RF Operation of the TTF I Cryomodules

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Outline

- The TTF I LLRF system
- LLRF performance
- Modules RF commissioning
- Conclusion and Outlook
The TTF I LLRF System

DSP System
- New hardware, faster DSPs, input channels for the control of 24 cavities (16 connected)
- Exception handling DSP

DSP server software
- Parameter based operation, tables for setpoint, feedback gain and feedforward calculated by server

FSM server software
- Automated operation, simple operator interface
- Application tools
Parameter driven table generator

Tables for feedforward and feedback operation data are derived from the RF operational parameters:

- Setpoint:
  Voltage (calibrated)
  Phase (relative to beam)
  Fill time
  Delay time
  Flat top duration
DSP server features

- Feedforward:
  Derived from setpoint table
  Fill to flat top ratio
  Amplitude scaling
  Phase offset

- Beam compensation:
  Beam current
  Beam phase
  Beam start time
  Beam duration

- Loop Gain
  System Gain
Finite State Machine server features

Set Point
Amplitude
Phase

RF FSM
Control Signal
Amplitude
Phase

Vector Sum of 16 s.c. cavities
Amplitude
Phase

Klystron status
Technical Interlocks

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RF System Diagrams

- With Bunch Compressor

- SuperStructure test
- High gradient operation on Module 1*

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Phase Stability

- Loop phase measurements indicate that “energy jumps” are not a result of “phase jumps” in rf control.

Note: A change in loop phase indicates that a phase change in the forward path (klystron) or the phase reference signal occurs. The measured stability is excellent and demonstrates the superior performance of the klystron phase loop.
Vector-Sum Control of 2 Cryomodules

- Relative amplitude and phase error during 250 µs flat-top are about 0.2% and 2.0 deg. respectively.

![Graphs showing Amplitude Ratio and Phase Difference](image)
Phase adjustment

Before adjustment
First measurement

Module 1* (ACC2)

After adjustment

Module 1* (ACC2)
Lorentz Force Detuning

Measured during “high gradient” operation in Module 1*
- Flat-top detuning at 25MV/m is ~200-450 Hz
- Extrapolation to 30 MV/m yields 300-700 Hz detuning during the flat-top
Microphonics measurement

Module 1

Module 2

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Microphonics measurement (2)
Exception Handling

- Cavity quench detection mechanism (algorithms)
- Exception handling procedure

Module 1* at high gradient

1-st quench in Cavity 2
Eacc=19[MV/m]

2-nd quench in Cavity 6
Eacc=21[MV/m]

3-rd quench in Cavity 1
Eacc=24[MV/m]
Crosstalks

- from klystron 3 (rf gun) to Klystron 1 & 2

klystron 1 with 20 µs (conditioning pulse)
klystron 3 with 500 µs
Conclusion & Outlook

- TTF I LLRF system operational for >2 years
- Basic State Machine for automated operation

Future development

DSP system
- Fast quench detection mechanism by including detuning and loaded Q meas. within DSPs
- Exception handling capability for individual cavities

Extensive upgrade of FSM
- Implement automatic cavity/module tuning procedure
- Automated waveguide tuner control
- Simple common operation panel for all RF systems at TTF2

Adaptive feed forward
- Develop robust and fast algorithm

Improve hardware diagnostic system
- Integrate diagnostic system within operational programs