# Operational Status of PLS 2-GeV Linac

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Pohang Accelerator Laboratory (PAL) has constructed the 2-GeV Pohang Light Source (PLS) on August, 1994. The 2-GeV electron linear accelerator is used as a full energy injector to the storage ring. There are 42 accelerating sections, 11 klystrons of 80-MW maximum RF power which are driven by 200-MW modulators, and 10 RF pulse compressors in 150-m long linac. After the linac commissioning completed on June 30, 1994, we have operated the linac more than 6,000 hours by May, 1996. We present the current operational status of the PLS 2-GeV linac.

## 1. INTRODUCTION

The PLS 2-GeV linac is completed by the end of June 1994 as a full energy injector to the stroage ring, a third generation synchrotron light source (PLS). The PLS is serving as a low emittance source for various research such as basic science, applied science, and industrial and medical applications [1]. This linac consists of 11 klystrons and modulators, 10 pulse compressors, 42 accelerating structures 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 traveling structure with four cavities including the input and output coupler cavities. The beam is then compressed into three micro-bunches. This bunched beam passes 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 [2]. 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 required the RF pulse length 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.

The beam transport line (BTL) for 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 storage ring which is 6-m higher than that of the linac [3].

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 | 2856 MHz |
| Accelerating Structure Length | 3.072 m |
| Operating Mode | 2π/3 |
| Repetition Rate | 60 Hz(max.) |
| No. of Klystrons | 11 |
| No. of Pulse Compressors | 10 |
| No. of Accelerating Structures | 42 |
| No. of Quadrupole Triplets | 6 |
| Beam Exit | 0.1, 1, 2 GeV |

## 2. LINAC OVERVIEW AND PERFORMANCE

### *2.1 Klystron and Modulator System*

The klystron-modulator system of the PLS linac supplies high-power microwaves for the acceleration of electron beams. One module of the klystron-modulator system consists of an 80-MW class s-band (2856-MHz) klystron tube and a matching modulator which can supply 200-MW peak power at 60-pps with the equivalent square wave (ESW) of 7 μs.

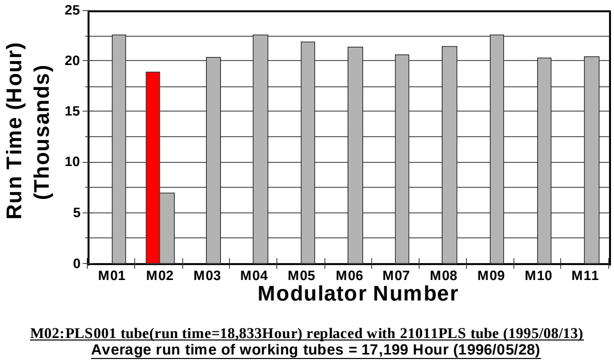


Fig. 1. Accumulated run time of klystron tubes installed at the PLS linac

The run time data for klystron tubes is shown in Fig. 1. Since the operation of the klystron-modulator system has been failed after 18,800 hours of operation time due to the short circuit problem at the focusing solenoid. We expect more than 30,000 hours of the tube life time because the operational power level is approximately 70 % of the manufacture's rated power, and the pulse repetition rate is only 30 Hz. Initial thyratron tubes installed in the PLS 200-MW modulator are F-303 from ITT company. We suffered from a few troubles, such as the infant failure (failure less than 500 hours of run time), frequent self-firing phenomena, and premature turn-off symptoms. However, 6 tubes out of 11 are still running, and they reached over 18,000 hour run time. The misbehaviors of the thyratron switch tubes cause most of frequent troubles.

### *2.2 RF Drive System*

There are three parts in the drive system; the signal source to drive the preinjector klystron, the main drive line to transmit the drive power to 10 klystrons out from the preinjector klystron, and IPA units to adjust the power level and the phase angle of the drive power. The high precision synthesized signal generator of which the frequency stability is $5\times10^{-10}$/day is used as a master oscillator. The solid-state amplifier amplify the output of the PSK from 1 W cw to the maximum 720-W.

The main drive line of 1&5/8" air dielectric rigid coaxial line transmits the 2856 MHz RF power from a cross coupler waveguide located in the preinjector waveguide system to the end of the accelerator. Approximately 120-kW power is supplied to the main drive line. The output power of each directional coupler located at about 14 meter interval is 2~3 kW ranges. The IPA is to provide the isolation of main drive signal from the reflected drive signals at each klystron as well as the phase and amplitude control of the drive power for 80-MW klystrons. There are two controllable components in the RF unit; a phase shifter and an attenuator. The phase shifter is a rotary-field type, and it is digitally controlled with a $1.4^o$ step from $0^o$ to $360^o$ by a current driver. The attenuation of an attenuator is variable from 0 to 20dB by a DC motor. At present, all components are working without any serious trouble.

### *2.3 Vacuum system*

The vacuum system of PLS maintains average pressure of $3.5\times10^{-8}$ Torr under high-power microwave loading of average 54 MW peak power per module with 4.1 μs pulse width and 10 Hz repetition rate. The base pressure is $1.9\times10^{-8}$ Torr without 45 $^o$C cooling water supply. With cooling water, this pressure increased into $3.2\times10^{-8}$ Torr. The outgassing rate of this system has decreased from $3.6\times10^{-12}$ Torr-l /sec-cm$^2$ at the end of 1994 to $1.6\times10^{-12}$ Torr-l /sec-cm$^2$ at present. All ion pumps are working below the saturated regime, and the effective pumping speeds of 60 l /sec, 120 l /sec, and 230 l /sec ion pumps maintain 45 l /sec, 65 l /sec, and 140 l /sec for the operating range, respectively.

### *2.4 Cooling System*

The cooling system for precision temperature control of 45 ± 0.2 $^o$C was operated with the total flow rate of 180 m$^3$/hr and the pump output pressure of 3.5 kg/cm$^2$. The normal water cooling system for conventional cooling of about 32 $^o$C 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 of the total power of 66 MW klystron output is about 225,212 kcal/hr, which amounted to 85% of the design capacity of the heat exchanger. The temperature of accelerating structures and pulse compressors has been precisely controlled within ± 0.23 $^o$C.

## 3. OPERATION RESULTS

The linear accelerator being operated as an full energy injector for the storage ring, the most important parameter is the electron beam energy. The beam energy usually depends on the RF power and the phase between RF and the electron bunches. In the PLS linac, 11 klystrons including one preinjector klystron are used for feeding the RF power to the accelerating structures. Each klystron except the preinjector klystron feeds the averaged RF power of about 50 MW to four accelerating structures. Also, 10 pulse compressors are used to obtain the required accelerating gradient. The operation 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 | 6000 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% |

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. As a matter of fact, in the early period of the linac operation, we sometimes decelerated the electron beam because of the phase mismatch between the RF and the micro-bunches of the electron beam. The RF phase of high power is controlled by adjusting the RF phase of the driving signal for the klystron through the isolator-phase shifter-attenuator (IPA) system. The prebuncher and buncher are another part related to the beam qualities.

They also influence the current delivery ratio in the preinjector.

There are 13 beam-current-monitors (BCM) and 12 beam profile monitors (BPRM) for the diagnostics of the beam in the PLS linac and the BTL including two beam analyzing stations. The delivery rate of the beam current mainly depends on the beam optics. Although the delivery rate was less than 20 % in the linac and 60 % in the BTL at the early stage of the operation, it is more than 60 % in the linac and 90 % in the BTL at present by improving the optics. The delivery rate of the beam current of the normal operation in the PLS linac and the BTL is shown in Fig. 2. Also, the relative ratio of fault counts from each system is shown in Fig. 3.

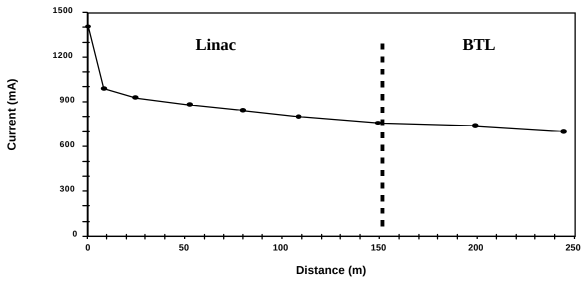


Fig. 2. Beam current of the normal operation at the PLS linac and BTL

There are 42 beam loss monitors in the linac and 11 in the BTL for measuring the beam loss. The loss monitor consists of an air dielectric coaxial cable and an aluminum case. There is a voltage difference of 500-V (DC) between the inner conductor and the outer conductor to detect the particles ionized by radiation resulted from the lost electron beam. The ionized particles are accumulated for about 100ms and converted to voltage. Fig. 4 shows a measured results of the beam loss in the linac.

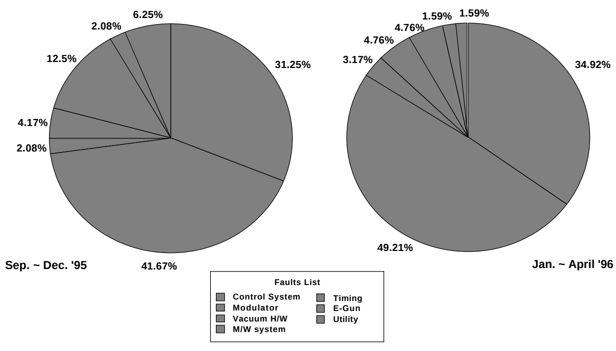


Fig. 3. Relative ratio of Linac operational faults

## 4. SUMMARY AND FUTURE PLAN

The PLS 2-GeV linac has served as a full energy injector to the storage ring of the Pohang Light Source (PLS)

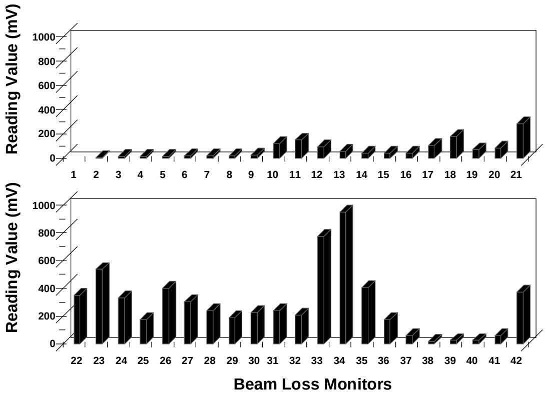


Fig. 4. Beam loss monitoring at the PLS linac

since September 1, 1994. Beam operation was carried out for 192 days in 1995 and about 82 days in 1996, and the total operation time is about 6,000 hours. 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 time of the klystron reached over 20,000 hours.

Most of vacuum troubles were occurred in the high power dummy loads. It sometimes is difficult to increase the RF power level of the klystron because of outgasing from the loads. Some vacuum troubles occasionally occurred in the ceramic windows of the pulse compressors due to the vacuum leak from very small crack. This problem was cured by applying the vacuum seal.

We have a plan to upgrade the PLS linac. There is an extra length about 15 m at the end of the PLS linac, just before the switching magnet. We will install K-12 module to 1998 years for the safe operation with one or two klystrons stand-by.

## ACKNOWLEDGEMENTS

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