# OPERATIONAL STATUS OF THE PLS STORAGE RING*

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*Abstract*

The PLS 2 GeV storage ring is a third-generation light source that has been in normal operation mode for users since September 1995. It had gone through the commissioning in two phases from September to December 1994 and from April to July 1995, respectively. During the commissioning period, efforts were made to optimize the machine performance by adjusting various parameters and to improve the vacuum pressure by photon beam cleaning of vacuum chambers. At present, the beam lifetime reaches 20 hours at 100 mA and normally the beam is injected two to three times per day. The average stored current is 80-130 mA. In this report, we present various activities performed during commissioning and the present operational status of the PLS storage ring.

## 1 INTRODUCTION

Since the completion of the construction in 1994, the PLS storage ring underwent the commissioning in two phases, the first one from September 1 to December 23, 1994 and the second one from April 4 to July 21 1995. During the phase I commissioning, the storage ring exceeded most of its commissioning goal. The maximum current reached to more than 300 mA at 2 GeV. The beam lifetime was however less than 50 minutes at 100 mA because of poor vacuum rendered by large amount of outgassing. The subsequent machine shut-down from January to March 1995 enabled us to make a significant improvement of vacuum by baking out all the chambers in-situ. In parallel, replacement of a few screen monitors and installation of new diagnostic instruments (ie. injection beam position monitors) were made. Effect of bake-out was apparent immediately after the machine start-up in April; the beam lifetime was 2 hours at 100 mA. As the accumulated beam dose was increased, the lifetime was also enhanced significantly and at the end of the phase II commissioning it reached 10 hours at 100 mA. Total dose attained during the phase II commissioning was about 114 ampere hours. While an effort was made to increase the beam lifetime during the phase II commissioning period, various machine physics related activities were also performed which include the optimization of the machine condition close to the design.

The ring had been shut down for three weeks during the summer of 1995 to replace the injection kicker power supply by a more powerful and stable one. This new kicker power supply was installed to make it possible for 2.0 GeV beam injection without employing a DC bump by corrector magnets. After machine tuning and study from August 21 to 31, the PLS was finally launched to the user service mode on September 1, 1995.

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## 2 OPERATION SUMMARY OF 1995

After three month shut-down from January to March 1995, the phase II commissioning began on April 4. It was essentially made up of four consecutive days (from Monday to Thursday) of machine studies and optimization followed by two maintenance days per a week. During machine studies the ring was operated for 24 hours a day. Usually at overnight the storage ring was filled with high current in order to clean up the chamber by accumulating the total beam dose. Such an operation scheme enabled us to get rapid increase in beam lifetime as time went by.

Sometimes, the beam stacking was difficult because of frequent failure of the injection kicker power supply. As mentioned, that power supply also had a limited capability such that it could generate the orbit bump only up to $-15$ mm whereas the design value was $-21$ mm for 2.0 GeV injection. Therefore, a DC bump by four correctors had to be applied on top of the bump by injection kickers. This problem was solved later during the summer shut-down by installing a new kicker power supply. Nevertheless, performance of the machine was gradually improved. At the same time, the ring was carefully optimized in accordance with the design parameters. At the end of the commissioning, beam lifetime increased to about 5 hours at 200 mA and 10 hours at 100 mA.

On September 1st, PLS finally began to open for user service mode. Total eight runs were scheduled till the end of 1995. However, at 9:50 AM on October 19 the stored beam disappeared because of water leak from the flange in No.1 sector. Therefore it was inevitable to shut down the machine to replace these flanges.

Machine run was resumed on November 13 and after two week of machine tuning and study the user service began on December 1.

The machine shift was performed on two weeks basis including two to six days for tuning and machine study. Total 45 technically competent people have been participated in the machine operation. Each shift consists of two operators who are responsible for the operation for 12 hours. Due to the limitation in man-power there are no full-time operators in PLS.

In the user service mode of operation, the ring is filled up to 130 mA with 200 buckets consecutively occupied out of 468.

Depending on the initial condition of the injected beam from the injector, the injection efficiency varied greatly. After long shut-down, machine operation usually starts defining the injection point though it does not change much. Average injection rate was 1 mA/sec with maximum performance obtained so far 4 mA/sec.

Total beam storage time during 1995 was 3329 hours. From September to December, beam was stored for 1944 hours, out of which 1142.4 hours was devoted to supply a beam to users. Average beam availability to users was 64%, in which most of the failure was due to the vacuum failure ocurred on the 19th of October. If the vacuum failure is excluded the rate becomes about 95%. Other failure includes the time taken for injection which is normally less than 10 minutes and equipment failure such as magnet power supply trip, control and interlock malfunctioning mainly associated with grounding problem, RF failure by circulator arc trip, and injector failure by modulator trip caused by vacuum interlock.

## 3 MACHINE PERFORMANCE

### *3.1 Beam Stability*

Photon beam stability was measured at the entrance and exit slits of the VUV beamline (ie, spherical grating mochromator beamline) by recording the intensity change as a function of time. By varying the slit height from 50 to 400 micron, instantaneous intensity of photon beam was sampled once per second. Total duration of the measurement was 45 minutes and 8 hours. The result indicated that when the slit height was 100 micron, the peak to peak relative intensity variation was $\pm 0.05\%$ and the rms value was $0.02\%$. When the slit height was reduced to 50 micron, peak to peak variation was increased to $\pm 0.1\%$. Fig. 1 shows the relative intensity variation for the period of 40 minutes when the slit height was 100 micron. Fig. 2 depicts the rms relative variation of the photon intensity as a function of slit height.

### *3.2 Beta and Dispersion Functions*

Beta functions are measured by two different methods; a quadrupole tweaking method and a method based on the measured sensitivity matrix [1]. Both results agree well with the designed values as shown in Ref. [1]. The measured sensitivity matrix has an advantage such that it provides not only the beta and phases at the position of all correctors and monitors but also the fractional tune values. Measured dispersion function also shows that it is very close to the designed value and rms spurious vertical dispersion function is 0.9 cm indicating that the vertical beam emittance would be approximately $1.8 \times 10^{-11}$ meter radian.

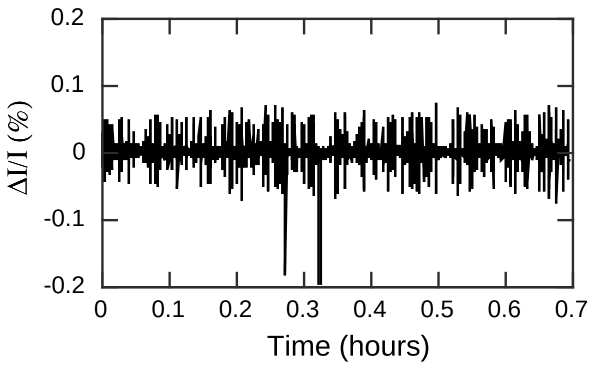


Figure 1: Relative intensity variation of a photon beam for 40 minutes when the slit height was 100 micron

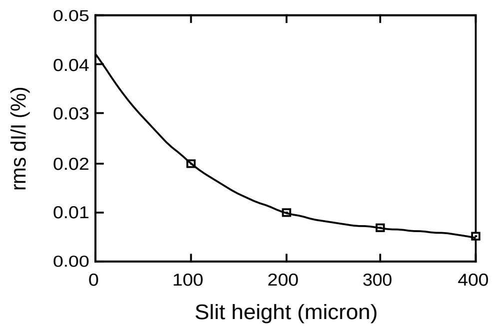


Figure 2: Relative rms intensity variation of a photon beam as a function of the slit height

### *3.3 Chromaticities*

Natural chromaticities were measured by changing bending magnet current and monitoring the subsequent tune change. The measured results are $\xi_{x_0} = -18.96$ and $\xi_{y_0} = -13.42$ whereas design values are $-23.36$ and $-16.19$ respectively. The discrepancies are considered to be due to multipole components in magnet, especially the sextupole component in bending magnets. With two families of sextupole magnets the chromaticities are corrected to the point where the head-tail instability does not show up. The corrected chromaticities are then measured by changing RF frequency and monitoring the corresponding tune change. The measured results are $\xi_x = +2.9$ and $\xi_y = +1.4$.

### *3.4 Linear Coupling*

Linear coupling constant is measured by driving the tunes close to the coupling resonance. The minimum separation of tunes is defined as the coupling coefficient. Fig. 3 shows the horizontal and vertical tune variation as a function of quadrupole power supply current. The minimum tune separation which is a coupling coefficient is shown to be $\kappa = 0.0089$. Since the coupling constant $K$ is defined as

$$K = \frac{\epsilon_y}{\epsilon_x} = \frac{\kappa^2}{\Delta^2 + \kappa^2}, \tag{1}$$

where $\Delta = |\nu_{0x} - \nu_{0y}|$. Here $\nu_{0z}$ is the operating tune in $z$ plane. The beam emittances are related with the coupling constant $K$ through

$$\epsilon_x = \frac{\epsilon_n}{1+K}, \quad \epsilon_y = \frac{K\epsilon_n}{1+K}, \tag{2}$$

where $\epsilon_n$ is the natural emittance which is 12.1 nm in PLS. By substituting $\Delta = 0.28 - 0.18$=0.1, one gets $K = \epsilon_y/\epsilon_x$=0.0078. The PLS was designed to keep the coupling constant within 10%. In order to control the coupling, thereby changing the vertical beam size as well as beam lifetime, four skew quadrupole circuits have been installed in the storage ring. These skew quadrupoles are generated by employing additional trim windings on sextupole magnets. By exciting one of the skew quadrupoles the coupling constant is kept about 1-3% for the user service mode while the minimum is 0.4% [2].

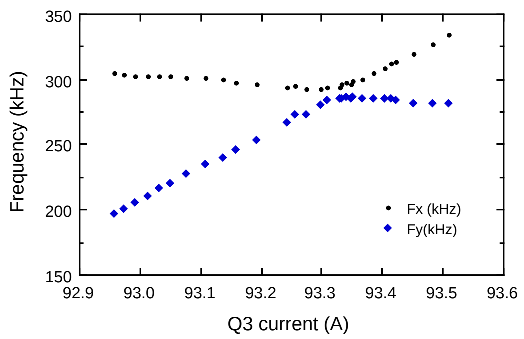


Figure 3: Beam oscillation frequency change as a function of quadrupole power supply current

### 3.5 *Orbit correction*

Closed orbit is corrected globally by using least-square minimization with householder transformation. Uncorrected rms closed orbit is 3 mm and after correction the rms orbit is reduced down to 0.4-0.5 mm. So far, a beam-based alignment system has been successfully tested for one sector of the ring. This scheme finds an offset of the magnetic center of a quadrupole magnet with respect to the adjacent beam position monitor. For this purpose, a shunt circuit was installed to every quadrupole magnet power supply of one sector of the ring.

### 3.6 *Energy Ramping*

Energy increase from 2.0 GeV to 2.5 GeV was achieved by slowly ramping magnet power supply currents. An automatic ramping program has been implemented for this purpose. Per each step the energy is increased by 0.5% and due to the difference in magnet hysterisis curves, tune deviation becomes greater as the ramping is in progress. Therefore, an automatic feedback of the tunes is applied after five steps (ie, 2.5% energy change). Total time taken to reach 2.5 GeV is 13 minutes.

### 3.7 *Momentum Compaction Factor*

Momentum compaction factor can be obtained approximately by measuring the variation of synchrotron tune as a function of the RF voltage. The measured value is $\alpha_c = 0.00163$ whereas the design value is 0.00181.

### 3.8 *Beam Instabilities*

Occasionally coupled bunch instability is observed which is very sensitive to the machine operation conditions especially cooling temperature of the RF cavity. By varying the temperature of each cavity such instabilities could be cured to some extent. The cavity cooling temperature is regulated within ±0.2°C. In parallel with this, a transverse feedback system is being developed which is to be installed in September 1996 and a longitudinal feedback system is planned to be developed in 1997.

In addition, other instabilities have been observed such that the individual bunches are oscillating at about 100 Hz frequency or part of the beam bunch is slowly oscillating at a few Hz. These instabilities could be due to the presence of ions, though there is no concrete evidence so far. See Ref. [3] for more details on the instability study of the PLS.

Ring broadband impedance has been measured in a single bunch mode by recording the tune variation as a function of beam current. This gives a transverse impedance. Longitudinal impedance was obtained from this through a simplified formula. The result is Z/n≈ $1\Omega$.

## 4 SUMMARY

Operational status of the PLS has been described. Measured parameters were found to be well in agreement with the design values. Table I summarizes the designed, achieved and supplied for users parameters.

Table I Target vs. achieved PLS parameters

| | design | achieved | supplied |
|---|---|---|---|
| Energy (GeV) | 2.0 | 2.5 | 2.0 |
| Current (mA) | | | |
| multi-bunch | 400 | 308 | 80 -130 |
| single-bunch | 7 | 26 | none |
| Lifetime (hrs) | | | |
| at 100 mA | 10 | 10-20 | 15 -20 |
| at 7 mA | 3 | 4 | none |
| Tune ($\nu_x/\nu_y$) | 14.28/8.18 | 14.28/8.18 | 14.28/8.18 |
| Emittance (nm) | 12.1 | - | - |
| Coupling(K) | $<10$ % | 0.4 % | 1-3% |
| Z/n ($\Omega$) | $<2$ | $\sim 1$ | $\sim 1$ |

## 5 REFERENCES


[1] M. Yoon, H. K. Jeong, and T.Lee, In these proceedings.

[2] T. Lee and M. Yoon, In these proceedings.

[3] M. Kwon et. al., In these proceedings.