BEAM COOLING AT ION ACCUMULATION/COOLER RING, S-LSR

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Abstract

Electron beam cooling of hot ion beam and 3-dimensional laser cooling of $^{24}Mg^{+}$ ion are planned at S-LSR. Laser produced ions in the energy interval of ±5% around 2 MeV/u are to be phase rotated and are to be applied electron cooling after injection into S-LSR so as to be reduced to ±1% in their energy spread. For laser cooling of $^{24}Mg^{+}$ ions, static electric field is to be superposed with the magnetic field of each deflection element to cancel out the orbit dispersion, which is considered to be effective to stabilize the crystalline state by suppression of the shear heating. Construction of S-LSR is close to be completion and beam commissioning is scheduled early in this autumn.

1 INTRODUCTION

At Institute for Chemical Research (ICR), Kyoto University, an ion accumulation/cooler ring, S-LSR has been under construction. In Fig.1, the layout of the beam facility at the Advanced Research Center for Beam Science is shown. S-LSR aims at the demonstration of feasibility of tailoring the laser-produced ion beam with combined use of phase rotation and electron beam cooling of hot ion beam. Three dimensional laser cooling is also included in its research scope and possibility of controlling the orbit dispersion by superposing the electric field with the magnetic one. In table 1, the main parameters of S-LSR are listed up.

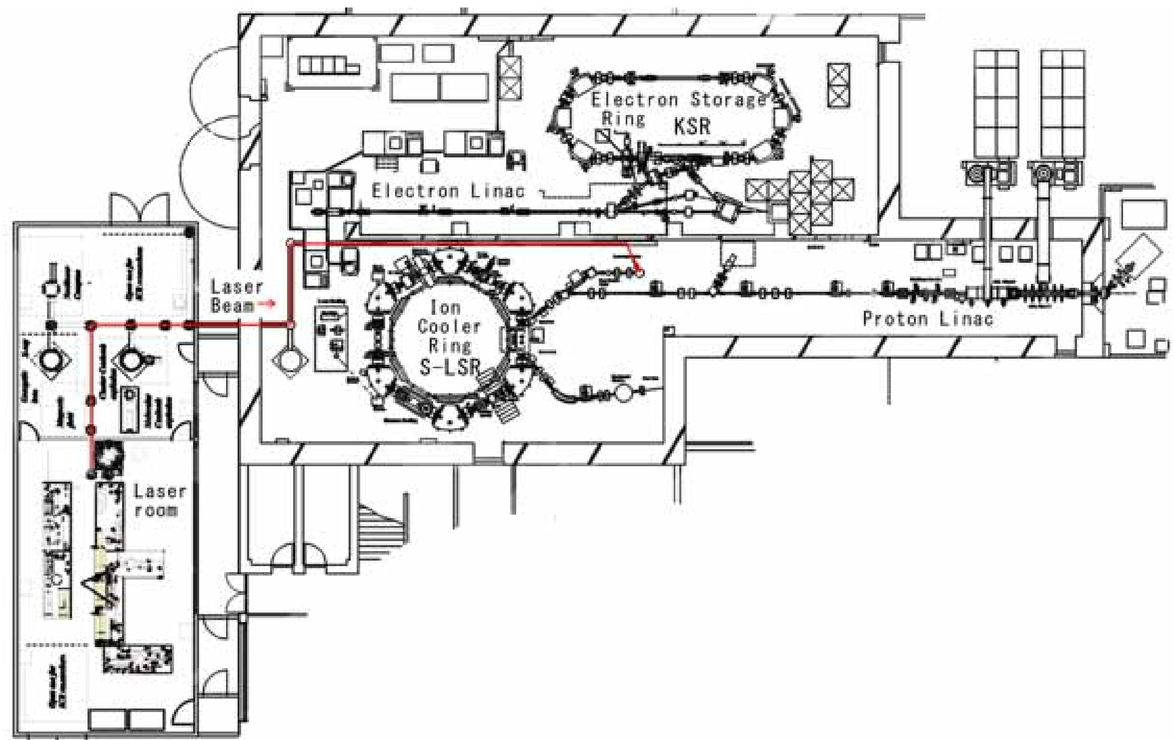

Fig. 1 Layout of the beam facility of Advanced Research Center for Beam Science at ICR, Kyoto Univ.

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Table 1 Main Parameters of S-LSR

Circumference	22.557 m
Average radius	3.59 m
Length of straight section	2.66 m
Number of periods	6
Betatron Tune	
Crystalline Mode	Normal Operation Mode
1.45 (H) , 1.44 (V)	1.872(H), 0.788 (V)
Bending Magnet	(H-type)
Maximum field	0.95 T
Curvature radius	1.05 m
Gap height	70 mm
Pole end cut	Rogowski cut+Field clamp
Deflection Angle	60˚
Weight	4.5 tons
Quadrupole Magnet	
Core Length	0.20 m
Bore radius	70 mm
Maximum field gradient	5 T/m

2 ELECTRON BEAM COOLING OF HOT ION BEAM

2.1 Motive Force

S-LSR is promoted as the research and developments to realize compact injector of heavy ions (Carbon or proton) to be used as an injector of a synchrotron dedicated for cancer therapy. Laser-produced ions are directly to be utilized as the injection beam into a pulse synchrotron[1]. The intensity of such laser-produced ions, in general, decreases exponentially as the increase of their energies[2], which is not suitable for real application. As the remedy of such situation, phase rotation scheme combined with an electron beam cooling has been proposed [1]. Ions produced by a pulse laser with ultra-high peak power (~100 TW) within the energy spread of ±5% are selected and are to be reduced to ±1% in energy spread by phase rotation and further cooled down another one order of magnitude by an electron beam cooling after injection into a cooler ring. We have already demonstrated the feasibility of such "Electron Beam Cooling of Hot Ion Beam" with use of sweeping of the relative velocity between the ion and electron beam utilizing TSR at MPI at Heidelberg with the hot ion beam artificially made by application of noise[3]. At S-LSR, an overall feasibility is to be demonstrated for real laser-produced ions with the T6 laser guided from the laser building next to the accelerator facility.

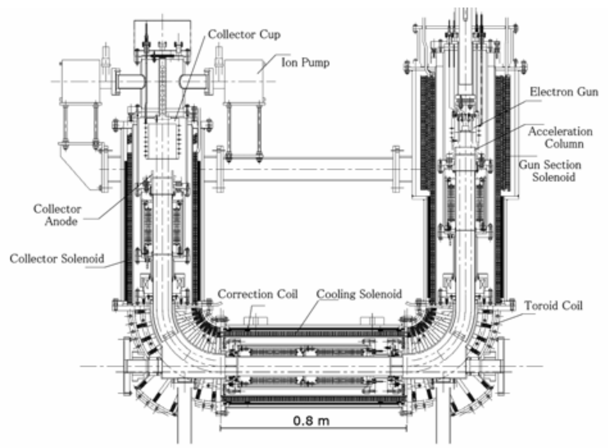


Fig.2. The cross-sectional view of the electron cooler for S-LSR.

2.2 Construction of Electron Cooler

As the main purpose of S-LSR is the downsizing of the accelerator for cancer therapy, its design is required to be as compact as possible and its long straight section is determined to be 1.86 m, which is very short and required a lot of technical developments in the electron cooler[4]. The cross-sectional view of the electron cooler for S-LSR is shown in Fig. 2 and the photo of the real fabricated electron cooler for S-LSR is shown in Fig. 3.

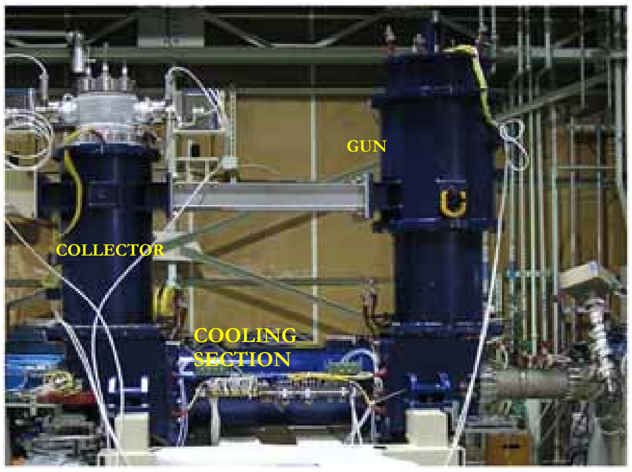


Fig. 3 Fabricated electron cooler for S-LSR.

2.3 Evaluation of the Fabricated Cooler

The magnetic fields of the solenoids and toroids for the electron cooler have been evaluated with hall probes position controlled both in Cartesian and curved coordinates along the electron beam path at National Institute of Radiological Sciences. After field measurements of each component, the total electron cooler has been assembled, the field property of which is evaluated at ICR, Kyoto University with Hall probe. In Fig. 4, the measured vertical component of the magnetic field is compared with computer calculation by TOSCA. Their agreement is quite good and effective cooling length is found to be 440 mm for the central solenoid 800 mm in length. The electron beam test has also been performed and electron beam up to 300 mA has been safely attained as shown in Fig. 5

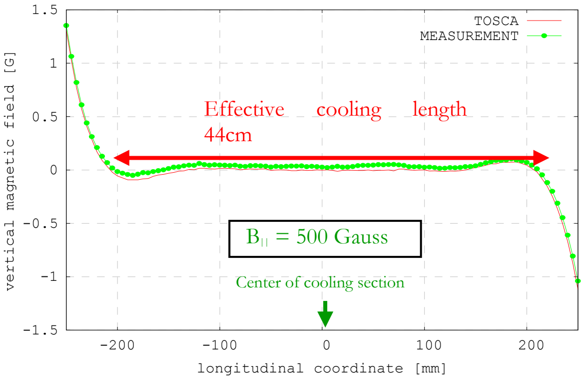


Fig.4 Vertical component of the magnetic field in the cooling section. Measured results are compared with the calculation by the 3 D computer code TOSCA.

3 LASER COOLING OF MAGNESIUM IONS

3.1 Longitudinal Laser Cooling

$^{24}Mg^{+}$ ions with kinetic energy of 35 keV is to be laser cooled with use of the ring dye (Rhodamine110) laser (λ=560 nm) pumped with a solid-state green laser with the wave length of 532 nm. A frequency doubler is used to match the wave length of the laser with the energy level gap of ^{24}Mg atom. At the first stage, a single laser with an induction accelerator is utilized (Fig. 6(a)) while at the advanced stage, two counter propagating lasers are to be utilized (Fig. 6 (b)) in order to avoid the beam loss due to penetration into the region below the critical velocity, v_c by intra beam scattering.

3.2 Transverse Laser Cooling

So as to reduce transverse oscillation amplitude by laser cooling, coupling between the longitudinal and transverse degrees of freedom is inevitable, which is to be realized by placing the RF acceleration cavity at the position with finite dispersion size[5].

3.3 Approach to 3-D Crystalline State

Although ordered state in 1 dimension has been reported with electron cooling, three dimensional crystalline state is considered to be unstable as illustrated in Fig. 7[6]. So as to avoid this situation, dispersion free lattice is proposed[7], which, however, needs additional coupling cavity between longitudinal and transverse degrees of freedom because no dispersion exists throughout the whole circumference. Tapered cooling with use of Wien Filter set at one of the long straight sections is proposed[8], which is claimed to reduce the super-periodicity of ring down to 1. If the Wien Filter is excited after ions are well cooled down, its effect is expected to be negligibly small because Wien Filter does not deflect the ion at all if the ion has a certain velocity, which requires quantitative evaluation by MD simulation from now on.

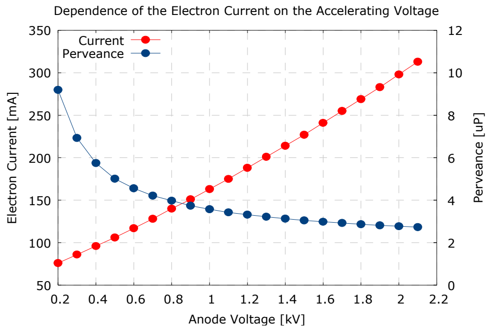
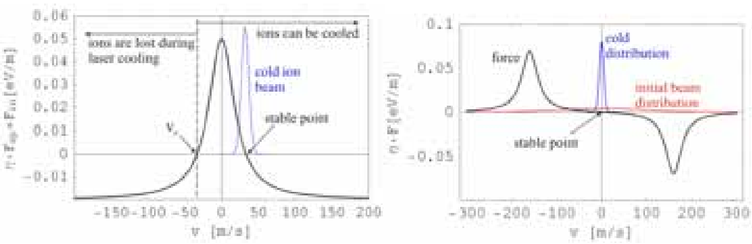


Fig.5 Characteristics of the electron cooler for S-LSR tested at the electron energy of 3.8 keV (corresponding to 7 MeV proton)



(a) (b)

Fig. 6 Longitudinal laser cooling (a)with a single laser and an induction accelerator, (b)with two counter propagating lasers.

ACKNOWLEDGEMENT

The present work is financially supported by Advanced Compact Accelerator Development by Ministry of Education, Culture, Sports, Science and Technology and 21COE at Kyoto University.

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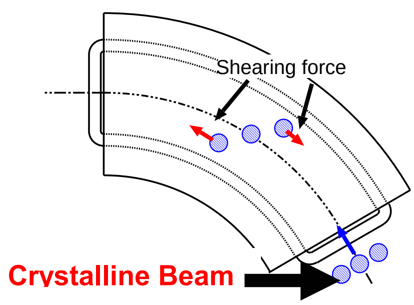

Fig. 7 Illustration of shear heating.