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Frequency Characteristics of Single-Resonator Type Silencers

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Abstract
Experiments have been made of the transmission loss of Helmholtz resonator type silencers in order to examine factors changing resonator characteristics. It is shown that the effective length of connector, which affects the resonance frequency without flow, depends on the configurations of the connector and volume chamber. It is further shown that the resonance frequency with flow shifts to the higher region as flow speed is increased.
Keywords: Helmholtz resonator, connector length, end correction, flow, Transmission Loss

1. Introduction
The Helmholtz resonator-type silencer functions effectively at the resonance frequency, being useful to control narrow-range frequency noise in piping systems. The concept of the acoustical design of a resonator is to determine its dimensions so that the resonance frequency may agree with the predominant frequency of a noise component which should be reduced. The connector length, that is one of the factors forming such a resonance effect, is corrected at its open ends, however, there is merely a little information about geometric parameters and flow speed contributing to the connector effective length.

In order to enable more exact estimations of resonance frequency of this type of silencers for ventilation systems, transmission loss characteristics of resonators were measured. From obtained data in the without flow case, the end-correction coefficients are presented in connection with resonator configurations. Based on the results, the change of resonance frequency by flow is investigated.

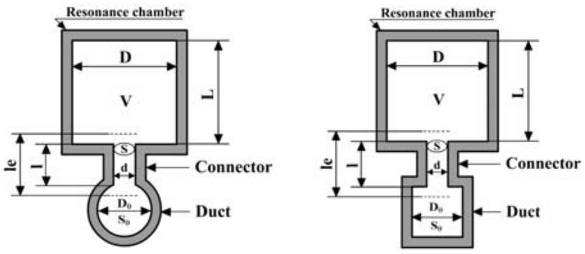
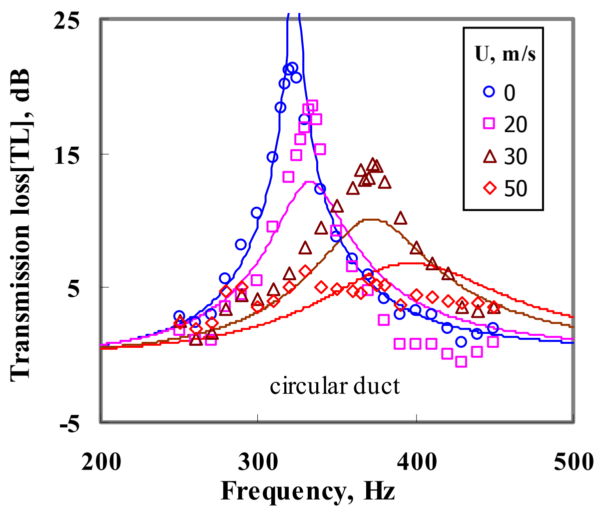


Fig.1 Resonator models: (a) circular, (b) square

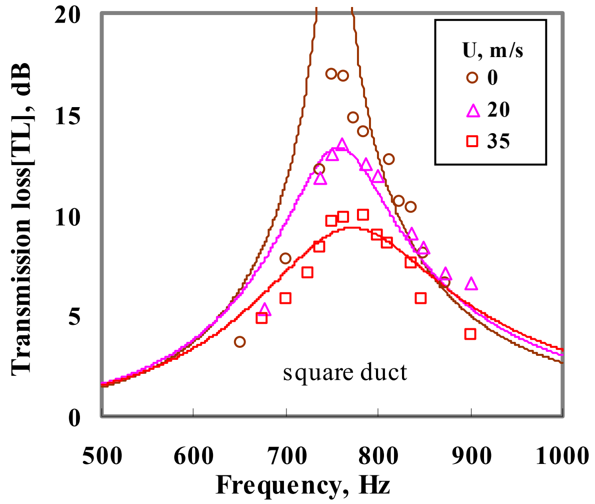
2. Experimental models
Figure 1 shows the resonator models which were produced with cylindrical pipes, attached to the circular duct (diameter: D_0=48mm) and the square duct (side length: D_0=51mm), respectively. Each dimension of resonators was decided in the following ranges of the configuration parameters; D_0/d=1.1-2.6, l/d=0.4-2.0, D/d=1.5-5.3 and L/D=0.2-2.0, where d, l, are diameter and length of connector and D, L are diameter and length of resonance chamber. Additionally, S_0 is duct cross-sectional area, S connector cross-sectional area and V volume of resonance chamber.

Transmission loss of the test resonators was measured using the former set-up which mainly consisted of the blower, loud speaker, anechoic duct-end and probe-tube microphone connected with FFT analyzer[1]. The upper limit of mean flow velocity U was 80m/s.

3. Results
3.1 Transmission loss characteristics of resonators
In Fig.2, experimental resonance transmission loss is lowered by flow[2], and it is observed that resonance frequency shifts to higher region as flow velocity is increased exceeding a certain value. Namely the mean flow changes resonator characteristics from a sharp-ridge shape to a gentle-hill one around its top frequency. Experimental points well accompany the solid lines



(a)



(b)

Fig.2 Transmission loss characteristics of an ordinary type silencer: (a) circular, (b) square

calculated by the equation containing the terms of impedance and Mach number[3], if the resonance frequencies for calculations are adjusted to peak frequencies measured.

Figure 3 shows transmission loss characteristics of the resonator attached to the small-sized cavity which is set in the square duct. As flow velocity is increased, the resonance transmission loss lowers in its level, however, the resonance frequency is kept unchanged. This suggests that the change of frequency characteristic of a resonator occurs when an air mass oscillating in the connector touches the separated flow passing over the connector entrance.

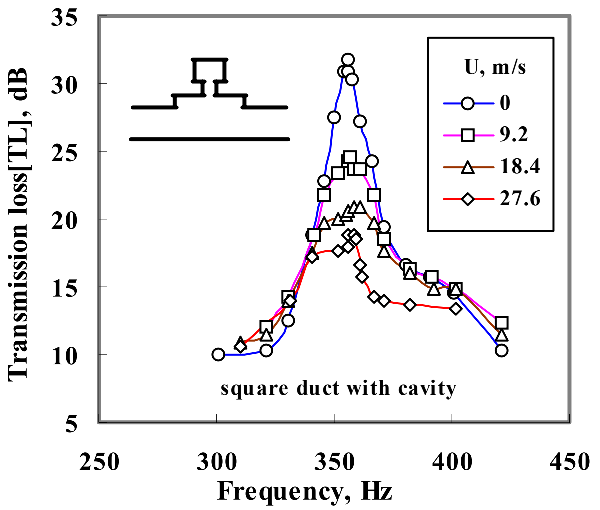


Fig.3 Transmission loss characteristics of a cavity type silencer

3.2 End correction for connector

For the low flow-speed range in which the resonance frequency is unaffected by flow, the ratio of effective length to diameter of connector is given by the following equation derived from the classical resonator impedance[4].

$$\frac{l_e}{d} = \frac{l}{d} + \beta = \frac{1}{16\pi}\left(\frac{f_{ro}}{c}\sqrt{\frac{V}{d}}\right)^{-2} \qquad (1)$$

where β is the coefficient for the open-end correction, that is, the ratio of corrected-portion length to diameter of connector.

Figure 4 shows relationship among parameters regarding the connector-end correction. The parameter denoted on the vertical axis, that is dimensionless frequency, has been given experimentally by f_{ro} corresponding to the peak frequency of transmission loss without flow. When connector configuration(l/d) is fixed, dimensionless frequency becomes constant up to the chamber configuration L/D of about 0.7 and then decreases with comparatively slight discrepancies, and it is viewed as a quantity independent of both open-end configurations of connector (D_0/d and D/d).

From the data in the region of the constant dimensionless frequency in Fig.4 and Eq.(1), the averaged basic value of correction coefficient β_1 can be expressed for every connector configuration as shown in Fig.5(a). The difference between respective data for both ducts may take place for the reason that the minimum is adopted as a real length of the connector in the circular duct because it cannot be specified for the complicated structure of the connector-set place (see Fig.1(a)). In Fig.5(b), the coefficient β_2, which has been obtained in the region where the dimensionless frequency is changeable with chamber configuration, is shown by the subtraction with β_1 as the values to be added to the basic data arranged in Fig.5(a). Eventually the two charts give the end-correction coefficient from 0.45 to 0.90 as a whole according to the connector and resonance-chamber configurations within the limits of general use.

3.3 Effects of flow on resonance frequency

As shown in Fig.6(a), the ratio of resonance frequency with flow to that without flow, f_r/f_{ro}, increases with Mach number of mean flow, finally converging a constant value. Such a frequency change by flow begins and stops at higher Mach numbers ,respectively, as the basic frequency f_{ro} becomes higher. The fact is considered as follows.

If a period of air oscillation in the connector is sufficiently short as compared with a time during which a flow passes over the connector, the bulk of the mass portion projected from the connector entrance will nearly be equal to the bulk without flow. As a cycle of the mass oscillation is delayed against a flow moving toward the duct end, the mass projection into the duct will be reduced in its bulk to be restrained to avoid the mass shedding, and finally limited to the connector exit opened into the resonance chamber. The sound energy inducing the resonance effect appears to be attenuated only by its

duct	square											circular						
Do/d	1.1	1.1	1.3	1.3	1.3	1.3	1.3	1.7	1.7	2.6	2.6	1.2	1.2	1.2	1.6	1.6	1.6	1.6
D/d	2.2	3.0	1.5	1.8	2.1	2.6	3.7	2.0	2.8	4.3	5.3	1.5	1.8	2.6	1.6	2.0	2.8	4.8
symbol	⊠	⊠	▲	◆	◎	△	■	⊞	⊟	◇	▣	⦾	●	◎	◇	▲	△	■

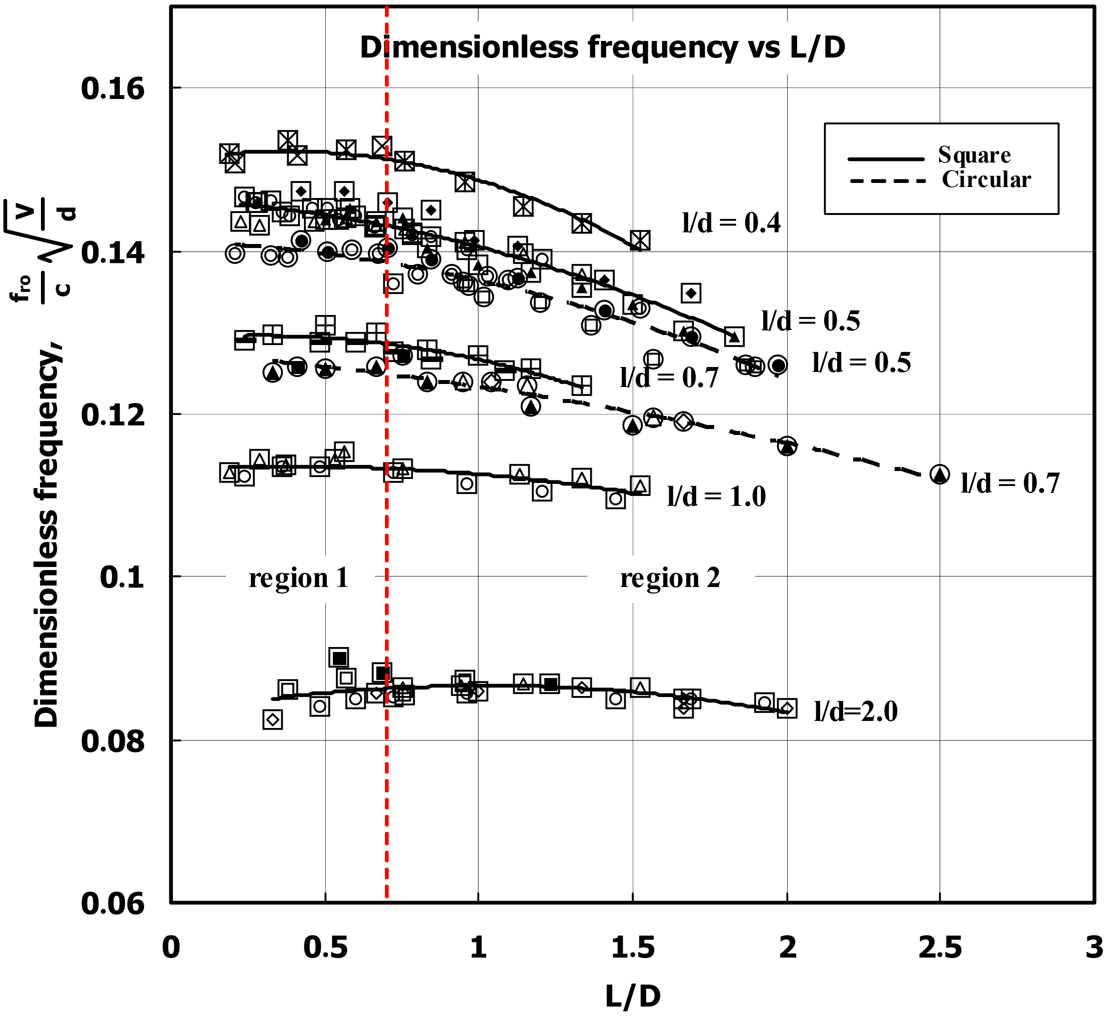


Fig. 4 Dimensionless frequency regarding end correction

dissipation at the connector discontinuity where the flow separation occurs and conserved for the process mentioned above. Therefore it is thought that the resonance frequency is raised corresponding to the reduction of the amplitude of mass oscillation and finally becomes constant once more at higher Mach number with the stabilization of mass projection at the only open end on the chamber side.

Fig.6(b) indicates that the move of resonance frequency to the higher region is marked as the connector configuration becomes flat for shortening in its axial direction. This means that the changing rate of connector effective-length by flow depends on its real length.

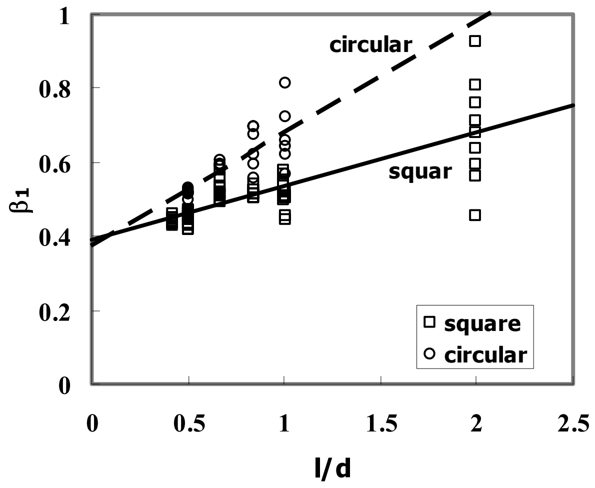
4. Conclusions

The parameters concerned with frequency characteristics of a single resonator have been investigated. The results indicate the followings.

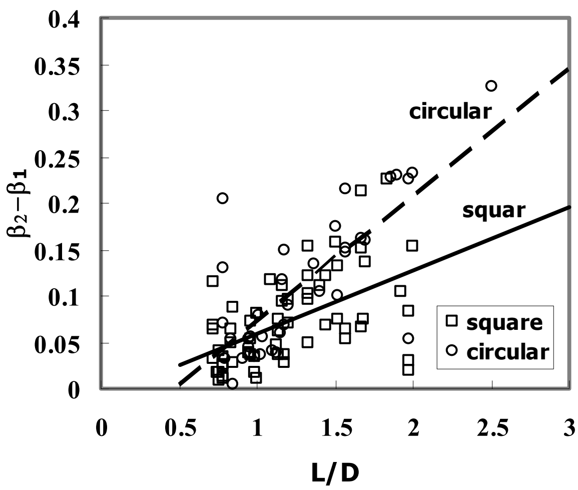
(1) The resonance frequency is much the same as without flow up to the limits of relatively low Mach number. In this case, the end correction for connector length is determined as a rule by the configurations of connector and resonance chamber independently of both open-end configurations of the connector.

(2) As Mach number increases exceeding the above limits, the resonance frequency characteristic moves to higher region, finally again stabilized. Such a change by

flow depends on the originally-fixed resonance frequency without flow and connector configuration.

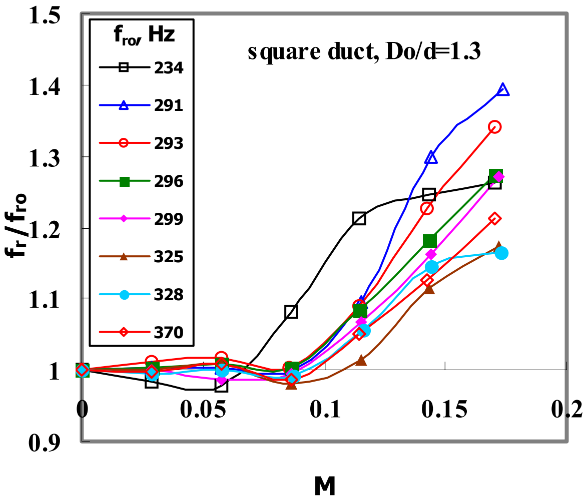


(a)



(b)

Fig. 5 Coefficients β for end correction region (a) 1, (b) 2



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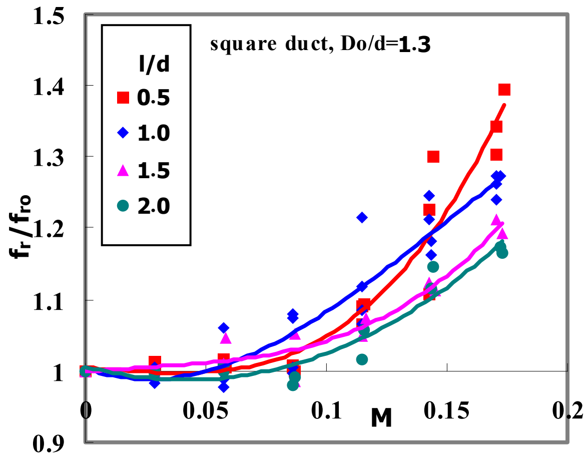

(b)

Fig. 6 Change of resonance frequency by flow

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