STATUS OF THE PLS 2-2.5 GeV ELECTRON LINAC

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Abstract

Pohang Accelerator Laboratory (PAL) finished construction of the Pohang Light Source (PLS) on August 1994. The PLS is a third generation light source that is consisted of a 2.0-2.5 GeV full energy injection linac and a 2.0-2.5 GeV storage ring (SR). After completion of the linac commissioning on June 1994, we had commissioned the PLS SR from September 1994 to July 1995. Since then, the PLS has provided low emittance beam to users from various research areas. The PLS linac has been operated continuously as a full energy injector. The linac system has been continuously upgraded to improve overall system stability and reliability. Seven klystrons out of 12 tubes are survived since the beginning of linac operation. The average high voltage operation time of the survived klystrons (E-3712, Toshiba) has been reached near 49,000 hours as of December 2001. Current overall system availability is well over 95%. In this paper, we report the major linac system performance for the nominal 2.0 GeV operations as well as relevant machine statistics such as lifetime of klystrons and thyratrons, and overall system's availability. In addition, recent R&D activities, such as new modulator controller, high power klystron, diagnostics, high power microwave components, will be presented.

1 INTRODUCTION

The Pohang Light Source (PLS) is a third generation light source that has operational energy of 2.0-2.5GeV. The PLS is consisted of a 2.0-2.5GeV injection linac and a 2.0-2.5GeV storage ring (SR) [1]. Pohang Accelerator Laboratory (PAL) finished construction of the Pohang Light Source (PLS) on August 1994. After completion of the linac commissioning on June 1994, we had commissioned the PLS SR from September 1994 to July 1995. Since then, the PLS has provided low emittance beam to users from various research areas. The linac is consisted of 12 klystron-modulator (K&M) systems, 11 pulse compressors, 44 accelerating columns. Preinjector section of the linac has a 1-ns, 80kV, 2A thermionic electron gun, a prebuncher, and a buncher. After passing through the preinjector section, the beam is compressed to three micro-bunches. Operation frequency of the linac is 2,856MHz. A SLAC 5045 klystron is installed in the preinjector section, and Toshiba E3712 klystrons are used in other eleven stations. To achieve the required acceleration gradient of ~15-18 MV/m, SLAC-type pulse compressors with TE015 mode are employed in the PLS linac. We can obtain up to 2.5 GeV electron energy at the PLS linac. For 2.0 GeV operations, only eleven K&M systems are engaged, and one is usually kept as a stand-by unit. Current operation mode of the PLS SR is 2.0 GeV injection and ramping to 2.5 GeV at the SR. The injection and ramping operation of SR is due to limits of injection septum and kicker that have maximum operation energy of 2.0 GeV. The limits are recently overcome by correcting orbit, which changes due to septum leakage field, and applying local DC bump to compensate the kicker bump capability. Therefore, it now becomes possible to inject 2.5 GeV full energy from the linac to the SR. Table 1 shows major parameters of the PLS linac.

Table 1: Major parameters of the PLS linac

Beam energy (GeV)	**2**
Beam pulse length (ns)	**1**
Pulse beam current (A)	**> 2**
Bunch Length (ps)	**17~20**
Number of columns	**44**
Operating mode	**$2\pi/3$**
Operating frequency (MHz)	**2,856**
Pulse length (μs)	**4.0**
Number of klystrons	**12**
Klystron output power (MW)	**80**
Number of Energy Doublers	**11**
Energy Doubler gain factor	**1.5 ~ 1.6**
Total length of the linac (m)	**160**
Accelerating column wall temperature (°C)	**45±0.2**
Number of quadrupole triplets	**6**
Number of steering magnet sets	**6**
Number of bending magnets	**3**

2 LINAC OPERATION STATISTICS

Table 2 summarized the yearly operation hours of the PLS linac since the commissioning.

Table 2: Yearly operation history of the PLS linac

Year	1995	1996	1997	1998	1999	2000	2001
Hour	3,428	4,810	5,481	5,116	5,224	5,280	5,646

The linear accelerator operated 5,646 hours in 2001, with a 1-ns pulsed electron beam at 10 Hz repetition rate with beam energy of 2.045GeV. The SR beam time scheduled to users was 4,056 hours, divided into 18 ten-day periods in 2001. Actual beam time available to users was 3,806 hours with a beam availability of 93.8%. The beam availability was calculated by excluding injection time that was about 2 % of the total scheduled hours. Total linac fault time that interrupted injection was about 4 % of the scheduled time, and the linac fault number was counted as 30 in 2001, which was 40% less than that of 2000. Table 3 shows fault statistics of the PLS linac that affected injection time in 2001. The major fault of the linac was due to the klystron and modulator (K&M) system.

Table 3: Faults that affected injection in 2001

Fault	Number	%
Klystron/Modulator	16	54
Control	3	10
Magnet Power Supply	7	24
Vacuum	1	3
E-Gun	1	3
Cooling	1	3
Personal Safety Interlock	1	3
Total	30	100

3 K&M SYSTEM

Key features of the K&M system design include 3-phase SCR phase controlled DCHV power supply, resonant charging of the PFN, resistive De-Q'ing, end-of-line clipping with thyrite disks, pulse transformer with 1:17 step-up turns ratio, and high power thyratron switch. The major operational parameters of the K&M system (PLS-200MW modulator) are listed in Table 4 [2].

Table 4: K&M operation parameter summary

Peak beam power	200MW*max.* (400kV @500A)
Beam vol. pulse width	ESW 7.5µs, 4.4µs flat-top
Pulse rep. rate	120pps *max.* (Currently 30pps)
PFN impedance	2.64Ω (5% positive mismatch)
Voltage stabilization	SCR, DC feedback & 5% De-Q'ing
Pulse transformer	1:17(turn ratio), L_L:1.3µH, C_D:69nF
Thyratron switch	Heating factor: 46.8x10^9VApps, 8.5kA peak anode current
Klystron tube	Drive power:~300W, Efficiency:40%, gain:~53dB, Peak power:80/65 MW (currently running at 50 to 65MW)

The linac K&M system has started its normal operation at the end of 1993, and the total accumulated high voltage run time of the oldest unit has reached beyond 61,000 hours as of December 2001. At the end of 1997, we have installed one more additional K&M module (total 12 modules with 44 accelerating structures) for the higher beam energy margin. The K&M system is normally operating in 70 to 80% of the rated peak power level to reduce multipactoring phenomena occurring occasionally in random fashion in the waveguide networks and accelerating structures. The sum of all the high voltage run time of the K&M system is approximately 667,000 hours as of December 2001. Operation time of the K&M system was 7,080 hours with a system availability of 97.5% in 2001. Fig. 1 shows the operational status of the PLS linac K&M system. Since the linac operation in 1993, four out of twelve klystrons had been failed. Based on the available failure data, an anticipated lifetime of the klystron (Toshiba E3712) is calculated as 110,600-hr [3]. This anticipated lifetime is not yet realistic due to lack of enough data. The anticipated lifetime will be constantly upgraded. Average lifetime of failed klystrons is 25,339-hr. Thyratrons (F-303) that are the most critical component in the PLS modulator has an anticipated lifetime of 36,500-hr [3]. Average lifetime of failed thyratrons is 19,000-hr. Table 5 summarizes the yearly performance of klystron-modulator. The failure counts shown in the table include all faults regardless of injection time. Overall, the operation of the linear accelerator in 2001 was more stable than in previous years.

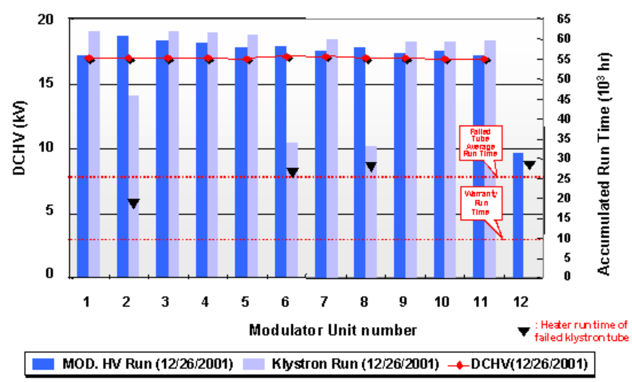

Figure 1: Status of the PLS linac klystron-modulator.

Table 5: Linac Klystron-Modulator Availability

Year	1998	1999	2000	2001
Operation Time (Hr.)	6,144	5,616	6,936	7,080
Failure Counts	283	39	105	30
Down Time (Hr.)	449	116	340.1	171.3
MTBF (Hr.)	22	144	74	230
MTTR (Hr./Failure)	1.58	2.97	3.24	5.71
Availability (%)	93.0	97.9	96.0	97.5

4 ELECTRON GUN

We use a dispenser cathode (Eimac Y-824) thermionic electron gun that has a cathode-grid assembly. A fast risetime (<1ns) avalanche grid pulser is used in the gun system. For initial acceleration, we use an 80 kV DC power supply. Normal operating frequency of the gun is 10 Hz. The first gun, which started its operation from 1994, was replaced with a new one on March of 2000 after 32,700 hrs of operation.

5 MICROWAVE SYSTEMS

The microwave system for the PLS 2-GeV linac consists of an RF drive system and waveguide networks for klystrons. The RF drive system provides low-level microwaves to drive klystrons using a signal source of 2,856 MHz, a phase-shift-key (PSK), an 800-W pulsed solid-state amplifier, a main coaxial driveline and an IPA (Isolator, Phase-Shifter, Attenuator) unit. The master oscillator has 5x10^{-10}/day frequency stability. The PSK has <50 ns phase reversing time and maximum operating power of 2 W CW. The solid-state amplifier has <0.2 µs risetime. The IPA has >30 dB isolation, 360° phase shift range with a 1.4° step, and 20 dB maximum attenuation range with a 0.1 dB step. The S-band waveguide network transmits the klystron output power to accelerating columns. This network consists of various microwave components such as a pulse compressor (SLED-cavities), power dividers, and others. We maintain <1° phase difference among four branches of the waveguide network. The pulse compressor has unloaded Q of 10^5, coupling coefficient of 4.8 and gain of 7.5 dB. A prebuncher and a buncher are installed in the pre-injector section of the linac. In the prebuncher, rotary-vane cylindrical type attenuator and phase shifter have been used. Waveguide attenuator and phase shifter have been used in the buncher system. Resolutions of the attenuators and phase shifters are 1.5×10^{-4} dB and 18×10^{-4} degrees, respectively.

6 COOING

Cooling of the linac has two dynamic control loops; a high precision loop of 45±0.2°C and a normal loop of 32°C. The cooling is as dynamic as the K&M system and was operated 8,145 hours and showed 99.5 % availability in 2001. Total operation time of the cooling water system reached about 68,975-hr since its normal operation on Dec. 1993. Examples of the SLED output waveforms of pulse compressor are shown in Fig. 2. As shown in Fig. 2, the SLED output waveform is distorted if the cooling water temperature control is out of control range of 45±0.2 °C. Improper control results in beam energy change.

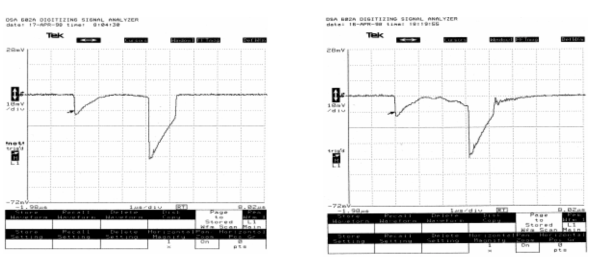

Figure 2: The RF waveform of pulse compressor output power; within temperature control (left, 45±0.2 °C) and beyond temperature control (right, 45±0.5 °C)

7 RESEARCH AND DEVELOPMENT

Various research and development (R&D) activities are under way, such as a new K&M controller [4], EPICS linac control system, high power pulsed klystron, precision timing, high power microwave components (high power load, waveguide valve, SLED, etc.), diagnostics, etc. We will finish the new K&M controller installation on August 2002 during summer shutdown. The new controller will function as an input-output controller (IOC) for future EPICS control environment. The PLS control system including linac control will be replaced with EPICS that is globally adopted as a large-scale facility control system. As a first step for the high power pulsed klystron development, we repaired one damaged klystron, tested with high power, and installed in the number twelve station in 2001.

8 SUMMARY

It has been over 9 years since the PLS 2-GeV linac has started its normal operation. We have analyzed the klystron modulator system performance record for the period, which is the major source of the beam injection failure. It is observed that average lifetime of failed klystrons is over 25,000-hr. Lifetime of the thyratron tube also appears to be reasonable except the occurrence of the infant failure. The machine availability of the K&M system is well over 95%. The cooling water system was operated with 99.5% availability in 2001. Through the temperature control within 45±0.2℃, the rf phase of pulse compressor output power has been maintained very stable.

9 ACKNOWLEDGEMENTS

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