Capillary cooling of AC superconducting coils

with preliminary experiments using nitrogen

A.T.A.M. de Waele, B. Oswald, J. Oswald, T. Reis

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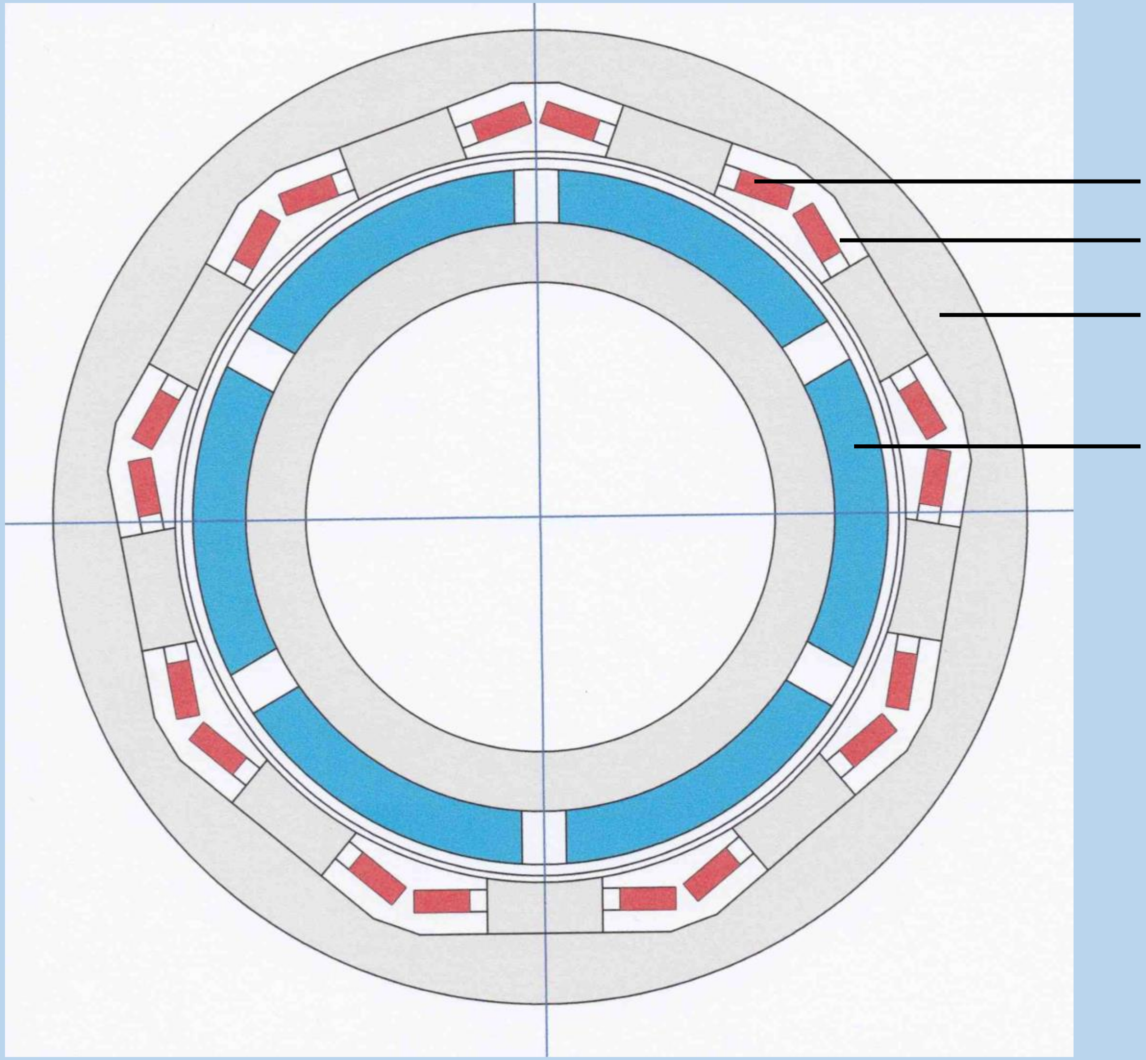
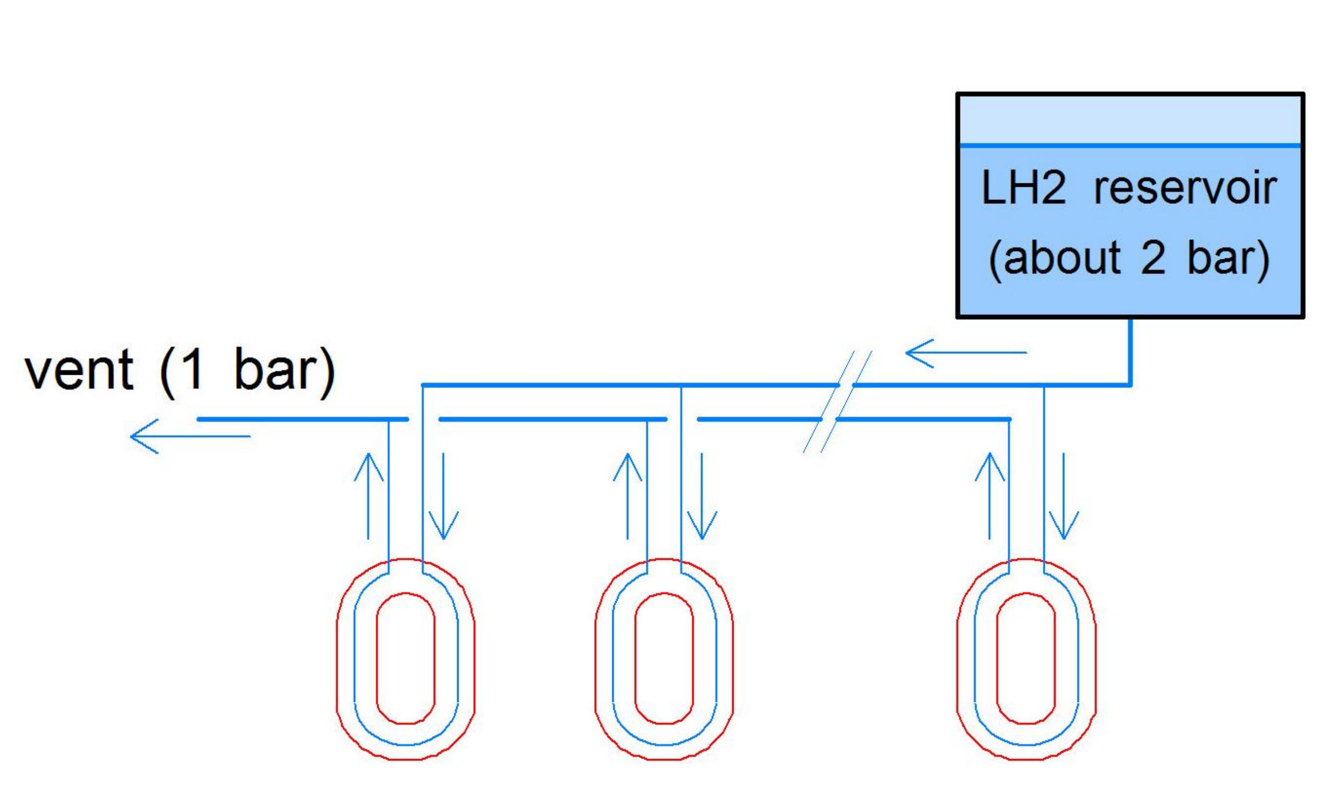
schematic cross section of a superconducting motor (capillaries and other cooling infrastructure not shown)



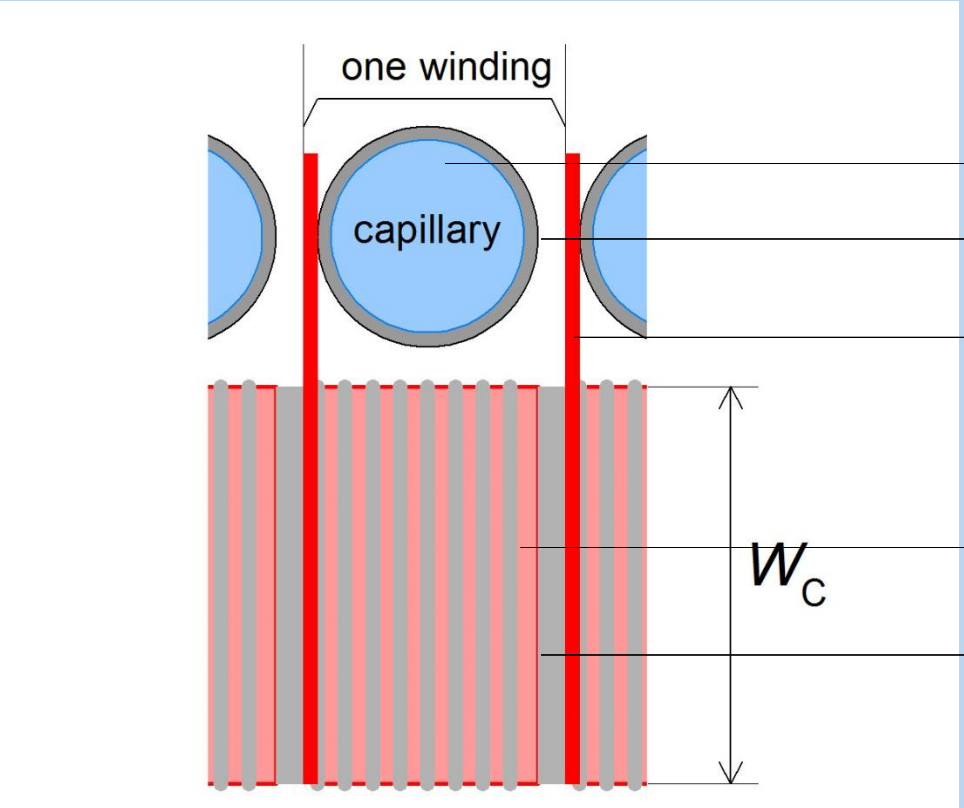
flow of cryogenic liquid



über 100 OSWALD

100 Jahre Elektromotoren

schematic cross section of part of a winding



blue: LH2

dark grey: capillary wall

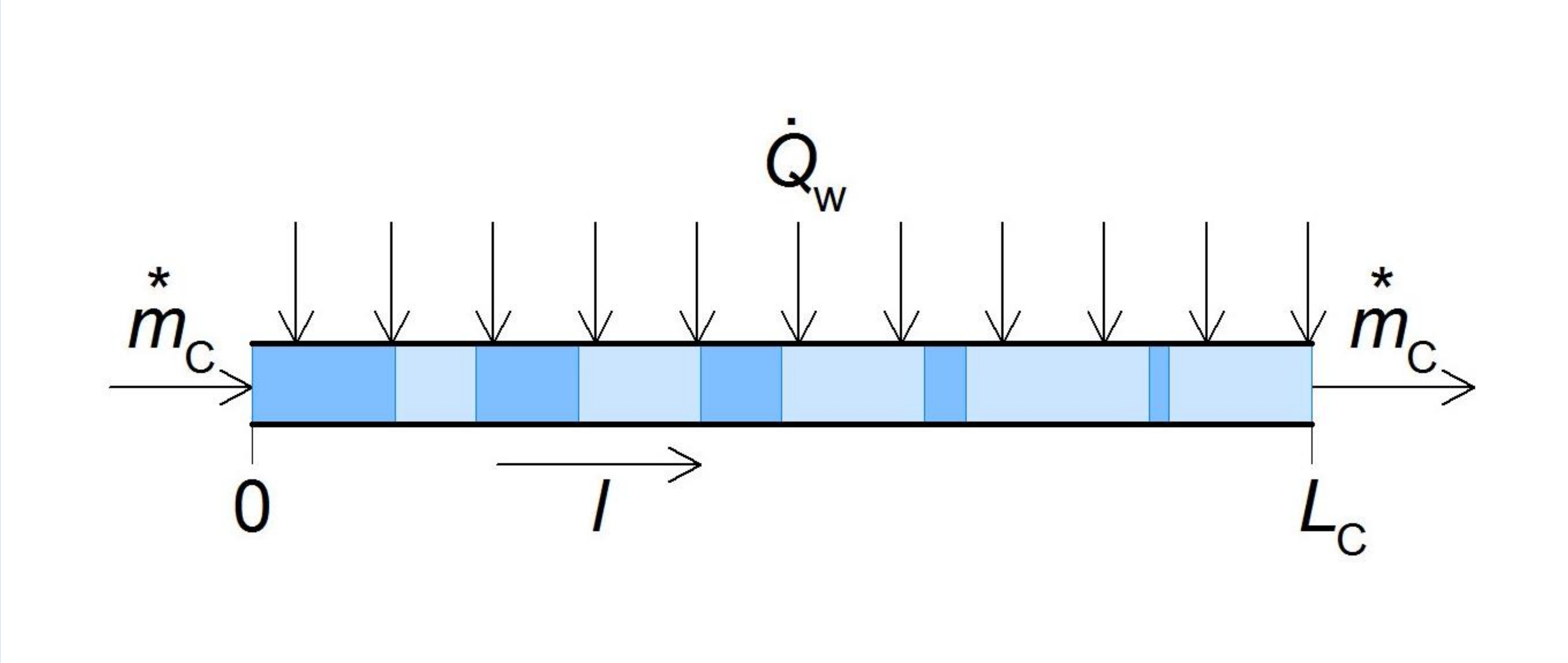
dark red: copper strip

light red: superconductor

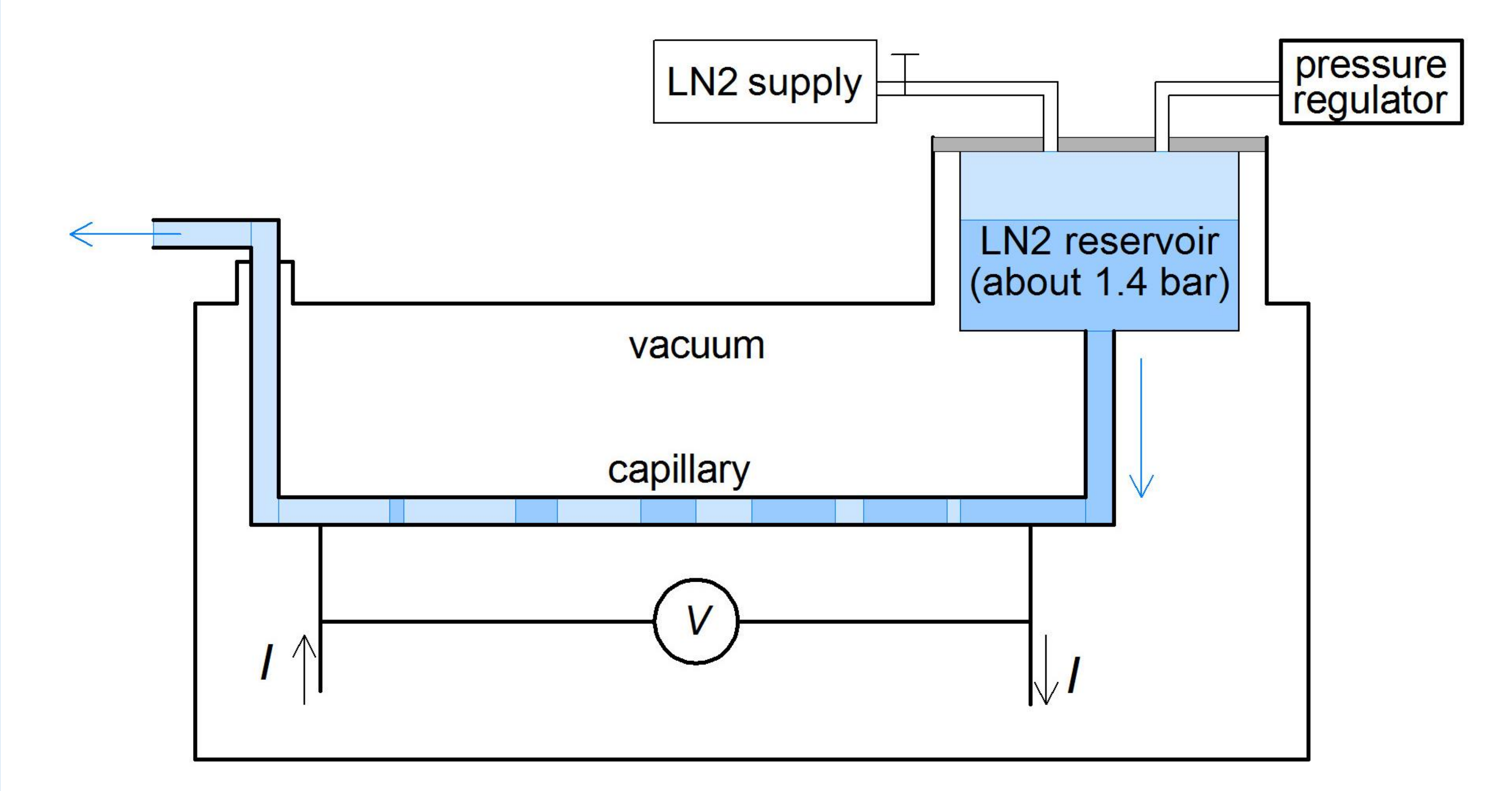
light grey: insulation

idealized flow in the capillary

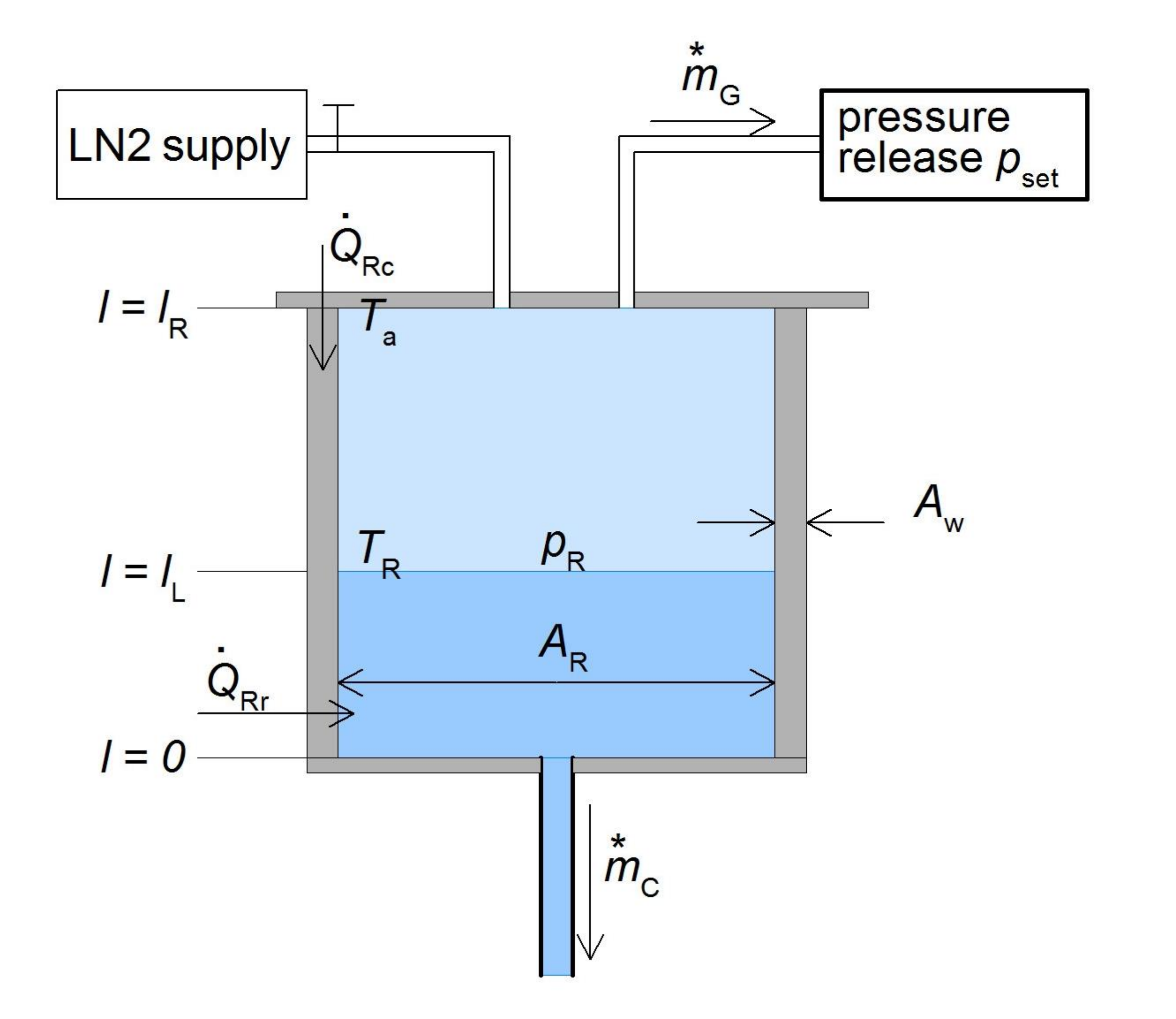
$$p_0 - p_1 \approx \frac{4}{\pi^2} f_{\mathrm{r}} \frac{L_{\mathrm{C}}}{\rho_{\mathrm{V}} D_{\mathrm{C}}^5} \overset{*}{m}_{\mathrm{w}}^{\,2}$$



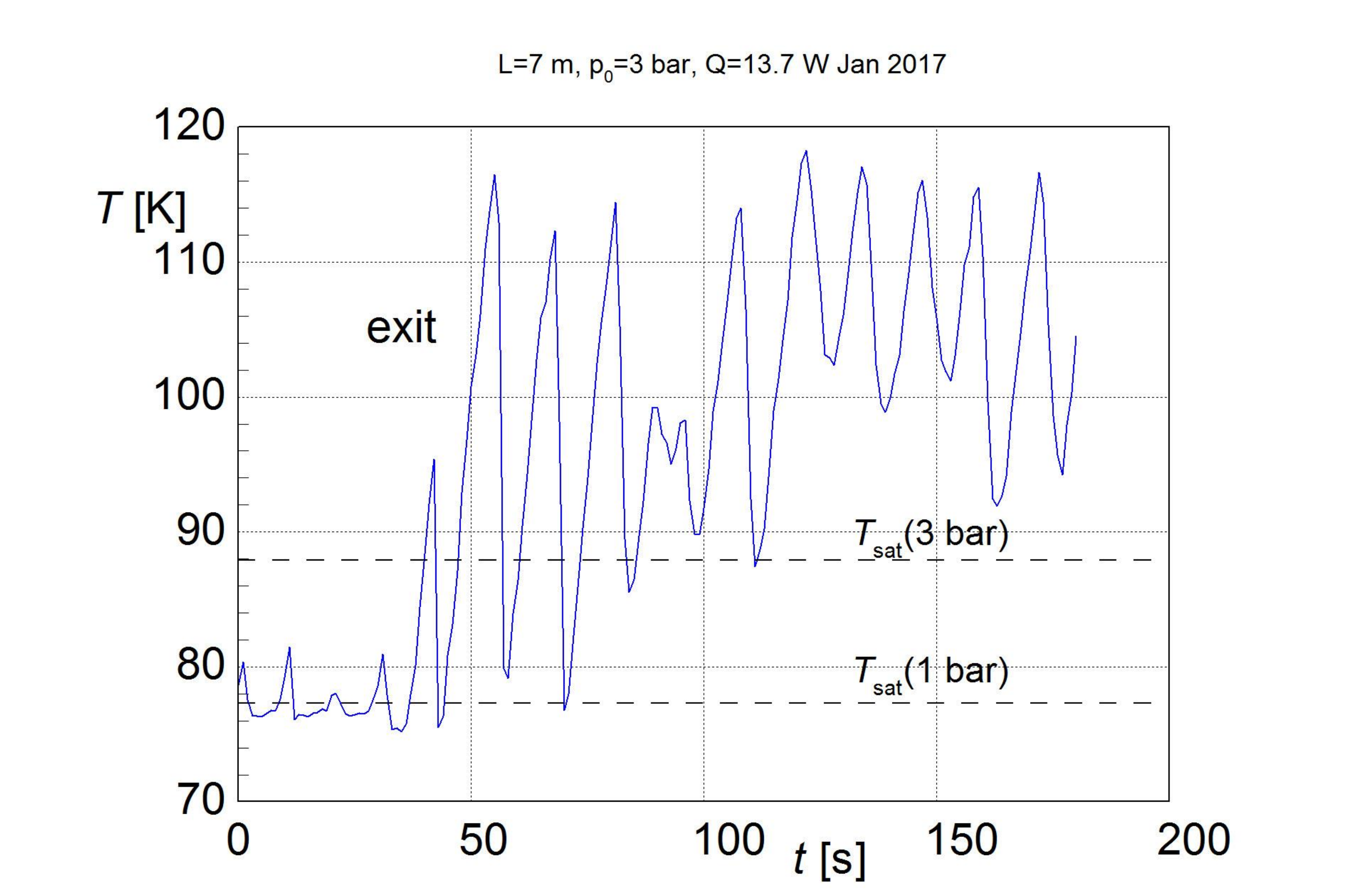
AC losses simulated by Joule heating in the capillary wall



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

$$\dot{Q}_{\mathsf{Rc}} = \frac{A_{\mathsf{W}}}{l_{\mathsf{R}} - l_{\mathsf{L}}} I_{\mathsf{aR}}$$

energy conservation

$$\dot{Q}_{\mathsf{R}} = \frac{\mathrm{d}U_{\mathsf{R}}}{\mathrm{d}t} + \overset{*}{m}_{\mathsf{C}} h_{\mathsf{L}} + \overset{*}{m}_{\mathsf{G}} h_{\mathsf{G}}$$

mass conservation

$$\frac{\mathrm{d}m_{\mathsf{R}}}{\mathrm{d}t} = -\overset{*}{m}_{\mathsf{C}} - \overset{*}{m}_{\mathsf{G}}$$

capillary flow properties

$$p_{\mathsf{R}} \approx p_0 + \frac{4}{\pi^2} f_{\mathsf{r}} \frac{L_{\mathsf{C}}}{\rho_{\mathsf{G}} D_{\mathsf{C}}^5} \overset{*}{m}_{\mathsf{C}}^2$$

Dynamic situation

$$\frac{\mathrm{d}T_{\mathsf{R}}}{\mathrm{d}t} = \frac{A_{\mathsf{W}}}{\rho_{\mathsf{L}} A_{\mathsf{R}} \frac{\mathrm{d}u_{\mathsf{L}}}{\mathrm{d}T_{\mathsf{R}}} \left(l_{\mathsf{R}} - l_{\mathsf{L}} \right) l_{\mathsf{L}}} I_{\mathsf{aR}}$$

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

Steady state with open relieve valve if

$$\dot{Q}_{\mathsf{R}} > L_{\mathsf{L}} \frac{\rho_{\mathsf{G}}}{\rho_{\mathsf{L}}} \overset{*}{m}_{\mathsf{C}} \approx 0.1\ \mathrm{W}$$

conclusion

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