PAL-XFEL LINAC RF SYSTEM

Heung-Soo Lee, Soung-Soo Park, Sang-Hee Kim, Young-Jung Park, Hoon Heo, Jinyul Heo, Kwang-Hoon Kim, Heung-Sik Kang, Kwang-Woo Kim, In-Soo Ko, Pohang, Korea
Hiroshi Matsumoto, KEK, Japan

Abstract

The PAL-XFEL hard X-ray linac has a 716 m long gallery and tunnel for 10 GeV. Forty nine modulators are necessary in the hard X-ray gallery for an X-band linearizer, an S-band RF gun, two S-band deflectors and 45 S-band klystrons for accelerating structures. They have been installed completely from March 15, 2015 to December 30, 2015 after completing the building construction. There are 51 modulators, 178 accelerators structures, 42 SLEDs in the hard X-ray linac and the soft X-ray linac. The RF conditioning of the klystrons, SLEDs and accelerating structures were stated from November 24, 2015. We describe the PAL-XFEL system and the current status of the linac RF system.

INTRODUCTION

The Pohang Accelerator Laboratory X-ray Free-Electron Laser (PAL-XFEL) project was started in 2011 [1–3] for the generation of X-ray FEL radiation in a range of 0.1 to 10 nm for users. This machine consists of a 10 GeV electron linac, two undulator tunnels for hard X-ray and soft X-ray generation and two beamlines with three experimental stations. The building construction was started in October 8, 2012. We got a buildings using approval on February 17, 2015. The installation of major accelerator components was begun in March of 2015 after getting the buildings using approval. Before getting that approval, survey works were started in January of 2015 for marking the anchor positions of high power RF components in the linac tunnel to advance an installation beginning.

There are two separated spaces in the linac building of the PAL-XFEL, so called klystron galleries and tunnels for hard X-ray and soft X-ray generation. The hard X-ray (HX) tunnel is 716 m long and the soft X-ray (SX) tunnel is about 87 m long. There are 49 Modulators for forty six 80MW S-band klystrons, two 25MW S-band klystrons, and a 50 MW X-band klystron for a linearizer in the hard X-ray gallery. And there are two modulators for an accelerating module and a deflector in the soft X-ray gallery.

MODULATOR & KLYSTRON

The PAL-XFEL machine requires very stable modulators with the beam voltage stability of less than 50 ppm to get a 10 GeV electron beam with the energy spread of less than 5×10^{-4}. Therefore, we had to develop a new modulator system to reach this goal. So we did joint researches with two domestic companies for developing a precise capacitor charging power supply (CCPS) with the maximum output voltage of 50 kV. These joint reaches were very successful and two kinds of CCPS with the stability of about 10 ppm were made by two companies.

During the test of a CCPS type modulator, we found some distortions of the voltage and the current of the input AC line caused by the CCPS. These distortions were measured and analysed. The second and fourth harmonics were sprung up largely as shown in Fig. 1. For suppressing these harmonics, we added an inductor of 600 uH to every modulator and increased the capacitance of the DC link of the CCPS. As a result, these harmonics were reduced to less than 5%.

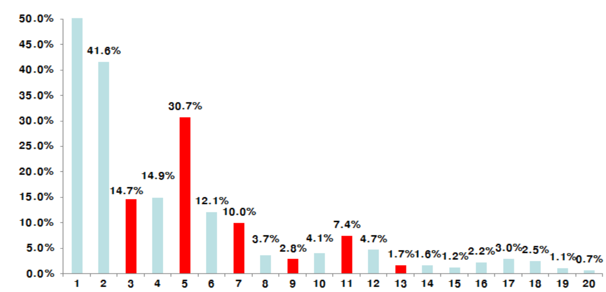

Figure 1: Current spectrum of the input electric power of the CCPS.

We began to place the modulators in the HX gallery on March 15, 2015 and completed on September 19, 2015. Six or seven modulators are delivered from two companies after factor acceptance tests (FAT) monthly. They did high power test again after the installations of them on site for site acceptance tests (SAT). And the major stabilities of the parameters of all modulators are measured and shown in Fig. 2.

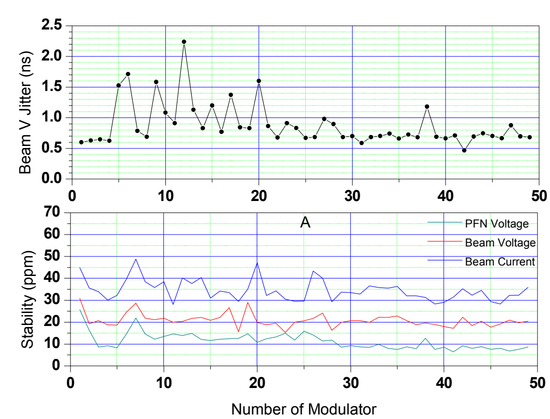

Figure 2: PFN voltage (green), measured stabilities of beam voltage (red) and beam current (blue), and timing jitter of beam voltage.

ISBN 978-3-95450-147-2

The average variation of the pulse forming network (PFN) voltage of every modulator is about 9.6 ppm. The average beam voltage and current changes were respectively 16 and 27.4 ppm. And the average timing jitter of the beam voltage was about 0.72 ns.

In addition, we considered the ways to minize the electrical noise and sound noise. We made the cabinet with a low resistance as much as possible to minimize the electrical noise by using the RF contacting materals in the door contacting area. We also made radiation shields made of steel plates of 2.5 mm thick and lead plates of 5 mm thick to reduce the radiation level from the klystron tube. Also, we attached eggs type soundproofing materals at inside walls of the radiation shield to decrease the sound noise level. We measured sound noises for several cases with a sound measuring instrument. The radiation shield without the soundproofing material can reduce a sound noise level of 6.8 dB at the distance of 2m from the klystron tank. And the sound level was decreased 2.3dB by attaching the soundproofing materials at the inside wall of the shield. Eventually, the PAL-XFEL gallery is more comfortable for working compare to the PLS linac.

We added a fire prevention system to the PAL-XFEL PFN cabinet due to our experiences of the fires caused by capacitors in the cabinet. This system can detect a fire through a heat detector and a smoke detector. When it detects a fire, the interlock system is turned on. And the modulator is shut down immediately.

WAVEGUIDE NETWORK AND ACCELERATING STRUCTURES

There are 41 S-band SLEDs and 172 S-band accelerating structures in the HX tunnel. To transmit the RF pulses from the klystron output to the accelerating structures, several waveguide components are necessary, such as a power combiner (PC), vacuum ports (VP), H-bends (HB), E-bends (EB), directional couplers (DC), 3dB power dividers (PD), straight waveguides (SW) and power loads (PL). More than 2300 components are necessary for the linac.

To complete the installation of these components by the end of 2015, we needed ways to minimize assembly work time. For this reason, we designed a PAL-XFEL type S-band waveguide flange at the beginning time of the project for the easy assembly of the components without vacuum leakage. There was no problem in assembling the components with assembly jiggers by the beginners. They could complete the assembly work without big vacuum problems.

We had to start mechanical works like anchoring in the HX tunnel as early as possible to meet our installation schedule. These works had been done from on January 13 to on February 6, 2015, even if building using approval was not issued. After that, all supporters for the RF components were installed from on February 12, to on April 23, 2015.

Partial assembly works of the waveguide components were started on February 7 and ended on July 20, 2015. Partially assembled components were moved on supporters side by side from on March 20 to on July 20. In addition to these works, connecting works of these partial assembled components were begun on May 12, 2015 and finished on November 23, 2015.

After completing the assembly works and connecting the cooling lines, RF phase tunings of waveguide networks were conducted during the period of installing waveguide components, SLEDs, and accelerating structures. These phase tuning results of the networks are displayed in Fig. 3. The maximum RF phase differences of the waveguide networks were measured like Fig. 3. The phase length is measured from the input port of the SLED to the output of the accelrarting structure in the condition of the vacuum level of about 10-6 torr and the cooling temperature of 30 ℃. The maximum phase error of each module was less than 0.5 degrees except two modules.

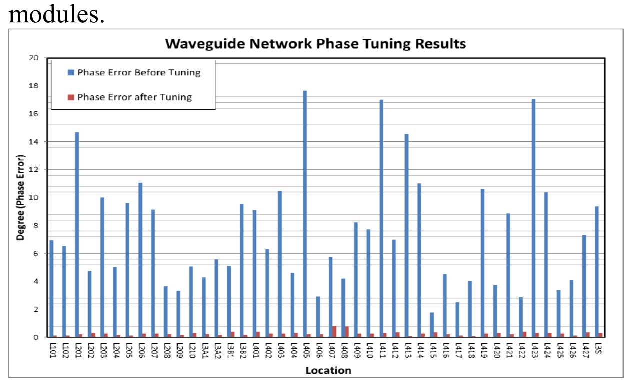

Figure 3: Tuning results of the waveguide networks (Blue bars are the phase error before tuning and red bar phase error after tuning).

During the waveguide phase tuning, we also checked and tuned the resonant frequency of the SLED cavities, even though we did the resonent frequency tunings of the SLED cavities in a vacuum before installation. The measured largest resonant frequency errors were about 70 kHz in the cavities, even though the resonant frequency tuning error was reduced less than 1 kHz in the tset laboratory.

The directional coupler among the waveguide components is a very important. Because the RF amplitude and phase of the input RF power of the structure is measured through this device. If we measured them accurately, we could do feedback correctly. The directivity of the DC is a critical parameter to decide the measurement accuracy. So we tried to manufacture DCs with high directivity. The average directivity of them is about 36.1 dB.

The conditioning of the waveguide components, SLED and accelerating structures was begun on November 24, 2015. At the same time, we did installation works, waveguide tuning and etc. in the day. The conditioning was done in the night. The average spent time for the conditioning is about 51 days to arrive the maximum operation condition of 80 MW with 4us pulse length. The PSK is turn on after 3us from the beginning of the 4us pulse. The conditioning results are shown in Fig. 4.

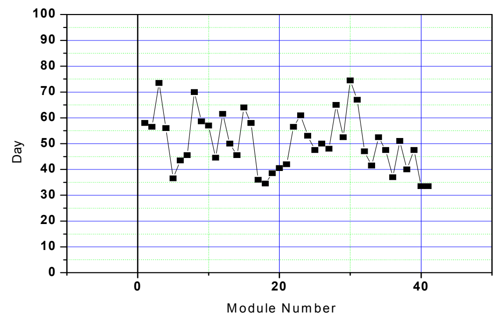

Figure 4: Spent time for conditioning the high power components.

LLRF AND SSA

The frequency, the phase and the amplitude of the RF are very important parameters in linac operation. The change of these gives influences on the electron beam energy and the energy spread. The long-term RF phase drift is largely related to cooling water temperature and air temperature. The long-term drift caused by temperature variations can be corrected by a RF phase feedback system. But pulse to pulse short-term variations cannot be corrected by the feedback system. A stable high voltage modulator can make the short-term variations minimize.

We need 50 S-band LLRFs and an X-band LLRF for supplying the drive power of the all klystrons. 50 SSAs were delivered and installed in the HX and SX galleries on August 13, 2015. A LLRF system consists of a phase and an amplitude detector (PAD), and the phase and the amplitude control (PAC). The function of PAC is to control the phase, amplitude and pulse length of the klystron drive power, and to reverse the RF phase in the middle of the 4us pulse through a PSK (180 degrees phase shifter).

We measured the variations of the amplitude and the phase with the RF signals from the DC located in front of input coupler of the accelerating structure. The maximum variation of every module is measured for the first time and displayed in Fig. 5.

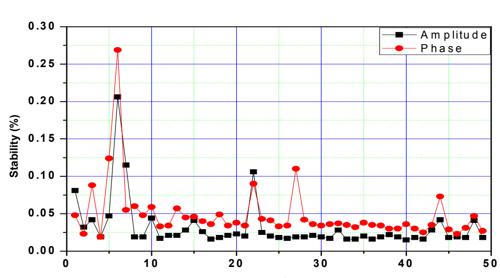

Figure 5: Maximum variations of the amplitudes and the phases of the all modules in the HX linac.

As previously mentioned, the PAL-XFEL machine is using an X-band system as a linearizer. However, only SLAC can supply the X-band system satisfying our requirements. Therefore, we ordered an X-band RF system except a modulator, a klystron tank and a klystron drive system. So, we tried to develop an X-band SSA as the drive source of the X-band klystron for a linearizer. But we don't have enough time to develop it. Therefore we prepared a 174X model TWTA made by Applied Systems Engineering, Inc. as a back-up drive source. We started the RF processing of the X-band system with this TWTA on February 22, 2016. Fortunately, a new X-band SSA was successfully developed prior to the beginning of the beam commissioning. So, we replaced the TWTA with the X-band SSA on April 8, 2016 and began the beam commissioning on April 15, 2016. And it has no problem in operation yet.

SUMMARY

We accomplished our goals of the installation of the RF components and devices, the phase tuning of the waveguide network and the RF conditioning of the high power components such as modulators, klystrons, waveguides, SLEDs, accelerating structures as scheduled. During this period, we have measured most parameters of them. And then, we operate the linac and confirm that the linac RF system is working well. However, we have to spend much time to optimize the operating parameters of them and to measure the beam performance of them in future.

REFERENCE

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