NUMERICAL STUDY ON SIMULTANEOUS USE OF STOCHASTIC COOLING AND ELECTRON COOLING WITH INTERNAL TARGET AT COSY

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Abstract

The small momentum spread of proton beam has to be realized and kept in the storage ring during the experiment with a dense internal target such as a pellet target. The stochastic cooling alone cannot compensate the momentum spread increases due to the internal target. Also, the dense proton beam in the six dimensional phase space includes intra-beam scattering as one of emittance growth mechanisms. The simulation results on the simultaneous use of stochastic cooling and electron cooling at COSY are presented in this study.

INTRODUCTION

The small momentum spread is essential requirement for the high resolution experiment in the storage ring with internal target. For the realization of such a beam quality, the stochastic cooling is envisaged as the main cooling scheme at the High Energy Storage Ring (HESR) of the FAIR project [1]. It is found from the simulation study of stochastic cooling that the stochastic cooling could attain the required energy resolution of anti-proton beam in the energy range 3-15 GeV [1].

However the better quality of circulating anti-proton beam could be obtained with the simultaneous use of stochastic cooling and electron cooling [2]. As a test pilot of this concept, the 2 MeV electron cooler is under construction at FZJ to be installed in 2011 to the existing COSY 2 GeV proton storage ring [3].

In this study, we propose the simultaneous use of the stochastic cooling and electron cooling for the internal target experiment in the COSY. The results of numerical investigation of the cooling process at COSY are presented.

SIMULATION MODEL

A Fokker-Planck equation is often used as an investigation tool in the stochastic momentum cooling process. The simplified Fokker-Planck equation for a model of a stochastic momentum cooling is given by [4]

$$\frac{\partial \Psi}{\partial t} + \frac{\partial}{\partial E}\left(F\Psi - D\frac{\partial \Psi}{\partial E}\right) = 0, \qquad (1)$$

where $\Psi \equiv \Psi(E,t) \equiv dN/dE$ is the particle distribution function, $F \equiv F(E)$ is the coefficient for the cooling force, and $D \equiv D(\Psi(E),t)$ is the coefficient for the diffusion process.

The coherent term coefficient includes the electron cooling force as

$$F = F_{scool} + F_{ecool} - F_{IT}, \qquad (2)$$

where F_{scool} is the cooling force due to the stochastic cooler and F_{ecool} is the cooling force caused by the electron cooler. The terms are derived by the electrical characteristics of the feedback system for the stochastic cooling [5]. For the calculation model of the electron cooling drag force, we carry out the Parkhomchuk empirical formula [6]. F_{IT} is the mean energy loss by the interaction due to the internal target. The barrier bucket cavity will help this energy loss. The coherent energy loss term due to the internal target is ignored in this study.

The incoherent term coefficient is obtained by

$$D = D_s + D_{IBS} + D_{IT}, \qquad (3)$$

where D_s is the Schottky noise due to the stochastic cooling, D_{IBS} is the diffusion coefficient due to the intra-beam scattering, and D_{IT} is the diffusion effect due to the internal target, respectively. The cluster or pellet target is used for the internal target experiments at COSY. Typical target thickness is 2×10^{15} atoms/cm^2, and the measured mean energy loss is 24 meV/turn and the straggling effect is expressed with the formula in [7]. D_{IT} is given by

$$D_{IT} = \frac{1}{2} f_{rev}\left(\frac{1+\gamma}{\gamma}E_k, \delta_{loss}\right)^2, \qquad (4)$$

where f_{rev} is the revolution frequency, γ is the relativistic factor of the beam, and E_k is the kinetic energy of the beam. The measured δ_{loss} is 2.4×10^{-8}. The multiple scattering induces the transverse emittance increase. Typical emittance increase is calculated, and the emittance increase of $2\sim7\times10^{-9}$ m-rad/sec is used for the present simulation study [7].

When the particle density in 6 dimensional phase space becomes dense by the beam cooling, the scattering effects between particles become dominant. The Intra-Beam-Scattering (IBS) effect is formulated by Martini [8], and

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the numerical results of growth rates are used for the diffusion term by IBS in the present study. The equilibrium momentum spread is determined by the IBS effect in the case without the internal target. However when we use the internal target, the diffusion effects by the target is order of magnitude larger than the IBS term.

Table 1 shows the parameters for COSY simulation [9] including the electron cooler option [3].

Table 1: Parameters for COSY Simulation

Beam	
Kinetic energy	2.0 GeV
Particle number	10^{10}
Energy spread (1σ)	0.774 MeV
Ring circumference	184 m
Ring dispersion	-0.1
Momentum acceptance	+/- 2.5×10^{-3}
Stochastic cooling system	
Band width	$1 \sim 1.8$ GHz
Gain	106 dB
Effective temperature	80 K
Electrode length	32 mm
Electrode width	20 mm
Gap height	20 mm
Impedance	50 Ω
Number of pickup and kicker	24
TOF from pickup to kicker	0.3229 μsec
System delay	-0.04 ns
Electron cooling system	
Beta function at cooler	6 m
Dispersion at cooler	0 m
Effective energy spread	0.001 eV
Cooler length	2.7 m

NUMERICAL SIMULATION RESULTS

In this study, we simulate numerically the particle distribution during the cooling process using the Fokker-Planck equation solver [10].

Stochastic Cooling

At first, the cooling results are shown in the cases with the stochastic cooling without the electron cooler. Figure 1 shows the momentum spread history during the internal target experiment with the stochastic cooling in COSY parameters. Here the rms momentum spread $\Delta p/p$ is calculated by

$$\frac{\Delta p}{p} = \frac{1}{E_t \beta^2} \sqrt{\frac{1}{N} \int_{-\infty}^{\infty} E^2 \Psi(E,t)\, dE}, \qquad (5)$$

where N is the total particle number in the ring, E_t is the total energy of the beam, and β is the beam velocity divided by light speed.

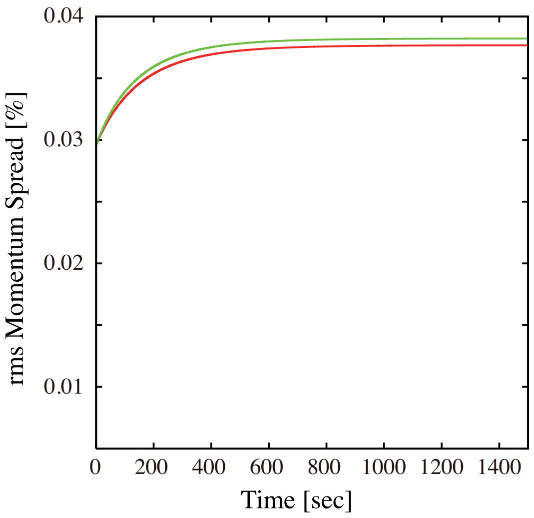

Figure 1: Momentum spread history with stochastic cooling. The red and green lines show the result without and with IBS effect.

As shown in Fig. 1, it is found that the IBS effect causes the additional increase of the momentum spread. However, the momentum spread was not decreased in comparison with the initial momentum spread by using the stochastic cooler alone.

Simultaneous Use of Stochastic and Electron Coolers

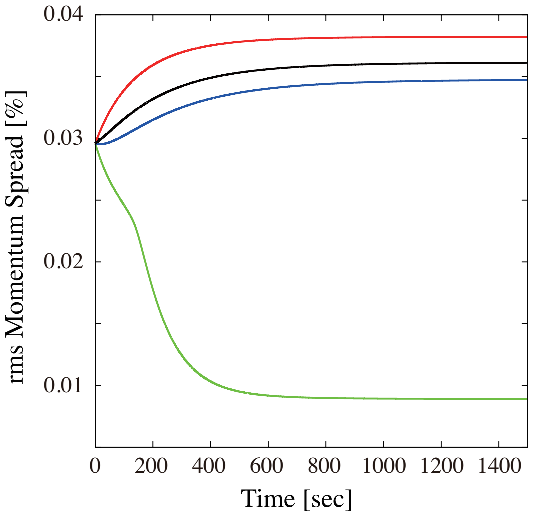

Figure 2: Momentum spread history with simultaneous operation of stochastic and electron coolers. The emittance increase of 7×10^{-9} m-rad/sec is assumed with the transverse stochastic cooling time of 250 sec. The red, green, blue, and black lines show the cooling results for I_e =0 A, I_e =1 A at d =1 cm (J_e =1.27 A/cm^2), I_e =2 A at d =2 cm (J_e =0.64 A/cm^2), and I_e =3 A at d =3 cm (J_e =0.42 A/cm^2), respectively.

Figure 2 shows the momentum spread history during the internal target experiment with the simultaneous use of the stochastic and the electron coolers. As shown in Fig. 2, the electron cooling can decrease the momentum spread according to increase the electron beam current density $J_e = I_e/\pi(d/2)^2$, where I_e is the electron beam current and d is the diameter of the electron beam. In comparison with Figs. 1 and 2, the momentum spread can be compensated well by the simultaneous operation of the stochastic and the electron coolers.

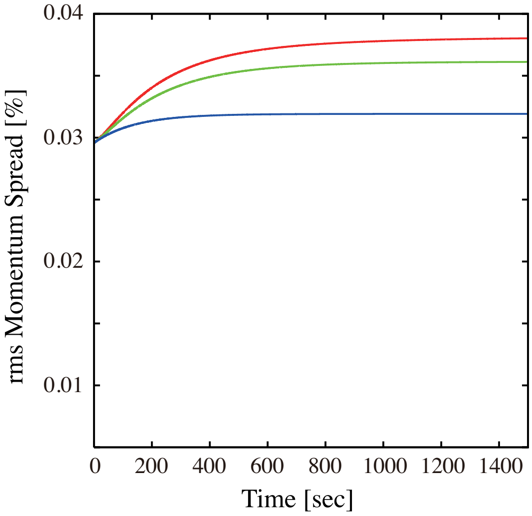

Figure 3: Momentum spread history with stochastic and electron coolers (I_e =3 A at d =3 cm (J_e =0.42 A/cm^2)). The emittance increase of 7×10^{-9} m-rad/sec is assumed. The red, green and blue curves show the results without the transverse stochastic cooling, and with the transverse stochastic cooling time of 250 sec and 100 sec, respectively.

Figure 3 shows the momentum spread history with the emittance increase effect of 7×10^{-9} m-rad/sec. When the fast stochastic cooling in the transverse direction of the beam is carried out, the momentum spread will be decreased during the internal target experiment.

Figure 4 shows the momentum spread history with the emittance increase effect of 2×10^{-9} m-rad/sec. As shown in Figs. 3 and 4, the transverse emittance growth due to the internal target interaction and the transverse cooling with the small cooling time are important to realized the small momentum spread.

CONCLUSION

The simultaneous use of the stochastic cooling and electron cooling was proposed, and was investigated numerically using the Fokker-Planck equation solver including the IBS effect in the internal target experiment at the COSY. The simulation results showed that the simultaneous operation method of the stochastic cooling and the electron cooling is useful scheme even in the case with the internal target. The momentum spread and the transverse emittance were increased due to the IBS effect and the internal target interaction. The results indicated that the momentum spread can be decreased by the proposed method if the electron current density is high enough. It is found that the transverse emittance growth and the transverse cooling are also important to maintain the small momentum spread.

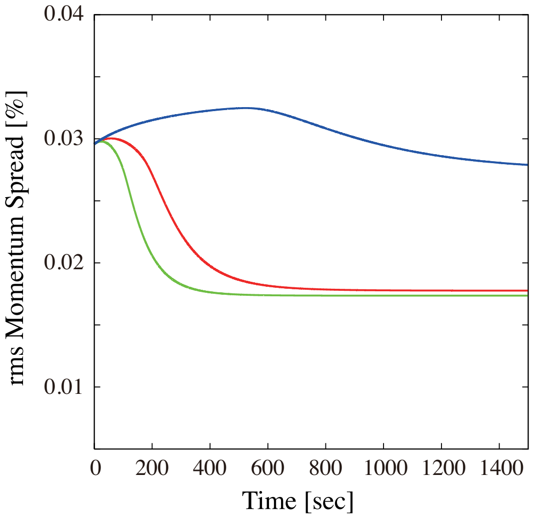

Figure 4: Momentum spread history with stochastic and electron coolers (I_e =3 A at d =3 cm (J_e =0.42 A/cm^2)). The emittance increase of 2×10^{-9} m-rad/sec is assumed. The red, green and blue curves show the results with the transverse stochastic cooling time of 250 sec and 100 sec, and without the transverse stochastic cooling, respectively.

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