PHASE MEASUREMENT AND COMPENSATION SYSTEM IN PLS 2.5GEV LINAC FOR PAL-XFEL*

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Abstract

In Pohang Accelerator Laboratory (PAL), we are preparing the 3.7 GeV PAL_XFEL project by upgrading the present 2.5GeV Linac. In present Pohang Light Source (PLS) Linac, the specifications of the beam energy spread and rf phase are 0.6 % (peak) and 3.5 degrees (peak) respectively. The output power of klystron is 80 MW at the pulse width of 4 μs and the repetition rate of 10 Hz. In XFEL, the specifications of the beam energy spread and rf phase are 0.03 % (rms) and 0.02 degrees (rms) respectively. We developed an analogue and a digital phase measurement as well as an rf phase compensation system for stable beam quality. This paper describes the microwave system for the PAL_XFEL, and the rf phase measurement and phase compensation system.

INTRODUCTION

The PLS 2.5 GeV linac is operated as a full energy injector to the PLS storage ring, a third generation synchrotron light source. The schematic diagram of the linac rf system is showed in Fig. 1 [1, 2]. The designed energy spread of the linac is 0.6%. The beam voltage of a modulator is stabilized within the design specification of ± 0.5% in two stages [3]. The electron beam is accelerated with pulsed rf of 2856 MHz. The rf frequency, phase, and power are very important factors in linac operations. The change of these factors gives influences on the electron beam energy and the energy spread. This paper describes causes of beam energy drift, and rf phase feedback to cure the beam energy drift.

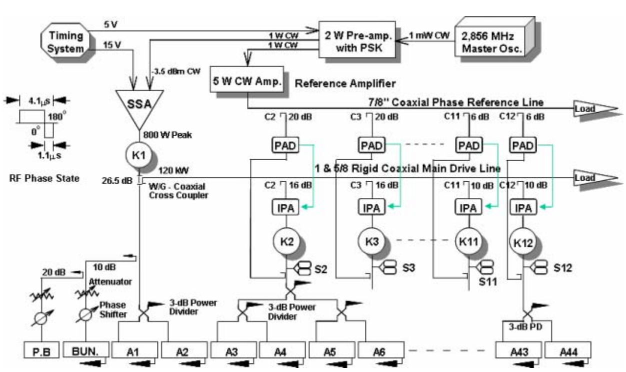

Figure 1: Schematic diagram of linac rf system

CAUSES OF BEAM ENERGY DRIFT

We measured beam energy variation and investigated its causes. As shown in Fig. 2, the long-term beam energy drift during 9 hours is 5 MeV and short term energy deviation is about 20 MeV maximum. The beam energy measurement was performed by BAS#3 BPM (Beam Position Monitor) at the end of 2.5 GeV linac. The data was obtained after averaging for 1minute.

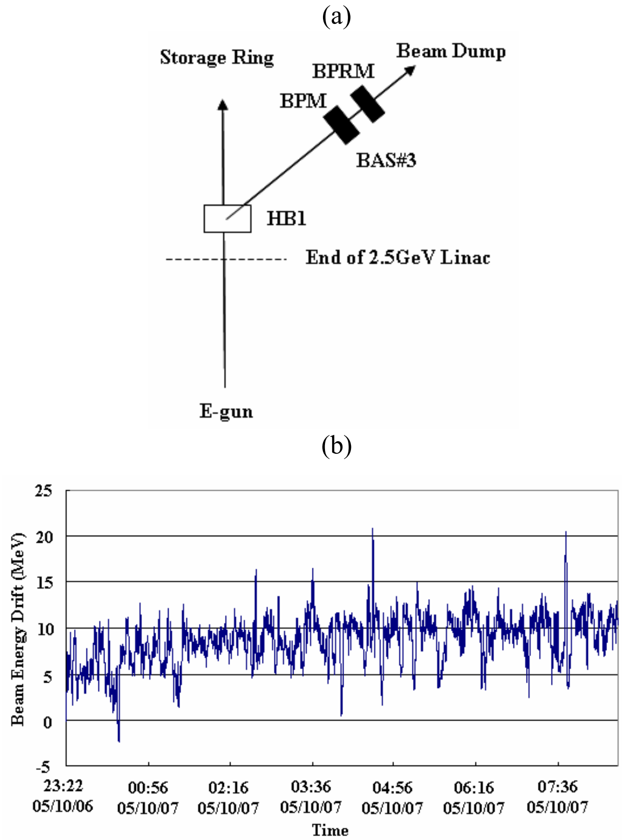

Figure 2: Beam energy drift measurement by BAS#3. BPM (Beam Position Monitor). (a) Beam energy measurement analyzer (b) Results of beam energy drift during 9hours

Table 1: RF design parameters

Parameters	PLS Linac	PAL-XFEL
Beam Energy	2.5 GeV	3.7 GeV
Energy Spread	0.6%	0.03% (rms)
Phase Stability	$\pm 3.5^o$	0.02^o (rms)
Amplitude Stability	±0.5%	0.01% (rms)

The rf design parameters for XFEL as shown Table 1 is tighter than for present PLS Linac. We examined the rf performance of the present PLS linac. After then, we are preparing the new rf system to provide stable beam in PAL_XFEL. The rf phase variation caused by cooling water temperature variations affected beam energy drift.

*Supported by MOST
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Normal cooling condition of accelerating column is controlled within ± 0.2 ^{0}C keeping the beam energy drift within 0.5%. But, the measured energy drift by cooling temperature variation of accelerating column is about 0.9% by the variation of 0.52 ^{0}C during 3 hours, much larger than 0.6% of designed value [4].

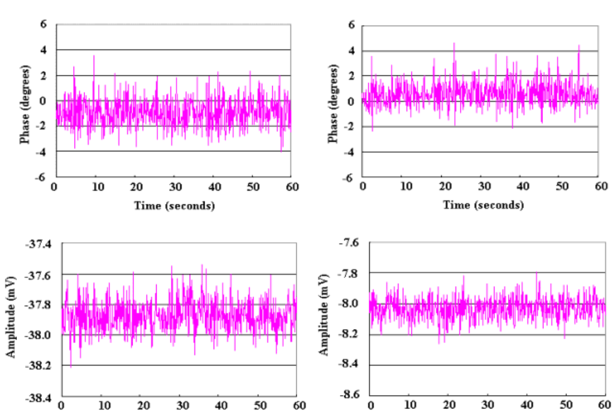
The rf phase of the SLED output in MK10 module was found to be changed by the room temperature variations in the MK1 module. As the air temperature in MK1 module change, the rf phase of SLED #10 is affected by the output phase of #1 klystron because of the thermal expansion of MDL (Main Drive Line) and reference line. In this case, the rf phase is changed by 3 degrees with 1^{0}C change in the room temperature. The room temperature of klystron gallery was controlled to within 23 ± 2^{0}C. Currently it is controlled within 0.5^{0}C in normal operation.

Also, the rf phase variation of SLED output with its cooling temperature is about 10 degrees per 1^{0}C variation of the cooling water temperature. In normal operation, the temperature of the SLED is controlled to within 45 ± 0.2^{0}C. The rf phase of klystron output is changed about 1 degree per 1^{0}C variation of the cooling water temperature of klystron tube. The temperature of klystron tube is controlled within 32 ± 1^{0}C in normal operation.

PHASE AND AMPLITUDE MEASUREMENT SYSTEM

Analogue Measurement System

Since the beam energy drift is related to the rf phase, so phase measurement system is constructed to measure rf phase of the SLED output referring the SLAC phasing system [5]. In this measurement [4], the rf amplitude coupled by 10dB coupler and the rf phase information from mixer output send to an oscilloscope. The temperature of cooling water, room, and outer are recorded by PC through a GPIB. Also the oscilloscope and power supply are controlled by PC through a GPIB.



(a) Klystron (b) SLED

Figure 3: Pulse to pulse phase and amplitude variation during 60seconds in K5 module.

Amplitude-independent phase measurement is achieved by an in-situ compensation process that was done by the controller based on the LABVIEW program. The phase accuracy of pulse to pulse phase measurement is 0.1^{o} (peak-peak) and 0.03^{o} (rms) within rf phase variation of 10 degrees. But as the phase variation is increased, the phase error is increased.

A pulse-to-pulse phase and amplitude measurement for each klystron and modulator module is important to design the PAL_XFEL. The measurement is conducted in K5 module of PLS linac. As shown in Fig.3, the phase and amplitude variation at klystron output are 1.16^{o} and 0.27% rms respectively. The phase and amplitude variation at SLED output are 0.98^{o} and 0.9% rms. To meet the PAL_XFEL specification, we need improvement of the short-term and long-term rf stability. To improve the long-term stability, we will use a phase feedback system. The high voltage modulator De-Q'ing will be also upgraded for short-term stability.

Digital Measurement System

The digital detector system as shown in Fig. 4 consists of a local oscillator, a power combiner and an rf digitizer PXI module made by Aeroflex Co. [6]. The reference cw 2856 MHz signal and pulsed signal is added in a combiner. The phase of the pulsed 2856MHz signal is obtained by comparison cw signal with cw+pulse signal. The phase measurement is achieved by the controller based on the Labview program. The phase accuracy of pulse-to-pulse phase measurement is 0.2^{o} (peak-peak).

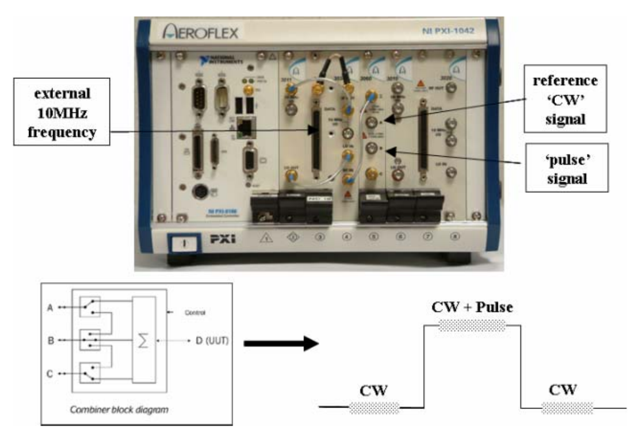
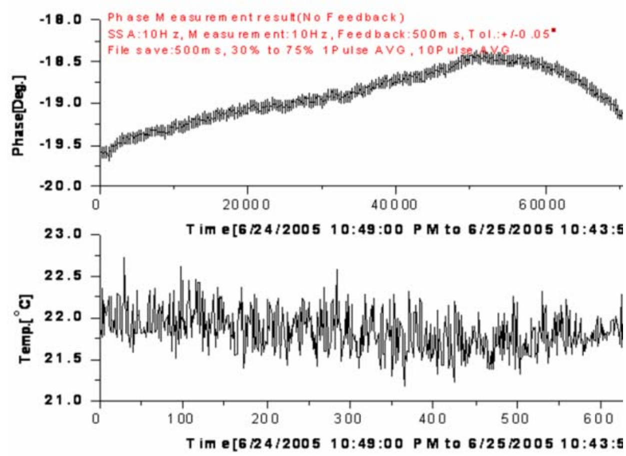
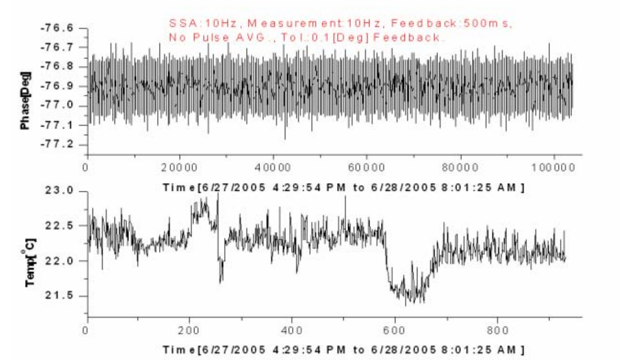


Figure 4: Digital pulse to pulse phase feedback system.

The phase feedback is achieved by using digital measurement system and analogue phase shifter. The phase of 600 watts SSA (Solid State Amplifier) with pulsed 2856 MHz is compared with cw 2856MHz reference signal. The phase change by the temperature variation is compensated by analogue phase shifter controlled by Labview program. The rf phase without the phase feedback is changed about 1 degree per 1^{0}C variation of the room temperature as shown in Fig. 5. Using the phase feedback, the phase of SSA output is controlled pulse by pulse within 0.3^{o} (peak-peak) during temperature variation of 1^0C. The phase is maintained within 0.1^o (peak-peak) with averaging of 10 samplings during temperature variation of 1^0C. This value can be adopted for the PAL_XFEL.



(a)



(b)

Figure 5: Phase feedback results of pulsed 2856 MHz SSA by digital phase measurement system (a) without feedback (b) with feedback

SUMMARY

We examined the causes of energy drift in PLS linac. The beam energy is changed by cooling temperature and air condition for long-term, and it is changed by modulator high voltage jitters for short-term. To cure the problem of energy drift, the phase feedback system is needed for long-term stability and the De-Q'ing system is needed for short-term stability. We measured beam energy and phase variation caused by environmental condition. We developed the analogue and digital phase measurement system. The performance of digital system with phase accuracy of 0.2^o (peak-peak) is similar to analogue system of 0.1^o (peak-peak). The diversity of digital system is better than the analogue system.

The phase and amplitude variation of 1^o (rms) and 0.3% (rms) at klystron output is larger than the design value of 0.02^o (rms) and 0.01% (rms) for PAL_XFEL. But, the long-term phase variation can be controlled within 0.1^o (peak-peak) by the phase compensation system. The short-term phase variation by short-term condition can be stabilized by improvement of high voltage modulator stability. We will install the digital phase feedback system at K1 injector PLS Linac in this year. Also we are going to install energy feedback system as shown in Fig. 6 at last module of the linac in next year.

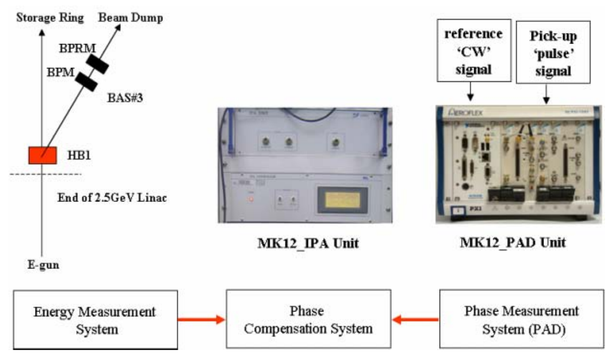


Figure 6: Energy compensation system.

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