PECULIARITIES OF BUNCH SHAPE MEASUREMENTS OF HIGH INTENSITY ION BEAMS

A.V. Feschenko, V.A. Moiseev, Institute for Nuclear Research, Moscow, 117312, Russia.

Abstract

Bunch shape monitors with low energy secondary electrons transverse modulation have found a use for measurements of longitudinal distribution of charge in bunches for ion linear accelerators. Temporal bunch structure is coherently transformed into the spatial distribution of low energy secondary electrons through transverse rf scanning. The fields of the analyzed beam influence the trajectories of the secondary electrons thus resulting in a distortion of the transformation and hence to a deterioration of measurement accuracy. Two models have been used for the effect analysis. The results of simulations for variety of beam parameters are presented.

INTRODUCTION

Influence of electromagnetic field of the analyzed beam on bunch shape measurement accuracy has been estimated and analyzed elsewhere by several authors including the authors of this report [1-4]. However wide use of Bunch Shape Monitors (BSM), more strict requirements to the accuracy of measurements and a need to measure more intense beams results in a necessity of more detail studies of the effects.

There are two main errors of bunch shape measurements: phase resolution and phase reading error [4]. Electromagnetic field of the bunch is one of the reasons influencing phase resolution and is the only reason for phase reading error. Deterioration of phase resolution results in a loss of a fine longitudinal structure and phase reading error distorts the shape of the measured distribution.

As the majority of modern linear ion accelerators is intended for H^- ions acceleration we confined our study by an influence of H^- bunch fields. Influence of the fields of detached electrons was neglected.

In the simulation the bunch repetition frequency was taken to be 366 MHz which is something average for modern H^- linacs.

MODEL DESCRIPTION

The results of simulation depend on many parameters including beam current, beam energy, longitudinal and transverse bunch dimensions, beam position with respect to the target etc. as well as on BSM geometry. The geometry used is shown in Fig. 1. The basic dimensions correspond to those of existing or being developed BSMs. Target potential has been selected to be equal to -10 kV. To our opinion this is about the maximum value when a reliable detector operation is provided.

Target 1 represents a tungsten wire of 0.1 mm diameter fixed in two holders 5. Due to small diameter of the target electric field is concentrated in the vicinity of the target. Figure 2 shows the distance passed by secondary electron versus time (in 366 MHz degrees) as well as electron energy versus distance. One can see that the main effects occur in the vicinity of the target. Time of flight of the electron across the near target area is comparable with the typical bunch durations.

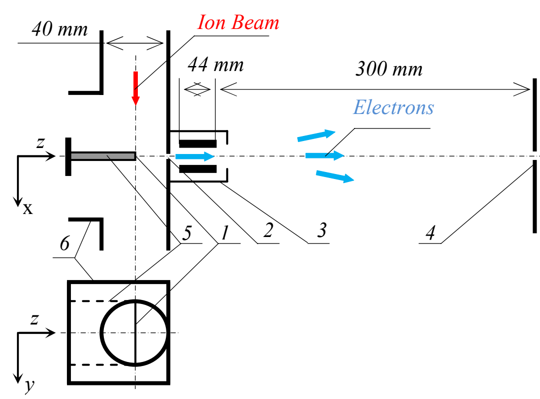

Figure 1: Geometry of the Bunch Shape Monitor (1-target, 2-input collimator, 3-rf deflector combined with electrostatic lens, 4-output collimator, 5-target holders, 6-detector chamber).

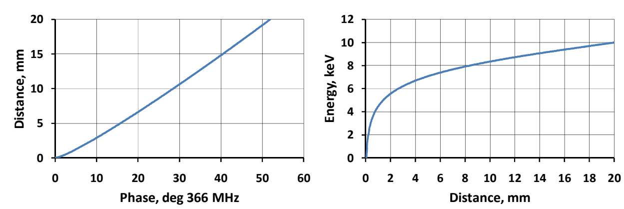

Figure 2: Distance passed by electron versus time and electron energy versus distance.

Two models have been used in the analysis of bunch field influence.

Model 1 described in [4] implies that the boundary conditions are kept constant while the bunch passes the detector chamber. The fields are found by multiple solving of a Poisson equation in the beam frame for fixed bunch positions as the bunch passes the chamber. Electrostatic fields found in the beam frame produce both electric and magnetic components in the lab frame. The field effecting secondary electrons is represented as a superposition of electromagnetic field of the bunch and an unperturbed electrostatic field due to target HV potential. The assumption about invariability of boundary conditions requires additional explanations. The most critical element is thin wire target. Target potential keeps constant if an appropriate charge distribution in the wire is provided by the current flowing in the wire connected to more massive target holders. We suppose that the target potential is kept invariable and hence the described model is valid if the time of flight of the bunch through the wire $\Delta\Phi/(360 f)$ is essentially smaller than the time of signal propagation from the target center to the holders $L/(2c)$. Here $\Delta\Phi$ is the bunch duration (deg), f - bunch repetition frequency, L - target length and c - velocity of light. In our case L =45 mm and the model is supposed to be valid for $\Delta\Phi$ essentially larger than 10º.

Model 2 is used if $\Delta\Phi/(360 f)$ is smaller than $L/(2c)$. In this case the charge distribution providing invariability of target potential has no time to be formed. Electrostatic fields of the bunch in the beam frame are found by Poison equation multiple solving for boundary conditions with the target absence. The field effecting secondary electrons is found similarly to the first model as a superposition of electromagnetic field of the bunch and an unperturbed electrostatic field due to HV potential applied to the target.

To estimate applicability of the models we also use the approach described in [4]. The target is considered as a transmission line. The current in the wire keeping invariable target potential results in arising of traveling wave of the voltage. If the voltage amplitude multiplied by electron charge is much smaller than electron energy modulation by the bunch fields in the first model then we suppose that the first model is applicable. This approach with transmission line consideration is not quite correct because typical wavelengths are smaller than typical system transverse dimensions. However, as the main fields are concentrated in the vicinity of the wire and the main effects also occur in this area we believe that this approach is acceptable.

SIMULATIONS

Space charge distribution in bunches was supposed to be a three dimensional truncated Gaussian one. Initial electron energy emitted from the wire was set according to a typical energy distribution of low energy secondary electrons and initial direction – uniform within a hemisphere. The simulations have been done for ten sets of H^- beam parameters and two models (Table 1). The parameters σ_y, σ_z and σ_φ are transverse and longitudinal rms bunch dimensions; z_0 is bunch center displacement with respect to the target (coordinates according to Fig.1). The simulations have been done for beam currents of 0 mA, 10 mA, 25 mA, 50 mA and 100 mA.

At the first stage the electron motion is simulated for the area from the target to the input collimator. Intensity of the secondary electrons increases with increasing of input collimator size. However increasing of collimator size deteriorates phase resolution. As for phase reading error, it is independent of input collimator size. The simulations have been done for 0.5 mm input collimator which is sufficient for most practical cases.

At the second stage the electron motion from the input collimator to the output collimator is simulated. Initially an optimum focusing potential applied to the deflector plates providing the best focusing of all the electrons at the output collimator plane for zero deflecting field is found. Then the simulations are done for different points along the bunch with the deflecting field turned on for an optimum focusing potential. Phase resolution is evaluated as $\Delta\varphi = \dfrac{2\sigma_L}{X_{\max}}$, where σ_L is an rms size of electron beam at the output collimator plane for the electrons knocked out of the target by the ions belonging to a definite longitudinal point of the bunch, $X_{\max}$ is an amplitude of electron deflection by rf deflecting field. Phase reading error arises due to variation of time of flight of electrons from the target to the deflector for different points along the bunch. The effect results in changing of beam position δX_L at the output collimator plane and phase reading error can be found as $\delta\varphi = \dfrac{\delta X_L}{X_{\max}}$. All the simulations have been done for rf deflecting voltage of 1000 V which is about an optimum value for the selected geometry.

Table 1: Beam parameters and models used for simulation.

	1	2	3	4	5	6	7	8	9	10
Energy, MeV	3	100	200	200	200	200	200	200	200	1000
σ_y, mm	2.6	1.5	1.2	1.2	1.2	2.4	1.2	1.2	1.2	1.2
σ_z, mm	2.6	1.5	1.2	1.2	1.2	2.4	1.2	1.2	1.2	1.2
σ_φ, deg	13	2	1.1	2.1	4.1	1.1	1.1	1.1	1.1	1.1
z_0, mm	0	0	0	0	0	0	1	-1	0.5	0
Model	1	2	2	2	2	2	2	2	2	2

SOME RESULTS OF SIMULATIONS

Figure 3 shows an example of energy deviation at the input collimator as well as deviation of time of flight from the target to the input collimator versus longitudinal position in the bunch for parameter set #3 (Table 1). Head of the bunch corresponds to negative phases.

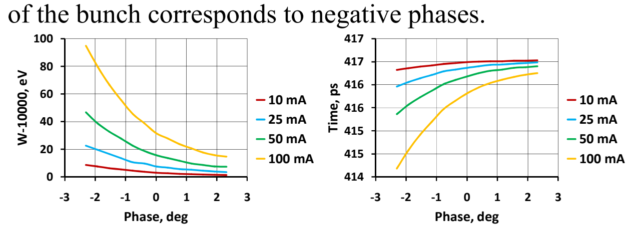

Figure 3: Energy deviation and time of flight of electron from target to input collimator for beam parameter set #3.

Figures 4 through 13 show a behavior of phase resolution and phase reading error along the bunch for beam parameter sets 1÷10. Comparing Fig. 3 and Fig. 6 one can observe a similarity of behavior of phase reading error to energy and time of flight deviations.

Figure 14 shows the results for the distance from the target to the input collimator increased by 30 mm. Due to concentration of the fields in the vicinity of the target the 30 mm distance was considered as an extra drift space.

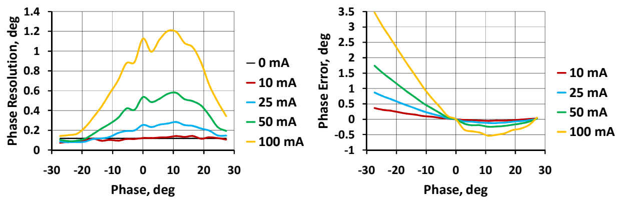

Figure 4: Resolution and phase reading error for set 1.

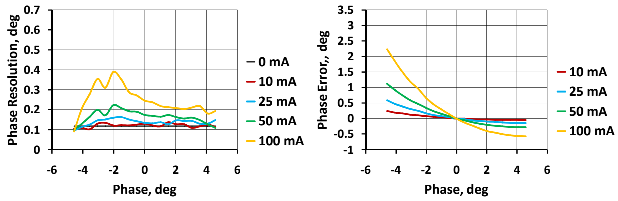

Figure 5: Resolution and phase reading error for set 2.

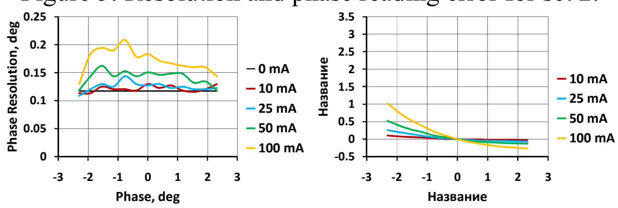

Figure 6: Resolution and phase reading error for set 3.

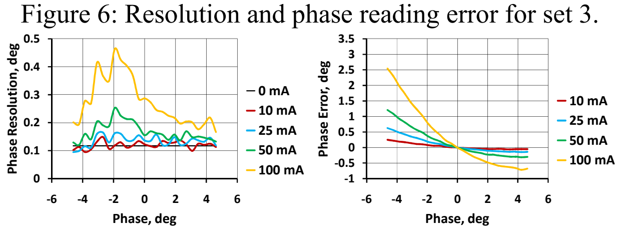

Figure 7: Resolution and phase reading error for set 4.

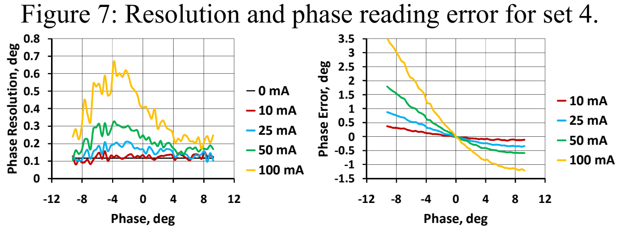

Figure 8: Resolution and phase reading error for set 5.

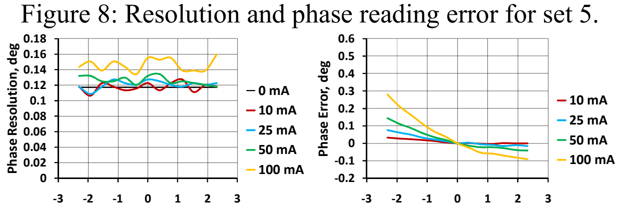

Figure 9: Resolution and phase reading error for set 6.

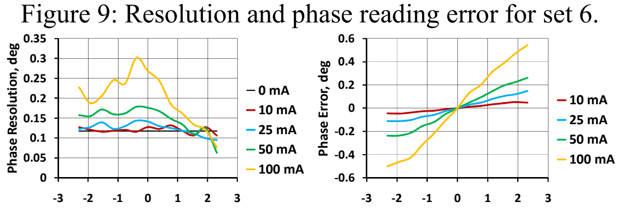

Figure 10: Resolution and phase reading error for set 7.

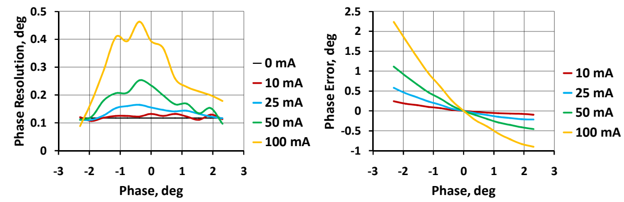

Figure 11: Resolution and phase reading error for set 8.

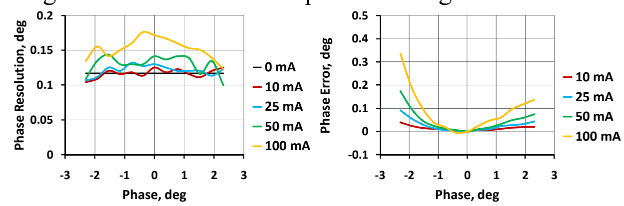

Figure 12: Resolution and phase reading error for set 9.

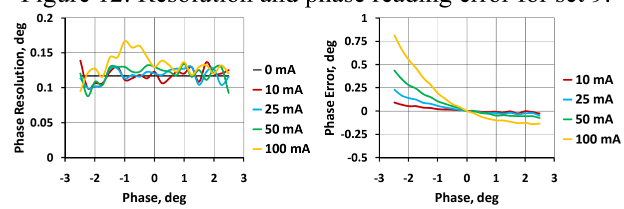

Figure 13: Resolution and phase reading error for set 10.

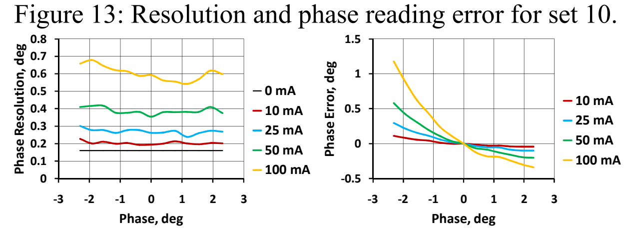

Figure 14: Resolution and phase reading error for set 3 with increased distance from target to input collimator.

CONCLUSION

Generally there are two errors of bunch shape measurement: phase resolution and phase reading error. Evaluation of these errors represents a multiparametric problem which can not be solved for general case but for definite parameters only. Nevertheless one can conclude that the errors decrease with decreasing of both longitudinal and transverse bunch dimensions and increasing of energy due to decreasing of duration of interaction of secondary electrons with the bunch. One should note that for monotonically decreasing function of phase reading error the measured bunch duration is smaller than a real one.

REFERENCES

[1] V.Vorontsov, A. Tron. Proc of the 10th All-Union Workshop on Part. Acc. Dubna 1986, V.1, pp.452-455 (in Russian).

[2] A.Tron, I.Merinov. Proc. of the 1997 PAC, Vancouver, 1997, V.2, pp.2247-2049.

[3] E.McCrory et al Proc. of the XVIII Int. Linear Acc. Conf., Geneva, 1996, pp.332-334.

[4] A.V.Feschenko, V.A.Moiseev. Proc. of XX Int. Linac. Conf., Monterey, Ca, 2000, pp.178-180.