A bunch extension monitor for the SPIRAL2 LINAC

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Abstract

Measurements of the bunch longitudinal shape of beam particles are crucial for optimization and control of LINAC beam parameters and maximization of its integrated luminosity. The non-interceptive bunch extension monitor for the LINAC of SPIRAL2 facility is being developed at GANIL. Five bunch extension monitors will be installed at the beginning of the LINAC between superconducting cavities. The principle of operation is based on the registration of x-rays induced by ions of accelerator beam interacting with a thin tungsten wire positioned on the beam path. The monitor consists of two parts: a system for wire insertion and positioning, and an x-ray detector based on microchannel plates (MCP). A detector prototype has been developed for three years and was tested using protons and heavy ions beams. The influence of the cryomodule operation on the diagnostic measurement was also studied.

INTRODUCTION

The SPIRAL2 project [1] is based on a multi-beam LINAC driver in order to allow both ISOL and low-energy in-flight techniques to produce RIB. A superconducting light/heavy-ion LINAC capable of accelerating 5 mA deuterons up to 40 MeV and 1 mA heavy ions up to 14.5 MeV/u is used to bombard both thick and thin targets. These beams could be used for the production of intense RIB by several reaction mechanisms (fusion, fission, transfer, etc.) and technical methods (ISOL, IGISOL, recoil spectrometers, etc.). The production of high intensity RIB of neutron-rich nuclei will be based on fission of uranium target induced by neutrons, obtained from a deuteron beam impinging on a graphite converter (up to 10^{14} fissions/s) or by a direct irradiation with a deuteron, ^{3}He or ^{4}He beam.

The accelerating RF of the LINAC [2] is 88.0525 MHz. It means that time distance between two bunches is 11.26 ns. The extension of the phase for bunch ($\pm 2\sigma$) is 60° or ~1,6ns for bunch length. The LINAC can operate at continuous or pulsed mode with period of macropulse between 100 µs and 1s.

Correct adjustment of the LINAC is necessary for obtaining maximal intensity and luminosity on the target. Adjusting includes synchronization of phase for each acceleration section. For this reason, information about bunch length distribution is needed and will be obtained using a Bunch Extension Monitor (BEM). These diagnostic detectors will be placed inside the warm sections between superconducting acceleration cavities. Each warm section consists of two quadrupoles and diagnostic box placed in between. Five BEM will be mounted into the first five diagnostic boxes at the LINAC entrance where deuteron beam energy will be between 1.46 and 2.29 MeV.

BEM DESCRIPTION

Bunch extension monitor is a non-destructive beam diagnostic detector for estimation of the length of LINAC bunches. The principle of BEM measurement is based on registration of x-rays emitted from a thin tungsten wire due to the interaction with ions beam. All components of BEM should meet UHV requirements since the LINAC will be operated at 10^{-8} mbar. Moreover, all BEM materials must satisfy required purity conditions for preventing cavity pollution.

BEM Working Principle

The photons emitted from the tungsten wire will be produced due to ionization of atoms hit by beam ions. The ions can knock-out electrons from inner shells and produce electron vacancy. Electrons from outer shells fill this vacancy and emit the difference of energy of bound states as characteristic x-ray photons. The energies of emitted characteristic photon are unique for each element and in case of tungsten they are 60 keV and 11 keV for K- and L-shell ionization respectively. A two stage microchannel plates is used to produce photoelectrons and multiplied them. Output signal is transmitted through coaxial cable to the input of a constant fraction discriminator CFD 7174. Signal of accelerator RF comes to another channel of CFD. The two logical signals from CFD output are sent to a time-to-amplitude converter Ortec 566 as "start" and "stop" signals. The output signal from TAC (whose amplitude is proportional to the time difference) is digitized by multichannel analyzer CANBERRA Multiport II. The Schema of BEM electronics operation is presented in Fig. 1.
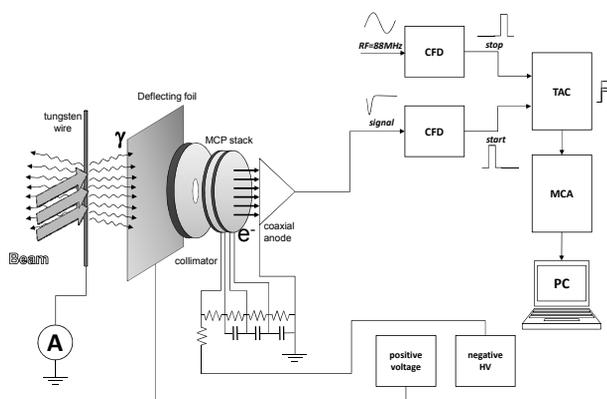

Figure 1: Principal schema of operation of BEM electronics.

X-rays of ^{55}Fe was used to measure the electronic temporal resolution. Output signal from detector prototype was transmitted through a long coaxial cable of 70 meters length and split in two signals. Both signals

were going to CFD inputs with one of them delayed by 10 ns. Measured time resolution for electronics was 12 ps (FWHM) for MCP high voltage of 1.85 kV.

BEM Design

The BEM consists of two parts which are installed inside the diagnostic box that can be seen on Fig. 2.
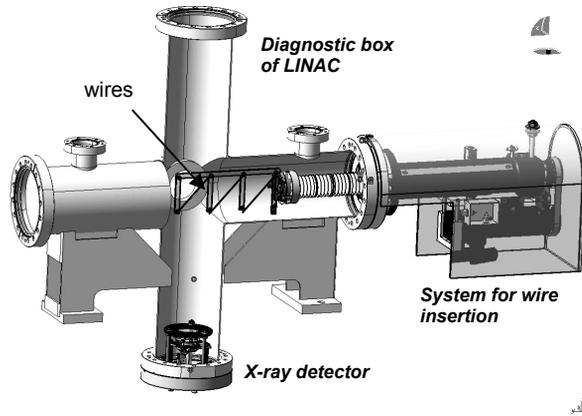

Figure 2: General view of BEM installed at diagnostic box of LINAC.

The first part of this detector is the system for wire insertion which allows inserting the wire into the beam with precision better than 100 μm. Three different tungsten wires of 150 microns diameter are fixed on a stainless steel frame. Each holder has dimensions 50mm × 50mm where tungsten wire is fixed along the diagonal. Wires of the next BEM are fixed at a perpendicular direction compared to the previous BEM wires to minimize beam distortion. Three wires are installed to have some spare in case of wire damaging without dismounting. The rod is moved by a brushless motor through a system of screw-nut mounted on air side of flange CF100.

The system for wire insertion allows also to perform measurements of current on the wire. Frame with tungsten wires is isolated and electrically connected through vacuum feedthrough on the flange. Current from the wire is measured by a card developed at GANIL and also used for measurements of current from Faraday Cups and slits.

The second part of BEM is the x-ray detector used for registration of photons emitted from wire. Two MCPs Hamamatsu F1551 (∅ 18mm) are used assembled in chevron configuration and provide gain up to 10^7 at applied voltage -2kV. For obtaining short signal front, the output electrons are collected by a fast readout coaxial anode of 50 Ohms impedance connected on the CF100 flange with N-type connector. Entrance of first MCP is covered by an 8 mm thick copper plate with a 4 mm hole. This collimator permits to select x-rays coming from the center of the wire.

To avoid background signals from ions coming from residual gas ionization, a deflecting grid polarized at +30V is positioned on the top of the collimator.

TEST OF PROTOTYPE

Test at GANIL on IRRsud Ligne

A test was performed at GANIL with a beam of $^{36}Ar^{+10}$ ions of 0,98MeV/n energy. A 60s acquisition time with 2.4 μA intensity has given the spectra shown Fig. 3 with a good signal over noise ratio.
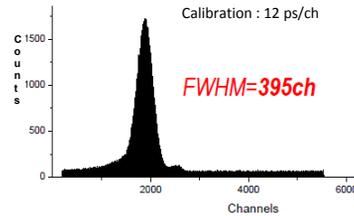

Figure 3: Measured bunch profile of $^{36}Ar^{+18}$ with 2.4 μA beam intensity (Value of MCP applied voltage of 1.95kV and time acquisition =60 s).

Bunch length measurements were done at various intensity up to 2.5 μA using a continuous wave beam with adapted voltage on MCP (see Fig 4). FWHM values are stable and the difference of the three curves is due to a different background subtraction for the FWHM calculation.
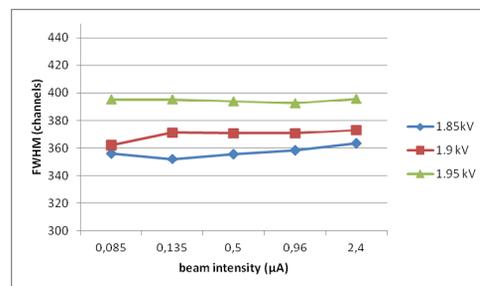

Figure 4: Measured FWHM bunch of $^{36}Ar^{+18}$ versus beam intensity.

Comparison with Theoretical Estimation

Results of the beam test were compared with analytical calculation of x-ray production from the wire (see Fig 5). To perform these calculations the cross section of tungsten wire was divided into small elemental cells. For each cell the value of ionization cross section was calculated. The cross-section can be implemented as a function of scaled velocity of projectile ion to velocity of electron on the shell V_{proj}/V_{elect} and can be represented through Gryzinsky function (see Eq.1) [3].

$$\sigma_{ionis}(E) = \frac{N \cdot Z^2 \cdot \sigma_0}{U^2} \cdot G(V) \qquad (1).$$

Where N is a number of electrons on the shell (K-shell=2, L-shell=8), Z is charge of projectile ion, U is binding energy of electrons at the given shell, $G(V)$ is a function of the scaled velocity $V=V_{proj}/V_{elect}$ and $\sigma_0 = \pi \cdot e_0 = 6.56 \times 10^{-14} cm^2 eV^2$

To estimate the scaled velocity the value of beam energy loss is calculated in each cell. The attenuation of x-rays in the wire is also taken into account.

The total value of emitted photon from the wire can be obtained by summing the x-ray production in each cell [4]. The final expression for total number of photons emitted in solid angle ratio $\Omega/4\pi$ and registered by MCP can be written as:

$$Q = \frac{\Omega}{4\pi} \cdot \varepsilon \cdot N_{atoms} \cdot \omega_{k,l} \cdot \sum_{ij} I_{ij} \cdot \sigma_{ionis}\left(E(x_i)\right) \cdot e^{-\mu \cdot L_{ij}} \quad (2).$$

where $\Omega/4\pi$ is a solid angle ratio of detector, ε is the photon registration efficiency by MCP, N_{atoms} is the concentration of target atoms per cm^2, $\omega_{k,l}$ are fluorescence yields of photons for K-, L-shell ionizations, I_{ij} is number of incident ions of the beam at ij-cell per second, σ_{ionis} is ionization cross-section for K-,L-shells as function of incident ion energy, $exp(-\mu \cdot L_{ij})$ is x-ray attenuation.

The calculations (see Eq. 2) were done for both cases of ionization for K- and L- shell. The relative yield of photons due to ionization of L-shell is almost 10^5 times higher than for K-shell. For this reason, only the L shell calculation is shown in comparison with experimental results (see Fig. 5).

An experimental count rate comparison to the theoretical calculation has been made for different beam intensities and MCP applied voltage (see Fig. 5). Variation of the experimental count rate measurement is similar to the calculation curve but values are lower of these due to different parameters not take in count in the calculation like MCP opacity and gain.
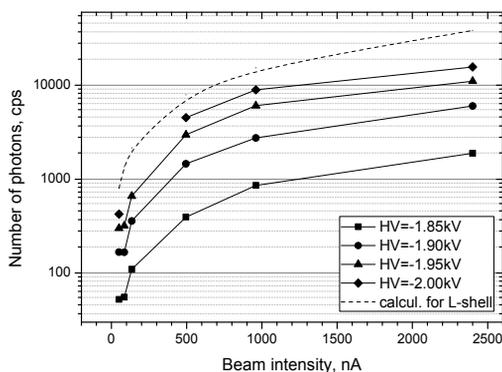

Figure 5: Comparison of count rates for different values intensities and applied voltage. Theoretical estimation of count rate due L-shell ionisation is presented.

Test of BEM Close to Cryomodule

To verify if x-rays emitted from the cavity could disturbed the BEM acquisition, a BEM has been mounted in a LINAC diagnostic box and connected to a SPIRAL2 cryomodule type B (with two superconducting cavities) (see Fig. 6). This test was performed at ORSAY IPN. The principle of operation for bunch extension monitor (BEM)

is based on the registration of x-ray emitted from thin tungsten wire.. A superconducting cavity inside of cryomodule can produced x-rays due to electrons bremsstrahlung inside the cavity at high applied accelerating field. The emitted x-rays from cavity can be directly registered by BEM or can create x-rays on the wire and produce unwanted background in both cases.
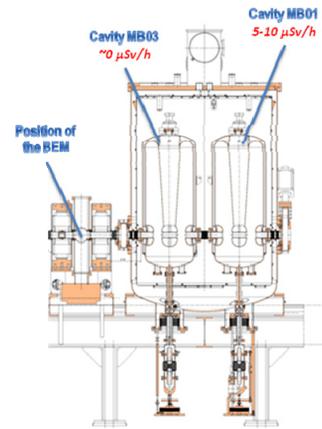

Figure 6: Installation of BEM set close to cryomodule B.

Two series of measurements for each cavity were carried out and average count rates were measured. Each series of measurements contains several points at different values of electric field gradient starting from zero and exceeding of nominal value (operating acceleration field value is 6.5 MV/m).

Also for each value of electric field gradient two measurements were done with inserted wire and without. The average count rate measured without insertion of the wire permits to estimate global x-ray background generated by cavity. The ratio of count rates obtained with inserted wire and without gives the number x-rays number emitted from the wire due to x-ray fluorescence.
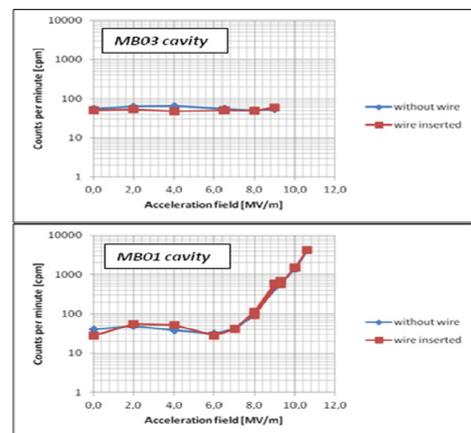

Figure 7: value of count rate emitted from cryomodule and detected by BEM.

At the maximum value of 10.6 MV/m, the count rate was about 50 Hz on the worst cavity (Fig. 7). This value

is lower by about two to three orders of magnitude compared to normal conditions in beam.

SUMMARY

A prototype of non-interceptive beam diagnostic detector for bunch length measurements was developed. Test with proton and ions beams were performed in various conditions. The time resolution for detector and electronics is approximately 10 ps using analogical electronics. The results of test were compared with theoretical estimation of x-ray production. The test of BEM installed close to the cryomodule has shown that BEM measurements will not be perturbated by it during beam acceleration. A test with high intensity proton beam at SARAF facility is scheduled in October 2014 to estimate the maximum count rate possible with this detector. The set of the five BEM will be installed on the LINAC at the beginning of 2015.

ACKNOWLEDGMENT

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