

Vector Sum accelerating field parameters regulation of single EX-FEL module working in CW mode in high QI (6e7) conditions

<u>Wojciech Cichalewski</u> (LUT-DMCS), Andrzej Napieralski (LUT-DMCS), Jacek Sekutowicz (DESY/ SLAC/NCBJ), Julien Branlard (DESY), Radoslaw Rybaniec (DESY), Valeri Ayvazyan (DESY), Holger Schlarb (DESY)

Second Topical Workshop on Cryomodule Microphonics and Resonance Contro

Hosted by Brookhaven National Laboratory and Jefferson Lab October 25-26, 2018 Vector Sum accelerating field parameters regulation of single EX-FEL module working in CW mode in high QI (6e7) conditions Wojtek Cichalewski et. al, wcichal@dmcs.pl



Agenda

- 1. Introduction,
- 2. Motivation,
- 3. Challenges in this solution
- 4. Control mechanisms used
- 5. Performance results
- 6. Summary.

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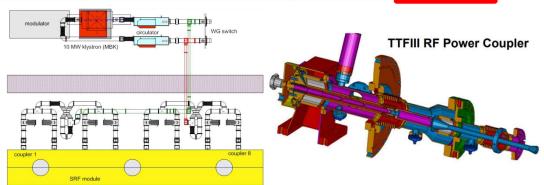


Motivation

- High gradient operation of superconducting resonators in CW,
- Evaluation of cryomodule setup (CMTB env.) feasibility for CW/LPO, VS and single cav. operation
- Different mechanical and RF effects determination (effects not visible in the short pulse work regime)
 - Various operation conditions scenarios evaluation.

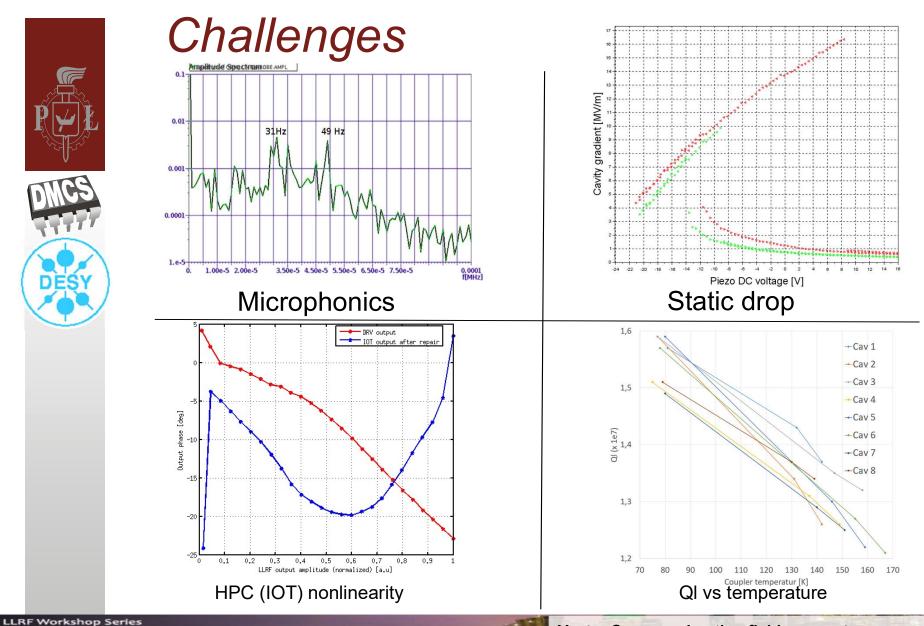
	FLASH	XFEL	CW I	CW II	CW III
<u>Ql value</u>	3,00E+06	4,60E+06	2,00E+07	4,00E+07	6,00E+07
Half BW [Hz]	216,67	141,30	32,50	16,25	10,83
Input Power [W] @ 16 MV/m	2,08E+04	1,36E+04	3,13E+03	1,56E+03	1,04E+03
Input Power [W] @ 25 MV/m	5,09E+04	3,32E+04	7,63E+03	3,81E+03	2,54E+03





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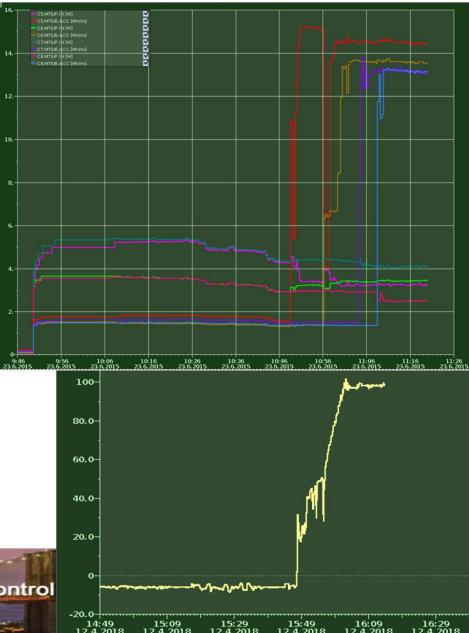


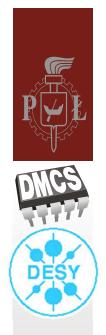
Some other system limitations

- Coupling between cavities -> full reflection from one structure changes conditions for neighboring resonators,
- Limited cryo system capacity -> heat load up to 120 W,
- Couplers overheating -> temperature have been kept below 160 K limit,
- Vacuum pumps oscillations.

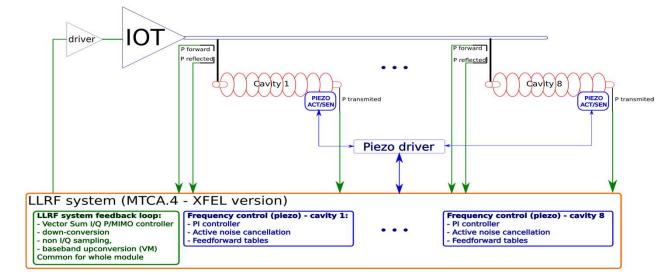
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CW - LLRF system setup



- RF field regulation loop:
 - P and MIMO controller,
 - similar to short pulse with 4,5MHz feedback sampling,
- Cavity frequency regulation:
 - DC voltage offset,
 - PI controller (mainly I component used) for low freq (<10Hz) regulation,
 - ANC based solution for persistent microphonics effects reduction

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Pyr Pyr

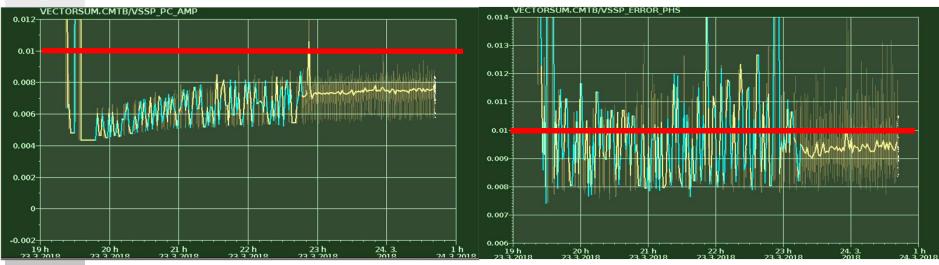


CW test	SИ	/ith	Q	L ~	-4e	7 (@~	-15-	16 MV/m
	C1	C2	C3	C4	C5	C6	C7	C8	Regulation
FOR power [kW]	1.582	1.784	1.735	1.804	1.622	1.716	1.969	1.736	- dA/A (%)
Gradient [MV/m]	15.98	16.63	16.46	17.02	16.67	15.20	14.56	13.14	- 0.006
Expected Eacc [MV/m]	16.48	17.68	17.20	17.83	16.98	17.18	15.31	13.77	- 0.000
QI	41.96M	42.84M	41.68M	43.04M	43.43M	41.01M	29.11M	26.71M	dP [deg]
FPC temp (70K)	90.37	94.27	93.78	90.67	99.99	97.36	98.20	91.99	0.009

RF feedback loop and piezo PI loop + ANC filters (30 or 50 Hz) used.

Amplitude regulation (red line – XFEL spec.)

Phase regulation



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CW tests with QI ~6e7 @~17,5 MV/m

C4

1.579

19.28

20.12

C5

1.402

19.02

19.18

C6

1.502

17.85

19.91

C7

1.704

13.78

14.55

C8

1.419

12.63

13.05

C3

1.551

19.06

19.80

Cl

1.361

18.62

18.08

FOR power [kW] Gradient [MV/m]

Expected Eacc [MV/m]

CZ

1.527

19.34

19.41



V	QI	58.72M	60.28M	61.74M	62.67M	64.12M	64.5M	30.37M	29.31M		
DMCS	FPC temp (7	70K) 90.60	95.89	95.69	90.91	99.76	95.81	98.32	92.22		
					0.012-	VECTORSUM.C	MTB/VSSP_PC	AMP			
7777											
RFGate ON FF enable ON Amplitude SP 00 Amplitude SP 00 Amplitu	VQ V2UQ Porverd AP VSSPAP ming (model) Reflected	Status (DCI C1 ON 5-87 0 ENABLED \$2 C2 ON 5-87 0 ENABLED \$3 C3 ON 5-87 0 ENABLED \$3 C4 ON 5-87 0 ENABLED \$3 C4 ON 5-87 0 ENABLED \$3 C5 ON 5-87 0 ENABLED \$3 C6 ON 5-87 0 ENABLED \$3 C7 ON 5-87 0 ENABLED \$3	ezo Control sias) [V] FF Ta . 30 0 OFF . 30 0 OF	Find \$0000 Find \$0000	l ≚	14.4 ECTORSUM.CM	Hist:TTF.RF/L	LRF.DIAGNOSTICS/VEC	. 6-h 3 14.4.201 ТОЛЯЗИИ.СМТВ/УЗБР_ЕАКОД Р		12 h 14.4.201
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CW study with QI~6e7 @ 20 MV/m

	Cl	C2	C3	C4	C5	C6	C7	CS	
FOR power [kW]	1.61	1.851	1.826	1.894	1.665	1.76	2.126	1.9	
Gradient [MV/m]	20.00	20.52	20.28	20.60	20.12	18.99	0.10	0.08	
Expected Eacc [MV/m]	20.14	21.69	21.71	21.69	20.38	21.19	15.63	14.30	
QI	61.55M	62.1M	63.09M	60.7M	60.94M	62.37M	28.1M	26.29M	
FPC temp (70K)	1.03E2	1.13E2	1.11E2	1.07E2	1.16E2	1.11E2	99.52	93.78	



VS composed from 6 cavities (last two detuned) Achieved performance $dA/A \sim 0.007\%$, $dP \sim 0.01 deg$



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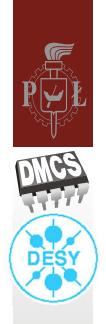


Summary

- VS operation of the X-FEL cryomodule in CW mode that can satisfy performance criteria have been achieved,
- Narrow bandwidth cavity operated in high gradient may require more tuning range from fast tuners (piezos),
- VS focused RF loop and cavity oriented frequency tuning loop not always play together – amplitude control decoupling from phase control have to be used,
- There is still a place for improvement (higher gradients, improvement in phase regulation, QI vs. temp. compensation),
- LPO challenges to be investigated......

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