PATHWAY TO INCREASING THE QUALITY FACTOR OF SRF CAVITIES

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Introduction

- CW operation of SRF cavities
- Cryogenics = cost driver
- Minimize cryogenic load $P_{\text{diss}} \sim R_{\text{surface}} \sim \frac{1}{Q_0}$
- $R_{\text{surface}} = R_{\text{BCS}}(f, T) + R_{\text{residual}}(?)$
  - physics
  - originates to great fraction from trapped vortices (incomplete Meissner effect)
- We found a way to reduce trapped flux
$Q_0$ measurements

- HoBiCaT test facility
- Temperatures down to 1.5 K
- Horizontal, fully equipped cavity weld into Helium tank
- Near $\beta=1$
Cavity cool down procedure

Temperatures of cool down

Fast transition through (150 K – 50 K)

- Large temperature differences $\Delta T$
- Large spatial gradients $dT/dz$
- Large temporal gradients $dT/dt$
$R_{\text{surf}}$ after initial cooldown

$Q_0 = 1.5 \cdot 10^{10}$ at 1.8 K

$R_{\text{res}} = 13.2 \text{ n}\Omega$

$4 \text{ MV/m}$

Temperature of Helium bath / K

$R_{\text{surf}}$ [nΩ]
Thermal cycling procedure

- Start with superconducting cavity
- Turn off Helium supply (JT valve)
- Evaporate Helium in tank
- Wait. Make sure cavity is just above $T_c$ and normal conducting.
- Restart cryo plant
Influence of thermal cycling on $R_{\text{surf}}$

- Initial cooldown: $R_{\text{res}} = 13.2 \, \text{n}\Omega$
- 1st cycling: $R_{\text{res}} = 5.4 \, \text{n}\Omega$
- BCS theory

Temperature of Helium bath / K

- $Q_0 = 1.5 \cdot 10^{10}$
- $Q_0 = 2.7 \cdot 10^{10}$

4 MV/m
Effect reversible?
Effect reversible?

Temperatures of second cycle

- He inlet
- Coupler side #1
- Coupler side #2
- Tuner side

Log scale for temperature and time.
Influence of thermal cycling on $R_{surf}$

**Graph Description:**
- X-axis: Temperature of Helium bath / K
- Y-axis: $R_{surf}$ [nΩ]
- Data points:
  - Initial cooldown: 5.4 nΩ
  - 1st cycling: 13.2 nΩ
  - 2nd cycling: 7.4 nΩ
  - 3rd cycling: 5.3 nΩ
- Magnetic field strength: 4 MV/m
Discussion: Reason for $R_{res}$ variation

$R_{res}$ development: $13.2 \, \text{n}\Omega \rightarrow 5.4 \, \text{n}\Omega \rightarrow 7.4 \, \text{n}\Omega \rightarrow 5.3 \, \text{n}\Omega$

Cycling leads to decrease ... increase ... decrease

- **Efficacy of magnetic shielding?**
  No! Permeability measurements of shield yielded no temperature dependance in relevant region AND $R_{res}$ increase should not be possible.

- **Chemistry? Adsorbate removal?**
  No! $R_{res}$ increase should not be possible.

- **But! Increase could have been caused by Q-disease in heavier cycling run.**
  No! Subsequent $R_{res}$ decrease should not be possible.

- **Thermocurrents due to temperature gradients**
  Possible. Performed measurements in model system.
Thermocurrents

Thermoelectric effect:
Voltage due to material and temperature dependent charge carrier velocity

\[ U_{\text{thermo}} = (S_{\text{Niobium}} - S_{\text{Titanium}}) \cdot \Delta T \]

S are Seebeck coefficients

Set up model experiment

Master thesis Julia Vogt, see poster WEPWO004 for further details
Trapped flux and temperature gradient

Findings:

• Thermocurrents could be measured (mA range)

• Thermocurrents create a magnetic field and this field can be trapped as frozen flux

• Linear correlation between trapped flux and temperature gradient
Trapped flux and temperature gradient

\[ B_{\text{trapped}} \quad \Delta T \quad \text{Slope: } (-0.565 \pm 0.04) \mu T/K \]
Flux expulsion at different cooling rates

Measurement: Keep rod isothermal and cool through $T_c$
Logarithmic dependence of expelled flux from cooling rate
Flux expulsion at different cooling rates

Slope: \((-0.029 \pm 0.002\) \(\mu T/\log(mK/s)\)
Flux expulsion at different cooling rates

Measurement: Keep rod isothermal and cool through T_c
Logarithmic dependence of expelled flux from cooling rate

Interpretation:
• Meissner state = energetically lowest state
• Flux expulsion not instantaneous (unlike Meissner transition)
• Mobility of flux lines highest near T_c
• The less time is available in the high mobility region, the less field is expelled from the sc
Conclusion

• Improve $Q_0$ by thermal cycling
• Factor of 2 improvement is demonstrated
• It appears that thermal currents are responsible for extra flux trapping
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