Operation experience from CW/LPO@CMTB

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


DESY/WUT/DMCS-LUT

25.11.2015
Overview

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

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

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

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

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

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

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

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

Figure: Cavities Q\textsuperscript{l} at CMTB

W.Cichalewski et. al (DESY)

“SRF controls and CW operation”

25.11.2015 5 / 16
In presence of high gradient of accelerator field the mechanical modes impact on the cavity voltage increases.
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
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.

**Figure:** Cavity 1
Figure: Cavity 2 (QI lowered - HOM heating issue)

Figure: Cavity 3
Cavities tests results (3/4)

Figure: Cavity 4

Figure: Cavity 5
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
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
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.
Update on current performance results

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

**CW/LP operation**

- Piezo BW
- RF Feedback
  - Feedback gain: 6.91
- Expert Piezo
- Piezo plots
- Detuning (model)

**Parameters**

- SP
- RFGate: ON
- FF enable: ON
- Amplitude SP: 96.00 MV
- Phase SP: 0.00 deg

**Status**

- C1: ON, Status: ENABLED, Gain P: --, Gain I: --, FB: OFF, Relay: 0
- C2: ON, Status: ENABLED, Gain P: --, Gain I: --, FB: OFF, Relay: 0
- C3: ON, Status: ENABLED, Gain P: --, Gain I: --, FB: OFF, Relay: 1
- C4: ON, Status: ENABLED, Gain P: --, Gain I: --, FB: OFF, Relay: 0
- C5: ON, Status: ENABLED, Gain P: --, Gain I: --, FB: OFF, Relay: 1
- C6: ON, Status: ENABLED, Gain P: --, Gain I: --, FB: OFF, Relay: 1
- C7: ON, Status: ENABLED, Gain P: --, Gain I: --, FB: OFF, Relay: 0
- C8: ON, Status: ENABLED, Gain P: --, Gain I: --, FB: OFF, Relay: 1

**Pulse phases duration in % of 1s**

- Delay: 0.00%
- Filling: 0.00%
- Flat-top: 100.00%

**STD**

- STD = 0.0097 dA/A = 1e-4
- STD = 0.016 deg

**Module cryo loss**

- Module cryo loss: 32.77

**FOR power [kW]**

- C1: 1.879
- C2: 1.69
- C3: 1.83
- C4: 2.167
- C5: 1.896
- C6: 1.965
- C7: 1.953
- C8: 1.465

**Gradient [MV/m]**

- C1: 10.67
- C2: 8.21
- C3: 10.33
- C4: 12.12
- C5: 11.03
- C6: 10.12
- C7: 10.73
- C8: 10.01

---

W. Cichalewski et. all (DESY)

**SRF controls and CW operation**

25.11.2015