Investigation on acoustic characteristics of regenerator in the thermoacoustic apparatus

Xie X. J., Li Q., Chen X*., Yu Z. B.

Technical Institute of Physics and Chemistry, GSCAS, Beijing, China
*Cryogenic laboratory, Huazhong University of Science and Technology, Wuhan, China

An acoustic-driven thermoacoustic device, which is used to investigate on acoustic characteristics of regenerator, has been built. The transfer function method is used to measure the transfer function H of regenerator over a broadband frequency range. Reflection coefficient R, transmission loss TL, characteristic impedance Z_c and propagation constant g are calculated from measured H. Furthermore, comparison about acoustic characteristics versus frequency between case a (only regenerator) and case b (regenerator and heat exchanger) is investigated. Different heat power influence on acoustic characteristics of regenerator is also discussed.

INTRODUCTION

Acoustic parameters, i.e. reflection coefficient, transmission loss, characteristic impedance and propagation constant of regenerator, are used to describe acoustic characteristics of regenerator in the thermoacoustic apparatus [1, 2]. Acoustic characteristics of regenerator are important factors influencing on the heat-power transfer efficiency. However, more quantitative investigation on acoustic characteristics of regenerator is still lacking.

In this paper, an acoustic-driven thermoacoustic device for the acquisition on acoustic characteristics of regenerator has been built. A series of experiments has been performed. The transfer function method [3] was applied, which uses a broadband random signal as a sound source to measure the transfer function of regenerator over a broadband frequency range. Based on the model given in this paper, reflection coefficient, transmission loss, characteristic impedance and propagation constant are calculated from the measured transfer function to enrich network parameters of regenerator. Furthermore, heat exchanger and temperature difference influence on acoustic characteristics is investigated in this paper.

EXPERIMENTAL APPARATUS AND RESULTS

The thermoacoustic apparatus, which is filled with nitrogen of 1.6MPa, is shown in Fig. 1. Three pressure sensors were used to measure transient pressures in the tube. The regenerator, 38mm long, is made of stainless steel screen with mesh 300. Case a (only regenerator) and case b (regenerator and heat exchanger) are investigated. Different heat power to the hot heat exchanger is also measured. The experimental results of transient pressure are shown in Fig. 2. Based on the transfer function method, the transfer function H between P1 and P2 was measured using a two-channel fast Fourier transform.

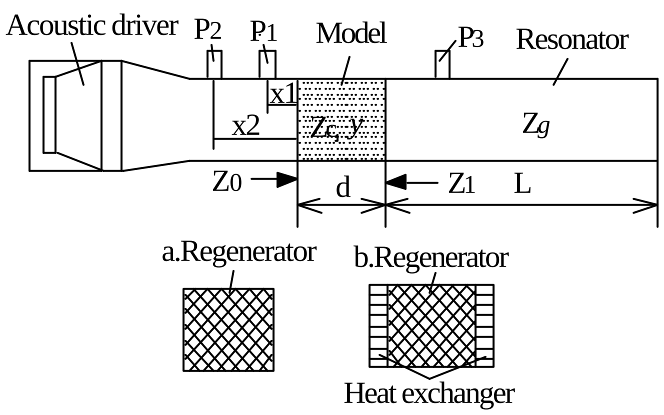

Figure1 Thermoacoustic apparatus for the transfer function method of measuring acoustic impedance

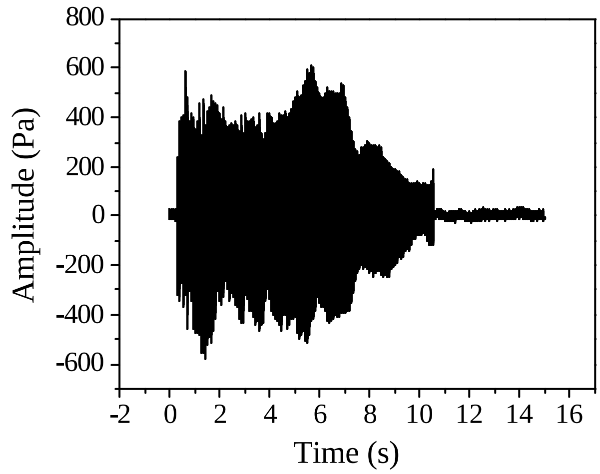

Figure 2 transient pressures in the P1 sensor

DISCUSSION

In order to compare the differences of acoustic characteristics between case a and case b, and investigate temperature gradient influence on acoustic characteristics, reflection coefficient, transmission loss, characteristic impedance and propagation constant are analyzed from the above transfer function.

Comparisons of reflection coefficient and transmission loss at different conditions are shown in Fig. 3. According to Fig. 3 (a), reflection constant R decreases as frequency increases at case $a.Q = 0$ W. When $f = 400$ Hz, R has minimum, and then increases versus frequency. Comparing between case a. Q=0W and case b. Q=0W, R in case b is larger than that in case a, i.e. increment of R will be caused by additional heat exchanger. At the same time, different heat power to the hot heat exchanger has significant influence on R. Heat power is higher; the curve R is lower at the same frequency range. Furthermore, the minimum of R will shift rightward with the increase of temperature gradients.

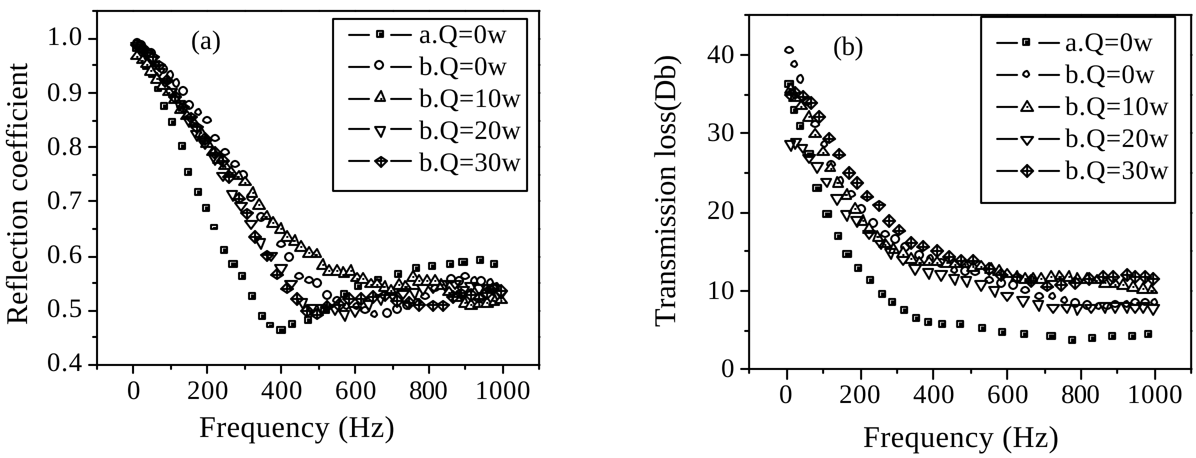

Figure 3 Comparison of reflection coefficient (a) and transmission loss (b) of tested model at different model and heat power.

Transmission loss decreases with frequency at all conditions (see Figure 3 (b)). Additional heat exchanger is equal to the additional impedance to the regenerator, and enlarges transmission loss in the regenerator. In addition, transmission loss increases, when heat power to the hot heat exchanger gradually increases, which is caused by the increase of the thermal resistance.

Investigation on characteristic impedance and propagation constant

Z_c, g in the regenerator can be related to the transfer function measured from transient pressure, which can be inferred based on Ref. [4]:

$$Z_c = \pm\left(\frac{Z_0 Z_0^*\left(Z_1 - Z_1^*\right) - Z_1 Z_1^*\left(Z_0 - Z_0^*\right)}{\left(Z_1 - Z_1^*\right) - \left(Z_0 - Z_0^*\right)}\right)^{1/2} \tag{1}$$

$$g = \frac{1}{2id}\ln\left(\frac{Z_0 + Z_c}{Z_0 - Z_c}\frac{Z_1 - Z_c}{Z_1 + Z_c}\right) \tag{2}$$

$$Z_0 = iZ_g \frac{-H\sin(kx_1) + \sin(kx_2)}{H\cos(kx_1) - \cos(kx_2)} \tag{3a}$$

$$Z_1 = -iZ_g\cot(kL) \tag{3b}$$

With Z_g: characteristic impedance of nitrogen, k: wave number of nitrogen. The superscript (*) is used when L is changed to another length L^*. Using Equations (1) - (3), Z_c and g can be obtained from the measured transfer function (see Figure 4).

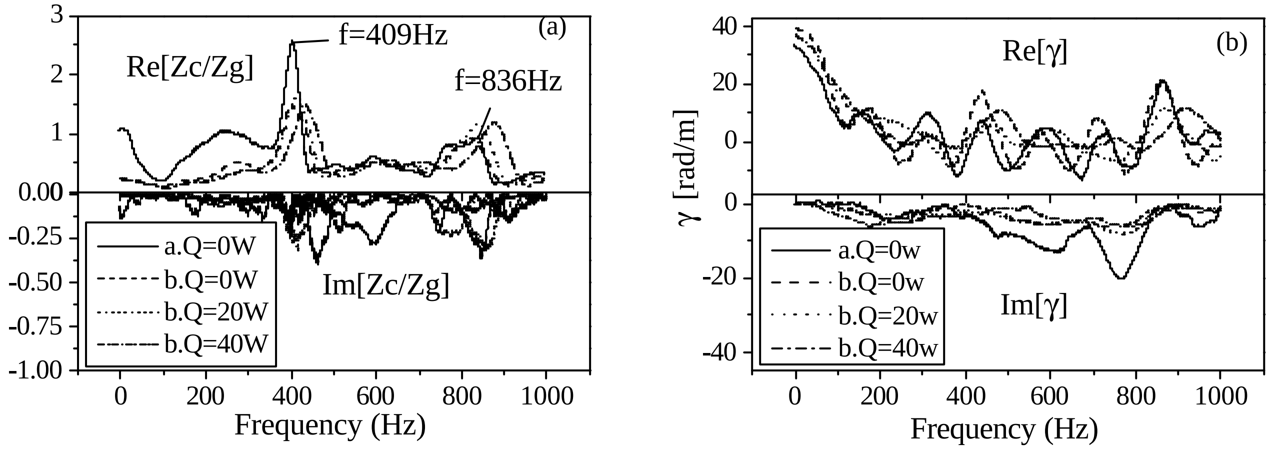

Figure 4 Comparison of characteristic impedance normalized by nitrogen (a) and propagation constant (b) of tested models, where both properties were obtained at case a. Q=0W (solid line), b. Q=0W (dash line), b. Q=20W (dot line) and b. Q=40W (dash dot line)

Figures 4 (a) and (b) show comparisons of characteristic impedance and propagation constant at different conditions. With the reference to Fig. 4 (a), characteristic impedances of regenerator were maximums at $f_1 = 409$ Hz and $f_2 = 836$ Hz. If Z_1 approaches Z_1^* in equation (1), then Z_c approaches Z_1. This incorrect conclusion is caused by elimination of the terms (Z_0-Z_0^*) in equation (1), and that situation arises when the frequency f satisfies $f(L-L^*)=nc/2$, with c: speed of sound in the nitrogen, n: the positive integral. The frequencies of the distinctive peaks f_1 and f_2, shown in Fig. 4 (a), are in complete agreement with the frequencies calculated from the above equation, so the appropriate set of the resonator must be selected so as to not satisfy the above equation. Furthermore, characteristic impedance in case b is smaller than that in case a, i.e., additional heat exchanger will decrease characteristic impedance of tested model. The curve of characteristic impedance will shift rightward with the increase of temperature difference.

Propagation constant of regenerator is shown in Fig. 4 (b) over the same frequency range as characteristic impedance. Propagation constant $g = a + ib$, with a: attenuation constant, b: phase constant, which stand for the amplitude and the phase variation of the pressure per length along the tube respectively. When $f < 400$ Hz, a falls down quickly; and $f > 400$ Hz, a fluctuates diminutively as the frequency increases. When the frequency is about 800Hz, a and b increases sharply, and then level off. Propagation constant of case b is larger than that of case a. It is observed that when the frequency is about larger than 400Hz, heat exchanger has a significant influence on the phase constant b (see Figure 4 (b)). a and b decrease with the increase of heat power to the hot heat exchanger..

CONCLUSION

Heat exchanger has significant influence on acoustic characteristics, which results in acoustic characteristics larger than the case without heat exchanger. Reflection coefficient, characteristic impedance and propagation constant decrease with the increase of heat power to the hot heat exchanger, whereas transmission loss increases with the increase of heat power.

ACKNOWLEDGMENT

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