STATUS OF POHANG LIGHT SOURCE

In Soo Ko
Pohang Accelerator Laboratory, POSTECH, Pohang 790-784, Korea

Abstract

The Pohang Light Source (PLS) is national users' facility for basic and applied science research using synchrotron radiation. It consists of a 2-GeV linac as a full-energy injector and a low-emittance, third-generation storage ring. It has been serving users since September of 1995. The beamlines have been increased from two to eight units as the increased number of users. First undulator U7 was installed in July 1997. In order to reduce the HOMs from RF cavities, we installed new precision cooling system for RF cavities. We are also preparing longitudinal feedback system to reduce the beam instabilities. We will introduce recent activities to improve the PLS operations and key statistics of the machine operations.

1 INTRODUCTION

The PLS, a third generation light source, consists of the 2-GeV linac and the storage ring [1]. The project started in 1988 and the construction was completed in 1994.

1.1 Linac

The PLS linac is working as the full energy injector to the storage ring. It consists of 11 klystrons and modulators, 10 pulse compressors, and 42 accelerating sections including those for the preinjector.

The 1-ns long output electron beam from the 80-kV e-gun pass through the bunching system. The prebuncher is a re-entrant type, standing-wave cavity, and the buncher is a travelling structure with four cavities including the input and output coupler cavities. The beam is compressed into three microbunches by passing through the buncher section. The bunched beams pass through 42 accelerating structures and get the 2-GeV energy from microwaves of 2,856 MHz in the structures. The required accelerating gradient of the main linac is at least 15.8 MV/m. Considering one or two klystrons as stand-by, it requires an accelerating gradient of 17.8 and 19.8 MV/m, respectively. In order to achieve this accelerating gradient, we adopted high power klystrons of 80-MW maximum output and SLAC-type pulse compressors with TE015 operation mode. In addition, we require the RF pulse length at least 4 μs for a higher energy multiplication factor from pulse compressor cavities.

The beam transport line (BTL) connecting the storage ring and the linac consists of 5 bending magnets, 24 quadrupoles, 5 vertical correctors and 8 horizontal correctors. The 2 GeV electron beam leaving the linac is bent to 20 degrees horizontally by two bending magnets toward the injection area of the storage ring. After the beam travels about 65-m behind the end of the linac, it is bent upward to the beam plane of the storage ring that is 6-m higher than the plane of the linac.

1.2 Storage Ring

The PLS storage ring lattice is a triple bend achromat structure (TBA) with 12 superperiods and 280.56 m circumference. Each superperiod has a mirror symmetric configuration. Each half superperiod contains six quadrupoles -- three in the dispersion section and three in the non-dispersion section.

Since the completion of the construction in August 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. The maximum current reached to more than 300 mA at 2 GeV during the phase I commissioning. However, the beam lifetime was less than 50 minutes at 100 mA because of poor vacuum. During the machine shutdown from January to March 1995, which was between the two commissioning periods, all the chambers were baked out. When the phase II commissioning started, the beam lifetime was 2 hours at 100 mA. By the end of the phase II commissioning, it reached to 10 hours at 100 mA. The total dose attained during this commissioning was about 114 ampere-hours (A-H) [2].

On September 1, 1995, the PLS finally began to open for user service mode. However, on October 19, there was water leakage from the flange in No.1 sector, and we could not supply the beam to users for 40 days. Total beam storage time during 1995 was 3,329 hours. From September to December in 1995, the beam was stored for 1,944 hours, among which for 1,142.4 hours the beam was available to users. During this period, the average beam availability to users was 64%. If the vacuum failure from the water leakage is excluded, the availability becomes about 95% [3].

2 FY1997 OPERATIONAL STATUS

There are two different operation modes for the storage ring: user service mode and accelerator study mode. In 1997, the PLS has operated for 252 days in total. There were two long-term maintenance periods: the first period from February 23 to March 18 and the second period from June 30 to August 20. During these periods, we made regular maintenance work for the accelerator and installation work for new beamlines. Also, we made several system upgrades including new RF cooling system and additional accelerating sections in the linac.

2.1 Accelerator Operation

In 1997, there were 15 user service runs. Each run included two days of machine study and beamline alignment period followed by average 10days of user service period. Then, we had two or three days of maintenance period to fix small problems. Table 1 shows the annual operation time and user service time from September 1995 when the PLS started its user service [2].

Table 1. Operational statistics for 1997 run.

	1995*	1996	1997	1998#
Operation time (hours)				
Linac+	1,870	4,810	5,481	5,500
SR	1,820	4,680	4,839	5,000
User service time (hours)				
Planned	1,275	3,236	3,960	4,272
Serviced	1,142	3,034	3,618	4,000
Availability	89.6%	93.8%	91.4%	93.6%

* From September to December
\# Estimated
\+ Counted only for scheduled operations

In the 1997 operation, the total accumulated beam dose was 500 A-H and the average beam lifetime was about 18 hours at 100 mA as shown in Fig. 1. After the summer maintenance period, we made a low-emittance lattice. The horizontal emittance measured by a streak camera for the visible synchrotron radiation is 11.3 nm-rad. It is clearly shown that the lifetime was decreased significantly due to the smaller size of the beam. However, there were strong demands from the user to increase the beam lifetime despite of degrading the beam size. So, we added small vertical coupling by introducing the skew quadrupole. The average stored current (max. value) was improved from 120 mA to 180 mA as shown in Fig 2 by improving the precision temperature control system for RF cavities. With new cooling system, we could avoid harmful higher order modes from the RF cavities better than before.

Major failures of beam delivery are listed in Table 2. There were 231 failures in the linac and 214 failures in the storage ring. For the linac, a half of total failures came from 11 modulator systems. Control system, vacuum system and the timing system were also major sources of the linac failure. For the storage ring, RF system, MPS system, and control system were major sources of SR failure. To improve this situation, several upgrade plans are being carried out in 1998.

Table 2: Accelerator failures in 1997.

Storage Ring		Linac	
RF system	65	Modulator	127
MPS system	48	Control system	35
Control system	28	MPS system	30
LCW system	19	Timing system	25
Vacuum system	18	Vacuum system	8
Interlock system	13	Power failure	8
Timing system	12	Microwave system	3
Power failure	6		
Injection system	5	E-gun	1
Total	**214**	Total	**231**

2.2 Linac

In 1997, the operation time of the linac was about 7,598 hours based on the auxiliary systems run-time, and that of the klystron-modulator system was 7,128 hours. This run-time corresponds to about 93% of system availability, similar to the 94% of availability in 1996.

Maintenance work for the klystron–modulator

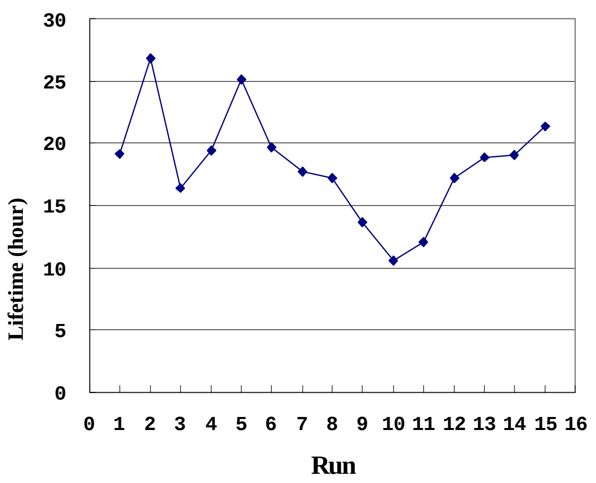

Figure 1: Average beam lifetime for each run.

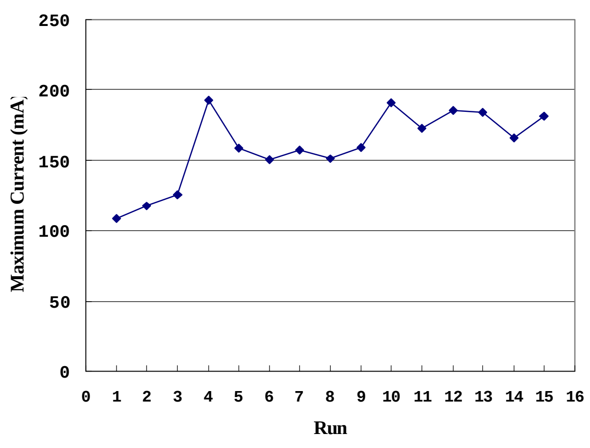

Figure 2: The average stored current (max. value).

system is a major role in the linac operation. We replaced two klystrons in 1997. At the time of replacement, the heater running time for each klystron was 26,772 hours and 27,290 hours, respectively. We also replaced three thyratrons that had been operated for an average of 31,754 hours. For the high power RF load, we replaced 4 units with new SiC loads developed by ATF team of KEK, Japan. We will replace old high power loads with new SiC loads in the near future.

During the 1997 summer shutdown period, a couple of preventive maintenance reinforcements were added to the linac system for more reliability and stability. The klystron heater current circuit was modified and the integrated electronic board of thyratron tube was installed to obtain a stable operation in case of power failure. Also, flow switches for cooling water interlock in the BTL bending magnets were modified, so that the potential local burnout problem of magnet coils due to high current was solved.

In addition to 11 accelerating modules installed during the accelerator construction, we added one more module at the end of the linac. This module includes two accelerating sections manufactured by Mitsubishi Co., Japan and one Toshiba E3712 klystron. At present, there is no SLED cavity, but we will install it at later time. This module can provide extra 100 MeV beam energy, so the linac can deliver the 2-GeV beam with one or even two-klystron failure. The installation was completed in January 1998. At the time of this report, this module is still under the RF conditioning period.

Because of this module, the beam transport line (BTL) was changed accordingly. We removed first two BTL quadrupoles and installed one small quadrupole triplet just before the new module. We also re-arranged several beam diagnostic monitors and vacuum components to accommodate new module.

2.3 Storage Ring

For SR RF system, we added one more RF station in summer 1996 to provide enough RF power to store up to 400 mA with 1.6 MV of the accelerating voltage at 2 GeV and 200 mA at 2.5 GeV. New control electronics were also added for enhanced performance of the phase feedback and the automatic gain control. A transient data acquisition system was installed for better analysis of the unknown beam loss. Efforts to identify the higher order modes causing the collective instabilities were made, and a strategy to reduce their effects was established. Also, a disk-type input coupler with better HOM-absorbing capability has been developed and tested [3].

The cooling water control system for the RF cavities was massively upgraded during the summer maintenance period of 1997 to shift the harmful HOMs and to regulate the operation temperatures of cavities at stable condition. Upgraded temperature control system should be a closed loop system and should have larger control range (~30 degrees) and better stability within 0.2 degrees at each set value. To achieve this requirement, the cooling line was designed to have two loops: the primary and the secondary loops. The primary loop has two circuits; cold water from the heat exchanger and hot water from the electric heaters. The temperature of cold circuit is maintained at about 27^0C and that of hot circuit is variable between 30 and 65^0C, depending on the operation temperature of the cavities after tuning. The secondary loop is connected with main utility system through the heat exchanger, and the low conductivity water (LCW) of about 25^0C should be circulated into heat exchanger to dissipate the RF power.

The temperature control of the input water into the cavity is performed in two stages. The first rough control is obtained by three-way electric motor-driven control valve with a full range of linear characteristics, provided by the proportional-integral-differential temperature controller. Regulating two-way valves installed downstream at each cold circuit and hot circuit with computer controllers carries out the fine temperature control. A linear-coefficient type, quartz crystal with oscillator circuit is used as a temperature sensor. It showed excellent resolution and linearity. Simultaneously, the thermal shield for the cavity body and cooling channel were strengthened by ‘jackets’ and foam tubes. Cooling lines of the cavity were also rearranged better for reducing thermal stress and replaced for the stainless steel tubes [4].

After installing new system, the maximum stored current with stable condition was increased to 200 mA and the designed emittance of 12 nm-rad has been achieved. With optimization and tuning, it is anticipated to achieve higher current and quiescent operation soon.

2.4 Control System

There is no significant upgrade in the linac and the SR control system. However, for the storage ring control system, we made an improvement for high-level computer system such as a change of the operating system for SUN workstations from SunOS 4.1.3 to Solaris 2.x. The timing software was also modified to achieve uniform bucket fill function necessary to carry out the experiment of fast beam ion instabilities. We also added necessary control system for U7 undulator [5].

2.5 Survey and Alignment

After the completion of the storage ring installation in 1994, we surveyed the storage ring two times a year and determined the change of positional errors from 1994 to 1997. As shown in Fig. 3, the comparison of each ENET survey shows changes of the reference elevation which was established in June 1993, the settlement of the storage ring tunnel keeps going on unevenly about 3.0

mm (peak to valley) per year. The lateral deformations are within the range of ±1.0 mm. When the storage ring installation was completed in August 1994, the magnets were aligned to the ideal beam path with the positional accuracy (rms) of 0.15 mm in both transverse and vertical directions. Then it was found the storage ring had a deformation at the end of 1994. We realigned the storage ring to the ideal beam path in February 1995.

Results of the case studies for the estimation of relative positional errors by a smoothing analysis from 1995 to 1997 are summarized as follows: a low filter method for the smoothing analysis was successfully employed, and the storage ring magnets are placed within 2σ (±0.3 mm) range from the smoothed curve. While the relative positional errors are well within the tolerance of 0.15 mm, the absolute positional tolerance that is the range of maximum deviations of magnets from the ideal beam path is extended to ±3 mm, which is derived from the experience of storage ring operation. Therefore, it is expected that the PLS storage ring is to be realigned in every two years [6].

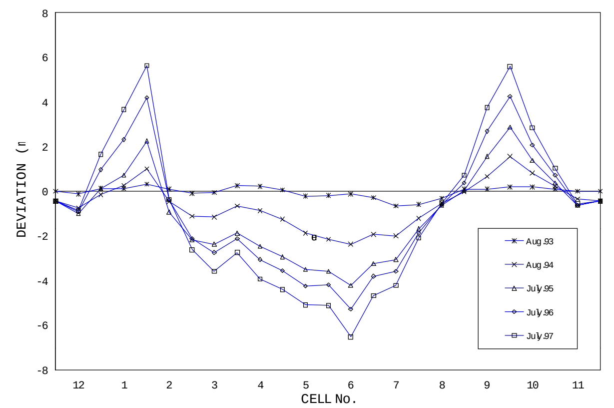

Figure 3: PLS storage ring settlement surveys.

3 R&D ACTIVITIES

There are several R&D activities to improve the performance of the accelerator and to add new facility in the laboratory. Here, we list two most important R&D activities being carried out.

4.1 Fast Beam Ion Instabilities

To study a new type of instabilities predicted for the high-current accelerator such as B-factory, we carry out a series of fast beam ion instability (FBII) experiments with KEK, Japan. We observed this instability directly by using the streak camera mounted at the end of the diagnostic beamline. The instability is enhanced by injecting He gas into the storage ring [7].

4.2 100-MeV Test Linac

We finished the installation of 100-MeV test linac located in parallel to the main linac. This linac is constructed for nuclear physics and free electron laser experiments. This linac consists of a thermionic RF gun, an alpha magnet, two accelerating structures, a SLAC 5045 klystron, and a beam analyzing station. The RF gun is one cell cavity with a tungsten dispenser cathode of 6-mm diameter. The longitudinal matching from the RF gun to the first accelerating section is done by the alpha magnet. The SLAC klystron feeds two accelerating sections and the RF gun. At present, the construction was completed and the commissioning is being carried out. Major parameters of this linac and achieved values up to now are summarized in Table 3 [8].

Table 3: Major parameters and key components for 100-MeV test linac.

Parameter	Designed Value	Achieved Value
Beam Energy	100 MeV	40 MeV
Beam Current	50 mA	30mA
Pulse Width	6 μs	3 μs
Energy Spread	< 1 %	3 %
Repetition Rate	60 Hz (max.)	12 Hz
Emittance	< 30 π mm-mrad	
RF-gun Energy Current	 1 MeV 500 mA max.	
Alpha magnet Pole radius Filed gradient Bend angle	 6.5 cm 1.8 T/m 278.6°	

4 INSERTION DEVICES

At present, one insertion device (U7) is installed in the storage ring. It was installed during 1997 summer maintenance period. We have tested the U7 operation with 1 mA beam because there was no beam abort system installed at the time of test. The U7 will start its operation from August 1998. The U7 undulator has 59 periods with 7 cm of period length. Its overall length is 4.3 m and the peak magnetic field is 1.01 T. We are also planning to install an elliptically polarized undulator (EPU6) with 6-cm period. It has 25 periods and its overall length is 1.57 m. The EPU6 will be available in 1999 [9].

5 BEAMLINES

When PLS started user service in September 1995, the number of beamlines was 2. This number is increased to 8 under normal operation. And two more beamlines will be available by the end of 1998. Table 4 summarizes the beamlines under normal operations and under construction.

In 1997, there were 173 proposals applied to carry out the experiment using above beamlines and 135 experiments were approved. Since September 1995, a total of 226 experiments have been conducted at PLS. At present, the number of users' association member is increased to 433.

Table 4: Summary of beamlines

Beamline	Area of Research	Status
Whitebeam	X-ray Microprobe	1996
Photoemission	Surface Science	1995
NIM	Atomic/Molecular Science	1995
EXAFS	Chemical Engineering	1996
X-ray Scattering	X-ray Diffraction	1995
Lithography	Semiconductor	1996
Crystallography*	Marchromolecule Crystallography	1997
SAXS*	Small Angle X-ray Scattering	1997
U7 undulator		1998
Slitless		1998

* These beamlines are completed in November 1997, there is no user in 1997.

6 FUTURE PLAN

In the near future, we will try to store up to 400 mA. Major obstacles to achieve this designed current are strong instabilities (especially longitudinal instability) caused by higher order modes of RF cavities. To suppress this instability, we already improved the precision temperature control system for the RF cooling system. In this way, we have increased the beam current up to about 200 mA. However, we need a longitudinal feedback system (LFS) to increase the stored beam current up to 400 mA. We have ordered fast signal processing electronics of the LFS to SLAC while we are manufacturing the kicker system. This kicker is similar to the one developed by DAΦNE, Italy. We will start the LFS commissioning from August 1998. This LFS will help to operate the U7 undulator from August 1998 [10, 11].

There is also a great demand on the higher X-ray beam from users' community. To achieve this demand, we will operate the storage ring at 2.5-GeV energy. We have operated the storage ring at this energy by ramping. However, we need more study to reduce the ramping time and to improve the lattice at 2.5-GeV. This effort will continue throughout the year of 1998.

In addition to these efforts, we are planing to upgrade the control system of the linac and the storage ring by introducing recent technologies such as JAVA, EPICS, and better hardware.

7 ACKNOWLEDGMENTS

This work is supported by Ministry of Science and Technology, Korea and Pohang Iron & Steel Company.

8 REFERENCES

[1] Design Report of Pohang Light Source (revised ed.), Pohang Accelerator Laboratory, 1992.

[2] J. Choi, et al., "Operational Status of Pohang Light Source," Proc. of 1997 Particle Accelerator Conference, Vancouver, Canada, 1997.

[3] M. Kwon, et al., "The PLS RF System Upgrade Activities," in these proceedings.

[4] I. S. Park, et al., "Operation Results of Upgraded Cooling Water System for the PLS Storage Ring RF Cavities," in these proceedings.

[5] E. H. Lee, et al., "Improvement of High Level Computer System for PLS Storage Ring," in these proceedings.

[6] S. C. Lee, et al., "Determination of Magnet Realignment Period Based on Smoothing Analysis," in these proceedings.

[7] J. Y. Huang, et al., "Observation of the Fast Beam-Ion Instability in Pohang Light Source," in these proceedings.

[8] H. S. Kang, et al., "Beam Acceleration Results of Test Linac," in these proceedings.

[9] D. E. Kim, et al., "Fabrication and Measurement of PLS EPU6 Undulator," in these proceedings.

[10] M. K. Park, et al., "The Interlock System for U7 Undulator in PLS," in these proceedings.

[11] M. K. Kim, et al., "Effects of Insertion Devices on PLS Storage Ring," in these proceedings.