3P4-16

Proceedings of Symposium on Ultrasonic Electronics, Vol. 34 (2013) pp. 461-462
20-22 November, 2013

Numerical analysis of the effect of local diameter reduction on the critical temperature of thermoacoustic oscillations in a looped tube

ループ管内の熱音響振動の臨界温度に局所内径縮小が与える影響の数値解析

Yuichiro Orino[1‡], Shin-ichi Sakamoto[1], Yoshitaka Inui[1], Takumi Ikenoue[1], and Yoshiaki Watanabe[2] ([1]Univ. of Shiga Pref.; [2]Doshisha Univ.)
折野裕一郎[1†]，坂本眞一[1]，乾義尚[1]，池之上卓己[1]，渡辺好章[2]　([1]滋賀県立大, [2]同志社大)

1. Introduction

Thermally driven thermoacoustic systems have attracted attention as a potential technology for waste heat utilization. Loop-tube-type thermoacoustic cooling systems[1,2] are thermally driven coolers under development. This system involves thermoacoustic prime mover and heat pump in a looped tube. Heat input to the prime mover part forms temperature gradient in a *stack* and spontaneous gas oscillation occurs. Sound wave propagates to the heat pump part, which causes thermoacoustic heat pumping effect for cooling.

To improve energy conversion efficiency, we proposed installing a hollow circular cylinder, called as a phase adjuster (PA), in a looped tube.[3] Installing PA in a circular tube is equivalent to reducing the tube diameter locally. PA changes acoustic conditions and affects thermoacoustic effects in stacks. It is experimentally confirmed that PA maintains desirable one-wavelength resonance and improves cooling effect of the loop-tube-type cooling system.[3] Experimental studies for a loop-tube-type thermoacoustic prime mover, omitting a heat pump part from the cooling system, showed that the efficiency of heat-to-sound energy conversion depends on the inner diameter of PA.[4] Effects of PA would depend on other parameters of PA, i.e. the tube-axial length and the installation position. The optimum configuration of PA is an interesting issue. In this paper, we present numerical investigations of the critical condition of thermoacoustic oscillation in a loop-tube-type thermoacoustic prime mover with various diameter reductions and positions.

2. Calculation method

Numerical investigations were performed based on the linear stability analysis using the transfer matrix method.[5] This method is based on two equations derived by Rott[6] under “long tube” approximation. Using the complex notation for a steady gas oscillation at the angular frequency ω, equations are given as

$$\frac{dP}{dx} = -\frac{i\omega\rho_m}{A(1-\chi_\nu)}U \qquad (1)$$

$$\frac{dU}{dx} = -\frac{i\omega A}{\gamma P_m}\left\{1+(\gamma-1)\chi_\alpha\right\}P + \frac{(\chi_\alpha-\chi_\nu)}{(1-\chi_\nu)(1-\mathrm{Pr})}\frac{1}{T_m}\frac{dT_m}{dx}U, \qquad (2)$$

where P and U respectively denote complex sound pressure and volume velocity. ρ_m, P_m, γ and Pr are the mean density, the mean pressure, the ratio of specific heats, and the Prandtl number of the working gas, respectively. A is the cross-sectional area of the channel. T_m is the mean temperature depending on the tube-axial position x. χ_α and χ_ν are complex functions that allow us to describe the three-dimensional phenomena in the channel using two one-dimensional equations,[5] which are defined by using Bessel functions as functions of the channel radius, the thermal diffusivity, the kinematic viscosity, and ω.

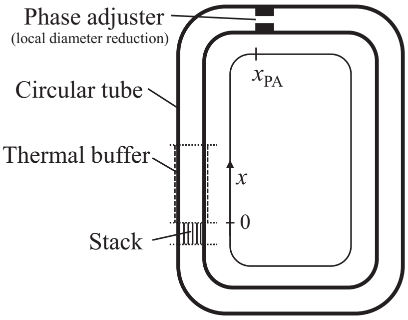

Fig. 1. Schematic illustration of the loop-tube-type thermoacoustic prime mover model.

Investigated loop-tube-type thermoacoustic prime mover model is schematically illustrated in **Fig. 1**. For simplicity, heat exchangers located on both sides of the stack were omitted from the model.

---

orino.y@office.usp.ac.jp

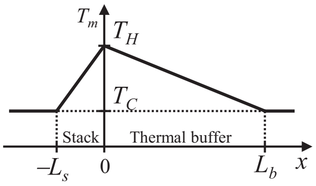

Fig. 2 Temperature distribution near the stack.

The basic tube diameter D was 42.6 mm, and the total tube-axial length L was 3.340 m involving the stack and PA. The working gas was air at atmospheric pressure. We simply assumed that the stack and the thermal buffer area adjacent to the hot side of the stack have linear temperature gradients between T_C and T_H as illustrated in **Fig. 2**, other tube areas are in uniform temperature of T_C. T_C was 293.16 K. We assumed and the thermal buffer length L_b of 200 mm. The stack was assumed as parallel narrow channels with the channel radius of 0.474 mm, the porosity of 0.715, and the length L_s of 50 mm. Configuration parameters of PA considered in this paper are the installation position x_{PA} and the reduced inner diameter D_{PA}: the length of PA was constantly 45 mm.

Equations (1) and (2) allow us to calculate 2×2 transfer matrices for all tube areas analytically or numerically. For areas with temperature gradient, we utilized the fourth-order Runge-Kutta method. A product of all transfer matrices results in a open-loop transfer matrix of M_{loop}, the critical condition of the gas oscillation in the looped tube is given as $\det(M_{\mathrm{loop}} - I_2) = 0$, where I_2 is the 2×2 unit matrix. We calculated the critical temperature of T_H by evaluating the critical condition varying T_H for various configurations of PA.

3. Calculation results

Calculated critical temperature ratios T_H/T_C are shown in **Fig. 3** as functions of the diameter reduction ratio D_{PA}/D for different positions. Results show that a certain level of local diameter reduction at an appropriate position results in decrease of the critical temperature ratio. Calculated results as functions of the installation position are shown in **Fig. 4**. These results show there are certain ranges of desirable installation position, which does not conflict with positions used in past studies for similar looped tubes, e.g. 1.2 m.$^{4)}$

4. Summary

The critical temperatures of thermoacoustic gas oscillation in the looped tube with a local diameter reduction by PA were numerically investigated. Results indicate configurations to decrease the critical temperature, which are correspond to empirical configurations chosen in past studies. It is expected that the analysis of the critical temperature is helpful for designing PA.

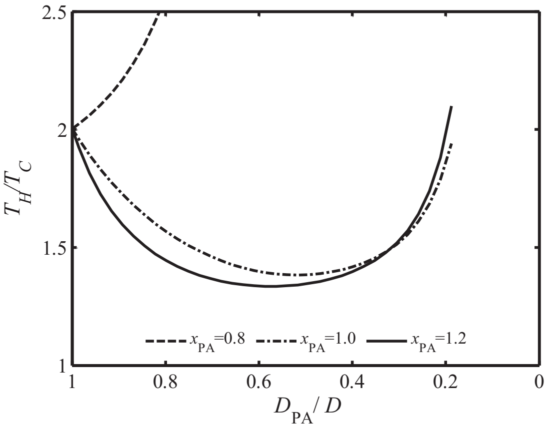

Fig. 3. Calculated critical temperature ratios as functions of the diameter reduction ratio of PA for installation positions.

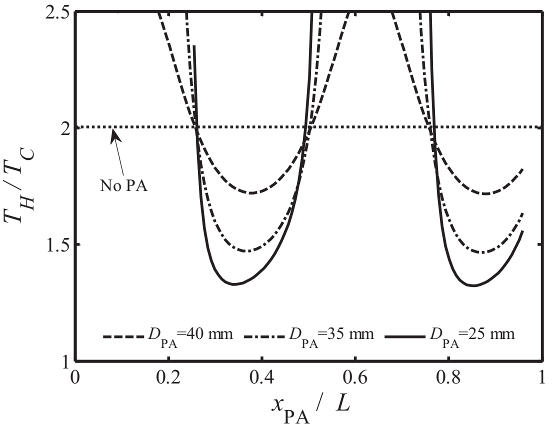

Fig. 4. Calculated critical temperature ratios as functions of the installation position for reduced inner diameters of PA.

Acknowledgments

This work was partially supported by JSPS Grant-in-Aid for Young Scientists A (22686090), B (19710072), a JSPS Grant-in-Aid for Challenging Exploratory Research (23651072), JST A-STEP (AS242Z01219L), and MEXT Regional Innovation Strategy Support Program.

References

1. T. Yazaki, T. Biwa, and A. Tominaga: Appl. Phys. Lett., **80** (2002) 157.
2. S. Sakamoto and Y. Watanabe: Ultrasonics **42** (2004) 53.
3. S. Sakamoto, Y. Imamura, and Y. Watanabe: Jpn. J. Appl. Phys. **46** (2007) 4951.
4. S. Sakamoto, M. Nishikawa, T. Ishino, Y. Watanabe, and J. Senda: Jpn. J. Appl. Phys. **47** (2008) 4223.
5. Y. Ueda and C. Kato: J. Acoust. Soc. Am. **124** (2008) 851.
6. N. Rott: Z. Angew. Math. Phys. **20** (1969) 230.