Status of CW cryomodule testing at Cryomodule Test Bench.

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Abstract

CryoModule Test Bench (CMTB) is a facility at DESY to perform CW and pulsed tests on European XFEL like cryomodules for CW operations. The facility is equipped with a 120 kW Inductive Output Tube (IOT), and more than 180 W of cryogenic power at 2 K can be used for the tests. Since last summer, a new accelerating module, namely XM50.1, is installed at CMTB. This is the first series production European XFEL module to be tested in CW. This module is equipped with eight superconducting TESLA cavities that are driven in a vector sum scheme. These tests are essential to define the operational constraints and validate technologies for the proposed European XFEL CW upgrade. Of particular importance is the mitigation of microphonic related effects to lower the RF power requirements. Such a task is achieved using an Active Noise Controller (ANC) that uses piezo actuators to reduce the mean square detuning of each cavity. Another effect of interest is the RF-induced heating of the cavity couplers that make the Qext drift over time. Then a proper characterization of this effect is useful to optimize the RF power consumption of the accelerating system. Other important tests that are ongoing or foreseen at CMTB include the online detection and measurement of quenches and detuning, the characterization of Q_0 at different cryogenic temperatures, and the achievable field regulation using RF feedback.

Cryo Module Test Bench (CMTB)

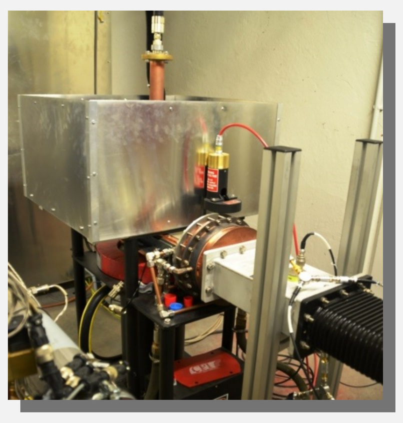
Module XM50.1

- European XFEL production module
- Equipped with eight TESLA cavities
- Q_0 ~ 1.8x10^{10} at 2 K and 15 MV/m
- Modified couplers to operate in a range of Q_L between 10^6 - 10^8
- At CMTB since the beginning of this year
- Over 180 W of available cryogenic power at 2K

Cavity	Max gradient in CW reached* (MV/m)	Max Q_L (10^7)
1	10.0	4.1
2	19.38	11.5
3	17.44	4.5
4	20.41	11.6
5	18.12	3.2
6	17.97	9.9
7	18.15	3.6
8	20.17	3.9

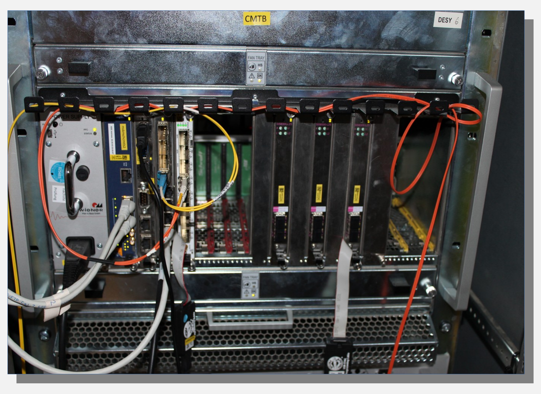
* except cavity 1, which was limited by field emission, all the other cavities were limited by the maximum cryogenic cooling power available.

IOT



- 120 kW output
- 22.3 dB gain
- 54 % efficiency

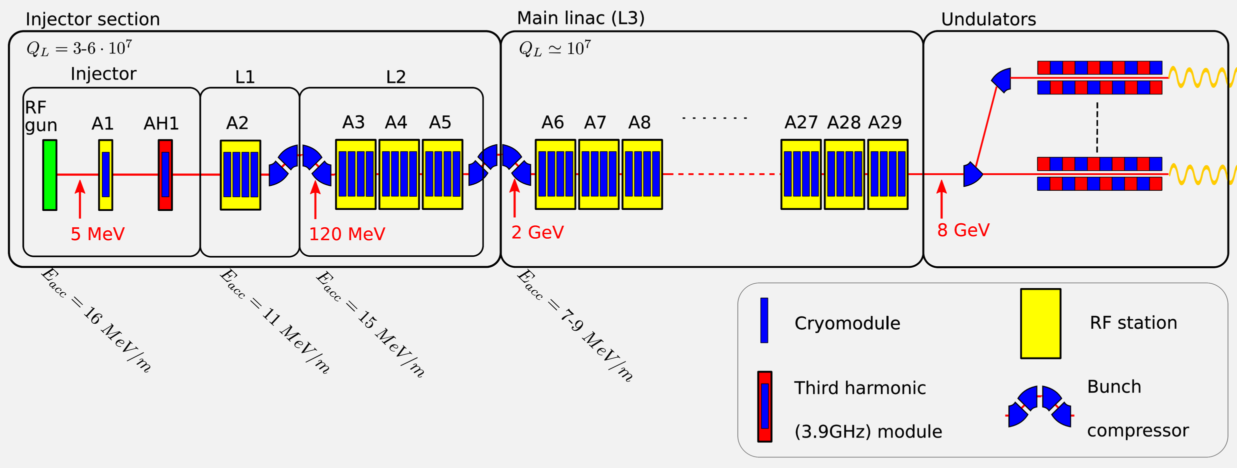
LLRF crate



- Based on MicroTCA.4
- 12 slot crate 9U
- NAT MCH
- Concurrent CPU
- Wiener 1kW uPM
- 3x Struck SIS8300 ADC + DWC
- Vadatech DAMC-TCK7 + DESY VM2
- 19" XFEL 16 ch piezo driver (external)

European XFEL CW/LP upgrade

Layout

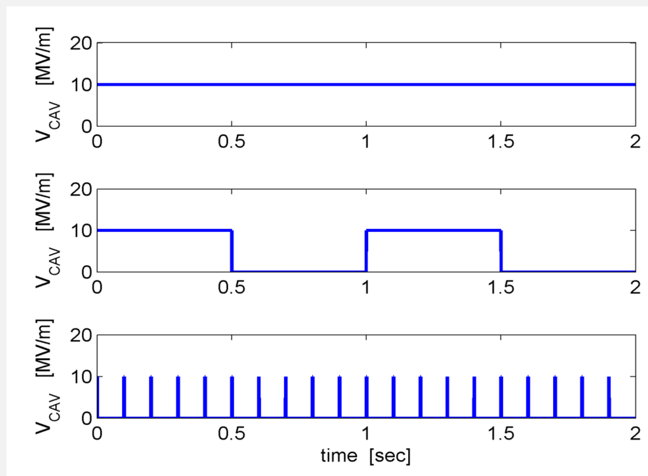


Modes of operation (at 0.1nC)

Continuous wave (CW)
E = 8.6 GeV
$N_{bunches}$/s = 100k

Long Pulse (LP)
E = 12.6 GeV
$N_{bunches}$/s = 50k

Short Pulse (SP) (actual)
E = 17.5 GeV
$N_{bunches}$/s = 27k



Mode	Bunch number	Bunch spacing	Energy
CW	↑	↑	↓
LP	=	↑	=
SP	↓	↓	↑

Benefits

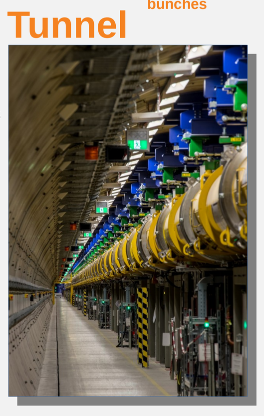
- Higher bunch repetition rate and current up to 0.025 mA
- Higher bunch spacing is beneficial for many FEL experiments
- Bunch repetition rate and spacing can be traded for beam energy for more flexible operations

After the upgrade European XFEL will be able to switch between SP and CW/LP mode of operation!

To do

- Double the cryogenic plant capacity to 5kW
- Replace injector cryomodules with higher Q_0 ones (> 2.8 10^{10}). These cryomodules will be able to operate in the range of Q_L ~ 10^6 - 10^8
- Install Induction Output Tubes (IOT) next to existing pulsed multi beam klystrons
- Modify the RF distribution system to allow selectable SP or CW/LP operations
- Add 12 modules to the main linac

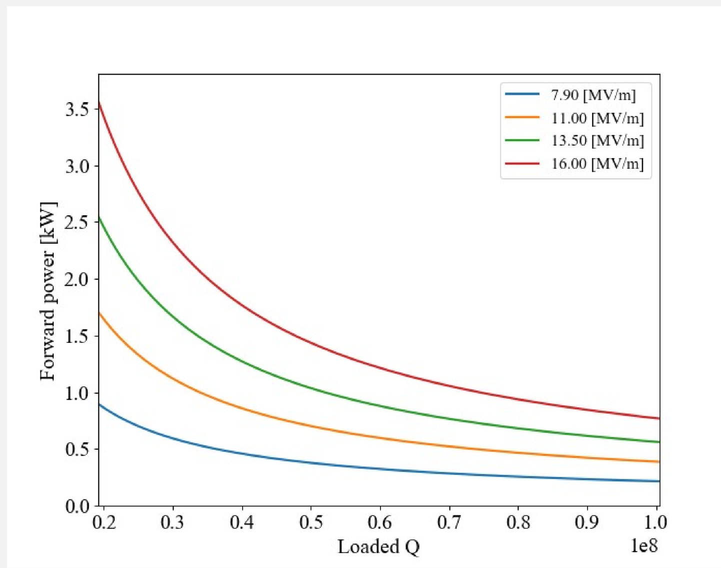
Tunnel



- European XFEL has a single, 5.2 m diameter, 1.5 km long tunnel for the accelerating section
- For the upgrade the size of every component has to be optimized
- Because of RF costs, size and the need to keep SP mode of operation, the Vector Sum drive scheme will be used for CW/LP and SP mode

Coupler Heating

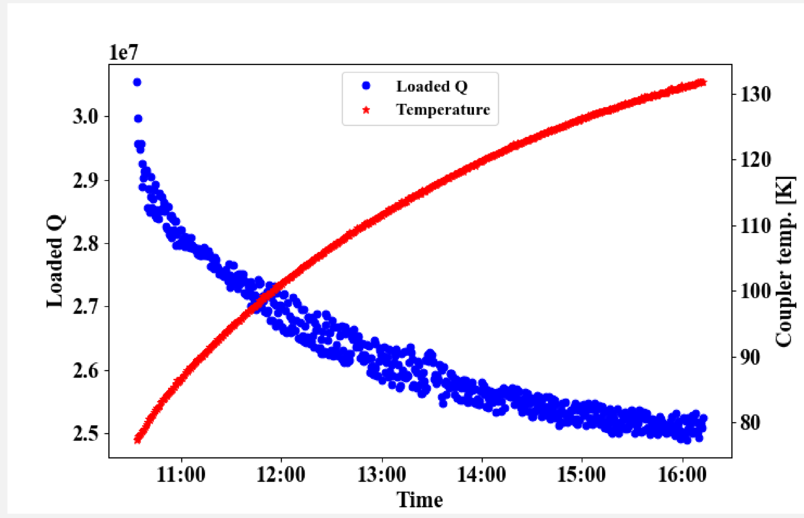
Power in function of loaded Q



Beam current of 0.025 mA

- Because of the expected loaded quality factor during CW operations, between 10^7 and 10^8 every cavity is expected to need some kilowatts of RF power to reach the desired gradient of 16MV/m in the injector
- This produces a noticeable coupler heating. The Q_L is changed due to the mechanical variation of the coupler

Variation of loaded Q due to coupler heating

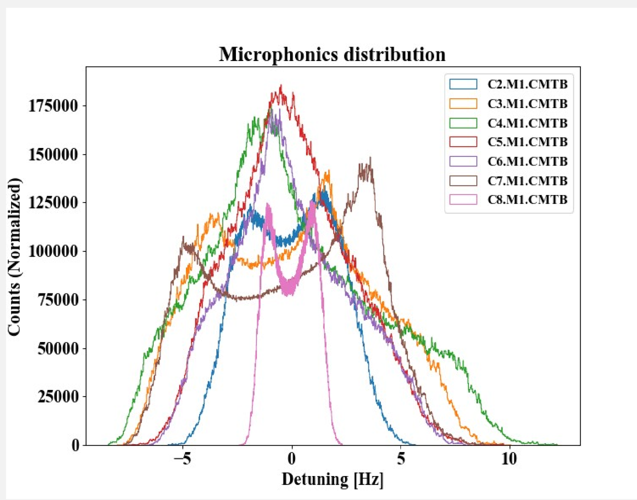


P_{for} = 4 kW Q_L = 3x10^7 measured at CMTB

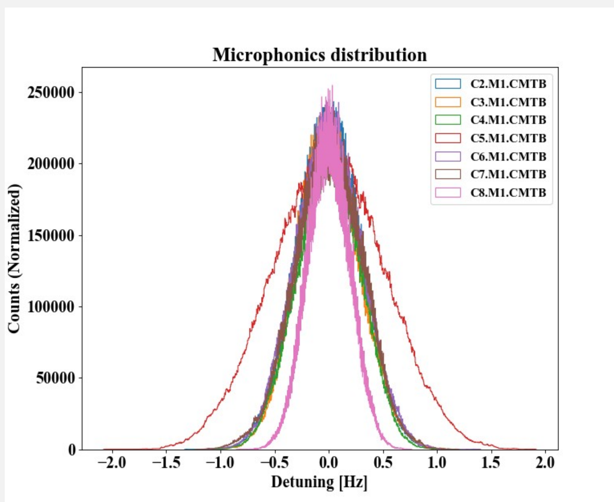
Microphonics

- For Q_L > 10^7 the bandwidth of the cavities is in the order of some tens of hertz.
- Microphonics disturbances that originate from pump vibrations, helium bath pressure variations and other mechanical excitations increase the mean quadratic detuning.
- To lower the power consumption in closed loop such errors have to be reduced.
- The narrowbandwidth Active Noise Controller (ANC) is able to reduce the microphonics of about 20 dB

ANC Off

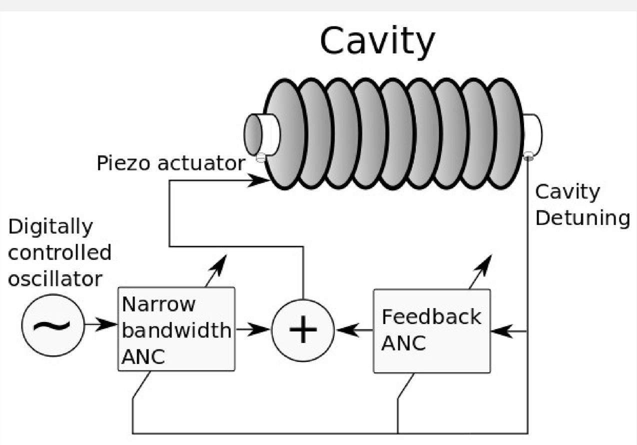


ANC On



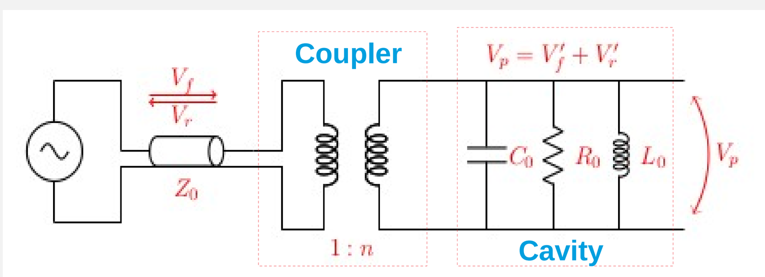
Future plans

ANC extension



- Due to the narrow bandwidth ANC limitations, the correction can be applied only to a limited number of disturbance lines in the detuning spectrum. These lines have to be set by an operator
- A broadbandwidth LMS-based algorithm could improve the detuning correction capabilities of the LLRF system without the need of a manual fine-tuning.
- Due to the complexity of the algorithm, the usage of a soft core processing unit in the LLRF FPGA logic is foreseen.

Q_{ext} estimation



$(V_p)_{virt} = V_f + V_r$ Virtual probe

$Q_{ext} = Q^* \frac{V_p^2}{(V_p)_{virt}^2}$ with Q^* a calibration factor

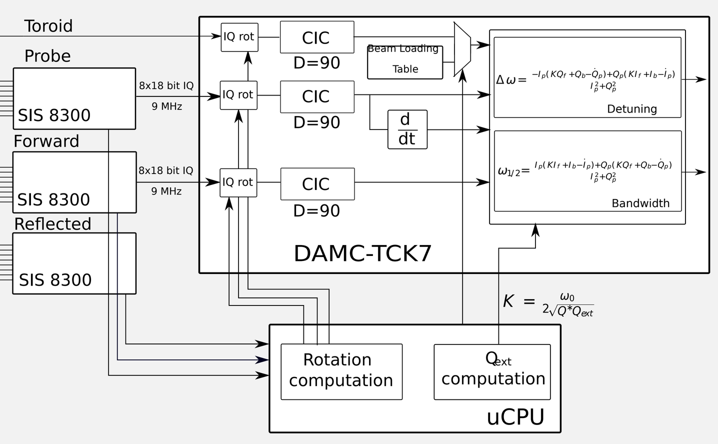
- To avoid to switch off the beam delivery an alternative to the decay method has to be found to compute the coupling.
- A possibility is to use the transmission line equations
- This method helps to track the coupler heating related bandwidth variations

Q_0 measurement

- In CW the cryogenic cooling power limits the maximum achievable accelerating gradient on the cavities
- Therefore a measurement of Q_0 at different gradients and helium bath temperatures is important to define the operating point of the proposed European XFEL CW upgrade

Detuning and quench detection

- A possible way to compute the detuning and to detect quenches is to add a dedicated component in the LLRF FPGA logic
- To filter the noise and to reduce the computational requirements, the cavity signals will be decimated using a Cascaded-Comb-Integrator filter
- The computed detuning will be used by the ANC component



Cavity conditioning

- Cavity 1 emits a strong radiation (> 1mGy/min) for gradients higher than 10 MV/m. Therefore it has to be conditioned
- Such conditioning procedure needs high power MW-rated short pulses
- The conditioning of cavity 1 will be performed in November, after the installation of a new pulsed klystron

Closed loop measurement

- In order to meet the European XFEL specifications, the maximum error on the accelerating field on amplitude and phase should be within 0.01 % and 0.01 deg
- To achieve a stable field the usage of a RF feedback loop is necessary

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