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Onset of thermoacoustic oscillations in flexible transfer lines for liquid helium

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Abstract

Thermoacoustic oscillations in flexible transfer lines result in an increased evaporation rate of stored cryogen. This kind of oscillation is barely regarded since it only occurs in idle state, i.e. no liquid helium is transferred and a considerable part of the transfer line is close to ambient temperature. The examination of prototype transfer lines with built-in sensors has resulted in a unique knowledge of the oscillation characteristics. As a consequence thermoacoustic oscillations are considered as a common phenomenon in idle flexible transfer lines. The presented paper discusses the conditions for the establishment and a strategy for mitigating thermoacoustic oscillations.

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1. Introduction

In general, thermoacoustic oscillations occur spontaneously if a half-open tube e.g. a transfer line is inserted into a liquid helium reservoir. The transfer line is open at the cold end (i.e. the liquid helium reservoir) and closed at the warm end (i. e. angle valve of the transfer line). Since the temperature at the cold open end is equal to the saturation temperature of helium and the warm end temperature is close to ambient temperature, the temperature ratio $\alpha = T_h/T_c$ is usually greater than 60 and the system will tend to oscillate. Besides the general requirements of a half-open tube and a large temperature ratio, the onset of a thermoacoustic oscillation is influenced by the transfer line geometry and the ratio between the warm and the cold length of the tube $\xi = l_h/l_c$, too. Existing publications consider the onset of thermoacoustic oscillations theoretically [1] and experimentally [2], [3] in straight, mostly uninsulated pipes. Since the geometry of a transfer line, e.g. u-bend shape, vacuum insulated pipes, differs from the simple geometry of a straight pipe the applicability of published results has to be verified. For that purpose a standard storage vessel has been equipped with an experimental transfer line of typical dimensions. The latter can be monitored during the

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transfer of liquid helium and in idle state by inbuilt temperature and pressure sensors. If thermoacoustic oscillations do occur in liquid helium transfer lines their impact on the stored cryogen has to be considered. This concerns mainly the increased evaporation rate which results in a greater re-liquefaction effort. Besides that a steeper rise of the storage pressure might cause safety issues if not detected. Furthermore, a strategy to reduce the intensity of thermoacoustic oscillations is presented which does only require minor modifications of the transfer line design.

2. Experimental setup

In order to examine the onset of thermoacoustic oscillations in cryogenic transfer lines, a liquid helium storage vessel of 2.5 m^3 capacity has been equipped with an experimental transfer line whose detailed description is published in [4]. The transfer line consists of two rigid vertical and one flexible horizontal sections. Its flexibility is achieved by a corrugated tube with an inner diameter of 8.3 mm. The rigid conduits inner diameter is 6 mm whereas the corresponding outer pipe has a diameter of 12 mm. A pneumatically actuated angle valve is located at the end of the flexible section. The experimental transfer line can be equipped with an optional spring-loaded foot valve at the inlet to examine its influence on the onset of thermoacoustic oscillations during idle state. In idle state no liquid helium is transferred and the line is allowed to warm up.

The applied in-line pressure transmitters and temperature sensors are numbered according to their appearance in the flow direction (see Figure 1a). Pressure transmitter 1 is located at the upper end of the first vertical section. Transmitter 2 is situated right before and transmitter 3 right after the flexible horizontal section. The temperature sensors 1 to 3 are numbered and positioned accordingly. The temperature sensor labeled T_{in} is located 260 mm from the inlet of the transfer line. All temperature values are acquired with a frequency of 0.25 Hz whereas the pressure signals are acquired with a sampling rate of 500 Hz. The applied pressure transmitters have a maximum error band of ± 0.1 % and a range of 80 kPa_g. All pressure transmitters are connected with the inner conduit of the transfer line via capillaries. During the commissioning of the experimental transfer line measurements were conducted to ensure that these capillaries do neither influence the onset of thermoacoustic oscillations nor dampen the achieved pressure signals. Silicon diodes type DT-670-SD, having a measurement error of ± 0.25 K, are applied to the outer wall of the inner conduit.

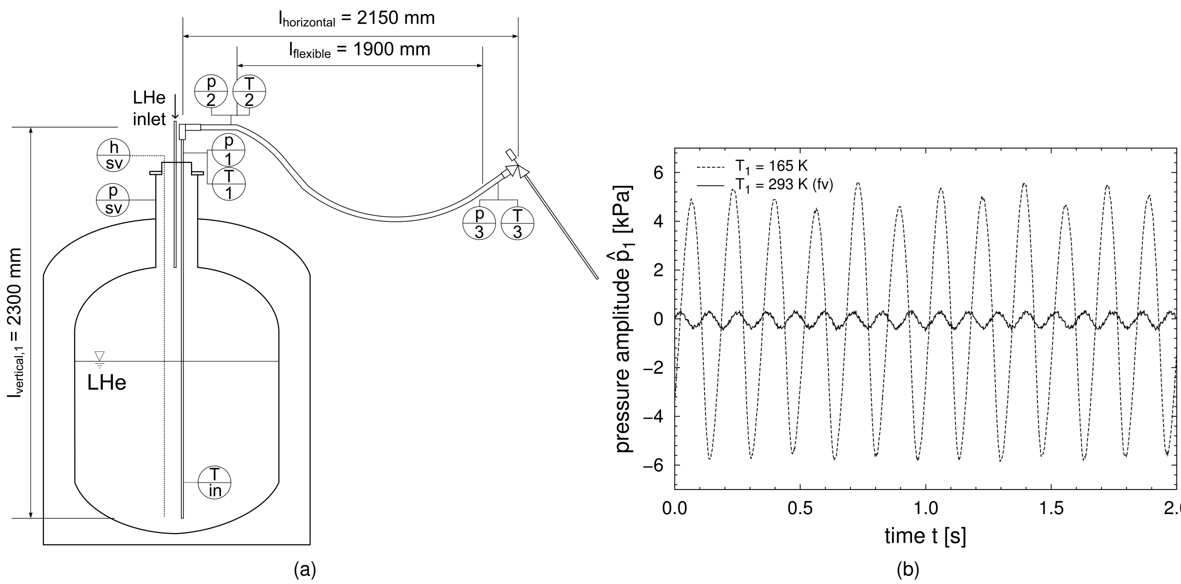

Fig. 1: (a) Scheme of the test setup at the liquid helium decant station (all horizontal dimensions refer to an elongated line); (b) Pressure amplitudes of a thermoacoustic oscillation at different temperatures T_1 (abbreviation *fv* indicates that values are achieved with an continuously opened foot valve installed at the transfer line inlet).