Operation experience from CW/LPO@CMTB

Ponderomotive effects measurement, IOT study, LPO operation - mechanical modes excitation, regulation performance update

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Overview

- Introduction and background
- Cavities operation parameters
- Ponderomotive tests conditions
- Cavities tests results
- Cavity transient behaviour
- IOT studies
- Linearization scheme proposal
- Current performance results

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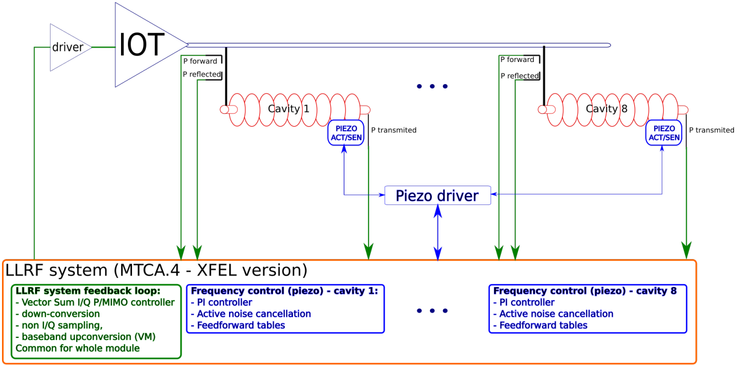
Introduction and background

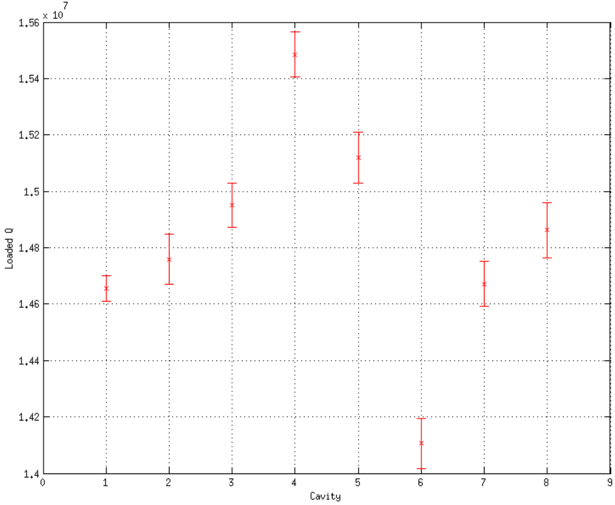


- Vector-Sum based control (LLRF system MTCA.4 based),
- Individual cavity frequency control: step motors - wide range regulation, piezos - fine freq. tuning,
- CPI IOT (max. output of 100kW) used as a main power source (prototypes)

Cavities operation parameters

- 8 TESLA cavities cryomodule under test (XFEL - XM4),
- Cavities operated in CW mode (1Hz repetition rate, Duty Factor $= 1$) up to 12MV/m
- Long pulse operation (1Hz repetition rate, various DF) up to quench limit (up to 22MV/m by now)
- Cavities loading quality factor on the level of 1.5e7 (half BW 40 Hz),

Cavities operation parameters



Ponderomotive effect

- In presence of high gradient of accelerator field the mechanical modes impact on the cavity voltage increases.

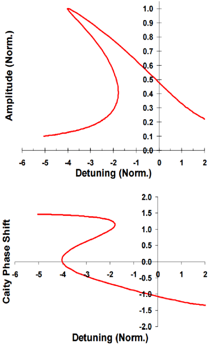


Figure: Ponderomotive effect - cavity "jump"

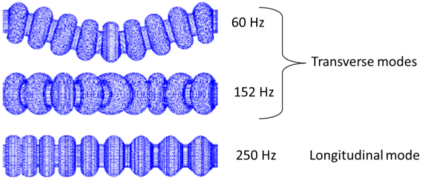


Figure: Cavity mechanical modes

Ponderomotive tests conditions

- Test with piezo DC voltage scan has been performed (in order to characterize LFD influence on the cavity behaviour),
- Test has been performed for constant cavity input power (each scan) in open loop operation mode,
- Cavities have been characterized for 4 different operating power levels,
- Piezo DC voltage has been changed from -20V (from resonance position) to +20V in steps of 1V,
- Piezo tuning coefficient is on the level of 7-8Hz/V

Cavities tests results (1/4)

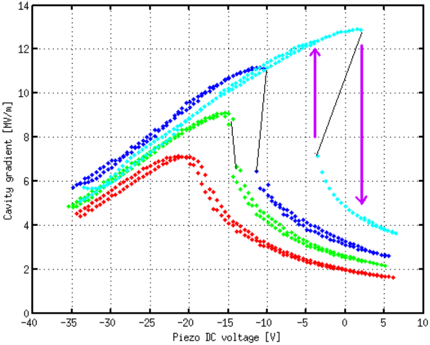


Figure: Cavity 1

- Two (positive, negative direction) scans to evaluate hysteresis,
- Phenomenon more significant for higher cavity gradients,
- Can be challenging in high gradient conditions for CW and for Long Pulse operation,
- Can be **critical in vector-sum control**. Single cavity jump can cause extensive action of RF feedback that leads to next resonator jump - domino effect.

Cavities tests results (2/4)

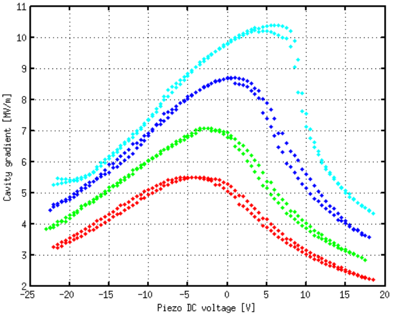


Figure: Cavity 2(QI lowered - HOM heating issue)

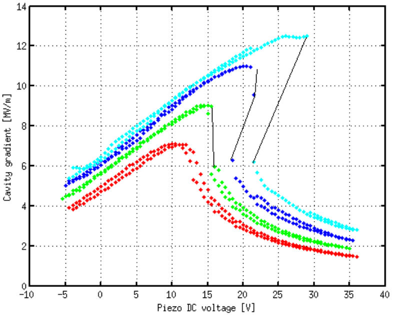


Figure: Cavity 3

Cavities tests results (3/4)

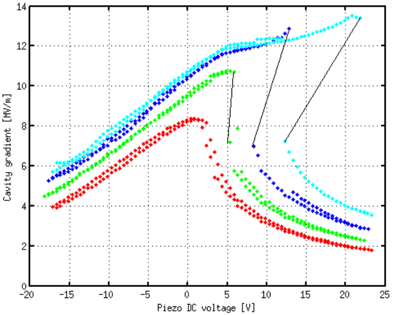


Figure: Cavity 4

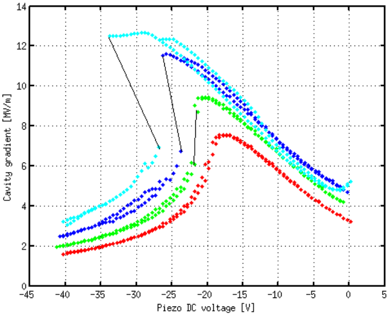


Figure: Cavity 5

Cavities tests results (4/4)

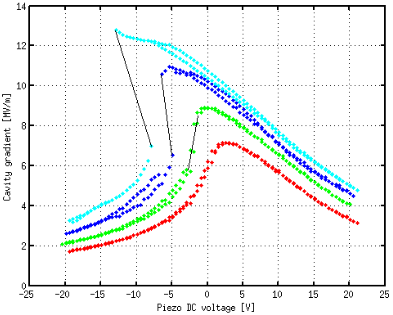


Figure: Cavity 6

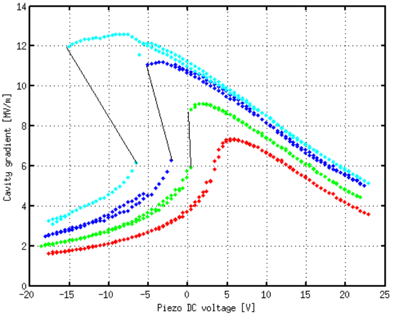


Figure: Cavity 7

Cavity transient behaviour during gradient "jump"

- Operation next to resonance - careful configuration of RF field and resonance regulators,
- **Resonance offset** introduced **for piezo controllers** to maintain safe regulation margin - under investigation,
- **Transient behaviour** suitable for LLRF controller based **exception handling**,
- Different approaches under consideration (controller limiter, piezo based gradient recovery).

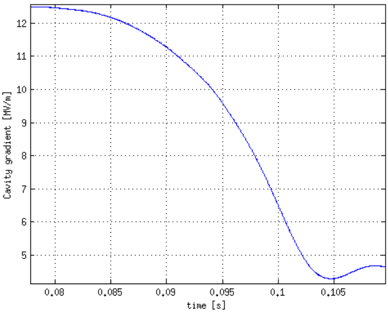
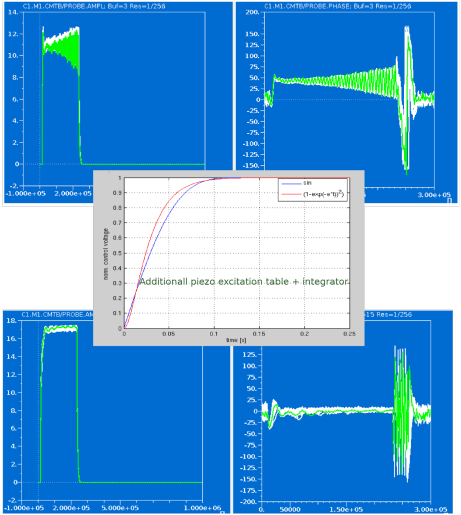


Figure: Cavity 1 transient behavior

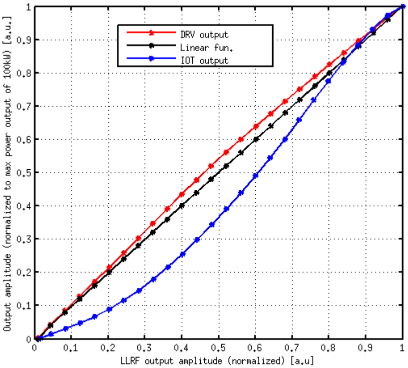
Ponderomotive and Long Pulse Operation case

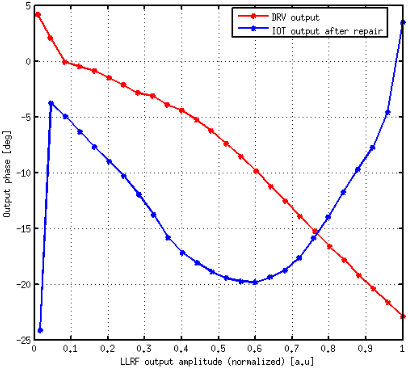
- **LPO introduces** transient behaviour to cavity (IOT **output power drop, phase slope**),
- **Mechanical modes** can be **excited** - not suitable for VS based RF regulation and hardly suppressed by piezo integrator,
- Additional feed forward piezo tables introduced for compensation (extension of piezo controller),
- Successful suppression of fundamental mechanical mode oscillations achieved,
- Idea of **in resonance cavity filling** under investigation,



IOT studies

- **IOT prototype** behaviour characterized (input/output amplitude and phase),
- Examined up to the output power of 100kW (out of 120kW - specs.)

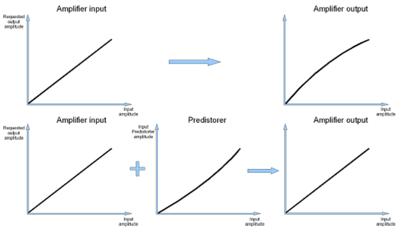


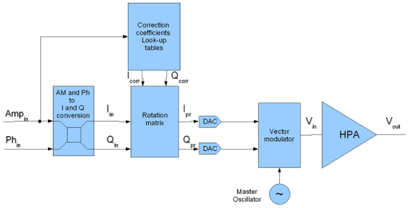


- Amplitude gain nonlinearity as well as phase deviation has to be minimized.
- Digital predistortion scheme is being implemented in LLRF controller

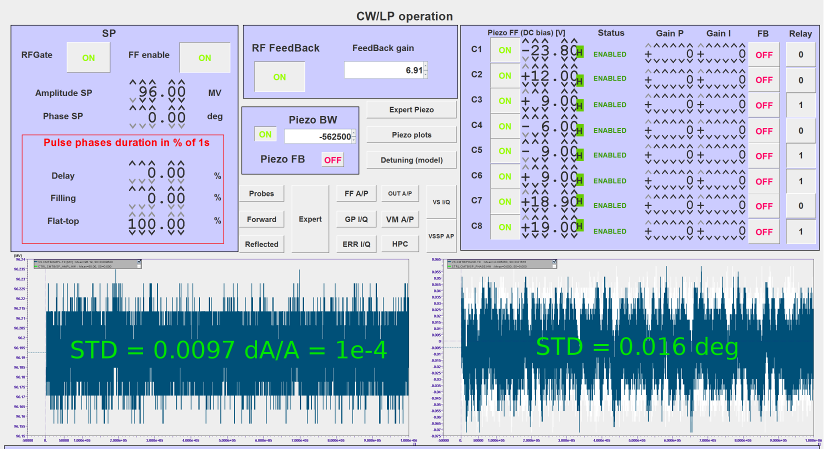
Linearization scheme proposal

- **Different microwave linearization approaches** : Feedforward (with smaller error amplifier), LINC (Linear Amplification with nonlinear amplifiers), Feedback, Predistorter,
- Digital predistortion based on high power amplifier chain characterization have been chosen.





- CW operation VS regulation performance (measured in-loop),
- Both RF fedback and piezo integral controller in operation,



	C1	C2	C3	C4	C5	C6	C7	C8
FOR power [kW]	1.879	1.69	1.83	2.187	1.896	1.965	1.953	1.465
Gradient [MV/m]	10.67	8.21	10.33	12.12	11.03	10.12	10.73	10.01