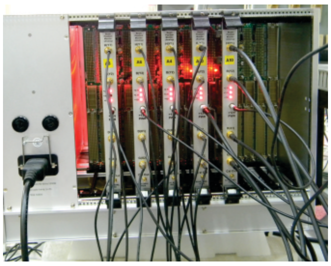
किरणपुंज स्थिति अनुवीक्षक

4

जीएएनआईएल, फ्रांस में SPIRAL2 के रैखिक त्वरक हेतु कणपुंज स्थिति अनुवीक्षक इलेक्ट्रॉनिक्स प्रणाली का विकास एवं अधिचालन

गोपाल जोशी, *परेश डी. मोतीवाला, संदीप भराडे, जी.डी. रंदाले, आलोक आगाशे, पी. ज्योथि और श्याम मोहन
त्वरक नियंत्रण प्रभाग, भाभा परमाणु अनुसंधान केंद्र (भापअ केंद्र), ट्रांबे-400085, भारत



VME64 चेसीस में पांच बीपीएम मॉड्यूल

सारांश

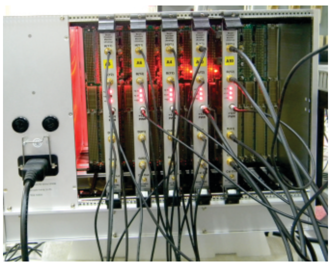
भापअ केंद्र-टीआईएफआर और जीएएनआईएल के बीच "नाभिकीय भौतिकी, अनुसंधान और विकास सहयोग" हेतु समझौता ज्ञापन और भारतीय एवं फ्रांसीसी वैज्ञानिक संस्थानों के बीच संबद्ध अंतर्राष्ट्रीय प्रयोगशाला (एलआईए) अनुबंध के तहत त्वरक नियंत्रण प्रभाग (एसीएनडी), भापअ केंद्र में किरणपुंज स्थिति अनुवीक्षक (बीपीएम) इलेक्ट्रॉनिक्स और नियंत्रण का अभिकल्पन और विकास किया गया। प्रोटोटाइपिंग और परीक्षण के बाद, 20 बीपीएम इलेक्ट्रॉनिक सिस्टम बनाए गए और जीएएनआईएल, फ्रांस में SPIRAL2 के रैखिक त्वरक (लिनाक) में कमिशनन किया गया। बीपीएम प्रणाली न केवल बीम की स्थिति का मापन करती है, बल्कि त्वरक के प्रचालन के दौरान कणपुंज रेखा के चरण, आकार और तीव्रता का भी मापन करती है, SPIRAL2 एक उच्च तीव्रता वाला कण त्वरक है, जो दिसंबर 2021 से जीएएनआईएल में कमीशन हुआ और प्रचालनरत है।

Beam Position Monitor

4

Development & Commissioning of Beam Position Monitor Electronics Systems for LINAC of SPIRAL2 at GANIL, France

Gopal Joshi, *Paresh D. Motiwala, Sandeep Bharade, G. D. Randale, Alok Agashe, P. Jyothi and Shyam Mohan
Accelerator Control Division, Bhabha Atomic Research Centre (BARC), Trombay-400085, INDIA



Five BPM modules in a VME64 chassis

ABSTRACT

Design and development of Beam Position Monitor (BPM) electronics and control was carried out at Accelerator Control Division (ACnD), BARC under the MOU between BARC-TIFR and GANIL for “Nuclear Physics, Research and Development Co-operation” and Associated International Laboratory (LIA) agreement between Indian and French scientific Institutes. Subsequent to prototyping and testing, 20 BPM electronic systems were fabricated and commissioned in the LINAC of SPIRAL2 at GANIL, France. BPM system performs the measurement of not only beam position, but also phase, shape and intensity of the beam line during the operation of the accelerator. SPIRAL2 is a high intensity particle accelerator commissioned and operational at GANIL since Dec 2021.

KEYWORDS: *Beam position monitor, Beam diagnostics, Auto-gain equalization.*

**Author for Correspondence: Paresh D. Motiwala
E-mail: parmot@barc.gov.in*

Introduction

The LINAC of SPIRAL2 at GANIL, France uses non-intrusive, capacitive type Beam Position sensors and the related electronics. Accurate tuning of the LINAC is essential for the operation of SPIRAL2 and requires measurement of various vital beam parameters such as beam transverse (X-Y) position, phase of the beam with respect to the RF Reference, beam ellipticity, beam energy etc. with high precision and accuracy. BPM systems are being used for this purpose.

A BPM system typically consists of a sensor and associated electronics for processing these signals. BPM electronics system based on digital implementation incorporating a novel implementation of 'Auto-Gain Equalization' technique has been developed. It carries out measurement of various beam parameters over a wide dynamic range of beam current.

The electronics system has been designed, developed and commissioned at SPIRAL2 by ACnD, BARC jointly with GANIL team. The system performs processing at both the fundamental (88 MHz) and the first harmonic (176 MHZ). This article briefly discusses the system architecture, specifications and features of the BPM electronic system and results.

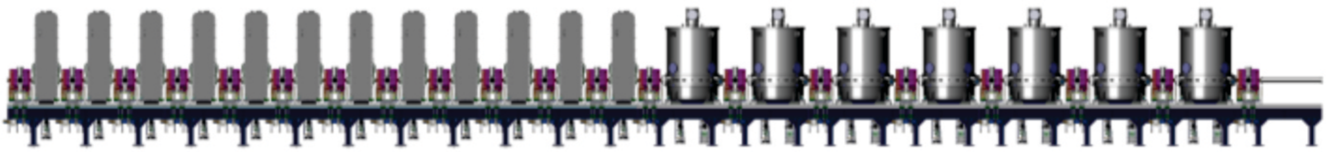
The Beam Position Monitor (BPM) System

SPIRAL2 at GANIL is a high intensity particle accelerator. The LINAC of SPIRAL2 is designed to accelerate 5 mA deuteron beams up to 40 MeV, proton beams up to 33 MeV and 1mA light and heavy ions up to 14.5 MeV/A. The LINAC is composed of two types of cryomodules, A and B for lower and higher energy sections, respectively. All the cavities of the LINAC operate at RF reference of 88.0525 MHz. There are twelve cryomodules of the type A and seven of type B as shown in Fig.1 [1]. One BPM sensor is placed before and after each of the cryomodules, making the total no. as twenty.

Each BPM system consists of a sensor portion and the signal readout & processing electronic module. Each BPM sensor consists of four electrode sensors that transduce the beam electromagnetic image into electrical signals. The electronics associated to each BPM sensor processes the electrical signals and enables the measurement of beam transverse position, phase, energy and transverse beam ellipticity.

The BPM electronic modules commissioned at SPIRAL2 LINAC are required to have the capability to perform the measurements using either the beam induced signal at fundamental frequency 88.052500 MHz (F) or at the first harmonic 176.1050 MHz (2F). Block diagram for the measurement principle is shown in Fig.2 [1]. The electronic processing system performs following measurements:

- Amplitude and phase w.r.t. the RF Reference.
- Amplitude and phase of the vector sum of the 4 electrode voltages of each BPM sensor.
- Phase shift between the vector sum of the four electrode voltages and the RF Reference frequency at, F and 2F.
- Horizontal and Vertical beam positions.
- Ellipticity of the beam.



Courtesy GANIL, France

Fig.1: Layout of the 19 Cryomodules in LINAC of SPIRAL2 (12 of type A and 7 of type B).

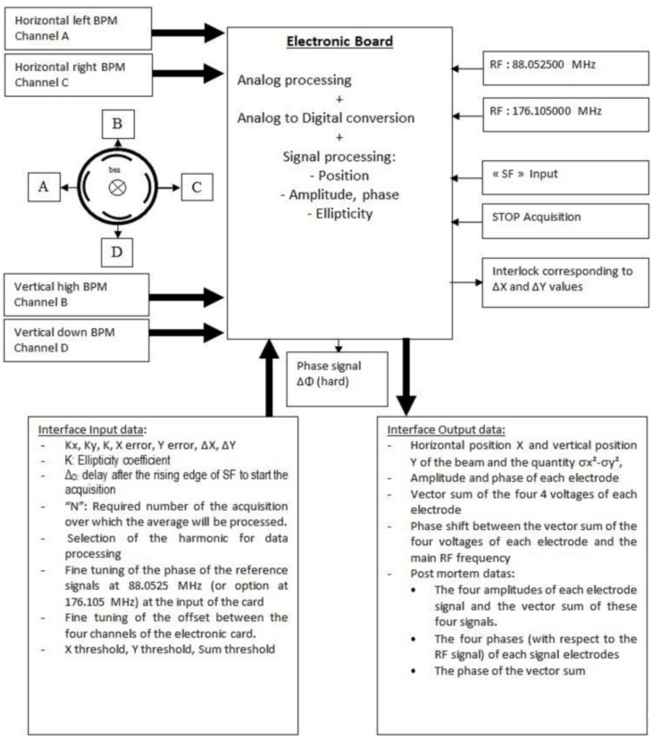


Fig.2: BPM measurement Principle.

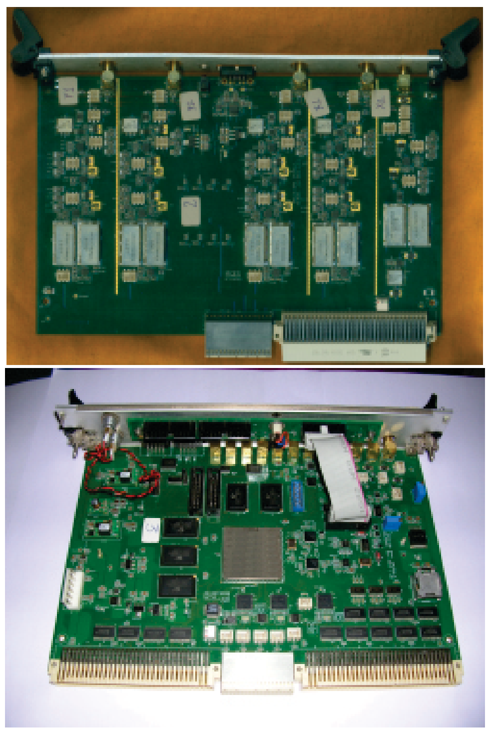


Fig.3: Analog and Digital boards comprise of one BPM electronic system.

Table 1: BPM measurement Specifications.

Parameter		
Position	± 50µm	Over ± 10 mm
Accuracy	± 150µm	Over ± 20 mm
Phase	± 0.5deg	±180 deg
Ellipticity	± 20%	-
Beam current		0.15 – 5 mA

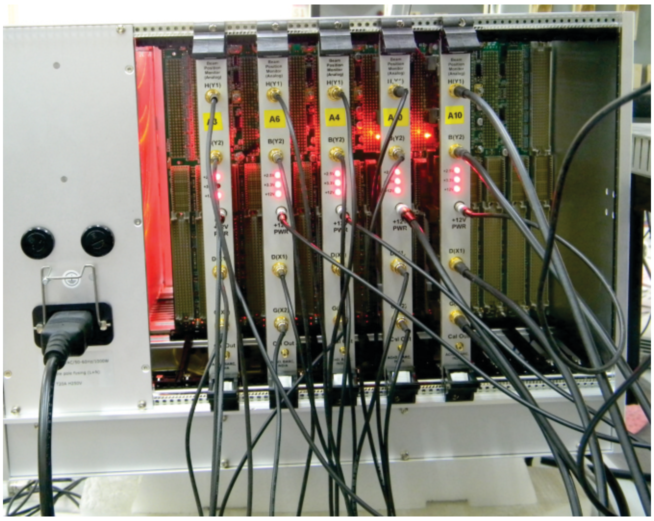


Fig.4: Five BPM modules in a VME64 chassis.

- Digital samples to reconstruct shape of the bunch from the signal received from a given electrode, over one RF Period.

General description of the BPM electronic module and sensor signal processing

The hardware of the BPM electronics system consists of a pair of VME64 based Analog and Digital boards (See Fig.3). The analog front end board conditions incoming signal from the sensors. The digital board consisting of high speed ADCs, DACs, FPGA and other devices, and processes the digitized signal and controls the overall operation of the module.

Each BPM sensor feeds an electronic module through eighty meter long coaxial cables. The electronic design is based on the novel scheme of auto-gain equalization using offset tone. The electronic module is able to work either at F or 2F frequencies to deliver the required measures. In this scheme the gain of different channels is equalized with respect to the internally generated and stabilized offset tone. This offset tone is added to each of the four incoming signals from BPM sensor and variation in the four channels compensated. The scheme of equalization is also effective in compensating the drift due temperature and ageing.

As far as electronic processing is concerned, the accuracy of position measurement is dependent on the ability to equalize the gain of the four channels. The various calculations are to be performed in the FPGA taking care that the addition of noise due to finite precision is kept low enough such that it does not degrade the signal to noise ratio significantly.

Regarding the phase measurement- the phases of both the RF reference and the electrode signals are measured with respect to a common reference signal. Even though the phase of either of these signals change, depending on the phase of

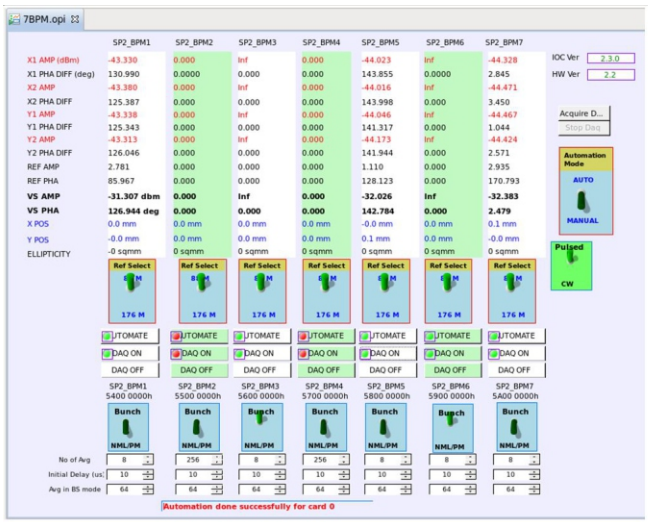


Fig.5: Command control application screen for control of 7 BPM systems.

the common reference, the difference of phase between the measured signal and the selected RF reference remains unambiguous. Fig.4 shows a VME64 chassis holding five BPM electronic modules. Fig.5 shows screen shot of the front end software application developed using EPICS platform supporting 7 BPM modules.

BPM data acquisition modes

The BPM system supports extensive data acquisition schemes viz; Normal, Post mortem & Bunch shape reconstruction for diagnostic as well as during the system operation. The Normal mode of acquisition makes available various beam parameter measures at the rate of 1 kHz to the command control via the EPICS IOC. In the Post mortem mode data acquisition is very useful in case of system malfunction. A unique acquisition mode for reconstruction of the beam bunch shape has been incorporated in the system. The BPM system is able to deliver the pulse shape of the beam bunch over one RF period (11.356 ns) by acquiring 256 samples in 345 clock cycles resulting into an effective sampling rate of 44.36 ps. These samples are arranged in the software to form one period of the bunch shape which is as narrow as 11.356 ns. See Fig.13.

BPM Tests on the SPIRAL2 Intermediate Test Bench (ITB)

Before characterizing the BPM system in the "Intermediate Tests Bench" (ITB) assembled at GANIL, the BPM

Fig.6: BPM characterization test bench at ACnD, BARC.

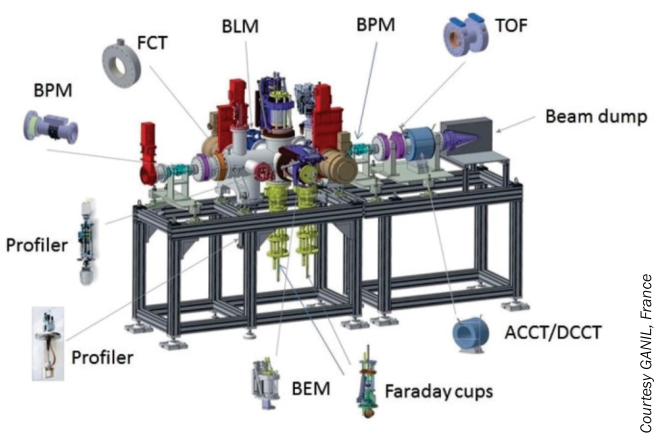


Fig.7: ITB at GAINL for testing various beam diagnostic equipment including BPM.

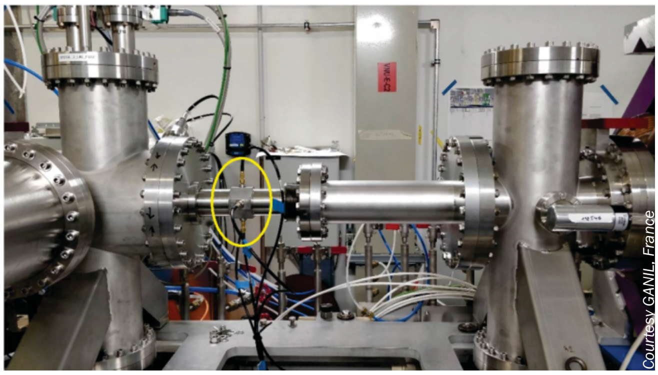


Fig.8: BPM sensor installed in MEBT line.

electronic was tested using precision test bench at ACnD. Fig.6 shows the characterization test bench having a resolution better than 25 μm. The BPM system was subsequently installed with the ITB at GANIL as a part of the injector commissioning plan. The aim of the ITB was to fully characterize the properties of the beam accelerated by the RFQ and also to study the behaviour of the diagnostic elements including the BPM developed at ACnD, BARC. All kinds of measurements were carried out; beam intensity, transverse beam position, profiles and emittance, phase and longitudinal emittance with a beam energy equal to 750KeV/A. Control command operation gathered the measurements performed by all these diagnostics almost on real time (every 200ms). Fig.7 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 is working properly. The dynamic range was observed to be 75μA - 5.5mA at 88MHz and 60μA – 5.5mA at 176MHz.

BPM phase measurement

The phase relative to the accelerating RF signal has been measured simultaneously by the BPM and by one of the three

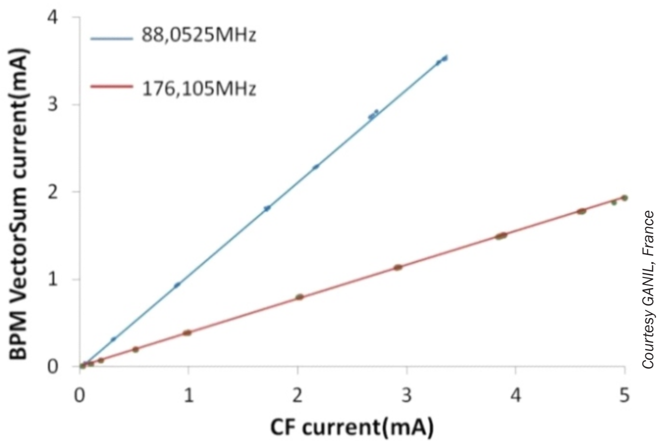


Fig.9: Beam current dynamic range.

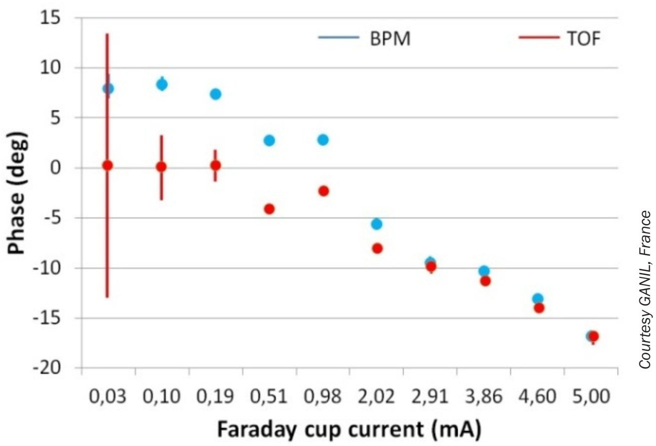


Fig.10: Beam phase measurement by a BPM and TOF probe at 88.0525MHz.

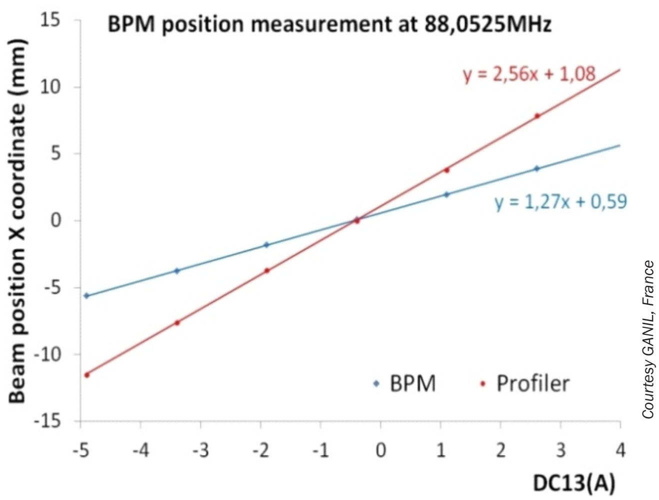


Fig.11: Beam position measurement at 88.0525MHz using BPM and beam profiler.

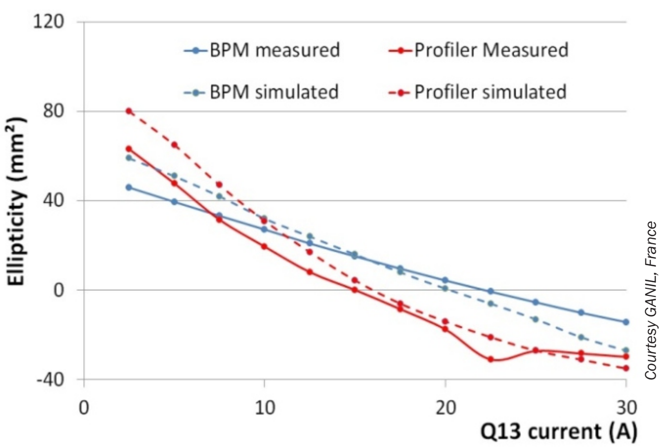


Fig.12: beam ellipticity measurement at 88.0525MHz.

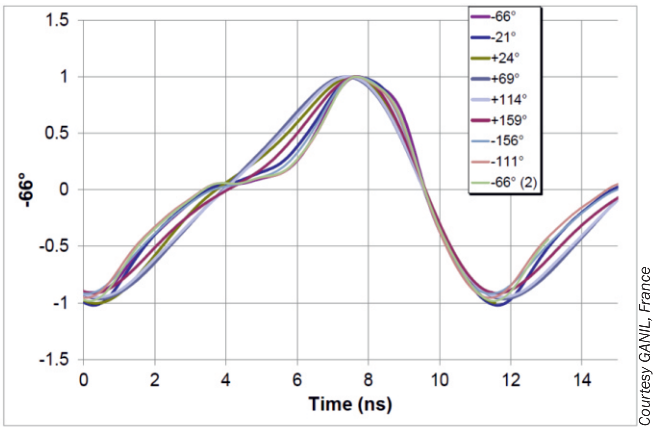


Fig.13: Reconstructed bunch shape construction at different phases for 1mA beam current.

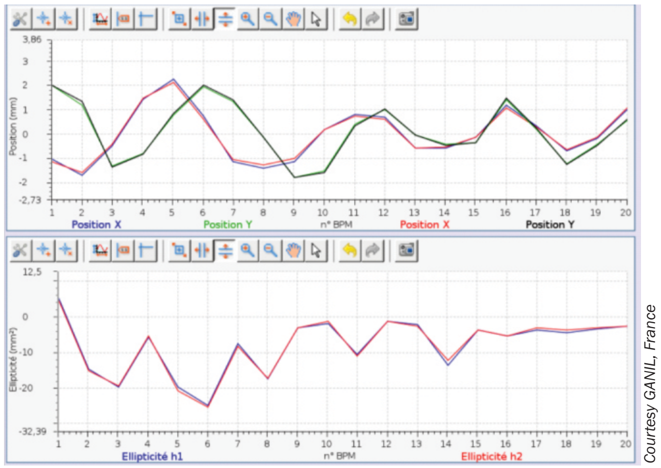


Fig.14: Beam position and ellipticity measurements by 20 BPM system.

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 2F whereas the TOF is only measuring it at F. The results showed a proper behaviour and a good agreement with the electrode of the TOF system over the measured beam current dynamic range.

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 2F have been compared to the profiler measurements (frequency independent). It was observed that the response of the BPM over the required range was satisfactory. The BPM position sensitivity remains roughly constant over the current dynamic range.

Fig.15: 8 of the 20 BPM modules at SPIRAL2 LINAC tunnel.

BPM Ellipticity measurement

The linear behaviour of the BPM ellipticity was confirmed by the measurement at 88MHz and 176MHz.

Software Command Control

The command control application has been developed using the EPICS DAQ platform. The system adheres to SPIRAL2 command control architecture. The EPICS device support, record support and bpm custom record have been implemented such that one IOC supports 7 BPM systems per each VME chassis.

BPM Operation Results

The BPM systems are in regular operation in the SPIRAL2 LINAC. The performance of all the 20 BPM systems for a proton beam of 4.1mA, energy 31.9MeV and power 10kW is shown Fig.14.

Conclusion

The BPM electronic system designed at ACnD, BARC have undergone extensive testing in the lab and then at SPIRAL2 facility. Before commissioning 20 BPM systems at GANIL it has undergone 2-3 phases of prototyping. Various performance related parameters such as RMS noise, cross coupling, linearity, dynamic range, calibration constants, etc. have been measured / computed to ascertain system performance. The fabrication of multi-layer PCBs and assembly of SMD components during the prototyping and delivery phases were done using internationally accepted standards by an Indian MSME firm.

The team at GANIL has been very helpful during the prototyping and commissioning phases. They facilitated testing by collecting enormous amount of data, processing and presenting in suitably in reports. This has helped us to improve the performance of the system. The 20 BPM systems are currently operational in the LINAC of SPIRAL2 and enabling smooth operation of the accelerator.

Acknowledgment

It is a pleasure to acknowledge the constant support of all the colleagues from ACnD, the SPIRAL2 team and the IPNO team during prototyping, testing and commissioning of the BPM systems.

References

[1] “Technical Specifications of the Electronics for the BPM of the SPIRAL2 LINAC”, SPIRAL2 document 'SP2_CC_8234_lo18118V1.0, SPIRAL2, GANIL.

[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] M. Ben abdillah et al., “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.

[4] P.Ausset et al., “Development of the Beam Position Monitors system for the LINAC of SPIRAL2”, in Proc. 2nd Int. Beam Instrumentation Conf. (IBIC'13), Oxford, UK, Sep 2013, paper WEPC15, pp. 702-705.

[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.

[6] P.D. Motiwala et al., “Beam Position Monitoring System for LEHIPA”, in InPAC-2015, Dec-2015, TIFR, Mumbai.

[7] P. Ausset et al., “OPERATION OF THE BEAM POSITION MONITOR FOR THE SPIRAL2 LINAC ON THE TEST BENCH OF THE RFQ”, International Beam Instrumentation Conference (IBIC) 2016, Barcelona, Spain

[8] G.D. Randale et al., “Performance analysis of BPM electronics for SPIRAL2, GANIL, FRANCE”, InPAC 2019, Nov 18-21 2019, IUAC, New Delhi.