THE FIRST RESULTS OF BUNCH SHAPE MEASUREMENTS IN THE SNS LINAC

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Abstract

Three Bunch Shape Monitors with transverse scanning of low-energy secondary electrons have been developed and fabricated for the SNS Linac. A novel feature of the detectors is the use of energy separation of the electrons. The separation allows minimizing the influence of detached electrons originated from dissociation of H-minus ions in the detector wire target. The first detector was used at the exit of the first DTL tank during its commissioning. The results of Bunch Shape measurements are presented and discussed. These results were used to verify beam quality, to set parameters of the accelerating field, to estimate longitudinal beam halo and to estimate the longitudinal beam emittance.

INTRODUCTION

Bunch Shape Monitors (BSMs) are used to measure longitudinal microstructure of the accelerated beam in a number of accelerators. A review report [1] includes details of the principle of operation and description of BSM parameters as well as thorough list of references. Briefly, the principle of operation is based on the coherent transformation of a longitudinal distribution of charge of the analyzed beam into a spatial distribution of low energy secondary electrons through transverse RF modulation. The main parameter of the monitor is its phase resolution. Typically the value of resolution is about 1° at the frequencies of hundreds of MHz.

In the case of an H-minus beam the results of measurements are distorted by the electrons detached from the ions in the wire target of a BSM [2]. The influence of the detached electrons essentially depends on the analyzed beam energy. In the majority of cases this influence is not essential for bunch core measurements but is of extreme importance for measurements of a longitudinal halo. Information on halo intensity is vital for the new generation of high intensity linear accelerators. That is why a special measure for diminishing the influence of the detached electrons has been foreseen in BSMs developed for the SNS linac. Due to the difference in energy of the low energy secondary electrons used for bunch shape measurements and the detached electrons, an effective way of diminishing the influence of the latter ones is energy separation of the two electron fractions [3]. The standard configuration of the BSM (fig. 1) was modernised by adding bending magnet 5 along with slit 6 between output collimator 4 and electron collector 7. Bending magnetic field is selected to provide separation of electrons with the energy corresponding to target potential U_{targ} (typically 10 kV) Separated energy range must be sufficient to provide loss-less propagation of the low energy secondary electrons. With the radius of 47 mm, the slit size of 3 mm and the image size of 1 mm the energy range equals about 20%.

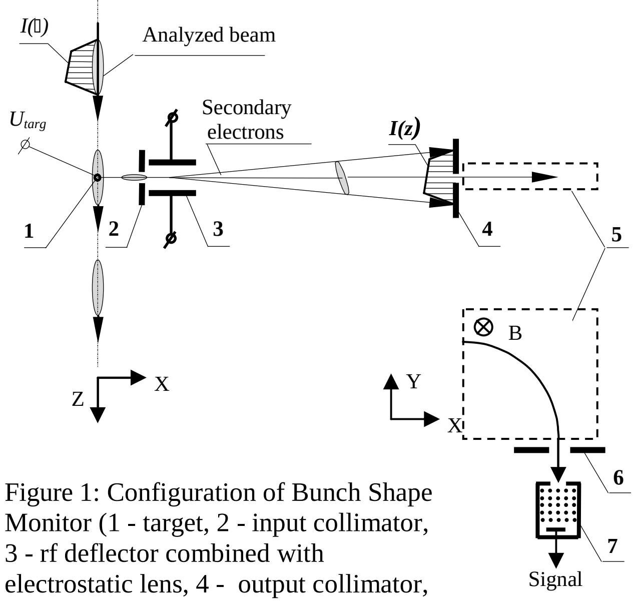

Figure 1: Configuration of Bunch Shape Monitor (1 - target, 2 - input collimator, 3 - rf deflector combined with electrostatic lens, 4 - output collimator, 5 – bending magnet, 6 – collimator, 7 – Secondary Electron Multiplier).

Energy separation also improves halo measurements due to decreasing the influence of electrons inelastically scattered on the plates of input collimator 2.

Three Bunch Shape Monitors have been built for the SNS linac. Now they are installed in intersegments 7, 9 and 11 of CCL Module #1. The first one, shown in fig. 2, was used during the commissioning of the DTL Tank 1 in autumn 2003.

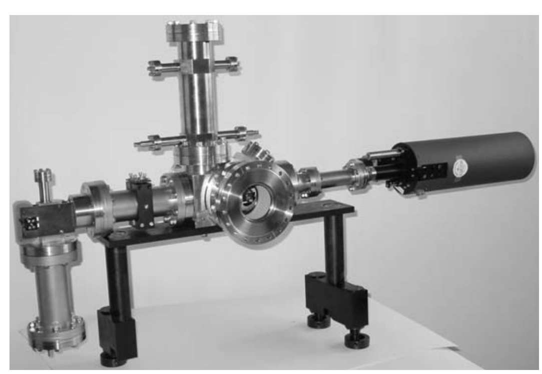

Figure 2: General view of BSM.

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EXPERIMENTAL RESULTS

The first BSM was installed in D-plate 1.27 m downstream of Tank 1 exit. Tank 1 is a 4.152 m drift tube cavity operating at 402.5 MHz and accelerating the beam from 2.5 MeV to 7.5 MeV. To avoid thermal destruction of a BSM wire target the beam pulse repetition rate and the beam pulse duration were limited to 2 Hz and 50 µs correspondingly. The pulse current was about 12-18 mA.

During the bunch shape measurement the phase of the deflecting field is adjusted between beam pulses: that is, different points of the longitudinal distribution are measured for different beam pulses. This feature implies a repeatability of beam parameters from pulse to pulse. A signal from the electron collector is digitized along the beam pulse. The result of the measurement is a two-dimensional array of data representing the evolution of the bunch shape within the beam pulse. A typical experimental distribution for nominal accelerator parameter settings is given in fig. 3.

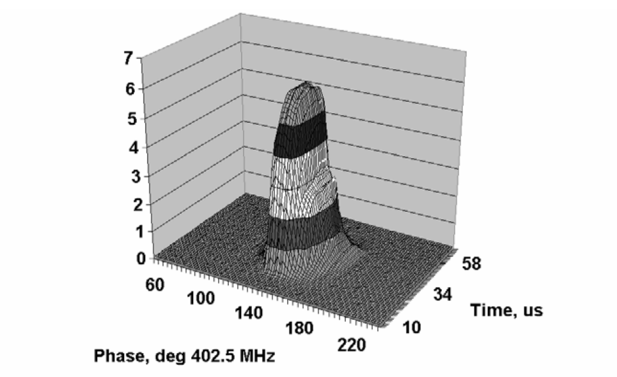

Figure 3: Typical evolution of bunch shape along the beam pulse.

Longitudinal Halo Measurements

To detect the electron intensity a Hamamatsu R596 Electron Multiplier 7 (fig. 1) is used. Changing of the multiplier supply voltage enables to adjust its gain over 5 orders of magnitude resulting in the possibility of more precise measurements of bunch tails. The results of bunch shape measurements done for relative gains 1, 5, 30 and 150 are shown in fig. 4. After removing the points with signal saturation at higher gains one can reconstruct the bunch and present it in a wide intensity range (fig. 5). A background level is also presented in fig. 5. The latter was measured with a decreased current of bending magnet 5 (fig. 1) to 75% of the nominal value. It was observed that variation of the bending magnet current below 90% of the nominal value does not change the background level.

After subtracting the background level a percentage of beam particles within a given phase range can be found (fig. 6). One should note that phase range of measurements of BSM is equal to half a period of the deflecting field: the signal from electron collector represents a superposition of two points in longitudinal distribution shifted by 180°. With this the result in fig. 6 is valid assuming that the amount of particles in a phase range shifted by 180° with respect to the bunch is negligible.

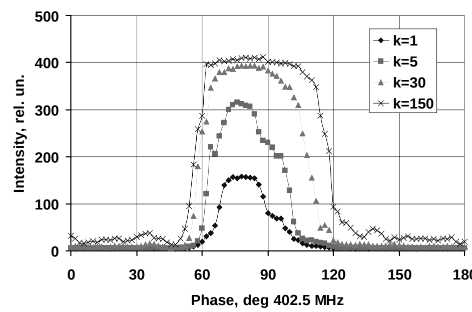

Figure 4: Result of Bunch Shape Measurement for different electron multiplier gains.

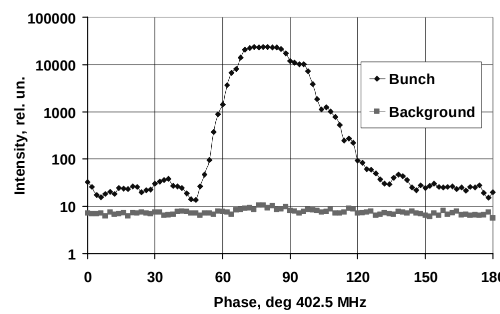

Figure 5: Presentation of bunch shape in a wide intensity range.

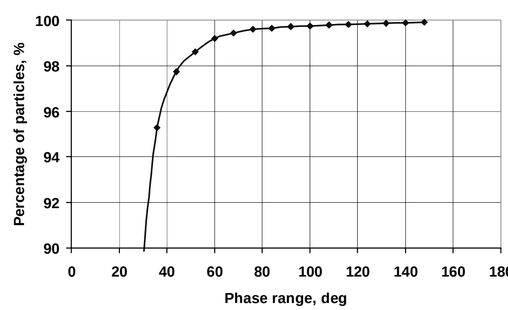

Figure 6: Particle portion as function of phase range.

Longitudinal Emittance Measurements

The method of longitudinal emittance measurement [4] is similar to the one widely used for transverse phase space. The emittance is found as an equivalent phase ellipse in the phase - energy plane using the results of several bunch length measurements downstream of the element(s) providing known linear transformation of the ellipse. To restore the ellipse at the entrance of Tank 1, bunch shape measurements were executed for different amplitudes of accelerating field with appropriate adjustment of tank phase to stay in the vicinity of the synchronous phase. The transformation matrix from Tank 1 entrance to the BSM position for different amplitudes was calculated numerically.

The calibration of amplitude was done by comparing the measured dependence of the variation of bunch center phase position Φ on Tank 1 phase shift φ with a calculated function. Indeed the derivatives $d\Phi/d\varphi$ of experimental and calculated functions were used for comparison. Fig. 7 shows bunch shapes measured for different tank phases and the behavior of bunch center. Comparing the tilt of experimental function $d\Phi/d\varphi$=1.45 at the inflection point with the theoretical curve (fig. 8), one can find the current accelerating field amplitude to be 1.02 of the nominal value. One should note that the tank phase corresponding to inflection point (φ =-124°) agrees well with the tank synchronous phase found preliminary using a phase scan method.

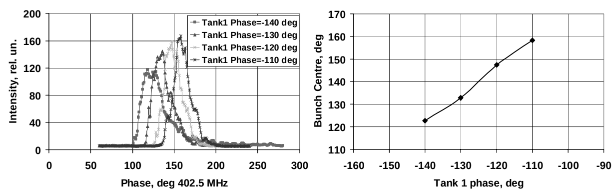

Figure 7: Bunch phase position for different Tank 1 phases.

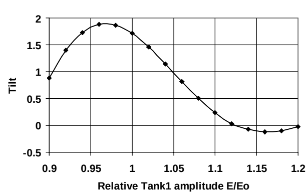

Figure 8: Theoretical dependence of $d\Phi/d\varphi$ on field amplitude.

Bunch shapes have been measured for eight Tank 1 amplitudes within the range of (0.96÷1.17) with respect to nominal value. The rms bunch length has been found for four cut off levels with respect to maximum: 0.025, 0.05, 0.1 and 0.2. The results of the measurements are summarized in Table 1.

Table 1: Results of bunch phase length measurements

Tank 1 Amplitude	Rms bunch phase length for different cut-off levels, deg			
	0.025	0.05	0.1	0.2
$1.17E_0$	21.0	18.6	16.2	13.6
$1.14E_0$	19.3	17.1	14.2	10.5
$1.11E_0$	16.0	14.0	10.9	7.6
$1.08E_0$	13.6	11.8	8.7	6.5
$1.05E_0$	9.8	8.8	7.6	6.6
$1.02E_0$	10.1	9.6	9.0	8.0
$0.99E_0$	15.5	14.1	12.5	9.8
$0.96E_0$	16.7	14.8	12.3	10.5

The values of rms bunch phase lengths were used to plot boundary lines of phase ellipse. These lines transformed to the entrance of Tank 1 for one cut off level are shown in fig. 9. The optimum ellipses inscribed inside the polygons produced by the lines are presented as well. The values of emittance for different cut off levels are given in table 2.

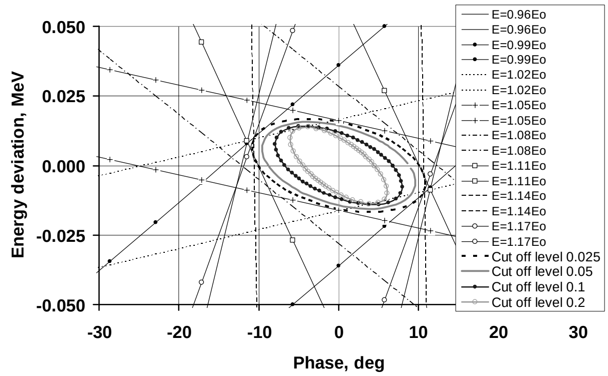

Figure 9: Phase ellipses at the entrance of Tank 1 for different cut off levels (The tangents are shown for 0.025 cut off level).

Table 2: Longitudinal emittance value

Cut off level	0.025	0.05	0.1	0.2
Emittance, MeV·deg	0.171	0.138	0.095	0.062

Figure 10 shows the ellipses for a cut off level of 0.05 transformed to the exit of Tank 1 and to the BSM position for nominal amplitude.

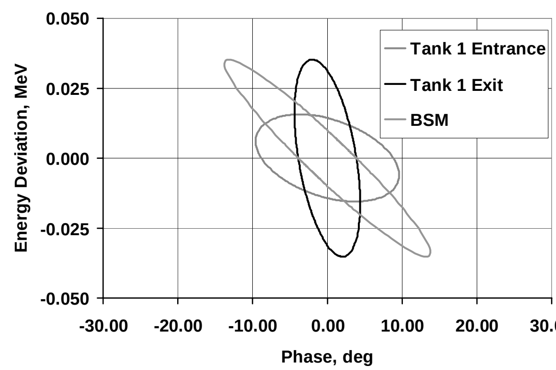

Figure 10: Phase ellipses at the entrance of Tank, the exit of Tank 1 and at the BSM position.

ACKNOWLEDGEMENTS

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