR* response and finally matches four feed-through to form a single BPM. Four feed-through are matched if the difference between there capacitances is less than 0.1pF and their TDR responses are identical.

The 110 feed-through delivered by CoorsTek had capacitances measuring 1.35pF with a margin of ±0.05pF.

Therefore, feed-through matching only takes account of their TDR response.

BPM Realization

Once the needed feed-through matched, they were sent back to CoorsTek for BPM block realization.

Twenty BPM blocks were delivered by CoorsTek, their isolation was verified, and their capacitance were measured and verified to be within ±0.2pF per block. The TDR responses of each block were verified as well: An example is illustrated in Figure 3.

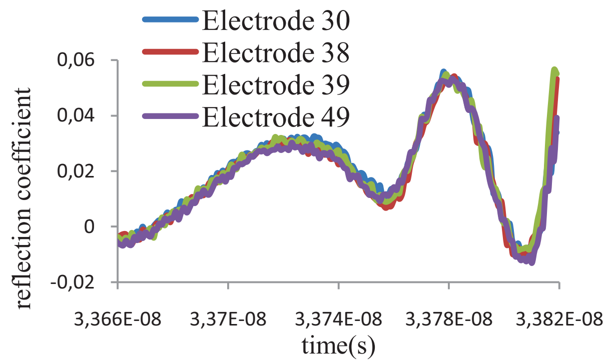

Figure 3: BPM block TDR responses (zooming at feed-through location).

Each block is again sent back to CoorsTek for final integration in the BPM.

BPM CALIBRATION

Due to different speeds of the beam particle, expected signals at each electrode have different shapes along the LINAC: As shown in Figure 4 , low β beams mainly induce fundamental tone signals at the electrodes output and more energetic beams with β up to 0.2 induce signals with harmonic tones as well. To manage different β values, the generator sends signals at two different tones: the fundamental frequency (88.0525MHz) and its first harmonic (176.0525MHz). Processing higher tones is abandoned.

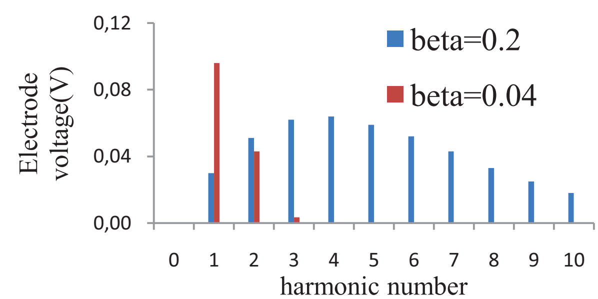

Figure 4: Electrode voltage FFT at different beta beams.

Thanks to BPM calibration, two main parameters are measured: BPM sensitivity and the displacement between mechanical and electrical centres of the BPM.

To achieve these goals, the BPM is mounted inside the automated test bench shown in Figure 5. The BPM is mounted onto an automated XY table that moves the sensor into a predefined point with coordinates (X, Y). The signal generator continuously sends a signal along a copper wire inside the BPM. The copper wire could have a circular or elliptical shape and it simulates the beam at β=1. At each position, the power received by each electrode is measured by the probes and the power meters, the measurements are then saved sequentially into appropriate files.

*CoorsTek: www.coorstek.com
*TDR: Time Domain Reflectometry

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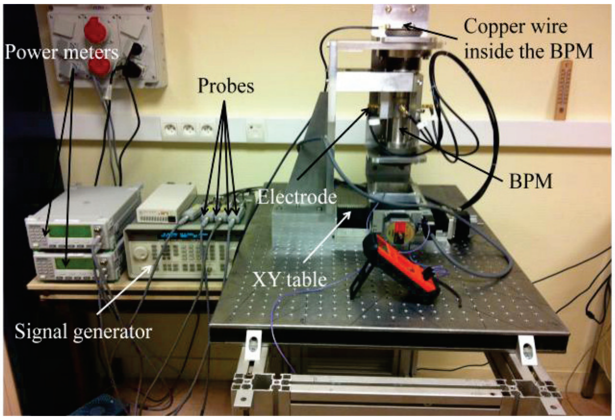

Figure 5: BPM automated test bench.

The following steps are performed:

BPM Mechanical Centre Measurement

The cable inside the BPM has a fixed position. The XY table moves the BPM on four predefined axes until the cable touches the BPM boundaries.

The four positions measured are then combined to find the BPM mechanical centre coordinates X_m and Y_m with a precision less than 20µm.

BPM Electrical Centre Measurement

The cable is placed at the BPM mechanical centre position; the power received by each electrode is then measured. These powers are combined to find BPM electrical center coordinates X_e and Y_e.

Cables between BPM feed-throughs and probes induce differences in magnitude and phase between measured voltages at BPM electrodes. To annihilate these additional differences, measurement is performed at four different cable configurations: for a given electrode, the received signal is measured using a different cable at each configuration, therefore, four power measurements are performed and averaged.

X_e and Y_e are computed in mm using Eq. 1 and Eq. 2:

$$X_e = X_m + \frac{P(Elec3) - P(Elec1)}{Sc}. \quad (1)$$

$$Y_e = Y_m + \frac{P(Elec4) - P(Elec2)}{Sc}. \quad (2)$$

P is the power received by each electrode and Sc is the BPM sensitivity to beam displacements at the BPM electrical centre. After a couple of iterations, Sc is found to be equal to 1.36dB/mm at fundamental frequency and 1.41dB/mm at the first harmonic.

BPM Sensitivity Measurement

Once the BPM electrical centre is measured, two sweeps of the XY table (one is horizontal and the other is vertical) are performed and the powers received by each electrode are recorded. These sweeps are over a range of 40mm with a step of 0.5mm. The goal out of these sweeps is to measure BPM sensitivity for off centered beams.

The same technique mentioned above is used to annihilate differences in cables attenuation and phasing.

BPM sensitivities at a given point (X, Y) are computed using Eq. 3 and Eq. 4:

$$S_x(X,0) = \frac{P(Elec3) - P(Elec1)}{X - X_e}. \quad (3)$$

$$S_y(0,Y) = \frac{P(Elec4) - P(Elec2)}{Y - Y_e}. \quad (4)$$

This measurement is performed at the fundamental frequency and its first harmonic.

BPM Mapping

BPM mapping aims to measure the difference between theoretical and measured wire positions. Beam measured position coordinates X_b and Y_b are computed in mm using Eq. 5 and Eq. 6:

$$X_b = X_e + \frac{P(Elec3) - P(Elec1)}{S_x(X,0)}. \quad (5)$$

$$Y_b = Y_e + \frac{P(Elec4) - P(Elec2)}{S_y(0,Y)}. \quad (6)$$

The XY table follows the predefined map shown in blue in Figure 6 (distance between adjacent dots is 0.5mm).

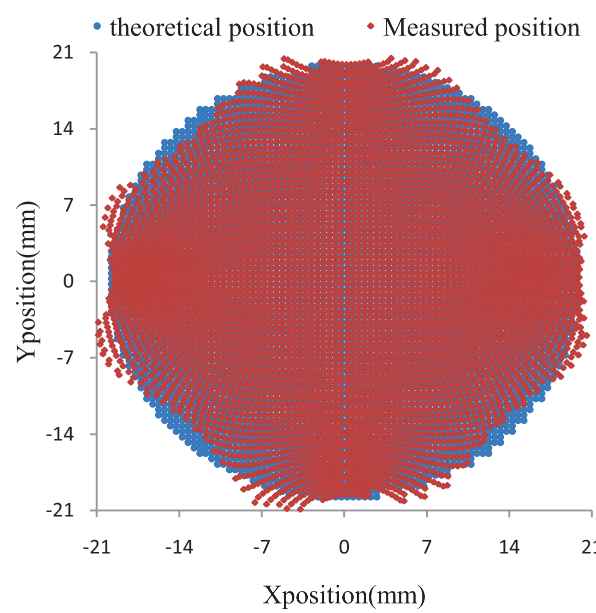

Figure 6: Example of BPM mapping at 88.0525MHz.

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Figure 6 shows good agreement between theoretical and measured position around BPM centre. This agreement is distorted at BPM boundaries because of the approximation in the sensitivities S_x and S_y

BPM Quadrupole Moment Measurement

Estimation of beam shape is based on the computation of σ_x^2-σ_y^2 that uses the following formula given by R.H.Miller [2]

$$\sigma_x^2 - \sigma_y^2 = \frac{1}{K}\frac{V_1 - V_2 + V_3 - V_4}{V_1 + V_2 + V_3 + V_4} - X_b^{\ 2} + Y_b^{\ 2}$$

Where σ_x and σ_y are the beam rms half widths in the x and y directions, X_b and Y_b are beam position coordinates regarding its electrical centre and V_1, V_2, V_3 and V_4 are the sensing electrodes voltages.

The parameter K depends on beam velocity β, BPM radius and the electrode angular coverage. For β=1, K=0.0028mm^{-2}.

Two different copper wires were used to check Miller's formula: A cylindrical wire with diameter of 5mm and an elliptically shaped wire with major axe length of 5mm and minor axe length of 3mm. The two wires were mounted at the BPM electrical centre. 2mm sweeps (horizontal and vertical) were performed around the BPM electrical centre, the ratio at the left of Miller's formula was measured and the difference σ_x^2-σ_y^2 was deduced. As shown in Figure 7, σ_x^2-σ_y^2 is close to 0 for circular shaped cable and around 2 for elliptical shaped cable.

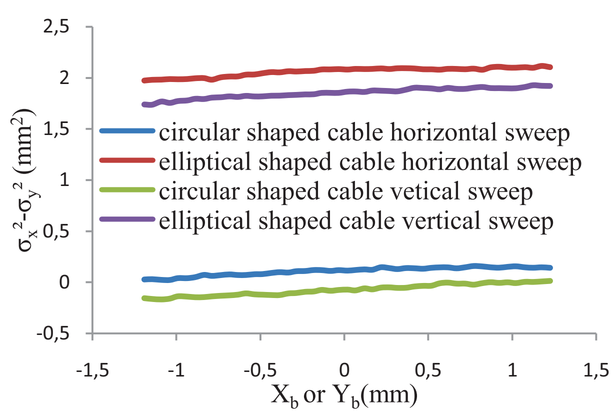

Figure 7: σx^2-σy^2 for different beam positions.

The factor K is expected to be stronger for low beta beams, exhaustive studies shows K=0.0051mm^{-2} at β=0.04.

BPM ACQUISITION CARD

Each BPM is supplied with an electronic acquisition module. The module processes fundamental frequency or the first harmonic tones contained in the signals delivered by BPM electrodes in order to deliver beam position, shape, energy and phase. It also warns the operator if the beam is 5mm close to BPM boundaries.

The design of the BPM is done in collaboration with our partner BARC*. The BPM module, shown in Figure 8, consists of an analogue board and a digital board. The design of the BPM module is based on the scheme of auto-gain equalization using offset tone. In this scheme the gain of different channels is equalized with respect to the injected offset tone. The scheme consists of digitally generating an amplitude and phase stable calibration tone having frequency slightly offset from the RF Reference. This calibration tone is added to each of the 4 incoming sensor signals. Each combined signal is then passed through respective analogue channel, which essentially incorporates the functionality of programmable amplification and selectable band-pass filtering. The amplification/attenuation is identically set for all the four analogue channels.

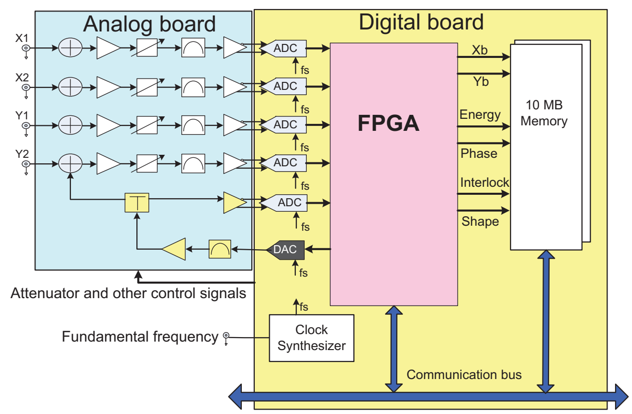

Figure 8: BPM acquisition module.

These conditioned signals (four electrodes, one selected reference and one calibration tone) are digitized by respective ADCs on the digital board. The digitized data from the ADCs is sent to FPGA for calculation of output parameters. The results are also stored in a local memory for analysis and diagnostic purposes. Two DACs are kept for diagnostic purposes for viewing the variables in the signal path. A clock synthesizer generates the sampling clock for ADCs, DACs and FPGA using the 88.0525 MHz reference signal. The system has provision for digital input and output signals on the front panel for interfacing to the external world or to be used during testing and debugging.

CONCLUSION

SPIRAL2 BPM measurements show a good agreement to expected sensitivity and quadrupole moment. The next step is to realize and test the BPM acquisition card.

REFERENCES

[1] P. Ausset and al "Beam diagnostics for the SPIRAL2 accelerator, SPIRAL2 week, Jan 2011, Caen, France.
[2] J.Bosser, "Beam instrumentation", CERN Editions, CERN-PE-ED-001-92.
[3] R.H. Miller and al., "Nonintercepting emittance monitor" 12th Int. Conf. on high-energy accelerators. Fermi Nat Accelerator Lab, 11-16 Aug 1983.

*BARC: Bhabha Atomic Research Centre www.barc.ernet.in

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