OPERATIONAL STATUS OF PLS 2-GEV ELECTRON LINAC

I. S. Ko, M. H. Cho, J. S. Bak, J. Choi, H. S. Lee, and W. Namkung
Pohang Accelerator Laboratory
Pohang University of Science and Technology
Pohang, 790-784, Korea

Abstract

The PLS 2-GeV electron linac at the Pohang Accelerator Laboratory (PAL) has been served as a full energy injector to the storage ring called the Pohang Light Source (PLS) since September 1994. The linac uses eleven 80-MW klystrons driven by 200-MW modulators. There are 42 constant gradient accelerating sections and 6 quadrupole triplets. During the period from September 1994 to December 1995, the accumulated beam operation exceeded 4,000 hours. However, the average operation time of individual klystron reached to 17,200 hours as of December 1995. This time was counted after the installation of individual klystron starting from November 1992. We have lost one klystron which was the oldest one placed at the module #2 during the summer maintenance period in 1995. The expected beam operation in 1996 is about 5,000 hours. We report the current status of the linac and several upgrades - mostly computer control system and beam diagnostics - based on our operational experiences achieved during the commissioning and normal operations.

Introduction

The PLS 2-GeV linac was completed at the end of June 1994 as a full energy injector to the storage ring. The PLS, a third generation synchrotron radiation source, is designed to serve as a low emittance light source for various researches such as basic science, applied science, and industrial and medical applications [1]. The 2-GeV linac consists of 11 klystrons and modulators, 10 pulse compressors, and 42 accelerating sections including those for the preinjector.

The electron beam is generated from the thermionic e-gun applied with DC 80 kV. The pulse length of the electron beam is 1-ns and its repetition rate is 10 Hz. Electron beams from the e-gun are then entered to the bunching system which consists of a prebuncher and a buncher. The prebuncher is a re-entrant type, standing-wave cavity, and the buncher is a traveling structure with four cavities including the input and output coupler cavities. The bunched beam is then accelerated to 2-GeV by passing through 42 accelerating sections. The accelerating section has a SLAC-type constant gradient structure with $2\pi/3$ operating mode. Its length is 3.072 m. The RF frequency used is 2,856 MHz.

In order to obtain 2-GeV beam with 42 accelerating sections, the accelerating gradient of the linac should be at least 15.5 MV/m. If we take one or two klystrons as stand-by, this number is increased to 17.5 or 19.5 MV/m, respectively. In order to achieve this requirement, we adopt high power klystrons of 80-MW maximum output and SLAC-type pulse compressors with TE_{015} operation mode. In addition, the RF pulse length should be at least 4 μs for a higher energy multiplication factor from pulse compressor cavities. Major parameters of the PLS linac are shown in Table 1.

Table 1 : Major parameters of the PLS linac

Beam Energy	2 GeV
Machine Length	150 m
Energy Spread	+/- 0.3 % or less
E-Gun	> 2 A / 1, 2, or 40 ns
RF frequency	2,856 MHz
Length of Accelerating Section	3.072 m
Operating Mode	$2\pi/3$
Repetition Rate	60 Hz (max.)
No. of Klystrons	11
No. of Pulse Compressors	10
No. of Accelerating Sections	42
No. of Quadrupole Triplets	6
Beam Exit	0.1, 1, 2 GeV

The beam transport line (BTL) which connects 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 20 degrees horizontally by two bending magnets toward the injection area of the storage ring. After the beam travels about 65-m from the end of the linac, the beam is bent upward to the beam plane of storage ring which is 6-m higher than that of the linac.

Subsystems of the PLS 2-GeV Linac

The PLS 2-GeV linac consists of several subsystems such as klystron-modulator, vacuum, control, and cooling system. Here, we report the performance of individual subsystems.

Klystron and Modulator System

The klystron-modulator system provides high-power microwave to accelerate electron beams. One module of the klystron-modulator system consists of a s-band (2,856-MHz) klystron of which maximum output is 80-MW and a matching modulator which supplies 200-MW peak power with a repetition rate of maximum 60-Hz. The pulse length of the modulator output is about 7 μs [2].

Run-time data of the klystron tube are shown in Fig. 1. The first failure in eleven klystrons using in the linac occurred at #2 klystron after 18,800-hour operation time. The cause of this failure was a faulty lead connector of the focusing solenoid. Even though this unit is not able to provide designed output, it is still being used in the test lab as an RF source to the resonant ring. Thyratron tubes installed in the PLS 200-MW modulator are originally F-303 type from ITT. We had a few problems such as a high infant failure (which occurs in less than 500 hours of run-time), frequent self-firing phenomena, and premature turn-off symptoms. However, six tubes out of 11 are still running, and they reached over 18,000 hours of run-time. The most frequent failure of the klystron-modulator system comes from thyratron switch tubes.

General failures occurred during the linac operation are summarized in Fig. 2.

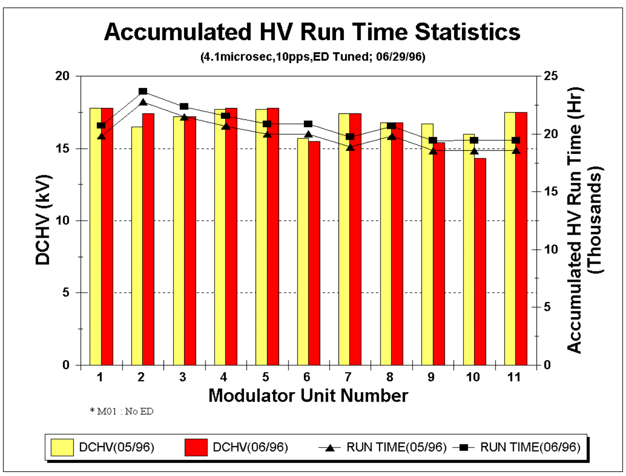

Fig.1: Accumulated run time of klystrons.

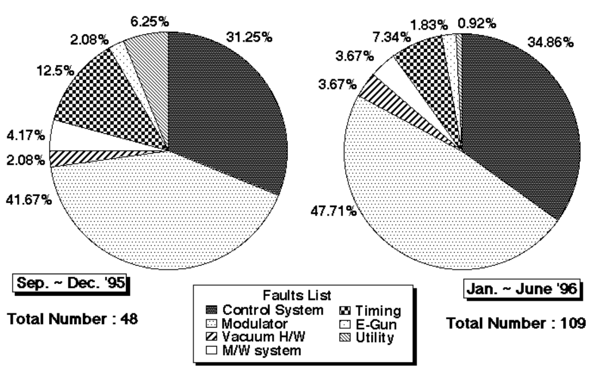

Fig. 2: Relative ratio of the linac operational faults.

RF Drive System

There are three parts in the drive system; the signal source to drive the first klystron, the main drive line to transmit the drive power to remaining 10 klystrons, and IPA (isolator, phase shifter, and attenuator) units to adjust the power level and the phase angle of the drive power to the klystron. A high precision synthesized signal generator is used as a master oscillator. The frequency stability of the master oscillator is 5×10^{-10}/day. A solid-state amplifier boosts the input RF power of 1-W CW coming from the PSK (phase shift key) unit to the maximum 720-W. The PSK is a phase reverse unit required to the pulse compressor.

The main drive line is an 1&5/8" coaxial line. It transmits the 2,856 MHz RF power from the cross coupler waveguide located in the preinjector waveguide system to the remaining klystrons. Approximately, 120-kW RF power is supplied to the main drive line. The output power of each directional coupler located at about 14 meter interval is in the range of 2 to 3 kW.

The IPA unit provides an isolation of the main drive signal from the reflected drive signal at each klystron as well as best conditions of the drive RF signal in phase and amplitude. The IPA unit consists of an RF unit and a controller unit. There are two key components in the RF unit; a phase shifter and an attenuator. The phase shifter is a rotary-field type. It is digitally controllable from 0^o to 360^o with a step of 1.4^o. The attenuation of the attenuator is variable from 0 to 20dB and it is controlled by a DC motor. The remote control of this unit is made by a VME computer system.

Vacuum System

The vacuum system of the PLS linac maintains the average pressure at about 2.0×10^{-8} Torr under high-power microwave loading of average 54 MW peak power per module with a pulse width of 4.1 μs and a repetition rate of 30 Hz. The base pressure is 1.0×10^{-8} Torr without 45^oC cooling water supply. With cooling water, this pressure increases up to 1.8×10^{-8} Torr. The outgassing rate of this system has decreased from 2.0×10^{-12} Torr-l/sec-cm^2 at the end of 1994 to 9.5×10^{-13} Torr-l/sec-cm^2 at present.

Control System

The linac control system is based on the VME realtime control system linked with the SUN UNIX workstation as an operator interface to the linac. There are two important features added after the commissioning of the linac. During the summer maintenance period of 1995, a feature of automatic report generation was added. Since then, most of the activities done by duty operators can be recorded in the report. As an additional beam diagnostic system, 53 beam loss monitors are installed and linked to the main control system [3].

Cooling System

The cooling system for precision temperature control of 45 +/- 0.2^oC is in operation with the total flow rate of 180 m^3/hr and the pump output pressure of 3.5 kg/cm^2. The temperature of accelerating sections and pulse compressors are precisely controlled by this system. The normal water cooling system of about 32^oC for solenoids and other conventional components is maintained with the total flow rate of 85 m^3/hr and the pump output pressure of 6.0 kg/cm^2.

The heat dissipation rate for normal operation is about 225,000 kcal/hr, which is about 85% of the design capacity of the heat exchanger.

Operation Results

As an injector to the storage ring, primary duty of the PLS linac is to provide stable beams with an energy of 2-GeV precisely. The beam energy depends on the RF power and the phase between RF and the electron bunches. The RF phase influences not only the beam energy but also the beam qualities such as the energy spread, the beam emittance and the current delivery ratio. The RF phase of high power is controlled by adjusting the RF phase of the driving signal for the klystron by the IPA system. Either the prebuncher or the buncher influences the beam qualities significantly. Throughout the normal operation in 1995 - 1996 period, we improve the relation between the RF phase and electron bunches. Thus, we can get same 2-GeV beams with less RF power [4]. This condition reduces the required high voltage in the modulator system and it provides more stable beam operations.

The operational parameters of the PLS linac and the BTL are summarized in Table 2.

Table 2 : Operation parameters of the PLS linac

Normal Beam Energy	2 GeV
Accumulated Operation Time	7,000 hours
Accelerating Gradient	15.5 MeV/m (average)
Beam Pulse Length	1 ns
E-Gun High Voltage	80 kV
Energy Spread	< 0.4 %
Klystron Output Power	50 MW (80 MW max.)
Pulse Compressor Gain Factor	1.51~1.63
Beam Delivery Rate (BTL)	> 50%

There are 13 beam-current-monitors (BCM) and 12 beam profile monitors (BPRM) for the beam diagnostics in the PLS linac and the BTL. There are also two beam analyzing stations in the linac. The delivery ratio of the beam current depends mainly on the beam optics. This ratio was less than 20 % in the linac and 60 % in the BTL at the early stage of the operation. Currently, it becomes more than 60 % in the linac and 90 % in the BTL by improving the optics.

There are 42 beam loss monitors in the linac and 11 units in the BTL to measure the loss of electrons during the acceleration. The loss monitor consists of an air dielectric coaxial cable placed inside an aluminum case. A voltage of 500-V DC is applied between the inner and the outer conductor to detect the particles ionized by radiation resulting from the lost electrons. The ionized particles are accumulated for about 100 ms.

Summary and Future Plans

The PLS 2-GeV linac is served as a full energy injector to the storage ring of the Pohang Light Source (PLS) since September 1, 1994. The beam operation was carried out for 192 days in 1995 and 82 days in the first half of 1996. The total operation time is about 7,000 hours by the end of June 1996. The average availability of RF system was about 85 % in the first half of 1995, and it increased to 90 % in the latter half of the year by improving the protection circuits. The accumulated operation times of most klystrons reached over 20,000 hours.

Most of vacuum troubles occurred at the high power dummy loads because of severe outgassing. Also, troubles occurred occasionally at the ceramic windows of the pulse compressors due to the vacuum leak from very small crack. This problem was normally cured by applying the vacuum seal.

We have a plan to install one more klystron and four accelerating sections just after the end of the linac. At present, this section is a part of BTL. This extra section will provide the electron beam to 2.5-GeV. Also, we are planning to replace current high power loads to newer and better performed ones.

Acknowledgments

We are grateful to thank to the team of the linac division for their endless efforts to improve the performance of the linac operation. This work is supported by Ministry of Science and Technology and Pohang Iron & Steel Company.

References

1. "Design Report of Pohang Light Source (revised ed.)," Pohang Accelerator Laboratory, 1992.
2. M. H. Cho, S. S. Park, J. S. Oh, and W. Namkung, "Klystron Modulator System Availability of PLS 2-GeV Electron Linac," these proceedings.
3. I. S. Ko, J. H. Kim, J. M. Kim, S. C. Kim, G. S. Lee, J. Choi, and W. Namkung, "Current Status of Control System for PLS 2-GeV Linac," these proceedings.
4. W. Namkung, "PLS 2-GeV Linac," Proc. of 1994 Int. Linac Conf., Tsukuba, Japan, p14 (1994).