TECHNICAL OVERVIEW OF THE PAL-XFEL LOW-CONDUCTIVITY WATER COOLING SYSTEM *

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Abstract

Pohang Accelerator Laboratory (PAL) started operation of an X-ray Free Electron Laser (XFEL) based on 10GeV linear accelerator in FY2015. For accurate temperature control of the various XFEL accelerator devices, a low-conductivity water (LCW) cooling system were installed. The LCW pump station generates LCW controlling the temperature variation within ±0.1℃. The LCW is supplied to klystrons including modulators and various control devices. On the other hand, the precision temperature controlled water to minimize temperature variation down to ±0.02℃. This water is supplied to accelerating columns, wave guide and SLED. Therefore, this paper shows the design, construction and operation of the LCW cooling system.

INTRODUCTION

The accelerating devices of PAL-XFEL require very precisely temperature-controlled cooling water. And, accelerator components made of copper are routinely cooled by deionized (DI) low-conductivity water (LCW) [1]. Temperature of cooling water is determined by the characteristics of accelerating devices. In particular, the performance of accelerating devices around injector are determined by the temperatures of cooling water, since the characteristics of those devices were designed to be optimally functional by the specific temperatures of cooling water. The LCW cooling system is divided into the 30ºC and 25ºC LCW. The 30ºC LCW system is adopted for accelerating columns and SLAC energy doublers (SLEDs). The 25ºC LCW system is adopted for the other devices. The normal cooling system makes the 25ºC and 28~29.7ºC LCW. The 28~29.7±0.1ºC LCW is heated to 30ºC through the precision temperature control system. The precision temperature control system can precisely control the temperature of LCW to ±0.02ºC.

NORMAL LCW COOLING SYSTEM

PAL-XFEL is composed of one main building including the accelerator and six auxiliary buildings including utility stations. The main building and auxiliary buildings are separated in order to prevent vibrations occurring in the auxiliary buildings. The auxiliary buildings are connected to main building by bridges for utility supply. Two normal LCW machine rooms belong to utility buildings. Because PAL-XFEL is a heavy building with length of 1,110m, the flow velocity has to be maintained below 1.5m/s (main pipes) and 3.0m/s (sub pipes) for available flow rate. Four 630usRT turbo refrigerators for cooling the LCW and six plate-type heat exchangers for controlling precise temperature were installed shown in Fig. 2. The normal LCW is zoned due to characters of acceleration devices as shown in Fig. 1.

Table 1: Criteria of PAL-XFEL Normal LCW

Zone	Temp. variation	Pressure	Flow velocity	Purity (DI)	Total flow rate
25ºC	25±0.1ºC	5 kg/cm²	<1.5m/s	>1MΩ·cm	325m³/h
28ºC	28~29.7±0.1ºC	5 kg/cm²	<1.5m/s	>1MΩ·cm	1,950m³/h
Total					2,275m³/h

For satisfying the criteria shown in Table 1 of temperature variation and flow velocity, the computational fluid dynamics simulation is conducted. The conditions for analysing the simulation are shown in Table 2. The simulation was the basis for confirming the diameter of pipes and capacity of cooling equipment. The simulation was based on the turbulence model (k-ε model) and design data of the normal LCW cooling system. The simulation shows that the normal LCW cooling system has stable flow velocity and temperature variation in total areas shown in Fig. 3. This means the design of piping and machine room is available.

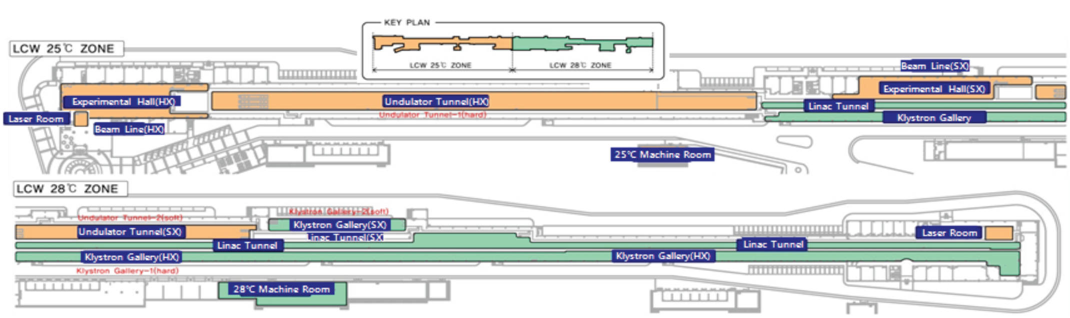

Figure 1: Zoning of 25ºC and 28ºC normal LCW.

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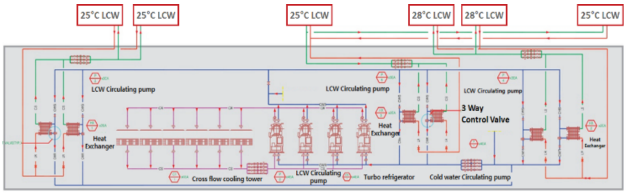

Figure 2: Block diagram of normal LCW machine room.

Table 2: Conditions for Variation Simulation of Normal LCW

Zone		Flow rate (kg/s)	Room Temp.(ºC)	U-Value (W/m²K)
25ºC	Main pipe	36.476	26ºC	0.8489
	Exp. hall	-21.242	26ºC	0.8489
	Undulator	-9.260	26ºC	26.8653
	MPS	-3.983	26ºC	26.8653
	Laser room	-1.991	26ºC	26.8653
28ºC	Main pipe	471.481	26ºC	0.8489
	Manifold 1	-431.453	26ºC	0.8489
	Manifold 2	-25.888	26ºC	0.8489

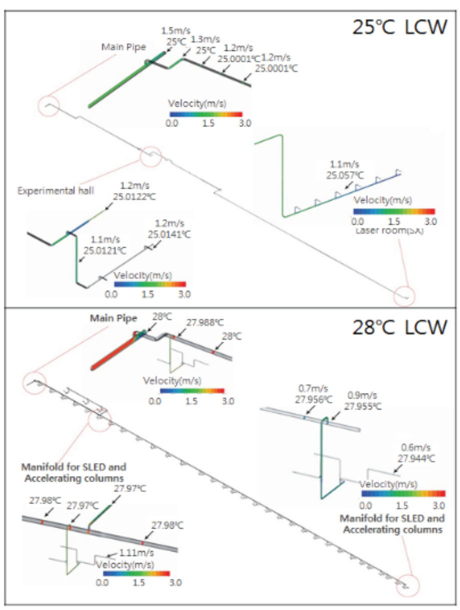

Figure 3: Results of normal LCW variation simulation.

The pipes of normal LCW have to be installed in a straight and with vibration proof pads shown as Fig. 5 because of maintaining the flow velocity and reducing vibration. The vibration was designed below 1.46Hz using the vibration simulation shown as Fig. 4. PAL used the building information modeling (BIM) for avoiding interference between the architectural building and facility like pipes and cables shown in Fig. 6.

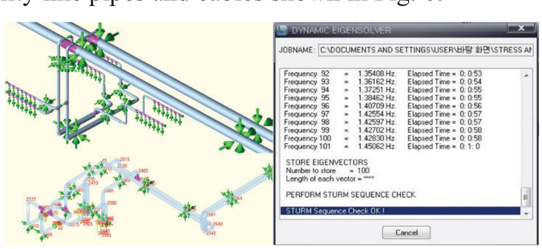

Figure 4: Results of LCW vibration simulation.

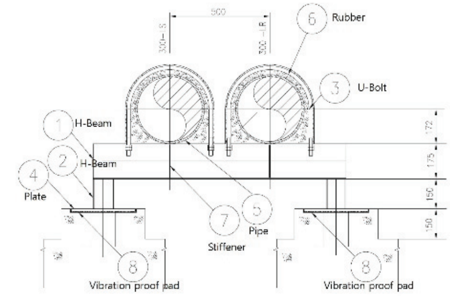

Figure 5: Cross section of normal LCW piping.

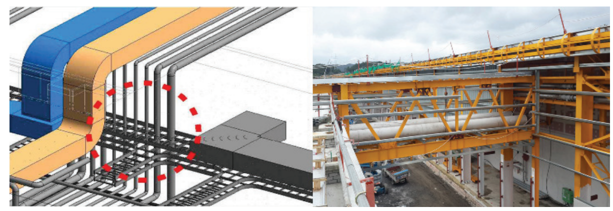

Figure 6: BIM and construction of PAL-XFEL facilities.

The deionized (DI) water system is divided into DI make-up system and DI polishing system. Mixed bed polisher (MBP) system was adopted as the DI make-up system. MBP system uses ion exchange resin for making DI water above 1MΩ·cm. MBP system has cheap construction cost and closed circuit system. Because of this closed circuit system, DI water could be reused. When reusing DI water, DI polishing system is operated with 3% bypass of total flow rate.

PRECISION TEMPERATURE CONTROL

Accelerating columns and SLEDs have to be operated in very stable temperature conditions. For maintaining precise temperature variation, 28~29.7±0.1ºC normal LCW is heated to proper temperature shown in Table 3 through the precision temperature control system. The zones of precision temperature control system are divided into 4 ranges such as 30~80±0.02ºC, 30±0.02ºC, 30±0.05ºC and 30±0.1ºC shown in Fig. 7.

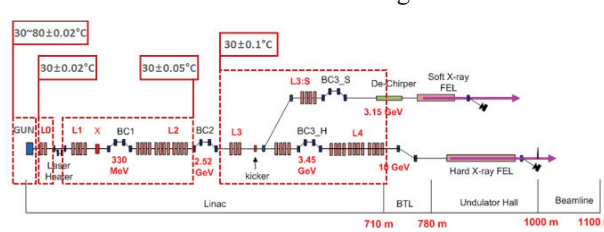

Figure 7: Zoning of precision temperature control system.

In the injector area of PAL-XFEL, wide range of temperature is required within 30~80ºC. However, the allowable temperature variation is quite small within ±0.02ºC. PAL tested the heater (XT550) of injector area in an injector test facility building and adopted to the main facility shown as Fig. 8. Because L0 zone also has to be controlled within ±0.02ºC, direct current (DC) heaters adopted. AC heaters adopted to the other zones except Gun and L0 zones shown in Fig. 9.

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Table 3: Criteria of the Precision Temperature Control

Zone	Temperature		Allowable Temp. variation	No. of Acc. column	Heater type
	Acc. column	SLED			
Gun	30~80ºC	-	±0.02ºC	1	XT550
L0	30ºC	-	±0.02ºC	1×2	DC
L1	30ºC	-	±0.05ºC	2×2	AC
X-band	30ºC	-	±0.05ºC	1	AC
Deflector(H1)	30ºC	-	±0.1ºC	1	AC
L2	30ºC	30.5ºC	±0.05ºC	4×10	AC
L3	30ºC	30.5ºC	±0.1ºC	4×4	AC
Deflector(H2)	30ºC	-	±0.1ºC	2	AC
L4	30ºC	30.5ºC	±0.1ºC	4×27	AC
L3S	30ºC	30.5ºC	±0.1ºC	4	AC
Deflector(S1)	30ºC	-	±0.1ºC	1	AC
Total				180	

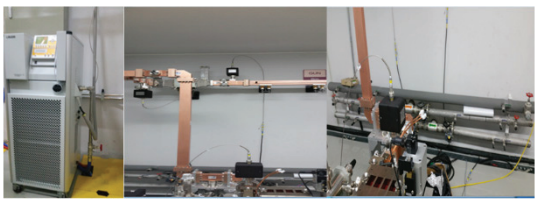

Figure 8: XT550 heater of the injector in PAL-XFEL.

For deciding the capacity of heaters, the wall loss, normal LCW flow rate and supply LCW temperature were used as variables shown as Fig. 10 and Table 4. The capacity applied to the design of system shown in Fig. 11.

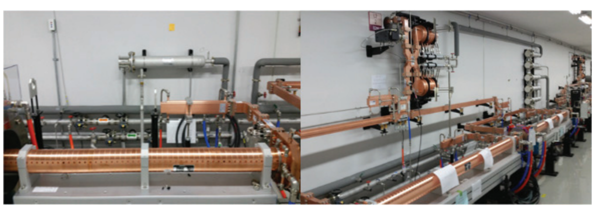

Figure 9: DC (left) and AC (right) LCW heater.

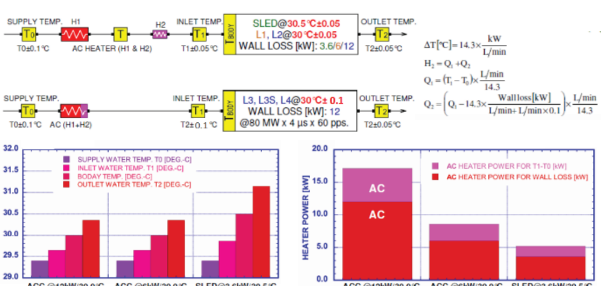

Figure 10: Calculation progress of LCW heater capacity.

Table 4: Calculation of LCW Heater Capacity

	SLED	L1 Acc.	L2,L3,L4 Acc.
Wall loss (kW)	3.60	6.00	12.00
Flow rate (ℓ/min)	40	120	240
Supply Temp. (T0)	29.40ºC	29.40ºC	29.40ºC
Inlet Temp. (T1)	29.857ºC	29.643ºC	29.643ºC
T1-T0	0.457ºC	0.243ºC	0.243ºC
Body Temp.	30.500ºC	30.000ºC	30.000ºC
Outlet Temp.	31.144ºC	30.358ºC	30.358ºC
H1 Heater Power (kW)	3.60	6.00	12.00
H2 Heater Power (kW)	1.60	2.58	5.16
H1+H2 Power (kW)	5.20	8.58	17.16

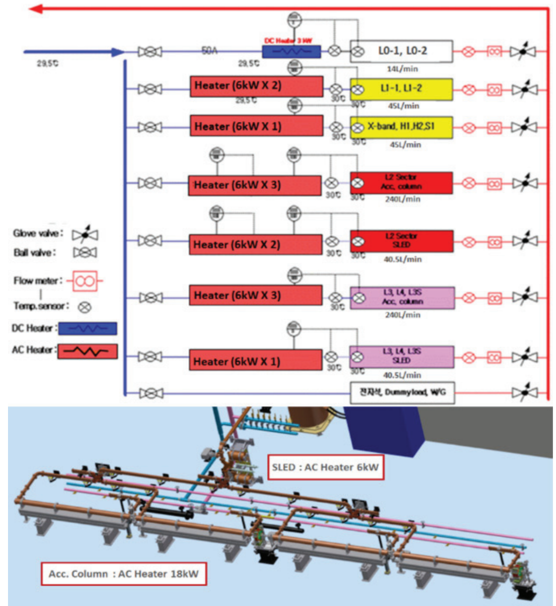

Figure 11: Block diagram of precision temperature control system.

OPERATION AND CONCLUSION

The normal LCW cooling system and precision temperature control system of PAL-XFEL are being maintained within the criteria shown in Fig. 12. And, the system is controlled automatically using high sensitive sensors and the auto controllers (Eurotherm 2704). Operators can monitor the system using Ethernet communication and PAL-XFEL local area network. When the accelerating devices are operated, the temperature of accelerating columns increases within 0.01~0.02ºC. This figure is supporting successful commissioning and operating of PAL-XFEL.

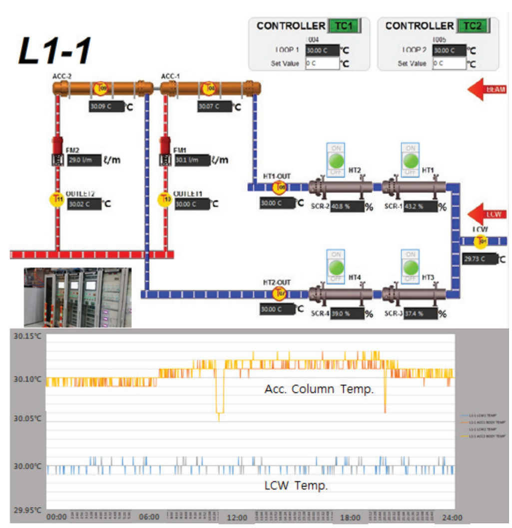

Figure 12: Display of LCW monitoring system.

REFERENCES

[1] R. Dortwegt, “Low-conductivity water systems for accelerators”, 2003, Proceedings of the 2003 Particle Accelerator Conference