Exploring the continuous wave mode performance of the spare Eu-XFEL third harmonic cryomodule

Karol Kasprzak on behalf of SRF team

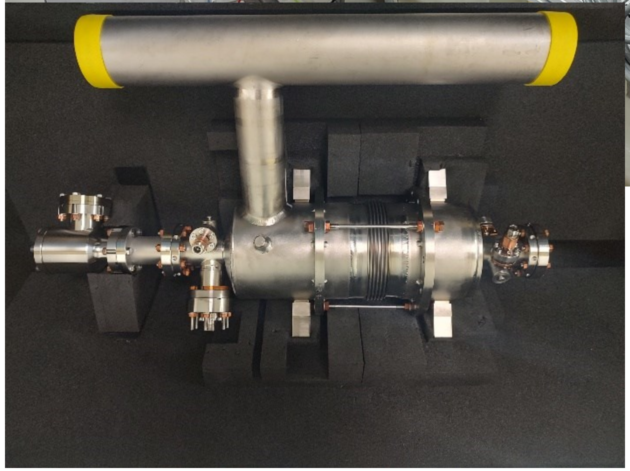
TTC Meeting, 6.12.2023

What’s on the menu?

- 3.9 GHz (spare) cryomodule for the Eu-XFEL
- 3.9 GHz cavities/cryomodules test
  - SINGLE CAVITY measurements in vertical cryostat (LASA)
  - MODULE PULSE MODE (2018)
  - MODULE PULSE MODE (2023)
  - MODULE CONTINUOUS WAVE MODE (2023)
- Challenges
  - Maximum gradients (Pulse/CW)
  - CW
    - HOM Coupler Temperature
    - Tuner Backlash
    - Microphonics

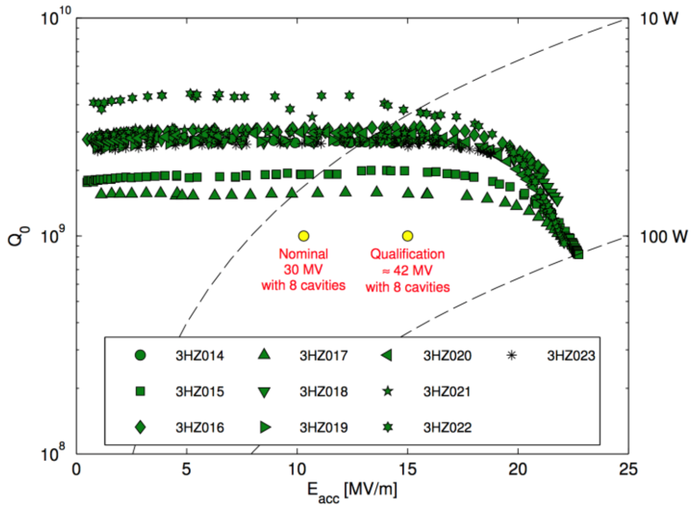
Third harmonic (spare) Eu-XFEL cryomodule

SELECTED PARAMETERS OF 3.9 GHz CAVITIES AND CRYOMODULES	
Operating frequency	3900 MHz
Numer of cavities per cryomodule	8
Number of cells per cavity	9
Active Length of a cavity	0.346 m
R/Q	750 Ohm
G	280 Ohm
Gradient at maximum gain (40 MV)	≈15 MV/m
Ep/Eacc	2.3
Bp/Eacc	4.9 mT/(MV/m)
Design Q_0	> $1x10^9$
Cold Tuning Range	≈750 kHz
Tuner Mechanism	Blade Tuner



Results (vertical / pulse mode)

SINGLE CAVITY (2016-17,LASA)
PULSE/CW



Courtesy:P.Pierini

MODULE
PULSE MODE (**2018**/DESY)
750+**300µs**/0..3dB (FT)
Rep.rate:**5Hz** (open loop)

CAVITY	LIMIT [MV/m]	REASON
1	24.6	POWER
2	20.7	BD
3	22.5	BD
4	27.0	BD
5	21.7	BD
6	23.2	BD
7	23.0	BD
8	25.7	BD

MODULE
PULSE MODE (**2023**/DESY)
750+**650µs**/0..3dB (FT)
Rep.rate:**10Hz** (open loop)

CAVITY	LIMIT [MV/m]	REASON
1	23.5	POWER
2	21.0	BD
3	22.2	BD
4	24.5	BD
5	21.2	BD
6	21.7	BD
7	21.1	BD
8	22.7	BD

In the pulse mode, the results are consistent and above the specification.
A difference in results is a consequence of the longer flat-top time and higher repetition rate during the test in 2023.

Comparison (pulse / CW)

MODULE
PULSE MODE (2023)
750+650µs/0..3dB (FT)
Rep.rate:10Hz (open loop)

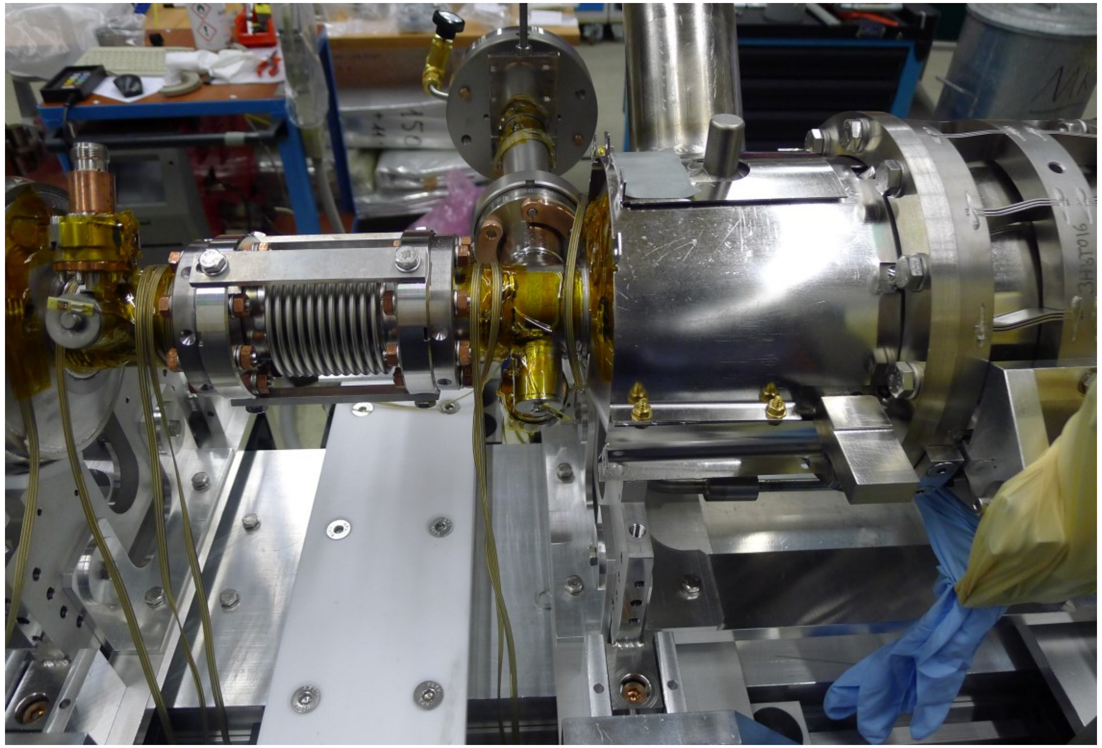
CAVITY	LIMIT [MV/m]	REASON
1	23.5	POWER
2	21.0	BD
3	22.2	BD
4	24.5	BD
5	21.2	BD
6	21.7	BD
7	21.1	BD
8	22.7	BD

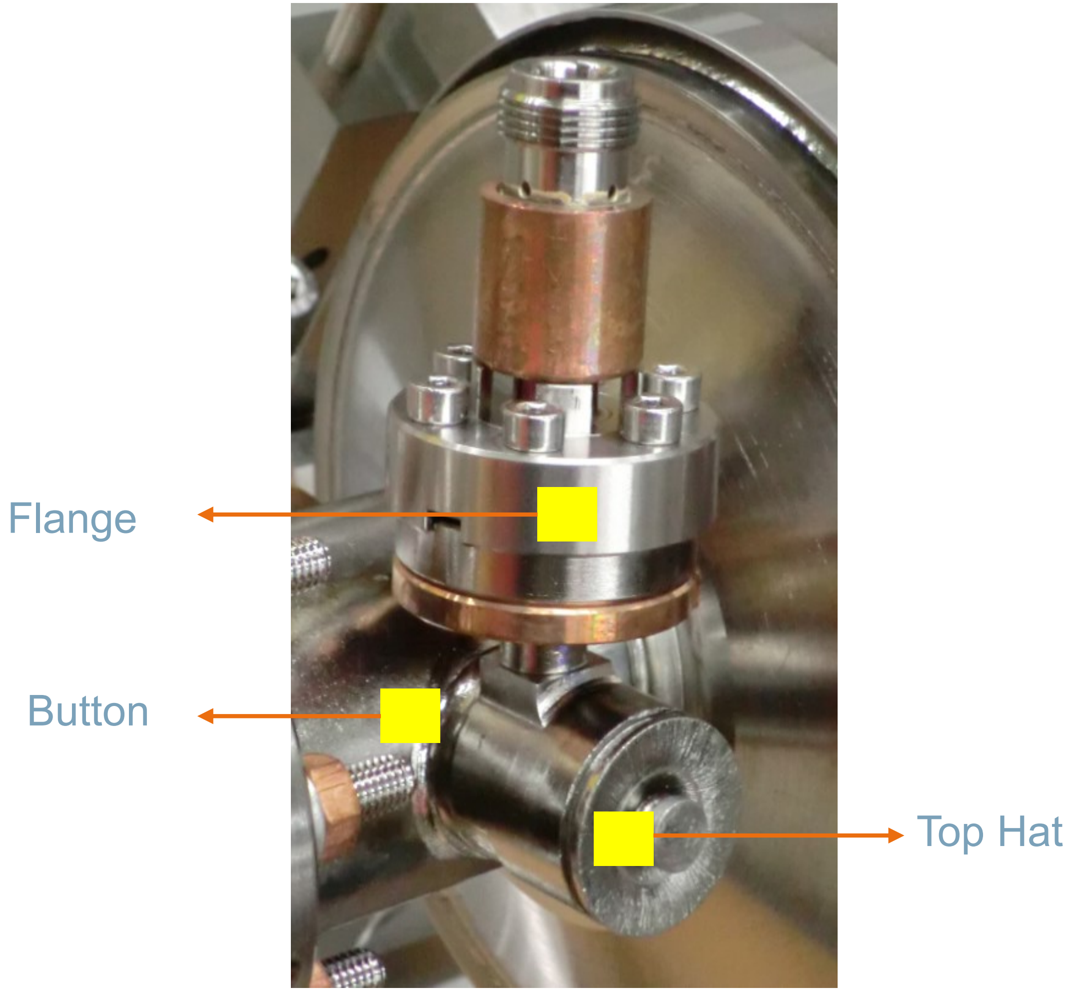
MODULE
CONTINUOUS WAVE MODE (2023)
(open loop)

CAVITY	LIMIT [MV/m]	REASON
1	5.5	HOM1 overheating
2	1.5	HOM1 overheating
3	5.5	HOM1 overheating
4	3.0	HOM1 overheating
5	5.0	HOM1 overheating
6	7.0	POWER
7	5.0	HOM1 overheating
8	8.0	POWER

- **Main limitation in the CW mode is significant rise of the temperature at the first HOM coupler.**
- **A reduction of a maximum accelerating gradient in the CW mode.**

Temperature measurement





- Temperature sensors connected to both HOM couplers
- Sensors located at „Button" & „Top Hat" showed similar temperature (±0.5K)
- Temperature measured in „Flange" is 2-3K higher (without RF)
- At „ Flange" an avalange increase of the temperature occures - >which was limiting max. Eacc

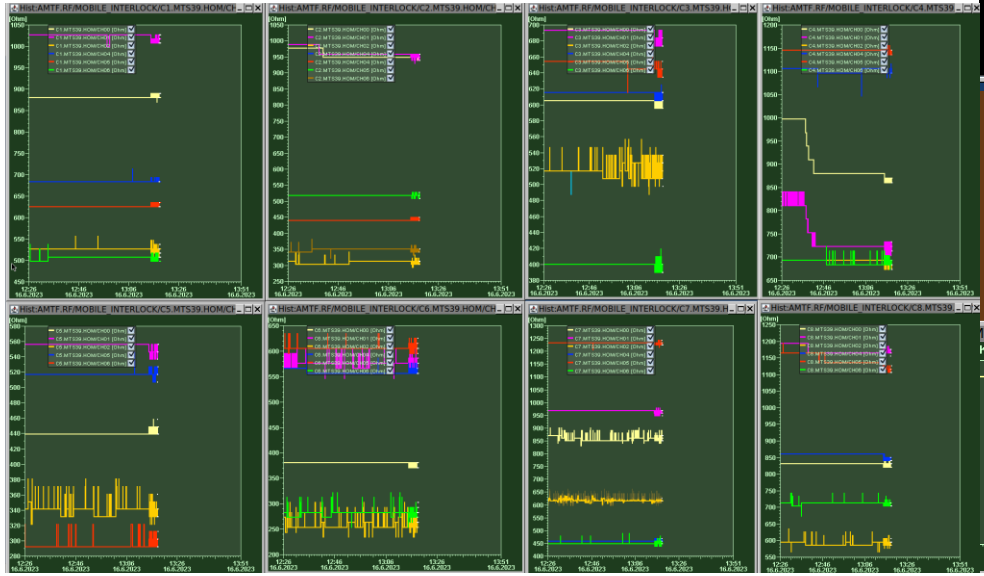
HOM couplers (heating in the pulse mode)

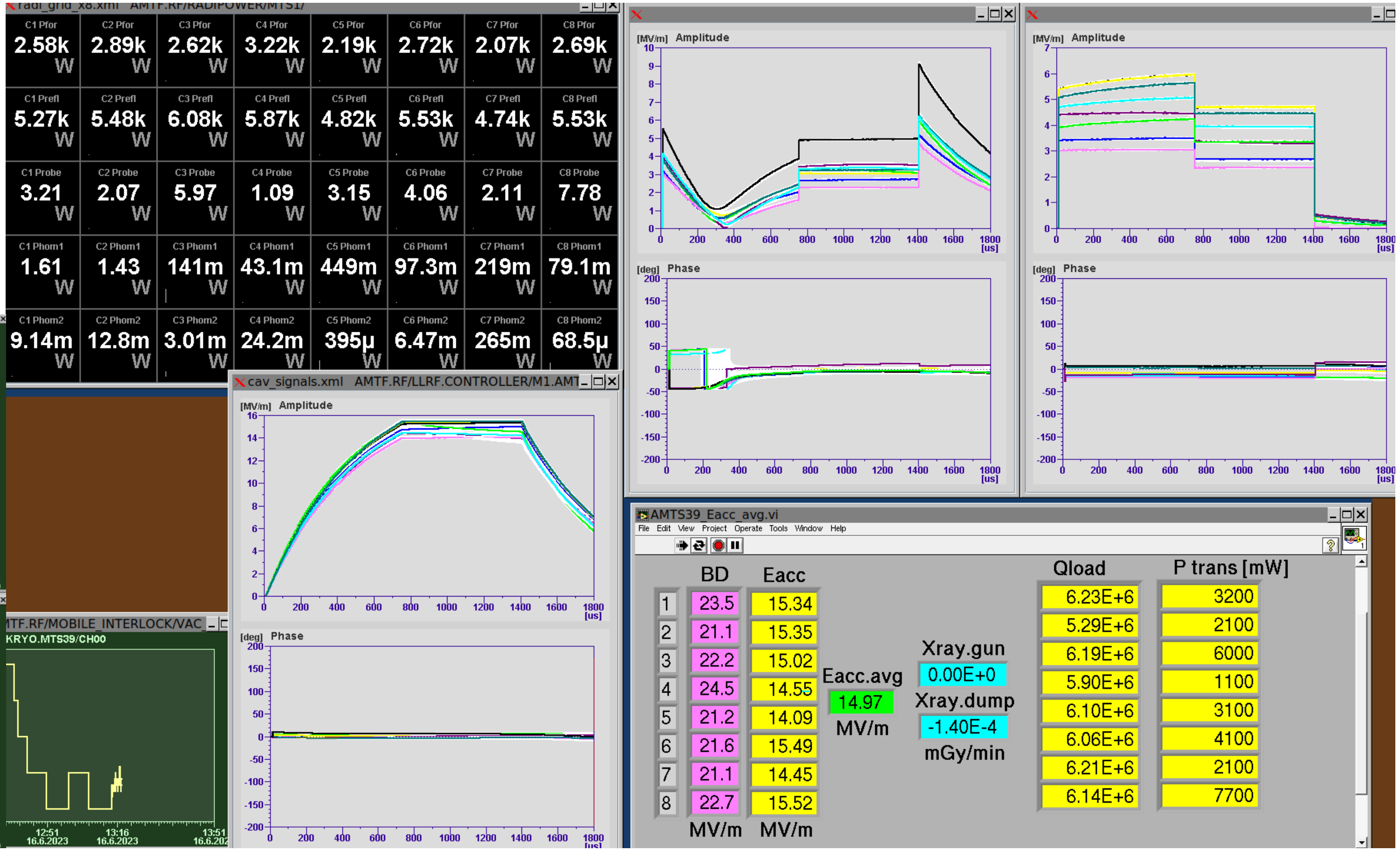
DURING THE HEAT LOADS measurement

Temperature at HOM couplers stable,

@ 15 MV/m and 18.7 MV/m

max. difference was 0.5 K

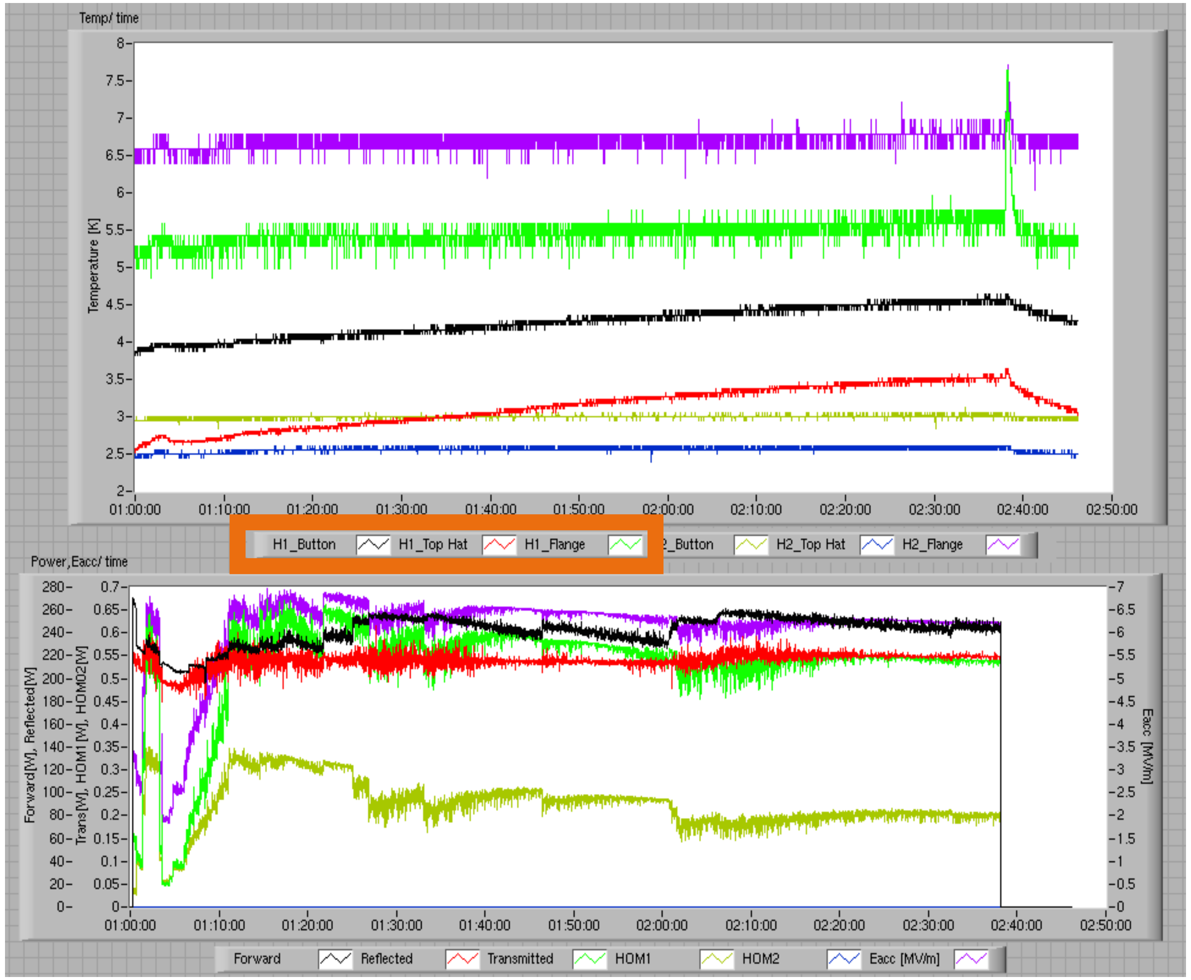




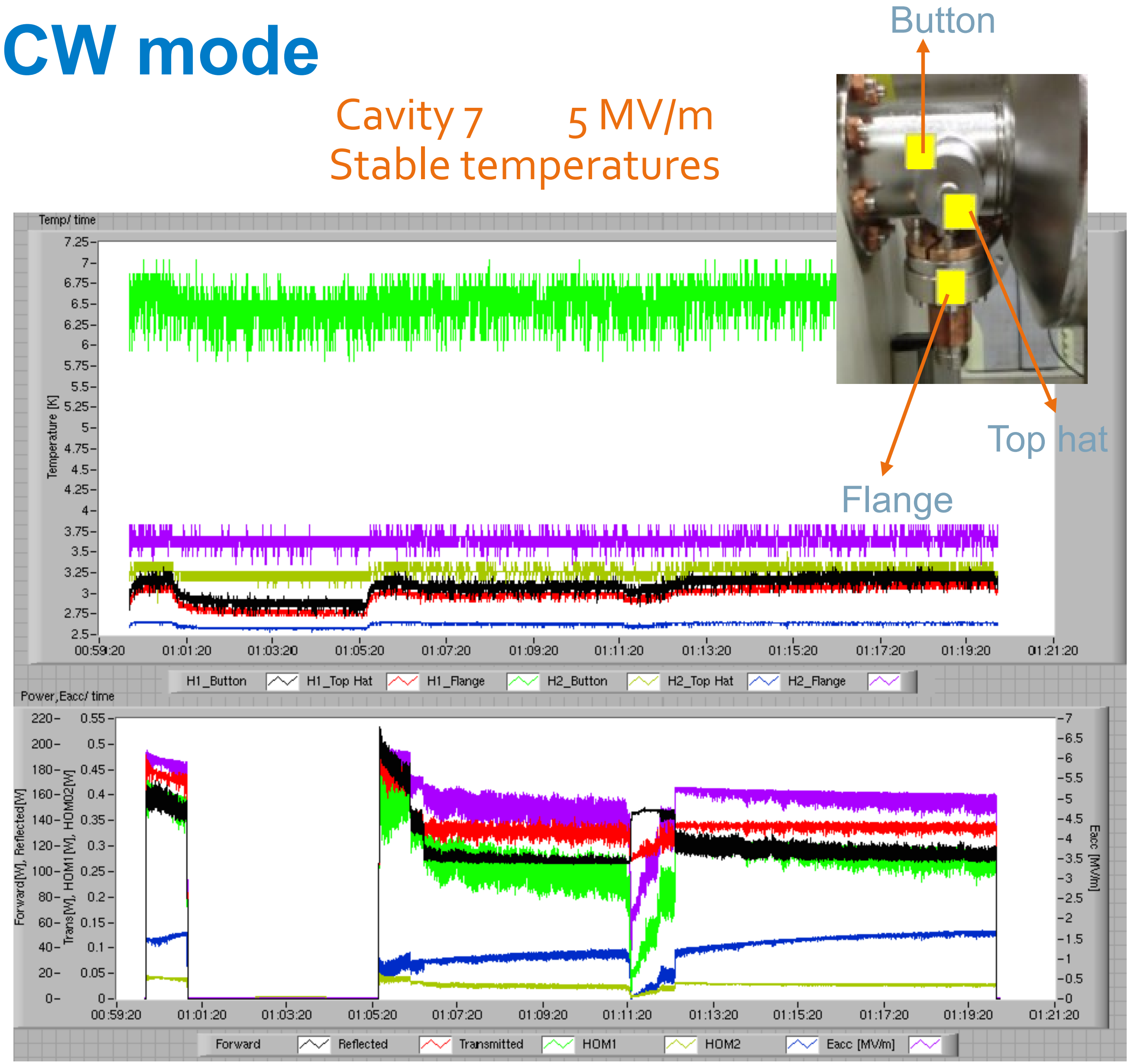
No overheating in PULSE mode.

HOM couplers overheating in CW mode

Cavity 1 6 MV/m
Temperature increase at HOM1



Cavity 7 5 MV/m
Stable temperatures



Avalange increase of the temperature observed only at the first HOM coupler!

HOM couplers (overheating in CW mode)

Check of the quality factors and rejection filter tuning

Cavity	Qtrans	QHOM1	QHOM2
1	1.2e+10	2.2e+10	6.1e+12
2	1.9e+10	3.6e+10	3.1e+12
3	7.0e+09	1.6e+11	7.9e+12
4	4.2e+10	1.1e+12	1.6e+12
5	1.1e+10	7.1e+10	6.7e+13
6	9.5e+9	2.7e+11	6.1e+12
7	1.4e+10	1.4e+11	9.9e+10
8	5.1e+09 **	7.4e+11	2.4e+14 **

CONTINUOUS WAVE MODE (2023)

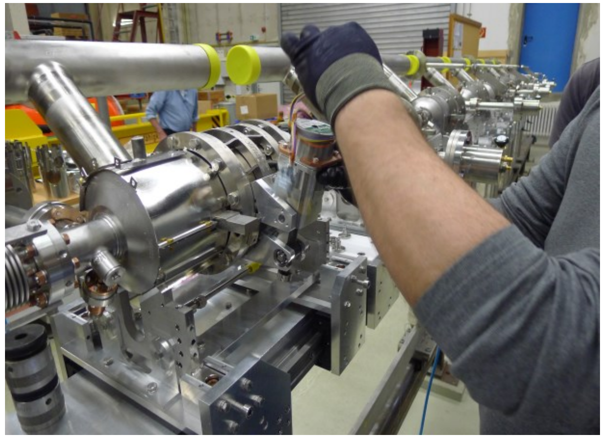
CAVITY	LIMIT [MV/m]	REASON
1	5.5	HOM1 overheating
2	1.5	HOM1 overheating
3	5.5	HOM1 overheating
4	3.0	HOM1 overheating
5	5.0	HOM1 overheating
6	7.0	POWER
7	5.0	HOM1 overheating
8	8.0	POWER

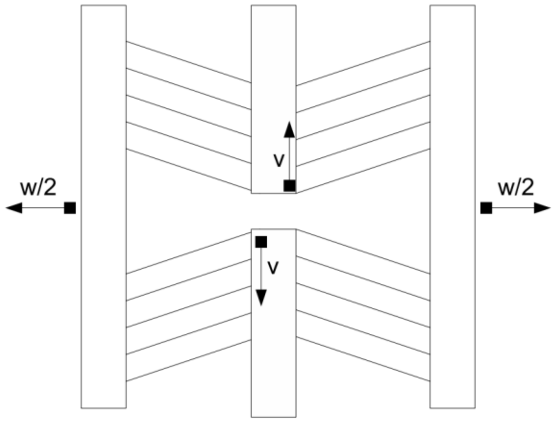
** Mismatch

No clear correlation between the overheating and the rejection filter tuning.

Backlash* in tuning mechanism

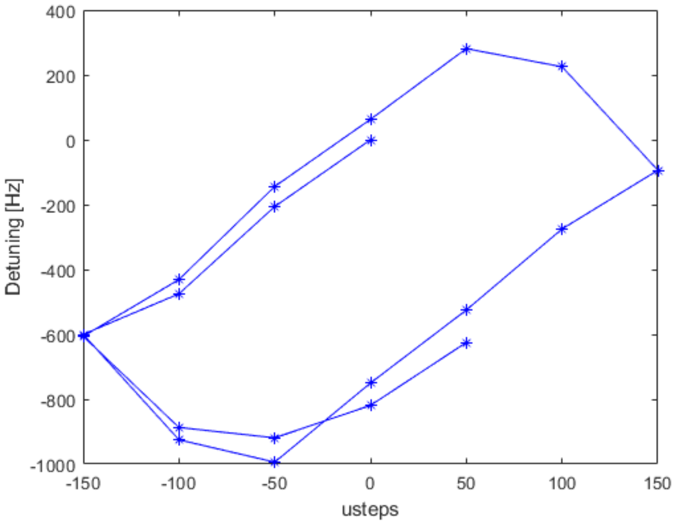
Blade tuner and kinematics principle



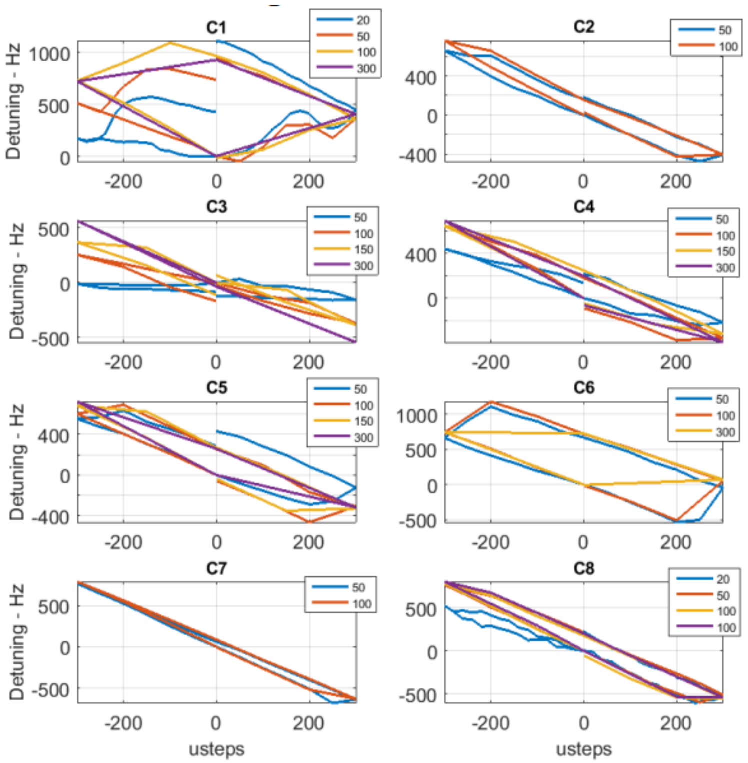


Courtesy:R.Paparella

CAVITY	50 steps
1	---
2	---
3	---
4	Backlash
5	Backlash
6	---
7	hysteresis
8	---



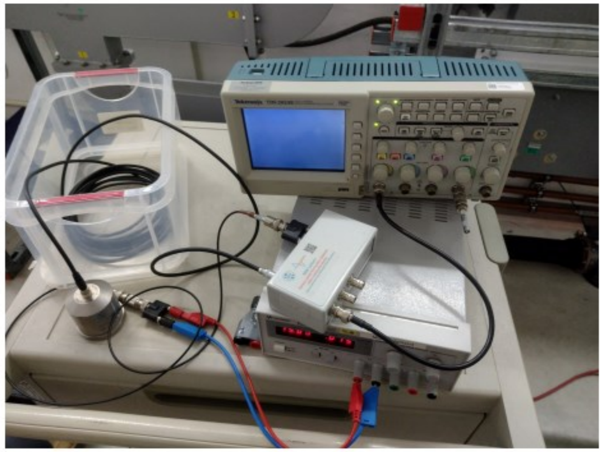
The same effect observed in 2017 in the 3.9 GHz cryomodule in tunel of E-XFEL

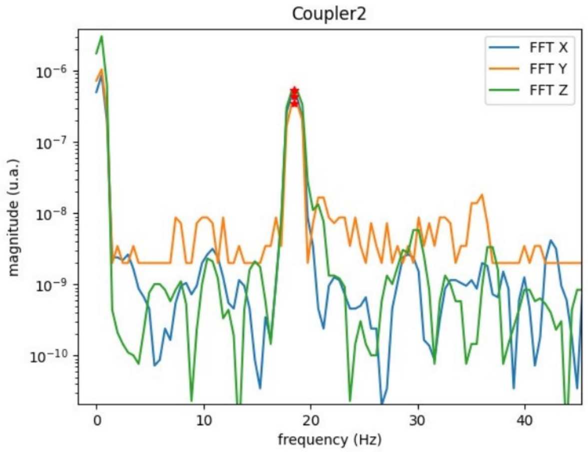


Courtesy:R.Paparella

*An amount of lost motion visible due to clearance or slackness when movement is reversed

Microphonics





Courtesy:A. Bellandi

- Mechanical resonance at 18.6 Hz detected.
- This limits the ultimate closed loop performance of LLRF system.
- The source was found in cryogenic piping (many other sources excluded).
- Counteraction
  - Shift the frequency of the own mechanical resonance.
  - Suppress the source by changing the pressure in the 4K shield of the module. By reducing pressure to 1 mbar and by having a liquid helium in the shield - vibration disappears.

Further studies are planned at the injector during the winter shutdown of the Eu-XFEL in order to check whether the mechanical resonance is also visible in the third harmonic module in the tunel.

Summary

- The module behavior in the pulse mode exceed the specification.
- Maximum accelerating gradient in the CW mode much lower than in the pulse mode.
- Main limit in the CW mode is an overheating on the <u>first</u> HOM coupler.
- No clear correlation between the overheating and the rejection filter tuning.
- A backlash effect visible, which makes tuning with the small number of steps (e.g. 50) difficult.
- Strong mechanical resonance at 18.6 Hz visible, which is limiting the closed loop operation.
- Further measurements are planed for a long pulse operation (e.g. 50% duty factor).

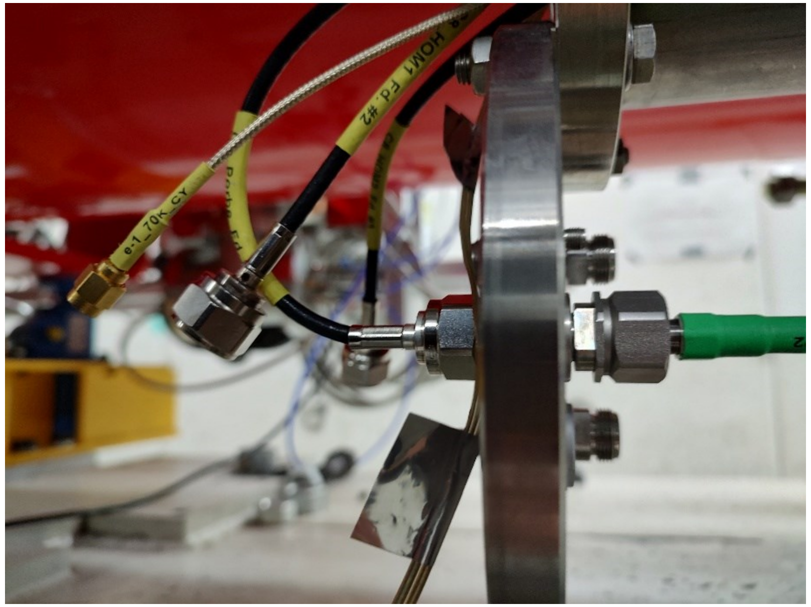
Acknowledgements

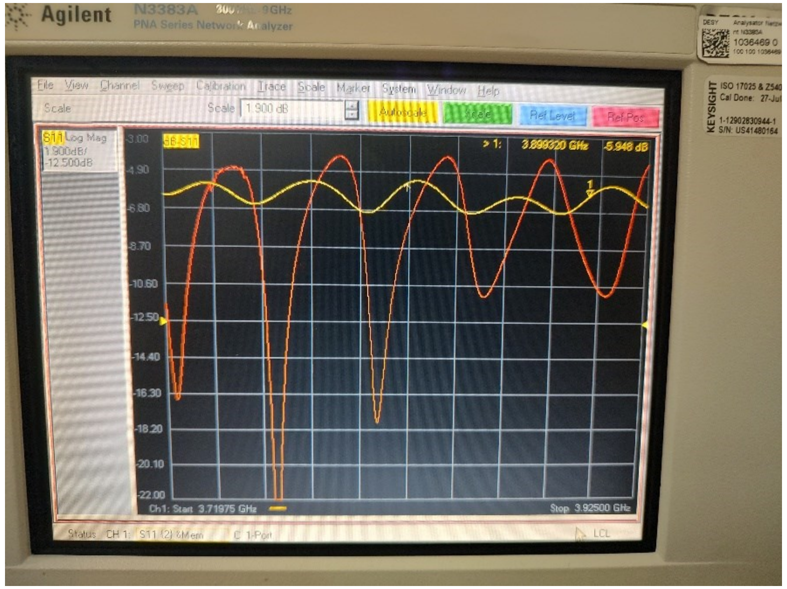
- -The M-groups at DESY (MIN, MSK, MKS, MSL, MVS ...)
- -Daniele Sertore, Paolo Pierini, Cecilia Maiano

SPARE SLIDES

Mismatch

- Characteristic ripples visible during the cold cable calibration (Return Loss measurement)
- At some frequencies resonances in the cable!
- It was an effect of the mismatch in the feedthrough
- Effect disappeared after exchange
- Exchange was done after warmup





Cav	Probe [dB]	HOM1 [dB]	HOM2 [dB]
1	1,40	1,33	1,49
2	1,55	1,50	1,53
3	1,56	1,68	1,71
4	1,69	1,50	1,59
5	1,72	1,55	1,72
6	1,55	1,47	1,57
7	1,49	1,49	1,59
8	2,09**	1,46	2,89**
8	1,43	1,33	1,46

Values with a mismatch → (row 8: 2,09** / 1,46 / 2,89**)

Values after feedthroughs exchange → (row 8: 1,43 / 1,33 / 1,46)

Heating of the Fundamental Power Coupler