BEAM LIFETIME WITH THE VACUUM SYSTEM IN S-LSR*

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Abstract

S-LSR is a compact ion storage and cooler ring to inject beam of 7MeV proton and 40MeV Mg^+. The average vacuum pressure measured by 6 vacuum gauges without beam was achieved up to about $4x10^{-9}$ Pa. The beam lifetime can be estimated with the vacuum pressure or the loss-rate of the beam energy. The values of the estimated lifetime are nearly equal to the measured lifetime values (the stored current).

INTRODUCTION

Ion storage ring S-LSR, which was constructed at Institute for Chemical Research, Kyoto University, is the experimental studies machine that takes an important part of Advanced Compact Accelerator development project. The injectors for S-LSR are a 7MeV proton Linac and a 40MeV Mg ion source. We successfully performed the experiments by using S-LSR, for example the one-dimensional beam ordering of protons utilizing the electron cooler [1], the extraction tests of the short bunched beam [2] and so forth.

S-LSR is ion storage ring that designs the lattice structure to realize the crystal beam by using the laser cooling. And the experiment of Mg^+ beam three dimensions cooling by the laser cooling is advanced aiming at the achievement of the crystal beam [3] [4] [5]. The crystal beam is an ultimately cold beam. The crystal beam has been researched about the theory and the experiment in each research facilities. However, it has not come to be confirmed still experimentally.

An enough beam lifetime for the cooling and the measurement time is necessary because of the beam cooling experiment. So, the improvement of the vacuum system in the beam cooling experiment is important. The present relation between the vacuum pressure and the beam lifetime is so important due to improvement of the beam lifetime. Therefore the present status of the proton beam lifetime and the vacuum pressure is reported.

VACUUM SYSTEM

The vacuum system of S-LSR was designed to achieve average vacuum pressure $5x10^{-9}$ Pa in the calculation. All almost the vacuum ducts for S-LSR adopted pre-baking process of 950 degrees in order to reduce out-gassing [6]. The titanium getter pumps and the spatter ion pumps have been installed as main exhaust system. And non-magnetism NEG pump was used for the beam inclination part without the pump installation space. The room temperature is greatly influenced by the outside temperature, because the room temperature is not positively controlled in accelerator experiment room where S-LSR is set up. The average vacuum pressure has reached 4×10^{-9} Pa at the period when the temperature is low. The average vacuum pressure has been estimated with 6 vacuum gauges, which are installed in each straight section of S-LSR.

BEAM LIFETIME

The beam loss is decrease of the stored beam current. The 1/e beam lifetime (T) is defined by

$$I(t) = I_0 \exp(-t/T) \qquad (1)$$

where I, and I_0 are the stored beam current and the initial beam current.

The beam scattering occurs by the interactions between the residual gas and the ion beam. The scattering consists of the electron capture, the electron stripping and the multiple scattering. The beam loss occurs when proton or Mg^+ goes out the acceptance by the scattering. The acceptance of S-LSR is limited the aperture by the minimum inside area of the vacuum ducts for quadrupole magnets. The vertical and horizontal aperture sizes are ±23 mm and ±60 mm.

As shown in Fig.1, main loss factor of the proton beam and the Mg^+ beam are the multiple scattering and the electron capture, respectively. The electron stripping process never occurs in the case of the proton beam because it is fully stripped. The lifetime of Mg^+ beam is very short compared with the proton beam. The S-LSR

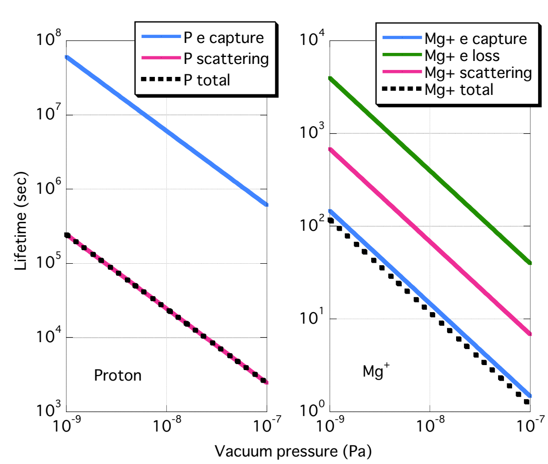

Figure 1: 1/e beam lifetime is calculated from vacuum pressure.

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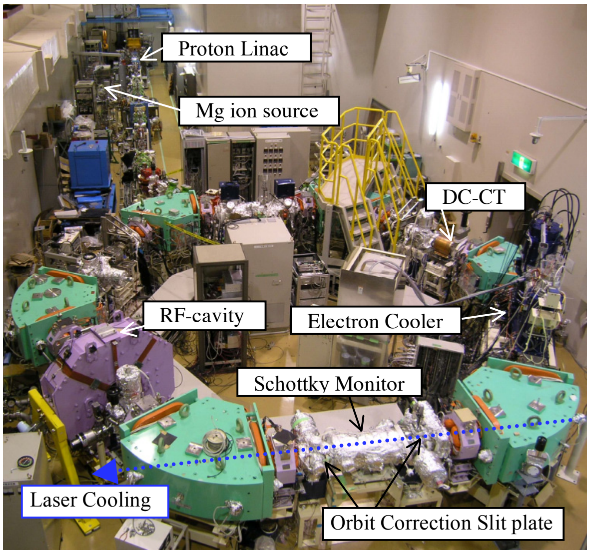

Figure 2: Layout of S-LSR

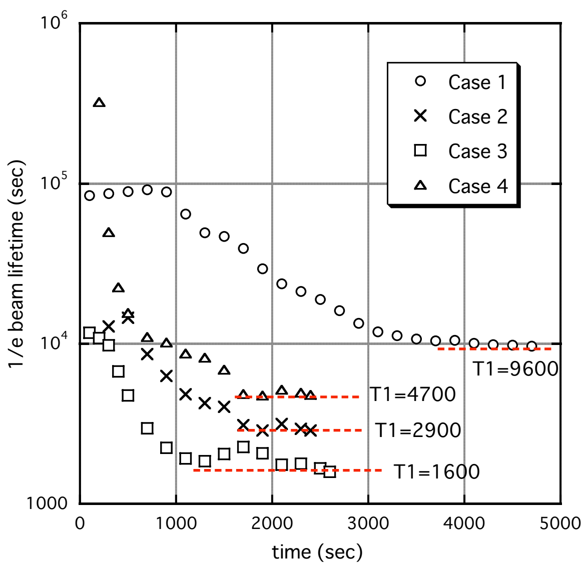

Figure 3: The measured proton beam lifetime. The plots are the resorts of the curve fitting for the 20 sec average stored current.

vacuum system has to achieve the vacuum pressure of under $1x10^{-8}$ in order to obtain over 10 sec of Mg^+ beam lifetime. The lifetime account of the beam scattering is estimated with the beam energy loss-rate. And the beam lifetime is calculated from the measured stored current. Status of the residual gas at the beam orbit is guessed by these results.

MEASUREMENT RESOLTS

Proton beam

Fig. 3 shows the beam lifetime calculated from the measured beam current by using DC-CT. Plots of the beam lifetime in Fig. 3 decrease just after the start of the measurements (the stop of the electron beam cooling). The beam emittance was so small by the electron beam cooling before the measurement. But the beam emittance without the cooling force suddenly becomes to increase by the intrabeam-scattering. The beam scattering proceeds all the time of above process. Because the proton beam that will loss by the scattering are little according to the small emittance, it is considered that the beam lifetime is long at the first. And the lifetime values are nearly constant after some time without the influence of the intra-beam scattering. The measurement lifetime (T1) of the constant values fit for the formula (1). The estimated results are shown in Table 1.

Table 1: Proton beam lifetime.

	1/e beam lifetime x1000 sec		
	Measurement of Stored current T1	Estimation with Vacuum pressure T3 (pressure Pa)	Estimation with Beam energy T2
Case 1	9.6	16 (1.9e-8)	11
Case 2	2.9	12 (2.6e-8)	4.3
Case 3	1.6	3.3 (9.4e-8)	2.4
Case 4	4.7	7.9 (3.9e-8)	5.5

The beam loss-rate depends on the stacking proton number (the beam current) and the vacuum pressure (the density of the residual gas) according to the beam scattering theory. The beam lifetime (T2) can be estimated with the pressure as shown in Table 1.

The measured Schottky-noise is the 34th harmonics as the revolution frequency is 1.61 MHz. The noise signals were measured just after the electron cooling was stopped. spread is the beam momentum spread, and shift of the noise signal is proved the shift of the momentum center that is caused the beam energy loss for the beam scattering with the residual gas at the beam orbit. The density of the residual gas (vacuum pressure at the beam orbit) can be obtained by Bethe-Bloch's formula. And then the beam lifetime (T3) can be obtained by calculating as well as the estimation with the vacuum pressure, as shown in Table 1.

Mg^+ beam

Compared with the proton beam, the Mg^+ beam was low current, and it was impossible to be measured by DC-CT. Therefore, the stored current was estimated with the pick up signals, which was measured by an electro-static position monitor.

The beam cooling had not been used in Mg^+ beam injection unlike the proton beam. Table 2 shows the result of calculated the measurement lifetime (T4) form its measured current values. And the beam lifetime (T5) is estimated with the vacuum pressure like the proton beam.

Table 2: Mg beam lifetime.

	Betatron Tune	1/e beam lifetime (sec)	
		Measurement of Stored current T4	Estimation with Vacuum pressure T5 (pressure Pa)
Case 5	(1.64, 1.20)	27.5	30.8 (3.9e-9)
Case 6	(2.07, 0.72)	8.8	10.1 (8.3e-9)
Case 7	(2.07, 1.07)	3.8	5.6 (1.7e-8)

Figure 4: The orbit correction slit plate for the beam and the cooling laser. Alumina fluorescent plate and the hole of ϕ10, 6, 3, 2mm has been installed on the stainless plate. Aperture size is adjusted by using the lower side of a stainless plate.

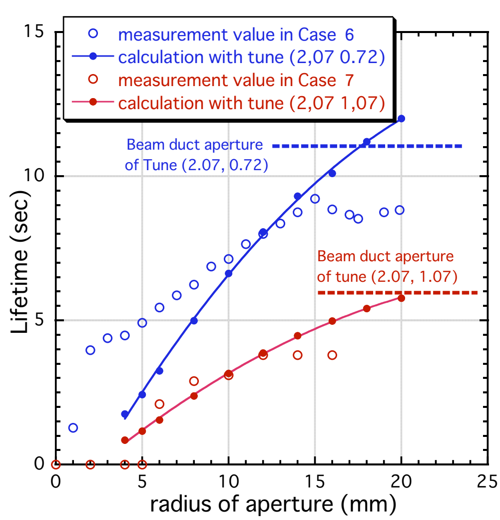

Figure 5: 1/e beam lifetime as a relation of aperture sizes for different betatron tune.

Because machine-time of the measurements is different, the parameter like betatron tune and the vacuum pressure, etc. is different. In all cases, the tendency witch the measurement lifetime values (by beam energy or by stored current) are a little shorter than the estimation values (by vacuum pressure) is corresponding as well as the proton beam.

In case 6 and case 7, vertical aperture was positively narrowed by utilizing the orbit correction slit plate in Fig. 4 and the beam lifetime was measured as shown in Fig. 5. The measurement values are reasonable compared with the calculation values.

SUMMARY

A little out-gassing in the small partial area has much influence on the average vacuum pressure (beam lifetime) in S-LSR which the average vacuum pressure has be achieved up to about 4×10^{-9} Pa. Sensitively of the vacuum gauges is nothing about that little out-gassing. Therefore the measurement lifetime values are shorter than that of the estimated values by the vacuum gauges. And its tendency of the proton beam is strong. We guess that this reason is the difference of out-gassing amount by the stored current value. In these machine-times, the stored current of the proton beam and Mg^+ beam are from 30 to 60 μA and a few μA, respectively.

As shown in Fig. 5, Mg^+ beam lifetime is reasonable for the calculation value when the vertical aperture is wide. And upper limit of the beam lifetime by aperture of the vacuum ducts agree well with the calculation value. However measurement values don't agree with the calculation value as the aperture narrowed, because resolution of the beam orbit correction is not enough for the aperture center. We utilized a hole of φ10 mm in Fig. 4 in order to correct the beam orbit. But the results above will be useful for the understanding of the relation of between residual gas and the beam lifetime.

We are planning to experiment about the three-dimensional laser cooling in the future. It is important to improve the beam lifetime for the beam cooling. We would like to research the way of efficient improvement of the beam lifetime under the present status of S-LSR vacuum system.

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