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New approach of silencer based on the thermoacoustic effect
熱音響効果を用いた新しい消音システムについて

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1. Introduction

The thermoacoustic effect can be regarded as a result of the mutual energy conversion of sound energy and heat energy. Exemplary applications of the thermoacoustic effect are the Sondhauss Tube and the Rijke Tube, which were first reported in the mid-19th century [1]. Sound is generated when parts of these tubes are heated because that heat energy is converted to sound energy in the tubes. Until now, the thermoacoustic effect has been proposed for application to cooling systems; many studies have been conducted throughout the world [2–9].

2. Thermoacoustic Effect

The period of compression and expansion of the sound is very short when ordinary sound propagates through free space. The medium through which the sound propagates undergoes an adiabatic change because of the absence of objects into which heat energy dissipates. When sound propagates through narrow channels such as a stack, and when the period of compression and expansion of the sound is very long, the medium close to the channel wall undergoes an isothermal change and the medium exchanges heat energy with the channel wall. This heat exchange induces mutual energy conversion of sound energy and heat energy. That mutual energy conversion induces the thermoacoustic effect [2, 4, 5, 9]. That is one example of the thermoacoustic effect [2, 4, 5, 9]; it is the principle of the Sondhauss Tube and the Rijke Tube. In those tubes, the heat energy is used by the thermoacoustic effect for generating sound. In contrast, in an unprecedented silencer described below, the heat energy is used for attenuating sound with the thermoacoustic effect.

3. Experiment

Figure 1 shows an experimental setup. A 6-m-long brass tube with 42 mm inner diameter is used as a resonance tube. An electrodynamic full-range speaker is placed at one end of the tube. A stack is placed in the tube 1 m distant from the speaker. The stack is tightly piled up with many stainless-steel screen meshes (mesh size and channel radius of #16: 0.65 mm). The stack length is 10 mm. At the speaker-end of the stack, an electric heater is placed as a hot heat exchanger; the temperature of a cold heat exchanger at the counter-speaker-end of the stack is maintained using circulating water. These heat exchangers engender a temperature gradient in the stack.

A single sine-wave is transmitted from the speaker; the sound pressure after passing through the stack is measured using a probe microphone (4182; B&K) set 1.4 m distant from the speaker.

The temperature gradient created in the stack is set to 0 K, 165 K, or 400 K by varying the heat energy supplied to the heater. The low temperature is 300 K and the high temperatures are 465 K and 700 K. The sound pressure after passing through the stack without a temperature gradient (temperature gradient of 0 K) is defined as the reference sound pressure.

The rate of sound pressure change of the sound pressure after passing through the stack with a temperature gradient of 165 and 400 K is calculated based on the reference sound pressure amplitude. The frequencies of the sound transmitted from the speaker are 50, 100, 200, 500 Hz, and 1000 Hz. The rate of sound pressure change is calculated for each frequency.

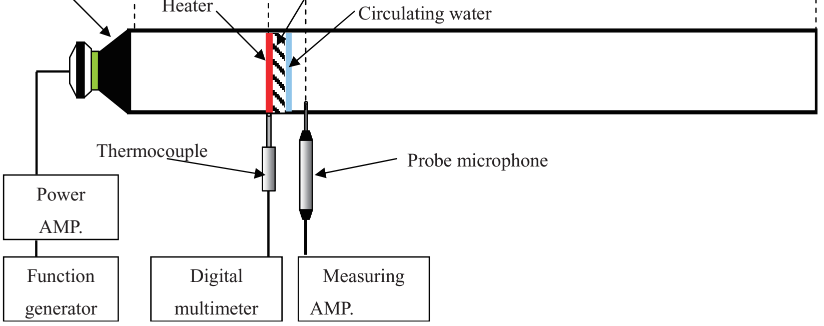

Fig.1 Experimental setup.

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4. Results

The respective sound pressure values after passing through stacks with temperature gradients of 0 K, 165 K, and 400 K are 46 Pa, 40 Pa, and 34 Pa when the frequency of the transmitted sound is 50 Hz and the mesh size of the stack is #16. Under this experimental condition of the frequency and the mesh size, 46.1 Pa is defined as the reference sound pressure (the rate of sound pressure change is 100%). The rates of sound pressure change with a temperature gradient of 165 K and 400 K are found to be 88% and 73%.

Figure 2 shows the rate of sound pressure change calculated in the manner described above, as a function of the frequency when the mesh size is #16. Figure 3 shows the rate of sound pressure change as a function of the temperature gradient when the mesh size is #16.

5. Summary

Application of the thermoacoustic effect to a silencer is experimentally discussed. Results confirmed that the sound pressure after passing through the stack with a temperature gradient is less than that without a temperature gradient.

In this experiment, sound pressure attenuation of 25% was observed. The rate of sound pressure change is greater with lower frequency of the transmitted sound and with a larger temperature gradient in the stack.

The relation between the rate of sound pressure change and the boundary layer thickness was considered. Results confirmed that the rate of sound pressure change depends on the relation between the thicknesses of the boundary layers formed in the stack channel and the stack channel radius.

The results obtained in this study suggest that a silencer based on the thermoacoustic effect can be developed. However, the rate of sound pressure change is insufficient to apply a silencer to practical use. The mechanism of the sound attenuation will be investigated to improve the attenuation effect.

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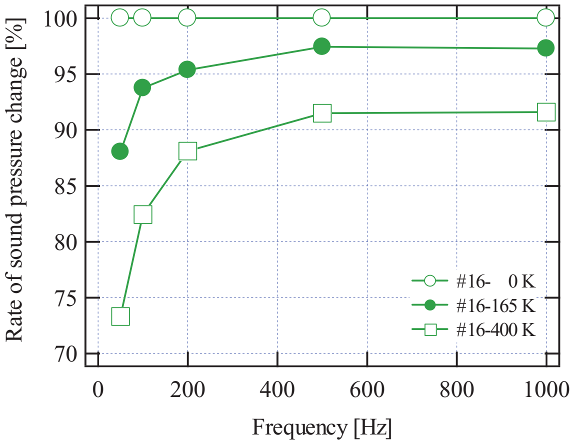

Fig. 2 Rate of sound pressure change as a function of frequency, focusing on the effect of the temperature gradient. Mesh size: #16.

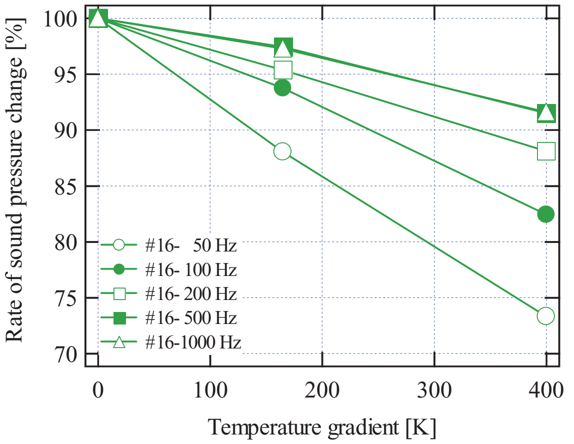

Fig. 3 Rate of sound pressure change as a function of temperature gradient, focusing on the effect of the frequency. Mesh size: #16.