INTRABEAM SCATTERING OF HEAVY ION IN DSR

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Abstract

The Multi-USe Experimental Storage rings (MUSES) is proposed for RIKEN RI beam factory. Calculations of the intrabeam scattering growth rates for heavy ion beam stored in the MUSES are described in this paper. Also, equilibrium beam properties determined by a balance between cooling and heating due to the intrabeam scattering are presented.

1. INTRODUCTION

In the static operation of a heavy ion storage ring with electron cooling at constant energy, intrabeam scattering (IBS) is the dominant heating mechanism which restricts the resolution limits[1] of stored ion beam. This paper aims at simulation of the intrabeam scattering process for a bunched beam $^{238}U^{92+}$ of 150MeV/u in the proposed DSR[2], by using the extended Piwinski's IBS growth rate expressions[3], taking into account betatron and synchrotron oscillations of particle. Furthermore, simulation results of the time evolution of beam emittance and momentum spread under joint action of IBS and the electron cooling are shown. Finally, the dependence of the beam emittance and momentum spread in equilibrium between the IBS and electron cooling on the number of particles and the cooling electron current are presented.

2. SIMULATION OF INTRABEAM SCATTERING BLOWN-UP

The intra-beam scattering growth rates are connected with the 6-dimensional phase space density of the ion beam and the specific ion optics of the storage ring. Usually, the growth rates are described by the relative time derivatives of rms betatron angles σ'_h, σ'_v, and rms relative momentum spread σ_p.

It is frequently assumed that the betatron amplitude would grow at the same rate as the betatron angle, and for a bunched beam, the bunch length would grow at the same rate as the momentum spread. As a consequence, there is a factor 2 between the emittance growth rates and the angle growth rates by

$$\frac{1}{\varepsilon_l}\frac{d\varepsilon_l}{dt} = 2\cdot\frac{1}{\sigma_p}\frac{d\sigma_p}{dt}, \frac{1}{\varepsilon_j}\frac{d\varepsilon_j}{dt} = 2\cdot\frac{1}{\varepsilon'_j}\frac{d\sigma'_j}{dt}, j = h,v$$

The extended A.Piwinski's IBS growth rate formulae are used to investigate the beam blown-up. These formulae are given in eq.(33) of ref.[3]. Starting from the exit of cooling section with given initial emittance ε_{j0}, the three emittance growth times (inverse of the growth rates) are calculated at series of lattice points through numerical integration of the scattering functions[3] and then averaged around the ring. The three emittance growth are given as

$$\varepsilon_j = \varepsilon_{j0}\cdot e^{\frac{t}{\tau_j}}$$

Due to the growth of emittance, coordinates on phase ellipses of the ion at the entrance of cooling section after N_{ibs} turns are increased by a factor

$$\sqrt{\frac{\varepsilon_j}{\varepsilon_{j0}}} = e^{\frac{t}{2\tau_j}}$$

in which an small amplitude approximation is employed for the synchrotron oscillation, and the ion is assumed to be still positioned on an ellipse after scattering.

Fig.1 examplifies the calculated IBS blown-up of a 150MeV/u $^{238}U^{92+}$ beam of 7×10^8 particles per bunch, supposing that the beam has been cooled down to an emittance of $5.0\pi mm\cdot mrad$ transversely and momentum spread of $\pm5..0\times10^{-4}$.

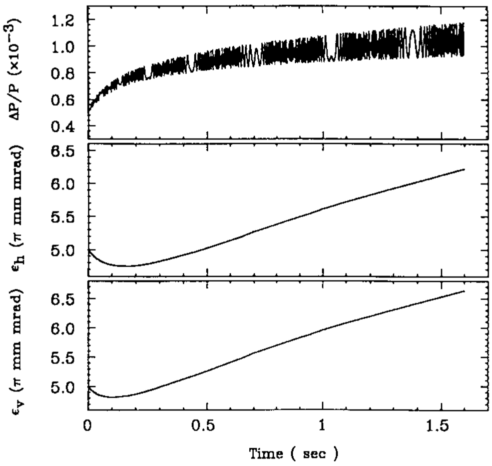

Fig.1 Blown-up of the momentum spread and horizontal, vertical emittance with IBS for a $^{238}U^{92+}$ beam of 150Mev/u.

3. EQUILIBRIUM BETWEEN INTRABEAM SCATTERING AND ELECTRON COOLING

A simulation is performed to investigate the beam behavior in the presence of both the IBS and electron cooling, in which some peculiarities like the betatron and synchrotron oscillations, the electron beam space charge effect are taken into account[4].

In principle, beam evolution under the joint action of electron cooling and intrabeam scattering can be described by the differential equations

$$\frac{d\varepsilon}{dt}=\frac{d\varepsilon_{ec}}{dt}+\frac{d\varepsilon_{ibs}}{dt},$$

$$\frac{d(\frac{\Delta P}{P})}{dt}=\frac{d(\frac{\Delta P}{P})_{ec}}{dt}+\frac{d(\frac{\Delta P}{P})_{ibs}}{dt}$$

The equilibrium state are obtained from the conditions

$$\frac{d\varepsilon}{dt}=0, \quad \frac{d(\frac{\Delta P}{P})}{dt}=0$$

In the practical simulation, the IBS and electron cooling are calculated according to the procedures described above and in ref.[5]. When the rms value of the relative changes of emittance during a specific time interval is smaller than a given tolerance, i.e. the condition

$$\sqrt{(\frac{d\varepsilon_h}{\varepsilon_h})^2+(\frac{d\varepsilon_v}{\varepsilon_v})^2+(\frac{d\varepsilon_l}{\varepsilon_l})^2}\le tole .$$

is fulfilled, then an equilibrium is arrived at.

Fig.2 examplifies variations of beam emittance and momentum spread under the combined action of intrabeam scattering and electron cooling with electron current $I_e=0.4A$ and particle numbers $N_i=7.0\times10^8$ per bunch. The results show that the intrabeam scattering comes into function significantly when the emittance(2σ) and momentum spread(2σ) are cooled down to values lower than ~2.0 πmm·mrad and ~6.0×10^{-4} respectively. Table 1 lists the parameters pertained to this simulation.

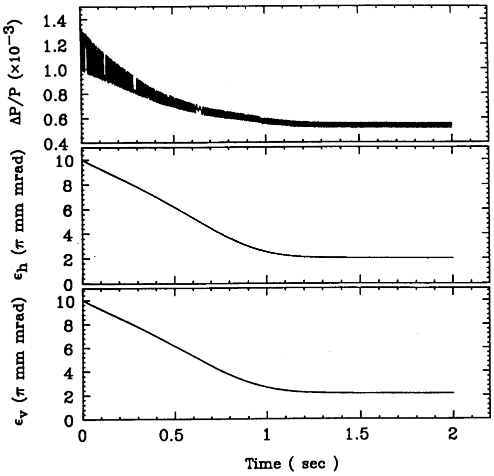

Fig.2 The time evolution of beam momentum spread and emittance with IBS and electron cooling.

Simulation results of the emittance and momentum spread as a function of the number of stored particles for $^{238}U^{92+}$ beam with $I_e=0.4A$ are shown in Fig.3. An increase of the phase space volume with the number of stored ions N_i is evident. The momentum spread dependence is close to $N_i^{0.36}$,whereas the horizontal and vertical emittance grow with $N_i^{0.64}$.

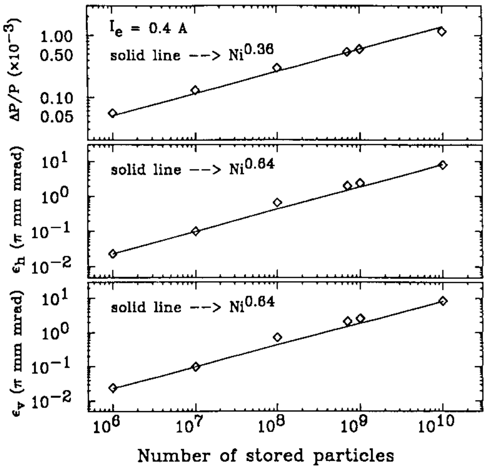

Fig.3 Equilibrium momentum spread and momentum spread as a function of number of stored ions for $I_e=0.4A$.

Table 1 Parameters involved in the simulation

Storage ring parameters	
Ring perimeter C[m]	258.732
Length of cooling section L_{cooler}[m]	4.8
Betatron tune	Q_h=7.420037, Q_v=5.811131
Mean β value in cooling section [m]	β_h=6.2, β_v=7.6
α value in cooling section	α_h=0.0, α_v=0.0
Dispersion in cooling section D_h[m]	0.0
Transition gamma γ_{tr}	5.14866
Chromaticity	ξ_h =-11.182, ξ_v=-8.337
RF harmonic number h	46
RF peak voltage U_a[V]	40000
Electron beam parameters	
Electron energy [keV]	82.3
Electron beam radius r_b[mm]	25
Electron beam current I_e[A]	0.4
Electron density n_e[cm^{-3}]	8.3×10^{6}
Transverse temperature kT_t[eV]	0.01
Longitudinal temperature kT_l[eV]	5.0×10^{-4}
Space charge neutralization factor	50%
Solenoid field strength B_0 [Gs]	1000
Ion beam parameters before cooling	
Ion	$^{238}U^{92+}$
Energy [MeV/u]	150
Particles/bunch	7.0×10^{8}
Transverse emittance [πmm·mrad]	ε_{h0}=10, ε_{v0}=10
Momentum spread $(\Delta P/P_s)_0$	±0.1%

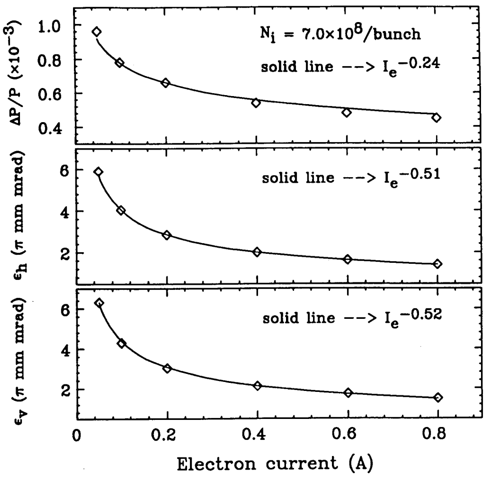

Fig.4 Equilibrium momentum spread and emittence as a function of electron current for $N_i = 7.0\times10^{8}$ /bunch.

The equilibrium properties must depend on the electron beam current which determine the cooling rate. A higher electron current yields increased cooling rate which results in a lower equilibrium temperature of the ion beam. Assuming an independence of the electron beam transverse temperature kT_e on the electron current up to 0.8A, i.e. remaining kT_e constant at 0.01eV, the obtained ion beam emittance and momentum spread as a function of the electron current are shown in Fig.4.

The momentum spread shows a $I_e^{-0.24}$ -dependence, the decrease of the horizontal and vertical emittance can be described by a $I_e^{-0.51}$.

ACKNOWLEDGEMENT

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