# From pulse to continuous wave operation of TESLA cryomodules – LLRF system software modification and development

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## Abstract

Higher efficiency of TESLA based free electron lasers (FLASH, XFEL) by means of increased quantity of photon bursts can be achieved using continuous wave (CW) operation mode. In order to maintain constant beam acceleration in superconducting cavities and keep short pulse to CW operation transition costs reasonably low some substantial modification of accelerator subsystems are necessary. Changes in: RF power source, cryo systems, electron beam source, etc. have to be also accompanied by adjustments in LLRF system. In this paper challenges for well established pulsed mode LLRF system are discussed (in case of CW and long pulse (LP) scenarios). Firmware, software modifications needed for maintaining high performance of cavities field parameters regulation (for CW and LP cryo-module operation) are described. Results from studies of vector sum amplitude and phase control in case of resonators high Ql factor settings (Ql=1.5e7) are shown. Proposed modifications implemented in VME and microTCA (MTCA.4) based LLRF system have been tested during studies at CryoModule Test Bench (CMTB).

Results from these tests together with achieved regulation performance data are also presented.

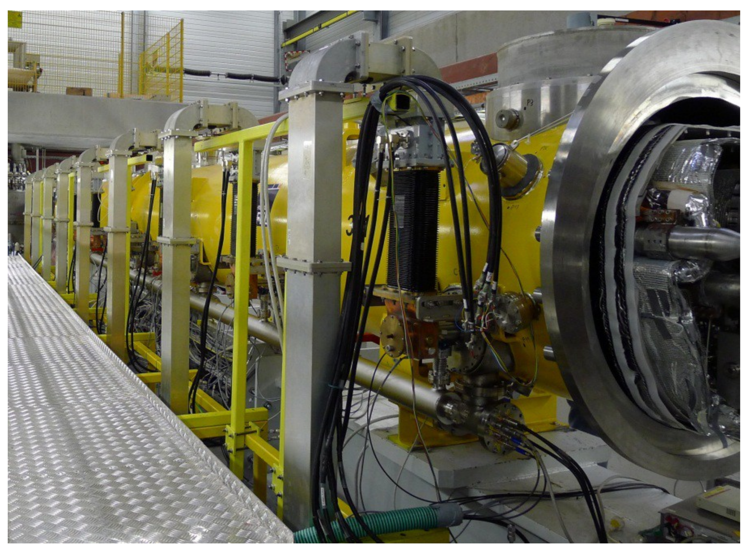
## Introduction

Although the **European X-ray Free Electron Laser** (XFEL) is still in the construction stage possible facility upgrades are already under discussion. The possibility of constant beam acceleration is one of the attractive option of future laser operation. In order to evaluate the potential impact of the operation scenario change to the existing infrastructure and define initial requirements for linac systems adjustments set of tests have been done on CMTB.

CW/LP operation limitations:
- increased load on the cryogenic system (limit 20W/module),
- input cavity coupler acceptable power level (different duty factor scenarios needed).

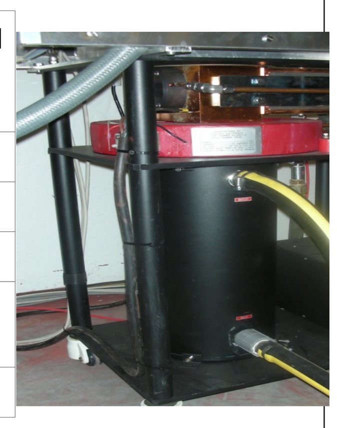
## CW/LP test environment

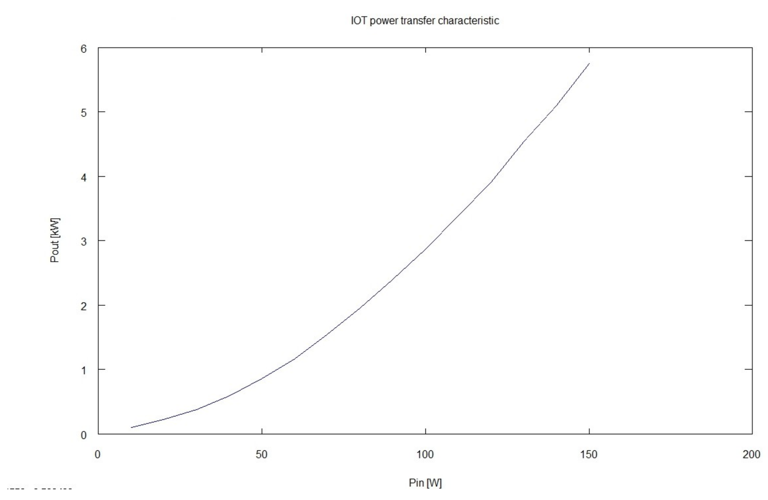
CMTB facility equipped with:
- single 8 TESLA cavities cryomodule
- cryogenics system,
- high power RF sources (klystron and IOT),
- LLRF system infrastructure (VME and MTCA.4),
- slow motor frequency tuners,
- piezo tuners control system



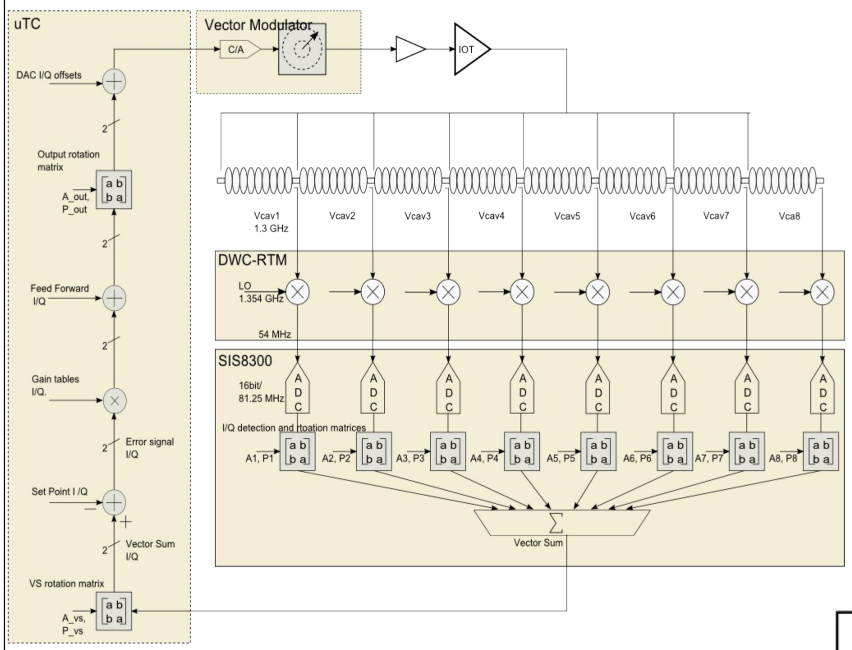
## IOT for cavities supply

| Parameter | Unit | Spec | Measured CPI and (DESY) |
|---|---|---|---|
| Frequency | [MHz] | 1300 | 1300 |
| Output P | [kW] | 60-120 | 85 (80) |
| Gain | [dB] | >21 | 22.3 |
| Efficiency | [%] | >60 | 54 |
| Voltage | [kV] | 36-50 | 45-48 |





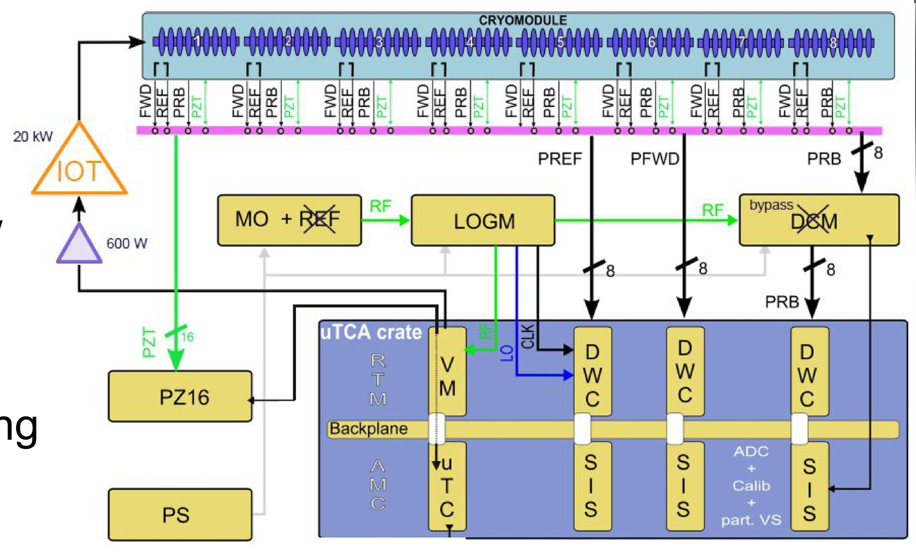

## LLRF feedback (actual implementation - MTCA.4)



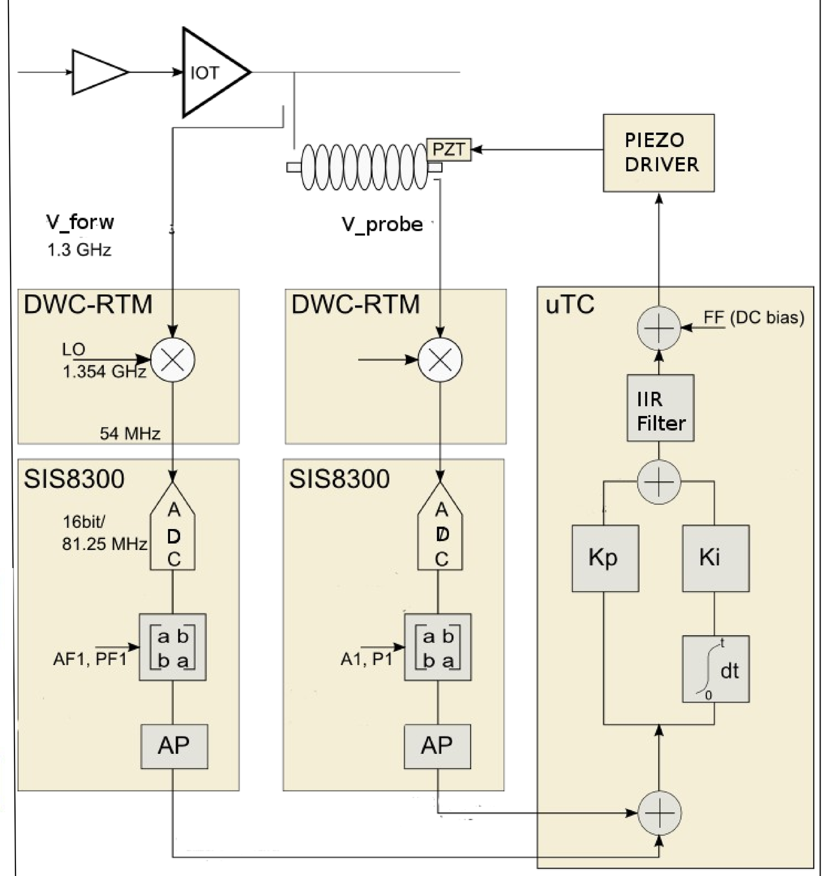

The system consists of MTCA.4 hardware components for data acquisition fast feedback loops realization, cavities signals down-conversion, drive signal up-conversion, piezo driver communication and others.

The CPU hosts few DOOCS servers responsible for:
- LLRF system management and slow control algorithms realization,
- timing signal distribution and synchronization.

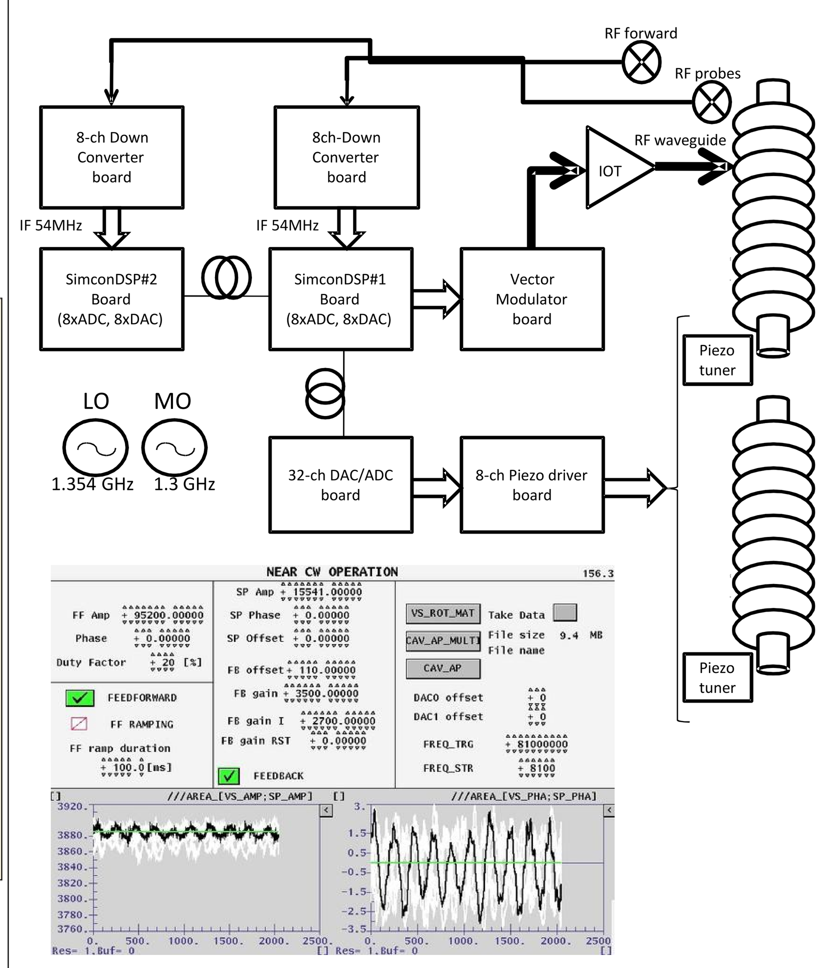
Operators GUI has been provided using JDDD environment.




## Piezo Feedback




## Initial system structure and results

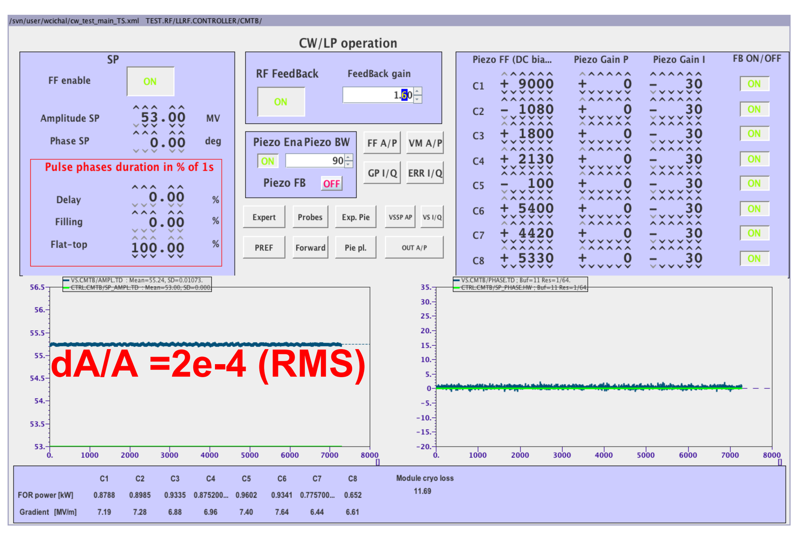


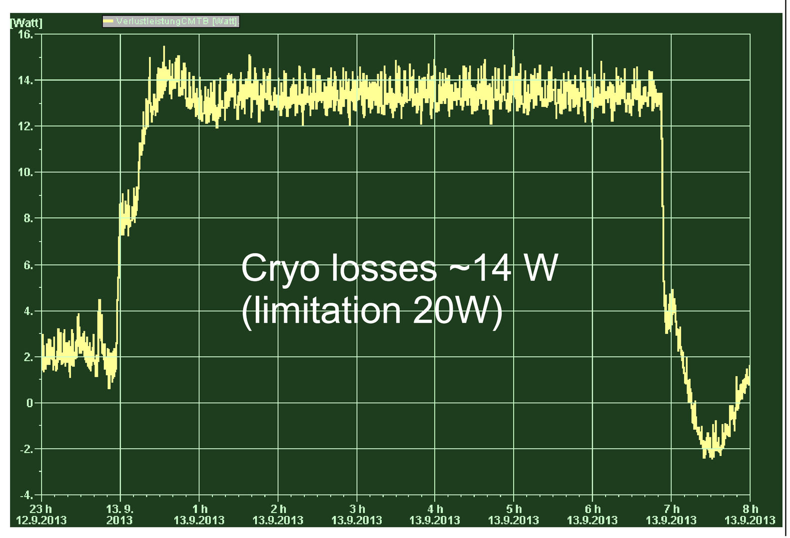

Vector sum amplitude stabilization dA/A = ~3E-3 pp

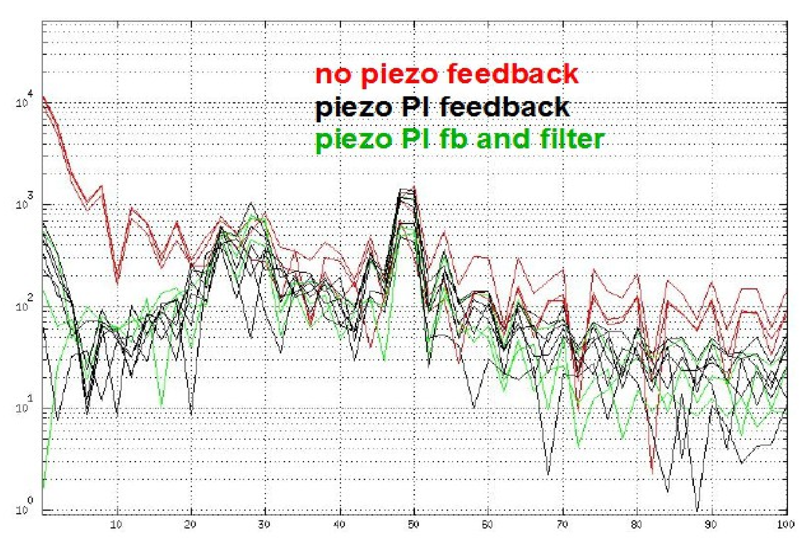
## MTCA.4 system based results

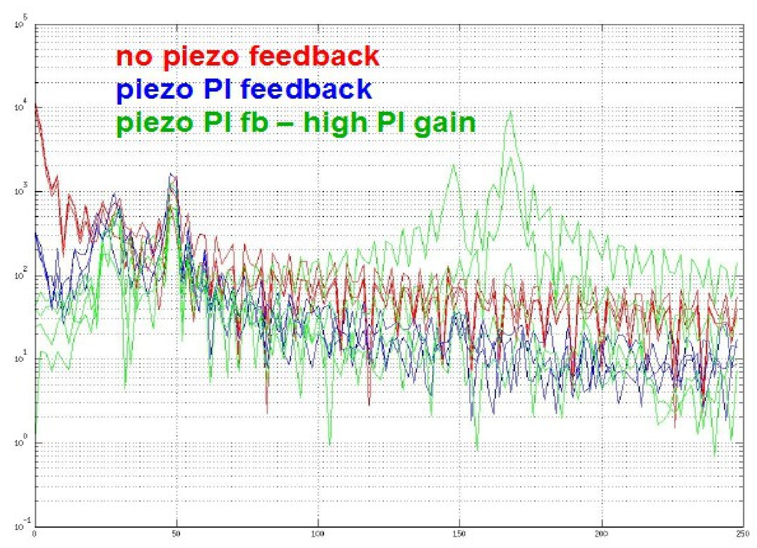
Usual (short pulse operation) conditions:
- pulse ~1,3ms length
- repetition rate = 10Hz,
- sampling rate = 9MHz,
- 16384 samples/waveform (acquisition window of ~1.8ms).

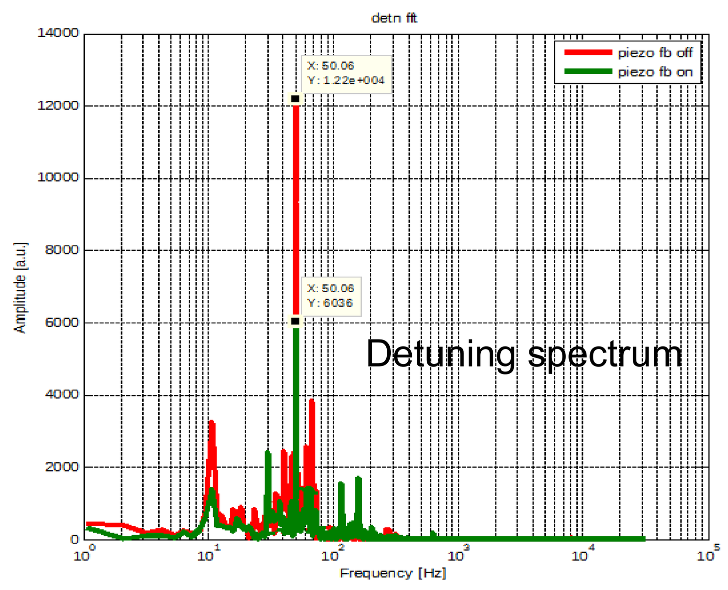
Continuous wave operation:
- repetition rate = 1 Hz,
- acquisition time window = 1s,
- data transfer rate 65kHz – 9MHz,
- 65536 samples/waveform.




## Conclusions & next steps

### Possible improvements

As the CW operation level was achieved according to expectation the LP was not successful for LLRF/piezo loops for operation with higher gradients (above 10 MV/m). Perturbation (50Hz) have not been successfully suppressed. This additional excitation has been caused be the cryo and vacuum pumps. Because of its mechanical nature this distortion has been expected to be minimized by the piezo FB loop. Although the tuner feedback was able to reduce the impact of this oscillations its performance has to be improved

### Conclusions

The successful tests of CW and LP operation of TESLA cryomodule has been presented. Development of control algorithms as well as firmware/software infrastructure towards this test was beneficial in achieved RF and piezo feedback loop performance. Achieved field regulation is near to the X-FEL specification. Options for improvements have been identified, further tests will be performed to identify main microphnics sources and minimize field parameters regulation error.

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