BUNCH EXTENSION MONITOR FOR LINAC OF SPIRAL2 PROJECT

R. Revenko†, J.-L. Vignet,
GANIL, Caen, France

Abstract

A semi-interceptive monitor for bunch shape measurement has been developed for the LINAC of SPIRAL2. A Bunch Extension Monitor (BEM) is based on the registration of X-rays emitted by the interaction of the beam ions with a thin tungsten wire. The time difference between detected X-rays and accelerating RF gives information about distribution of beam particles along the time axis. These monitors will be installed inside diagnostic boxes on the first five warm sections of the LINAC. The monitor consists of two parts: X-ray detector and mechanical system for positioning the tungsten wire into the beam. Emitted X-rays are registered by microchannel plates with fast readout. Signal processing is performed with constant fraction discriminators and TAC coupled with MCA. Results of bunch shape measurements obtained during commissioning of RFQ for SPIRAL2 are presented.

INTRODUCTION

Semi-interceptive beam diagnostics for measurements of longitudinal bunch profile have been designed for LINAC of SPIRAL2 [1, 2]. It will be used for measurement and control of bunch extension during LINAC tuning and optimization of beam parameters. The operation principle of BEM is based on the registration of X-rays emitted by interaction of ions of the accelerator beam with a thin tungsten wire. The monitor performs precise measurements for X-rays arrival time that gives information about average distribution of ions along the time axis. The LINAC of SPIRAL2 is operated at 88 MHz that corresponds to period 11.36 ns between bunches and its extension of phase typically σ_φ rms = 7°–8° (or σ_t rms = 220–260 ps). Main beam parameters for LINAC specified in Table 1. Five BEMs will be installed at the beginning of the LINAC inside the first five warm sections.

Table 1: Parameters of LINAC Beam

Parameter	Value
Frequency	88.0525 MHz
Period	11.36 ns
Energy at LINAC entrance	0.75 MeV/A
Maximum intensity (deuterons)	5 mA
Maximum power (deuterons)	7,5 kW
Minimum σ_φ rms	7°
Minimum σ_t rms	220 ps

The BEM will operate with high-intensity beams up to 5 mA and must provide reliable measurements with temporal resolution not worse than 1° of phase at 88 MHz of accelerated frequency. Some restrictions are imposed to the BEM design. A lack of space inside of the diagnostic box imposes to have a compact system. Also materials used for the BEM should not contaminate the superconducting cavities of cryomodule. These requirements were taken into account during the BEM design.

Different working principles of longitudinal bunch measurements were compared. Registration of SEs emitted from the wire would have required an accelerating potential of few kV. That leads to steering effect for the beam ions and requires an additional electrostatic compensation system. Using of backscattered ions does not provide required temporal resolution due to energy spread and a considerable difference of ions drift times depending on the point of interaction on the wire. Registration of X-rays is more suitable to avoid the use of accelerating potential and to minimize time spread for different drift paths. A disadvantage of this method is a longer time of acquisition related to low efficiency for X-rays registration. In our case it varies between 0.5 and 3 minutes.

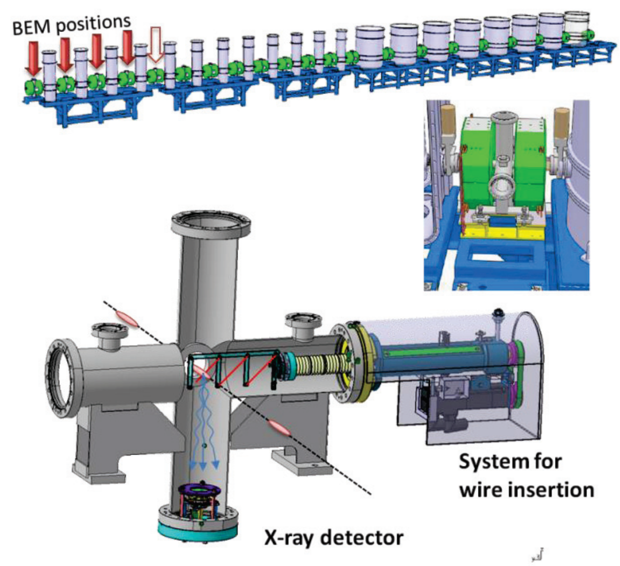

Figure 1: BEM installed at diagnostic box and its positions on LINAC warm sections.

HARDWARE

The BEM is mounted inside of warm section and occupies two flanges of diagnostic box (Fig. 1). It consists of an X-ray detector and a mechanical system for positioning the wire inside the beam.

The mechanical system of wire insertion is able to perform positioning of the wires with accuracy better than few tens of microns. A wire holder has three identical positions with wires and allows replacing one wire with another in case of damage (Fig. 2, right). Integrity of the wire can be verified using measurements of collected beam current. The wire holder is electrically isolated from the other mechanical parts of actuator and connected to I/V converter

ISBN 978-3-95450-177-9

with ADC. It allows measuring current from the wire with accuracy of 7.6 nA (least significant bit). These measurements permit to obtain a distribution of the beam current on the transverse plane and to optimize the wire position in the maximum of the beam density. Preliminary simulations with TRACEWIN have found the optimal configuration for wire placement with minimal influence on the beam emittance. Placing of five BEM in series requires placing of wires in a sequential alternating orientation (Hor-Ver-Ver-Hor-Ver). However, orientations of all wires were tilted by additional 45° since the top flange of diagnostic box is occupied with a turbo molecular pump.

Tungsten wire with 150 microns diameter was chosen for X-ray production. Thermal loading and mechanical durability of this wire were studied for SEM grid profiler for used at LINAC and a limitation factor of duty cycle for maximum beam current was found. For proton beam with $I_{macropulse}$ = 1mA, it is 10 ms at a maximum repetition rate of 10 Hz. It was empirically found that if the duty cycle is bigger than 10 ms, it induces unproportional increasing of X-rays emission. It totally destroys information about temporal structure of the beam and can be explained as a process of X-rays emission due to thermal heating of the wire.

The X-ray detector of BEM (Fig. 2, left) is based on microchannel plates coupled with fast readout anode. Two MCPs HAMAMATSU F1551-01 with channel of 12 microns diameter are assembled in chevron configuration. Entrance of the MCP is covered by a copper collimator of 10 mm thick with 4 mm diameter hole. The distance between beam axis and surface of the first MCP is 255 mm and gives solid angle for registration of 2×10^{-4} str. A gap of 3 mm between the first and the second microchannel plates was implemented to increase the amplitude of output signal. It was necessary to transmit this signal through a cable of 55 meters length to put the electronics outside the LINAC cave.

Aluminum foil of 22 microns thick polarized at +50 V is placed before detector. This foil serves to stop charged particles such as electrons or ions from backscattering of the beam and ionization of residual gas. At the same time, it stays practically transparent to X-rays with energies >10 keV with the coefficient of transmission more than 86%. Aluminum foil protects the detector from saturation and decreases its loading by three orders of magnitude due to differences in efficiency of registration for X-rays and ions.

Signal processing is performed with constant fraction discriminator and time-to-amplitude converter coupled with multichannel analyzer. The resolution of electronics was measured and estimated better than 15 ps [3].

Figure 2: Photos of X-ray detector (left) and mechanical system for wire insertion (right) of BEM.

TEMPORAL RESOLUTION

Preliminary estimation of temporal resolution for detector with two BEMs and β+ - decay source of ^{22}Na have been done. The source of ^{22}Na has a decay schema with emission of positron and 1.27 MeV gamma simultaneously. Emitted positrons have average energy about 150 keV. Positrons at energies below a few eV are able to interact with electrons by annihilation into two photons with energies of 511 keV emitted in opposite directions. A copper foil of 300 microns thickness was used for thermalisation of positrons. The coefficient of transmission for positrons in this foil is 4.5×10^{-6} thus practically all positrons escaped from the source are stopped in the foil. A source of ^{22}Na with copper foil in a sandwich arrangement was placed between two X-ray detectors of BEM. Detectors were included in coincidence schema and distribution of coincidence times between them was measured.

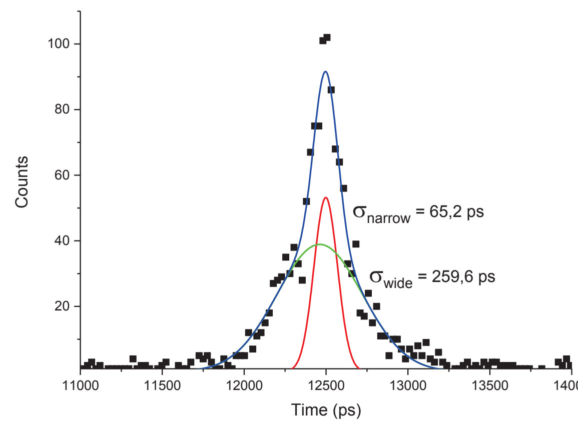

Figure 3: Coincidence spectrum obtained with source ^{22}Na.

Measured coincidence spectrum is depicted on Fig. 3. This spectrum is the convolution of several coincidence spectra with different values of width. Spectrum with the narrowest distribution is related to registration of two photons with energies 511 keV as they are emitted simultaneously. Spectrum with wider distribution is corresponded to coincidence of one photon of 511 keV with gamma of 1.275 MeV. The time delay for the positron to thermalize depends on the properties of matter (concentration of electrons) and is used in the technique of PALS (Positron Annihilation Lifetime Spectroscopy). In this case the time coincidence spectrum has broader distribution and is the convolution of several spectra with exponential decays. To analyze the obtained spectrum we have used simplified approach. Coincidence spectrum was fitted as superposition of two Gaussians with different widths. Width of the narrowest Gaussian divided by $\sqrt{2}$ has been used for estimation of temporal resolution for BEM. Thus the preliminary evaluation of temporal resolution for bunch shape measurements can be estimated as σ = 47 ps or 1.5° of phase resolution at 88 MHz acceleration frequency. It should be noticed that optimization of electronics was not possible due to a low coincidence count rate. Measured value of temporal resolution is an upper bound and therefore obtained value could be improved.

ISBN 978-3-95450-177-9

MEASUREMENTS

Series of tests for BEM with beams of protons and helium ions have been done during the commissioning phase of for 88 MHz RFQ of the LINAC. During this period an intermediate test bench (BTI) was installed at the place of medium energy line just after the first rebuncher (Fig. 4). This test bench is used for characterization of beam diagnostics of SPIRAL2. Variations of rf-amplitude and phase of rebuncher produce a strong effect on a longitudinal bunch shape and were used for characterization of longitudinal profile measurements. The BEM was installed at one position with Fast Faraday Cup (FFC) on a beam axis. That allows making direct comparisons of the results BEM and FFC [4].

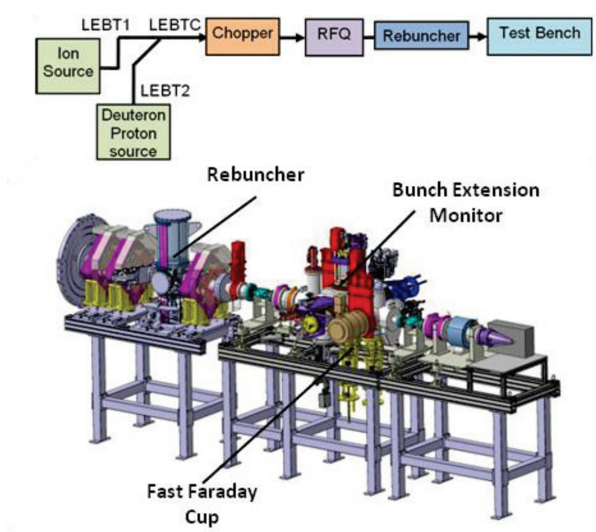

Figure 4: Diagram of injector (top) and general view of intermediate test bench (bottom).

Count rate at the detector without wire insertion into the beam was measured before performing bunch extension measurement. Background count rate was estimated less than 0.1 counts per second. Typically operating count rate for BEM is few tens counts per second that gives ratio noise to signal better than 1%. Measurement of background count rate of BEM placed at vicinity of operated cryomodule has been performed previously [3]. Results of this measurement are shown a lack of background produced by superconducting cavity in the range of applied acceleration field up to 8 MV/m (nominal value for acceleration field is 6.5 MV/m).

Comparison of measurements BEM and FFC have been done for phase variation of rebuncher with beam of protons and obtained results are in a good agreement (Fig. 5, top). Widths of bunches were measured in the range from 240 to 1400 ps (Fig. 5, bottom). FCC has a restriction for a minimal measured width σ rms= 320–330 ps due to limitation of bandwidth.

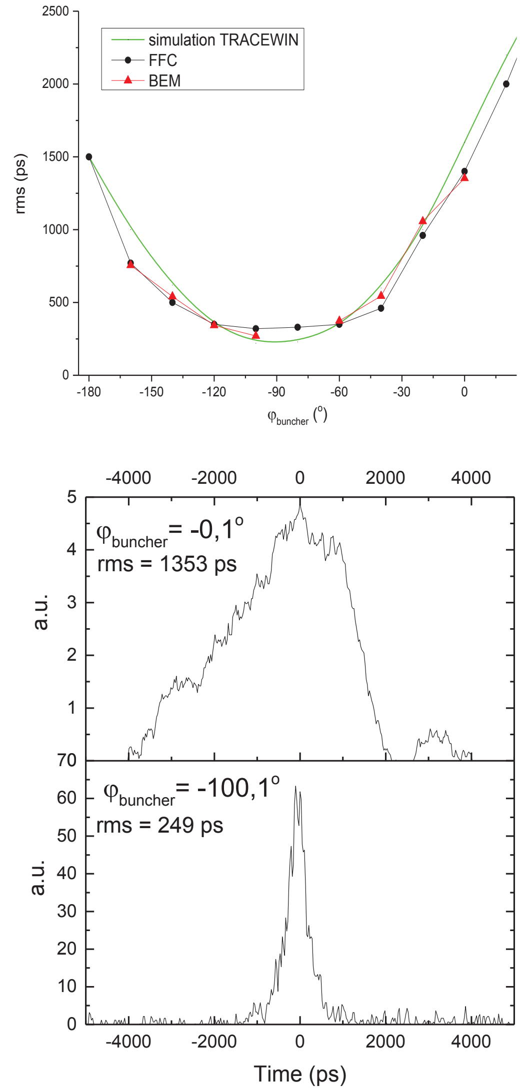

Figure 5: Width of bunch as function of buncher phase for proton beam $I_{macropulse}$ = 5mA (top) and measured longitudinal bunch profiles (bottom).

Series of measurements with beam of ions $^{4}He^{2+}$ and variation of rf-amplitude applied to the buncher cavity have been done (Fig. 6). Measurements with BEM show modification of bunch profile at different values of voltage of rebuncher. At the low voltage of rebuncher the second peak at the left side from principal ones corresponds to the ions that have velocities less than main part of ions inside a bunch. Increasing of voltage at rebuncher accelerates these ions to the energies of the main part and at high values of voltage it results to over-acceleration and formation of a bump on the right side bunch profile.

ISBN 978-3-95450-177-9

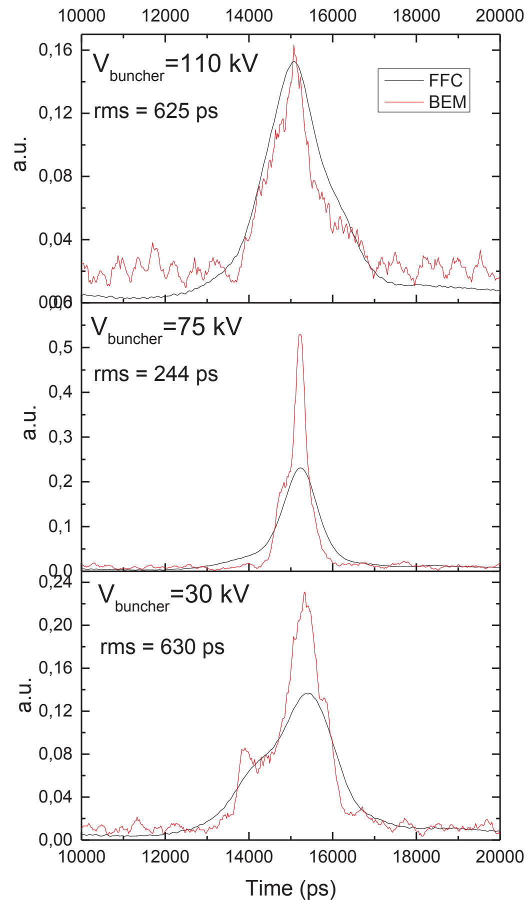

Figure 6: Bunch shapes measured with BEM and FFC at different values of applied $V_{buncher}$. Parameters: $^4He^{2+}$, $I_{macropulse}$ = 0.6 mA, $\phi_{buncher}$ = -67.9°, duty cycle = 1 ms/100 ms.

Some differences between shapes of longitudinal profile measured with FFC and BEM probably can be explained due to fact that only small beam fraction 3-4% in transversal plane interacts with a wire while FFC collects all ions of the beam in transversal plane. Additional investigation with measurements of bunch shape profile at different transversal positions of the wire will be performed.

Measurements of bunch profile have been performed with variation of $I_{macropulse}$ from 1 mA to 0.1 mA with helium beam (Fig. 7). Other parameters as rf-amplitude and phase of buncher stayed constant during these measurements. Measured longitudinal bunch profiles have shape variations from quasi-gaussian at maximal intensity to the shape with more fine structure with several satellite peaks at lower values of intensity. That can be explained as decreasing of influence of space charge forces inside the bunch. Coulomb repulsion forces of the space charge produce smoothing of fine structure. As it can be observed from Fig. 7, measured profile for intensity 0.2mA has structure with two principal peaks. More narrow peak has FWHM = 129 ps (σ = 55 ps) that is also confirms to previous estimation of temporal resolution for the BEM.

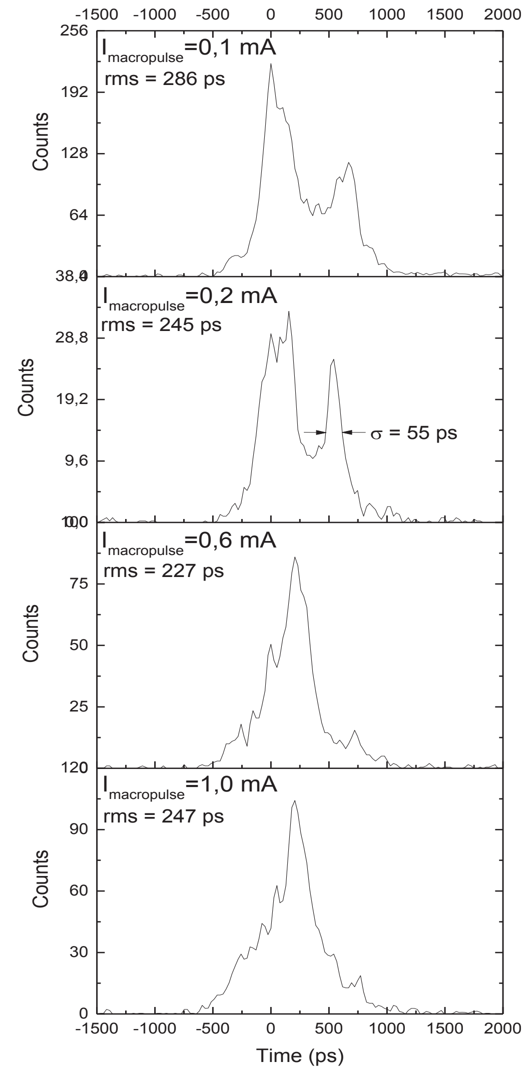

Figure 7: Longitudinal bunch profiles measured for different values of $I_{macropulse}$. Parameters: $^4He^{2+}$, $V_{buncher}$ =75 kV, $\phi_{buncher}$ = -67.9°, duty cycle varies from 1 ms/100ms to 10 ms/100 ms.

CONCLUSIONS

A novel device for bunch shape measurements have been developed and successfully tested with beam conditions of LINAC for SPIRAL2. Results of measurements were compared with measurements of FFC and were shown complete reliability in a range from 240 to 1400 ps of rms. Estimation of time resolution have been performed for this detector and confirmed with measurements. It was shown that it is not worse than 47 ps or 1.5° of phase at 88 MHz acceleration frequency and sufficient for bunch shape measurements. Further improved with optimization of some parameters of electronics could be done in a future. Some additional measurements with different positions of wire in the beam transversal plane will be performed.

ISBN 978-3-95450-177-9

REFERENCES

[1] R. Revenko *et al.*, "Bunch Extension Monitor for LINAC of SPIRAL2 facility", IBIC13, Oxford, UK, (2013), WEPC20, http://jacow.org/

[2] J.-L. Vignet *et al.*, "A Bunch Extension Monitor for the SPIRAL2 LINAC", IBIC2014, Monterey, California, USA (2013), MOPD26, http://jacow.org/

[3] R. Revenko *et al.*, "Spiral2 Bunch Extension Monitor", LINAC 2014, Geneva, Switzerland (2014), THIOC01, http://jacow.org/

[4] C. Jamet *et al.*, "Energy and Longitudinal Bunch Measurements at the SPIRAL2 RFQ exit", IBIC2016, Barcelona, Spain (2016), WEPG42, http://jacow.org/

ISBN 978-3-95450-177-9