Basic study on inset position of stack in the system with branch tubes for applying thermoacoustic silencer to multi cylinder engine muffler

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ABSTRACT
We have proposed an automobile muffler that uses the thermoacoustic effect. Application of the thermoacoustic effect to a silencer was investigated experimentally in previous studies. Results confirmed that the sound pressure after passing through the stack with a temperature gradient was less than that without a temperature gradient. From these experiment results, a silencer based on the thermoacoustic effect was developed. This study specifically examined the stack installation position. The muffler of a multi-cylinder engine has branch tubes. We investigated the influence of the stack installation position of the branch tube. A branch tube has a confluence. A stack was installed on the front and back of the confluence. When the stack was installed on the front and back of the confluence, a silencing effect was confirmed. When the stack was installed on the back of the confluence, the silencing effect was effective.

Keywords: Thermoacoustic effect, Thermoacoustic silencer, Stack
I-INCE Classification of Subjects Number(s): 13.2

1. INTRODUCTION
The thermoacoustic effect can be regarded as a result of the mutual energy conversion of sound energy and heat energy. Representative thermoacoustic effects are the Sondhauss Tube and the Rijke Tube, which were first reported in the mid-19th century [1]. When parts of these tubes are heated, sound is generated because the heat energy is converted to sound energy in the tubes.

Thermoacoustic systems [2–15] are driven by the thermoacoustic phenomenon [3–5] which is energy conversion between heat and sound. Systems have various benefits (i.e. to derive driving energy from various waste heat and longer driving time with no moving parts). Therefore, these systems have attracted emphasis as global warming countermeasure technologies. Various related studies have progressed.

Especially in these studies, we have proposed a thermoacoustic silence system using waste heat from an automobile's engine.

A thermoacoustic silence system [12–15] provides various benefits from use in automobile mufflers. For example, this system can derive driving energy from engine waste heat and can reduce the muffler weight because the silencing effect caused by the thermoacoustic phenomenon occurs in a stack, which consists of numerous narrow channels smaller than 1 mm. In the stack, sound energy is converted to heat energy. This

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silence system is realized through energy conversion. Recently, conventional mufflers have come to weigh more than 5 kg to attenuate low-frequency sound waves [16]. An acoustic automobile muffler will have greatly reduced weight and increased fuel economy when the system is used practically.

Earlier studies experimentally investigated the application of the thermoacoustic effect to a silencer. Results confirmed that the sound pressure after passing through the stack with a temperature gradient was less than that without a temperature gradient. In these experiments, a silencer based on the thermoacoustic effect can be developed. In this study, we specifically examined the installation position of the stack. The muffler of a multi-cylinder engine has branch tubes. We investigated the influence of the stack installation position of the branch tube. A branch tube has a confluence. A stack was installed on the front and back of the confluence. When the stack was installed at the front and back of the confluence, a silencing effect was confirmed. When the stack was installed at the back of the confluence, the silencing was effective.

2. THERMOACOUSTIC EFFECT

When ordinary sound propagates through free space, the period of compression and expansion of the sound is extremely short. The medium through which the sound propagates undergoes an adiabatic change because of the absence of objects into which heat dissipates. However, when the sound propagates through narrow channels such as a stack and the period of compression and expansion of the sound is extremely long, the medium near the channel wall undergoes an isothermal change. The medium exchanges heat with the channel wall. This heat exchange induces mutual energy conversion of sound energy and heat energy. The mutual energy conversion is the thermoacoustic effect [5].

The thermoacoustic effect can occur easily. In a resonance tube, hot and cold heat exchangers and a stack are arranged. Tightly piled stainless-steel screen meshes and honeycomb ceramics are often used as stack materials. The stack is sandwiched between the hot and cold heat exchangers. When heat is supplied to the hot heat exchanger, a temperature gradient is created in the stack because of the temperature difference between hot and cold heat exchangers. Then, in the stack channel, heat is exchanged between channel walls and the working fluid, and heat energy is converted to sound energy. As a result, sound is generated.

This is one example of the thermoacoustic effect [1, 5]. It represents the principles of the Sondhauss Tube and the Rijke Tube. In these tubes, heat energy is used for generating sound by the thermoacoustic effect. The heat energy is used for attenuating sound by the thermoacoustic effect [12–15].

3. EXPERIMENTAL METHOD, AND RESULTS

3.1 EXPERIMENTAL METHOD

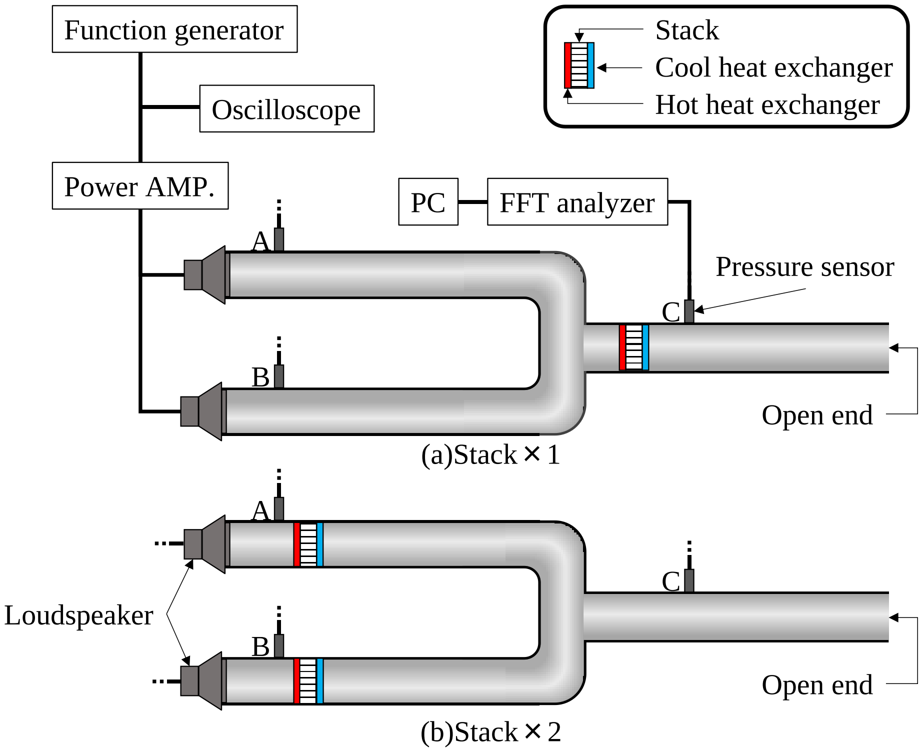
Figures 1(a) and 1(b) present the experimental setup with a muffler of a multi-cylinder engine. Figure 1(a) shows that the condition of the stack was installed on the back of the confluence. Figure 1(b) portrays the condition of a stack installed in front of the confluence. A stainless tube with 42 mm inner diameter was used. A loudspeaker was connected at the left end of the tubes. Stacks were placed on the front and back of the confluence in the tube. The 50-mm-long stack is made of honeycomb ceramic (hole size and channel radius of 1200 cpsi: 0.35 mm).

At the loudspeaker-side of the stacks, an electric heater was placed as a hot heat exchanger. The temperature of a cold heat exchanger at the counter-loudspeaker-end of the stack is maintained using circulating water. These heat exchangers create a temperature difference in the stack.

A single sine wave was transmitted from the loudspeaker. The sound pressure before and after passage through the stack was measured using pressure sensors A, B, and C.

The temperature difference created in the stack was set to 0 K, 200 K, and 400 K by varying the heat energy supplied to the heater. The low temperature was 300 K. The frequencies of the sound transmitted from the loudspeaker were from 100 Hz to 1000 Hz.

Peak sound pressure of pressure sensors A, B, and C installed in the tube were defined respectively as PA, PB, and PC. The rate of sound pressure change calculated using 2PC / (PA + PB) and by dividing the sound pressure change ratio of 0 K to remove the difference in propagation loss at each frequency.



Figures 1(a), 1(b) Experimental setup with muffler of a multi-cylinder engine. Figure 1(a) shows the condition of stack was installed on back of the confluence. Figure 1(b) shows the condition of stack installed in front of the confluence.

3.2 RESULTS

Figure 2 shows the rate of sound pressure change as a function of the frequency. From Fig. 2, results show that the sound pressure after passage through the stack with a temperature gradient of 200 k and 400 K is lower than that with a temperature gradient of 0 K. In other words, a silencing effect was observed in all conditions in this experiment. The rate of sound pressure change is higher with a greater temperature gradient in the stack and is larger with lower frequency. The highest rate of sound pressure change is about 70% when a temperature gradient in the stack is 400 K and the frequency is 100 Hz. In addition, silencing effects were changed only slightly depending on the stack installation position. From these results, it is considered that the silencing effect with same temperature gradient was effective when the stack was installed on the back of the confluence.

4. CONCLUSION

We have proposed an automobile muffler using thermoacoustic effect. This paper describes an experiment of a thermoacoustic silencer created for practical use. We specifically examined the stack installation position. A muffler of a multi-cylinder engine has branch tubes. We investigated the influence of stack installation position of the branch tube. A branch tube has a confluence. A stack was installed at the front and back of the confluence. The silencing effect was observed in all conditions in this experiment. The rate of sound pressure change is higher with a larger temperature gradient in the stack and is higher with lower frequency. The largest rate of sound pressure change is about 70% when a temperature gradient in the stack is 400 K and the frequency is 100 Hz. In addition, silencing effects were changed only slightly depending on the stack installation position. From these results, it was inferred that a silencing effect with same temperature gradient was effective when the stack was installed at the back of the confluence.

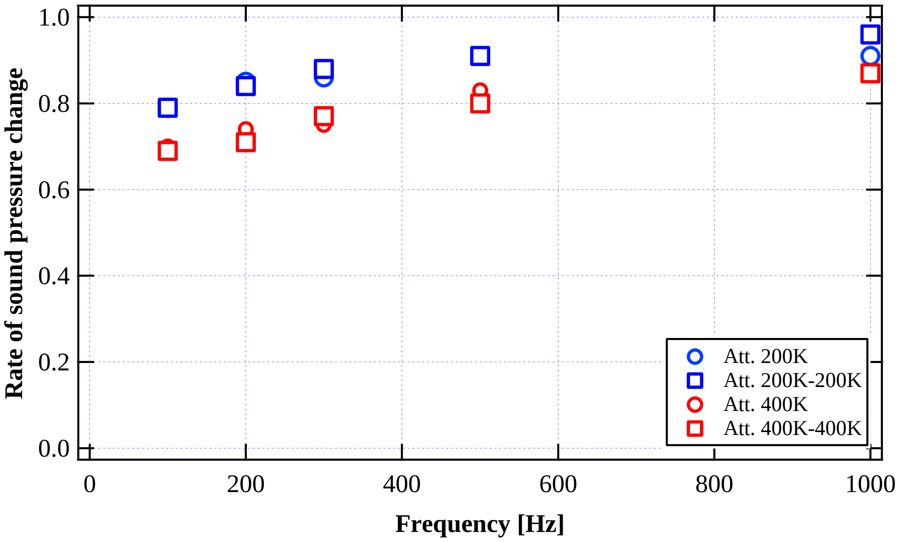


Figure 2 Rate of sound pressure change as a function of the frequency.

ACKNOWLEDGEMENTS

This work was partially supported by JSPS Grant-in-Aid for Challenging Exploratory Research (23651072), JSPS Grants-in-Aid for Young Scientists A (22686090), B (19710072), the MEXT Regional Innovation Strategy Support Program, and Tateisi Science and Technology Foundation.

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