29th Linear Accelerator Conference
LINAC2018

MEASUREMENT OF DIAGNOSTICS RESPONSE BY RF PARAMETERS FOR HARD X-RAY LINE IN PAL-XFEL*

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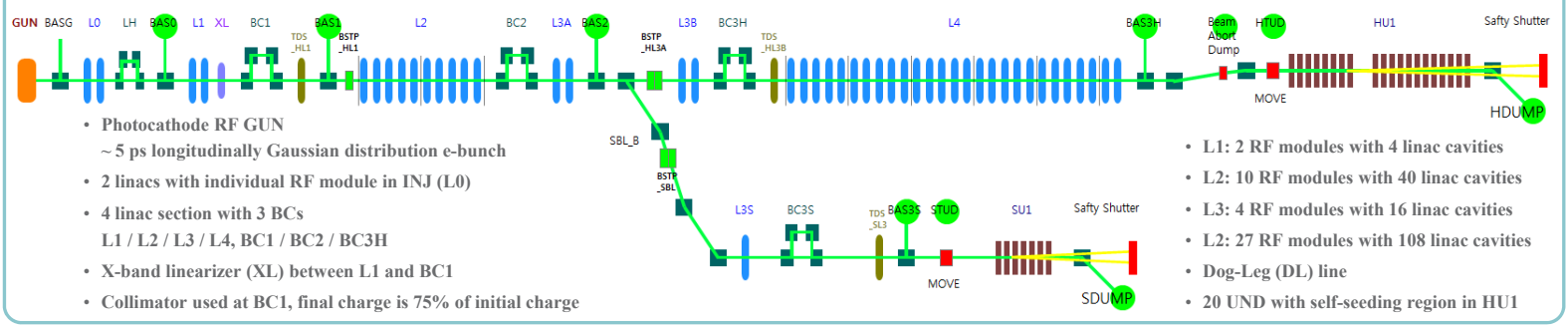
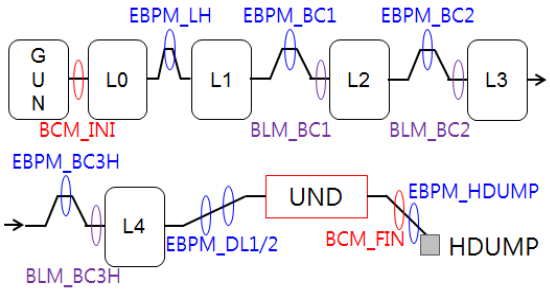
Layout of PAL-XFEL



- Photocathode RF GUN
  ~ 5 ps longitudinally Gaussian distribution e-bunch
- 2 linacs with individual RF module in INJ (L0)
- 4 linac section with 3 BCs
  L1 / L2 / L3 / L4, BC1 / BC2 / BC3H
- X-band linearizer (XL) between L1 and BC1
- Collimator used at BC1, final charge is 75% of initial charge

- L1: 2 RF modules with 4 linac cavities
- L2: 10 RF modules with 40 linac cavities
- L3: 4 RF modules with 16 linac cavities
- L2: 27 RF modules with 108 linac cavities
- Dog-Leg (DL) line
- 20 UND with self-seeding region in HU1

Diagnostics in HX



EBPM: Energy BPM
BCM: Bunch Charge Moni.
BLM: Bunch Length Moni.

Initial Setting

Parameters	Value
Initial charge	248 pC
Final charge	185 pC
Bunch energy at LH	0.14 GeV
Bunch energy at BC1	0.35 GeV
Bunch energy at BC2	2.50 GeV
Bunch energy at BC3H	3.50 GeV
Final bunch energy	8.70 GeV
Initial peak current	20 A
Peak current after BC1	87 A
Peak current after BC2	390 A
Peak current after BC3H	2000 A
FEL energy	9.7 keV
FEL Pulse Energy	1.0 mJ

Parameters	Value
Gun RF phase	33.7°
L0_01 RF phase	0.00°
L0_02 RF phase	-2.00°
L1 RF phase	-11.05°
L2 RF phase	-20.85°
L3 RF phase	-10.50°
L4 RF phase	-2.00°
BC1 bunching angle	4.97°
BC2 bunching angle	3.00°
BC3H bunching angle	1.60°

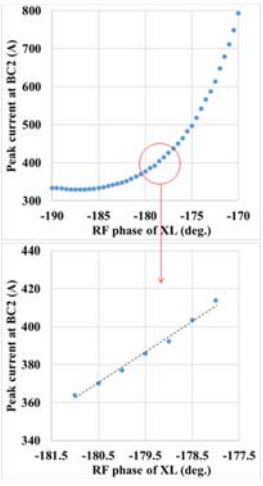
Resolution & Sensitivity

RF module	Sensitivity
GUN RF phase	0.020°
S-band linac RF phase (L0 – L4)	0.020°
X-band linearizer RF phase	0.065°
Gun RF amp.	0.02%
S-band linac RF amp. (L0 – L4)	0.02%
X-band linearizer RF amp.	0.12%

Diagnostics	Resolution
BCM_INI/FIN	0.1 pC
EBPM_LH	5.4 keV
EBPM_BC1	8.8 keV
EBPM_BC2	67.1 keV
EBPM_BC3H	168.8 keV
EBPM_HDUMP	85.5 keV
BLM_BC1	0.075 A
BLM_BC2	0.4 A
BLM_BC3H	5.0 A
QBPM (FEL pulse energy)	10 uJ

Diagnostics Response

Measurement



- Vary the RF variables
  - all RF amp. and phase of GUN, S-band linacs, and X-band linearizer
  - one by one
  - range: around initial setting, over 20 points
- All diagnostics and RF variables read out bunch synchronously for each step.
- Select linear variation region around initial setting, obtain the elements for response matrix by linear fitting.
- Diagnostics responses divided by their resolutions, RF variations divided by their sensitivities
- Diagnostics responses by the same kind of RF modules in linac sections are similar.
  → *R* classified by the sections for L1 – L4

Response Matrix (*R*)

R	Φ_{GUN}	Φ_{L0_01}	Φ_{L0_02}	Φ_{L1}	Φ_{XL}	Φ_{L2}	Φ_{L3}	Φ_{L4}
C_INI	**1.348**	0.328	0.031	-0.232	0.368	-0.079	-0.034	-0.003
C_FIN	-1.053	0.606	0.918	**3.515**	**-2.172**	-0.143	-0.078	-0.009
EBPM_LH	**0.662**	**-0.632**	-0.116	-0.038	-0.014	0.006	-0.003	0.008
EBPM_BC1	**0.780**	-0.055	-0.105	**-0.955**	-0.082	0.015	0.002	0.003
EBPM_BC2	-0.057	0.132	0.292	**1.961**	0.264	-0.517	-0.005	0.020
EBPM_BC3H	0.007	0.068	0.131	**0.868**	0.111	-0.187	-0.102	0.006
I_BC1	-0.354	-0.300	-0.216	**0.822**	**1.563**	-0.031	-0.040	0.006
I_BC2	0.237	-0.514	-0.308	0.973	**2.964**	-0.477	-0.003	0.025
I_BC3H	0.442	-0.170	0.664	**2.951**	**2.976**	-1.204	-0.027	0.060
EBPM_HDUMP	-0.618	-0.188	-1.018	**-6.576**	**-2.860**	**2.133**	0.393	-0.171
FEL_PWR	**-0.974**	0.332	0.212	**1.119**	**-2.291**	-0.201	-0.011	-0.010

R	A_{GUN}	A_{L0_01}	A_{L0_02}	A_{L1}	A_{XL}	A_{L2}	A_{L3}	A_{L4}
C_INI	-0.063	0.062	-0.032	0.005	-0.621	0.011	0.034	0.020
C_FIN	-0.176	0.482	0.410	0.858	-1.019	-0.012	0.015	0.012
EBPM_LH	0.132	-0.316	-0.245	0.007	-0.048	-0.002	0.000	-0.002
EBPM_BC1	0.118	-0.152	-0.163	-0.288	0.326	0.000	-0.003	-0.002
EBPM_BC2	0.057	0.386	0.318	**0.701**	**-0.844**	-0.087	-0.008	0.003
EBPM_BC3H	0.025	0.170	0.141	**0.310**	**-0.355**	-0.030	-0.039	0.001
I_BC1	-0.073	0.206	0.186	0.430	-0.523	-0.003	0.017	0.007
I_BC2	0.058	0.361	0.328	0.652	-0.830	-0.016	-0.003	0.003
I_BC3H	0.090	0.950	0.871	1.653	**-6.419**	-0.047	-0.043	0.000
EBPM_HDUMP	-0.300	-1.659	-1.466	**-3.062**	**4.125**	0.084	0.130	0.073
FEL_PWR	0.376	0.100	0.164	0.295	**0.752**	0.001	0.007	0.004

SVD Analysis

S

	1	2	3	4	5	6	7	8
1	**12.84**	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2	0.00	**5.80**	0.00	0.00	0.00	0.00	0.00	0.00
3	0.00	0.00	**2.99**	0.00	0.00	0.00	0.00	0.00
4	0.00	0.00	0.00	**1.84**	0.00	0.00	0.00	0.00
5	0.00	0.00	0.00	0.00	**0.86**	0.00	0.00	0.00
6	0.00	0.00	0.00	0.00	0.00	**0.77**	0.00	0.00
7	0.00	0.00	0.00	0.00	0.00	0.00	0.25	0.00
8	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.18

$$R = U \cdot S \cdot V^T$$

U

	1	2	3	4	5	6
C_INI	-0.03	-0.15	-0.14	**-0.63**	-0.31	0.24
C_FIN	-0.19	**0.67**	-0.19	0.12	-0.03	**0.57**
EBPM_LH	0.01	-0.06	-0.01	-0.28	**0.91**	0.24
EBPM_BC1	0.07	-0.11	-0.06	-0.38	0.08	-0.14
EBPM_BC2	-0.17	0.15	0.10	-0.05	0.02	0.05
EBPM_BC3H	-0.08	0.06	0.05	-0.04	0.00	0.06
I_BC1	-0.12	-0.13	**0.26**	0.39	0.06	0.26
I_BC2	-0.19	-0.33	**0.47**	0.23	0.08	0.07
I_BC3H	**-0.59**	-0.32	**-0.68**	0.22	0.09	-0.12
EBPM_HD	**0.72**	-0.16	**-0.42**	0.33	0.06	0.18
FEL_EN	0.03	**0.49**	-0.03	0.07	0.21	**-0.64**

V

	1	2	3	4	5	6
Φ_{GUN}	-0.04	-0.27	-0.01	**-0.93**	0.07	0.20
Φ_{L0_01}	0.00	0.15	-0.09	-0.14	**-0.83**	-0.06
Φ_{L0_02}	-0.10	0.15	-0.13	-0.10	-0.16	0.08
Φ_{L1}	**-0.61**	**0.53**	**0.34**	-0.04	0.14	**0.34**
Φ_{XL}	**-0.33**	**-0.73**	**0.48**	0.21	-0.17	0.10
Φ_{L2}	0.19	-0.01	-0.11	0.19	-0.04	**0.62**
Φ_{L3}	0.03	-0.02	-0.05	0.07	0.03	0.01
Φ_{L4}	-0.01	0.00	0.02	-0.02	0.00	-0.04
A_{GUN}	-0.02	0.01	0.03	-0.07	0.26	**-0.54**
A_{L0_01}	-0.16	0.05	0.07	-0.01	-0.33	-0.17
A_{L0_02}	-0.14	0.05	0.06	0.03	-0.20	-0.24
A_{L1}	**-0.29**	0.10	0.16	-0.08	0.08	-0.25
A_{XL}	**0.58**	0.23	**0.76**	-0.11	-0.06	0.00
A_{L2}	0.01	0.00	-0.01	0.01	-0.01	0.01
A_{L3}	0.01	0.00	-0.01	0.01	-0.01	0.06
A_{L4}	0.00	0.00	-0.01	0.01	0.00	0.03

- Singular values under the 6th mode are small.
  → their modes are ignored.
- U and V matrices are present here with 6 columns.

- MODE #1
  - final energy and peak current
  - Φ_{L1}, Φ_{XL}, A_{L1}, A_{XL}
  - RF variation before BC1
    → trajectory changed into BC1
    → phase offset of RF modules after BC1
    → large response of final e-beam energy and current
- MODE #2
  - final charge and FEL intensity
  - Φ_{L1}, Φ_{XL}
  - It seems to acting on linearization and slice energy chirp of e-bunch
- MODE #3
  - final energy and peak currents at BCs
  - Φ_{L1}, Φ_{XL}, A_{XL}
  - Due to phase offset from traj. change into BC1 by RF variation before BC1
- MODE #4 – initial charge
- MODE #5 – e-beam energy at LH
- MODE #6
  - final charge and FEL intensity like #2
  - Φ_{L1}, Φ_{L2}, A_{GUN}
  - It seams to acting on slice energy chirp of e-bunch adjusted by combination of Φ_{L1}, Φ_{L2}.

Conclusion

- Diagnostics response by RF variable was measured
- Response matrix obtained. Main RF variables are investigated roughly.
- SVD analysis applied
- Main variables for final energy and FEL power - Φ_{L1} and Φ_{XL}
- Effects for slice energy spread are classified with this analysis - Φ_{XL}
  - combination of Φ_{L1} and Φ_{L2}