ELECTRON CLOUD BUILD UP IN COASTING BEAMS

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Abstract

Electrons could in principle accumulate around coasting beams of positively charged particles until a balance between the beam force and space charge force from the electrons is reached.

But the continuous interaction between a non-ideal coasting beam and the growing cloud of electrons around it, and the reflection and secondary emission processes at the inner pipe wall, can alter this picture and cause a combined cloud or beam transverse instability long before the concentration of electrons reaches the theoretical equilibrium value. The issue is addressed in this paper by means of combined build-up and instability simulations carried out with the HEADTAIL code, with applications to SIS18 and RAL-ISIS

INTRODUCTION

We study the possibility of electron cloud build up around a coasting beam. When the beam distribution is uniform along z, we can expect the electrons generated via residual gas ionization and/or proton/ion losses at the walls, to accumulate up to saturation in the neighbourhood of the beam, as they get trapped in the static electric field potential of the beam itself. Assuming that the accumulated electrons do not influence the beam (and they certainly do not as long as their density is low enough), this process would reach saturation only when the electron density comes close to neutralizing that of the beam and the electrons can therefore escape the beam potential and diffuse to the walls. When this happens, the electrons eventually hit the pipe walls and are either elastically reflected or cause secondary emission, depending on their energy. At the end an equilibrium between production and loss is reached.

In fact, the electrons can significantly act back on the beam above a certain threshold density, which would change the picture described above. Studies of electrons accumulating around coasting beams have been initiated in the past [1, 2, 3], but the models adopted were not self-consistent. In Ref. [1] it is shown that a gas pressure of 10^{-3} Pa, corresponding to an electron/ion production rate of 4×10^{-5} $e^-/(m \cdot p)$, is needed to make the JPARC beam unstable. This study uses a simple macroparticle model for both electrons and protons, but it does not take into account of electrons being pushed out to the pipe wall and interacting with it. Ref. [2] deals with the electron creation and motion in coasting beams having small perturbations along the z axis. The result is that perturbations in the $0.1 - 1$ σ range can resonantly drive quick electron multiplication if the harmonic number of the perturbation is about twice the number of electron oscillations around the unperturbed beam. In this model, the beam is rigid and the electrons that accumulate around it feel its field and stay trapped or diffuse, but do not act back on it. Ref. [3] contains both analytical work (based on a wake field approach) and macroparticle simulation (with a beam represented by a line of macroparticles uniformly distributed in the z direction) for electron cloud formation and ep instability in the JPARC. From this work it turns out that, even if residual gas ionization is in general insufficient to drive any ep instability due to the very low pressures nowadays attainable in the beam chambers, electrons from proton/ion losses to the walls could still endanger the beam stability.

In the present paper we show first results from the use of the HEADTAIL code, adequately modified in order to handle coasting beams and electrons in a self-consistent fashion. Section II describes the main steps of the code upgrade. Applications to the GSI-SIS18 and to RAL-ISIS are then discussed in Sec. III. Conclusions and future work are shortly outlined in Sec. IV.

HEADTAIL FOR COASTING BEAMS

The newest version of HEADTAIL [4] allows the self-consistent simulation of electron cloud build up and instability for a coasting beam. As for bunched beams, all the electrons are lumped for computational purposes in one section of the ring and the beam (also represented by macroparticles) is subdivided into slices. The beam macroparticles slide over the slices, so that Landau damping from momentum spread is taken into account. Using the 1-kick approximation, electrons and coasting beam interact thus slice after slice. New electrons are in this case produced at each turn via residual gas ionization or proton loss on a rectangular boundary and they add up to those created at previous turns. These electrons also interact with the coasting beam, so that build up and beam-cloud interaction are treated in a combined fashion. When electrons hit the pipe, they may be elastically reflected or generate secondaries according to the SEY curves derived from the most recent Cimino-Collins parametrization [5].

It has been therefore necessary to introduce a number of new features into the code, which we summarize in the following:

1. A new set of values are added in input through an

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expanded version of the old input file, in order to specify: static pressure in the beam chamber, yield coefficients of the electron emission, ionization cross section, beam loss fraction, number of macroelectrons generated at each turn, amplitudes and harmonic number of a transverse perturbation..

2. Macroelectrons are generated at each turn (in a number given through the new input file, see above) according to the gas ionization or proton loss rate. The electron distribution is not refreshed at each beam passage, as was for bunched beams, but pre-existing electrons keep moving in the continuous field of the coasting beam while new electrons are generated and advanced at each beam-cloud interaction. Electrons feel also their own space charge field.

3. A secondary emission subroutine that changes the charge of the macroelectrons as they hit the beam pipe has been added. It directly comes from a simplified version of the subroutine 'seiler' in ECLOUD [6], and makes use of the quantum mechanics formula proposed by F. Zimmermann [5] to account for elastic reflection. Having macroelectrons with variable charges has required in addition an update of the PIC routines to enable them to distribute on a grid macroparticles carrying different charges and advance them.

4. The coasting beam can be perfectly on axis (apart from the random noise due to the discrete nature of the slices), or it can have an initial coherent slice by slice centroid perturbation (assumed to be sinusoidal) with amplitudes and harmonic number specified in the new input file.

5. A new set of output files is now available to monitor the e-cloud build up throughout the simulation time, the energy spectrum of the electrons that hit the walls and the trajectory of one sample electron.

ELECTRONS AND COASTING BEAMS IN GSI-SIS18 AND RAL-ISIS

The electron accumulation in coasting beams has been studied for the RAL-ISIS and GSI-SIS18 rings. Both ISIS and SIS18 operate with intense coasting proton beams at the injection plateau prior to bunching for acceleration. The parameters of both rings, as used for simulations, are summarized in Table 1.

Figures 1 and 2 show the electron density increase in ISIS for the two cases of residual gas ionization and proton/ion loss (different curves correspond to different static pressures or beam loss fractions). When the electrons are produced at the pipe walls by beam loss, they accumulate up to lower densities compared to those reached when they are produced within the beam section due to residual gas ionization (in spite of the higher production rate assumed for beam losses than for rest gas ionization). The saturation values depend strongly on the primary electron production rate, which suggests that in all these cases secondary emission does not play a significant role and electrons are essentially lost at the pipe walls since they hit with low energies. The saturation values of the electron cloud in the beam pipe are both far lower than the beam peak density ($\rho_m = 3 \times 10^{13}$ m^{-3}) and also than its average density over the transverse pipe section ($\bar{\rho} = 1.24 \times 10^{12}$ m^{-3}), with consequent neutralization degrees in the range 5×10^{-3}–0.1.

Table 1: SIS18 and ISIS parameters used in simulations.

Symbol	SIS18	ISIS
C	216 m	163.4 m
N_b	10^{10} U^{28+}	1.25×10^{13} p
E	11.4 MeV/u	70. MeV
$\delta p/p_0$	1.06×10^{-3}	2.5×10^{-3}
α	0.0356	0.039
$\sigma_{x,y}$	$5/5$ mm	$23/34$ mm
$Q_{x,y}$	4.308/3.29	4.31/3.83
$\xi_{x,y}$	-1.25/-1.39	-1.25/-1.2
δ_{max}	2.0	2.0
E_{max}	270 eV	270 eV
$h_{x,y}$	$10/5$ cm	$11.5/17$ cm
P_e	1 nTorr	50-500 nTorr
σ_{ion}	2 MBarn/u	2 MBarn

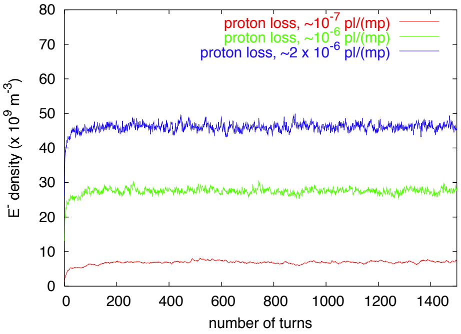

Figure 1: Electron accumulation in a coasting beam (ISIS). Electrons are generated from proton loss and three different loss fractions are considered.

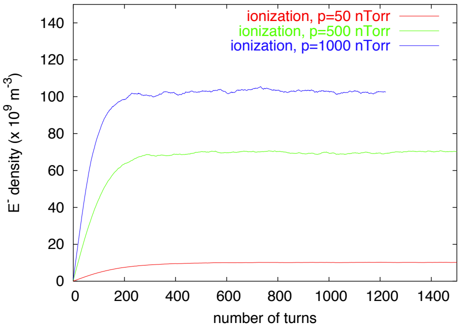

Figure 2: Electron accumulation in a coasting beam (ISIS). Electrons are generated from rest gas ionization and three different pressure values are considered.

Due to the much lower estimated production rates, the situation seems better in the SIS18, where, for primary production both from ion losses and from rest gas ionization, the saturation values of the electron cloud are also much lower and yield neutralization degrees around 10^{-4}. In reality, recent calculations have pointed out that the value assumed for the cross section of the gas ionization (2 MBarn/u, extrapolated from energetic protons, see Table 1) is far too optimistic for U^{28+} projectiles at 11.4 MeV/u, and could be higher by 3–4 orders of magnitude [7]. This is because the cross section of target ionization scales probably like the Z^2/E ratio of the projectile. This correction would thoroughly change the picture presented here, so that predictions for the SIS18 in realistic operation need re-examination. Also the value of current used in these simulations is about 1 order of magnitude below the goal value.

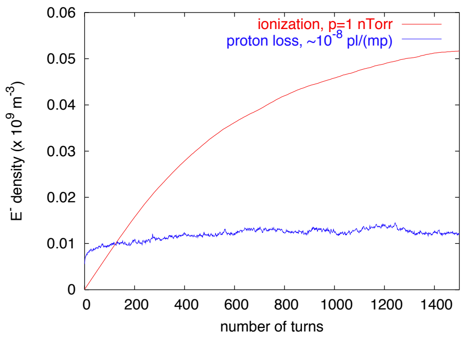

Figure 3: Electron accumulation in a coasting beam (SIS18). Electrons are generated from gas ionization or ion losses.

Independently of the mechanism of generation of the electrons, the process of electron accumulation around a coasting beam with a sinusoidal perturbation of the transverse centroid along the z direction appears not to be significantly affected by perturbations with amplitudes below or about $0.1\sigma_{x,y}$. For larger perturbation amplitudes (about $0.5\sigma_{x,y}$) the electrons start multiplying when they are generated from loss at the pipe walls (see Fig. 4).

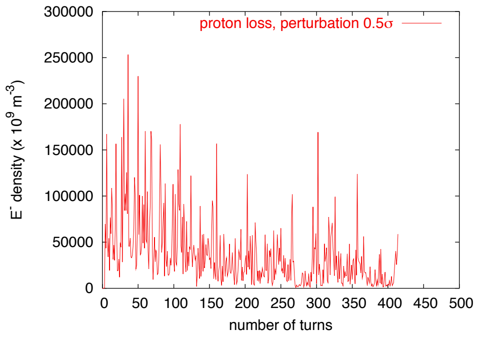

Figure 4: Electron accumulation in a perturbed coasting beam (ISIS). Electrons are generated from proton loss.

Unlike the case without perturbation, in which no significant emittance growth is caused by the electrons even for the highest densities we considered (Fig. 5), the values reached by the electron density in the case with perturbation can cause strong emittance growth and quick beam loss, as Fig. 6 depicts.

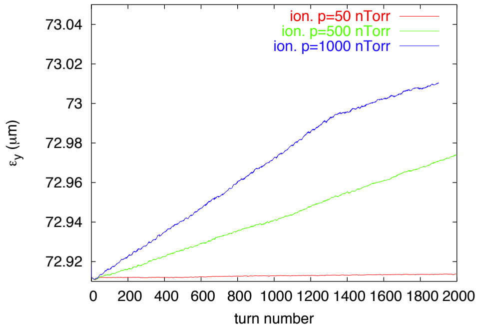

Figure 5: ISIS emittance evolution (y) for the cases in Fig. 2.

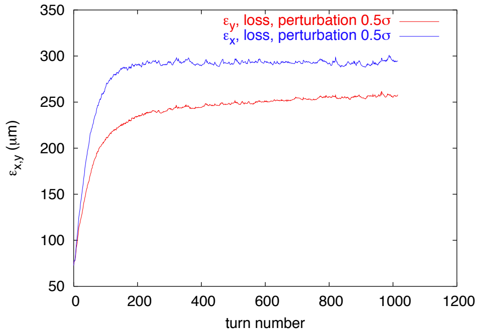

Figure 6: ISIS emittance evolution (x, y) for the case in Fig. 4.

CONCLUSIONS

First results from HEADTAIL, modified to describe the electron cloud in coasting beams, have been presented. The code uses the 1-kick approximation and deals with the interaction between electrons and beam particles as well as electrons and the pipe wall in a self-consistent manner. Electrons can accumulate up to fairly high neutralization degrees in the ISIS ring (≈ 0.1), but densities seem quite low in the SIS18 with the electron production rates currently considered. A more systematic exploration of parameters is planned as next step in this study.

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