DESIGN OF STOCHASTIC COOLING SYSTEM AT HIRFL-CSRe *

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Abstract

In the CSRm synchrotron, the beam is accelerated to energies of 500-1000 MeV/u. It can be fast extracted at energies of 200-700 MeV/u to produce radioactive ion beams (RIBs) or high Z beams at the target in the beam line. The secondary beams can be stored in the CSRe ring for internal-target experiments or β decay measurements. The secondary beams are very hot. Electron cooling to such beams would take several minutes, which is too long for experiments with short-lived ions. Stochastic cooling is very efficient for such hot beams. The large phase space after injection will be reduced to values which are well-suited for the subsequent e-cooling.

We report here the proposal and primary design of the stochastic cooling system at CSRe. The simulation results of the Palmer cooling and bunch rotation will be presented.

INTRODUCTION

HIRFL-CSR [1], a heavy ion synchrotron and cooler-storage ring system in Lanzhou, consists of a main synchrotron ring (CSRm) and an experimental storage ring (CSRe). The two existing cyclotrons SFC (K=69) and SSC (K=450) of the Heavy Ion Research Facility in Lanzhou (HIRFL) are used as its injector system. The heavy ion beams from the HIRFL with energies of 7-25MeV/u are injected into the CSRm. Electron cooling supports the accumulation at injection energy. The beams are accelerated and extracted slowly at energies of 500-1000MeV/u for external-target experiments, or fast extracted at energies of 200-700MeV/u to produce RIBs or high Z beams at an external production target for rare isotope beams. These beams are stored or decelerated in the CSRe for internal-target experiments or high precision spectroscopy with beam cooling. The radioactive fragments emerging from the target occupy a large transverse and longitudinal phase space which would lead to the e-cooling times of several minutes. This is too long for the experiments with rare isotope beams of short lifetime. Stochastic cooling at the CSRe would be very efficient to cool such hot beams and it will be used mainly for pre-cooling of RIBs. It is planned to reduce the momentum spread of ±1% and the horizontal and vertical emittances of 30 π mm mrad to the values which are well-suited for the subsequent e-cooling. The beam energy for stochastic cooling will be in the range of 350-500MeV/u.

CSRE RING

The layout of CSRe ring is shown in Fig. 1. It has a race-track shape and consists of two quasi-symmetric parts. One is the internal target part and another is the e-cooler part. Each part is a symmetric system and consists of two identical arc sections. Each arc consists of four dipoles, two quadruple triplets or one triplet and one doublet. Two long dispersion free straight sections house the internal target and the e-cooler. The major parameters of the CSRe are listed in table 1.

Table 1 Major parameters of CSRe

	CSRe
Circumference (m)	128.80
Ion species	Stable nuclei: C~U, RIB(A<238)
Max. energy (MeV/u)	600 (C^{6+}), 400 (U^{90+})
Intensity (Particles)	$10^{3\sim9}$
$B\rho_{max}$ (Tm)	8.40
B_{max} (T)	1.4
Ramping rate (T/s)	0.01~0.4
E-cooler Ion energy (MeV/u) Length (m)	 25~400 4.0
RF system Harmonic number f_{min}/f_{max} (MHz) Voltages (n × kV)	Capture 1 0.5 / 2.0 2 × 10.0
Vacuum pressure (mbar)	6.0×10^{-11}

In CSRe three lattice modes are adopted for different requirements. The first one is the internal-target mode with small β-amplitude at the target point, large transverse acceptance (A_h=150πmm mrad, A_v=75πmm mrad) and γ_{tr} = 2.457 for internal-target experiments. The second one is the normal mode with a large momentum acceptance of $\Delta P/P$ = 2.6% and γ_{tr} = 2.629 used for high-precision mass spectroscopy. The third one is the isochronous mode with a small transition γ_{tr} that equals the energy γ of beam in order to measure the mass of those short-life-time RIB. Figure 2 and Figure 3 show the distribution of the β-functions and the dispersions for those modes.

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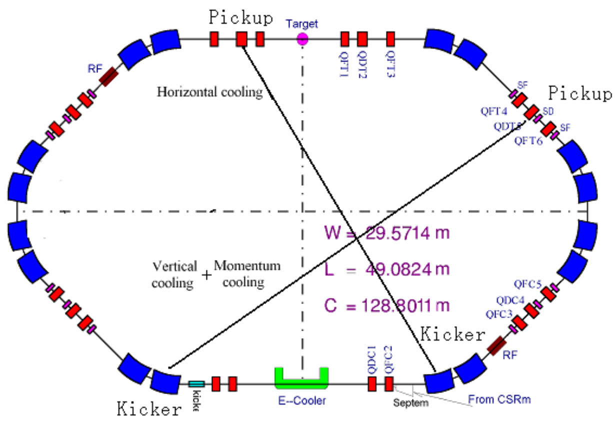

Figure 1: CSRe layout.

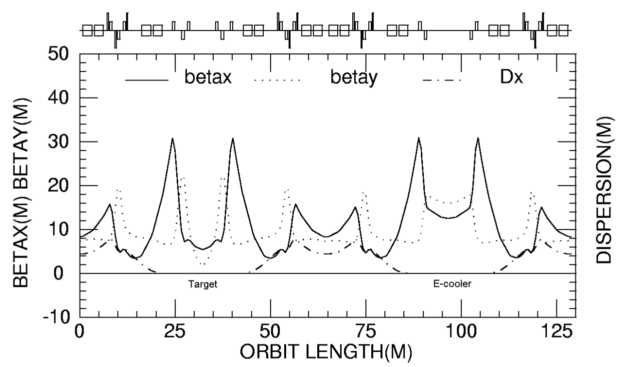

Figure 2: Distribution of the β-functions and the dispersion for the normal mode

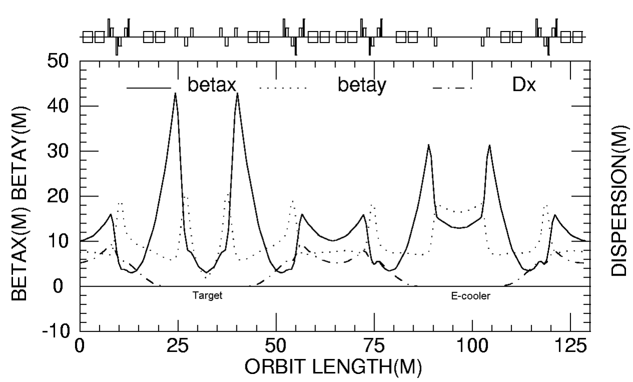

Figure 3: Distribution of the β-functions and the dispersion for the internal target mode

Because of space restrictions, all pickups and kickers will be installed inside the gaps of dipole and quadruple magnets. We plan to use Palmer cooling for longitudinal cooling and share the same pickup and kicker tank with vertical cooling. Twiss parameters at the pickups and kickers are shown in Table 2, where θ is the betatron phase advance between the pickup and kicker, L is the distance between them. The length of the quadruple is 750mm and 2.4m for the dipole. The vacuum cross sections in the quadruple and dipole magnets of CSRe are shown in Fig.4 and Fig.5.

Table 2 Twiss parameters for stochastic cooling (normal mode)

	Horizontal		Vertical+Momentum	
	Pickup	Kicker	Pickup	Kicker
β_x (m)	9.7-30.9	9.7-17	15.1-4.6	17.6-9.7
β_y (m)	22.2-6.7	7.6-6.9	8.9-18.4	6.9-7.6
D_x (m)	0	0-0.457	4.9-7.4	0-0.457
θ	68^0		92^0	
L(m)	57.8		54.2	

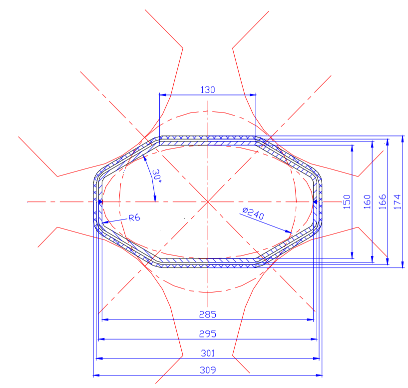

Figure 4: Vacuum cross section in the quadruple magnet

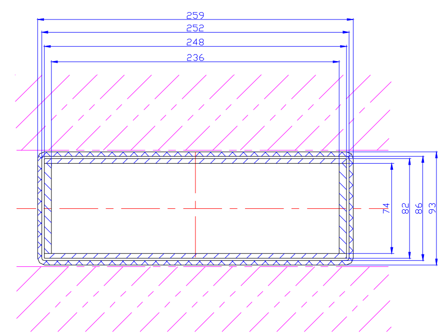

Figure 5: Vacuum cross section in the dipole magnet

SIMULATION RESULTS OF COOLING

Stochastic cooling will be used for internal target mode and normal mode which have large η values (0.25-0.36) with beam energy of 350 MeV/u - 510 MeV/u. As the injected momentum spread of RIB is as large as $\pm 1\%$, the maximum frequency of the stochastic cooling will be limited below 460 MHz due to the unwanted mixing effect from the pickup to the kicker. If the bandwidth is chosen to be 200 MHz – 400 MHz and $\lambda/4$ loop couplers are used, the electrode length will be about 262 mm and only two electrodes can be installed inside a quadruple. The signal to noise ratio will be poor in this case and the cooling speed will be slow. Figure 6 and figure 7 are the simulated results for Palmer cooling with initial momentum spread of ±1% (uniform) (All the simulations in this paper are for $^{132}Sn^{50+}$ beam with the particle number of 1.0e5 and the energy of 380MeV/u). From the results we can see that the best case is with 2 pickups and 8 kickers, with the gain of 150 dB and with the cryogenic pickup electrodes, then the microwave power needed is 230 W and the stochastic cooling will reduce the momentum spread to 1/5 of initial value within 10 s.

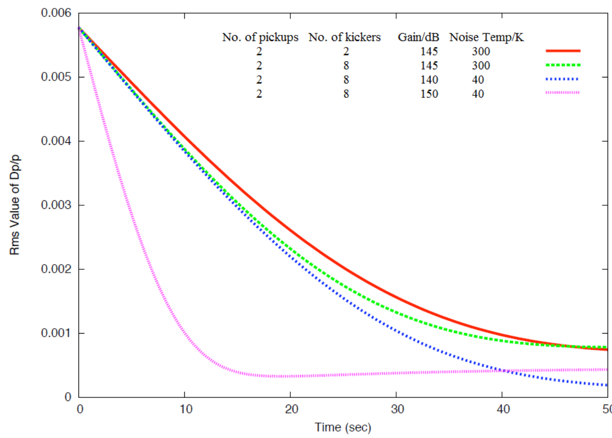

Figure 6 Rms value of $\Delta p/p$ & time

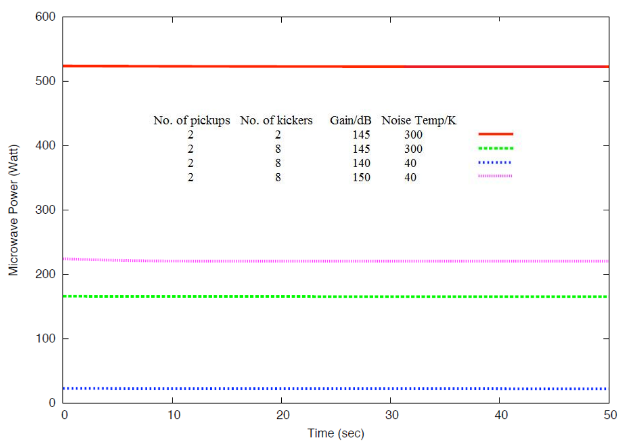

Figure 7 Microwave power

But for the rare isotope beams with short life, the cooling time should be as short as possible. There are several possibilities to improve this situation. One is to choose slot type pickups [2] and kickers. More of those by unit length could be installed, leading to an improved signal-to-noise ratio. Details of how to build such electrodes are not yet clear at such a low bandwidth. They would have to be installed into the quadruple with elliptic cross section. Furthermore there is still some flexibility to change the lattice mode to make η small. Then the bandwidth could be increased, but the acceptance would be decreased also. If the bunch length at extraction from the CSRm is not too large, one could install an additional bunch rotation system to decrease the initial momentum spread, so the bandwidth can be increased. Figure 8 is one simulated result during the bunch rotation with the initial bunch length of 100 ns and with 100 kV RF voltage applied during quarter synchrotron oscillation period and switched off. In a very short time the rms momentum spread can be reduced from 5.76e-3 to 1.44e-3, and the bandwidth can be increased to 0.5 - 1.0 GHz. With this initial momentum spread and bandwidth, the cooling time is shorter and the equilibrium momentum spread is smaller, which is shown in Fig.9.

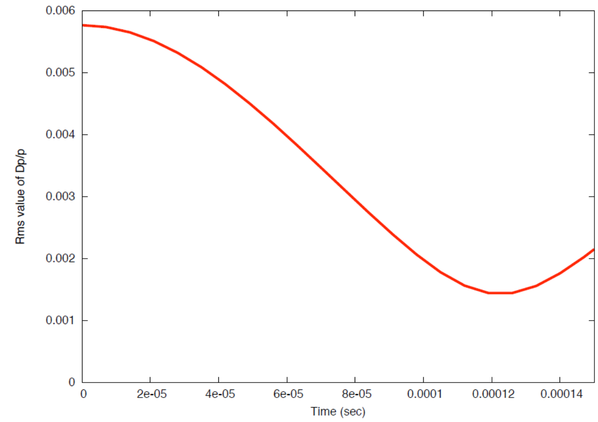

Figure 8 Rms value of $\Delta p/p$ & time during bunch rotation

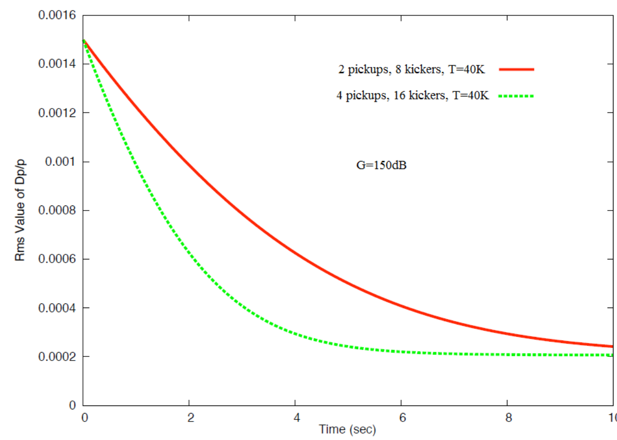

Figure 9 Rms value of $\Delta p/p$ & time

Table 3 shows a comparison for Palmer cooling with and without bunch rotation. There is no doubt that with bunch rotation we can get lower momentum spread in shorter time, which is better for the subsequent electron cooling. But the bunch rotation is effective only if the bunch length is less than 100 ns. The next step is to measure the bunch length after CSRm extraction.

Table 3 Palmer cooling with and without bunch rotation

Bunch rotation	Yes	No
$\Delta p/p$ (initial)	±1%	±1%
$\Delta p/p$ (after bunch rotation)	1.5e-3 (RMS)	±1% (uniform)
Bandwidth	0.5–1.0GHz	0.2-0.4GHz
Amplifier gain	150 dB	155 dB
Microwave power	540 W	750 W
$\Delta p/p$ (after 5 s)	2.2e-4	1.5e-3
N_{pu}/N_k	4/16	2/8

We also calculated the cooling process of e-cooling alone, e-cooling after stochastic cooling with and without the bunch rotation, shown in Figs.10, 11 and 12, where red line is the momentum spread, green and blue are transverse emittances. The e-cooling time is 900 s for initial momentum spread of ±1% and transverse emittance of 30π mm mrad, while they are 2.7 s for 2.2e-4 and 5 π mm mrad, 7 s for 1.5e-3 and 5 π mm mrad.

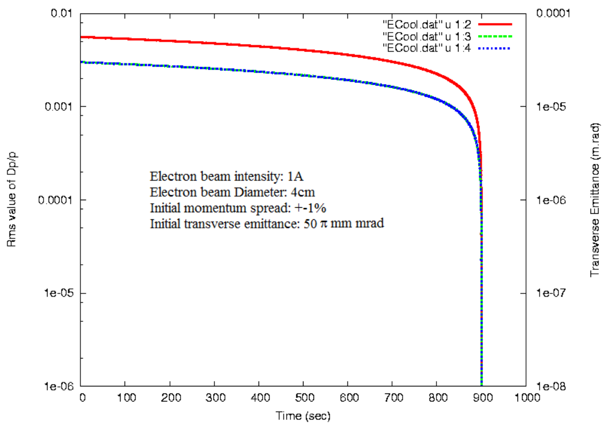

Figure 10: E-cooling process alone

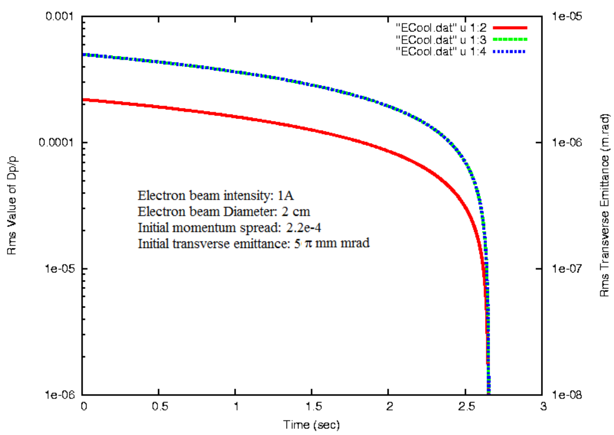

Figure 11: E-cooling process after stochastic cooling and bunch rotation

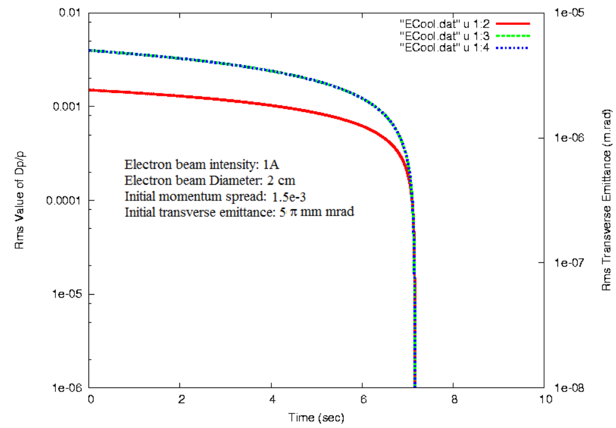

Figure 12: E-cooling process after stochastic cooling

SUMMARY ACKNOWLEDGMENTS

To get the same final cooled values with the same initial conditions, the cooling time is 900 s for the e-cooling alone, 7.7 s for the combination of the e-cooling and stochastic cooling after the bunch rotation, 12 s for the e-cooling and stochastic cooling without the bunch rotation. So the pre-cooling of stochastic cooling is quite helpful at CSRe for hot RIBs with short life time.

The authors gratefully acknowledge the helpful discussions about pickups with C. Peschke.

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