DISTORTION OF ION BEAM PROFILE MEASUREMENTS DUE TO THE SPACE CHARGE

M.E. Dolinska, N.L. Doroshko

Institute for Nuclear Research, Kiev, Ukraine
e-mail: kinr@kinr.kiev.ua

The results of the analytical and numerical calculations are presented in order to estimate the space charge effect influence on the beam profile measurements during carrying out the diagnostic procedure with the intense ion beams at the RF accelerators.

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1.INTRODUCTION

There are many methods for non-destructive beam profile monitoring taking advantage of the residual gas ionization. But usually one has to examine the effect of space charge on the corresponding trajectories of the collected particles. Because it is possible to receive the deformed information about a registered beam structure (see Fig. 1), if it is not taken into account the action of bunches space charge forces at carrying out of such measurements.

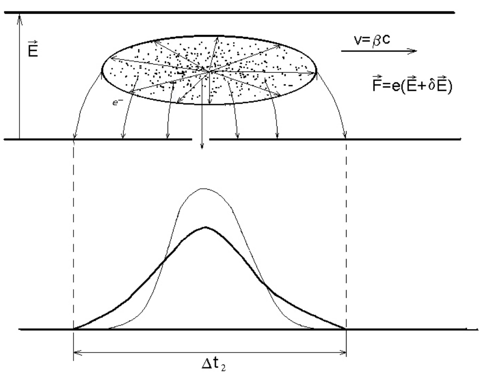

Fig. 1. *Action of the bunch space charge at the beam profile monitoring results. Top: ideal profile without space charge action; bottom: real distortion profile due to space charge effect*

To estimate space charge effects of the intense particle beams the electrical fields of moving bunches should be considered. At the last authors papers [1-3] the analytical definitions for the potential and electric field strength of the bunches with different configuration was given. In this work the trajectories of electrons and ions created within bunches by residual gas ionization are calculated taking into account the periodical electrical field of the moving bunches as well as constant collecting field of a residual gas ionization profile monitor. Some results of numerical calculations for the arrival positions of residual particles are presented.

2. DISTORTION OF COLLECTING ELECTRONS DIAGNOSTICS

In principle there are two different methods as far as the collected particle are considered. First one is collecting electrons and the second one is collecting of residual ions (this method will be described at the next chapter). It is known that the results of the collecting electrons methods have a good time resolution.

At this work the arrival position of residual electrons was calculated in order to estimate the space charge effect during carrying out the beam profile measurements in longitudinal direction at the diagnostic monitor, which was developed at GSI (Darmstadt, Germany). The scheme of such monitor to measure the time structure of bunches behind the high current linac of GSI is presented at Fig. 2 [4-6]. Since a time resolution in the order of some 10 ps is required for these measurements, the device is based on the collection of electrons being extracted by an external field of 600 V/mm. After passing the first analyzing slit, located 35 mm from the beam axis, the electrons within a given *Δp/p* pass the slit behind the electrostatic analyzer and are flayed rf-synchronously over a multi channel plate (MCP) which transforms the time information in a geometric one (according to the principle of a streak-camera [5]).

Obviously, the influence of the space charge results in a deflection of the electrons during their path to the first slit. In order to define the deviation of electrons from the required position of arrival, assuming a moving bunch, one has to solve the differential equations for the moving electron at the electric field of bunches. The similar problem already was solved in order to describe the oscillations of the charged particles created within a bunch [2].

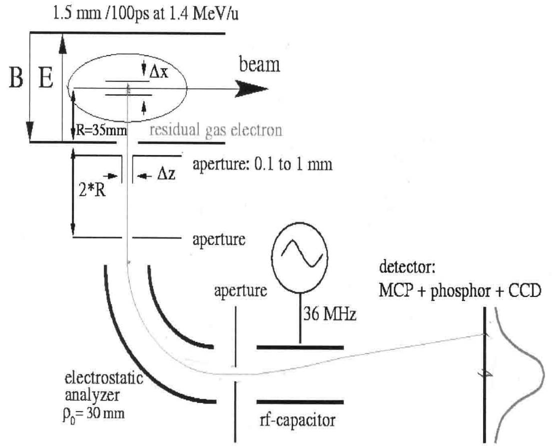

***Fig. 2.** Scheme of a bunch shape detector ([5])*

Here it is assumed the spherical shape bunches with velocity $\beta = 0.055$, radius $R = 10$ mm and parabolic charge distribution. The nonlinear differential equation for an oscillator, which describes the electron movement, is [2, 3]:

$$\ddot{z} = -\omega^2\left(\frac{5}{2}(z-\beta ct) - \frac{3(z-\beta ct)^3}{2R^2}\right), \qquad (1)$$

where z - longitudinal coordinate, t – time, ω - cyclic frequency. The equation (1) has the solution:

$$z(t) = \frac{v_z(0) - \beta c}{\omega}\sin(\omega t) + z(0)\cdot\cos(\omega t) + \beta ct, \quad (2)$$

where $z(0)$ and $v_z(0)$ – initial electron coordinate and velocity. In our case the electron starts in rest within the moving bunch with the initial parameters $x(0) = y(0) = 0$ – transversal coordinates, $v(0) = 0$ and $z(0) \neq 0$. Fig. 3 shows the calculated electrons deviation, using analytical presentation (2) for the U^{4+} beam with 10^9 ions within one bunch.

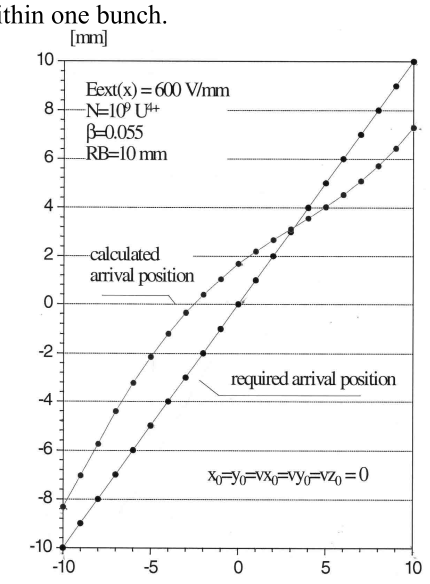

***Fig. 3.** Effect of the space charge on the trajectories of collected electrons (in horizontal axis is initial longitudinal coordinate along z – axis, mm)*

Obviously the trajectories distortions due to the space charge effect are in an order of magnitude that the monitor would not work good enough. The effect can be reduced by introducing a magnetic field in parallel to the electric one (see Fig. 2).

3. COLLECTING N_2 AND H_2 RESIDUAL IONS

In comparison to a monitor collecting electrons we have to consider such differences. The mass of N_2 and H_2 ions is much larger and therefore the deflection will be smaller. But, due to the lower velocity of the ions (assuming the same collecting field strength) we have to consider the action of more than one bunch.

It is assumed the same beam and bunches parameters as a previous chapter. Fig. 4 shows the calculated electrical fields acting on a Hydrogen ion starting in rest at position $x(0) = -7$ *mm* (about the maximum of field strength for parabolic intensity distribution within a sphere bunch [1]), $y(0) = 7mm$ and $z(0) = 0$, assuming a collecting field strength of 100 V/mm in x-direction. Such value of the collecting field is a typical for the diagnostic monitor GSI, which is used to carry out of the beam profile measurements in transversal directions [5].

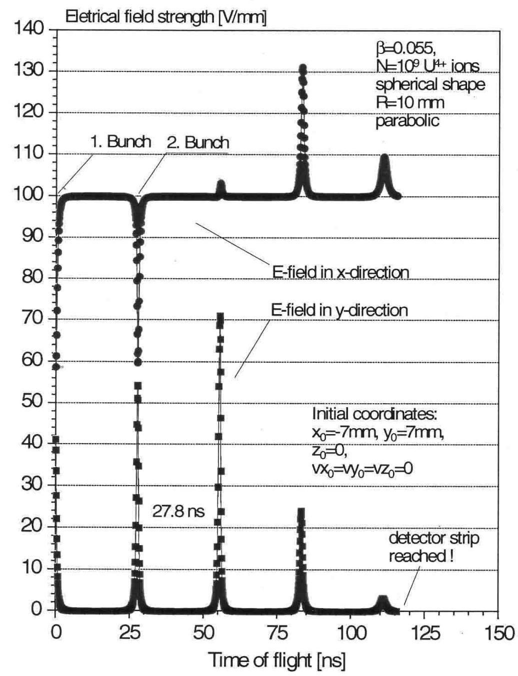

***Fig. 4.** Electrical field strength from a moving chain of U^{4+} bunches acting on a hydrogen ion*

Obviously, for the first two bunches acting on the hydrogen ion, the space charge reduces the collecting field strength, because the ion starts at the point $x = -7$ *mm*, where the space charge field repels the ion. Seeing the third bunch, the ion has crossed $x = 0$ and therefore, the space charge field adds to the collecting field. Of course, the action of the x-component of the electric field will only influence the time of flight to the detector strips, which will not influence the resolution of the monitor. On the other hand, the measured profile will be distorted by the action of the y-component of at least five bunches, which act always in the same direction shifting the y-coordinate.

Fig. 5 shows the space charge effect concerning the distortion of the trajectory of the Hydrogen ion. This calculation was made by numerical methods. Again it would be possible to improve the resolution by a parallel magnetic field. But since the effect of distortion shown in Fig. 5 is small it has been neglected in this case.

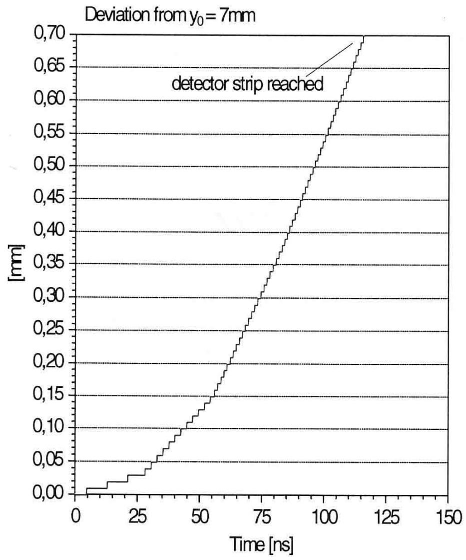

Fig. 5. *Effect of space charge of a moving chain of bunches on the trajectory of a Hydrogen ion*

4. CONCLUSIONS

Although analytical and numerical methods have to be applied to estimate the effects of space charge on the trajectory of residual electrons and ions, the analytical formulas from [1-3] may be needed for the description of the bunch fields in the numerical algorithm.

As the calculated have shown, effect of space charge have to be considered in each case if the corresponding space charge field are in the order of 10% of the external collecting field.

Since we have restricted us to low velocities of the moving bunches in this paper no relativistic effects have to be taken into account.

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ИСКАЖЕНИЕ РЕЗУЛЬТАТОВ ИЗМЕРЕНИЙ ПРОФИЛЯ ИОННОГО ПУЧКА ПОД ВЛИЯНИЕМ ПРОСТРАНСТВЕННОГО ЗАРЯДА

М.Э. Долинская, Н.Л. Дорошко

Представлены результаты аналитических и численных расчетов для оценки влияния эффекта пространственного заряда на результаты профильных измерений во время проведения диагностических процедур с высокоинтенсивными пучками на ВЧ-ускорителях.

СПОТВОРЕННЯ РЕЗУЛЬТАТІВ ВИМІРЮВАНЬ ПРОФІЛЮ ЙОННОГО ПУЧКА ПІД ВПЛИВОМ ПРОСТОРОВОГО ЗАРЯДУ

М.Є. Долінська, Н.Л. Дорошко

Наведено результати аналітичних та чисельних розрахунків для оцінки впливу еффекту просторового заряду на результати профільних вимірювань під час проведення діагностичних процедур з високоінтенсивними пучками на ВЧ-прискорювачах.