BUNCH SHAPE MEASUREMENT OF CW HEAVY-ION BEAM*

N. Y. Vinogradov†, P. Billquist, P. N. Ostroumov, R. C. Pardo, M. Portillo, S. I. Sharamentov,
G. P. Zinkann, ANL, Argonne, IL 60439, USA

Abstract

An accurate bunch shape measurement is one of the most important tasks during the fine tuning of multi-cavity accelerators. A device for the measurement of bunch time structure of cw heavy-ion beams with time resolution ~20 picoseconds was developed, constructed and commissioned at ATLAS which is a 50 MV superconducting heavy-ion linac. The Bunch Shape Monitor (BSM) is based on the analysis of secondary electrons produced by a primary beam hitting a tungsten wire to which a potential of -10 kV is applied. In a BSM the longitudinal distribution of charge of the primary beam is coherently transformed into a spatial distribution of low energy secondary electrons through transverse rf modulation. The distribution of secondary electrons is detected by a chevron MCP coupled to a phosphor screen. The signal image on the screen is measured by use of a CCD camera connected to a PC. This BSM analyzes cw beams rather than pulsed beams studied by a previous device [1]. Design features of the BSM and the beam measurement results are reported.

1 INTRODUCTION

Bunch Shape Monitors for the measurement of longitudinal distributions of proton, H-minus and heavy-ion bunches have found wide application in linear accelerators. The principle of operation, various applications and some historical review of the BSMs were reported elsewhere [1,2]. All previously developed BSMs operate in pulsed mode and are used for measurements in low duty-cycle accelerators. For bunch shape measurements of heavy-ion beams in the superconducting accelerator ATLAS [3] we have developed a BSM capable of operating in the cw regime. This type of BSM is particularly important for application in future high-intensity cw machines like the driver linac for the Rare Isotope Accelerator (RIA) [4] being developed in the US.

2 DESIGN FEATURES

As is well known [1, 2], in the BSM the time distribution of a beam bunch being analyzed is coherently transformed into a spatial distribution of low energy secondary electrons through transverse rf modulation. The general layout of the BSM developed for a cw heavy-ion linac is shown in Fig. 1. Secondary electrons are produced when a primary beam hits a tungsten wire to which a potential of -10 kV is applied. The electrons are accelerated by the target voltage, collimated and passed through the rf field of the deflector. The deflector is a quarter-wave parallel-wire line resonator (position 2 in Fig. 1) with the electrode plates installed at the maximum of the rf electric field. The deflector operates at 97.0 MHz and is synchronized with the master oscillator of the linac. The parallel-wire line of the rf deflector is located in the air and is isolated from the vacuum by a specially designed ceramic window provided by Ceramaseal™ [5]. To obtain the best time resolution of ~20 psec a significant rf power ~30 W is required. Therefore, water cooling of the rods of the parallel wire line is foreseen. The deionized water flows through coaxial copper tubes. As in the previous devices [1, 2] each rod is biased with respect to the ground by static voltage $V_0 + \Delta V$ and $V_0 - \Delta V$ applied through the HV connectors (8 in Fig. 1). The deflector electrodes serve as a one-dimensional focusing lens for secondary electrons. The voltage difference $2\cdot\Delta V$ can be adjusted in order to steer the electrons.

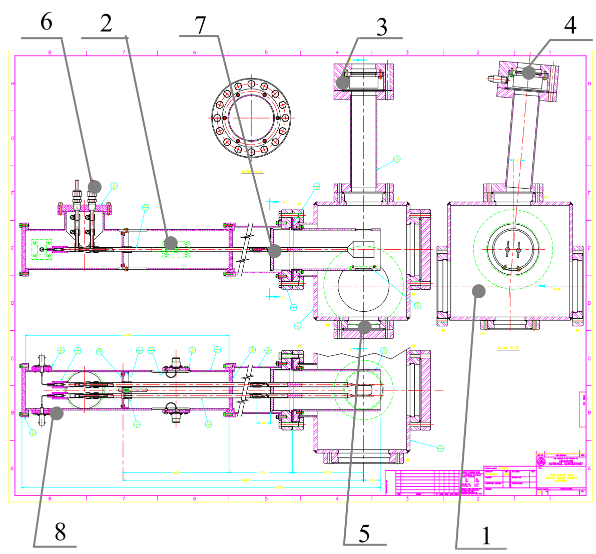

Figure 1: Assembly drawings of the BSM. 1 - the main vacuum chamber, 2 - the rf deflector, 3 – the electron beam detector based on the MCP (4), 5 - the port for the target assembly, 6 – the water cooling connectors, 7 – the ceramic window, 8 – the HV connectors.

Detection of the secondary electron beam is done with a combination of a phosphor screen and a light sensitive detector. A monochromatic CCD (charge coupled device) is sufficient for detecting the light signal. A dual multi-channel plate (MCP) detection system was used to obtain high gain. The second MCP lies 0.5 mm behind the first, such that the channel holes align. Both MCPs are identical at 41 mm in diameter and can sustain a maximum bias of 1000 VDC each. A resistive circuit was

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† vinogradov@phy.anl.gov

constructed to allow both MCPs to have equal biases and run off of a single power supply. The dual MCP system has a combined maximum gain of $4{\cdot}10^7$. About 0.5 mm behind the second MCP there is a type P-20 phosphor plate. It is biased at 3 kV relative to the MCP output to convert the accelerated electron's energy into photons of predominantly 560 nm wavelength. Upstream of the MCP plates a grid with 90% of transmission is installed. By biasing the grid up to –1 kV parasitic low energy secondary electrons can be prevented from producing a background signal. This type of registration device has several advantageous: wide dynamic range of measurements and real time observation of the bunch time profile. Bunch center fluctuations in time or with respect to the reference rf phase can be observed on-line. The MCP and phosphor screen assembly was obtained commercially from COLUTRON [6].

A tungsten wire with a diameter of 0.17 mm is installed on a U-shape holder connected to a linear motion actuator. The actuator is inserted through the port 5 shown in Fig. 1.

The BSM was installed at the ATLAS beamline 4.06 m downstream of the last SC resonator of the Booster. The general view of the BSM is shown in Fig. 2. This view shows the main body (1), the rf deflector cavity (2) with HV cables and the target unit (3) with stepper motor.

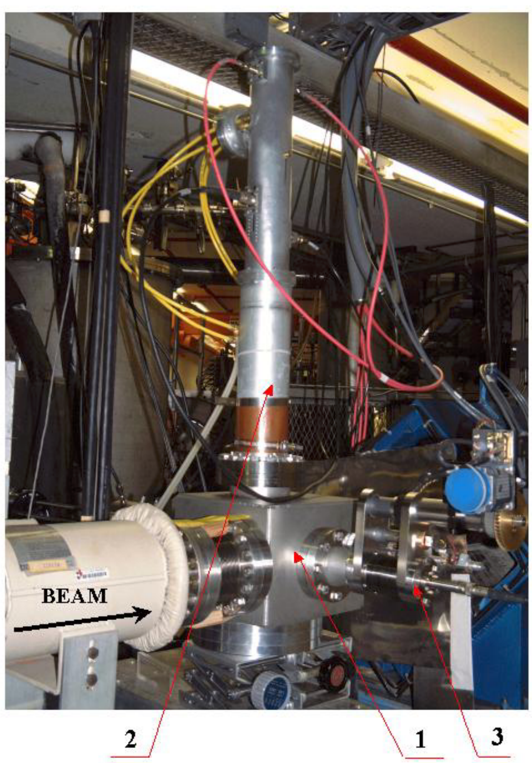

Figure 2: The BSM at the ATLAS beamline.

The BSM control system is implemented using the software package LabVIEW™. The system controls operation of the HV and rf power supplies, the stepper motor and the CCD camera. The electronics within the camera allow the CCD sensors to be read out using the RS-170 standard of rastering images. The signal is amplified and then fed into a PCI-1408 frame grabber circuit board. The image signal may also be split to be monitored simultaneously with a TV monitor. The PC also has a stepper motor control board and encoder reference input.

3 TIME RESOLUTION OF THE DETECTOR

Time resolution of the BSM depends on two main parameters: 1) the width of secondary electron beam image without the rf fields and 2) rf voltage amplitude. The rf voltage can be easily increased in order to improve the resolution while the width of the electron beam image depends on the properties of the secondary electrons and beam optics between the wire and phosphor screen. Numerical simulations of secondary electron beam motion from the thin wire to the location of the MCP were carried out with the code Simion 7 for the case when the rf voltage is not applied. In these simulations the realistic electron beam distribution according to ref. [7] was generated. The angular distribution of electrons is supposed to be cosθ in form, where θ is the observation angle. The average number of electrons ejected per ion event is taken to be proportional to the secant of the incidence angle [7]. Figure 3a) shows the measured and calculated electron beam distribution on the phosphor screen. The simulations show that the electron beam shape on the screen is mainly defined by the angular distribution of emitted electrons. In experiments we observed an asymmetric shape of the electron beam distribution which is probably related to the complex interaction of the primary beam hitting the edge of the wire tangentially. The beam image size, as a function of focusing voltage on the deflector plates, can be minimized by adjusting the focusing voltage V_0 (Fig. 3b).

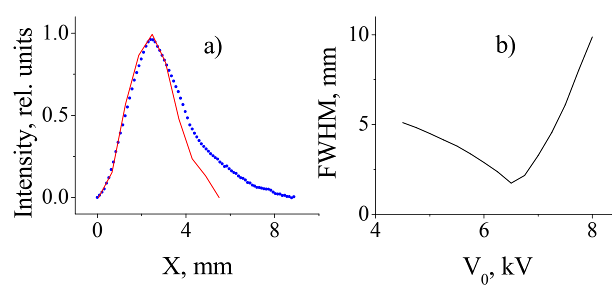

Figure 3: Electron beam distribution on the phosphor screen (a) and FWHM of the electron beam image on the phosphor screen as a function of focusing voltage V_0 (b). The solid curve represents simulation, the dots are measured data.

4 BEAM MEASUREMENTS

The tests of the BSM were done with $^{58}Ni^{15+}$ ions from the Booster section of the ATLAS. The beam energy was adjusted from 6.5 to 7.2 MeV/u both by varying the phase of the rf field and by turning off the last resonators in the

Booster. The beam intensity was in the range 10 -100 pnA. First, the electron beam optics was tuned while the rf-deflector was off. A typical electron beam image focused on the screen is shown in Fig. 4.

Figure 5 shows a typical bunch shape of the $^{58}Ni^{15+}$ beam accelerated up to 7.0 MeV/u in the Booster. The time resolution for this particular measurement was 40 ps which was set in order to observe the full bunch on the screen. The resolution can be easily improved by increasing the rf voltage. However, part of the bunch distribution can be outside of the screen if higher rf voltage is applied.

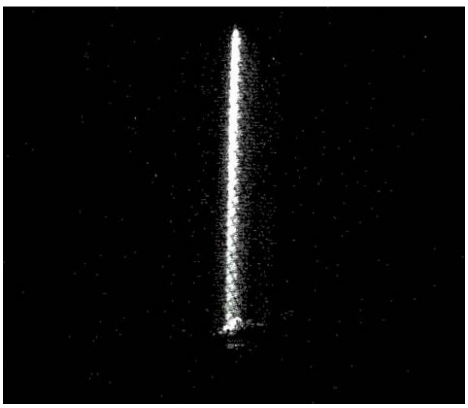

Figure 4: Image of the focused electron beam.

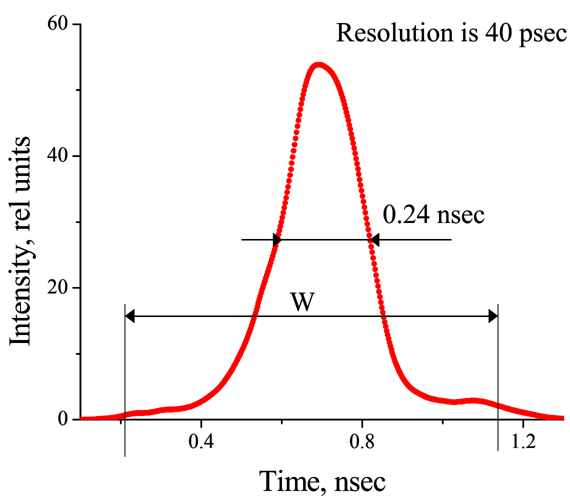

Figure 5: Typical time profile of the bunch. W is the width of the phosphor screen.

Beam energy was measured as a function of the rf field phase in the last SC resonator of the Booster. Knowing the distance between the resonator and BSM the absolute beam energy can be observed as a function of rf phase as is seen in Fig. 6a). In this case the BSM serves as a phase detector.

For the measurement of the longitudinal emittance of the beam several last resonators of the Booster except the very last one were turned off. The last resonator was used as a rebuncher. From the measurements of the bunch longitudinal profiles for different levels of rf field in the rebuncher, the rms widths of the bunch were calculated. A ray-tracing code was used to fit the simulated bunch widths to the measured data. In this procedure the initial ellipse parameters of the beam in longitudinal phase space are adjusted to obtain the best fit to the measured data. Figures 6b) shows the final results obtained for the rms longitudinal emittance which is equal to 2.6 π·keV/n-nsec.

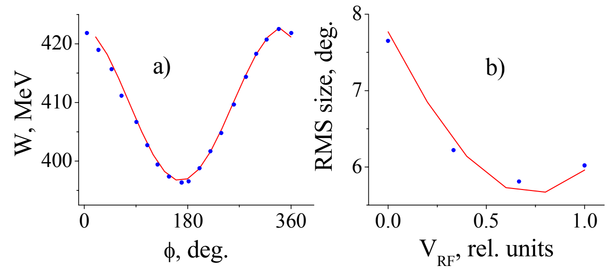

Figure 6: Beam energy as a function of rf field phase in the last resonator of the Booster (a) and rms beam size versus rf field amplitude in the last resonator of the Booster (b). The solid curve represents simulation, the dots are measured data.

5 CONCLUSIONS

A new device for the measurement of bunch time profiles was developed and commissioned at the ATLAS accelerator. The device is able to measure the bunch shape of cw heavy-ion beams with 20 psec time resolution. The test of the BSM was done with heavy-ion beam currents as low as 10 pnA and energies up to 7.2 MeV/u. The time resolution of the BSM was studied numerically and compared with the measured data.

6 REFERENCES

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