STATUS OF CRYOMODULE TESTING AT CMTB FOR CW R&D.

THP092

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Abstract

The CryoModule Test Bench (CMTB) is a facility to perform tests on European XFEL like superconducting accelerating modules. The 120 kW Inductive Output Tube (IOT) installed in the facility allows driving the eight superconducting cavities inside the module under test in a vector-sum or single cavity control fashion with average Continuous Wave (CW) gradients higher than 20 MV/m. The scope of these tests is to evaluate the feasibility of upgrading European XFEL to CW operation mode. Following the successful tests done on a prototype module XM-3, the initial performance results on the production module XM50 will be presented in this poster. Because of European XFEL requirements, XM50.1 is equipped with modified couplers that allow a variable Loaded Quality factor (Q_L) to values higher than $4x10^7$. A cost relevant open question is the maximum Q_L that can be reached while maintaining the system within the European XFEL field stability specifications of 0.01 % in amplitude and 0.01 deg in phase. Because of this the LLRF system capability of rejecting microphonic and RF disturbances, as well as Lorentz Force Detuning (LFD) related effects in open and closed loop is of prime interest.

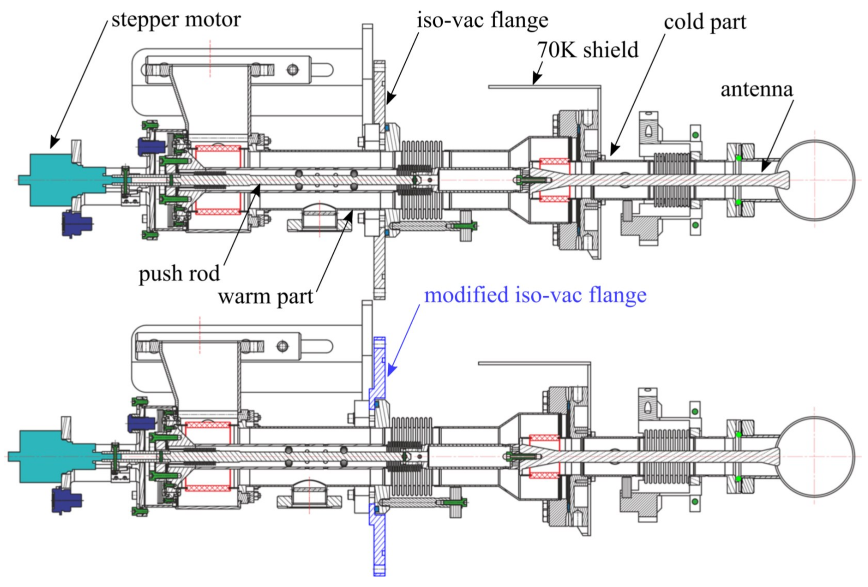
XM50.1 modifications

The series XFEL cryomodule XM50 was reassembled (due to problems during the first string assembly) and modified to study its suitability in CW operation. The new cryomodule is referred to as XM50.1

To accommodate for higher Q_L, the iso-vac flange was modified for all 8 couplers of XM50.1

By stretching outwards the warm part of the coupler, this modified flange effectively pulls the coupling antenna further away from the cavity central axis, hence shifting the range towards higher Q_L values.

The stretching of the bellows puts an upper bound on this modification.



XM50.1 pulsed tests at AMTF

Pulsed tests are first carried in the accelerating module test facility (AMTF). These tests allow us to establish:

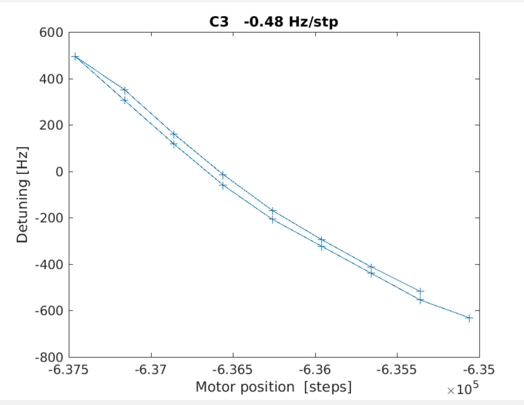
- The maximum usable gradient for each cavity
- The dynamic heat load in pulsed mode (for different gradients)
- The effectiveness of HOM absorbers
- The frequency tuner sensitivity
- The external coupling range
- The piezo sensitivity
- Lorentz force detuning coefficients and compensation
- Frequency of the sub-fundamental modes (8π/9 and 7π/9)

Note: not all test results are shown here

Slow frequency tuner scans

Goal: measure the tuner sensitivity and identify possible backlash / hysteresis issues

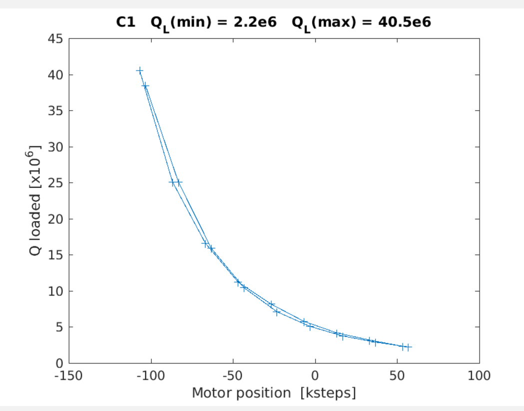
	C1	C2	C3	C4	C5	C6	C7	C8
Tuner sensitivity [Hz/stp]	-0.45	-0.47	-0.48	-0.48	-0.45	-0.47	-0.46	-0.48



Slow frequency coupler scans

Goal: measure the Q_L tuning range.
After the first measurement, the end switches were adjusted to allow for higher Q_L operation
After adjustment, all couplers can reach Q_L = 4e7 or higher

	C1	C2	C3	C4	C5	C6	C7	C8
Q_L(min) [x1e6]	2.2	1.2	1.9	1.0	1.5	1.1	1.4	1.9
Q_L(max) [x1e7] **before**	**4.1**	11.5	**4.5**	11.6	**3.2**	9.9	**3.6**	**3.9**
Q_L(max) [x1e7] **after**	**6.4**	10.4	**6.0**	9.3	**4.6**	7.4	**5.8**	**5.1**

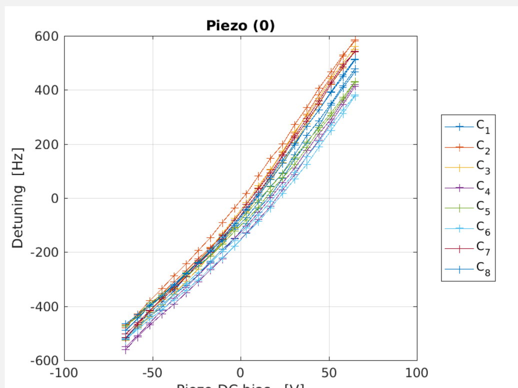


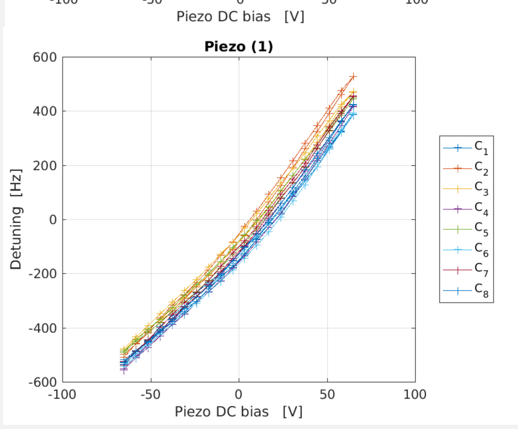
Piezo scans

Goal: measure the piezo tuning range (expected +/- 500 Hz)
Verify that the piezo polarity is correct (i.e. negative detuning for negative bias)

Piezo (0)	C1	C2	C3	C4	C5	C6	C7	C8
Detun. (-65V) [Hz]	-519	-469	-526	-560	-472	-524	-503	-465
Detun. (+65V) [Hz]	468	586	551	413	429	378	543	512
Total detun. [Hz]	987	1055	1077	973	901	902	1046	977

Piezo (1)	C1	C2	C3	C4	C5	C6	C7	C8
Detun. (-65V) [Hz]	-519	-498	-483	-557	-491	-543	-526	-526
Detun. (+65V) [Hz]	386	527	470	416	445	389	455	424
Total detun. [Hz]	905	1025	953	973	936	932	981	950





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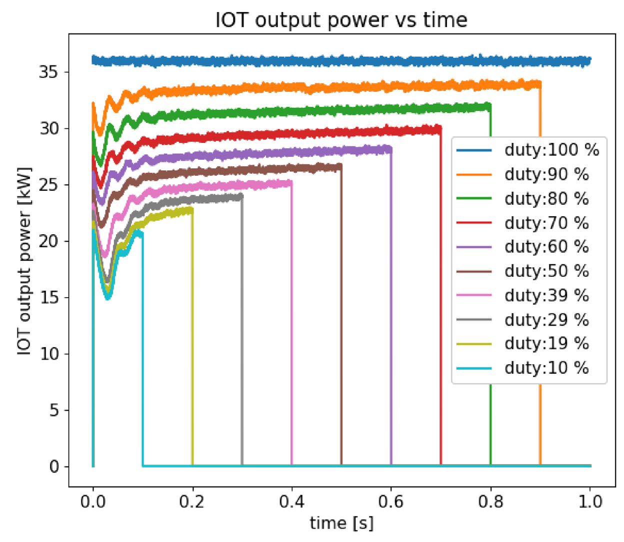
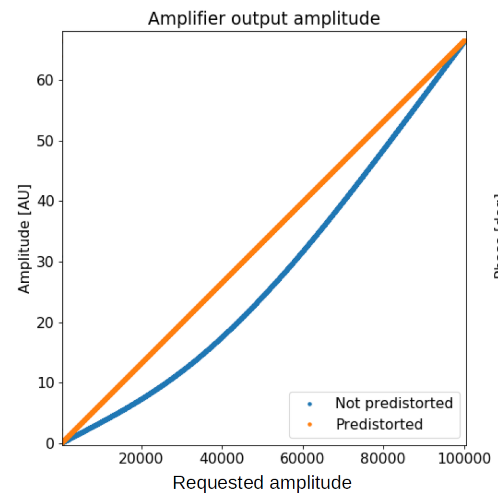
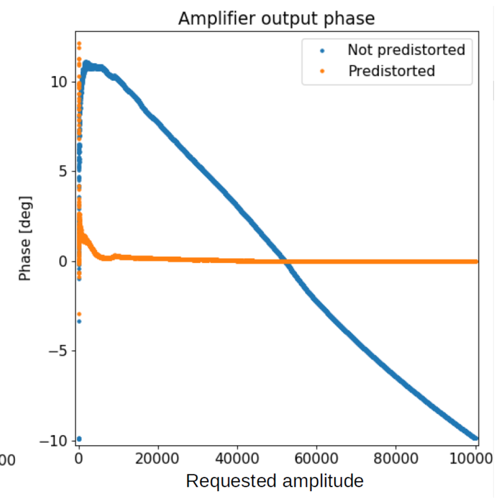
XM50.1 installation at CMTB and preparation tests





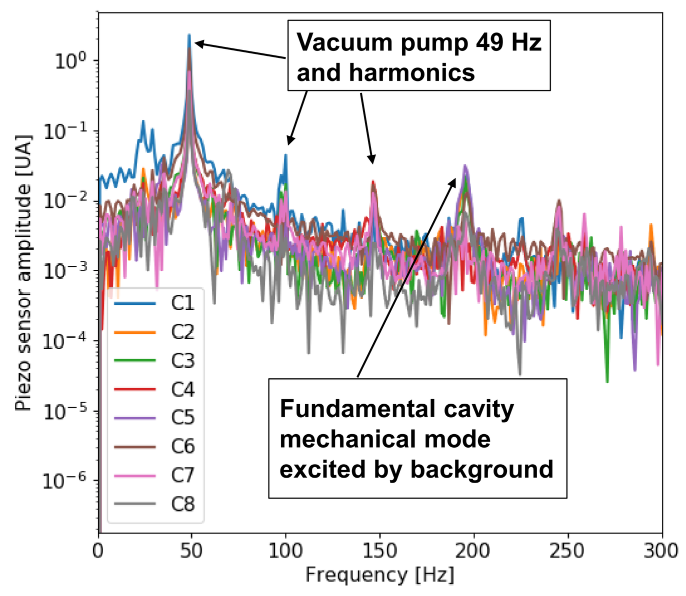


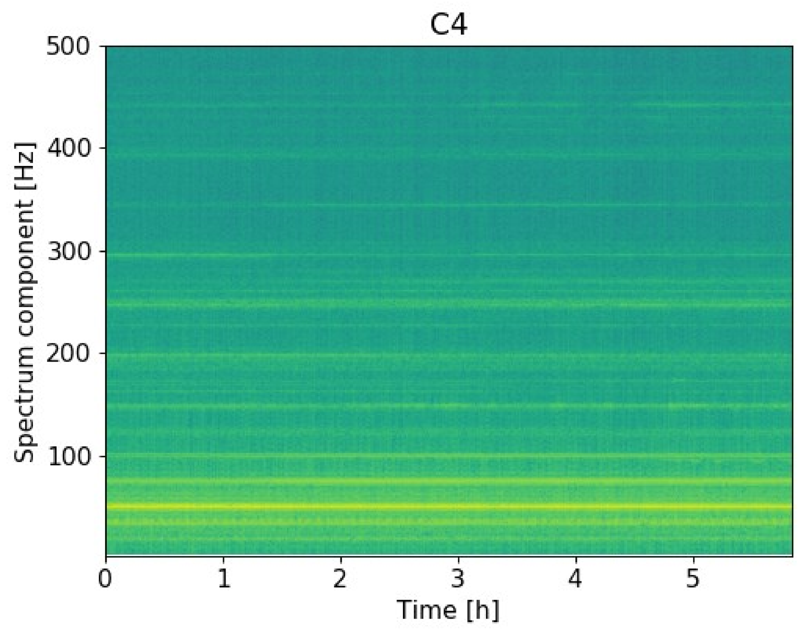
Investigation of IOT start up transients

- Transients in amplitude (figure above) and phase (not shown) are observed during the first 100 msec of IOT operation.
- These transients become problematic for long pulse operation.
- We suspect they are related to a thermal effect at the cathode. Increasing the duty cycle of operation minimizes the amplitude of transients oscillations
- A discussion with the vendor is on-going to understand how to mitigate the issue.

Demonstration of the IOT linearizer module (FPGA)

- After characterization, the IOT non linearity can be rectified in amplitude and phase.
- The benefits are a linear actuator chain, improving the system robustness and simplifying controls and setup
- A linearity improvement by a factor of 100 in amplitude and 45 in phase was demonstrated.



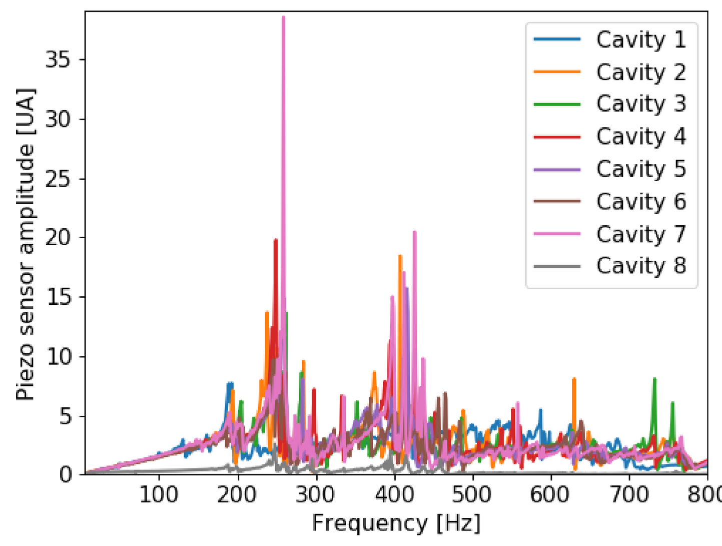


Background microphonics measurement

- Background microphonics is measured using piezo sensors
- The dominant frequency is 49 Hz, "well known" at CMTB, coming from vacuum pump. Other harmonics of the 49 Hz are visible.
- Around 200 Hz, the cavity fundamental mechanical mode is excited (from the background white noise)
- The microphonics spectra are stable over hours (plot on the right), however, the spectral content varies from cavity to cavity (hence the need for configurable noise cancellation techniques)

Cavity mechanical transfer functions

- A frequency sweep on one piezo is used to mechanically excite the cavity
- The transfer function of the piezo sensor identifies the main resonant modes
- Commonly observed mechanical modes are consistently found for all cavities around 200, 280 and 390 Hz.



What questions are we trying to answer and what these tests at CMTB can tell us:

What is the optimal cool down procedure to prevent flux trapping?

- **TEST**: Dynamic heat load measurements
- at 2K and 1.8K
- under fast and slow cool down conditions
- **OUTCOME** : expected heat load for a CW XFEL

What is the expected stability one can expect in vector sum operation at nominal gradient and Q_L ?

- **TEST**: stability performance measurement
- 8 cavities in vector sum control
- RF feedback
- piezo feedback and active noise cancellation (microphonics suppression)
- Benefit of using Kalman filter
- **OUTCOME**: can we meet the stability requirement and what will be the expected power consumption

How do environmental vibrations affect the RF regulation performance ?

- **TEST**: mechanical mode identification
- Using piezo sensor
- Using FFT of RF probe
- **OUTCOME**: can we suppress microphonics to stay away from monotonic instability
- **OUTCOME**: can we use external sensors to better suppress microphonics ?

Future work and outlook

Technical problems at CMTB delayed the IOT operation on the module, so that RF related results could not be reported in this contribution. Fortunately, XM50.1 will stay at CMTB for several months allowing to continue the R&D effort towards a CW upgrade of the European XFEL. Developing new diagnostics for online Q_L and detuning measurement is of particular interest.
Microphonics measurement and compensation is another very interesting topic. Operating high Q_L (> 4e7) cryomodules at relatively high gradient (> 16 MV/m) in vector sum is a challenge which requires advanced cavity resonance control. This R&D effort aims at demonstrating exactly this approach, which we see as a key milestone for the feasibility of the XFEL CW upgrade.

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