Capillary cooling of AC superconducting coils with preliminary experiments using nitrogen

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Cryogenics Vol.84 (2017) pp.29–36

This research is funded partly by the Bundes Ministerium für Bildung und Forschung (project executing organization: LR Projektträger) under project "Robuste Kühlung und Sicherheitsdiagnostik für supraleitende Motoren" (ROKSS) - KMU Innovativ Oktober 2014 (support code: 01LY1504B).
schematic cross section of a superconducting motor (capillaries and other cooling infrastructure not shown)

- superconducting coils
- vacuum
- iron joke
- rotor with permanent magnets
flow of cryogenic liquid

- LH2 reservoir (about 2 bar)
- vent (1 bar)
schematic cross section of part of a winding

- blue: LH2
- dark grey: capillary wall
- dark red: copper strip
- light red: superconductor
- light grey: insulation
idealized flow in the capillary

\[ p_0 - p_1 \approx \frac{4}{\pi^2} f_r \frac{L_C}{\rho_V D_C^5} m_w^2 \]
AC losses simulated by Joule heating in the capillary wall
the reservoir
T oscillations for heating near critical value
the instability may be an important sign for upcoming quench which is not trivial in AC applications and needs further analysis

ongoing investigation
Based on heat conduction

$$\dot{Q}_{Re} = \frac{A_w}{l_R - l_L} I_{aR}$$

energy conservation

$$\dot{Q}_R = \frac{dU_R}{dt} + m^* c h_L + m^* c h_G$$

mass conservation

$$\frac{dm_R}{dt} = -m^* c - m^* G$$

capillary flow properties

$$p_R \approx p_0 + \frac{4}{\pi^2} f_r \frac{L_C}{\rho_G D_C^5} m_C^2$$
Dynamic situation

\[
\frac{dT_R}{dt} = \frac{A_w}{\rho_L A_R \frac{du}{dT_R} (l_R - l_L) l_L} I_{aR}
\]

it takes about 25 minutes to build up a pressure of 0.4 bar.

Steady state with open relieve valve if

\[
\dot{Q}_R > L_L \frac{\rho G^*}{\rho_L} m_C \approx 0.1 \text{ W}
\]
Conclusion

Capillary cooling is a promising way to cool the coils of superconducting motors.