Commissioning of PLS 2-GeV Electron Linac*

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Abstract

The 2-GeV electron linac in the Pohang Accelerator Laboratory (PAL) has been constructed as a full energy injector to the Pohang Light Source (PLS). The 150-m long linac is powered by 11 klystrons of 80-MW maximum output power, which are driven by 200-MW modulators. There are 42 constant gradient accelerating columns and 6 quadrupole triplets. By December 10, 1993, the installation work for the linac has been completed. The beam analyzing station #3 and the beam transport line to the beam dump which is about 30-m long are also completed in order to deliver the beams into the dump safely. The microwave output power from klystrons is gradually increased as the vacuum condition inside the accelerating columns and waveguides is improved. The preinjector which is the first section of the 2-GeV linac is routinely operated up to the beam energy of about 100-MeV. The commissioning of the 2-GeV linac has been started from January 1994. On March 9, 1994, the 1.5-GeV beam was obtained without using SLEDs. We obtained 2-GeV beams on May 10, 1994. The 2-GeV commissioning goal was achieved.

1. INTRODUCTION

The PLS 2-GeV linac is a full energy injector to the storage ring which will serve as a low-emittance light source for various research: basic and applied science, and industrial applications. There are 11 klystrons and modulators, and 10 SLAC-type pulse compressors (SLEDs) in the linac gallery. In the tunnel, which is 6-m below the gallery floor, there are 42 accelerating columns, 6 quadrupole triplets, and various components to form the 150-m long linac [1].

Installation work started on July 1, 1992 has been completed by December 10, 1993. This includes the first section of beam transport line (BTL) to the beam dumps and the beam analyzing station #3 in order to measure the beam energy and other physical parameters.

The commissioning started on January 7, 1994. On March 9, 1994, we achieved the 1.5-GeV beam without using SLEDs. Exactly two months later, the 2-GeV beam was obtained, and it was declared that the 2-GeV linac commissioning was successfully completed 50 days earlier.

2. INSTALLATION

A. Technical Description

The nominal beam energy of the PLS linac is 2-GeV and the operating frequency is 2,856 MHz. The repetition rate of the linac is limited to 60 Hz in order to protect klystron output windows. However, this repetition rate will be reduced to 10 Hz when the linac serves as an injector the storage ring due to the limitation on the current storage ring injection system. The higher repetition rate will be useful for the testing of the machine or other purposes in the future. During the commissioning period, the repetition rate is 30 Hz.

The design value of the normalized emittance for the electron beam of the linac is 0.015 π MeV/c cm rad. It corresponds to 75 π nm-rad at 2-GeV. The energy spread of the electron beam is 0.6% FWHM. Major parameters are summarized in Table 1.

Table 1: Major parameters of PLS 2-GeV linac.

Beam Energy	2 GeV
Accelerating Gradient	15.5 MV/m (min.)
Energy Spread	$< \pm$ 0.3 %
Machine Length	150 m
RF Frequency	2,856 MHz
Repetition Rate	60 Hz (max.)
E-gun	> 2 A, 2 nsec
Emittance (theory)	75 π nm-rad at 2-GeV
Klystron Output Power	80 MW max.
No. of Klystrons	11 (=1+10)
No. of Pulse Compressors	10
No. of Accelerating Columns	42 (=2+40)
No. of Quadrupole Triplets	6
No. of Support/Girder	22
Beam Exit	at 100 MeV, 1 GeV, 2 GeV

The PLS linac consists of two parts: the preinjector and the main linac. The preinjector is the 100-MeV section of the whole linac. It consists of a triode type e-gun, an S-band prebuncher and buncher, two accelerating columns, beam analyzing station #1, and various components. The electron beam from the preinjector is accelerated to 2-GeV by 10 klystrons (Toshiba E3712) and 10 SLEDs.

B. Preinjector

This section was completed on February 28, 1992 with one HK-1 klystron (equivalent to SLAC XK-5 type) and INTEL bitbus-based control system. At that time, 61.2 MeV electron beam was obtained [2,3]. During summer period of 1993, intensive modification was made to improve RF output power to drive 10 klystrons in the downstream. A SLAC-5045 klystron and a PLS-200 modulator were installed, and the control system was changed to the VME system. The RF drive unit was also changed from the TWT system to the 800-W solid state amplifier. The preinjector system was restored by September 1993. Since then, it is very dependable system and the 100-MeV electron beam is routinely achieved.

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C. Main Linac

There are 40 accelerating columns and 20 supporter/girders in the main linac. All of these and various components were installed by December 10, 1993. The 3.072-m long accelerating column has a SLAC-type constant gradient structure with $2\pi/3$ operating mode. Its distinctive feature is the conflat flanges for easy installation and maintenance. It provided extreme convenience for replacing two accelerating columns after finding serious problems: one for unstable phase and one for severe vacuum contamination. It took only about 3 hours to remove the old unit and install the new one.

Klystrons, modulators, RF main drive line, and IPAs (isolator, phase shifter, attenuator) were also installed in the gallery by December 10, 1993. There are two islands for magnet power supplies - one for the preinjector and one for the rest of the linac - and three islands for vacuum and cooling system along the gallery. There are also one beam monitoring island where all the beam profile monitors (BPRM) are locally controllable. Currently, all magnet power supplies and BPRMs can be controlled remotely from the operator console.

There is one control room located in the middle of the linac building. The VME-based realtime control system is developed for the linac control [4].

3. COMMISSIONING

A. High Power Microwaves

Since 1993, eleven modulators and klystrons had started their operations one by one after completing the installation and test work of each unit. Fig. 1 shows the accumulated high voltage (HV) run-time for eleven modulators as of June 18, 1994. In particular, #2 modulator has the run-time more than 8,000 hours. The performance of the modulator that is built in-house is improved after installing a 3-phase reactor on the input section, so the DC high voltage can be reached over 20-kV steadily. After completing the installation, RF power is increased very slowly not to allow any permanent damages from RF breakdowns inside waveguides and/or accelerating columns. Vacuum pressures and RF power levels were stabilized to start the beam commissioning by the end of 1993, and the first commissioning for the whole linac started from January 7, 1994.

B. Detuned Case

After having January operations aiming to confirm the system integrity, the beam was delivered to the BAS#3 on January 28, 1994. The beam energy was approximately 800-MeV. The beam current was deliberately lowered to 50 mA at the end of the linac to avoid vacuum pressure increase and to lower the radiation level in the BTL tunnel.

During the second commissioning period (February 26 - March 10), our intention was to increase the beam energy to 1.5-GeV, which is the best achievable energy without using SLEDs. In this case, we limited the klystron output power to 64-MW in order to protect klystrons from any unexpected mischiefs. On March 9, we obtained 1.5-GeV beams. The average DC high-voltage for the modulator exceeded 19-kV, and the total RF power is about 600-MW. Fig. 2 shows the increase of the beam energy and the change of total RF power since January, 1994.

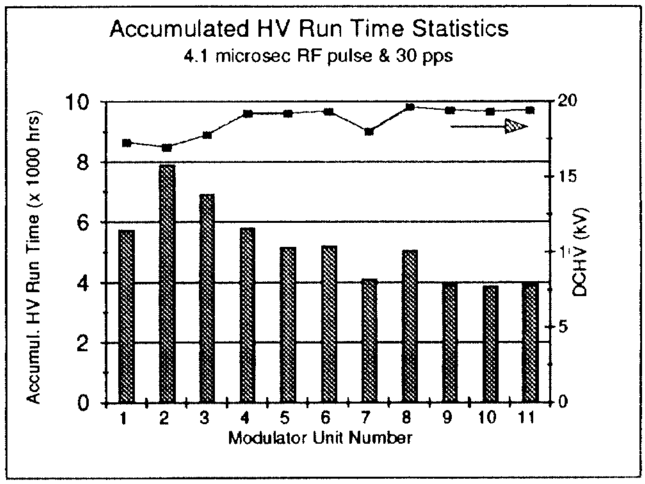

Fig. 1: Accumulated HV run time for modulators and DC high voltages for the operation on May 19, 1994.

C. Tuned Case

On March 15, 1994, we started vacuum conditioning again with SLEDs. There were total nine SLEDs installed, since we postponed the installation of the last SLED at #11 module. There is no SLED at the first module. The RF conditioning took about a month long before the beam operation was resumed. The RF pulse length and the phase shift key (PSK) trigger time varied slowly as shown in Fig. 3. It took two months to increase the RF pulse from 2 μs to 4.1 μs. The theoretical energy gain factor is also shown in the same figure.

First, we operated #1 klystron (K1) and #2 klystron (K2) with a SLED with 1.7 μs long RF pulse. The main objective of this operation was to see the performance of the SLED. We made a temporary beam analyzing station with #3 BPRM and #3 horizontal steering coil. The beam energy with tuned K2 is 280-MeV while the beam energy with detuned K2 is 235-MeV. The

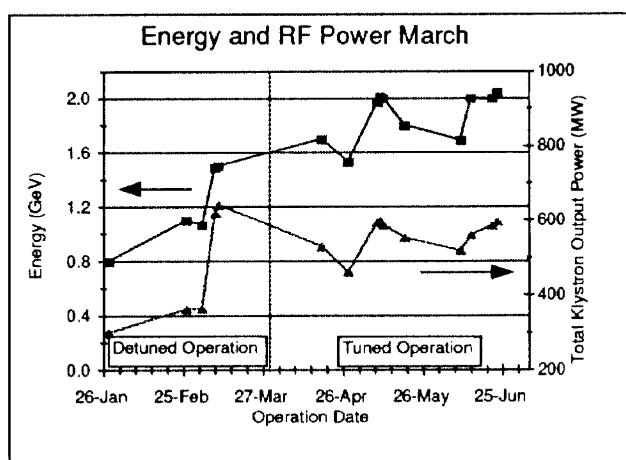

Fig. 2: Energy and RF power changes during the commissioning.

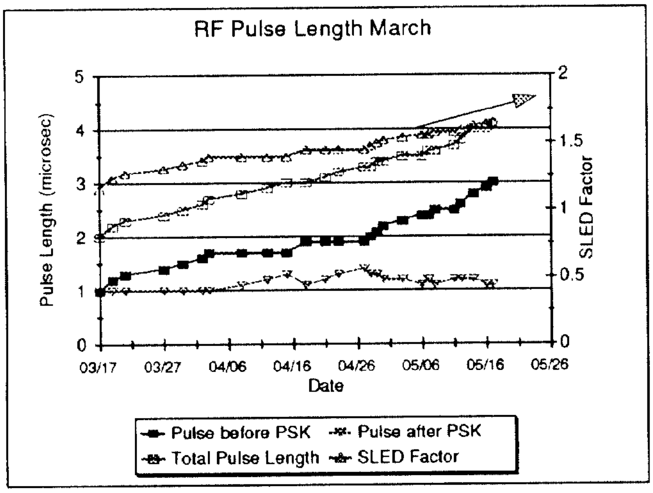

Fig. 3: RF pulse width change during the commissioning.

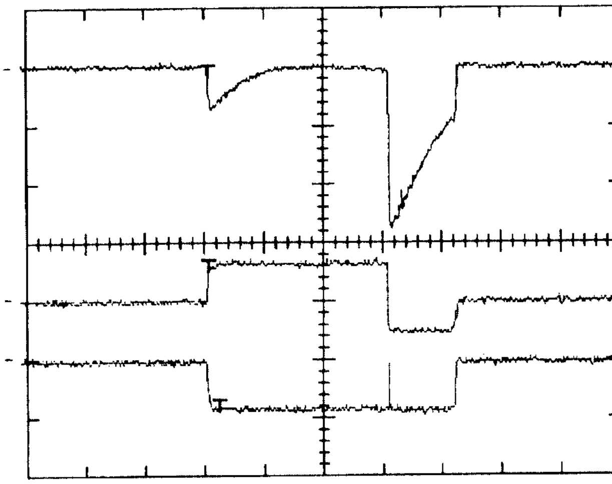

Fig. 4: Typical RF characteristics for tuned operation: 1 μs/div (horizontal) and relative unit (vertical).

Top: SLED output (250 MW peak)
Middle: Phase of klystron output (0 to π rad)
Bottom: Klystron output (45 MW) with 4.1 μs.

preinjector provides the beam energy of 100-MeV. Thus the energy gain factor by the SLED is 1.33 while the theoretical value is 1.4. Since then, we focused our effort to increase the beam energy. The 2.01-GeV beam was obtained on May 10, 1994, and the commissioning target was achieved. The DC high voltage for this operation is also shown in Fig. 1.

Another operation took place on May 19, 1994 to find physical parameters. During this operation, #2 and #7 klystrons were at low power level due to vacuum problems and the SLED at #3 module was detuned. The beam energy obtained was 1.8-GeV with the average energy gain factor 1.45. The energy spread measured was ± 0.25% at BAS#1 and ± 0.34% at BAS#3. The measured emittance is 90 π nm-rad. During this operation, the beam sizes (FWHM) were measured by using the image process routines running on a realtime VME system.

The last SLED was installed on May 24, and we had another beam operation on June 13. We obtained 2-GeV beam without #11 klystron since it had a new SLED. The average energy gain factor exceeded 1.5. It implies that we are able to provide 2-GeV beam with one klystron at stand-by.

On June 22, we measured the energy gain factor for a SLED at #10 module by comparing the tuned and detuned operation results. The energy gain factor showed 1.56 with PSK trigger at 3 μs.

D. Vacuum Conditioning

Based on the experiences for vacuum pressure changes, it takes about three months to clean up entirely new module by RF power and to ready to operational status. During the commissioning period, we made several maintenance and repair works requiring venting a whole module that has already been cleaned. We recover the vacuum system to original status by 2 ~ 3 weeks. After we installed the last SLED to the already cleaned #11 module, it took two months to recover the original operating status for the klystron.

E. Near Future Operations

For 6 weeks starting from July, 1994, the installation work for the beam transport line will take place. The linac operation will be resumed by mid-August. The beam injection to the 2-GeV storage ring is expected to start on September 1, 1994. Fine tuning of the 2-GeV linac will take place later in this year. Many improvements in the beam operation and the control system will be made on the basis of the experiences during the commissioning period.

4. ACKNOWLEDGMENTS

We are grateful to thank the linac technical staff for their hard work, and to POSCO and MOST for their commitment and endorsement to the PLS project. Most of all, we would like to dedicate this achievement to late Dr. Hogil Kim, who envisioned the PLS linac and had been waiting for this event with great eagerness.

5. REFERENCES

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