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PAL-XFEL LINAC RF SYSTEM STATUS*

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Abstract

The PAL-XFEL Linear Accelerator consists of forty-six modulators, Klystrons, LLRFs, SSAs and vacuum systems, respectively, and completed RF conditioning and beam commissioning for one year in 2016. When operating an HX linear accelerator with 6.838 GeV energy, the energy jitter was 0.013%. Beginning in March 2017, we began providing X-ray beams for our users. We have replaced four klystrons and ten thyratron switches by the end of 2017 since the accelerator was turned on. We also measured changes in RF component temperature and electron beam energy as the repetition rate of pulse operation changes. We will report this operational experience and measurement results.

INTRODUCTION

The Pohang 4th Generation FEL started construction (PAL-XFEL) in April 2011 and completed its construction in December 2015. This machine provides the user with a wavelength of 0.1 to 10 nm, consisting of an electron linear accelerator capable of achieving 10 GeV energy and two types of undulator. The HX linear accelerator with a length of 716 meters is equipped with two klystrons with up to 25MW output, one x-band klystron with up to 50MW output and 46 klystrons with up to 80MW output. They supply energy to one RF GUN, one X-band linearizer, two deflectors and 172 accelerating structures [1]. The total length of this accelerator is 1.1km and Fig. 1 shows the accelerator from the sky. The circular building on the right is the third generation synchrotron, and the fourth generation FEL accelerator is the long straight building on the left.

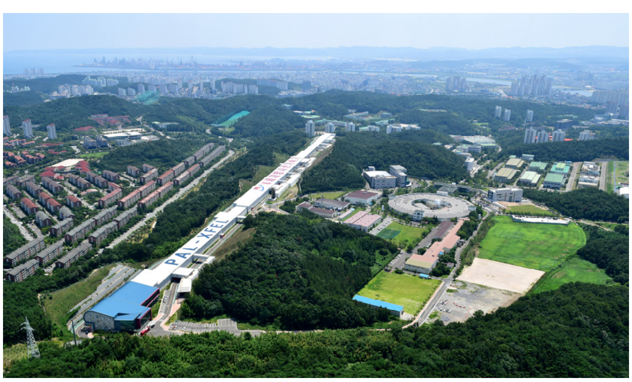

Figure 1: Arial view of PAL-XFEL.

After installing the linear accelerator device, we started RF conditioning on November 24, 2015 and finished RF conditioning on March 5, 2016. Since April 16, 2016, we started the linear accelerator beam commissioning and obtained an electron beam of 10 GeV energy at the end of the linear accelerator 10 days after commencing commissioning. On June 14 of the same year, we succeeded in X-ray FEL oscillation of 0.5nm wavelength [2], and the saturated X-ray raising of 0.1nm was successful on March 16, 2017 [3]. And official user beam time began on June 7of the same year. During user support, we had to keep the linac as stable as possible without problems. We observed problems occurring in each device during the operation of the linear accelerator. In addition, the temperature changes of the accelerating tube and the SLED and the change of the electron beam energy were measured according to the RF pulse repetition rates.

DEVICE OPERATION EXPERIENCE

The fourth generation linear accelerator has 51 total modulators and klystron in the hard x-ray section and the soft x-ray section. The X-ray beam officially provided to the beamline began on March 22, 2017. One shift is to provide X-ray beam to the beamline for five consecutive days. The operation schedule had a one-day break between shifts and a maintenance period for undulator realignment for one week in a month. From these operating schedules, we provided X-ray beams to the beamline for a total of 21 times until December 23, 2017. A total of 989 faults occurred during this period, 674 static faults and 362 dynamic faults. During this period, the average availability of the RF system was 99.4%. The operational statistics of the main devices are shown in Fig. 2.

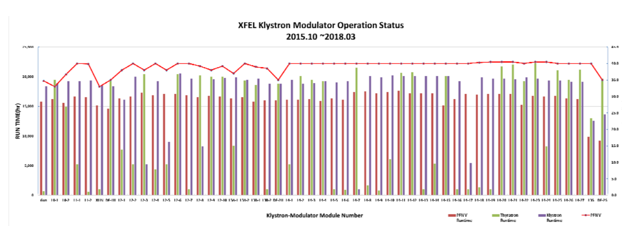

Figure 2: From October 2015 to March 2018, the operating times of modulators PFN, CYRATRON and KLYSTRON of each module and the current PFN operating voltages.

Each modulator Klystron system fault repairs can be largely divided into three parts, modulator, controller and klystron tank. The distribution of these faults is shown in the graph of Fig. 3. During the year 2017, the modular Klystron system had 278 repairs, of which the modulator section was 255, the klystron tank section was 7, and the

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controller section was 16 times. Most of the repairs of the modulator part was the part of the thyratron switch and the part of the CCPS high voltage cable.

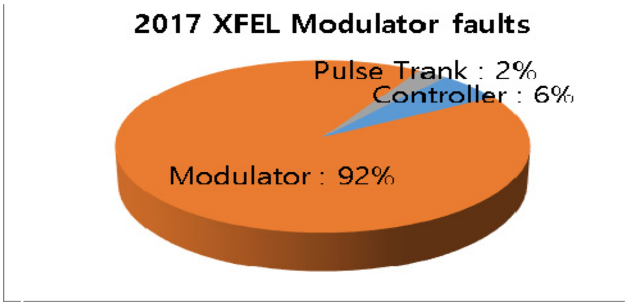

Figure 3: Distribution of repair statistics for 2017.

LLRF and SSA are devices that supply and control drive signals to the klystrons of the linear accelerator. The stability of these devices has a significant impact on the performance of linear accelerators. The total number of faults that these devices have made from January 2017 to January 2018 was 29. In the case of LLRF, as shown in Table 1, a total of 9 faults occurred, 6 of which were system suspension.

Table 1: Detailed LLRF Fault Distribution

Failure item	No. of events
System suspension	6
EPICS disconnection	2
RF module failure	1

For a semiconductor amplifier (SSA) system with a maximum output of 1 kW, a total of 20 faults occurred, 16 of which were caused by over-repetition interlocks. Details of these faults are shown in Table 2.

Table 2: Detailed SSA Fault Distribution

Failure item	No. of events
Over-repetition interlock	15
RS-232 freeze	2
Fan failure	1
Loose connection	1
Isolator failure	1

TEMPERATURE INFLUENCE TEST ACCORDING TO RF PULSE REPETITION RATE

The operation of the fourth generation linear accelerator affects the energy transfer to the electron beam by varying the amount of heat received by each RF component depending on RF repetition rate and the operation power. It is therefore important to analyse the effects of these components and to minimize the effects of these thermal changes. We investigate the effects of the most sensitive SLED systems on temperature changes in major RF components through experiments.

The PAL-XFEL linear accelerator is classified into devices that receive a first-controlled normal LCW (29.65 ± 0.1 °C) and devices that receive cooling water to maintain the temperature of the device at 30 °C. Normal LCW is supplied to Klystron tube and pulse tank, Klystron solenoid electromagnet, microwave window, LLRF rack, constant temperature duct, waveguide, SiC Load, electromagnet and collimator. Accelerators and SLEDs installed in linear accelerator tunnels use an electric heater as shown in Fig. 4 to maintain normal LCW at 30 °C for the devices. The acceleration tube and the SLED are designed to adjust the temperature of the device by controlling the heater power by measuring the temperature of the device because the heating value of the device varies according to the driving situation The cooling water in the inlet section L0 including the electron gun is controlled at 30 ± 0.02 °C and the L1 section, the L2 section, the X-band, and all the SLEDs are controlled at 30 ± 0.05 °C. The acceleration tube in L3 and L4 is controlled at 30 ± 0.1 °C.

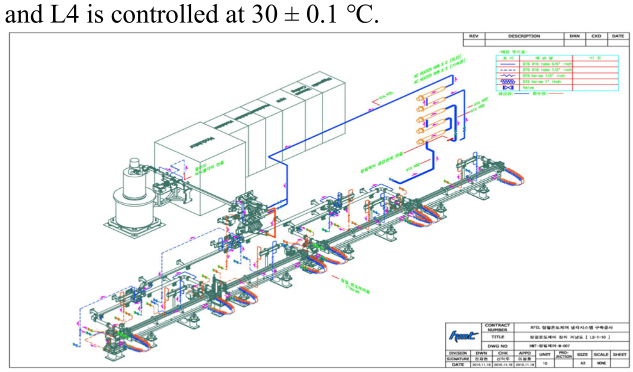

Figure 4: Acceleration tube and SLED cooling line connection drawing.

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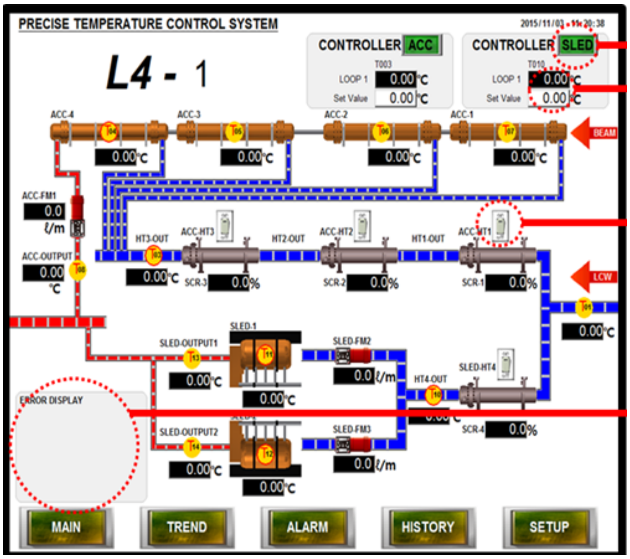

Figure 5: Acceleration tubes and SLED temperature control and monitoring screen.

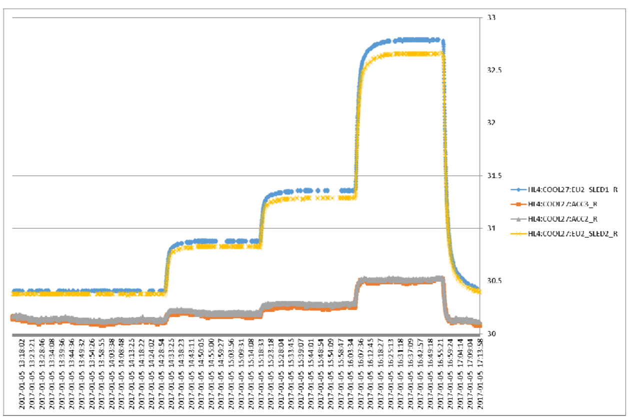

Figure 6: Surface temperature change of acceleration tube and SLED according to operating frequency.

Temperature control of these accelerators and SLEDs is possible on the control screen as shown in Fig. 5 and can be controlled remotely from the operating room.

PAL-XFEL Linear accelerator can afford 4 to 5 modules to wait during normal user support. Therefore, we can do various experiments using the standby module while supporting the user, so we carried out an experiment to observe the temperature change of the accelerating tube and the SLED according to the RF repetition rates using one module (L4-27) in standby mode at the end of the linear accelerator. At present, the cooling method of the accelerating tube and the SLED is designed to maintain the input temperature constant at 30 ℃. When operating at 10Hz, the surface temperature of the accelerating tube and the SLED were 30.12 ℃ and 30.41 ℃, respectively. However, when the pulse repetition rate is changed to 60Hz, each temperature rises to 30.51 ℃ and 32.79 ℃ as shown in Fig. 6. This data shows that the temperature change of the SLED is much larger than the acceleration tube. The temperature of both devices cannot be maintained at the same time due to the limitation of the heater capacity of the SLED and accelerating tube's precision temperature control system.

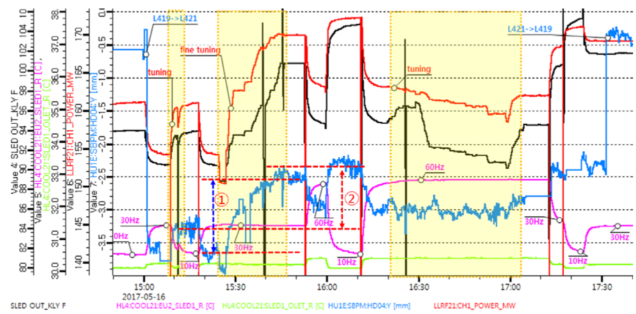

Figure 7: The black line is the RF phase, the pink is the SLED surface temperature, the green is the SLED output water temperature, the blue is the electron beam energy, and the red is the SLED RF output power.

We also conducted an experiment in L4-21 to see how this change in the pulse repetition rate affects electron beam energy. When changing the repetition rate of the RF pulse of this module, the RF output and RF phase change of the SLED output stage, the SLED surface temperature change and the SLED cooling output temperature change, and the electron beam energy change measured at the end of the linear accelerator were simultaneously observed. The results are shown in Fig. 7. As a result, it was found that the electron beam energy was reduced by about 4 to 5% only in this module at 60 Hz operation compared to at 10 Hz operation.

SUMMARY

We experienced a total of 989 static and dynamic interlocks during the user support period modulartor klystron system, and a total of 277 repairs were made during the year 2017. In the case of LLRF and SSA systems, there were 29 failures for one year.

In addition, temperature changes of the accelerating tube and SLED were observed according to the RF pulse repetition rate. It was confirmed that the temperature change of the SLED was about 6 times higher than the temperature change of the accelerating tube compared to the operation of 10Hz at 60Hz operation. It has been confirmed that the effect of the temperature change on the electron beam energy is about 4 to 5%. Therefore, we added a device that can remotely adjust the resonant frequency of the SLED.

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