The challenge of operating a superconducting cavity at 5 Hz bandwidth

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HIE-Isolde at CERN

- HIE-Isolde is a major upgrade of the radioactive beams facility at CERN
- 40 MV superconducting linac based on 32 independently phased superconducting quarter-wave resonators
- 20 SC cavities installed early 2018
HIE-Isolde at CERN

The challenge of operating superconducting cavity at 5 Hz bandwidth. LLRF 2017 workshop Barcelona
HIE-Isolde at CERN

- RF system runs at 101.28 MHz, direct RF sampling and RF generation, direct digital quadrature demodulation

- Cartesian P-I feedback controller, with dynamically calculated set-points, self excited loop, generator driven mode, closed loop operating modes

- Cavities are operated in CW at 5 Hz bandwidth \((Q_{\text{ext}} \sim 2 \times 10^7, \ P_{\text{fwd}} \sim 70 \ W)\)

- 700 W solid state power amplifiers

- Aim to keep the forward power below 100 W
QWR resonance control challenge

- The cavity tuning plate is very thin – large LFD
  - 75 Hz from zero to max field → 25x operating bandwidth (BW)

- Operational experience:
  - Typical microphonics ~0.5-1 BW_{\text{peak}}, perturbation frequencies 50++ Hz
  - Typical “slow” detuning due to “fast” IHe pressure variation up to 10 BW within 30 seconds

- Operating this cavity at high field is not always easy…
Transmitted power method

- The instantaneous cavity tune state can be calculated from the forward and antenna signals

\[ \Delta f = \frac{1}{2} BW \frac{|V_{fwd}|}{|V_{ant}|} \sin(\varphi_{ant} - \varphi_{fwd}) \]

\[ f_{RF}=101.28 \text{ MHz}, \ Q_0=6.6\times10^8, \ BW=5 \text{ Hz} \]
In reality...

- The instantaneous cavity tune state can be calculated from the forward and antenna signals
Reflection coefficient method

- The instantaneous cavity tune state can be calculated from the measured reflection coefficient

\[ I_{fwd} = \frac{V_{acc}}{2R/Q} \left( \frac{1}{Q_{ext}} + \frac{1}{Q_0} \right) - i \frac{V_{acc}\Delta\omega}{\omega R/Q} \]

\[ I_{rfl} = \frac{V_{acc}}{2R/Q} \left( \frac{1}{Q_{ext}} - \frac{1}{Q_0} \right) + i \frac{V_{acc}\Delta\omega}{\omega R/Q} \]

\[ \Gamma = \frac{I_{rfl}}{I_{fwd}} \]

\( f_{RF}=101.28 \text{ MHz}, Q_0=6.6\times10^8, \text{ BW}=0.5,1,2,5,10 \text{ Hz} \)
In reality...

- The instantaneous cavity tune state can be calculated from the measured reflection coefficient
In reality...

- The instantaneous cavity tune state can be calculated from the measured reflection coefficient.
In reality...

- No tuner movement in 2 hours, cavity freq. within +/-2.5Hz
In reality...

- Slow lHe pressure variation with a minute cycle
In reality…

- Then the perturbation comes…
A way out?

- Is there a more “quiet” signal representing the cavity tune state?
A way out?

- The integral loop contribution can be used to **estimate** the cavity resonant frequency instead of **measuring** it using the very dynamic Fwd/Rfl signals.

- Phase information seems to be sufficient for reliable tuning.

- No need for minimum finding regulator \(\rightarrow\) no tuner movement.

- Method already tested in the machine, very promising results.
Thank you for your attention
LLRF system for a complete cryomodule housing 6 cavities

- Fast RF interlock crate
- Front end computer
- 6x LLRF controller
HIE Isolde LLRF controller
Simplified function block diagram
HIE Isolde LLRF controller
Simplified function block diagram

Self Excited Loop mode
HIE Isolde LLRF controller
Simplified function block diagram

Generator driven (open loop) mode
HIE Isolde LLRF controller
Simplified function block diagram

Feedback mode (cavity locked)