New BPMs for the CERN L3 to LEIR transfer line

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Abstract

The injection line into the CERN Low Energy Ion Ring (LEIR) has recently been equipped with nine, new, electrostatic Beam Position Monitors (BPMs) in order to measure and optimize the trajectory of the low intensity ion beams coming from LINAC3. In this paper, we describe the design of the BPM, the low noise charge amplifier mounted directly on the BPM, and the digital acquisition system. There is special emphasis on the first commissioning results where the measured beam positions were perturbed by EMI and charging of the BPM electrodes by secondary particles. The effect of mitigation measures, including repelling voltages on the electrodes and external magnetic fields, are also discussed.

INTRODUCTION

The CERN Linac3 provides heavy ions, mainly PB^{53+}, at an energy of 4.2MeV/u to the Low Energy Ion Ring (LEIR). Here the ions (pulses of up to 30uA, 200us) are accelerated to 72MeV/u, extracted to the PS and further to the SPS where the fully stripped ions are either extracted to the LHC for proton - ion collisions or fixed target physics in SPS. In order to optimize the injection efficiency into LEIR the transfer line between L3 and LEIR has been equipped with nine highly sensitive electrostatic BPMs (Figure 1).

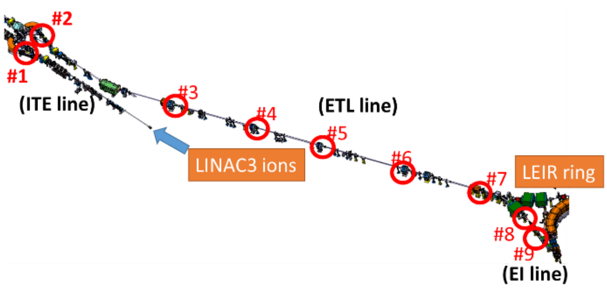

Figure 1: L3 to LEIR transfer line BPM layout

BPM DESIGN

Table 1 below summarises the BPM system specifications.

Table 1: BPM specifications

Parameter	**Value**	**Comment**
Accuracy	0.5mm	-
Resolution	0.2mm	For 4uA current
Time resolution	5us	Along 200us pulse
Max. Beam displ.	±15 mm	-
Max beam current	40uA	-
Nb. of injections	1-13	Every 100-200ms

The BPMs are of the dual plane electrostatic type with an aperture of 196mm and a length of 200mm. The azimuthal width of the electrodes is 75^0 and the distance to ground is 21.5mm. The ~20pF electrodes are connected to high impedance charge amplifiers mounted directly onto the BPM body, via 75-ohm cables, see Figure 2. The transfer impedance is about 30ohms yielding an electrode signal of ~0.1mV for a centred beam. All parts are of 316 LN stainless steel.

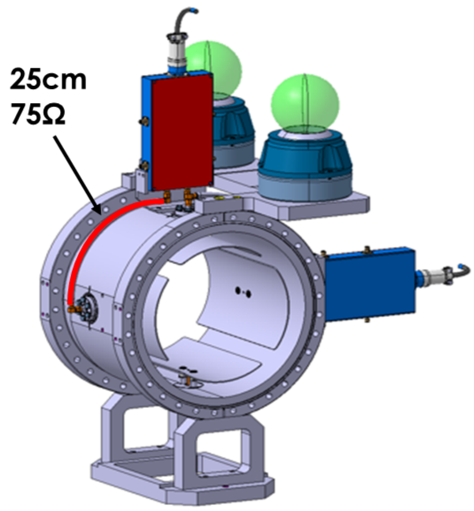

Figure 2: 3D model of the BPM

ACQUISITION SYSTEM

Electronics

The input stage of the front-end electronics mounted directly on the BPMs is a charge amplifier. Gain calibration is done by injecting a known charge into each input through a low value calibration capacitor (1pF). After charge amplification, sum and difference amplifier stages generates the sigma (3e12 V/C gain) and delta (6e12 V/C gain) signals respectively. The -3dB bandwidth is 60Hz to 2MHz. A more detailed description of the head amplifier can be found in [1]. Coaxial cables transmits the signals to the control room where commercial 8channel, 14 bits ADC samples the signals with a rate of 6MS/s.

Front-end software: FESA

The Front-End Software Architecture (FESA) is a framework used at CERN to design, develop, test and deploy real-time control software, written in C++. It is used to provide software control and monitoring of this instrument: acquisition triggers, data read-out and processing, calibration.

For each cycle of 2.4 or 3.6 second, depending on the configuration, the FESA class prepares the ADCs, and then start acquiring 200 us before each LEIR injection. Around 650 us of signal is acquired: 4096 samples at a sampling rate of 6.125 MHz and read out 10 ms after each injection trigger. We published these data in the FESA interface, which integrates easily with standard tools such as steering process GUI or logging to long-term database.

As the acquisition system is linear, positions are computed using a simple scaling of delta/sigma ratio of electrodes signal. Various algorithms are available to provide instantaneous or average positions. In particular using the ratio of the edges at the end of the pulse, which proved to be the most robust against baseline drifts due to secondary particles.

BEAM MEASUREMENTS

The installation of the two first BPMs in the ITE line took place in the beginning of 2017 and tested during 2017 with Ar^{11+} beams. The remaining seven BPMs were installed in beginning of 2018 and all nine BPMs now sees the nominal Pb^{53+} beam. The signals was from first beams perturbed by EMI from the nearby quadrupoles as well as low energy secondary particles hitting the electrodes.

EMI from quadrupoles

Figure 3 shows the perturbation of the baseline close to the beam passage. The cause of this perturbation is due to a nearby-pulsed quadrupole and ground currents running on the screen of the coaxial input cables to the front-end amplifiers. By adding high mu toroidal cores around these cables, this interference was completely supressed.

Secondary particles

Even though at the location of the first two BPMs the aperture of the up and down stream vacuum chambers are only 100mm compared to the BPM aperture of 196mm the electrode signals of BPM1 were completely saturated while BPM2 showed similar charging effect without being saturated. See Figure 3, which also shows the baseline distortion before and after the beam.

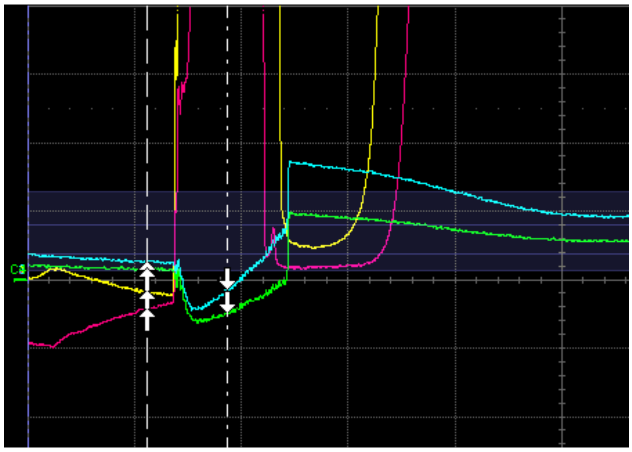

Figure 3: Horizontal and vertical sum signals from first two BPMs in the ITE line. Yellow /Blue: BPM1/BPM2 horizontal sum. Purple/Green: BPM1/BPM2 vertical sum.

Simulating a continuous negative charging of the electrodes along the beam pulse as shown Figure 4, one obtains a result similar what observed on BPM2 (e.g. Figure 3), indicating the presence of secondary low energy electrons hitting the electrodes

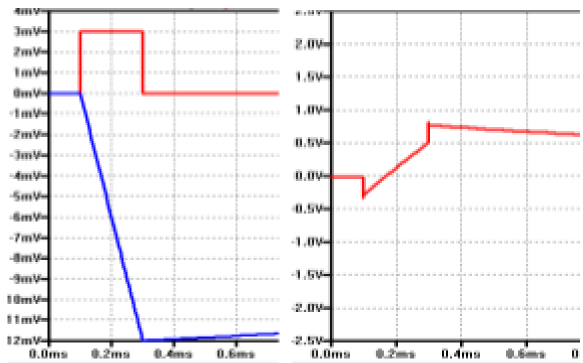

Figure 4: Left: Square 200us beam pulse (red) and continuously charging by electrons (blue). Right: Result of summation of the two signals and amplification.

Clearing potential on electrodes

Suspecting secondary electrons either from ionisation of the rest gas or desorption from the vacuum chamber the front-end electronics was modified to enable adding a repelling voltage on each electrode. This improved significantly the quality of the observed signals, Figure 5. When scanning the clearing voltages, it is possible to find an almost perfect response from the primary beam pulse close to -4V. Increasing further the voltage results in positive charging (amplifier response is inversed) of the electrodes, which we believe is due to ions from the rest gas ionisation being attracted. Unfortunately, a clearing potential of say -4V for a given BPM showed out not to be sufficient, due to changing beam conditions, e.g. position and RF settings. In addition, this "optimum" at e.g. -4V is an equilibrium between electrons and ions, which is not the same for each electrode.

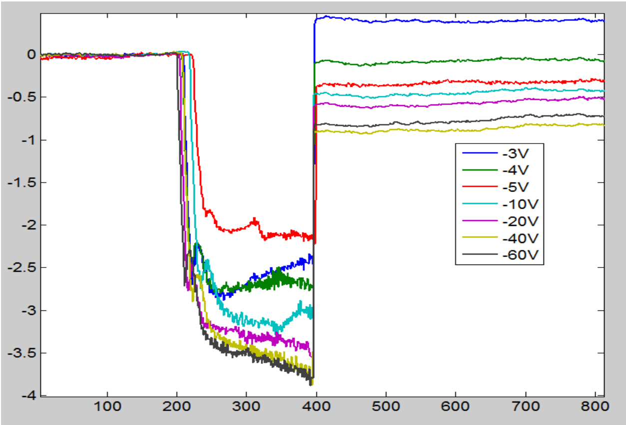

Figure 5: Electrode charging as function of clearing voltage

Solenoids and dipoles

A series of iterations with simulations (see later) and installations of low field solenoids and dipoles around or close to the BPMs confirmed the presence of secondary electrons (<100eV) generated close to the BPM. At present, all the BPMs have been equipped with solenoids as indicated on Figure 7, and the combination with an electrode potential of -5V gives decent results. Using the signal step at the end of the beam pulse (Figure 6) for both sum and difference signals it is possible to give one beam position number, but measurements along the pulse is not possible because the charging profile is unknown.

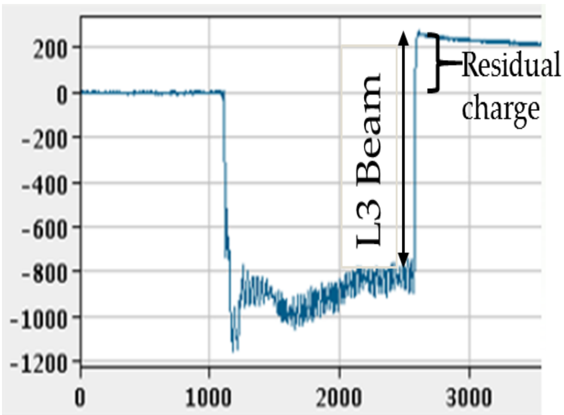

Figure 6: Sum signal from one BPM with a residual charge caused by electrons.

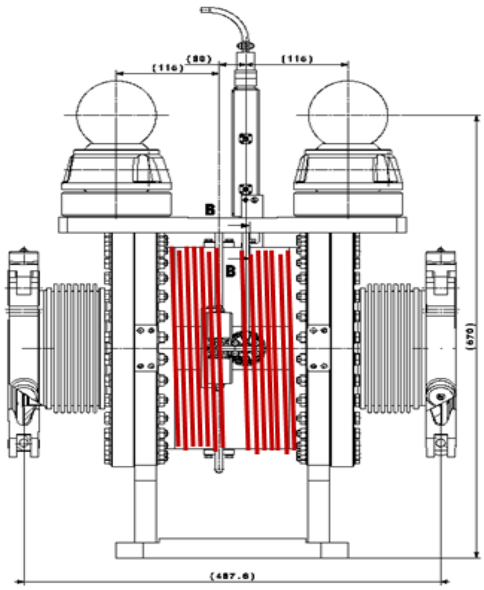

Figure 7: BPM with solenoid

SIMULATIONS

In order to understand the source of the secondary particles and how the suppression schemes work, simulations have been performed. Using the code IBSIMU [2], a simplified geometry is constructed, including the vacuum chamber and the four separated electrodes of the BPM, which can be electrically biased, and magnetic fields generated by solenoids or dipoles are imported into the simulation.

Secondary particles are generated as either a) secondary electrons from the walls, with an energy distribution based on [3] for the creation of low energy electrons (<100eV), and b) ionized hydrogen and electrons from the center of the vacuum chamber in order to represent residual gas ionization. The total number of particles, as well as the beam density is low enough that negligible space charge fields are present; hence, the different secondary particle types can be tracked separately. For simplicity, secondary particles from the beam pipe are emitted normally to the vacuum chamber, and at +/-45 degrees to the wall normal.

Images of the tracked secondary particles are shown in Figure 8, for a solenoid field of 0.6mT and an electrode bias voltage of -5V. In such a configuration, we see that only a small number of wall-emitted electrons can strike the electrodes, whereas a higher fraction of ions from the gas (level?) can reach the electrodes. Electrons from rest gas ionization are not shown, and do not reach the BPM electrodes.

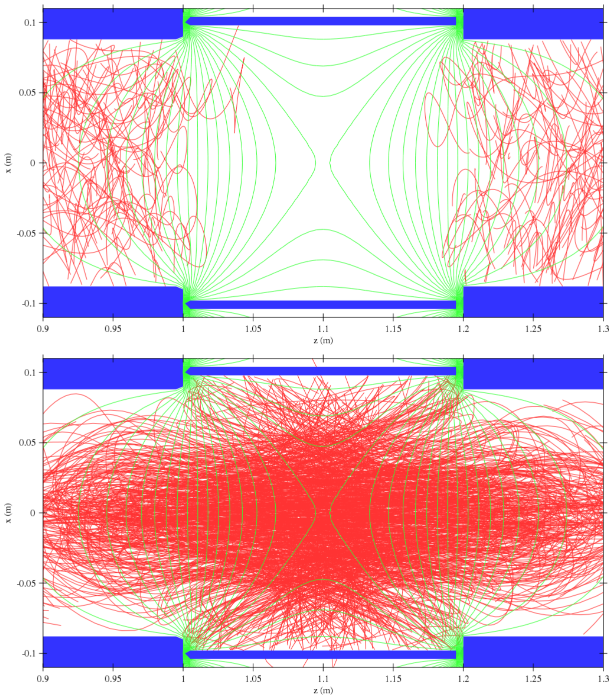

Figure 8: Secondary particle tracks in the simulation, with an applied magnet field from a solenoid, along the beam axis. Blue: Vacuum chamber and electrodes. Red: Secondary particle tracks. Green: Equipotential from electrode bias voltage. Top: Electrons emitted from the vacuum chamber walls. Bottom: Ions Generated from the gas ionization.

We expect that the production rate for secondary particles from the walls depends on local losses of a small fraction of the beam (the loss rate along the line is on average 10^{-3} per meter), and the production of gas ions depends on the local pressure (which can vary according to the line position). Therefore, at each BPM the production of secondaries from the two processes can be scaled to fit the measurements. Figure 9 shows such a comparison as a function of the applied solenoid field, which shows the shape of the collected charges function is well reproduced by the simulations. In this case the second BPM (right) is subject to three times as many secondary particles as the first (left). However, these simulations predict a fully symmetric collection of secondary particles on all four electrodes, whereas measurements can have a strong asymmetry. This asymmetry might be due to several factors (asymmetric loss pattern, influence of nearby magnetic components), it has not been possible to find magnetic, and electric field distributions that can suppress secondaries on all electrodes simultaneously in order to allow reliable beam position measurement.

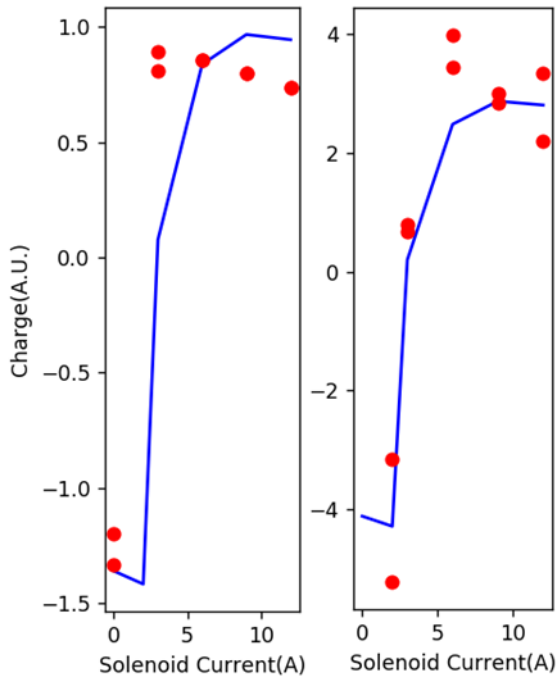

Figure 9: Collectected charge on BPM electrodes as a function of the applied solenoid current (with a peak field of 0.2mT/Ampere and electrode repelling voltage of -5V). Red dots show measurements of collected charge summed on all four electrodes, the blue line is the simulated collected charge. Left and right plots correspond to two different BPMs, based on the same simulation.

High frequency acquisition

The bunching frequency of Linac is 101.3MHz, and the beam was believed to be completely de-bunched at the end of the transfer line due to the energy spread. After having modified one of the front-end amplifiers to transmit this part of the beam spectrum, it turned out that sufficient bunching structure was still present at the last BPM before injection into LEIR. The signals in Figure 10 were obtained using an 8 bit oscilloscope running @ 500Ms/s and a Matlab script emulating a 2MHz bandpass filter and AM demodulation. Computing the position from this last BPM in the transfer line yields a resolution better than 0.5mm averaged over 5us. The signal to noise ratio is dominated by the 8-bit oscilloscope and a dedicated acquisition system is expected to perform significantly better.

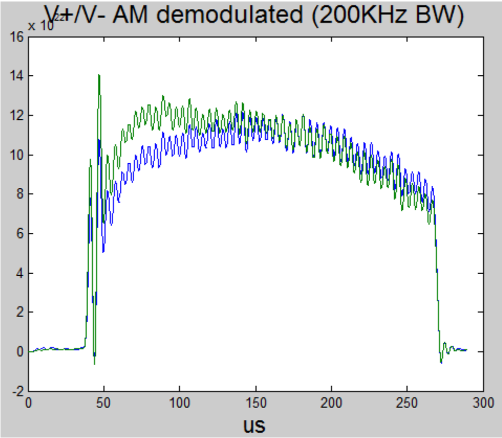

Figure 10: Electrode signals after filtering AM demodulation

CONCLUSION

Nine electrostatic BPMs were installed in the Linac3 to LEIR transfer line to measure the beam position along the line and along the beam pulse. The signals on all the BPMs but one, indicates that the BPM electrodes are charged by secondary particles, mainly electrons desorbed from the chamber walls. Different configurations of electrode polarisations and external magnetic fields significantly improves the signal quality but cannot guarantee a correct position measurement along the beam pulse. So far, only a single point measurement at the end of the pulse is reliable and used by operation.

Using the 101MHz bunching component, which is surprisingly high even at the last, BPM will enable us to comply with the requirement of beam position measurement along the pulse. This requires an upgrade of the acquisition system, which will be implemented in the CERN Long Shutdown 2 (LS2)

ACKNOWLEDGEMENTS

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