Software development for stochastic cooling study in the time domain

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The beam dynamics under the influence of the stochastic cooling forces can be studied by a particle by particle and turn by turn simulation in the time-domain. This treatment does not involve complicated, changing frequency spectra, which anyhow are likely to be incomplete by considering the Fokker-Planck Equation and its solution [1, 2]. To keep the computation times within reasonable limits, the scaling law that cooling times are proportional to the number of particles (for zero preamplifier noise and all other parameters remaining unchanged, except the gain) has been applied throughout. A special computer code has been developed to calculate beam cooling in the CR. Preliminary results for the Palmer method are presented. A typical simulation super-particle number is about $(1-10)\times10^4$.

Time domain approach

The time domain algorithm is developed and applied to the Palmer cooling method. The possibility of using this method for simultaneous longitudinal and transverse cooling by a suitable choice of the pickup to kicker distance was described by Hereward [3]. According to this algorithm the coasting beam is generated in a 6D normalized phase space (X,X',Y,Y',Δp/p, ΔT). In the time coordinate (ΔT) this beam is split a certain number of samples. The time length t_s of samples depends on the choice of system bandwidth W: t_s=0.5/W. Having the particle time distribution of each sample the particle mixing is simulated by a simple particle migration from sample to sample, which means the flight time variation of each particle in the sample turn by turn is calculated at $t_i = t + \Delta t_i$, where

$$\Delta t_i = T_{loc}|\eta_{loc}|\frac{\Delta p}{p_i} \quad (1)$$

Depending on the way T_{loc} and η_{loc} equal T_{PK} or T_{KP} and η_{PK} or η_{KP} respectively. At Pick-Up (PU) each sample produces a signal $<X_n>$, which is proportional to momentum error and transverse error displacement of this sample. At the kicker (KK) the accessory of a particle to the certain sample s is defined and depending on the sample number s the single particle correction is calculated by

$$\frac{\Delta p}{p_i} = \frac{\Delta p}{p_i} - \frac{g}{D_{PU}}\cdot\langle X_n\rangle_s\cdot\alpha_p\cdot s(\Delta t), \quad (2)$$

$$X_n' = X_n' + g\cdot\langle X_n\rangle_s\cdot\alpha_t\cdot s(\Delta t), \quad (3)$$

where the g is a normalized gain, $\alpha_{p,t}$ is damping factor, which reduces the gain efficiency due to the noise. s(Δt) is a time profile of the signal. The Eqs. (2, 3) describe the cooling effect in the time domain approximation. One can see that for the Palmer method the momentum error of particles is corrected proportionally to the center gravity of sample, which characterized by average value of coordinate $<X_n>$. In the transverse plane the particle coordinates are rearranged and calculated by

$$\begin{pmatrix} X_{n,P,K} \\ X'_{n,P,K} \end{pmatrix} = \begin{bmatrix} C_{KP,PK} & S_{KP,PK} \\ -S_{KP,PK} & C_{KP,PK} \end{bmatrix}\begin{pmatrix} X_{n,P,K} \\ X'_{n,P,K} \end{pmatrix} \quad (4)$$

$C_{KP,PK}$ =cos(ΔμKP,PK); $C_{KP,PK}$ =sin(ΔμKP,PK);, Δμ is a phase advance from kicker to pick-up (KP) or from pick-up to kicker (PK). The gain damping factor $\alpha_{p,x}$ can be calculated by

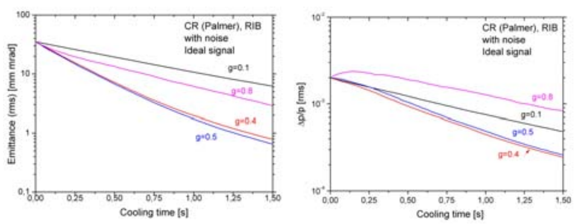
$$\alpha_{p,x} = 1 - \frac{g}{2}(1 + U_{p,x}) \quad (5)$$

Here, $U_{p,x}$ are the total noise-to-signal ratio. For Palmer cooling this value is taken from [3]

$$U_p = \frac{\epsilon^2_{rms}}{D^2_{PU}\delta^2_{rms}} + U_{N,S}; U_x = \frac{D^2_{PU}\delta^2_{rms}}{A^2_{rms}} + \frac{\epsilon^2_n}{A^2_{rms}} \quad (6)$$

Here, U_{NS} is the ratio of the thermal noise to the Schottky signal.

Numerical simulations



The calculated momentum spread and emittance evolution for different gain factors g are shown in Fig. 1. The Palmer cooling will be useful in the first stage of stochastic cooling of rare isotopes in the CR. After the rms Δp/p decreases below 0.1 %, it is possible to switch off the signals from the Palmer Pick up and turn to Notch filter cooling. From Fig.1 one can deduce that the rms Δp/p of 0.1 % becomes in 0.5 second for the U^{92+} beam if g=0.4.

References

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