DYNAMIC SIMULATION OF LASER COOLING AT CSRE*

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Abstract

Laser cooling of heavy ion beams at storage ring is one of the most promising techniques to reach high phase-space densities and achieve phase transition, ordered beam even crystalline beam. It has many advantages such as fast-cooling, ultra-strong cooling force and providing the ultra-low temperature ion beams. In this paper, we introduce the laser cooling system at CSRe in IMPCAS, and then present the main procedure of the simulation program. Finally, we show the preliminary test result of the laser cooling simulation program at CSRe.

INTRODUCTION

Laser cooling has recently emerged as a powerful tool for manipulating the longitudinal phase space distribution of ion beams in synchrotron storage rings. Now, the laser cooling system is being prepared at CSRe (experimental Cooler Storage Ring) in IMPCAS (Institute of Modern Physics, Chinese Academy of Sciences) [1]. The layout is shown in Fig.1.

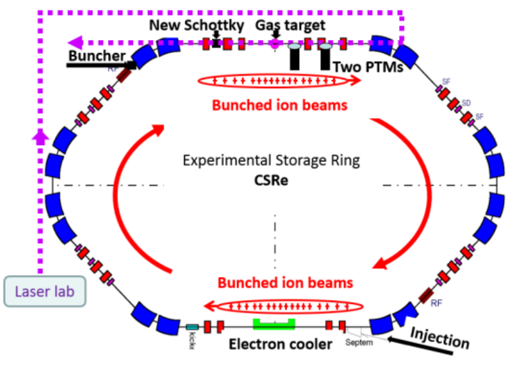

Fig.1. the layout of the laser cooling system at CSRe

A special designed RF-buncher system was installed at CSRe to provide a counterforce for laser scattering force by longitudinally modulating the ion beams [2]. But the laser system is not used in the laser cooling system.

In the dynamic simulation program, the matrix transmission is a very useful method to track particles. The main procedure of the simulation program is shown in Fig.2.

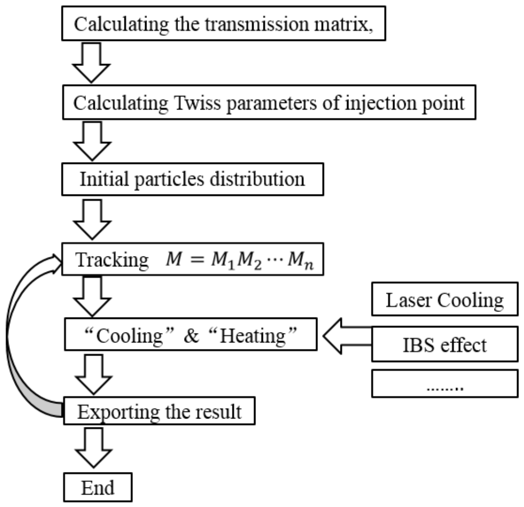

Fig.2. the main procedure of the simulation program

1. Calculating the transmission matrix of the elements.
2. Calculating the transmission matrix of CSRe to get the Twiss parameters of the injection point.
3. Writing a subprogram to produce the initial distribution in accord with the Twiss parameters of the injection point.
4. Tracking the particles with the matrix transmission method.
5. Adding in the laser cooling effect in the cooling section.
6. Exporting the results.

PRINCIPLE

Laser cooling is one of the efficient method to modulate the ion beams. The basic parameters describing this energy transfer in laser cooling between ions and laser is the cooling force. A

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very useful and practical formula of the cooling force is written as below [3], [4]:

$$F(v)=\frac{1}{2}\hbar kS\Gamma\frac{(\Gamma/2)^2}{(\delta-vk)^2+(\Gamma/2)^2(1+S)} \quad (1)$$

Here υ is the ion relative velocity. k is the wave number of photons, $k=2\pi/\lambda$. S is the saturation parameter of the laser, Γ is the inverse of the lifetime of the upper level. $\delta=\omega-\omega_0$, it is the tuning of laser and resonance transition, ω is the frequency of the resonance transition, ω_0 is the frequency of laser.

Acting on the ions of a coasting beam with force, the laser only burns a narrow hole in the velocity distribution of the ions. The laser force would not cool the beam if the different ions are not continuously pushed toward the resonance condition. Therefore, in the laser cooling system, a RF-buncher is necessary to provide an auxiliary force to push the ions to the resonance condition in the velocity distribution. The bunch potentials of the RF-buncher is produced by sinusoidal-wave, it is written as below:

$$V=V_0\sin 2\pi h\phi$$

Here h is the harmonic number of the RF-buncher. In the laser cooling system, the RF-buncher was operated at various harmonic of the revolution frequency to capture and bunch the ion beams for each new injection, such as 25th, 50th, 75th, 100th.

PRELIMINARY SIMULATION RESULTS

The main parameters of the simulation is shown in Table 1. In the simulation program, thousands model particles were generated in accord with the initial ion beam parameters. The initial particles distribution in transverse phase space is shown in Fig.3. The initial particles distribution in longitudinal phase space is shown in Fig.4. The velocity of ions were modulated by the RF-buncher, the result is shown in Fig.5. According to the initial velocity distribution, the cooling force was calculated by the formula (1), the result is shown in Fig.6. The preliminary test result of the laser cooling simulation program at CSRe is shown in Fig.7, the momentum spread of the ions were reduced by the laser.

Table 1: The Main Parameters of Simulation

CSRe	
circumference	128.80m
slip factor	0.64
Beam	
Ion species	C3+
beam energy	122MeV/u
revolution frequency	1.087MHz
relativistic β,γ	0.47,1.13
beam lifetime	~20s
Laser	
Wave length	257.5nm
RF-buncher	
harmonic number h	25th,50th,75th,100th

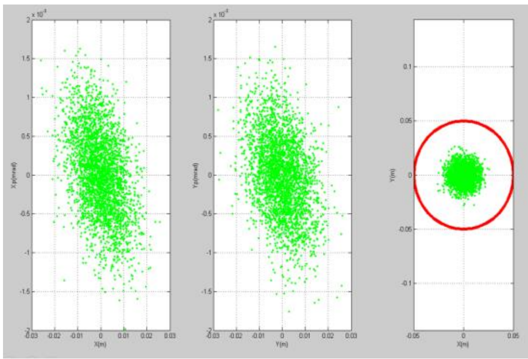

Fig.3. the initial particles distribution in transverse phase space

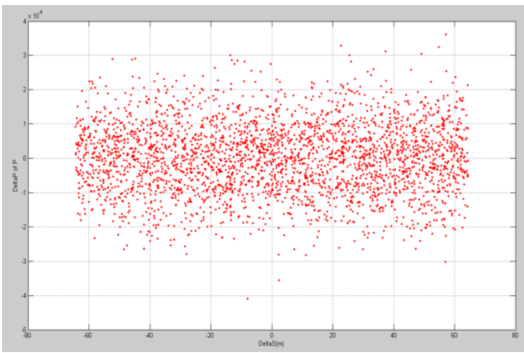

Fig.4. the initial particles distribution in longitudinal phase space

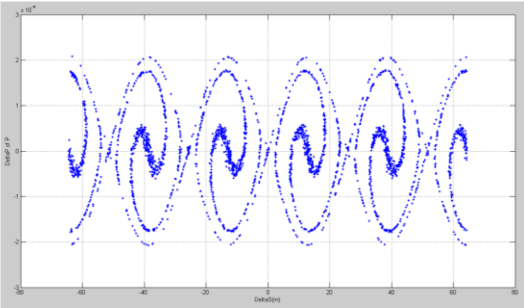

Fig.5. the effect of the RF-buncher in longitudinal phase space

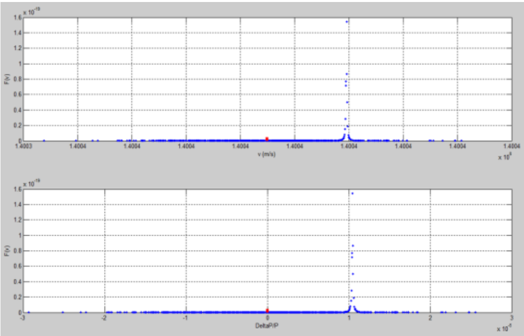

Fig.6. the cooling force distribution

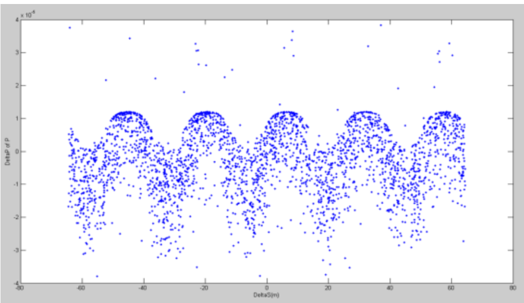

Fig.7. the preliminary test result of the laser cooling simulation program at CSRe

CONCLUTION

The laser cooling dynamic process was investigated by the simulation. The possibility for the laser cooling scheme of ions with large momentum spread has been studied. The preliminary test result of the simulation program were shown. The velocity of ions can be modulated by the RF-buncher, the longitudinal momentum spread can be cooled by the laser. It illustrated a reasonable process of the simulation program. Next step, the simulation program will be improved and optimized as soon as possible.

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