ACOUSTICAL LETTER

Observation of acoustic particle velocity around neck of Helmholtz resonator

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1. Introduction

The Helmholtz-type resonator is a well-known sound circuit of an enclosed volume of air that is connected to a short air column, called a neck.

It is explained that the resonance phenomenon is caused by interaction between the mass element of the air in the neck and the spring element in the back volume [1–3]. It is also explained that the strong reciprocal motion of the air mass is excited in the neck and around the neck. Therefore, confirming the excited motion of the air or the acoustic particle velocity instead of the motion in the resonator is an interesting acoustical theme. However, the air motion or the particle velocity cannot be simply measured using only a microphone, and a new device is necessary to observe them. To solve such a problem, the author tried the method of using a thin film and a laser vibration meter for such a phenomenological observation [4].

In this research for the same problem, a new attempt to observe the particle velocity around the neck using a hot-wire-type particle velocity sensor is carried out [5].

In this paper, the outline of the trial observations on this theme and their results are described.

2. Outline of observation experiments

Figure 1 shows the outline of the resonator and the equipment used for the observation experiments. The neck was made of a vinyl chloride pipe with a diameter of 40 mm and a length of 100 mm with a flat plate for connecting to the back volume. Hemispherical ball tableware with a capacity of 870 ml was used as the back volume part. The neck was tightly connected to the back air volume, and the resonator was formed. A small microphone was placed near the opening of the neck. A hot-wire-type particle velocity sensor was placed on and around the opening of the neck, and it moved with a distant pitch of 3 or 5 mm for many experimental observations. White noise was radiated from the loudspeaker at an upper point with a distance of about 1 m from the resonator.

Outputs from both the microphone and the particle velocity sensor were recorded on the data recorder (RION DA-20) simultaneously. The recorded data were sent to a personal computer as wave-type file, and then transfer function analyses on the particle velocity sensor output against the microphone output, for the reference, were analyzed by using the fast Fourier transform analysis software. In these experiments, calibrations for both the microphone and the particle velocity sensor were not executed. Therefore, analyzed results are displayed only in terms of the ratio between the outputs of both the particle velocity sensor and the microphone or its level value.

Because the acoustic particle velocity sensor used had bidirectional directivity with figure-eight-shaped sensing, observation experiments with both its sensitivity directed the parallel to the axis of the neck and toward the right-angled direction were carried out. Hereafter in this paper, these measured results are called "axial component" and "radial component."

3. Results and considerations

For examples of the analyzed result, the axial component when the particle velocity sensor was placed at the opening of the neck is shown in Fig. 2 together with the results when the sensor was set at certain distances from the opening. In this figure, sharp peaks appear near the frequency of 200 Hz at the opening and at a near by point. They are clear evidence or typical characteristics of acoustic resonance. In addition, it is recognized that some sharp peaks appear at a frequency about 1,400 Hz and multiples of this frequency, which are higher than the theoretical resonant frequency.

To confirm the existence of these peaks theoretically, an acoustic circuit model consisting of multi-air-layers, more than one hundred sections, with different acoustic impedances obtained by varying each sectional area from the bottom of back the volume to the opening of the neck was developed. The frequency characteristics of the ratio of the particle velocity u_s to the sound pressure p at the opening of the neck were calculated using the following equations:

$$Z_{n+1} = \left(\frac{S_n}{S_{n+1}} Z_{\text{air}}\right) \frac{\left(\dfrac{S_n}{S_{n+1}} Z_{\text{air}}\right) \sinh ikl_{n+1} + Z_n \cosh ikl_{n+1}}{Z_n \sinh ikl_{n+1} + \left(\dfrac{S_n}{S_{n+1}} Z_{\text{air}}\right) \cosh ikl_{n+1}}, \tag{1}$$

$$k = k_0{}' - ik_{0\_n+1}{}'', \tag{2}$$

$$u_s/p = \frac{1}{Z_s}, \tag{3}$$

where Z_n is the acoustic surface impedance at the n-th section, S_n is the area of the n-th section, l_n is the thickness of n-th

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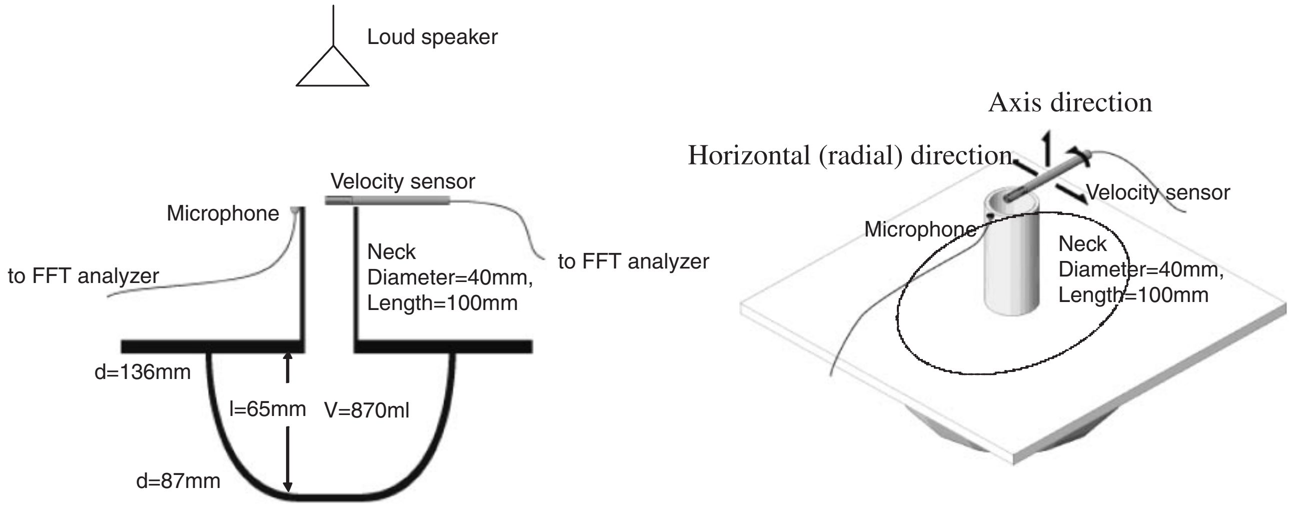

Fig. 1 Block diagram for observation of the acoustic particle velocity around the neck of a Helmholtz resonator.

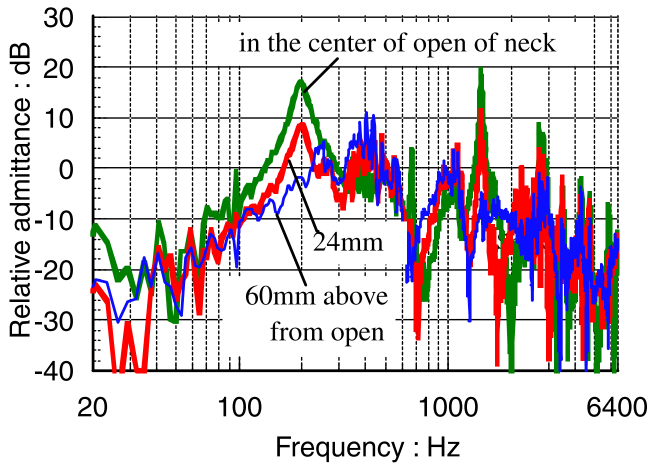

Fig. 2 Measured results of the axial component of particle velocity near the opening of the neck of a Helmholtz resonator.

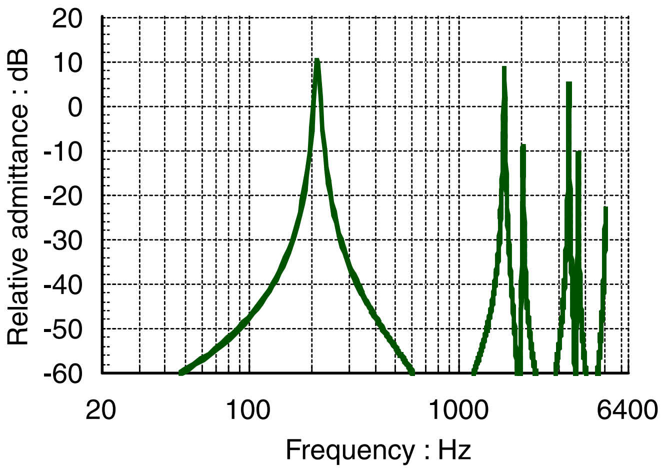

Fig. 3 Theoretically calculated particle velocity on the opening of neck of a Helmholtz resonator.

section, Z_{air} is the acoustic impedance in air, $k_0{}'$ is the wave number in air, $k_{0\_n+1}{}''$ is the attenuation constant [6] in the $n+1$-th section, i is imaginary number unit and Z_s is acoustic impedance on the open surface of the neck.

Theoretically calculated results are shown in Fig. 3. In this figure, the appearance of a series of peaks roughly corresponds to that in the experimental results. The calculated results on the phase change also corresponded to the results obtained in the observation experiments.

From the calculation tests for the peaks at frequencies higher than the theoretical resonant frequency of the Helmholtz resonator, it can be recognized that the peak was brought about by the air column resonance between both opening ends in a cylindrical neck, and that a lot of peaks for higher-order resonances were produced.

Next, while the particle velocity sensor was moved from the center of the opening of the neck to a certain extended distant point on the axis, the observation experiments were carried out. Then, alternative observation experiments were also carried out while the sensor was also moved from the center of the neck in the radial, outer, direction.

Three-dimensional displays of axial components based on both experimental results are shown in Fig. 4. In these examples, to limit the considerations of phenomena to only those in the Helmholtz type resonator, the analysis upper-limit frequency is set to 1,000 Hz.

In Fig. 4, the resonance phenomenon in the Helmholtz-type resonator is observed as the remarkable chain of peaks with the decrease in height with distance from the opening of the neck along the axis line. Such a gradual decrease in particle velocity shows the existence of the additional mass part related to “length correction at open end.”

In Fig. 5, the distribution of the amplitude of the axial component along the radial direction line at the opening of the neck and its extended points is shown. The rapid attenuation of the particle velocity on only the outer side of the opening of the neck can be recognized. These detailed observations can be realized the basis of the fine spacing distributions by moving the sensor and on the basis of the range resolution of the particle velocity sensor used.

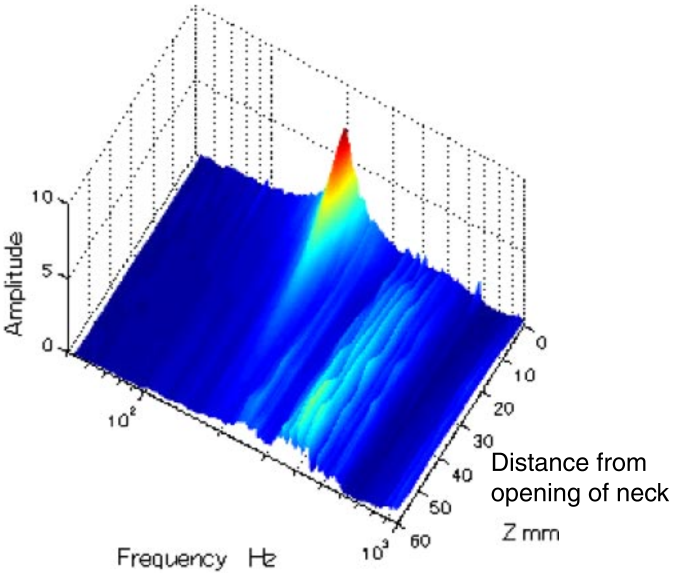

Fig. 4 Three-dimensional display of the distribution of axial component of particle velocity. Decrease in amplitude with distance from opening of the neck.

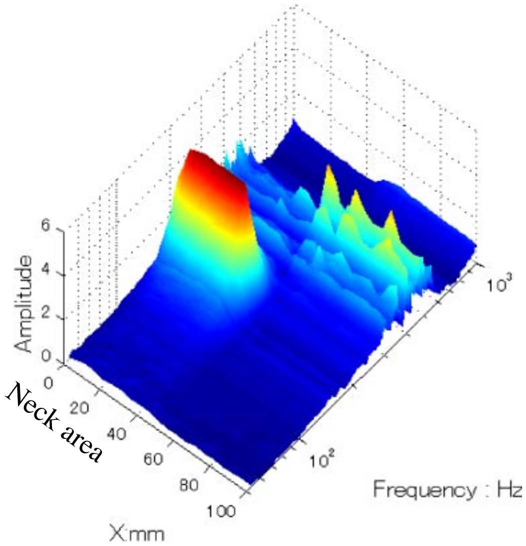

Fig. 5 Three-dimensional displays of the distribution of the axial component of particle velocity at the opening of the neck. Change along radial (horizontal) direction.

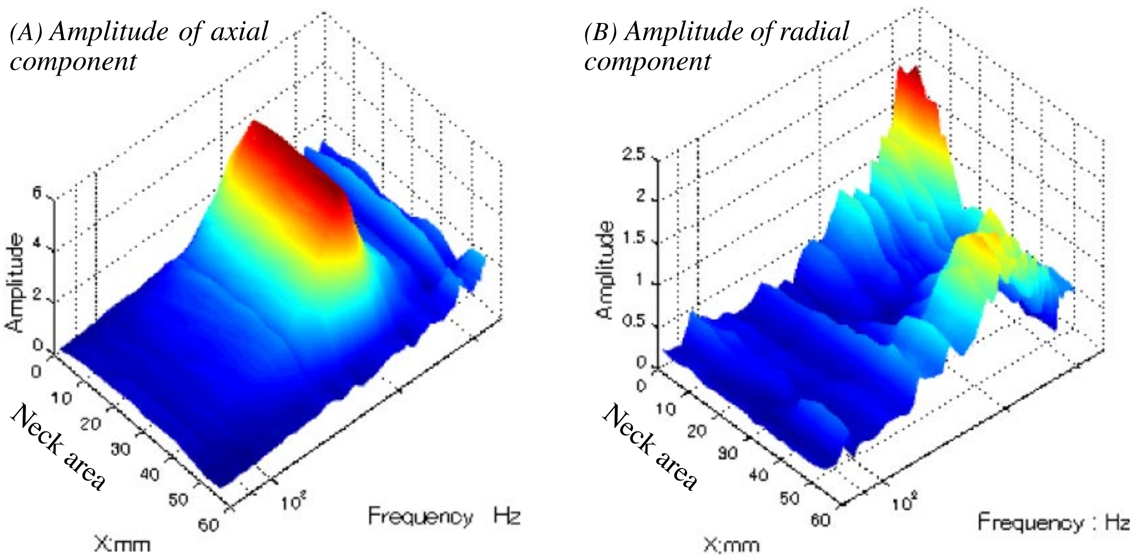

Fig. 6 Comparison of the distributions of both axial and radial components of the particle velocity at the opening of the neck (Frequency range 80 Hz–350 Hz).

Furthermore, the direction of the sensitivity of the particle velocity sensor was rotated by 90 degrees, and then the radial components of particle velocity were observed on the diametric line at the opening of the neck. The amplitudes of both the axial and radial components of the particle velocity are comparatively displayed in Fig. 6.

It can be recognized that the axial component at the resonant frequency of about 200 Hz is much stronger on the inner side of the opening of the neck. From these results shown in Fig. 6(B), it can be recognized that the radial components are minimum at the center of the opening and increase while leaving the center.

Finally, the particle velocity is displayed in vector form on the bases of results with these two-dimensional components only at the resonant frequency of about 200 Hz. In this observation experiment, the condition of placing a baffle plate at the opening of the neck was added. Figure 7 shows the analysis results.

The flow and outflow of sound waves between the opening and near the region of the neck are clearly observed, and their strengths become weak while parting from the opening of the neck. Moreover, the ratio of radial components to axial components seems to be relatively strong when the baffle plate is placed at the opening of the neck. It can be thought that the baffle plate makes the phenomenon of sound wave flow between the neck and the periphery, the induction effect of the sound wave flow, take place easily.

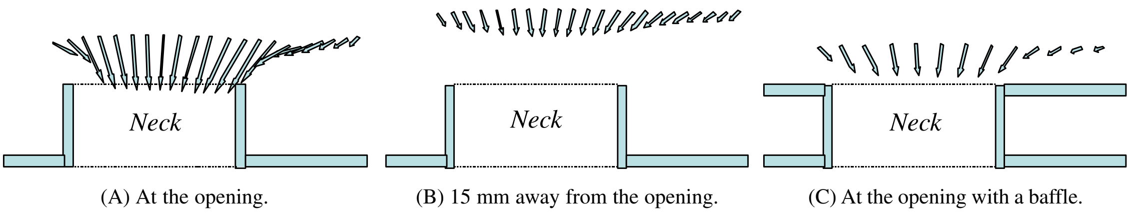

Fig. 7 Vector forms of particle velocity in front of the opening of the neck under each condition.

4. Summary

(1) Observation experiments for the particle velocity around the neck of a Helmholtz type resonator were carried out.
(2) A hot-wire-type velocity sensor was set with fine spacing and the observation experiments were performed.
(3) Resonant phenomena could be detected through sharp spectral peaks of the particle velocity.
(4) Resonant phenomena and the amplitude change were observed around the neck, providing apparent evidence of the existing of, for example, additional mass parts.
(5) Sound flow at the opening of the neck and its surround area could be observed, and some resonant characteristics or features of the Helmholtz resonator could be visually clarified.

Acknowledgements

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