PLS 2-GeV LINAC*

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Abstract

The accelerators for the Pohang Light Source (PLS) consist of a 2-GeV linac and a 2-GeV storage ring. The linac is designed not only for the injector of the storage ring but also for other facilities in the future. Construction for buildings and machines has smoothly progressed after the ground-breaking in April 1991. We completed the linac commissioning successfully in the period of January - June 1994. We used a total RF power of about 600-MW from 11 klystrons for 1.5-GeV and 2.0-GeV beams with and without pulse compressors, respectively. This paper describes design features and commissioning results of the PLS linac along with the future applications.

1. Introduction

The Pohang University of Science and Technology (POSTECH) which was established in December 1986 proposed to build a synchrotron radiation facility on its campus as a national users facility. With the initial fund from POSCO, a steel company, POSTECH officially launched the PLS project with a few faculty members in April 1988. After reviewing many options for a full-energy injector, we selected a 2-GeV linac in April 1989 due mainly to its usefulness of supporting other research facilities in the future [1]. A general site layout of the Pohang Accelerator Laboratory (PAL) is shown in Fig. 1 with possible future facilities.

Since the total cost for a linac is quite expensive than that of a booster synchrotron in the energy range of 2-GeV, we introduced a few goals in the design stage as cost reduction efforts; (1) to use most powerful klystrons and SLED-type pulse compressors for a high accelerating gradient, (2) to minimize the number of components and highly skilled man-power required for machine construction, and finally, (3) to establish in-house maintenance capabilities.

The building construction has taken two years in three phases from April 1991 to March 1993. We arranged to occupy finished portions of the linac building after each stage. In order to train our staff, we first built a preinjector linac of 60-MeV with a medium power klystron in February 1992. It was a good example of international collaboration with IHEP, China. The main installation took 18-months from July 1992 to December 1993. In this period, we also modified the preinjector to 100-MeV in accordance with our own design and tested subsystems by operating first two modules.

We applied RF power to waveguide systems as much as possible during this installation period. The RF conditioning for the whole system started after closing the tunnel in December 1993. During the commissioning period from January to June 1994, we operated the machine in two stages; first without SLED cavities to obtain 1.5-GeV and then with SLED cavities for 2.0-GeV. We kept the beam current as low as possible for radiation safety. However, we are now operating the machine routinely with beams of more than 2-GeV and 100 mA.

2. General Description

The nominal beam energy is 2-GeV with the operating frequency of 2,856 MHz. There are 42 SLAC-type accelerating columns and 11 klystrons including those for the preinjector. The total length of the machine is 150 m long with an extra-length of 15 m before the switching magnet. Therefore, the required accelerating gradient of the main linac is at least 15.8 MV/m. When we consider one or two klystrons as standby, 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 and SLED-type pulse compressors. In addition, we required the RF pulse length at least 4 μs for a higher energy gain factor from SLED cavities. Major machine parameters are summarized in Table 1.

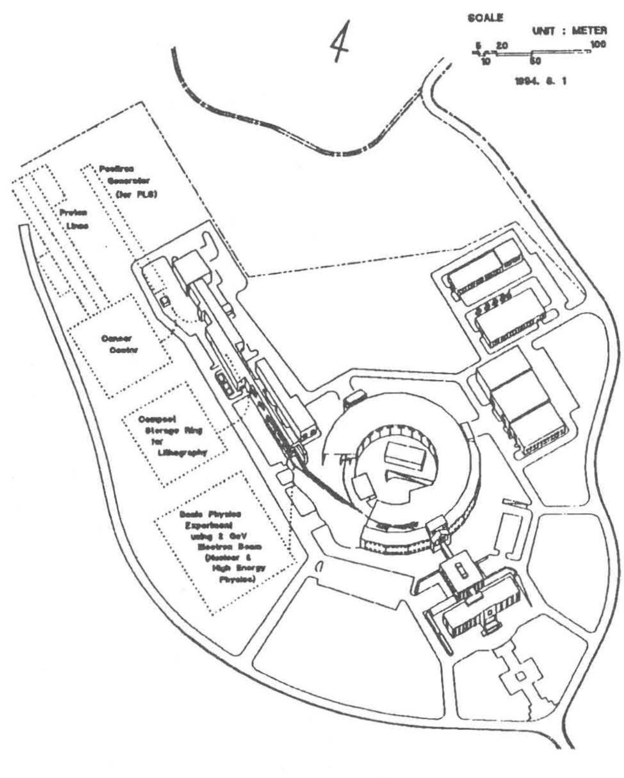

Fig. 1: Site Layout of Pohang Accelerator Laboratory

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The linac building has three levels; the tunnel in 6-m below the ground level for the centerline, the ground floor for the klystron gallery, and the second floor for utilities including air-condition and air handling units. There is 3-m thick concrete shielding between the tunnel ceiling and the klystron gallery. The klystron test laboratory with an over-head crane is located next to the preinjector area. There is a large slot of 2 x 9 m in the test laboratory for material access to the under-ground level where the prealignment and subassembly room locates. There are three beam switch yards in the tunnel at 100-MeV, 1-GeV, and 2-GeV locations for the beam extraction to other facilities. It also has a main and an auxiliary cooling stations using low-conductivity water. Both stations supply cooling water of temperature controlled at 45 ± 0.2 °C and non-controlled at 32 ± 1 °C. The auxillary station had been used for the preinjector initially and is now serving the test laboratory. The linac substation contains various transformers of total 8-MVA with three different groundings.

Table 1: Major parameters of PLS 2-GeV linac

Beam Energy	2 GeV
Accelerating Gradient	15.8 MeV/m (min.)
Energy Spread	< ± 0.3 %
Machine Length	150 m
RF Frequency	2,856 MHz
Repetition Rate	60 Hz (max.)
E-gun	> 2 A, 2 ns
Emittance (theory)	75 π nm-rad at 2-GeV
Klystron Output Power	80 MW max.
No. of Klystron	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

3. Special Features

3.1 Modulator System

The high-power RF system is the most challenging item for the project, since there were not many commercial subsystems with the required power level at the beginning of our project. However, TOSHIBA had a plan to produce its E3712 klystrons in 1992 based on the R&D collaboration with KEK. We decided to use this klystron and to manufacture matching modulators of 200-MW in house. It took 24-months for us to complete 11 units and two prototypes. It is a relatively compact unit of 3.5 x 1.5 x 2.5(H) m. Highlights of the system design are as follows; the SCR phase control with a feedback for the 3-phase AC-line power control, the fullwave high-voltage rectification, the resonant charging of the PFN, the resistive De-Q'ing system for the beam voltage stabilization, the ITT/F303 tyratron for switching tube, and the 1:17 turn ratio pulse transformer [2]. With this program, we established the in-house maintenance capability for the high-power RF system.

3.2 RF Drive System.

For the RF drive system, we extracted an RF power of 150 kW from the first klystron to distribute the drive power to the remaining 10 units as shown in Fig. 2. It certainly simplified the low-level RF system. However, we have to sacrifice high-power RF of about 0.1 μs due to the delay time between the first and the rest of klystrons. This affects the trigger time in the SLED operation.

3.3 Vacuum system

We adopted a vacuum system different from the traditional one. We attached ion pumps directly to the waveguide system so that it resulted in not only savings of materials and manpower, but also vacuum isolation between modules. It also provided us time required to develop waveguide valves at this power level. We also modified the flanges of accelerating columns to the UHV flanges for easy assembly. In case of replacement, we can handle the unit alone due to no welding work involved. It had taken three hours for us to replace an accelerating column in two occasions.

3.4 Control System

There is a control room dedicated to the linac operation. We developed a computer control system based on the VME-system, which consists of three interfacing layers; operator interface layer, data processing layer, and data acqusition layer [3]. It reflects the most modern concept of the real-time control so that one may access to the machine operation anywhere in the world with the proper communication equipment and the access permit.

4. Commissioning

4.1 High-Power Microwaves and RF Conditioning

As we completed a regular module assembly one by one both in the tunnel and gallery, we applied microwaves to the waveguide system as long as possible mainly during the nights.

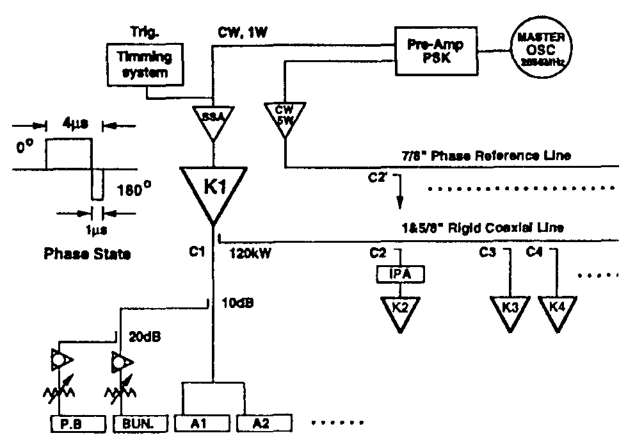

Fig. 2: Schematic diagram for RF drive system

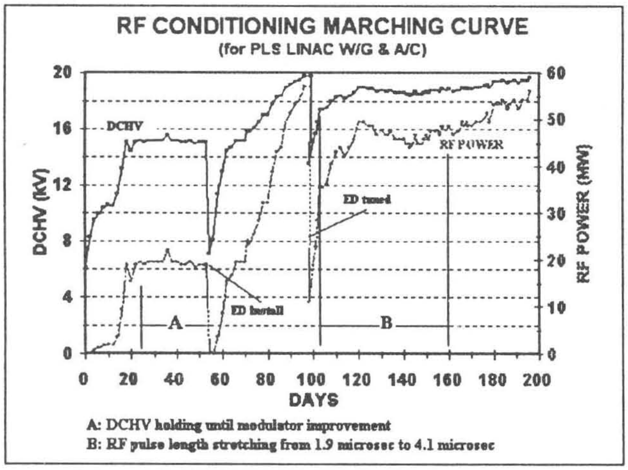

Fig. 3: Typical RF conditioning for new module

As a result, there is a difference in high-voltage runtime by more than 4,000 hours between the earliest and the latest klystrons. One notes that there is no loss of klystrons so far, and the oldest klystron shows the runtime of about 9,000 hours.

In order to RF clean inner surfaces of a newly assembled module of waveguides, SLED cavities, and accelerating columns, one should slowly increase the output power and the pulse length of a klystron. Fig. 3 shows a typical case for the RF conditioning. It has taken about six months for a module to be in a stable operational state. In Fig. 3, one notes that we spent about 30 days for the modulator improvement time as designated by "A". During the period designated as "B", we slowly increased the RF pulse length from 1.9 to 4.1 μs.

4.2 Beam Operation in Detuned Case

When we had a stable condition for all klystrons in a lower power level in January, we practiced to transport and accelerate beams by all units to the beam dump. On January 28, we measured the beam energy of 800-MeV and 50-mA at the Beam Analyzing Station (BAS) #3 at the end of the linac. Through our commissioning period, we tried to lower beam current deliberately for the radiation safety and for precaution.

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. 4 shows the increase of the beam energy and the change of total RF power since January, 1994.

4.3 Beam Operation in 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

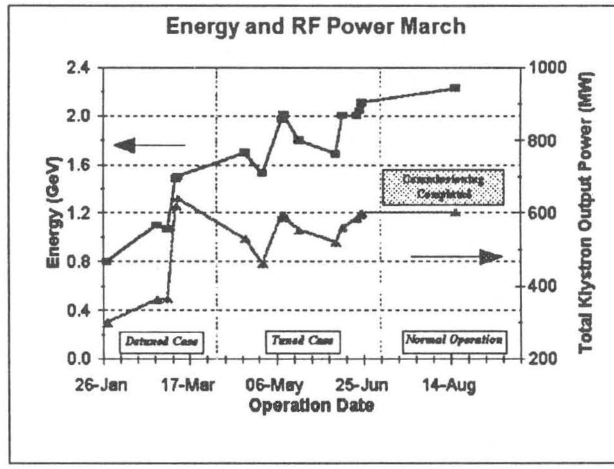

Fig. 4: Energy and RF power changes during the commissioning

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. 5. It took two months to increase the RF pulse from 1.9 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 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.

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 real-time 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. A typical RF characteristics is shown in Fig. 6 for the tuned operation. The bottom trace shows the klystron output power of about 60-MW with 4.1 μs. The middle trace shows the RF phase which is flipped by the PSK at 3.0 μs into the RF pulse. The top trace shows the SLED output power of 335 MW peak.

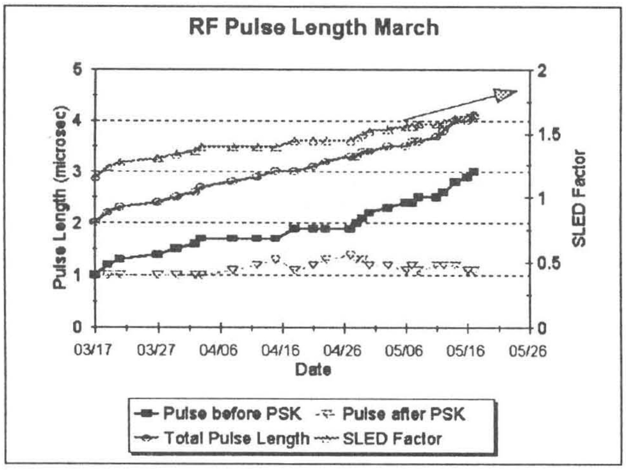

Fig. 5: RF pulse width during the commissioning

5. Normal Operation

Immediately after the completion of the linac commissioning, we had an annual preventive maintenance period from June 25 to July 31. Especially, the machine cooling system runs continuously, and it requires a regular maintenance every year. We also improved the preinjector cooling and vacuum systems which had been constructed for training our staff in 1992. Other two module had experienced vacuum vents for visual inspections. On the other hand, we opened the beam tunnel so that staff could complete the remaining installation tasks for the beam transfer line (BTL) to the storage ring. When we resume the RF conditioning, it had taken about two weeks to recover the stable operation condition regime. One notes that it is a special case, because the preinjector is involved.

Through the machine operations on August 17 and 18, we were able to obtain beams of 2.23 GeV with a total RF power of 600-MW. The accelerating efficiency with a given RF power is improved due mainly to the fine adjustment of the RF phase by the computer control. The final beam current is 250 mA with the e-gun current of 1.0 A. We observed a residual radiation of about 1 mR/H level in the beam switching yard at 24-hours after the two day operation with more than 100 mA current. The pulse repetition frequency is currently 30 Hz for convenience of diagnostics. However, we have to operate the machine at 10 Hz for the storage ring injection in September due to the limitations of the storage ring injection system. In this case, one should be very careful to protect the modulators. We plan to operate klystrons at 30 Hz and the e-gun at 10 Hz in synchronization with the storage ring clock. We have taken care of the case of missing trigger pulses from the ring.

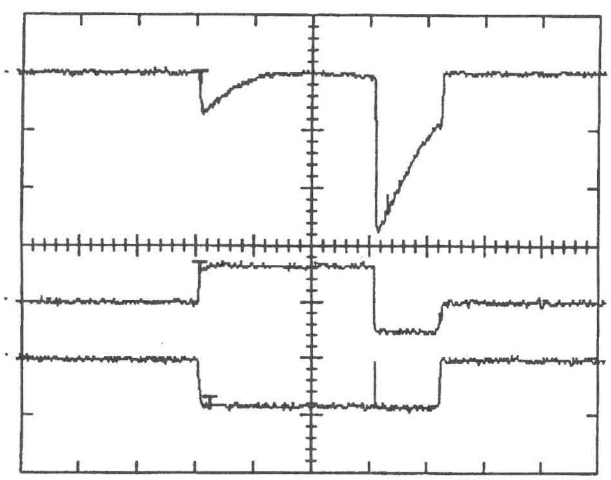

Fig. 6: Typical RF characteristics for tuned operation: 1 μs /div (horizontal) and relative unit (vertical).

Top: SLED output (335-MW peak)
Middle: Phase of klystron output (0 to π rad)
Bottom: Klystron (60 MW) with 4.1 μs.

6. Future Plan

The PLS project is the first attempt in Korea for constructing a major accelerator facility. In addition, the 2-GeV injector linac is the third largest electron linac in the world. The prime mission for providing beams to the storage ring requires a few minutes for each injection, and ultimately, it will be happen once or twice in a day. Therefore, we planned to use electron beams of various energies to promote other branches of basic and applied sciences.

First, we propose to add a "stretcher" ring of 2 - 3 GeV for nuclear physics experiments in the other side of the storage ring as shown in Fig. 1. Secondly, we may use 1.0-GeV beams for a compact ring dedicated to develop lithography techniques, since the semiconductor industry in Korea is currently leading worldwide competitions in the memory chips. The third one is free electron laser (FEL) experiments. We are now in progress on assembling a low-energy linac for an IR FEL by graduate students. They use the surplus equipment from replacement of the original preinjector. It provides an excellent opportunity in this educational institute. There are many possible applications such as a medical facility using lower energy beams and positron production for the PLS storage ring and other physics research.

In addition, we propose to build an intense proton linac of 200-MeV next to the PLS linac. This project would use the RF technology built during the PLS project. The prime purpose is to develop a prototype linac for transmutations in the next century. As a by-product, we would have intense proton beams in Pohang to be used for cancer therapy. It would be a great contribution to people in this area.

7. Summary

The PLS 2-GeV linac has been successfully commissioned in June 1994 as scheduled, and its performance exceeds the design values. We have demonstrated that it is a viable option as a full energy injector to storage rings up to this energy in the construction cost. Through the PLS project, we have established a technology base for particle accelerators and trained young scientists and engineers in Korea. We are mostly benefited from exchanges of personnel and information with other established laboratories through institutional collaborations. We expect to use our experiences for advanced accelerator R&D programs and for new projects.

8. Acknowledgments

The author thanks technical staff of the PAL Linac Division 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 the completion with great eagerness.

9. References

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