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Construction of Thermal and/or Electric Exchange System whereby Environmental Noise is Considered to be an Energy Source

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Abstract [612] Sound is a rarefactional wave of the air. Therefore, noise can be considered to be a sound energy. By thermoacoustic theory, noise is exchanged for thermal energy and is controlled. In addition, thermal energy is extracted from the noise. There are many applications of thermoacoustic theory such as Stirling engines. This system of heat supply whereby noise is considered to be an energy source is very unique. The purpose in this study is the development of this idea into practical levels. Because noise is usually absorbed by some substance and finally exchanged for thermal energy, this system never produces additional heat loads in a global environment, where normally, a noise is discharged to the external field. It is also very unique that energy of noise is actively consumed by the energy exchange. Noise is an unusual type of energy because waste of noise is encouraged. When noise which overflows in present-day life is decreased, the energy of the noise is exchanged, and is used as a heat supply such as air-conditioning. It is thought that noise is applied as an alternative energy. If it is difficult to use as the thermal energy, it can be another purpose of this paper that noise is furthermore exchanged for electric energy by Seebeck effect, though the efficiency of exchange is reduced.

1 INTRODUCTIOIN

Swift [1] believes it is very likely that practical uses will be found for thermoacoustic engines, because these engines have the advantages of reasonable efficiency and extreme simplicity. At the present day, it is another prominent advantage that these engines can transfer heat without chlorofluorocarbons.

Swift pointed out that there are two classes of heat engines: prime movers and heat pumps. In a heat pump, work is absorbed by the engine, resulting in the pumping of heat from low temperature to high temperature. Thus a source that produces work such as a loudspeaker or heater is indispensable for a thermoacoustic resonator, a kind of thermoacoustic heat pumps.

We research the capability of thermal exchange system whereby environmental noise is considered to be an energy source, and first report [2] about the exhaust noise of motorcycles was published. In this study, a system whereby railroad noise was considered to be an energy source was proposed and evaluated.

2 THE SIMPLIFIED MODEL FOR THE PROCESS OF THERMOACOUSTIC HEAT PUMP

Sound wave propagating without obstacles carries adiabatic change to oscillating fluid, while in the sound wave progressing through narrow paths there is heat exchange between the solid walls of the narrow paths and the fluid. The sound wave can transfer heat by the heat exchange on the solid walls.

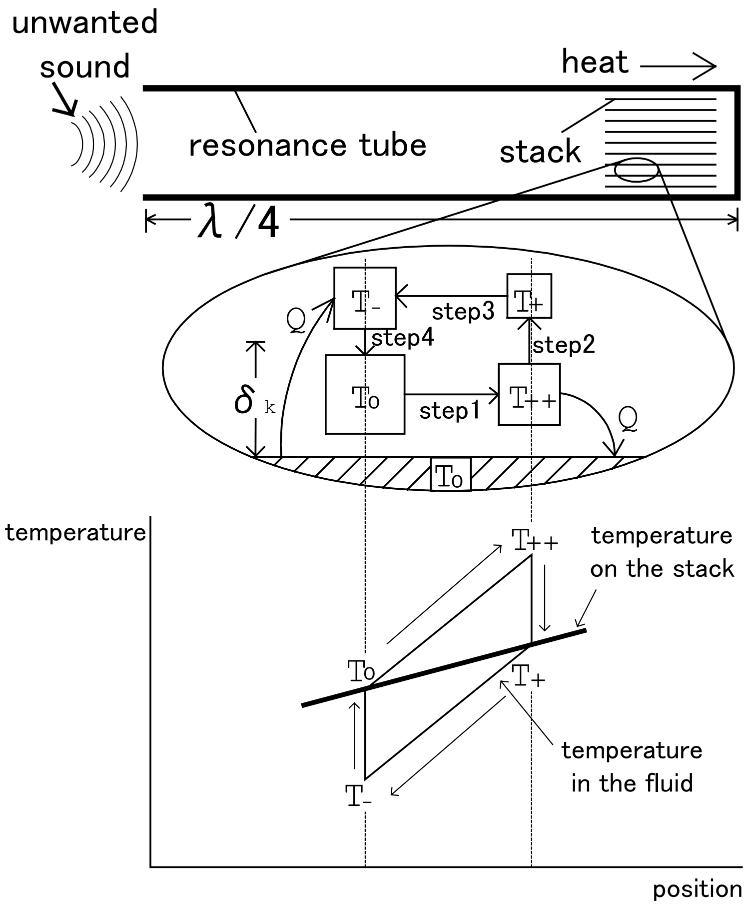

Figure 1: *Schematic Diagram of a Quarter Wavelength Thermoacoustic Refrigerator*

Figure 1 shows heat flux in the thermoacoustic resonator [3]. Standing wave arises in the resonator by the influx of sound wave from left end of the resonator. The resonance frequency which corresponds to a quarter wavelength of sound equals the resonator length.

Near the closed end of the resonator there are stacks whose spacing is chosen to be a few thermal penetration depths. The thermal penetration depth δ_κ represents the distance over which heat will diffuse through the fluid during a time $1/\omega$, and defined by $\delta_\kappa = \sqrt{2\kappa/\omega}$, where $\kappa = K/\rho_m c_p$

is the fluid's thermal diffusivity, ω is the angular frequency, K is its thermal conductivity, ρ_m is the mean density of the fluid, and c_p is the isobaric specific heat per unit mass.

This length scale is crucial to understanding the performance of the thermoacoustic cycle because the diffusive heat transport between the fluid and the stack is only significant within this region. Thus the distance from the solid stack material is small enough that a substantial amount of thermal conduction can occur in an amount of time $1/\omega$.

In the middle of Fig. 1, a small portion of the stack has been magnified and a parcel of fluid undergoing an acoustic oscillation is shown. The four steps in the cycle are presented by the four boxes, which are shown as moving in a rectangular path for clarity. In reality, they simply oscillate back and forth.

The temperature of the stack at the left-most position of the oscillating fluid parcel's excursion is therefore $T_m - x_1\nabla T$, and at the right-most excursion is $T_m + x_1\nabla T$, where T_m is the mean temperature on the stack, and ∇T is mean temperature gradient. The fluid is transported along the stack by a distance $2x_1$, and is heated from a temperature of $T_m - x_1\nabla T$ to $T_m - x_1\nabla T + 2T_1$ by adiabatic compression (step1), where T_1 is the adiabatic temperature change of the fluid. The warmer fluid parcel transfers an amount of heat dQ_{hot} to the stack by thermal conducction at the constant pressure and its temperature decreses to that of the stack $T_m + x_1\nabla T$ (step2). The oscillating fluid is transported back along the stack to position $-x_1$, and is cooled by adiabatic expansion to a temperature $T_m + x_1\nabla T - 2T_1$ (step3). The fluid parcel absorbs an amount of heat dQ_{cold} from the stack. In result, this raises its temperature back to its original value $T_m - x_1\nabla T$ (step4).

Thus, this system forms complete cycles back to the original situation, and the overall heat pumping process is analogous to a "bucket brigate" in which each fluid parcel picks up heat from its neighbor on the left at a lower temperature and hands off the heat to its neighbor on the right at a higher temperature.

3 EXAMINATIONS OF EXPERIMENTAL APPARATUS

To optimize the constitution of the stack, the following experiments were performed [2].

The resonator is 32mm diameter and 102mm long acrylic tube, and connected with a loudspeaker through a conoid tube. The right end of the resonator is closed by plastic plate. First of all, it was measured that the resonance occurs at 88Hz, an operating frequency which corresponds to a quarter wavelength of sound equals the resonator length and sound pressure distribution shown in Fig. 2 forms in the resonator by trailing condenser type microphone (6mm diameter) along the axis of the resonator.

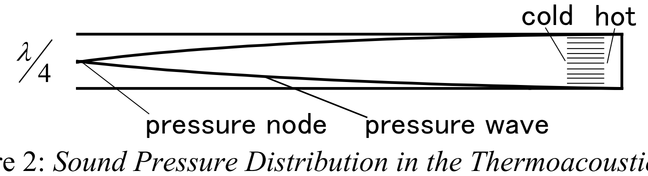

Figure 2: *Sound Pressure Distribution in the Thermoacoustic Tube*

The stack consists of a bundle of 50mm long polyimide tubes. Temperature distribution in the resonator was measured by inserting type K thermocouple probe (ϕ 1.5mm) at 88Hz. The measurements were performed for three types of polyimide tubes shown in Fig. 3. The diameters of the tubes are 0.8mm, 1.0mm, and 1.5mm, respectively.

(a) ϕ 0.8mm (b) ϕ 1.0mm (c) ϕ 1.5mm

Figure 3: *Cross Section of the Stack*

As a result, the lowest temperature shown in Fig. 4 was measured when diameter 1.0mm tubes were set in the resonator.

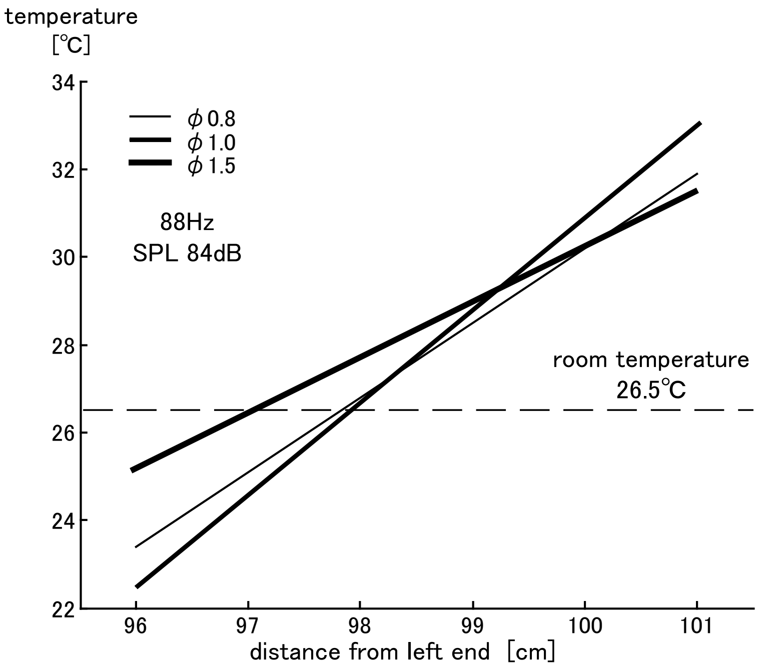

Figure 4: *Temperature Distribution around the Stack*

4 EXPERIMENT OF A SYSTEM BY RAILROAD NOISE

We proposed the system whereby railroad noise was considered to be an energy source shown in Fig. 5 and experimented to practical use.

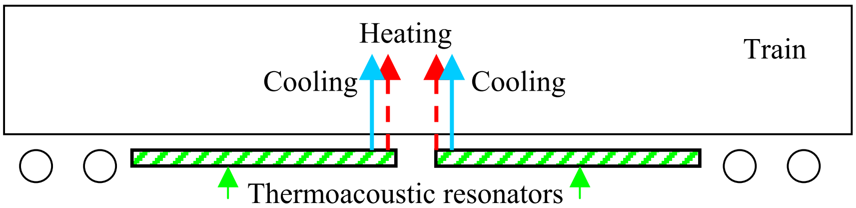

Figure 5: *Thermoacoustic System by Railroad noise*

The experiment that a sound source was railroad noise instead of the sinusoidal sound source was performed. Figure 6 shows the frequency distribution of the railroad noise used in this study.

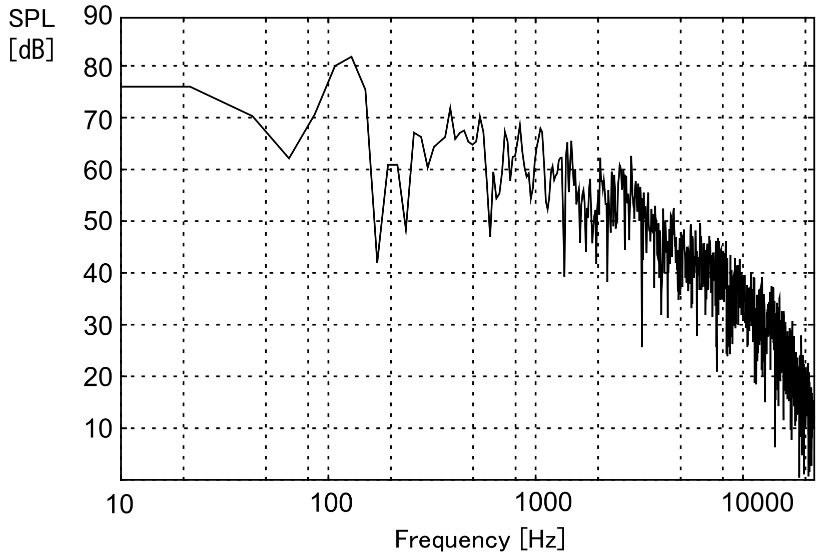

Figure 6: *Frequency Distribution of Railroad Noise Used in this Experiment*

It was seen that there is a dominant component at 135Hz. The experiment shown in Fig. 7 was therefore performed by 610mm long tube that corresponds to a quarter wavelength of sound at 135Hz.

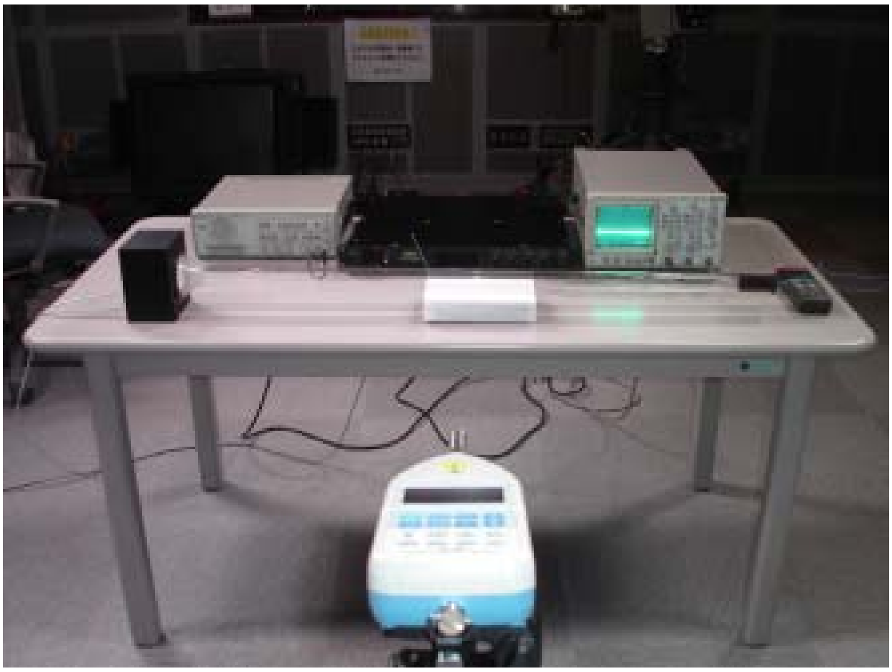

Figure 7: *View of the Experimental Apparatus*

Figure 8 shows the result of this experiment. Lower temperature 18.3℃ than the room temperature 19.3℃ was measured.

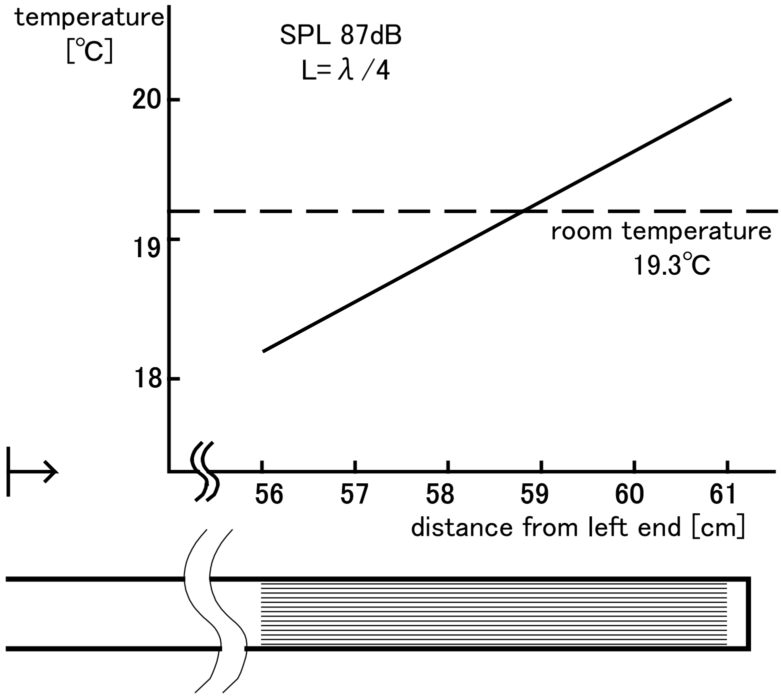

Figure 8: *Temperature Distribution around the Stack in Thermoacoustic System by Railroad noise*

There are possibilities of the energy consumption by cooling in the summer and by heating in the winter, but in periods that the air-conditioners are not operated, there are few possibilities of the energy consumption based on thermodynamics. A construction of electric exchange system from environmental noise, therefore, was tried to accomplish, although the efficiency of exchange may decrease severely.

Voltage generated by inserting several thermocouple probes that were connected in series near the closed end of the resonator was measured.

Accurate results could not be obtained, because there may be larger electric noises over 100mV than a predicted value under 10mV. It follows that many improvements of the whole system are necessary.

5 CONCLUSIONS

To optimize the constitution of the stack, the measurements were performed for three types of polyimide tubes. As a result, the lowest temperature was measured when diameter 1.0mm tubes were set near the closed end of the resonator.

The thermoacoustic system whereby railroad noise was considered to be an energy source was proposed. In the system, a temperature lower than room temperature was measured.

A construction of electric exchange system from environmental noise was tried. However, accurate results could not be obtained. Many improvements of the whole system are necessary.

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