NUMERICAL STUDIES ON THE INFLUENCE OF FILL PATTERNS ON ION CLOUDS*

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Abstract

Energy Recovery Linacs (ERLs) are the most promising candidates for next-generation light sources now under active development. An optimal performance of these machines requires the preservation of the high beam brightness generated in the injector. For this, the impact of the ionized residual gas on the beam has to be avoided as it causes instabilities and emittance growth. Obviously, the vacuum chamber has to be cleared out of ions but as the potential of the electron beam attracts the ions, it is not enough to install vacuum pumps.

One measure for ion clearing is the generation of gaps in the bunch train. In this paper, we present numerical studies of the behavior of an ion cloud that interacts with bunch trains taking into account the effects of the clearing gaps. In the studies different longitudinal distributions for the particles in the bunch and different “fill patterns” i.e. different spacings of the clearing gaps are investigated. The simulations are performed with the software package MOEVE PIC Tracking developed at Rostock University where recently new features for the simulation of ion effects have been implemented. The presented numerical investigations take into account the parameters of the ERL B*ERL*inPro with the objective to deduce appropriate measures for the design and operation of B*ERL*inPro.

INTRODUCTION

The expected extraordinary performances of the next generation light sources, such as ERLs, require intense hight brightness electron beams. Therefore, the ion-caused instabilities and emittance growth degrading the beam quality are serious threats to these sources and have to be avoided.

In an electron accelerator, several effects like collision with the electron beam, synchrotron radiation and field emission can lead to ionization of the rest gas in the beam pipe. The negative potential of the electron beam can trap the positive ions which in turn leads to an increase of the beam halo, to emittance blowup and to transverse and longitudinal instabilities by interacting resonantly with the beam. There are several measures of avoiding the ion-trapping such as utilizing clearing electrodes or using short or long clearing-gaps. A long gap between two trains of high-repetition rate bunches allows for ions to drift out of the beam potential and thus to reach the wall of the vacuum chamber, while a short clearing-gap causes large oscillations of ions around the beam which in turn clears the vicinity of the bunches from the ions.

Table 1: Main Parameters of B*ERL*inPro

maximum beam energy	50 MeV
maximum beam current I	100 mA
nominal beam charge Q	77 pC
maximum repetition rate	1.3 GHz
normalized emittance	10^{-6} m
bunch length σ_t	2 ps
vacuum pressure	10^{-10} mbar

However, the applicability of the long-gap approach in ERLs suffers from two effects. The first effect is the transient effect of the RF systems which requires very long ion-clearing-gaps [1]. The second effect is the fast beam-ion instability. This is because a long gap does not preclude ions from accumulating in a single bunch train and interacting resonantly with the beam [1, 2]. Therefore, short clearing-gaps seem to be favorable, in particular as experimental and numerical studies indicate that multibunch trains with short gaps are very effective in suppressing the ion trapping process [3]. Please note that in an ERL, also for a short clearing-gap the transient RF effects have to be avoided by ensuring that the clearing-gap in the accelerating and in the decelerating beam coincide.

Although short bunch gaps in the ERL-beam allow for suppression of the ion accumulation in the vicinity of the beam, they are not totally welcome because they change the cw characteristics of the radiation delivered by the ERL. Therefore, to keep the time characteristic as cw-like as possible, frequent but extremely short bunch gaps are favorable. In the presented paper we study whether a bunch gap as short as one accelerating bucket occurring very frequently can excite oscillations large enough to clear the vicinity of the beam. For this, we use the software package MOEVE PIC Tracking [4, 5] to investigate numerically the behavior of an ion cloud that interacts with bunch trains with short gaps betwixt. For the simulations the parameter settings planned for B*ERL*inPro [6] have been used. The parameters that are relevant for the simulations in this paper are given in the Table 1.

SIMULATION TOOL MOEVE

For the presented study, the behavior of an ion cloud that interacts with bunch trains and clearing-gaps has been sim-

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ulated with a further development of the software package MOEVE PIC Tracking [4, 5]. It tracks particles, where the space charge fields are taken into account in each time step of the tracking procedure. For more details we refer to [4, 7] and citations therein.

The electron beam parameters for the simulations are chosen according to the nominal B*ERL*inPro parameters published in [6]. The electron bunch is modelled with 100,000 macro particles using Gaussian and uniform distributions of cylindrical shapes. For the generation of these distributions the program *generator* of the tracking code ASTRA was applied [8].

In this study we restrict the model of the ion cloud to H_2^+ ions with a relative atomic mass of $A = 2$. Since the residual gas consists mainly of H_2^+ these ions are the most relevant species for investigations of ion effects in B*ERL*inPro. The density of the ion cloud was taken with $2.4 \cdot 10^6\ \mathrm{cm}^{-3}$ according to a vacuum pressure of $10^{-10}\ \mathrm{mbar}$. Hence, the ion cloud was modelled with 85,000 ions per cm.

SINGLE-BUCKET CLEARING-GAPS

Assuming that the ions are generated with near thermal velocities, it is a simple conclusion that they are not free to drift in the vacuum chamber. They experience the space charge potential of the electron beam as long as the beam is not fully neutralized. Of course there are also additional external magnetic fields such as dipole and quadrupole fields which we omit in the presented study. Their effects on the ions are subject to further studies in future. The beam potential – to be specific the electric field component of the electron beam – attracts the ions towards the centre of the beam thus causing transverse oscillations of the ions with an amplitude given by their transverse position at "birth" [9].

In contrary to a long clearing-gap which allows for the ions to fully escape the beam potential and reach the chamber wall, in a short clearing-gap the ions have not enough time to escape the beam. However, the short gap gives the beam potential a time structure. This leads to a time dependent attractive force with many frequency components which in turn excites large ion oscillations clearing the vicinity of the beam [1, 3].

However, also very short clearing-gaps change the cw characteristics of the electron beam. In order to keep the time characteristic as cw-like as possible, frequent but extremely short bunch gaps are favorable. This rises the question whether a bunch gap as short as one bunch occurring very frequently can excite oscillations large enough to clear the vicinity of the beam.

Figure 1 represents simulation results for three different repetition rates of the single-bucket-gaps in the B*ERL*inPro beam. It shows the transverse oscillation amplitude of the ion cloud around the beam as a function of time for each gap repetition rate. In the top of Figure 1 the single-bucket-gap occurs every 1000^{th} bunch. For better comparison, the case without clearing-gaps is also shown. The effect of the

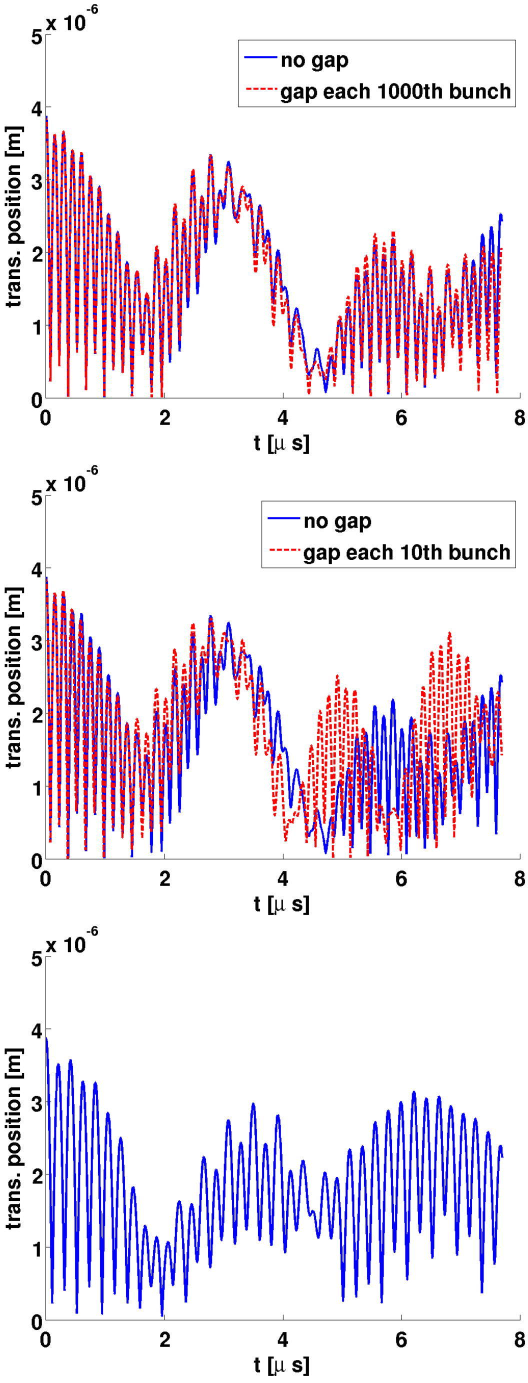

Figure 1: Transverse oscillations of an ion cloud around the beam as a function of time for three different repetition rates of the single-bucket-gap. In the top figure the single-bucket-gap occurs every 1000^{th} bunch, in the middle every 10^{th} bunch and in the bottom figure every second bunch. The longitudinal electron distribution is Gaussian and the beam parameters are given in Table 1.

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clearing-gap seems to be very small in this case. The second plot of Figure 1 shows the oscillation amplitude when the single-bucket-gap occurs every 10^{th} bunch. There is an increase in the oscillation amplitude nicely visible after some few microseconds and also a change in the oscillation frequency. However the increase in the amplitude is not strong enough to clear significantly the vicinity of the beam. A clearing-gap occurring every second bunch, shown in the bottom of Figure 1, does not seem to increase the oscillation amplitude either. Please note that the average current of the beam has been kept constant in these simulations by increasing the bunch charges accordingly. However, this correction has not been applied to the last case, where the clearing-gap occurs every second bunch. This is because an increase of a factor of two to the bunch charge would change bunch dynamics in B*ERL*inPro significantly and can not be assumed without further investigation on bunch dynamics. The bunches used for these simulations have Gaussian longitudinal profiles. Their other parameters are listed in Table 1.

Figure 2 represents simulation results for two different repetition rates of the single-bucket-gap. The bunches used for these simulations have uniform longitudinal profiles. In the top of Figure 2 the single-bucket-gap occurs every 1000^{th} bunch. Similar to the Gaussian case, also for a uniform longitudinal distribution, the effect of the clearing-gap seems to be rather small. The oscillation amplitude for single-bucket-gap occurring every 10^{th} bunch, shown in the bottom of Figure 2, is not strong enough to clear significantly the vicinity of the beam.

CONCLUSION

We have presented numerical studies investigating the effect of a single-bucket clearing-gap on ion clouds interacting with a high repetition rate multibunch beam. In the studies different longitudinal distributions for the particles in the bunch and different spacings of the clearing-gap have been investigated. The simulations were performed with the software package MOEVE PIC Tracking. The parameters of the ERL B*ERL*inPro have been used for the studies. Although the single-bucket-gap clearly leads to an increase of the ion oscillation amplitudes around the beam, the excited amplitudes are not large enough to clear the beam vicinity of ions. We conclude that either the clearing-gap has to be longer or other clearing measures such as utilizing clearing electrodes have to be envisaged for the operation of B*ERL*inPro.

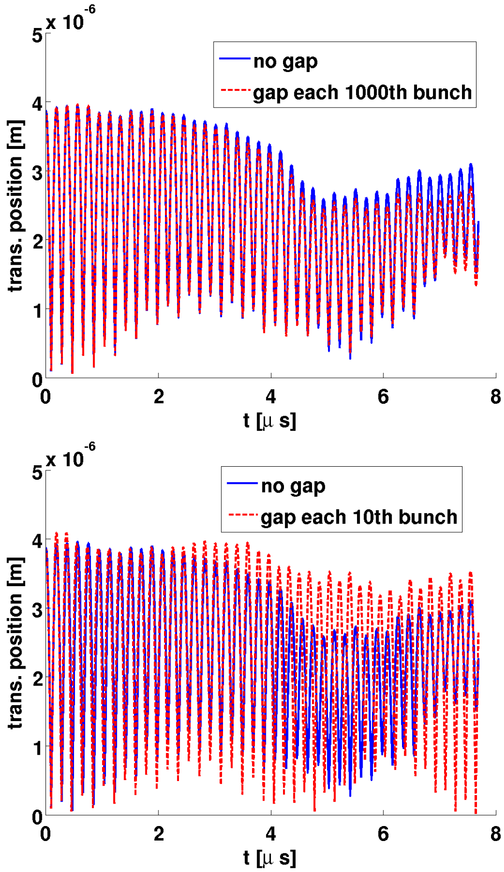

Figure 2: Transverse oscillation of an ion cloud around the beam as a function of time for uniform longitudinal electron distributions. In the top figure the single-bucket-gap occurs every 1000^{th} bunch, in the bottom every 10^{th} bunch. The beam parameters are given in Table 1.

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