BEAM COMMISSIONING OF ION COOLER RING, S-LSR*

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Abstract

The beam commissioning of the ion cooler ring, S-LSR was started from October 2005 using the 7MeV proton and the commissioning of the electron beam cooling was started from November 2005. The precise measurements of the lattice parameters were carried out using the cooled proton beam. The RMS values of the closed orbit distortion are 1.5 mm and 0.6 mm in the horizontal and vertical direction. The measured average β function at the quadrupole magnets are 2.1 m and 3.0 m in the horizontal and vertical direction. The calculated ones by MAD8 are 2.2 m and 3.2 m. The measured average horizontal dispersion function is 1.5 m at the position monitors, while the calculation one is 1.6 m.

The stored maximum current of the cooled proton is 1.2 mA ($5x10^9$ p^+) with the vertical feedback system. The minimum number of the particle of which the momentum can be measured is 1000 and the minimum momentum spread is $3x10^{-6}$.

INTRODUCTION

S-LSR is a new ion cooler ring in Kyoto University. It was constructed for the beam physics and the application using the beam cooling [1]. Figure 1 shows the layout of the ring. S-LSR has an electron cooler which will be used for the cooling of the laser accelerated ions and the short ion bunch generation. It also has a laser cooling system to study the ultra cold ion beam and to achieve the crystalline beam. Table 1 shows the main parameters of S-LSR.

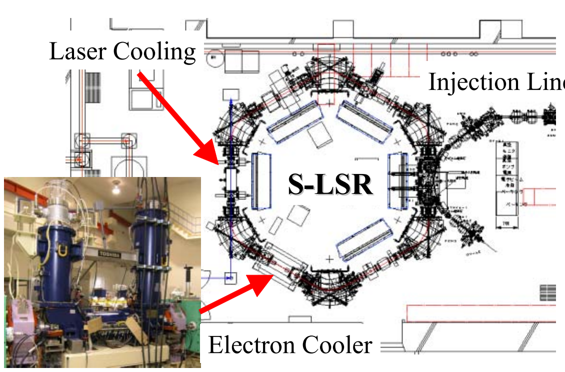

Figure 1: Layout of S-LSR.

Table 1: Main parameters of S-LSR

Ion species	
Proton$^+$ (for electron cooling)	7 MeV
Mg$^+$ (for laser cooling)	35 keV
Ring	
Circumference	22.557 m
Length of drift space	1.86 m
Number of periods	6
Bending magnet	
Maximum field	0.95 T
Curvature radius	1.05 m
Gap height	70 mm
Quadrupole magnet	
Length	0.20 m
Bore radius	70 mm

The beam commissioning of S-LSR was started from October 2005 using the 7MeV proton from the RF linac. The commissioning of the electron cooling for the proton beam was started from November 2005. The details are described in the reference [2]. The test of the fast extraction of the cooled beam was also done in January 2006 [3].

The beam commissioning of the 35 keV Mg$^+$ beam for the laser cooling was started from May 2006. The stored current of Mg$^+$ was 3 µA. The experiments of the laser cooling will be started. In this paper, the beam commissioning results and the parameter measurements of the ring are reported.

VACUUM AND LIFETIME

For the laser cooling experiments, we need to store the low energy heavy ion beam and the low vacuum pressure is necessary. Each vacuum chamber of the bending magnet has two NEG pumps and the electron cooler has three NEG pumps. The straight sections are evacuated by the 8 sputter ion pumps and the 5 Titanium sublimation pumps. The 5 months trend of the vacuum pressure after the first baking is shown in Fig.2 [4]. The baking temperature was 200 °C and the top period was 36 hours.

*Work supported by Advanced Accelerator Development Project of Ministry of Education, Culture, Sports, Science and Technology (MEXT) and the 21st COE program, Centre for Diversity and Universality in Physics at Kyoto University
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In January 2006, the average vacuum pressure reached $8\text{x}10^{-9}$ Pa.

Figure 3(a) shows the stored beam current of 7 MeV proton measured by DC current transformer (DC-CT) with and without the electron beam cooling. The average vacuum pressure was $2\text{x}10^{-8}$ Pa. The lifetime without cooling is 1400 sec, which is determined by the multiple scattering with the residual gas. With the electron cooling, the multiple scattering effect is suppressed and the lifetime extends to 23000 sec.

Figure 3(b) shows the lifetime of 35 keV Mg^+ beam when the average vacuum pressure was $1\text{x}10^{-8}$ Pa. The particle number was measured by the electrostatic pickup which is calibrated by DC-CT. The maximum current is 3 μA ($=8\text{x}10^8$ particles) and the lifetime is 15 sec, which is enough long for the laser cooling experiments. The lifetime is determined by the multiple scattering with the residual gas and the charge exchange.

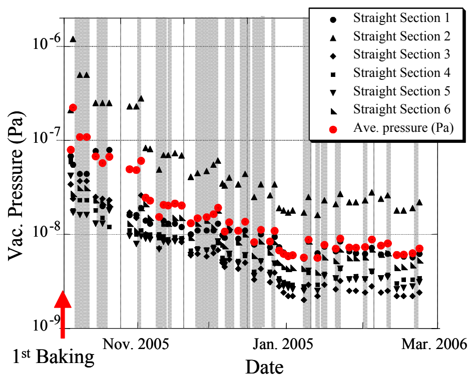

Figure 2: 5 months trend of the vacuum pressure after the first baking. There are 6 vacuum gauges in the 6 straight sections. The gray band shows the period of the operation.

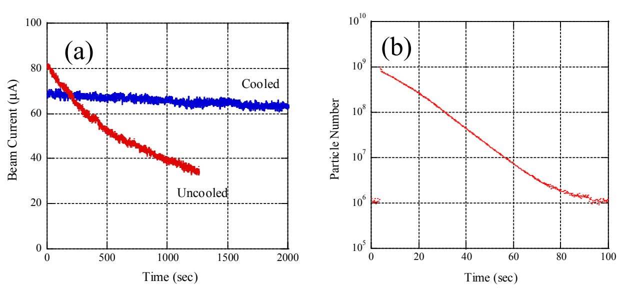

Figure 3: (a) Lifetime of the 7 MeV proton beam measured by DC-CT with and without the electron cooling when the average vacuum pressure is $2\text{x}10^{-8}$ Pa. (b) Lifetime of the 35 keV Mg^+ beam measured by the electrostatic pickup when the average pressure is $1\text{x}10^{-8}$ Pa.

LATTICE PARAMETERS

The lattice parameters of S-LSR were measured precisely using the cooled proton beam, because it has a small emittance, a small momentum spread and a long lifetime. The momentum spread is typically $2\text{x}10^{-4}$ and the beam size is 1.2 mm at the ion current of 30 μA [2]. The ion beam parameters for the lattice parameter measurements are shown in Table 2. The lattice parameters are calculated by MAD8. The field gradient of the quadrupole magnets in MAD8 are adjusted so that the calculated tune value agrees with the measured one.

The measured closed orbit distortion (COD) is shown in Fig.4 without any corrections. The beam position was measured by the electrostatic pickup [5]. The RMS values of the COD are 1.5 mm and 0.6 mm in the horizontal and vertical direction. The sources of the horizontal COD are the field difference and the alignment errors of the bending magnets and the quadrupole magnets. The compensation error of the horizontal deflection by the troid in the electron cooler is also a COD source. The vertical COD source is the horizontal magnetic field component in the electron cooler and the vertical electric field for the ion collection in the MCP residual gas monitor. The details of the COD correction are described in the reference [6].

The β−functions in the ring were measured from the following relation,

$$\delta\nu_{x,y} = \frac{\beta_{x,y}}{4\pi}\frac{\delta G \cdot L}{B\rho},$$

where δν is a tune shift, δG is a change of the field gradient and L is an effective length of the quadrupole magnet. Typically, when the field gradient is change by 5 %, the tune shift is around 0.003 in the measurement. The results are shown in Fig. 5(a). The error bar is determined by the resolution of the tune measurements, which is 10^{-4}. The average β function at the quadrupole magnets are 2.1 m and 3.0 m in the horizontal and vertical direction. The calculated ones by MAD8 are 2.2 m and 3.2 m, respectively.

The horizontal dispersion function (η_x) in the ring were measured from the following relation,

$$\delta x_p = \eta_x \frac{\delta p_i}{p_i} = \eta_x \frac{\delta E_i}{2E_i} = \eta_x \frac{\delta E_e}{2E_e},$$

where p_i, E_i are an ion momentum and an ion energy and E_e is an electron energy. The beam position shift was measured by the electrostatic position monitors and the electron energy was controlled by the cathode potential, which was changed by 0.1 %, typically. Figure 5(b) shows

Table 2: Ion beam for the lattice measurements

Ion Beam Current	30 μA
Ion Number	$1\text{ x}10^8$
Momentum Spread (2σ)	$2\text{ x}10^{-4}$
Beam Size (2σ)	1.2 mm
Revolution Frequency	1.6099 MHz
Betatron Tune	(1.6438, 1.2093)
Transition γ (calc.)	1.411

the measured horizontal dispersion. The average dispersion is 1.5 m at the position of the monitors, while the calculation one is 1.6 m.

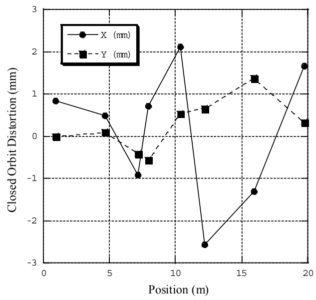

Figure 4: Closed orbit distortion of the cooled proton beam without corrections. The beam position is measured by the electrostatic pickup.

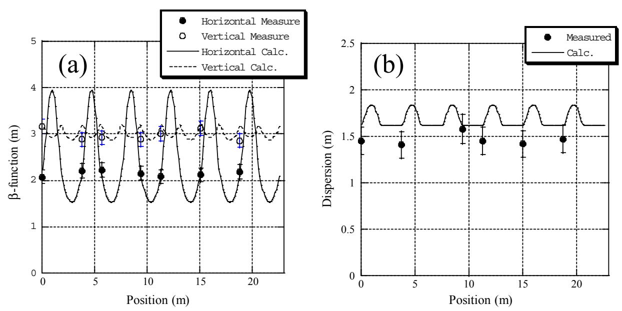

Figure 5: (a) Measured and calculated β-function in the ring. (b) Measured and calculated horizontal dispersion function in the ring.

COOLED PROTON BEAM

The cooled proton beam less than 100 μA (=4×10^8 particles) is very stable and has a long lifetime. But a small vertical coherent oscillation was observed when the stacking current exceeded 100 μA and a large oscillation occurred above 450 μA, which leaded to the beam loss [7]. The frequency components of the first small oscillation is less than 20 MHz but the frequency of the second large oscillation is around 86 MHz. It was difficult to store the cooled beam higher than 500 μA without the feedback. We installed the vertical feedback system of which bandwidth was 100 MHz to suppress the high frequency component. With the feedback, the maximum stacking current became 1.2 mA (5×10^9 particles).

On the other hand, we also measured the small number of the particles. One of the motivations is an observation of the one dimensional ordering, which was found for the cooled heavy ions [8]. Another motivation is a test of the cooler ring and the electron cooling system because it is possible to find the heating sources in the hardware by the measurement of the low temperature ion beam.

Figure 6 shows the momentum spread of the proton beam as a function of the particle number. The particle number was measured by the MCP residual gas monitor, which was calibrated by the DC-CT [5]. The momentum spread was measured by the Schottky monitor [9]. The minimum number of the protons is about 1000 where the Schottky signal can be measured. Figure 6(a) shows the momentum spread when the high voltage power supply of the electron gun had a ripple of 2×10^{-4} (p-p). The momentum spread becomes constant at 5×10^{-6}. Figure 6(b) shows the momentum spread after the improvements of the power supply with three kinds of the electron current. The ripple is less than 2×10^{-5} (p-p). The momentum spread does not become constant and the minimum spread reaches 3×10^{-6}, which corresponds to the longitudinal ion temperature of 100 μeV.

The clear transition of the 1-D ordering is not observed yet but this minimum momentum spread is close to the transition point, which is expected $1\text{-}2\times10^{-6}$ from the simulation [10, 11].

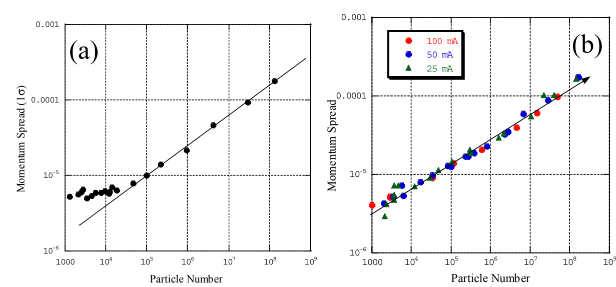

Figure 6: Measured momentum spread of the proton beam as a function of the particle number. The particle number was measured by the MCP residual gas monitor and the momentum spread was measured by the Schottky monitor. The voltage ripple of the cathode power supply is 2×10^{-4} (p-p) (a) and less than 2×10^{-5} (p-p) (b).

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