Operation of PAL-XFEL LLRF

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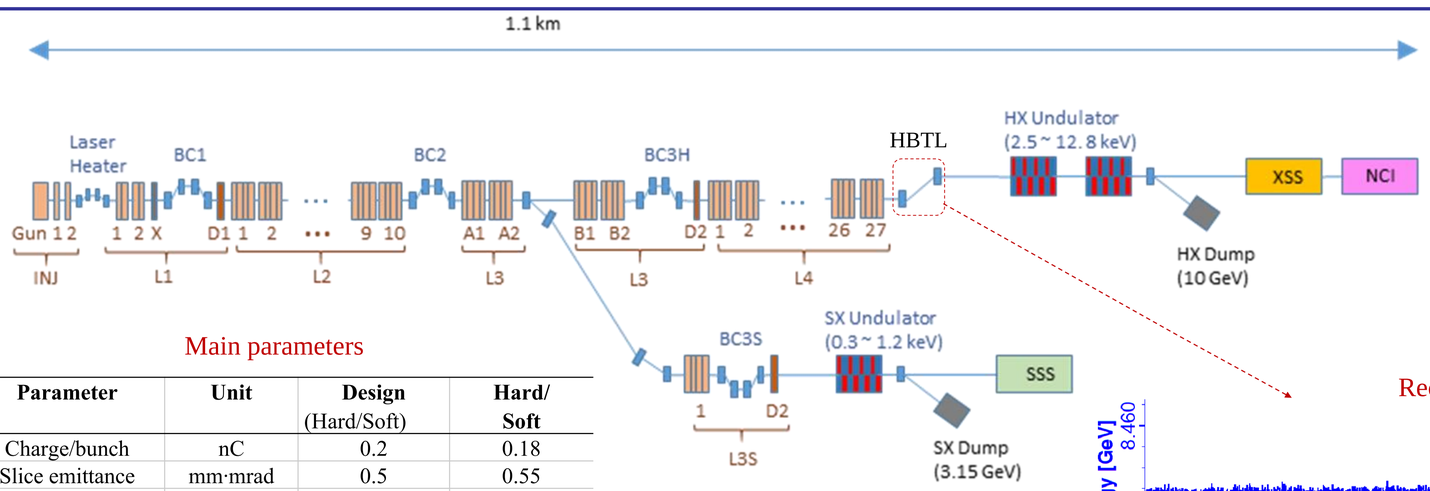
Abstract

PAL-XFEL(Pohang Accelerator Laboratory X-ray Free Electron Laser) started RF conditioning in October 2015 and has been operating reliably for ~ 4 years. The machine's LLRF and SSA systems contributed to the stable operation of PAL-XFEL with over 99% availability. The LLRF and SSA systems showed some problems in rare cases. The delay caused by the problem is very small, but PAL-XFEL can stop working. Some issues have been identified and resolved. We want to share the experience.

PAL-XFEL Overview

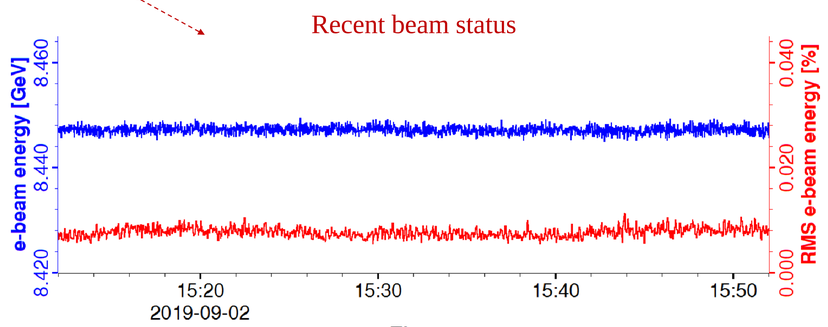
1



Main parameters

Parameter	Unit	Design (Hard/Soft)	Hard/ Soft
Charge/bunch	nC	0.2	0.18
Slice emittance	mm·mrad	0.5	0.55
e- energy	GeV	10/3.15	9.47/3.0
Pulse repetition	Hz	60	60
e- peak current	kA	3.0/2.5	2.5/2.2
FEL gain length	m	3.6/1.8	3.61/2.08
FEL λ	nm	0.1/1.0	0.104/1.52
Photons/pulse	1011	1.8	10.0

Recent beam status



Definition of Availability

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A "full system" is considered as single body consisted of 51 units corresponding to each RF station. So, A defect of a certain unit is counted as a defect of the full system

T_tot_plan ≡ the total time planned (Total period – Maintenance period)
T_tot_def_st ≡ the total delayed time due to defects of a specific unit.

$$\text{(Station) Availability(\%)} \equiv \left(1 - \frac{T\_tot\_def\_st}{T\_tot\_plan}\right) * 100(\%)$$

$$\text{(System) Availability(\%)} \equiv \left(1 - \frac{\sum_{st.=1}^{51}(T\_tot\_def\_st)}{T\_tot\_plan}\right) * 100(\%)$$

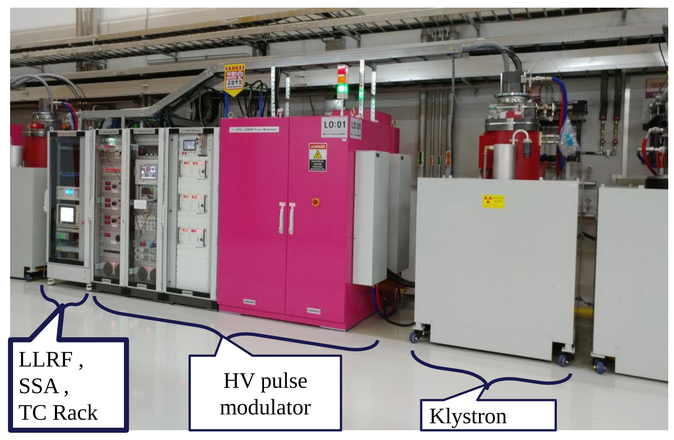
∴ (System) Availability ≤ (Station) Availability

System availability is not equal to beam availability because the PAL-XFEL beam can usually be supplied with normal stations when some stations are down(about 5~10 stations are spares).

Linac parameters

Parameter	Value
Linac type	Normal-conducting
Frequency	S-band (2.856 GHz; Gun, ACC, Deflector), X-band (11.424 GHz, linearizer)
Gun	S-band 1.6 cell photo-gun
Accelerating cavity	S-band 2/3 π mode
Total RF stations	51 (50 : S-band, 1 : X-band)
Cavities per klystron	1 ~ 4
Form of RF station	1 klystron(25 ~ 80 MW, ≤ 4 us, ≤ 60 Hz), 1 High-Voltage(HV) modulator, 1 SSA(pre-amplifier), 1 LLRF & 1 temperature-controlled rack (TC Rack)

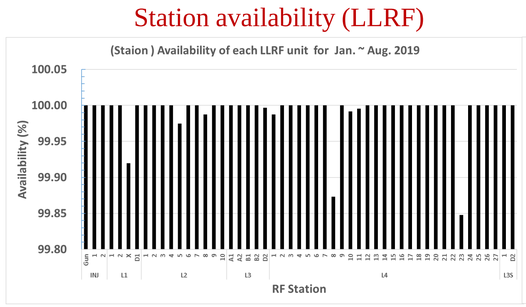
RF station



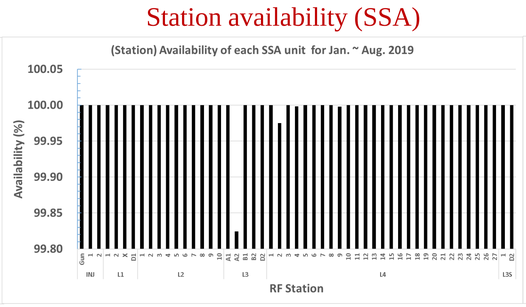
LLRF… system availability

System	(System) Availability for 2019		
LLRF	99.6 %	99.4 %	97.2 %
SSA	99.8%		
TC Rack	97.8 %		

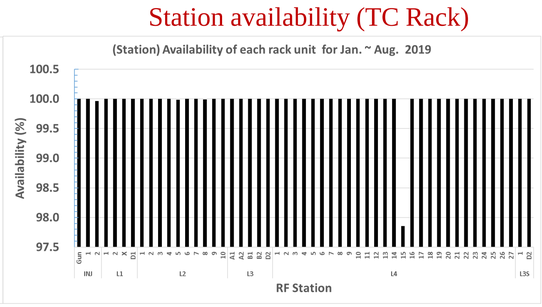
Station availability (LLRF)



Station availability (SSA)



Station availability (TC Rack)



Issue #1 (LLRF) : PPC Freezing

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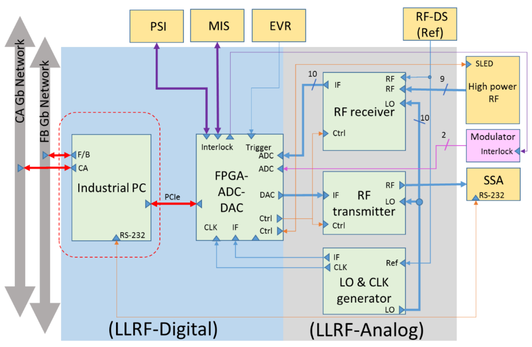
EVR : Event Receiver
RFDS : RF-reference-Distribution System
PSI : Personal-Safety Interlock system
MIS : Machine Interlock System
C/A : Ethernet for Channel Access
F/B : Ethernet focused on Feedback



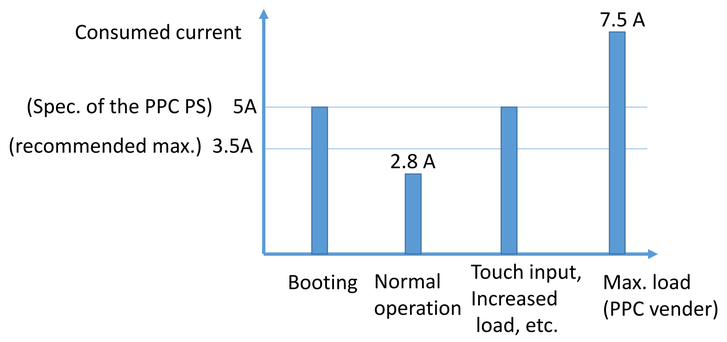
※PPC : Panel PC or Industrial PC

Symptom :
1) EPICS disconnection
2) PPC freezing
3) PPC shutdown
4) Occurred randomly and rarely
5) 1 occurrence/station for 9 LLRF units this year (most frequent problem of LLRF)

First aid :
1) Reboot of PPC
2) Irrecoverable cases by reboot
→ replacement of LLRF unit

※PS := Power Supply

- In non-recoverable cases, the cause was PS degradation
- From a simple current analysis, the cause was judged by the use of PS more than 70% of the indicated capacity.



Occurrence before/after PS replacement

- Based on the result, PS's were upgraded for all stations (5A → 8.3A, Feb. 2019)
- For the stations that caused the problem were resolved, but other stations showed new problems.
- We will be conducting further investigation

RF st.	Before	After
L1-1	Irrecoverable	
XLIN	1	1
L2-1	1	
L2-3	Several times	
L2-5		1
L2-8		1
L2-10	1	
L4-1		1
L4-10		1
L4-15	1	
L4-20	Irrecoverable	
L4-23	Irrecoverable	

Issue #2 (LLRF) : Incomplete Connection

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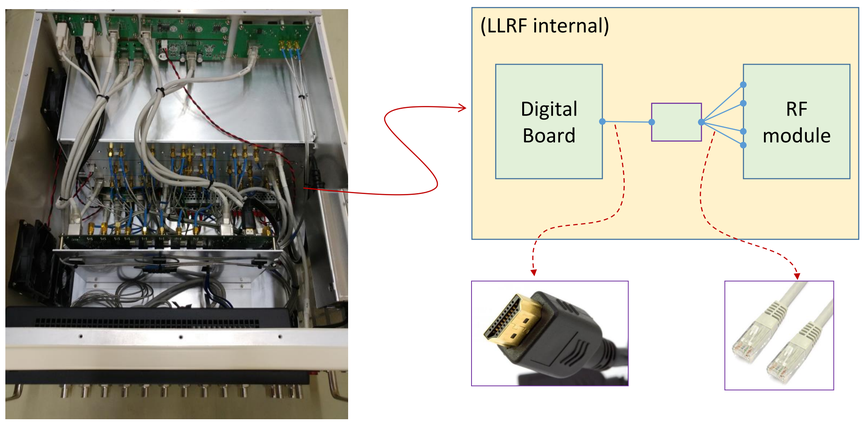
Symptom :
1) LLRF output failures(no output)
2) PSK switching failures
* PSK : Phase Shift Keying for SLED operation
3) Wrong temperature values

4) Common features :
* Normal operation until the moment of failure
* occurred randomly and suddenly
5) In total, less than 5 times for 4 years

First aid :
1) Replacement of the LLRF unit with a spare unit

Internal view of a LLRF



- Identified common cause : incomplete connection of connectors within LLRF case
- There are many RJ45 connectors and 2 HDMI connectors for compact cable connection and high-speed operation within PAL-XFEL LLRF box.
- The connectors prove very efficient and compact but not perfect.
- All problematic sets are recovered by reconnection of the connectors.
- We will search for better solution like better venders or new kinds of connectors.

Issue #3 (SSA) : Abnormal interlock

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There are many interlock items(10 items) in PAL-XFEL SSA.

Occasionally, some interlocks are occurred like "over repetition" or "over current"

Sometimes, RS-232 communications are lost between the LLRF and SSA pairs

Occurrence frequency : once/6~12 months

First aid :

Operator manually unlocks interlock and resumes beam operation in control room

Reboot of the SSA

At last, important hintswere found this year

Jan./2019
L3 – A2 SSA
Over Current interlock : several times
Replaced by a spare SSA

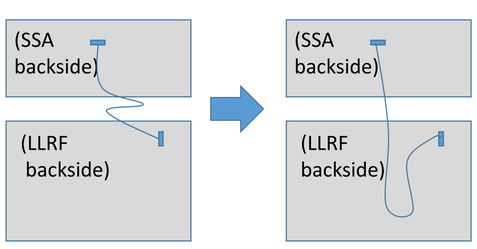
↳ Normal operation without the interlock in test room
→ Interlock at the klystron gallery is a fake interlock due to noise

Mar./2019
L4 – 2 SSA
Over Repetition interlock : several times
It suddenly appeared after the February maintenance period.

↳ Job in Feb. maintenance : Reinstallation of LLRF and reconnection of cables

Solved by rearrangement of the RS-232 cable path between the LLRF and the SSA, and no problems until now

- It is inferred from these hints that the strong noise from HV modulator affected RS-232 communication.
- For the L4-2 case, the abnormal interlock was disappeared as shown figure below, but some other cases, the reverse showed positive effects.
- As long-lasting solutions, noise countermeasures will be in place or more noise-resistant communications will be applied in the next version.



Issue #4 (TC Rack) : Water leakage

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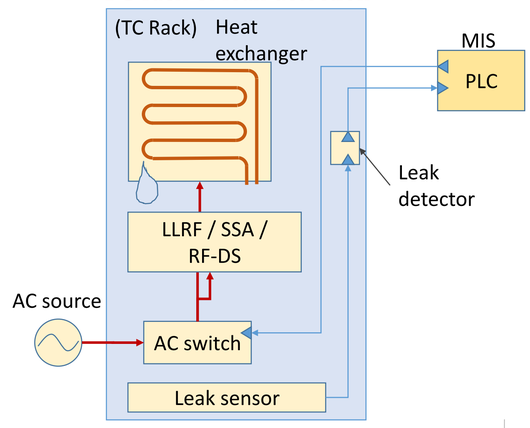
TC rack & leak detection



The occurrence frequency of water leakage is increasing this year → a serious problem

Treatment :
Replacing the leak exchanger to a spare (takes 1~2 hours/replace & only 2 spare parts available)

Occurrence of leak

Year	2018	2019
Station \ Month	1~12	1~8
L0-02		1
L2-02	1	
L2-04	1	
L2-05		1
L2-08		1
L4-15		2
Sum	2	5

For more reliable operation, the following works proceed :

1) Preparing more spare exchangers
2) Redesigning heat exchangers
3) Developing a rack easier to replace heat exchanger