PHASE AMPLITUDE DETECTION (PAD) AND PHASE AMPLITUDE CONTROL (PAC) FOR PXFEL*

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Abstract

Pohang Accelerator Laboratory, PAL, has been preparing the PLS-II project with 3 GeV Linac by upgrading the present 2.5 GeV Linac. The specification of the beam energy spread and rf phase should be much tighter than that of PLS Linac. In the present 2.5 GeV Linac of PAL, the specifications of the beam energy spread and rf phase are 0.6 % p-p and 3.5 degrees p-p respectively. The output power of the linac klystron is 80 MW at the pulse width 4 micro-seconds and the repetition rate of 10 Hz. The PxFEL for 10 GeV that is the future project plan requires 0.1 % rms and 0.1 degrees rms as specifications of the beam energy spread and rf phase respectively. We developed the Deqing system to keep modulator beam voltage stable less than 0.01 % rms for 3 GeV Linac and PxFEL. And the phase amplitude detection system (PAD) and phase amplitude control (PAC) system is also needed to improve the rf stability. This paper describes the microwave system for the PxFEL, PAD, and PAC system.

INTRODUCTION

As shown Table 1, the rf design parameters for XFEL need to have much tighter than those of present PLS Linac. In the PxFEL, the specifications of the beam energy spread and rf phase are 0.1 % rms and 0.1 degrees rms respectively [1]. 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. We measured beam energy variation and investigated its causes. We found it is related largely to cooling water temperatures. Also the rf phase variation by temperature variations affected to beam energy [2]. Pulse to pulse short-term variations cannot be corrected by feedback system. The new modulator can correct the short-term variations. The long-term drift can be corrected by feedback system.

Table 1: Design Parameters for PxFEL

Parameters	PLS Linac	PxFEL
Beam Energy	2.5 GeV	10.0 GeV
Energy Spread	0.6%	0.037% (rms)
Phase Stability	±3.5°	0.1° (rms)
Amplitude Stability	±0.5%	0.1% (rms)

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To meet the tighter design value of PxFEL as shown in Table 1, linac rf system needs to improve and modify the current PAL Linac systems which are modulator systems, rf systems, cooling systems, and etc.

MICROWAVE SYSTEM FOR PXFEL

Figure 1 and 2 show the schematic diagrams of the PxFEL rf system. The rf system consists of 66 S-band high power klystrons, 66 SLED-type pulse compressors, and 132 S-band constant gradient accelerating sections in the microwave network. A short X-band rf section, operating at 11.424GHz, provides 4th harmonic correction to the energy gradient along the bunch before it passes through the first bunch compressor chicane. This section requires a modest power source to operate at 37 MV/m over a length of 0.6m to generate the needed 22 MV of X-band rf [3]. The microwave system of the XFEL 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 (2856MHz), main drive line (MDL), solid-state amplifier (SSA), phase and amplitude detector (PAD), and phase and amplitude control (PAC) units.

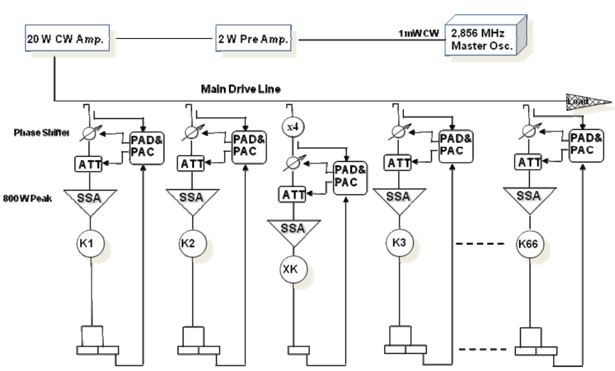

Figure 1: Microwave system for PxFEL.

High Power Microwave

One module of the waveguide network consists of 37 pieces of S-band standard waveguide components with 5 mm, a pulse compressor (SLED), and two accelerating sections. The pulse compressor can increase the peak power of microwaves instead of reducing the input pulse width.

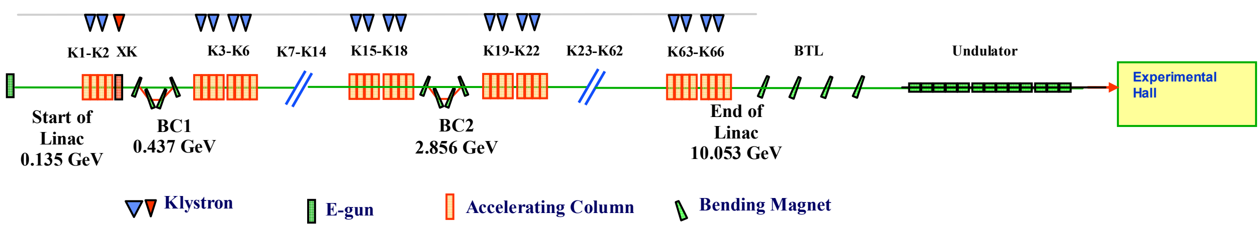

Figure 2: Layout of PxFEL.

A klystron feeds the microwave power to two accelerator sections as shown in Figure 3. The distance between the RF input ports of the accelerating sections is 31 wavelengths or 37 wavelengths. The phase difference among branches of the high power waveguide network must be adjusted within 1 degree by using a network analyzer (HP 8510C). During the phase adjustments, the vacuum of waveguide system must be kept in order of 10^{-5} torr to reduce the error occurred by distortion of the waveguides due to high vacuum. And the cooling temperature of waveguide system is controlled within 45 ± 0.1 °C.

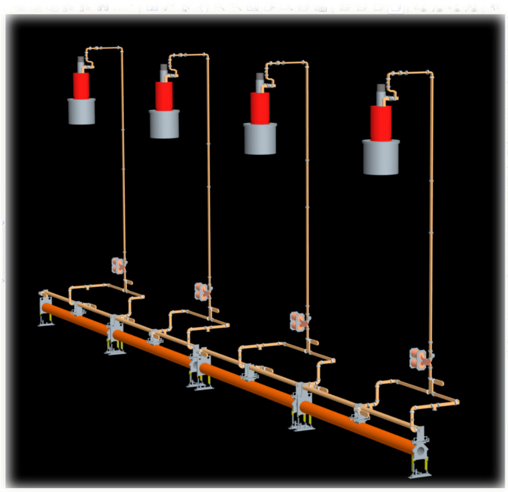

Figure 3: High power microwave system for PxFEL.

We use pulse compressors (SLED) to get a high energy gain in the accelerating sections. The unloaded Q-value is about 100,000 and coupling coefficient is about 4.8. The operating power of SLED is about 60 MW pulsed RF power. When the RF phase reversed at 3.17 micro-second after the RF pulse turns on, the power gain is higher than 7.4 dB. The SLEDs will be installed in the tunnel to prevent affect of room temperature variation

There are 132 accelerating sections in the main linac, which are SLAC-type constant gradient structures. Each accelerating section operated with 2π/3 mode is 3.138 m long and has conflate flanges for easy installation and maintenances. The power from one klystron is divided equally over 3-m section. The attenuation of an accelerating section is less than 4.9 dB. The RF peak power fed into each accelerating section is about 120MW.

Low Power Microwave

The signal source consists of a master oscillator, 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 preamplifier, CW RF amplifier, isolator, and PSK. The switching time of PSK will be shorter than 50 ns. To drive the klystron, the main drive line of 1&5/8" air dielectric rigid coaxial line transmits the 2856 MHz RF power. It's total length is about 700 meters. The expansion sections are needed to compensate the longitudinal thermal expansion due to the temperature variation. The C-class solid-state amplifier amplifies from 10 mW cw to 720 W pulse with the multi-cascade method. The output of the solid-state amplifier is adjustable from 400-W to 720-W and pulse width from 2 µs to 7 µs. It's rise and fall times are about 0.2 µs and 0.1 µs, respectively.

PAD and PAC

The function of PAD is to measure the phase and amplitude of klystron. The function of PAC is to control the phase and amplitude of the klystron drive rf power. We are going to develop the PAD and PAC based on SLAC LLRF system [4]. Preliminary, we developed the PAD and we measured the phase and amplitude of K1 and K2 klystron in the present linac as shown in Figure 4. The PAD clock is running at 102MHz which is 4 times the IF frequency 25.5 MHz. The 102MHz for the clock input and the 25.5MHz as a signal input to the 4 channel ADC board was used. S-Band PAD chassis has an EPICS on RTEMS Coldfire IOC which reads 4 FIFOs from the 16 bit 102MHz ADCs. The RF is down mixed with the 2830.5MHz LO reference to 25.5MHz IF, which is digitized at 102MHz as shown in Figure 5. The IOC does the down conversion to base band, averages over a specified number of points, up to 512, and the set the EPICS I and Q records.

The measurement has been conducted in the K2 modulator system of PLS Linac. The short-term phase and amplitude variation is 0.7° and 0.17% rms value at klystron output as shown in Figure 6. And it is 0.86° and 0.9% rms value at SLED output as shown in Figure 7. The measured values do not meet design value for XFEL. We need to develop a new modulator to reduce the short-term variation of the klystron output, a PAC System, and develop a PAD system for improving the measurement.

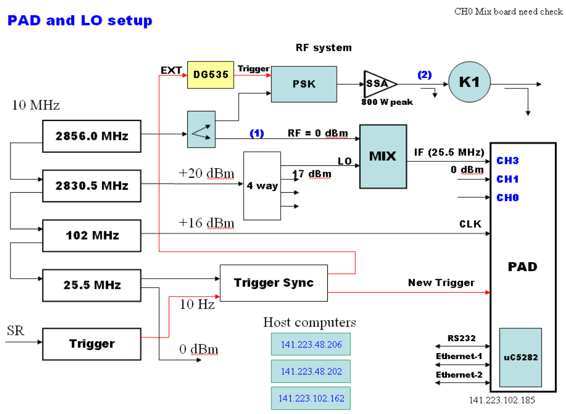

Figure 4: PAD system configuration for RF preliminary test.

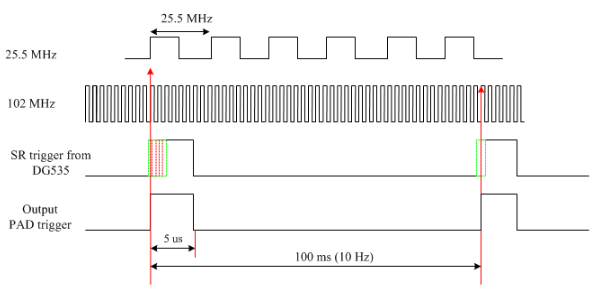

Figure 5: Timing system for PAD.

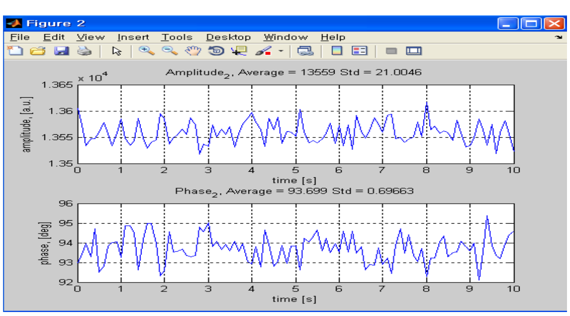

Figure 6: Pulse to pulse phase and amplitude variations during 1 minute at MK2 klystron output.

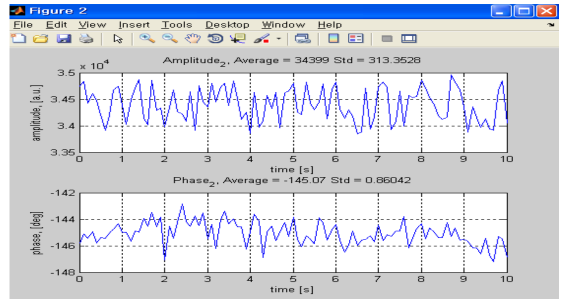

Figure 7: Pulse to pulse phase and amplitude variations during 1 minute at MK2 SLED output.

SUMMARY

A newly proposed 0.1 nm SASE FEL at the Pohang Accelerator Laboratory has been proposed. Among several possible options, we choose a layout which consists of a conventional normal conducting S-band rf linear accelerator. If a 60 MW klystron drives two accelerating sections, the S-band rf linac combined with the energy doubler can provide a maximum 27 MV/m accelerating gradient. As a result, the total length of the linac becomes approximately 550 m. There are two systems to obtain the beam stability. One is the phase feedback system for long-term stability. The other is the De-Q'ing system to keep modulator beam voltage stable less than 0.01 % rms for short-term stability. Development of PAD & PAC is undergoing. Preliminary, we developed the PAD and we measured the phase and amplitude variation from K2 klystron in the PAL linac. The phase and amplitude variation of 0.7° (rms) and 0.17% (rms) at klystron output is far larger than the design value of 0.1° (rms) and 0.1% (rms) for PAL_XFEL. However, the long-term phase variation can be controlled within 0.1° by the PAC. The short-term phase variation can be stabilized by improvement of the stability in the linac modulator systems.

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