IMPLEMENTATION OF LONGITUDINAL DYNAMICS WITH BARRIER RF IN BETACOOL AND COMPARISON TO ESME

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Abstract

The barrier bucket RF system is successfully used on Recycler storage ring at Fermilab. The special program code ESME [1] was used for numerical simulation of longitudinal phase space manipulations. This program helps optimizing the various regimes of operation in the Recycler and increasing the luminosity in the colliding experiments. Electron and stochastic cooling increases the phase space density in all degrees of freedom. In the case of a small phase space volume the intrabeam scattering introduces coupling between the transverse and longitudinal temperatures of the antiproton beam. For numerical simulations of the cooling processes at the Recycler, a new model of the barrier buckets was implemented in the BETACOOL code [2]. The comparison between ESME and BETACOOL codes for a stationary and moving barrier buckets is presented.

This article also includes an application of the barrier bucket numerical model for simulation of the luminosity distribution for RHIC colliding experiments. These simulations take into account the specific longitudinal distribution of the bunch and the vertex size of the detector.

BARRIER BUCKET MODELS IN THE BETACOOL PROGRAMM

Currently, the BETACOOL code has three algorithms that describes the synchrotron motion of the particles and which can be used for the simulation of the barrier bucket (BB) models. The first algorithm solves the standard equations of motion in the longitudinal phase space(s-s_0, $\delta=\Delta p/p$). The equations are:

$$\begin{cases} \dfrac{d(s-s_0)}{dt} = |\eta|\beta c\delta \\ \dfrac{d\delta}{dt} = -\dfrac{ZeV(t)}{Cp_0} \end{cases} \qquad (1)$$

where βc is the ion velocity, η is the ring off-momentum factor, Ze – the particle charge, $V(t)$ – the dependence of RF voltage on time, C – the ring circumference and p_0 – the momentum of the particles.

In the context of this algorithm the longitudinal motion any arbitrary RF voltage shape can be simulated. However, the problem of this algorithm is the calculation time because the integration step should be much smaller than the synchrotron period.

To avoid this problem, the analytical solution of the longitudinal motion between two square barrier buckets was introduced. In this case, the integration step can be independent on the synchrotron period. When the ion passes through the cavity gap at voltage $\pm V_0$ it gains (losses) an equal amount of energy ZeV_0, i.e.

$$\frac{d(\Delta E)}{dt} = \pm\frac{ZeV_0}{T_0} \qquad (2)$$

where ΔE is the energy deviation from the synchronous one, T_0 – the revolution period. The ion trajectory in the longitudinal phase space (t-t_0, ΔE) inside the bucket can be written in the following form:

$$(\Delta E)^2 = \begin{cases} A_E^2, \quad if\ |t-t_0| \le T_2/2 \\ A_E^2 - \left(|t-t_0| - \dfrac{T_2}{2}\right)\dfrac{2\beta^2 E_0 ZeV_0}{T_0|\eta|}, \\ \qquad if\ T_2/2 \le |t-t_0| \le (T_2/2)+T_1 \end{cases} \qquad (3)$$

where A_E is the maximum energy deviation from the synchronous energy E_0, V_0 is the voltage height, T_1 is the pulse width, T_2 is the gap duration. The phase space trajectory is composed of a straight line in the RF gap region and a parabola in the square RF wave region

The analytical model has static potentials for the barrier bucket with a rectangular shape which is resolved analytically in the longitudinal phase space. However, using of the analytical model is very difficult for the case of a moving bucket with an arbitrary shape.

A numerical model of the RF bucket is implemented in the BETACOOL code where the motion of one particle through each barrier is calculated independently. After crossing of the barrier the particle energy can increase (Fig.1a), decrease (Fig.1b) or the particle can be reflected by the barrier (Fig.1c).

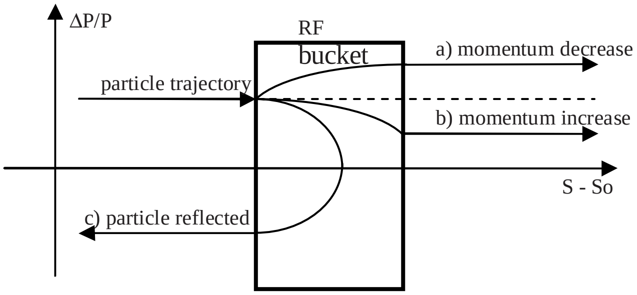

Figure 1: Particle trajectories trough a RF barrier in longitudinal phase space.

For the description of the individual synchrotron motion of each particle one can use a series of the barriers and numerical integration over the longitudinal phase

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is much higher than the amplitude of the RF voltage. Note that in real RHIC experiments satellites are not as strongly pronounced as in Fig. 11 [3]. In Fig. 11, the distribution was intentionally strongly cooled to produce clearly pronounced satellites for illustration purposes.

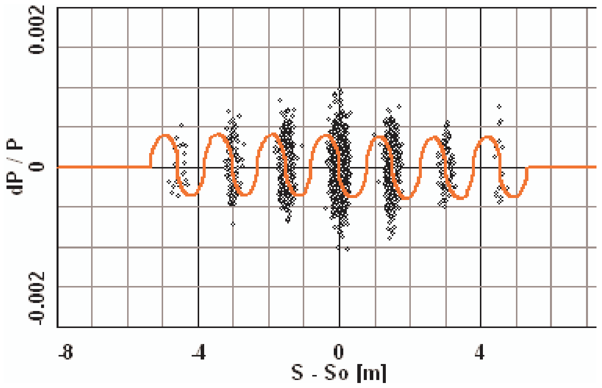

Figure 11: Particle distribution with satellites in longitudinal phase space.

Additional satellites are produced in neighbouring potential wells are due to the sum of two harmonics of the RF system (Fig.12). The luminosity calculation for such a specific particle distribution was implemented in the BETACOOL program (Fig.13). The time dependence can be calculated via the particle velocity. Note that the interaction region is twice smaller than the total bunch length.

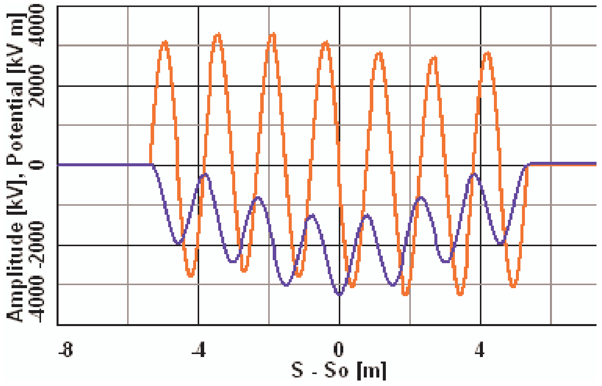

Figure 12: Distribution of the RF voltage as the sum of low and high RF harmonics (red line) and corresponding potential distribution (blue line).

The vertex cut defines as the interaction region where the colliding events can be registered (Fig.14). This algorithm permits to numerically calculate the hourglass effect for an arbitrary particle distribution in the longitudinally phase space. For example for Fig.13 and Fig.14 the hourglass effect factors are 0.76 and 0.75, respectively.

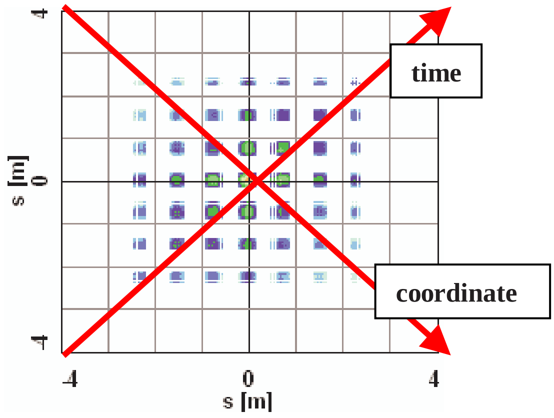

Figure 13: Luminosity distribution for colliding experiments without vertex cut.

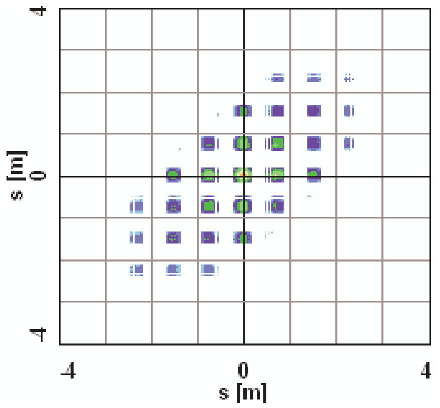

Figure 14: Luminosity distribution for colliding experiments with vertex cut (±100 cm).

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