HIGH-POWER MICROWAVE SYSTEM FOR PLS 2-GeV LINAC*

M.H. Cho, J.S. Oh, S.S. Park, and W. Namkung
Pohang Accelerator Laboratory, POSTECH
San 31, Hyoja-Dong, Pohang 790-784, Korea

Abstract

The PLS 2-GeV Linac employs 11 units of high-power klystrons (80-MW) and 10 units of SLED-type pulse compressors as RF sources. The matching modulators of 200-MW (400 kV, 500 A) provide flat-top width of 4.4 μs pulses with 120 Hz capability of the maximum pulse repetition rate at the full power level. For the good energy stability of the electron beams, the pulse-to-pulse flat-top voltage variation of the modulator requires less than 0.5%. In order to achieve this goal, we stabilized high-voltage power supplies within 1% by a phase controlled primary voltage regulator system. In addition, we employed a resistive De-Q'ing system to achieve less than 0.5% peak-to-peak voltage variation of the PFN. This paper presents the system design and the construction of the high power rf sources, and also results of the system operation during the commissioning of the PLS 2-GeV linac.

1. Introduction

Electron linear accelerator with the nominal energy of 2-GeV is constructed and commissioned, whose prime purpose is to inject full energy electron bunches to the Pohang Light Source (PLS), the third generation synchrotron light source under construction at Pohang University of Science and Technology, Pohang, Korea. The key features of the linac are as follows; 11 units of high power S-band (2,856 MHz) pulse klystrons (80-MW at 4 μs pulse width), 10 SLAC type energy doublers, 42 accelerating structures (SLAC type, 2π/3 mode, traveling wave structure), 3 beam switch yards (approximately 100-MeV, 1-GeV, and 2-GeV beam exits), vertical arrangement of klystron modulators and accelerator main body with 3 meter thick concrete slab for the radiation shielding. The first klystron with a prebuncher, a buncher, and two accelerating structures serves as the preinjector (100-MeV beam energy) for the main linac. The total length of the machine is 149.5-meter long. Actual machine construction has been completed in early December 1993. The rf conditioning and the beam commissioning have been alternatively performed since then. The details of the linac design parameters, construction, and commissioning are described in [1]. This paper presents the performance of the high power rf system of the linac -- mainly on the high power klystron and modulator systems, and the observations made during the rf conditioning operation for the waveguide networks and the accelerating structures are also described.

2. PLS Linac Microwave System Overview

The rf power split off by the 26.5-dB cross coupler from the first klystron is fed to the main drive-line made of phase stable solid coaxial line as shown in Fig. 1. A solid state amplifier (max 800W) is employed as a drive power source for the first klystron, which feeds power to the preinjector linac of 100-MeV beam energy. The rf power branched off from this main drive line using preset directional couplers is fed to an electronic phase shifter and a miniature servo-motor driven attenuator (IPA). This controlled drive power is amplified more than 50-dB by the high power klystrons (E-3712, Toshiba), and delivered to SLED and then to four accelerating structures through S-band waveguide network (see Fig. 2). One phase shifting key (PSK) unit for the energy doubler is installed only at the low power input side of the first klystron, and operated by a single trigger control.

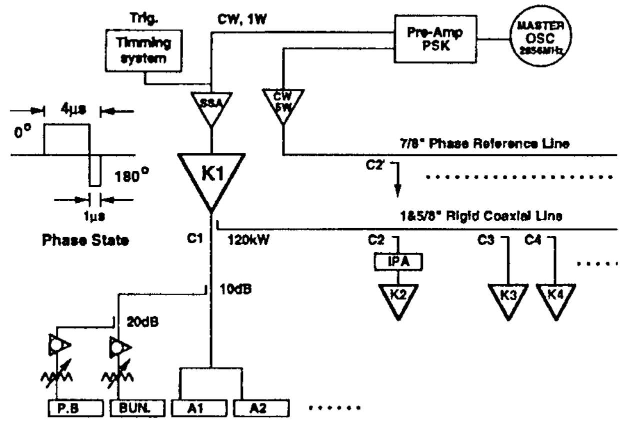

Fig. 1 Klystron power drive system schematic

3. PLS-200-MW Klystron Modulator System

Klystrons as high power rf sources employed in PLS 2-GeV linac are 10 units of E-3712, 80-MW (installed to main linac modules), and one SLAC-5045, 65-MW (installed to preinjector).

The design and operational parameters of the klystron modulator (model: PLS-200-MW) for the E-3712 klystron are summarized in Table 1. Highlights of the system design are as follows; the SCR phase control with a feedback is employed 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/F-303 thyratron tube for the pulse switching, and 1:17 turn ratio pulse transformer. The schematic circuit diagram is shown in Fig. 3, and the details of the PLS-200-MW klystron modulator is described elsewhere [2].

The stability of the beam voltage at the klystron cathode is achieved in two stage. DC high voltage is stabilized by the feedback controlled SCR within 1%, and then the PFN charging

* Work supported by Pohang Iron & Steel Co. and Ministry of Science and Technology of Korea.

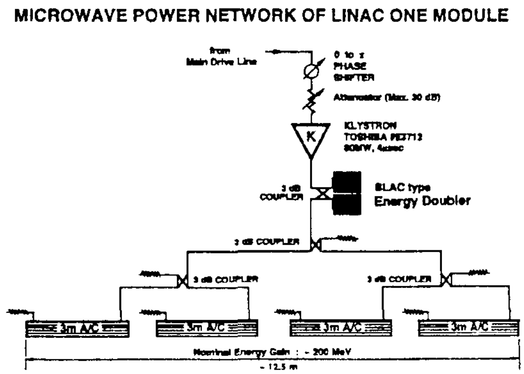

Fig. 2 Microwave power network of a regular linac module

voltage is stabilized within design specification of 0.5% by using the resistive De-Q'ing (3.6Ω, 50 μF).

The three types of system interlocks, namely dynamic and static fault interlocks and personal protection interlock, are integrated in the modulator circuit as a built-in system. All the static fault activation is initiated by the relay logic circuit, and the dynamic faults which usually require fast action are activated using the electronic comparator circuit. The system response time due to the sudden vacuum level increase by the bursting type outgassing is measured to be approximately 50 ms, which corresponds to about 2 more rf pulses in 30 Hz operation till the rf power level drops down well below 10-dB from the operating power level. The system has analogue comparator type (directly comparing the vacuum level) as well as the relay interlock type which uses the logic signal from the commercial product cold cathode gauge. Trigger holding type action can be very fast, however it is not recommendable method for the SCR phase controlled system (especially when the firing angle of an SCR is not fully open) because unavoidable high voltage jump may occur at the moment of the SCR gate trigger hold.

Table 1:Klystron Modulator Operation Parameters

Peak beam power	200 MW max. (400 kV at 500 A)
Beam pulse width	ESW 7.5 μs (flat-top: 4.4 μs)
Pulse rep. rate	120 pps max. (currently 30 Hz)
PFN impedance	2.64 Ω (5% positive mismatch)
PFN stage	14 section/set x 2 sets in parallel
De-Q'ing	5% (max), resistive
Pulse transformer	1:17 (turn ratio)
	1.3 μHy (leakage inductance)
	69 nF (stray capacitance)
Thyratron	8500 A (peak current at anode)
	46.8 GW (heating factor)
Klystron tube	~ 40 % (efficiency), ~53 dB (gain)
	~ 300 W (drive power)

Approximately 23% of the rms current harmonics is generated (see Fig. 4) from the modulator when the SCR's firing angle is about 120° (corresponds to 18 kV of DC high voltage). These harmonic distortions are compensated by connecting L-C tank

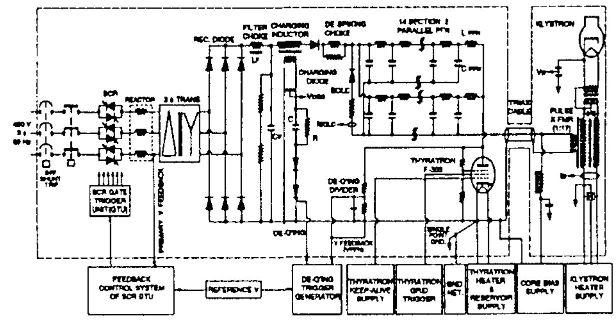

Fig. 3 Schematic circuit of the 200-MW modulator

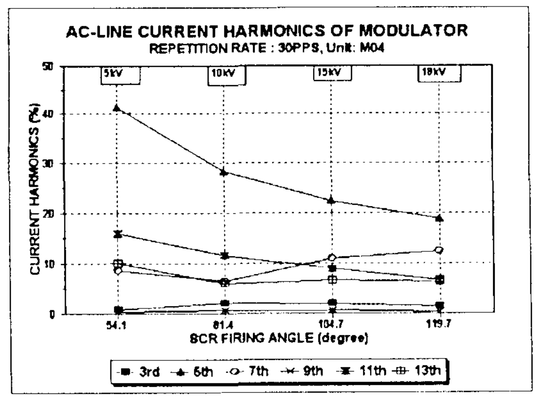

Fig. 4 AC-line current harmonics of the modulator

at the main power station to have higher than 98% power factor recovery.

4. High Power Microwave System Performance

The nominal pulse repetition rate is set at 30 Hz during the commissioning operation. Since the system design is based on the 120 Hz operation, i.e. ~6 ms charging time, the high voltage at the PFN should be held approximately 25 ms between pulse triggers. Due to the rather long high-voltage hold-on time thyratrons have shown random self-fire phenomena. Modest suppression of this self-fire was observed by installing negative bias on the trigger grid of the thyratron. Especially, when the self-fire occurs within the PFN charging period or the regular triggering occurs before the full recovery from the self-fire, the modulator system suffers the shorting of the DCHV power supply, which causes the main circuit breaker trip. To avoid this kind of main breaker trip, we have installed the trigger holding circuit which ensures the enough PFN charging period right after the thyratron's normal or self-fire. The average system fault rate by the main breaker trip without the trigger hold circuit was about 0.3/day, and with the trigger hold circuit the rate dropped far better than 1/month. We are currently working on the improved fault protection scheme which can allow remote recovery of the fault without risking any damage in the circuit. Another annoying behavior of the beam voltage pulse shape was observed when

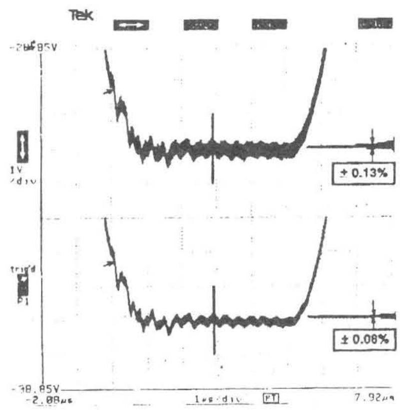

Fig. 5 Accumulated klystron beam voltage fluctuations (flat-top). Upper trace; SCR feedback control only. Lower trace; with De-Q'ing.

the premature turn-off of the thyratron occurs before the complete dissipation of the post pulse power remained at the pulse transformer. When this happens excessive voltage backswing at the klystron cathode occurs at the moment of the turn-off.

The voltage ripple in the pulse flat-top is controlled by the PFN tuning. The shot-to-shot stability of the beam voltage is controlled by the resistive De-Q'ing. The stability of the beam voltage measured in the PLS 200-MW modulator with the SCR feedback control alone and together with the De-Q'ing is shown in Fig. 5. The line voltage fluctuation during the measurement was ~3%, and the traces have been accumulated continuously for an hour (DSA-602 Tek oscilloscope).

5. RF Conditioning Operation

RF conditioning operation can be generally classified as follows; 1) low power (~100 kW) with short rf pulse (~1 μs) conditioning with the SLED detuned, 2) power ramping up to maximum with short rf pulse (~1 μs) with SLED detuned, 3) set SLED at tuned mode then power ramping with long rf pulse (~4 μs, see Fig. 6). With the above mentioned general procedure in mind the rf conditioning has been processed (see Fig. 7). To reach higher than 50-MW rf power level with SLED tuned it took almost 6-month in our linac system.

The vacuum level of the waveguide network after air exposure for the maintenance reached mid 10^{-8} torr range well within a week in our linac system. Careful vacuum interlock level adjustment has been made as the rf power level increased to avoid the corona or arcing discharge in the structure. The maximum care has been also taken to avoid possible multifactoring near the klystron ceramic windows. Rather weak vacuum leak points were ceramic windows for the Bethe-Hole directional couplers, however they were mostly curable by applying liquid type high vacuum sealant. As soon as the rf power reaches near 1 MW level the vacuum pressure near the window always kept well below ~5×10^{-8} torr. It is typical practice to use VSWR interlock to avoid damage caused by the reflected power, however with the well controlled vacuum interlock level it has been observed as almost unused.

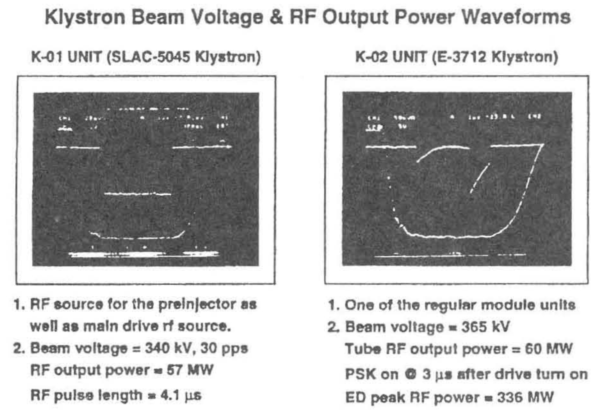

Fig. 6 Beam voltage and rf power waveforms.

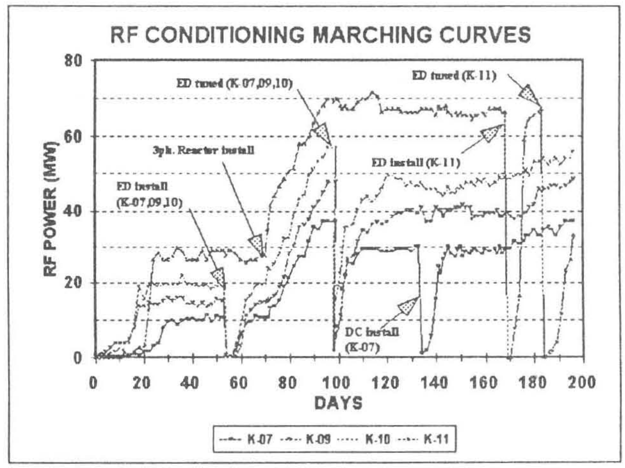

Fig. 7 Typical RF power marching history during the rf conditioning of the accelerating structures and waveguides.

6. Summary

Overall average of the rf power per klystron delivered to the waveguide and accelerating structures is reached approximately 55-MW after approximately 6-month of rf conditioning operation. Klystron modulator systems installed at the early phase of project have been reached close to 8,000 hours of hot operation time, and they show no degrade in performance quality. Current on going major works on the system are overall power efficiency improvement, further improvement of system stability, and fully computerized on-line monitor and control system installation.

7. References

[1]. W. Namkung *et. al.*, "Commissioning of PLS 2-GeV Electron Linac," Proceedings of European Particle Accel. Conf. London, U.K. June 27-July 1 (1994)

[2]. M.H.Cho *et. al.*, "Performance of Pulsed High Power Klystron Tube for PLS 2-GeV Linac Proceedings of IEEE Particle Accel. Conf. (Washington D.C., U.S.A.), p593 (1993)