Study of loss of vacuum in a tube cooled by liquid helium

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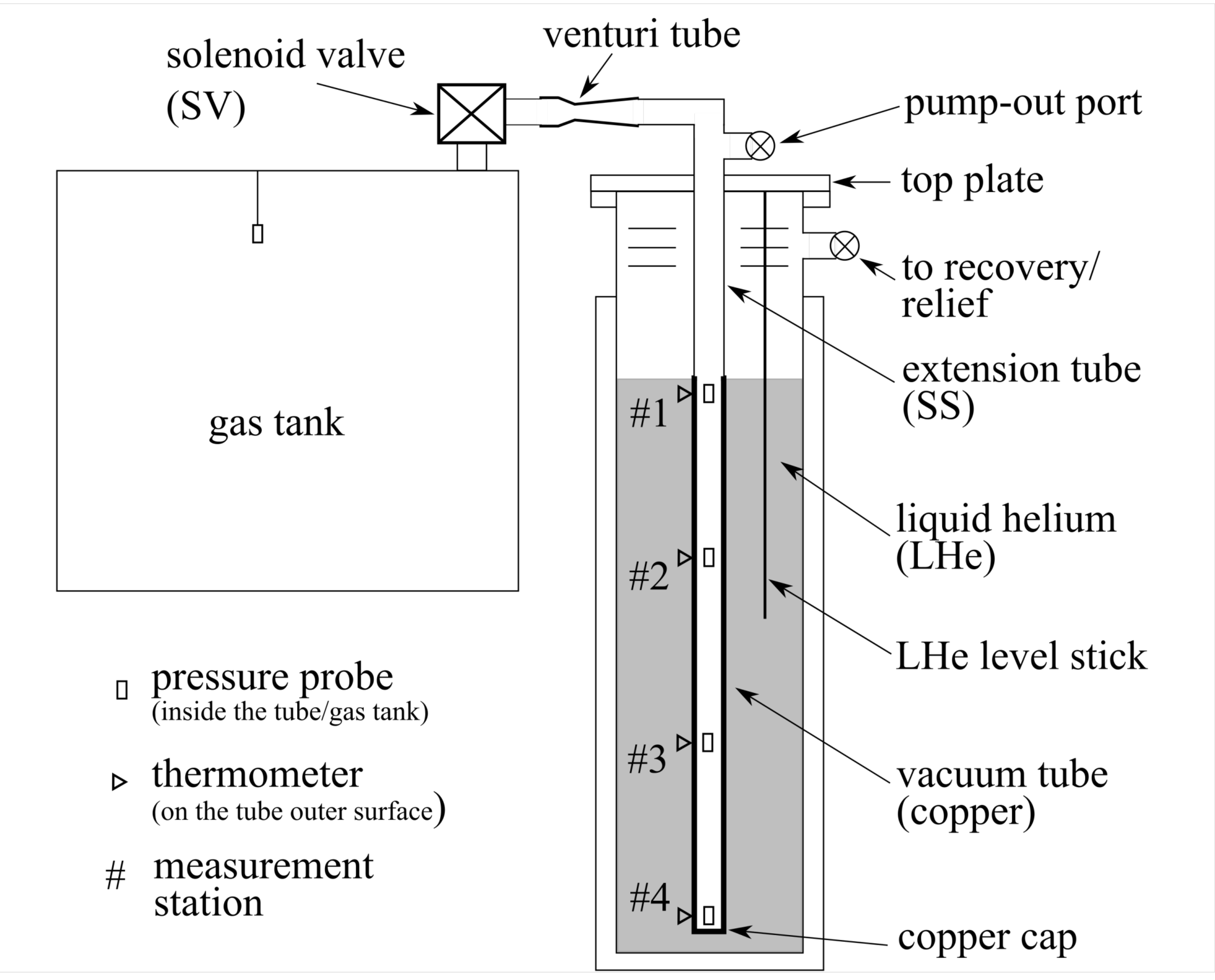
Introduction

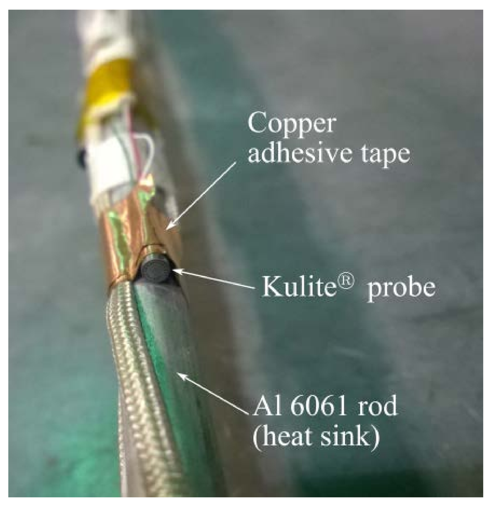
SRF accelerators can catastrophically fail due to an accidental loss of the liquid helium cooled cavity string vacuum to the surrounding atmosphere. The atmospheric air will propagate down the cavity channel vacuum, condense on the cold channel wall, and transfer large heat fluxes to the adjacent liquid helium. In this work, we study the effects of such a scenario using a laboratory scale simplified version of an SRF cavity channel. The parameters investigated are:

1) Speed of air propagation along the vacuum channel

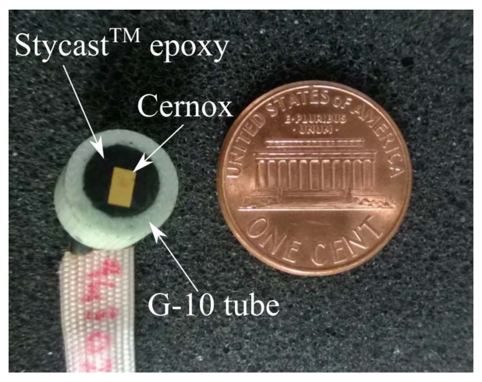
2) Air condensation heat transfer rate to the channel wall.

Experimental setup





Heat sunk pressure probe



Epoxied thermometer

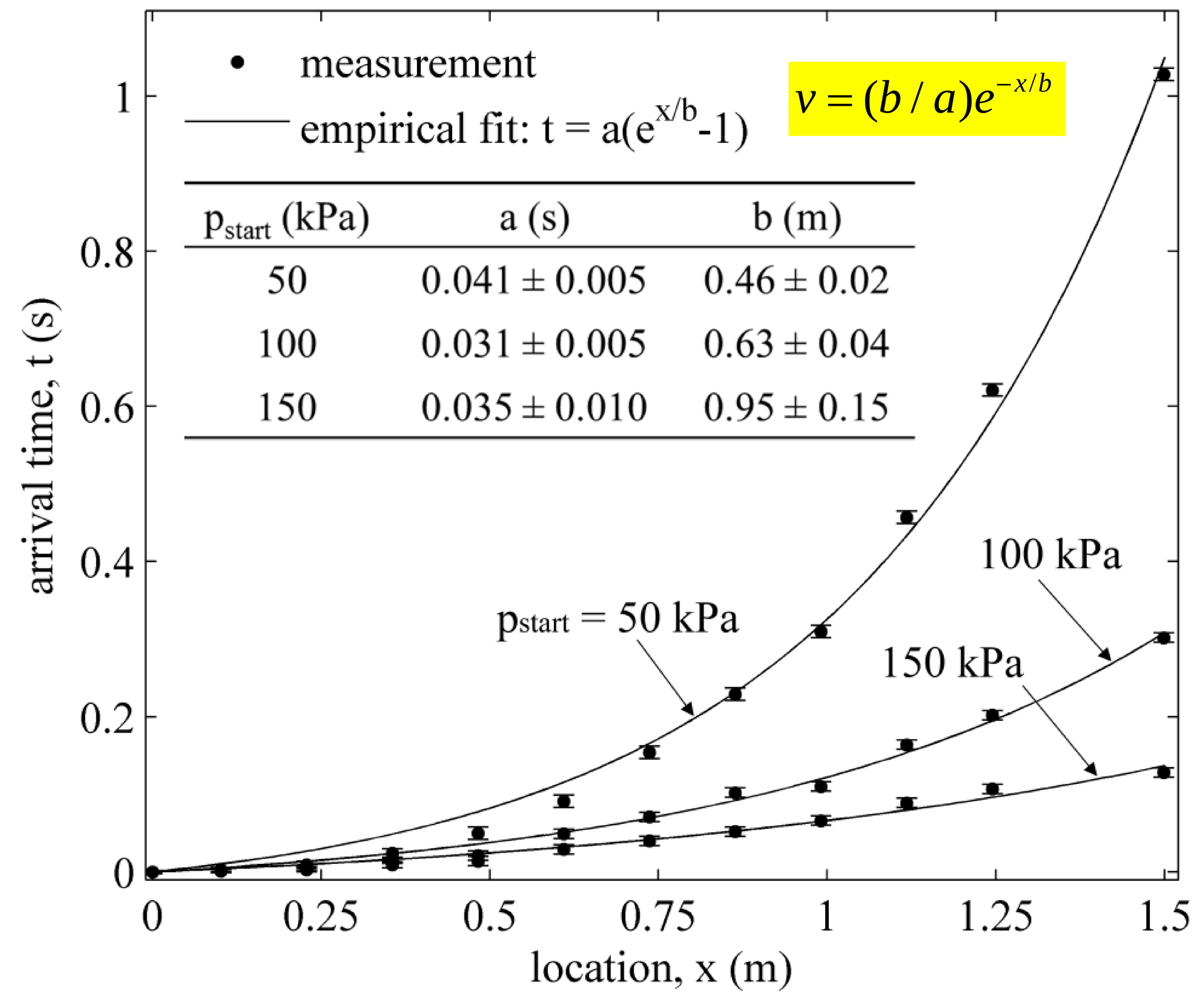
Schematic of the experimental setup (top) and photographs of the sensors used/developed (bottom) to measure the air propagation speed. The channel has twelve measurement stations, only four are shown to avoid crowding.

Air propagation speed

Based on conservation of mass in the gas phase, the front speed v in a vacuum tube of diameter D is given by:

$$v|_x = \frac{\dot{m}_{inlet} - \pi D \int_0^x \dot{m}''_{con}(X,t)\,dX}{\left(\pi D^2/4\right)\rho_{air}|_x} \quad (1)$$

where $\dot{m}_{inlet}$ is the mass in-flow rate, $\dot{m}''_{con}$ is the mass deposition rate, and $\rho_{air}|_x$ is the air density at the front. As the front propagates, x will increase and expression (1) tells that the integral should increase with x. Physically this means that a greater proportion of the in-flowing gas condenses on the tube wall. Intuitively then the front speed should decrease along the vacuum channel.

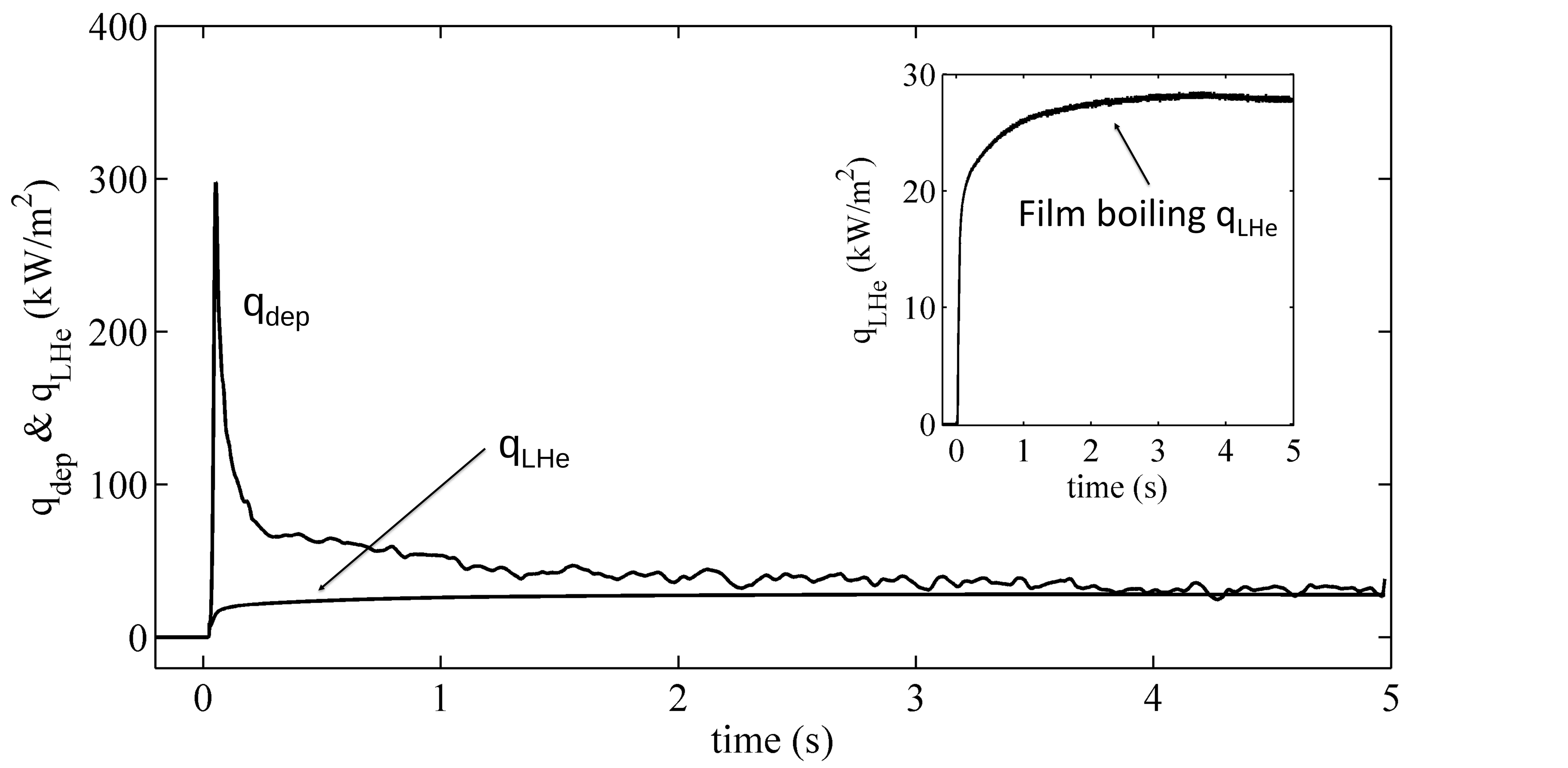


Measured front arrival times at twelve locations along the vacuum tube

What we observed from experiments: Gas front decelerates nearly exponentially along the channel.

Condensation heat transfer rate

The local air condensation heat transfer rate on the channel: $q''_{dep} = \frac{OD^2 - ID^2}{4ID}\left(\rho c \frac{dT}{dt}\right)_{wall} + \frac{OD}{ID} q''_{LHe}$



Representative local air condensation heat transfer rate and representative local heat load to liquid helium (inset) obtained from the channel wall temperature measurement. Similar behavior is seen at all the twelve measurement stations.

What we observed from experiments:

1) Vacuum channel can see very large transient heat deposition rates, although a major fraction of this incident heat remains in the channel wall heat capacity.
2) Heat actually transferring to the liquid helium is limited by film boiling in the liquid adjacent to the channel wall.

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