PERFORMANCE OF THE PLS STORAGE RING VACUUM SYSTEM*

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Abstract

The ultra-high vacuum system of the PLS electron storage ring has been operated since September 1994. Beam-on pressures of ~ $1x10^{-9}$ Torr have been maintained and beam lifetimes in excess of 15 hours with 200mA of stored beam at 2 GeV are regularly obtained. The beam-gas lifetime was measured using helium gas and the results are in good agreement with the calculated ones. This paper describes the performance and the experience obtained during the installation and operation of the vacuum system

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 was successfully commissioned in July 1995 and opened to users in September 1995. The completely oil-free ultra-high vacuum system of the PLS extending over 280 m in circumference, consists of 24 curved sector vacuum chambers (machined A5083), 10 straight section chambers (extruded A6063), injection straight chambers and RF cavities. The storage ring (SR) vacuum system has been operated over the last three years.

The vacuum system for the PLS storage ring is designed to maintain a beam on pressure of ~$1x10^{-9}$ Torr in order to achieve a beam lifetime of more than 10 hours. To achieve this goal in a reasonably short time, we have opted to use an antechamber design with massive discrete pumping. Most of the synchrotron radiation not going down the beamline is expected to be taken at the discrete photon stops where the gas loads are dealt with the large-capacity vacuum pumps which consist of lumped non-evaporable getter (NEG) pumps and sputter ion pumps (SIPs). A detailed description of the vacuum system has been reported elsewhere[1,2].

After three years of operation of the system, the average pressure of the SR is now around $2x10^{-10}$ Torr without beam and is about $6x10^{-10}$ Torr with 200mA of stored beam at 2 GeV so that improvement in pressure would have little effect on beam lifetime; the lifetime is mainly limited by the pressure independent Tousheck effect. In this article, we describe the performance and operation experiences of the PLS vacuum system, including beam-gas lifetime measurement using helium gas as well as the failure or leak statistics of the vacuum system.

2 VACUUM PERFORMANCE

2.1 Vacuum System Operation

Prior to installation of the vacuum system in the SR tunnel, the SR vacuum chambers had been assembled and pre-conditioned carefully in the PLS vacuum laboratory. The installation of the SR chambers was completed on June 7, 1994 and connected to each other in sequence and pumped down using sputter ion pumps. The ultimate static vacuum reached about $8x10^{-9}$ Torr before the first beam injection on September 1, 1994.

Owing to the photon induced gas loads (PIDs), the pressures increased abruptly with the electron beam stored, and the specific pressure rise was measured as high as $2x10^{-7}$ Torr/mA initially and gradually reduced to $1x10^{-9}$ Torr/mA at 7 AH, where the system was pumped by SIPs only. The measured lifetime was less than 50 min at 100mA because of high beam-gas scattering.

During the long maintenance period from January to March 1995, all vacuum chambers were opened to atmospheric pressure and the RF shielded bellows were replaced to reduce chamber impedance. The SR vacuum system was baked for the first time at 80 ~ 100 °C for 48 hours using hot water followed by lumped NEG activation. The average static vacuum was then low 10^{-10} Torr.

On April 4, 1995, the SR commissioning resumed and the specific pressure rise decreased immediately to $1x10^{-10}$ Torr/mA at 12 AH. During this period, the beam was stored as high as possible overnight in order to clean up the photon irradiating surfaces by accumulating the beam dose and hence to lower beam-gas scattering. As a result, the vacuum system reached its designed value of low 10^{-9} Torr with lifetime in excess of 10 hours after the accumulated beam dose of 50 AH and a rapid increase in lifetime from 150 min to 10 hours at 100 mA was achieved at the end of the commissioning. The pressure rise was finally reached to $3x10^{-11}$ Torr/mA with a slope of about -0.7 as expected.

The first beam was delivered to users on September 1, 1995. During the user service period, there was a machine shut down due to the water leak at one of the water cooled flanges on October 19, 1995. The machine resumed to store beam on November 13, 1995 after the repair work.

In August 1997, the first undulator (U7) vacuum chamber was installed. The U7 chamber is made of the same machined A5803 aluminum alloy as the sector chambers. Since the electron beam channel of the U7 chamber is very small (12 mm high), a distributed pumping is adopted rather than discrete pumping. The 4.5 m long strip NEG (ST707) is inserted in the antechamber. About three times higher effective pumping speed than that of discrete pumping was expected to be obtained by using the strip NEG pump and two SIPs.

After accumulated beam dose of 1000 AH, the pressure rise due to photons has been reduced to (2~3)x 10^{-12} Torr/mA, i. e, the SR pressure is about 6x10^{-10} Torr with 200mA of stored beam at 2 GeV. As for the composition of the residual gas, hydrogen has been the predominant component throughout the machine operation, followed by CO, CH_4, CO_2 and H_2O, which depends on the condition of the chamber bakeout. The system always shows very clean UHV with negligible traces of impurities.

An operation efficiency of the scheduled beam time was 65% in 1995 due to the water leak. After that, however, reliable operation of the vacuum system could be maintained and hence an overall machine operation efficiency of more than 90% is routinely achieved since 1996.

The PLS vacuum is now so good that the lifetime is mainly limited by intra-bunch scattering of electrons, not by electrons scattering with residual gas molecules. But the detailed discussion of the lifetime is in order.

2.2 Beam-Gas Lifetime

Among the loss mechanisms which determine the beam lifetime of the PLS electron storage ring, the beam-gas scattering lifetime, i.e., the Coulomb and the Bremsstrahlung scattering with the residual gas in the vacuum chamber was measured in order to identify its contribution to the beam lifetime, using helium at pressures from 1x10^{-8} to 5x10^{-7} Torr. Meanwhile the beam-gas lifetimes(τ) are calculated with the appropriate input parameters[3,4].

The calculations show that $P\cdot\tau$ = 41 [nTorr · hr] without insertion devices and 18 [nTorr · hr] for N_2 with U7. For an operating pressure of 1x10^{-9} Torr with 90% H_2 and 10% CO, the beam lifetime due to residual gas becomes $P\cdot\tau$ = 294 [nTorr · hr] without insertion devices and 136 [nTorr · hr] with U7.

Figure 1 shows the measured beam lifetimes (τ_m) obtained from the beam current decay as well as calculated lifetimes (τ_{cal}) for helium without insertion devices. At high pressures the measured lifetime clearly depends linearly on the pressure and the ratio of τ_{cal} and τ_m were 1.4 ~ 2.8. Based on the measurement, it can be concluded that at high pressures (>5x10^{-8} Torr), measured beam-gas lifetimes are in good agreement with the calculated ones within a factor of 3.

Discrepancies between measured and calculated ones are possibly due to errors involved in pressure measurements and in the choice of parameters such as beta functions and limiting apertures.

At pressures from 5x10^{-8} Torr down to 1x10^{-8} Torr, however the beam lifetime was increased, but not linearly, with decreasing pressures, implying that the lifetime is limited by the combination of beam-gas scattering and the Tousheck effect.

The lifetimes for helium with U7 insertion device have been also examined (not shown here). The lifetimes with U7 undulator decreased due to the small vertical chamber aperture as expected and τ_{cal} / τ_m was ~ 2.

Considering that the 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 percent. However the contribution is increased up to about 20 % when the SR is operated at a longer beam lifetime mode with 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.

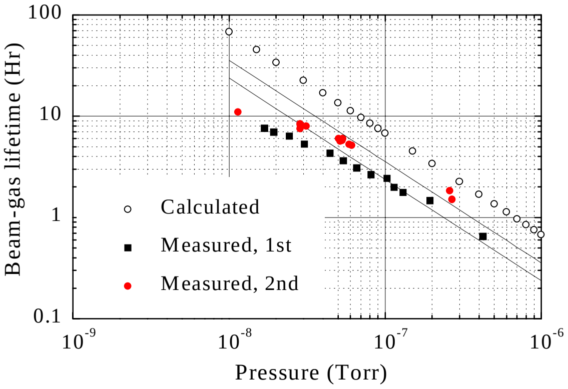

Figure: 2 Measured (●, ■) and calculated (○) beam-gas lifetimes without insertion devices.

2.3 Leak Statistics

Table I summarizes vacuum leaks detected during operation since the machine start-up on September 1, 1994. The statistics show 16 leaks. The PLS operation, however, was stopped only once due to vacuum failure over three years of operation. It was on October 19, 1995 during an user service period, because of the water leak on one of the water cooled flanges (WCFs). Due to the water leak of WCF increased the pressure abruptly to 8x10^{-6} Torr, which resulted in the beam lifetime of only 20 min with 45 mA stored beam current. With a new WCF replaced, the machine resumed to store beam on November 13, 1995. Shortly after the beam-on, the beam lifetime was restored to its previous value, with ~2 AH of accumulated beam current.

Further three WCFs out of twenty-four developed water leaks. Although they made negligible effect on lifetime, they were all replaced with spares during a long maintenance period. The water leaks were all occurred at the brazing point between copper and stainless steel of the cooling channel, exclusively at the narrow part (width of 2 mm).

Table 1: Leaks detected since machine start-up

Vacuum components	Number of leaks / total
Water cooled flange	4/24
Weld on Al chamber ; pumping port ; closure weld	1/388 1/700
Feedthrough(FT) ; ion pump ; beam position monitor	1/124 1/202
Gasket ; aluminum ; Helicoflex	2/388 3/200
RF ceramic window	2/4
Others ; beamline front-end gate valve ; electrical band heater	2 1

As shown in Fig. 2, the newly designed WCFs have been made and ready for use which incorporate no water-to-vacuum joints. It, however, will be installed just in case since the water leaks occurred only in the first stage of operation ($\leq$ 300 AH or $\leq$ 1.5 year) and have not developed leaks thereafter.

A total of two air leaks or inrushes delayed machine operation during the machine study periods. One is the air inrush from a view port in a beamline front-end, which was not equipped with a fast acting valve. The other is the air leak in the ceramic window of the RF cavity #2. The leak at the ceramic window was temporarily sealed by applying a vacuum sealant on November 11, 1997. In the same RF window, two more leaks were found on March 7, 1998. Another air leaks were developed at the RF cavity #4 on the same day. After long operation of RF cavity more than 12,000 ~ 15,000 hours, it seems that they are aged to develop air leaks. One of two leaking ceramic windows will be replaced in March 1998.

Most of air leaks had no effect on the machine operation because they were developed during maintenance periods or small enough not to justify an immediate repair even during normal operation periods. The leaks found in maintenance periods had something to do with chamber bakeout or venting. Helicoflex gaskets developed air leaks after the chamber bakeout probably due to the temperature gradients. Many efforts are made to reduce the risk of a leak on a gasket by using additional heating.

As for vacuum feedthroughs(FTs) including ion pump FTs, BPMs and NEGs, only two FTs developed air leaks. They were detected at a ceramic to metal brazing joint for both FTs. One is for an ion pump high voltage, the other for an injection BPM button.

For practical reasons, any small leaks, which do not require an immediate repair, have been fixed using a spray vacuum sealant.

The PLS vacuum system has been maintained in a good condition despite with such vacuum failures as one machine stop and two operation delays. Now ordinary vacuum works including leak detection, NEG reactivation conditioning of new vacuum components prior to installation to the SR, are the key tasks to keep the system in best shape.

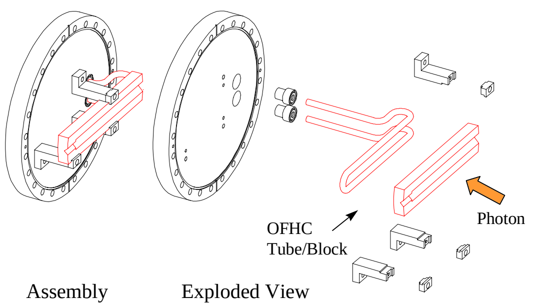

Figure: 2 Water cooled flange; version 2.

3 SUMMARY

The performances and the operation experience of the vacuum system for the PLS storage ring have been described. Thanks to the prolonged beam cleaning, the specific pressure rise has been reduced to ~3×10^{-12} Torr/mA and is still being reduced.

The beam lifetime of more than 15-hour with the stored beam of 200 mA at 2 GeV is now routinely achieved. From the lifetime measurements and calculations, the beam lifetime due to residual gas can be estimated to 136 [nTorr•hr] with a gas mixture of 90% H_2 and 10% CO and gives little effect on the total lifetime.

With only one machine shut down because of vacuum failure, the PLS vacuum system has been shown a good performance over three years of operation.

4 REFERENCES

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