BEAM-GAS LIFETIME MEASUREMENT IN THE PLS ELECTRON STORAGE RING*

M. Kwon, C. D. Park, S. M. Chung, and I. S. Ko
Pohang Accelerator Laboratory, POSTECH, Pohang, Kyungbuk, 790-784, Korea

Abstract

Among the various factors which determine the beam lifetime of the PLS electron storage ring, the elastic and inelastic scattering lifetimes were measured using helium in the pressure range from 1x10^{-8} to 3x10^{-7} Torr. The beam-gas lifetimes measured with helium as well as in the normal operations are compared with the calculated ones. In the high helium pressure range measured lifetimes agree with the calculated ones within a factor of 1.5. At low pressures discrepancies are found between measured and calculated ones, indicating that Touschek effect makes substantial contribution to the beam lifetime.

1 INTRODUCTION

The Pohang Light Source (PLS) of the Pohang Accelerator Laboratory is a third generation synchrotron light source with a nominal electron beam energy of 2 GeV. The PLS storage ring (SR) must provide a long lifetime of a stored electron beam. Since the electron beam lifetime is partly determined by the scattering with the residual gas in the vacuum chamber, the vacuum system must maintain the chamber pressure below a certain level. The SR vacuum system has been designed to meet such a requirement and has been operated since September 1994[1].

The beam lifetimes at the early stage of the commissioning were less than 50 minutes due to the beam-gas scattering. However, the lifetime has increased with the accumulated beam dose since the specific pressure rise has been gradually reduced owing to the beam-self cleaning effect. The average pressure is now around 3x10^{-10} Torr without beam and less than 1x10^{-9} Torr with beam so that the beam lifetime, we believe, is not limited by electrons scattering with residual gas molecules.

However, in order to identify the contributions of the beam-gas scattering to the total beam lifetime, the beam-gas lifetimes were measured using helium in the pressure range from ~1x10^{-8} to ~3x10^{-7} Torr. They are compared with the calculated values in this article. The effect of the installation of the U7 undulator on the lifetime will also be described. Finally, the beam lifetimes measured in the normal operations are presented and compared with the calculated ones.

2 BEAM-GAS LIFETIME

The beam lifetime of a stored electron beam is mainly determined by the four loss mechanisms, *i. e.*, quantum fluctuation due to synchrotron radiation, elastic and inelastic scattering with the residual gas in the vacuum chamber, and intra-bunch scattering [2]. From the vacuum point of view, the beam-gas scattering is the most important one among them.

Circulating electrons scatter elastically with nuclei of residual gas molecules. The electrons get lost from the beam if the resulting amplitude of the betatron motion exceeds the vacuum chamber aperture. The beam lifetime due to this effect is called elastic scattering lifetime and is given by

$$\tau^{-1} \propto P Z^2 \ \beta <\beta> d_m^{-2}$$

where P= pressure, Z= atomic number, β= beta function, and d_m= minimum aperture of the vacuum chamber. Circulating electrons also scatter in-elastically (emission of photons) with nuclei of residual gas molecules. The electrons get lost from the beam if the resulting energy loss exceeds the energy acceptance. The beam lifetime due to this effect is called inelastic scattering lifetime and is given by

$$\tau^{-1} \propto P Z^2 d_m^{-2} \quad Z^2 \ln(E_o / \Delta E_{rf}) \ln (Z^{-1/3})$$

where $E_o/\Delta E_{rf}$ = RF energy acceptance of the ring.

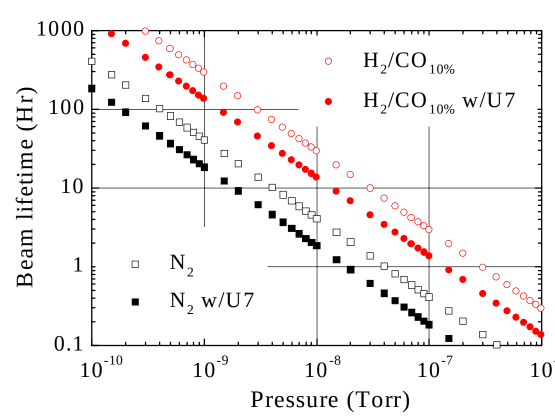

Figure 1: Calculated beam-gas lifetimes for N_2 and $H_2/CO_{10\%}$: with and without U7 undulator.

The beam-gas scattering lifetimes are calculated analytically based on the PLS storage ring parameters. Fig. 1 shows the calculated lifetimes for nitrogen gas. We find that P•τ = 41 [nTorr•hr] without insertion devices (IDs) and 18 [nTorr•hr] with the U7 undulator.

For an operating pressure of 1×10^{-9} Torr with $H_2/CO_{10\%}$, however, we get P•τ = 136 and 294 [nTorr•hr] with and without IDs, respectively.

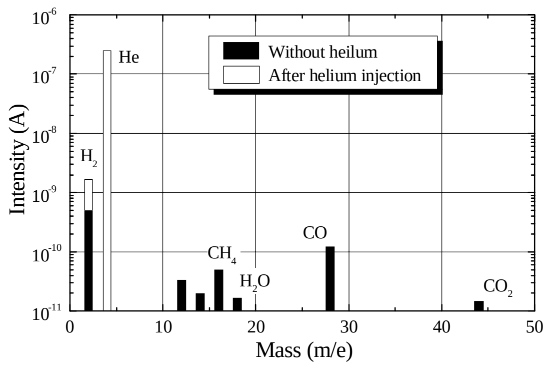

Figure 2: Typical residual gas spectrum taken before (2×10^{-9} Torr) and after helium injection (4×10^{-7} Torr).

3 EXPERIMENTS

When the lifetime measurements should be carried out, the so-called "Argon method" is normally used in an ion pumped vacuum system [3]. This is because Ar can be a dominant gas soon after turning off the ion pumps. However helium was chosen for the present work to control the chamber pressure, for the lifetime measurements were performed in parallel with Fast Beam-Ion Instability experiments [4]. In the latter, the gas was chosen for several reasons. First of all, the ion trapping effect could be minimized due to the light mass. Helium is non-reactive with chamber materials. It is not pumped out during measurements and uniformly distributed soon after injection. Since it is easily pumped out after experiments, it gives almost no effect on beam lifetime thereafter.

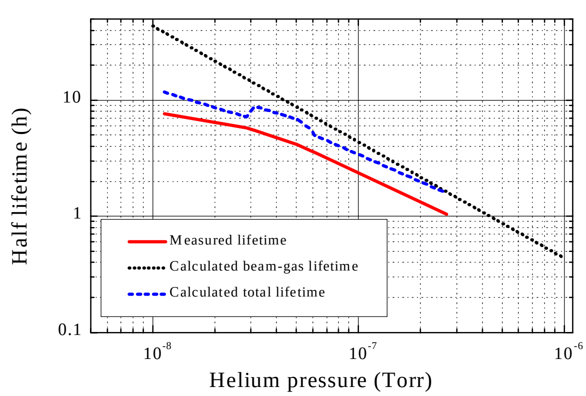

Figure 3: Measured and calculated beam-gas lifetimes without an insertion device. All are in half lifetimes.

The base pressure was about 3×10^{-10} Torr without beam and about 1×10^{-9} Torr with beam. When all sputter ion pumps (SIPs) were turned off, the average pressure went up to (2~3) $\times10^{-9}$ Torr due to the reduced pumping speed and CH_4 which is not pumped by the non-evaporable getters and stayed there. After the SIPs were turned off, the electron beam was stored around 100mA and then helium was injected using variable leak valve from 1×10^{-8} to 3×10^{-7} Torr into the SR. Helium was injected step by step with increasing pressures to allow both the lifetime and pressure distributions stabilized. The pressure is usually stabilized in a few minutes after He injection and beam lifetimes were measured from the beam current decay. Fig. 2 shows the typical residual gas spectra taken before and after He injection at a cell of the SR. As shown in Fig. 2, helium is the major gas with negligible fractions of impurities.

4 RESULTS

Fig. 3 shows typical beam lifetimes(τ_m) measured without IDs for He. The calculated beam-gas and total lifetimes(τ_{cal}), *i.e.*, including Tousheck lifetime, are also depicted. The lifetimes plotted in Fig. 3 are half lifetimes for simplicity. During the lifetime measurements, Tousheck half lifetimes ranged from 13 to 66 h depending on the operation parameters, such as beam current, filling pattern, etc.

The measured lifetime clearly depends linearly on the pressure at high pressures and the ratio of τ_{cal} to τ_m is about 1.5. From the measurement as shown in Fig. 3, it can be concluded that at high pressures (>5×10^{-8} Torr), measured beam-gas lifetimes are in good agreement with the calculated values with the scaling factor of about 1.5. Discrepancies between measured and calculated lifetimes are possibly due to errors in pressure measurements and calculation parameters such as beta functions, vertical and horizontal beam sizes and limiting apertures. The lower the pressures, the higher Tousheck effect. In the pressure range from ~5×10^{-8} Torr down to 1×10^{-8} Torr, the beam lifetime increased with decreasing pressures, but not linearly, which implies that the lifetime is limited by the combination of the beam-gas and Tousheck lifetime.

Fig. 4 shows the measured half beam lifetime for He with the U7 undulator. At high pressures, the measured lifetime again depends linearly on the pressure and the ratio of τ_{cal} to τ_m is about 1.1. Comparing with the Fig. 3, the effect of the installation of U7 on the lifetime is evident. Beam lifetimes decreased after U7 installation due to the small vertical chamber aperture (12mm) as expected. From ~5×10^{-8} down to ~1×10^{-8} Torr Tousheck effect starts to make more contribution to the total lifetime and around 1×10^{-8} Torr both the beam-gas scattering and Tousheck effects make nearly equal contributions to the lifetime. The lower the pressures, the higher the ratio of τ_{cal} to τ_m. The τ_{cal}/τ_m is 1.8 and 1.6 for without and with U7, respectively. This is due to errors in calculating Tousheck lifetime. However the measured lifetimes with the beam current and pressure show a tendency to agree well with the calculation.

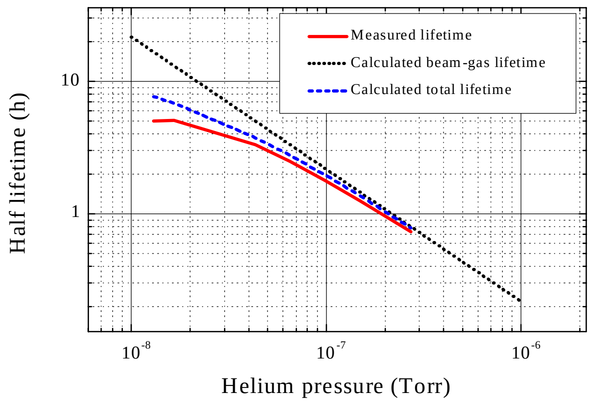

Figure 4: Measured and calculated beam-gas lifetimes with U7 insertion device. All are in half lifetimes.

The beam lifetime dependence on pumping speeds and residual gas compositions were also examined (not shown here). The measurements were performed with SIPs switched on and off. When SIPs were turned off, beam lifetimes decreased as pumping speeds changed and due to the gases such as CH_4 which can not be pumped by NEGs, but not much because Tousheck effect made more contribution to the lifetime than the pressure did. With an air leakage in the SR, when ion pumps were turned off, the lifetime decreased steeper than that without air leaks in spite of same total pressures. This is because of the high Z number of N_2, and Ar.

Fig. 5 shows the measured beam lifetimes at 100mA stored beam during normal operations since machine start-up and they are compared with the calculated ones. The beam-gas lifetime calculated with the gas compositions described in Ref 1. The measured lifetime at 100 mA-beam current agreed with the calculated one for low beam dose, meaning that the beam lifetime was limited by beam-gas scattering. The measured lifetime has been getting increased with accumulated beam time and reached to about 10 hours with 100 mA beam just before the opening to users. The scattered data in lifetime between 200~600 AH reflects the machine operation parameters. For example, the beam lifetime increases to more than 30 hours when the filling pattern of the electron beam is uniformly distributed, and decreases to about 10 hours at 100mA when the machine is operated to reduce the beam instability.

After the beam dose of 400 AH, the lifetime does not vary with the pressure, which strongly suggests that the lifetime is mainly limited by pressure independent Touschek effect. Considering that Touschek lifetime is about 10 hours for the best beam quality of the PLS storage ring, the contribution of the beam-gas lifetime to the total lifetime can be estimated to be only a few

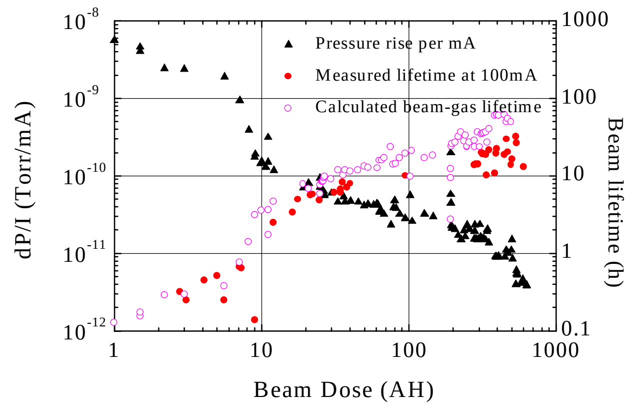

Figure 5: Measured and calculated beam-gas lifetimes with respect to accumulated beam dose.

percent. However the contribution is increased up to about 20 % when the SR is operated for long beam lifetime, *i.e.*, less Tousheck effect. Thus the vacuum is still a factor that determines the beam lifetime and lower pressures should be provided further to minimize beam-gas scattering lifetime.

5 SUMMARY

The beam-gas lifetime measurements were carried out with helium gas in the pressure range from $1x10^{-8}$ to $3x10^{-7}$ Torr in order to identify contributions of the beam-gas lifetime to the total beam lifetime. In the high helium pressure range measured lifetimes were limited by the beam-gas scattering and were in agreement with the calculated ones within a factor of 1.5. At low pressure around $1x10^{-8}$ Torr the lifetime was limited by the combination of the beam-gas scattering and Tousheck effect.

In the light of this trend at the operation pressure of $1x10^{-9}$ Torr, we believe that the lifetime will be limited by pressure independent Touschek effect and the contribution of the beam-gas lifetime to the total lifetime will be negligibly small. The beam-gas lifetime of 136 [nTorr•hr] can be easily estimated with U7 and the residual gas compositions of 90% H_2 and 10% CO.

6 REFERENCES

* Work supported by MOST and POSCO fund.

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