MICROWAVE SYSTEM OF PLS 2-GeV LINAC*

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The microwave system of the PLS 2-GeV linac is systematically divided into two parts. One is a drive system, the other is a waveguide system. The drive system consists of an RF signal source (2,856 MHz), a solid state amplifier (SSA), a phase shift key (PSK), a main drive line (MDL), and IPA units. There are 11 high power klystrons, 10 SLED-type pulse compressors, and 42 constant gradient accelerating sections in the waveguide network. One module of the waveguide network consists of 63 pieces of waveguide components and four accelerating sections. After installation of the waveguide system, phases for each branch of the system are measured, and phase differences between branches are adjusted within 1 degree. The attenuation of the waveguide system from the klystron output to the input port of each accelerating section is about 0.8 dB. This paper presents the design of the microwave system and its performance.

I. INTRODUCTION

The PLS 2-GeV linac is completed by the end of June 1994 as a full energy injector to the storage ring, a third generation synchrotron light source. There are 11 klystrons and modulators, 10 SLED-type pulse compressors, and 42 accelerating sections [1,2]. The electron beam is accelerated with a pulsed RF of 2,856 MHz. The RF frequency, phase, and power are very important factors in linac operations. The change of these factors gives influences on the energy and the energy spread of accelerated beams. The magnitude of the change of these factors depends on various reasons such as the drive signal of klystrons, modulator beam voltages, and even environmental conditions. The beam voltage of the modulator is stabilized within the design specification of +/- 0.5% in two stages [3]. The temperature of accelerating sections is routinely controlled within 45 +/- 0.2^{o} C. For the drive system, the design tolerance of phase stability is less than +/- 3.5^{o} during 72 hours for the entire 145-m long drive line.

The drive system was completely installed by the end of August 1993, and the waveguide system was completed in December, 1993. The RF conditioning for the whole waveguide system and the beam commissioning have been continued since then. Until now, the whole microwave system is being operated without a serious problem.

II. DRIVE SYSTEM

There are three parts in the drive system; the signal source to drive the preinjector klystron, the main drive line to supply 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 schematic diagram of the PLS linac drive system is shown in Fig. 1.

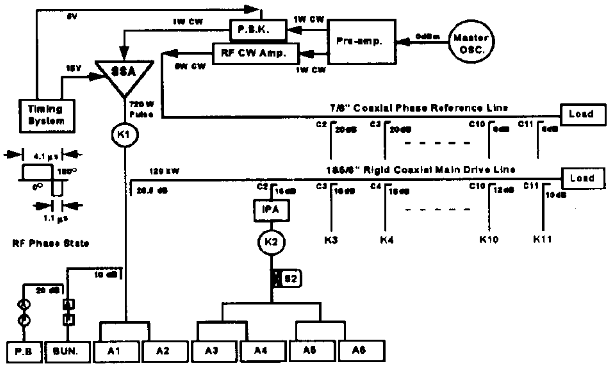

Fig. 1: Schematic diagram of PLS microwave system.

A. Signal Source

The signal source consists of a master oscillator, a low-level signal conditioning unit, and a solid-state amplifier. The high precision synthesized signal generator is used as a master oscillator. The frequency stability of the master oscillator is 5×10^{-10} /day, and the phase noise is -137 dBc/Hz at 10 kHz offset. The low-level signal conditioning unit consists of a pre-amplifier, a CW RF amplifier, an isolator, and a PSK. The PSK unit can be operated up to 2-W CW power and its switching time is shorter than 50-ns. The solid-state amplifier is a C-class pulse amplifier. The PSK output of 1-W CW is amplified by the SSA to 720-W pulse power by using the multi-cascade method and the power combination method. The SSA provides the drive power to the preinjector klystron. The output of the solid-state amplifier is adjustable from 400-W to 720-W, and the pulse width adjustable from 2 μs to 7 μs. Its rise and fall times are about 0.2 μs and 0.1 μs, respectively.

B. Main Drive Line

The main drive line of 1-5/8" air-dielectric rigid coaxial line transmits the 2,856 MHz RF power from a cross coupler waveguide located in the preinjector waveguide system to the end of the accelerator. It consists of 45 straight pieces, 2 right angle elbows, 2 expansion sections, 11 couplers, and a load. The total length of the main drive line is 145 m. The expansion sections are for compensations of the longitudinal thermal expansion due to the temperature variation in the drive line. There are 4 kinds of coupling coefficients in 10 couplers to extract proper drive power to the klystron from the main drive line. Approximately 120-kW

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power is supplied to the main drive line. The output power at each directional coupler is 2~3 kW ranges.

C. Isolator-Phase Shifter-Attenuator (IPA)

The IPA system provides the isolation of the main drive signal from the reflected drive signal at each klystron as well as the control of the phase and the amplitude of the drive power for each klystron. An IPA system consists of two units. One is an RF unit and the other is an electronic control unit. There are two controllable components in the RF unit; a phase shifter and an attenuator. The phase shifter is a rotary-field type and is digitally controlled from 0^{o} to 360^{o} by a current drive. The attenuator is a strip-line variable type and its attenuation is varied from 0 to 20 dB by a DC motor. An Intel 8751 microprocessor is used in the electronic control unit which is connected to the main control system via a special VME I/O port. The main parameters of the IPA system are shown in Table 1.

Table 1: Main parameters for the IPA unit.

Frequency Range	2,856 +/- 0.1 MHz
Total Insertion Loss	< 3.0 dB
VSWR	< 1.2
Max. In/Out RF Power	3/1.5 kW peak, 4 μs, 60 Hz
Phase Shift Range	Modulo 360^{o}
Phase Error	< +/- 3.0^{o}
Variable Attenuation Range	20 dB max.
Isolation	> 30 dB

III. WAVEGUIDE SYSTEM

The waveguide system consists of the waveguide network, pulse compressors (SLEDs), and accelerating sections. The waveguide network transfers the microwave power from the klystron to the accelerating sections. The pulse compressor is for increasing the peak power of microwaves instead of reducing the pulse width. The electron beam is accelerated in the accelerating section with microwaves as shown in Fig. 1.

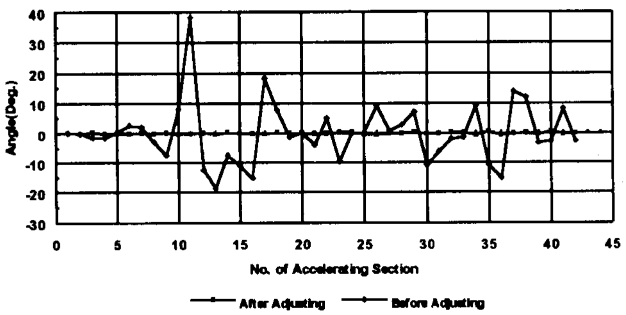

Fig. 2: Phase adjustment result of the waveguide system.

A. Waveguide Network

This system consists of 63 pieces of S-band standard waveguide components. The thickness of each component is 5 mm. The length of one branch from the klystron output to the input port of an accelerating section is about 16 m. One klystron feeds the microwave power to four accelerating sections. Each klystron is individually phased by an IPA system to obtain the correct phase relationship between bunched beams and the microwaves. In the PLS linac, the distance between the input couplers of accelerating sections in one module is 31 wavelengths. The high power waveguide network must be adjusted to be equal in phase length, or to differ by only integral numbers of wavelengths. The waveguide branches from a klystron output to the output ports of the four accelerating sections were adjusted to be equal in phase length within tolerance of +/- 1^{o} by using a network analyzer (HP 8510C). The results of the phase adjustment is shown in Fig. 2. During the phase adjustments, the vacuum pressure of the waveguide system was kept in order of 10^{-5} torr to reduce the error occurred by distortion of the waveguide due to the atmospheric pressure. And the temperature of adjusted waveguide branch was maintained within 45 +/- 0.1^{o}C. The pulse compressor was detuned during the adjustment. The average loss of the waveguide network between the klystron output and the input ports of accelerating sections was 0.8 dB.

B. Pulse Compressor

We use 10 pulse compressors to get a high energy gain in the accelerating sections. Several RF tests are conducted before being installed. The measured unloaded Q-value is about 100,000 and coupling coefficient is about 4.8. Also the measured power gain is about 7.5 dB. We have two kinds of pulse compressors which is different in detuning needles. One half of them are old type which is the same as the SLAC type. The others are a new type in which the position of the detuning needle is changed. Currently, all pulse compressors are operated at about 60-MW RF power. When the RF phase is reversed at 3 μs after the RF pulse turn-on, the measured power gain is higher than 7.4 dB.

C. Accelerating Section

There are 42 accelerating sections in the PLS linac. They are all SLAC-type constant gradient structures. Three kinds of accelerating sections are periodically arranged in order to compress higher order modes. To compensate disturbances on electron beams due to the coupler asymmetry, all accelerating sections are installed with BA-ABBA-AB-BABA etc. configuration. Each accelerating section operated with $3\pi/2$ mode is 3.072 m long and has conflat flanges for easy installation and maintenances. The attenuation of an accelerating section is less than 4.9 dB. Presently, about 70-MW of RF power (peak) is fed into each accelerating section.

IV. PERFORMANCE OF M/W SYSTEM

The slippage between RF wave crests and electron bunches may take place in accelerating sections. When the operation

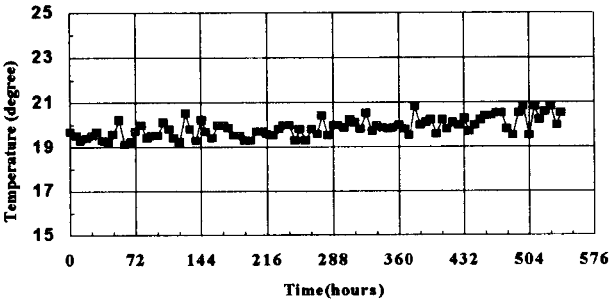

Fig. 3: Temperature variation of the main drive line.

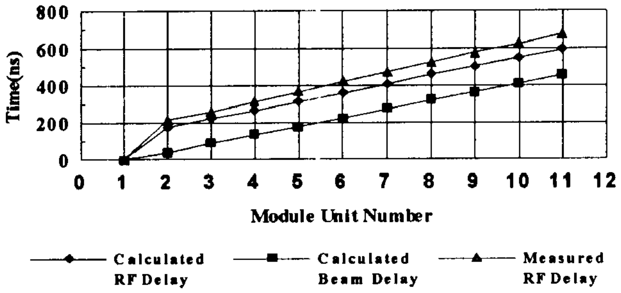

Fig. 4: Delay time of RF and electron beam.

frequency is drifted or the temperature of accelerating sections is shifted from the desired value, the derivation of the phase velocity from the speed of light occurs. The variation of the operating frequency is most influential to the beam quality than other reasons such as the phase shift in the main drive line. We observe that the operating frequency of the master oscillator varies within several Hz per day.

There are three relevant factors which affect the phase stability of the main drive line; the length, the dielectric constant of the gas inside the line, and the dielectric constant of the Teflon for supporting the center conductor. These factors vary as the temperature of the environment changes. The length variation causes the greatest phase errors compared to the phase errors raised by other two factors. The length variation of 145-m long main drive line is about 2.44-mm per 1°C change. This value causes a phase error of about 8.8° at the end of the main drive line. The temperature of main drive line is measured as shown in Fig. 3.

The phase variation of the drive signal of each klystron is measured at the RF input and output monitoring ports in IPA units with a double-balanced mixer. The measured result shows that the maximum phase variation of the drive signal in each klystron is less than +/- 3°.

There is usually a time delay between the microwave and the electron beam due to the propagation speed of the microwave in the main drive line and the drop-out cable. The length of the drop-out cable of each module is nearly the same to avoid the irregular delay time. The delay time of the RF signals between nearby modules is measured as shown in Fig. 4. In the PLS linac, the largest delay time between adjacent module is occurred at the preinjector and the #2 klystron. This raised from the PSK trigger time in SLED operations.

The energy multiplication factor is measured at #10 module by comparing the beam energy with the tuned and detuned pulse compressor. The energy multiplication factor shows 1.56 with PSK trigger at 3 μs.

V. SUMMARY

The microwave system is in a good working condition without any serious problem during the commissioning period and the normal operation at present. AS a result, the measured energy spread is 0.3% with 2-GeV beams. The beam energy is very stable even in 24-hour continuous beam operation. The preinjector klystron is SLAC-5045 type. The drive power of this unit is about 500-W. Currently, this klystron is operated at 50-MW output power. The drive power to operate a klystron at its saturation is usually increased as the output power of the klystron is decreased. The present system which is a little lower than to the saturation level can provide the maximum power of 500-W to the preinjector klystron.

The solid-state amplifier developed in the PLS whose maximum output power is about 800-W will be installed and tested in the near future. We will also test the TWT (travelling wave tube) system instead of the solid state amplifier for future improvement of the stability of the drive signal of the klystron.

VI. ACKNOWLEDGMENTS

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VII. REFERENCES

[1]. Design Report of Pohang Light Source (revised ed.), Pohang Accelerator Laboratory, 1992.

[2]. W. Namkung, "PLS 2-GeV Linac," Proc. 1994 International Linac Conf., Tsukuba, Japan, August 1994, pp. 14-18.

[3]. M. H. Cho, et. al, "High Power Microwave System for PLS 2-GeV Linac," Proc. 1994 International Linac Conf., Tsukuba, Japan, August 1994, pp. 418-420.