Occurrence of Thermoacoustic Phenomena at 0.8 K, 4 K and above

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Abstract

Thermoacoustics in cryogenics continues to be a very interesting phenomenon which is still poorly understood but often experienced unexpectedly in experiments where it causes unacceptable heat leaks. The authors report on the appearance and onset of this unwanted occurrence at temperatures below 35 K. A number of physical experiments are presented, where the authors had the means to take quantitative measurements of the heat leak caused by these pressure oscillations in apparatus with bent tubes ranging from 4.55 and 4.7 mm inner diameter, with heat stationing links. The parameters which indicate the likelihood of inadvertently developing these thermoacoustic oscillations are presented and means developed to avoiding them in that instance are given. Furthermore, we had the rare opportunity to record and analyze 4 K TAOs experienced on a test setup and present the simple method that was used to eliminate them..

I. Introduction

When designing a cryostat or component that will become part of a cryostat (e.g. an insert with tubing) one turns to well-established cryogenic practices and guidelines how the cryostat has to be built. Nowadays, we have good and field proven design tools at hand to analyze heat sources for minimum boil-off or for reduced heat leaks.

II. Cases

Sometimes however, desired cryostat functionalities force us to introduce components, and more specifically small diameter tubing we know that are likely to create thermoacoustic oscillations (TAOs) that we would rather leave out, if we had a choice. In any case, we need to be fully aware at the design stage of what the consequences would be and whether we are ready to accept that or need to plan ahead to minimize the impact on the planned thermal budget.

In the following we describe case studies of the onset of several unexpected thermoacoustic oscillations, that – according to theory – should not have been present.

Case 1

Non-spontaneous "driven" thermoacoustic oscillations of transient nature on a helium gas tank inlet line.

POC (point of contact)

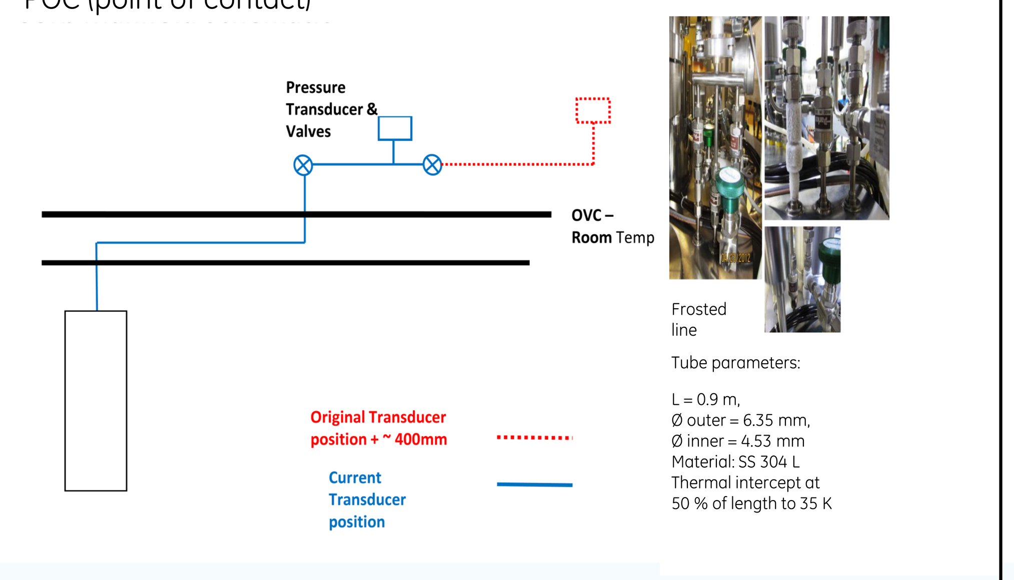

Fig. 1 Schematics gas tank inline

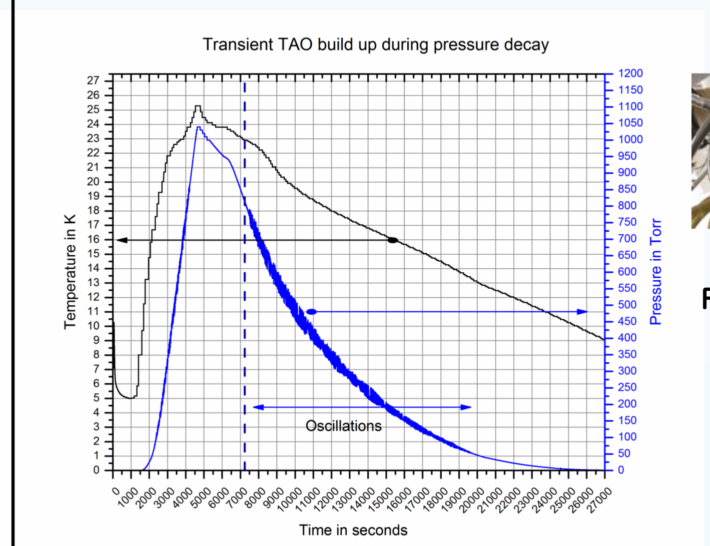

Fig. 3 Transient pressure decrease initiating non-spontaneous TAOs

Fig. 2 Quick "fix"

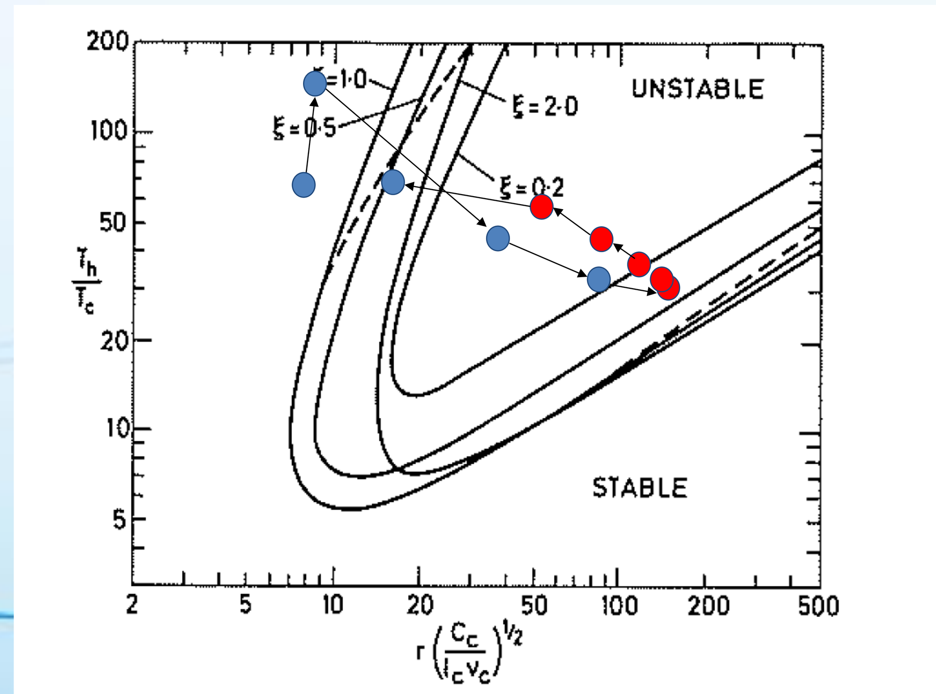

Fig. 4 Transient TAOs passing through the stability map

Case 2

Curved tube leading from room temperature down to a superfluid helium bath maintained at 0.77 K.

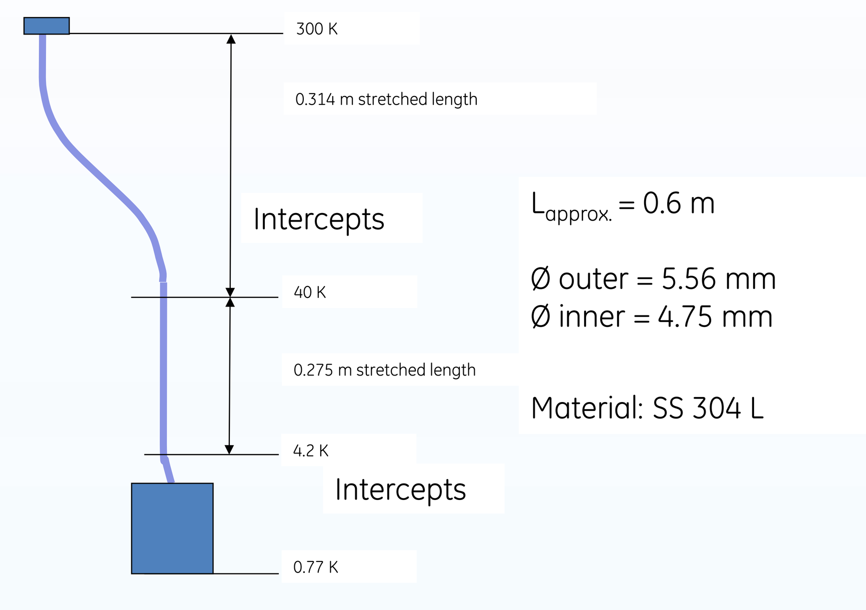

Fig. 4 Curved tube in cryostat, oscillation prone, extending into a 0.77 K helium bath

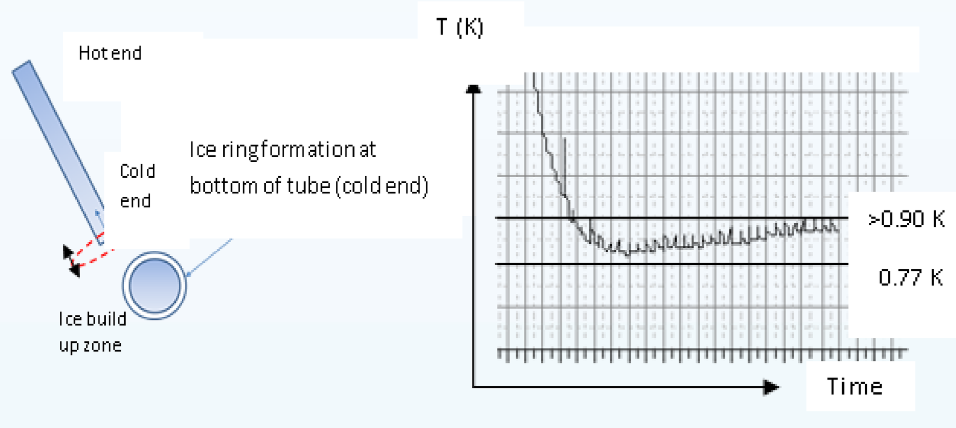

Fig. 5 Cold tube end as in Figure 4 during ice formation, right: resulting base temperature increase

Table 1. Stability Parameters

Parameter	Variable	Hot end / cold end		Unit
Temperature, hot end	Th	300	40	K
Temperature, cold end	Tc	40	5	K
α = Th / Tc *	-	7.5	8	-
ξ = Lh / Lc	-	0.12	0.58	-
Pressure	p	1. 10+05	1. 10+05	Pa
Tube internal radius	r	0.002375	0.002375	m
Cold length	lc	0.39	0.275	m
velocity of sound	Cc	373.40	119.70	m/s
Dynamic viscosity	η	5.542 10-06	1.388 10-06	Pa s
Density	ρ	1.2004	11.78	kg/m3
Kinematic viscosity	νc	4.6168 10-06	1.179 10-07	m2/s
r*(cc/(lc*νc))^0.5 *	-	34.202	144.31	-

Case 3

TAOs on a test set up tube at 4.2 K and with wide 20 mm diameter, slightly bent tube with closed funnel

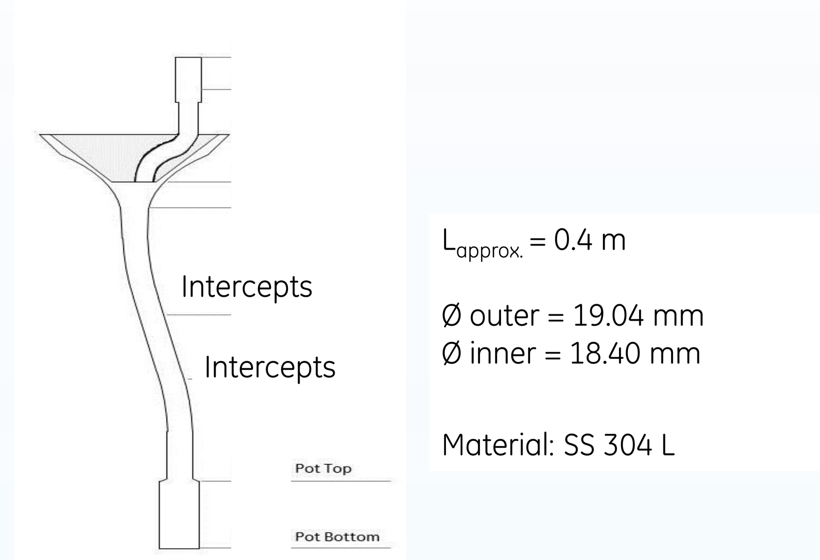

Fig. 6 Curved tube in cryostat extending into a 0.77 K helium bath

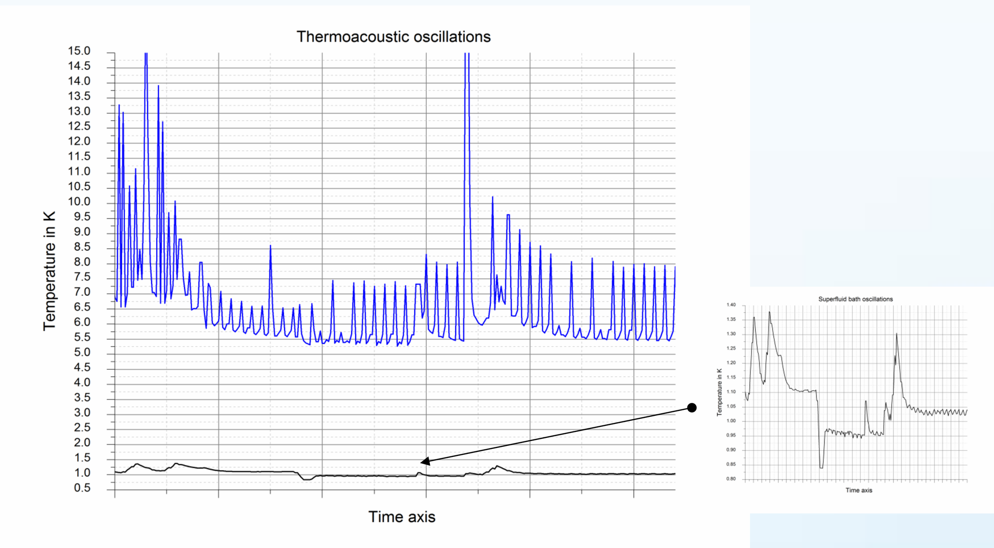

Fig. 7 Influence of TAOS on a superfluid helium bath and above

Case 4

TAOs on a test set up at 4.2 K

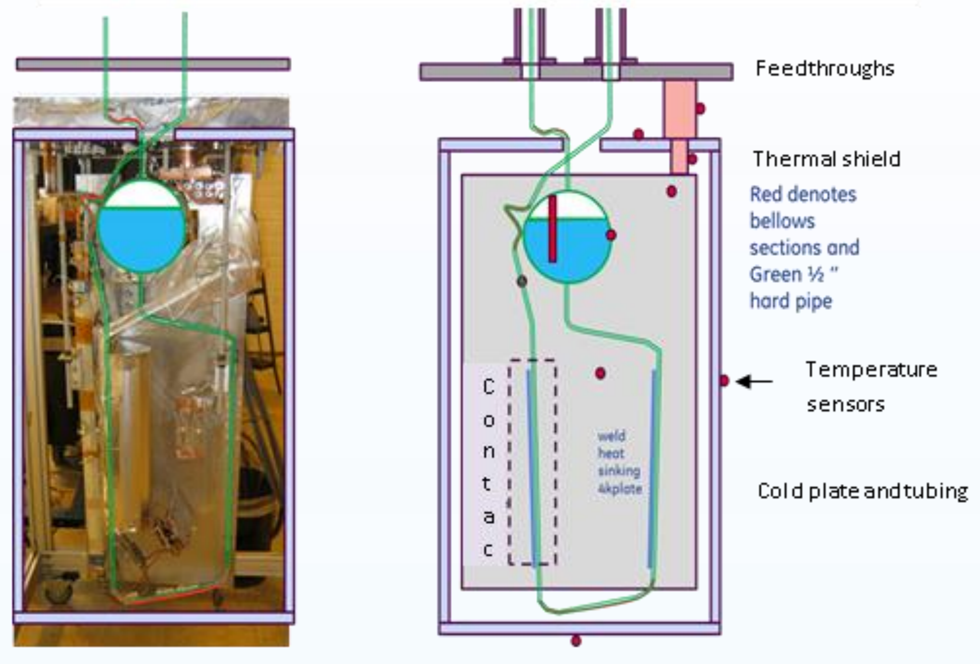

Fig. 8 Schematic test setup with tube routing fixed to a 4 K aluminum cold plate

Table 2. Stability Parameters

Parameter	Variable	No / with intercepts			Unit
Temperature, hot end	Th	300	300	54	K
Temperature, cold end	Tc	4.5	54	4.6	K
α = Th / Tc *	-	66.66	5.55	11.74	-
ξ = Lh / Lc	-	0.5	0.5	0.5	-
Pressure	p	1. 10+05	1. 10+05	1. 10+05	Pa
Tube internal radius	r	0.00585	0.00585	0.00585	m
Cold length	lc	0.5	0.5	0.5	m
velocity of sound	Cc	108.36	433.53	110.87	m/s
Dynamic viscosity	η	1.292 10-06	6.669 10-06	1.312 10-06	Pa s
Density	ρ	14.25	0.8894	13.645	kg/m3
Kinematic viscosity	νc	9.069 10-08	7.4984 10-06	9.612 10-08	m2/s
r*(cc/(lc*νc))^0.5 *	-	285.97	62.91	28.10	-
Regime status	-	Unstable	Stable	Stable	-

III. Conclusion

Even though engineers seem to have a practical handle on how to avoid TAOs at the design state for simple tube geometries and configurations and available data thanks to the theoretical and experimental work done, TAOs can still occur unexpectedly as we have shown.

What new was learned about the onset of TAOs is the following:

- transient TAOs can appear depending on pressure and temperature changes, e.g. at cooldown,
- they can show up in abrupt angled shaped tubing as well as in horizontal ones; research so far has only looked at straight tubes,
- they can show up if unforeseen design constraints ask for a change in the piping layout in the test bed at the hot end,
- the cold end tubing does not necessarily need to be in contact with a liquid surface, and TAOs are visible at high cold end temperatures,
- for the first time, parasitic heat loads due to oscillations have been recorded between 4.2 K (hot end) and 0.8 K (cold end),
- they can be present if the bottom tube radius decreases due to ice formation or they can excite if the cold end is fitted with a constriction, e.g. an orifice that decreases the tube entrance radius,
- they momentarily show up in tubes properly heat stationed and wide tube diameter, if the bottom tube end radius is reduced e.g. in an insertion process,
- to reduce heat loads we rely on heat intercepts anyway, but even though we believe TAOs are well-controlled by well-placed thermal intercepts, we could still run into TAOs if we slightly change the location of those intercepts for the case we are close to an unstable/stable region. Unfortunately those regions are not precisely defined, introducing a "safety margin" is therefore advisable.

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