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To cite this article: H. C. Li *et al* 2019 *IOP Conf. Ser.: Mater. Sci. Eng.* **502** 012107

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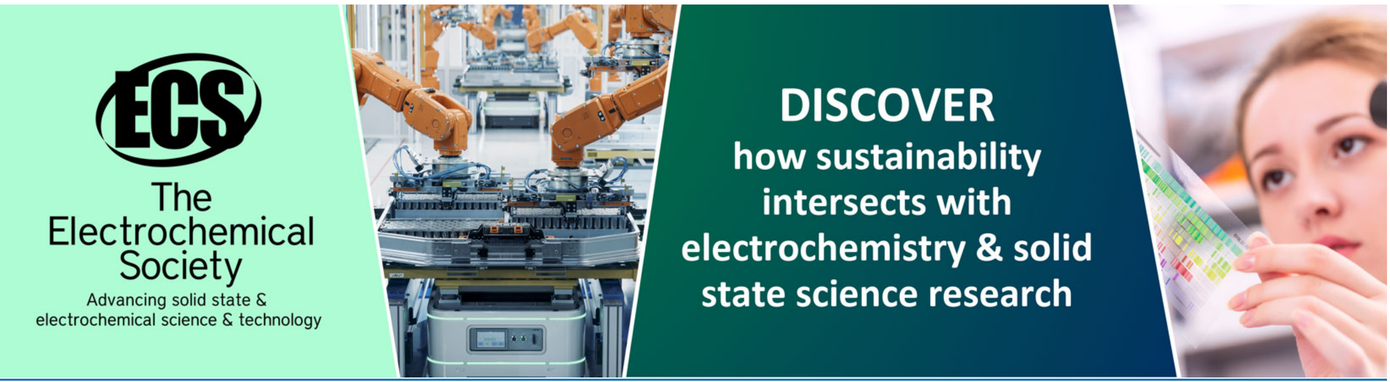

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IOP Conf. Series: Materials Science and Engineering **502** (2019) 012107 doi:10.1088/1757-899X/502/1/012107

Thermal acoustic phenomena in a cryogenic helium distribution system

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Abstract. During normal operation of the cryogenic helium distribution system for the TPS superconducting radio frequency (SRF) cavities, thermal acoustic oscillations (TAO) occur leading to pressure fluctuations in the cold helium gas processing lines up to 65 mbar at a high frequency. The thermal acoustic phenomena present an additional heat load and affecting the operational stability of the SRF cavities. Three gas buffers were attached to the exhaust pipelines of the helium gas processing lines and the isolation valve of the gas buffers was kept half open to prevent pulsation in the flow. These buffers successfully suppressed the TAO phenomena without modifying the exhaust pipelines. The pressure fluctuations were reduced to not more than 7 mbar satisfying the operational requirements for the SRF cavities. In this paper, we present and discuss the solution for the thermal acoustic phenomena in the cryogenic distribution system.

1. Introduction

The Taiwan Photon Source (TPS) is a 3 GeV electron accelerator at the NSRRC operating with a beam current of 500 mA. Two superconductive radio frequency (SRF) cavities have been installed in the storage ring to supply the necessary power. Each helium cryogenic system has a maximum cooling capacity of 890W at 4.5 K providing the required cooling power for these SRF cavities. One cryogenic distribution system was installed to transfer liquid nitrogen (LN_2) and liquid helium (LHe) from storage dewars to SRF cavities and also to recover the vaporized cold helium (GHe) and nitrogen gas (GN_2) from the SRF cavities through independent vacuum-jacketed multichannel lines (MCL) [1]. The relief valves and their exhaust pipelines penetrate the outer case of the distribution valve box (DVB) and then connect to the LHe, LN_2, GHe and GN_2 process lines inside the DVB. During normal operation of the distribution system, we found freezing phenomena at the surface of the exhaust line for the GHe process lines of the DVB, which was due to thermal acoustic oscillations (TAO). This phenomenon and its treatment are presented and discussed in this paper.

2. Study of TAO in the helium cryogenic distribution system

TAO are often observed in the fill or exhaust lines of low temperature dewars where the tube is capped at the hot end. The typical geometry of a half-open tube is shown in figure 2. A large axial temperature gradient makes the cold gas in the half-open tube to expand rapidly, pushing the heated gas into the cold open end. The gas flow causes a low pressure at the warm end causing the flow reverse and the cold gas

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enters the warm end creating a large radial temperature gradient. The gas is heated and duplicates the process. TAO are oscillation instabilities, which are observed frequently in helium cryogenic systems, because there is a sufficient temperature ratio between the cold and warm end of the tube, where the warm end is always closed. Experimental results show that the thermal load to the TAO lines can be 10-1000 times greater than its thermal conduction [2]. The complete solution for developing TAO is complex, even in a simple straight tube. This difficulty comes from the need to solve the complete hydromechanics equation. Predictions of the presence of TAO and preventing it from occurring in cryogenic systems for a geometry of a half-open tube and low temperature conditions has been presented in many studies [3-6]. Figure 2 shows the stability characteristics of TAO, which can be used to determine if TAO occur or not. Unstable regions are drawn using selected dimensionless parameters for various ratios of warm to cold lengths and ratios. If the value of the dimensionless parameter of a given system placed in the curved region exceeds unity, oscillation is expected. The stable characteristics of TAO in a liquid helium system is shown in figure 3. [2], where an one-meter long tube is used in plotting these stability curves, with r is tube radius, α is the ratio of the temperatures at the warm and cold ends of the tube (T_h/T_c), and ξ is the ratio of the lengths in the warm and cold section of the tube (L_h/L_c). The location separating the warm and cold sections of the tube is defined as the point where the temperature equals to $(T_h/T_c)/2$. The characteristic stability curve is plotted versus the same value of ξ. If the characteristic point, determined by α and r, is located under the curve, the TAO characteristic is stable, otherwise unstable. Although theory and experiment have successfully predicted TAO within a typical geometry of a half open tube, predicting TAO in a complex cryogenic system is still difficult or impractical.

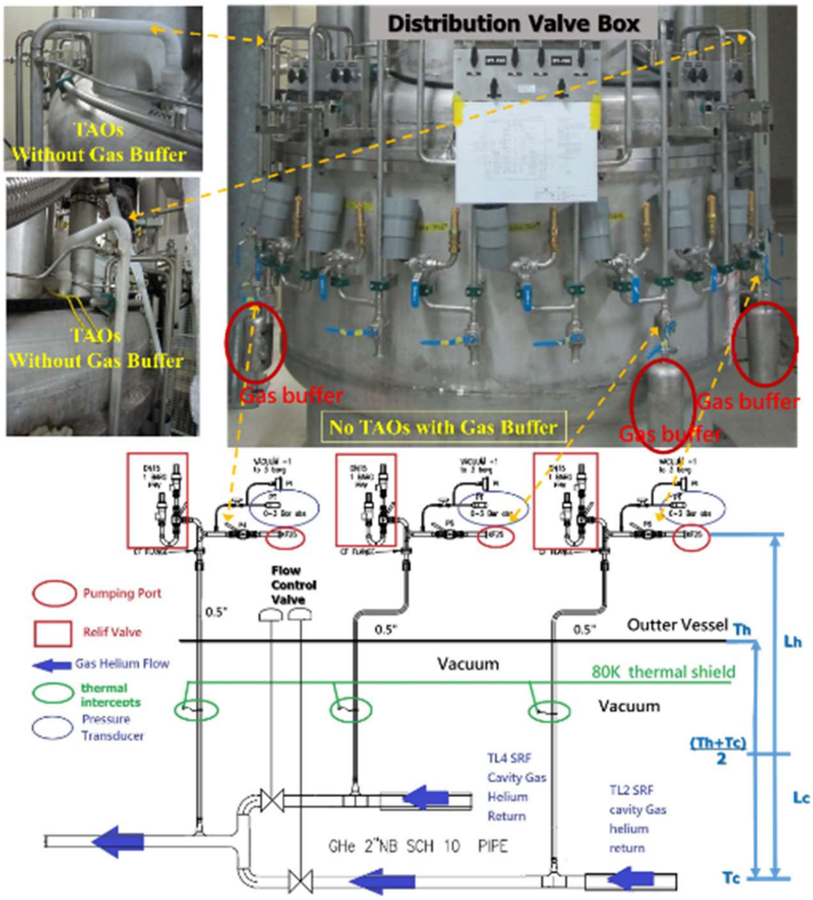

Figure 1. Configuration of exhaust pipeline and helium gas process lines in a cryogenic DVB

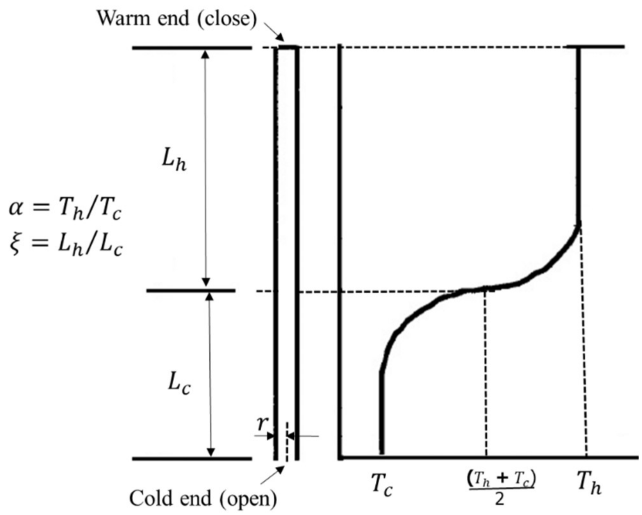

Figure 2. TAO in a typical half-open tube and associated parameter profiles.

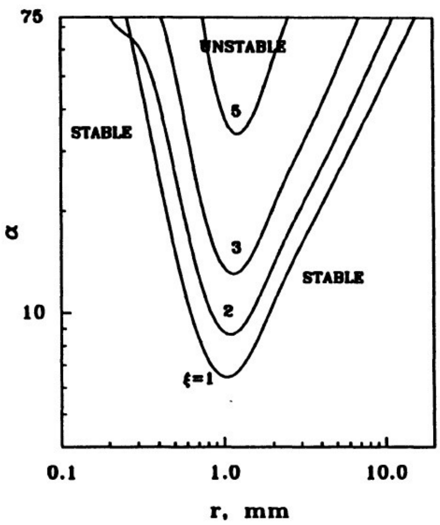

Figure 3. Stability curves for TAO in a helium system when $\xi \geq 1$.

The geometric structure of a single exhaust pipeline in the TPS distribution valve box, shown in figure1, is similar to the typical half open tube shown in figure 2. We can analyse the DVB by applying the TAO characteristic stability curves. The 80K intercepts connect to the thermal shield, cooled by liquid nitrogen, located between outer case of the DVB and gaseous helium process lines shown in figure 4. The 80K intercepts not only reduce the heat transfer from 300K room temperature environment but also mitigate the TAO [6]. As for stability, results were obtained with a tube length of one meter. The actual tube radius of the exhaust pipeline in the DVB has to be corrected before using the stability curves in figure 3. The values of the corrected tube radius r' is calculated from

$$r' = \frac{r}{\sqrt{L}}\sqrt{L'} \tag{1}$$

where r is the actual tube radius, L the actual tube length and L' is the tube length used in calculating the stability curves ($L'$is equal to one meter in figure 3). Table 1 shows the necessary parameters of the TAO for the DVB. Condition 1: we assume the 80K intercepts works properly, and the cold open end will be the location of the 80K intercepts. According to the stability curve, the TAO should not occur in the DVB, indicated as the characteristic point A in figure 5. If TAO do happen, the thermal link of the 80K intercepts is insufficient. In this case, we do not consider the thermal effect of the 80K intercepts in condition 2. We find the characteristic point B of condition 2 located in the unstable region, which is above the curve of $\xi = 2.67$ shown in figure 5.

Table 1. TAO calculation in the gas helium process line

Conditions	T_h (K)	T_c (K)	α	L (m)	L_h (m)	L_c (m)	ξ	r (mm)	r' (mm)	TAO Status
1. Thermal intercepts	300	80	3.75	2.1	1.8	0.3	6	8.6	5.9	No
2. No Thermal intercepts	300	7	42.9	3.3	2.4	0.9	2.67	8.6	4.7	Yes

3. Preventing TAO in Helium Distribution Systems

There are several methods to mitigate the effects of TAO [6]. Installing an additional buffer is the

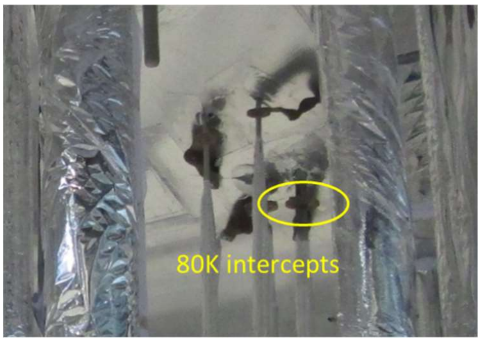

Figure 4. 80K Thermal intercepts

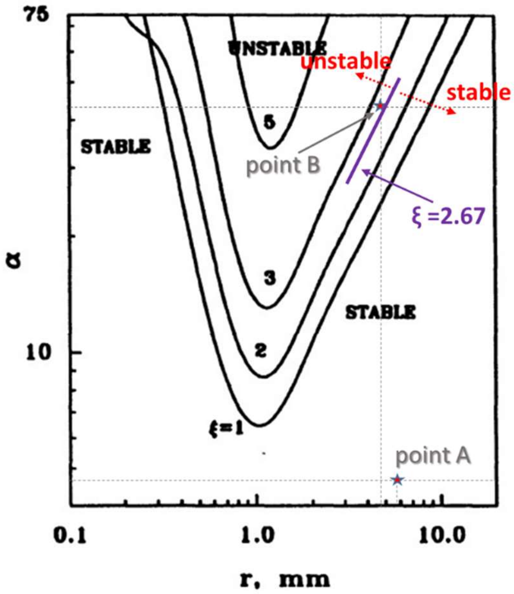

Figure 5. Characteristic stability points for the helium DVB.

easiest solution for the DVB. The additional gas buffers connect to the warm end of the tube (after its isolation valve) with the same effect as extending the length of the warm tube for the TAO system. The equivalent length ratio ξ' is always greater than the actual tube length ratio, which is determined by

$$\xi' = \frac{L_h + L_{hs}}{L_c} \tag{2}$$

where L_h is the actual warm tube length, L_c the actual cold tube length and L_{hs} is the equivalent length of the additional volume of the gas buffer. The quantity L_{hs} can be determined by

$$L_{hs} = \frac{V_s}{\pi r^2} \tag{3}$$

where V_s is the additional volume of the gas buffer and r the radius of the connecting port. Table 2 indicates the value after correcting with the stability curve. Note, that the volume correction can increase the value of the tube length ratio significantly when the additional buffer is large. The additional buffer is shown in figure 6. According to the parameters of Table 2, we can indicate the TAO characteristic point C in figure 7. It is clear that the condition 3 is located in the stable region, while $\xi > 5$.

Table 2. TAO calculation in the exhaust line of helium gas process line with buffer

Conditions	T_h (K)	T_c (K)	α	L_h (m)	L_c (m)	V_s (cm3)	L_{hs} m	ξ	r' (mm)	TAO Status
Additional buffer	300	7	42.9	2.4	0.9	2748	11.8	15.8	2.2	No

4. Experimental results

To understand the TAO effect of an additional buffer, we install one buffer to one pipeline and open its isolation valve, while the other two pipelines remain closed. Table 3 shows that the pressure vibration

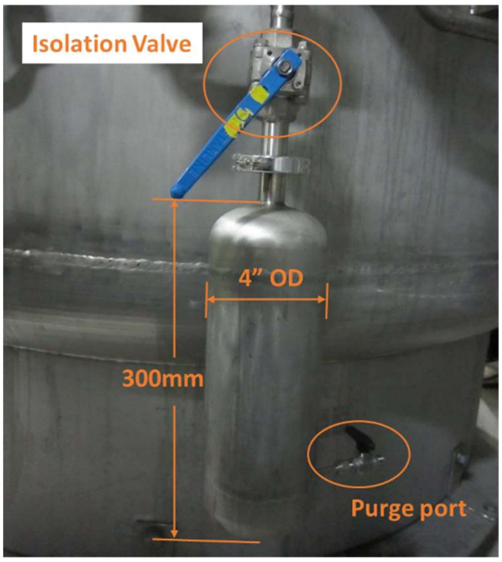

Figure 6. Gas buffers

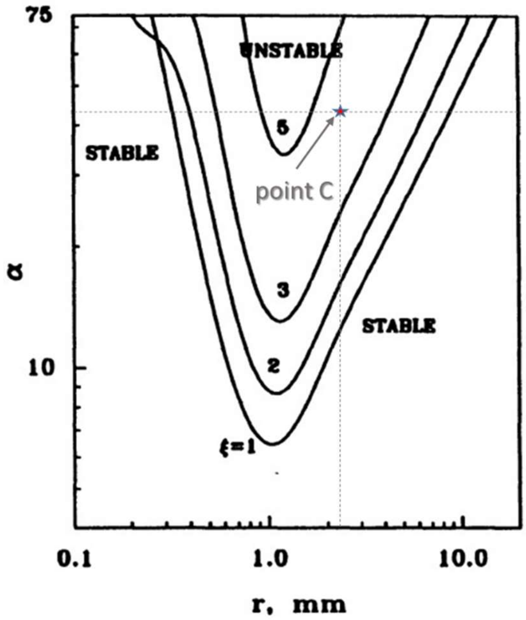

Figure 7. Stability characteristic points for helium DVB with gas buffer.

of the pipeline with the gas buffer is reduced significantly. There is one interesting phenomenon in case 4, when the TL2-GHe pipeline buffer is open. The pressure vibration of the other two pipelines become much larger than before. This phenomenon results from complex hydromechanics by interactions within the distribution system being a future research topic. Case 5 assumes that three buffers are installed on the isolation valve of the pipelines remaining fully open. The TAO phenomenon did not appear. The best situation was found in case 6 with half open isolation valve and installed buffer. The pressure vibration of the three gas lines were 3mbar, 7mbar, 3mbar, respectively. The minimum pressure vibration is due to the same effect between gas buffer with half-open isolation valve and resonator with a small radius neck tube, mentioned in reference [6].

Table 3. Pressure vibration in different cases

	DVB-GHe		TL4-GHe		TL2-GHe	
case	Valve status	Pressure vibration (mbar)	Valve status	Pressure vibration (mbar)	Valve status	Pressure vibration (mbar)
1	X	14	X	60	X	65
2	O	6	X	50	X	80
3	X	16	O	8	X	60
4	X	200	X	100	O	5
5	O	25	O	35	O	25
6	Δ	3	Δ	7	Δ	3

X: Close Δ: Half open O: Fully open

Figure 8 shows the pressure behaviour of the gas processing line in the DVB when the isolation valves are suddenly closed. The freezing phenomena appear on the exhaust pipeline with deteriorating pressure stability and inability to satisfy the operational requirements for the SRF cavities.

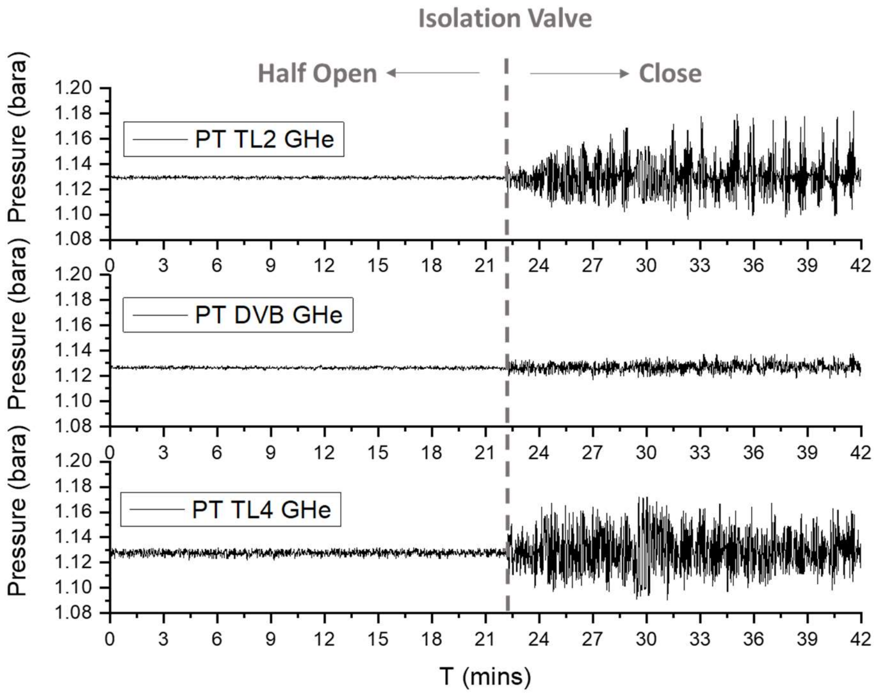

Figure 8. Gas helium pressure vibration with/without gas buffer

5. Conclusion

Thermal acoustic oscillations in a helium distribution system have been investigated in this study. TAO are a dynamic phenomenon occurring while the temperature and pressure fluctuations move the system into an instable regime. TAO can be well-controlled by thermal intercepts but a weak thermal link can still cause TAO. In our case, the thermal link will also be an alternative solution to mitigate the TAO. TAO not only introduce an additional heat load but also affect the operational stability of the SRF cavities. The pressure fluctuations for the helium gas process line were about 65 mbar during TAO. After three buffers were mounted to the pipeline and keeping the isolation valve half open, the system enters a stable TAO zone while the pressure fluctuations decrease to less than 7 mbar for all three gas pipes. These buffers successfully suppress the TAO phenomena and reduce the pressure fluctuations without modifying the tube in the DVB.

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