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Effect of Perforated Plate on Natural Acoustic Frequency of One Dimensional Sound Field Partitioned by Perforated plate

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***Abstract*— In previous studies, the natural acoustic frequency of an one dimensional duct partitioned by a perforated plate was clarified to come down with decreasing aperture ratio experimentally and analytically. The natural acoustic frequencies calculated by the Transfer Matrix Method are in good agreement with those obtained by the experiment and the natural acoustic frequency becomes lower with decreasing aperture ratio of the perforated plate. After this study, we calculated the mode of the duct with the perforated plate and focused the shape of the mode. Then the mode shape becomes the sine wave after the particle velocity passing through the perforated plate. The frequency was calculated by the 1/4 wave length of the mode and the frequency was compared with the experimental value. The both values coincide with each other. In this study, the sound propagation experiment was conducted in order to clarify the reason. As a result, it was clarified that the smaller aperture ratio was the longer the sound arrival time became. This is equivalent to the getting long of the duct and the natural acoustic frequency can be considered to become low.**

***Index Terms*— Natural Acoustic Frequency, Noise Control, One Dimensional Duct, Perforated Plate.**

I. Introduction

In a heat exchanger such as a boiler and a gas heater, tube banks exist in a duct to heat exchange from water to steam. The heat exchange can be performed by contacting the tube bank and the gas [1]～[4].

When the gas flows in the duct the karman vortices with frequency proportional to the flow velocity occur behind the tube bank. When the vortex shedding frequency comes close to the natural acoustic frequency determined by the sound speed and the duct size the high level sound generates. This phenomenon is well known as a “Lock in phenomenon”.

When the heat exchanger such as a large boiler is operated the noise problem caused by the self-sustained tone occurs and the factory is obliged to be stopped. Then it is very important not to cause the self-sustained tone [5]～[7].

The insertion of the baffle plate is generally used to suppress the self-sustained tone presently. However the insertion method has not been established and it is desired to get a new countermeasure.

One of the authors showed that when the perforated plate with the cavity was applied to the duct wall the self- sustained tone could be suppressed completely[8]. However the relation between the aperture ratio and the natural acoustic frequency has not been referred in that study. Then in this study, considering the duct with the cavity as one dimensional acoustic field, the effect of the perforated plate, especially aperture ratios, on the natural acoustic frequency will be discussed.

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II. Effect of the Perforated Plate on the Natural Acoustic Frequency

Fig.1 shows an experimental setup. The duct is made of Acrylic plate with 5mm thickness.

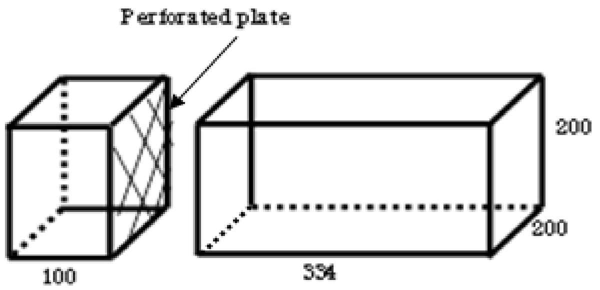

Fig.1 Experimental Setup

On the natural acoustic frequency of one dimensional acoustic field partitioned by the perforated plate as shown in Fig.1, the study of comparing the analytical results by the Transfer Matrix Method with experimental result exists [9]. And the reason why the natural acoustic frequency decreases with decreasing aperture ratio was explained by use of the acoustic mode shape variation in another study [10].

Fig.2 and Fig.3 are those results. Fig.2 shows the result in the case of considering the open end effect. The analytical results are in good agreement with the experimental results. “Anal.” and “Exp.” indicated in this figure show analysis and experiment respectively. Natural acoustic frequencies f1 and f2 show the first and the second natural acoustic frequencies respectively.

From Fig.2 it can be seen that the natural acoustic frequency decreases with decreasing the aperture ratio.

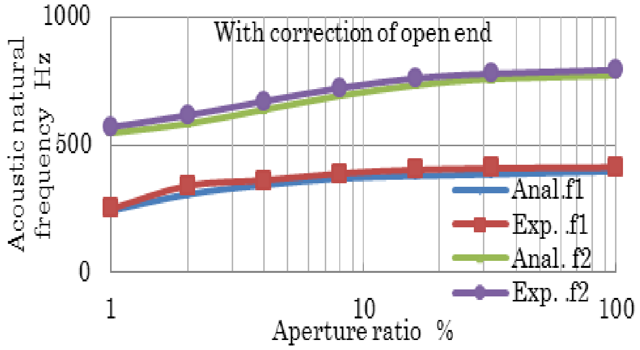

Fig.2 Comparison of Experimental Result with Analytical One

Generally, it can be considered that when the aperture ratio decrease the natural acoustic frequency increases because the perforated plate with small aperture ratio split up the acoustic field.

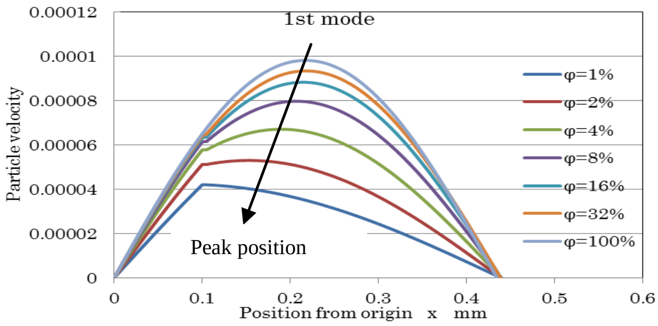

Fig.3 1st Natural Acoustic Modes against Various Aperture Ratios

Why does the natural acoustic frequency decrease when the aperture ratio decreases? We focused the variation of the wave length of the natural acoustic mode to answer the question.

Fig.3 shows the first particle velocity modes in various aperture ratios. The particle velocity is continuous before and after the perforated plate and becomes a sine wave mode after the sound passing the perforated plate and both ends satisfy with the boundary condition of "close (=particle velocity=0)". And watching the length of 1/4 wave length from the right end, it increases with decreasing the aperture ratio as shown by arrow in Fig.3. This was considered to be the cause of lowering the natural acoustic frequency.

Table1 Comparison of frequency between mode figure and analytical result (1st mode)

Φ (%)	P4	1/4 Wave Length	Wave Length	Freq. (Hz)	Analytical value(Hz) by Eq.(1)
1	-0.384	0.350	1.40	242.9	244.4
2	-0.751	0.284	1.15	296.2	301.1
4	-0.928	0.250	1.00	340.0	343.1
8	-0.983	0.233	0.932	364.8	367.0
16	-0.998	0.225	0.900	377.8	379.2
32	-1.004	0.222	0.888	382.9	385.1
100	-1.017	0.220	0.880	386.4	389.1

Obtaining the 1/4 wave length from Fig.3, the frequency calculated by $f=c/\lambda$ (First mode) is shown in shadow part of Table 1. It can be seen that the calculated values coincide with the analytical values obtained by T.T.M.in all aperture ratios.

This can be said about the second mode as well as the first mode. Fig.4 and Table 2 show the second particle velocity mode and the natural acoustic frequency calculated by 1/4 wave length, respectively. From above consideration, the roll of the perforated plate on the natural acoustic frequency is the variation of the wave length caused by phase lag due to the inertia effect at the hole. As a result, it can be understood that the natural acoustic frequency decreases with decreasing the aperture ratio. If so, the time lag (phase lag) must be generated when the sound wave passes through the perforated plate. In this paper, the sound propagation will be examined to ensure the presumption.

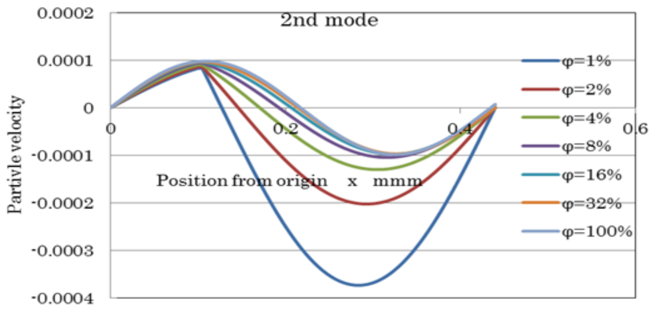

Fig.4 2nd Natural Acoustic Modes against Various Aperture Ratios

Table2 Comparison of frequency between mode figure and analytical result (2nd mode)

φ（%)	P4	1/4 Wave Length	Wave Length	Freq. (Hz)	Analytical value(Hz) by Eq.(1)
1	-0.315	0.156	0.624	544.9	546.2
2	-0.026	0.147	0.588	578.2	582.9
4	0.399	0.135	0.540	629.6	637.2
8	0.756	0.124	0.496	685.5	692.9
16	0.925	0.117	0.468	726.5	733.1
32	0.981	0.113	0.452	752.2	756.6
100	1.005	0.114	0.456	745.6	773.7

III. EXPERIMENT

A. Experimental Setup and Purpose

Fig.5 shows the outline of the experimental setup.Fig.5 (a), (b) and (c) are "open", "closed" and "open" at the right end of the duct as the boundary condition, respectively and "upper", "upper" and "lower" in microphone's position, respectively. The effect of the microphone's position on the measuring values will be examined by comparing (a) and (c). As well it can be examined the effect of the boundary conditions on evaluation of the sound speed by comparing (a) and (b).

B. Experimental Method

As shown in Fig.5, the speaker is set at 100mm apart from the left end of the duct and the sound is generated from the speaker by amplifying the sine signal given by the Personal Computer.

The perforated plates with various aperture ratios as shown in Fig.6 are set at the position as shown in Fig.5 and the variation of the apparent sound speed will be measured against the aperture ratio.

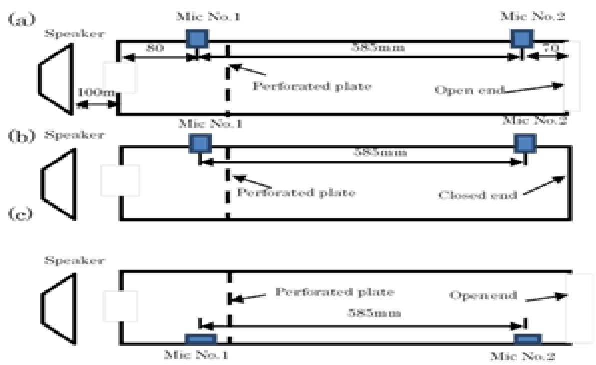

Fig.5 Outline of Experiment

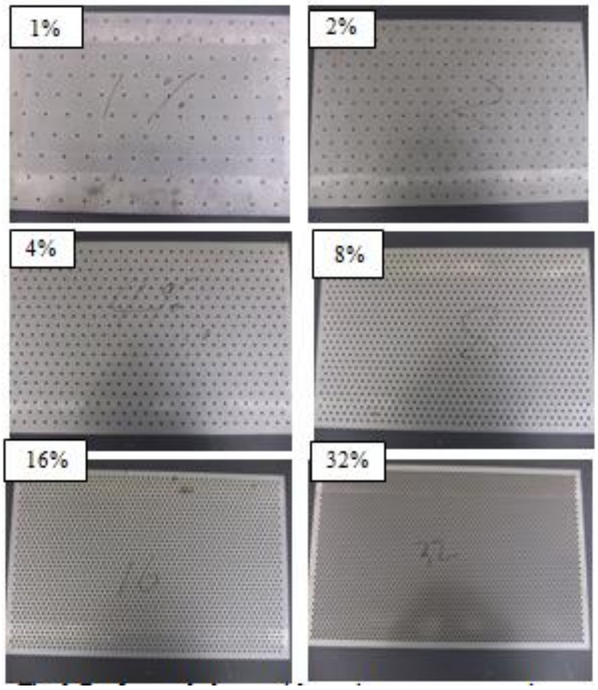

Fig.6 Perforated plates with various aperture ratios

For such occasions, two microphones are set before and after the perforated plate and the difference of the arrival time will be measured. In general, as the phase of each microphone is different from each other. Then the time difference (call the initial phase) between two microphones must be confirmed firstly. Therefore the two microphones are set at the same position and the sound pressures are measured at the same time after generating the sine signal. As shown in Fig.7, the time difference Δt_0 between microphone 1 and 2 is measured as the initial phase difference by using the peak times of two sine waves. Next, the microphone 1 and 2 are set on the duct as shown in Fig.5 and the sound is generated from the speaker by giving the sine wave from the PC.

The peak times of two microphones when the sound pressure become the maximum are denoted by t1 and t2, respectively. The propagation time Δt_p between two microphones can be obtained by subtracting the initial time differenceΔt_0 from the time difference $\Delta t = t_2 - t_1$. The apparent sound speed can be obtained by $\Delta l/\Delta t_p$. Where Δl is the distance between two microphones and it is 585mm here. Next, the apparent sound speed will be measured setting the reflection plate at the right end in the same manner as shown in Fig.5(b). Moreover setting the microphone lower position of the duct and removing the reflection plate as shown in Fig.5 (c), the apparent sound speed will be measured in the same manner. It will be examined whether the wave forms of the sound pressure before and after the perforated plate are different or not.

IV. Experimental Results and Considerations

A. Effect of the Microphone's Position on Measuring Results

Fig.8 shows the comparison of the natural acoustic frequencies in the cases of setting microphone upper (Fig.5(a)) and lower (Fig.5(c)) of the duct. In this case, the end of anti-speaker side is closed.

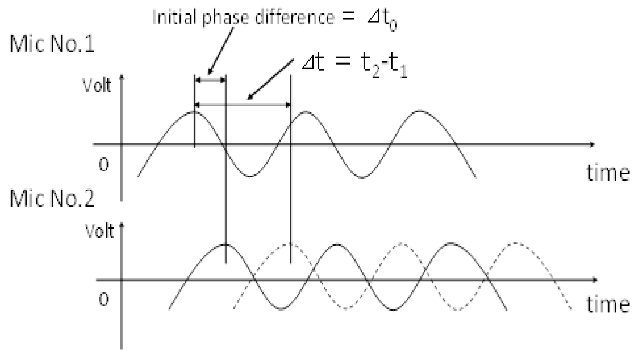

Fig.7 Evaluation Method of Sound Speed

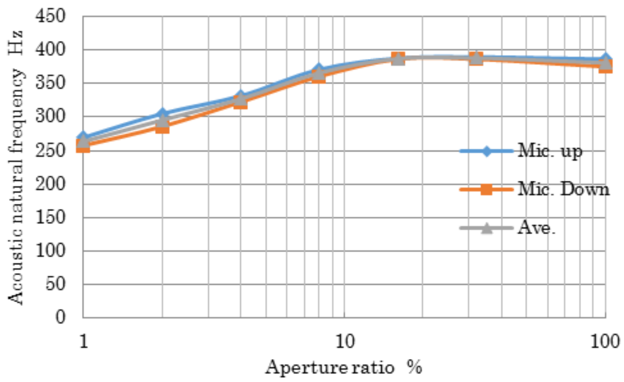

Fig.8 Comparison between Upper and Lower of Microphone's Position

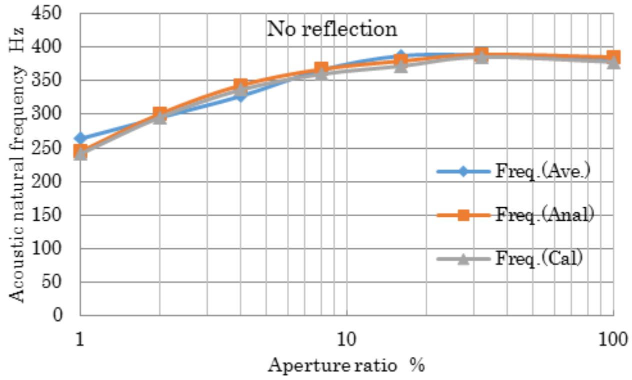

Fig.9 Comparison of Natural Acoustic Frequency Obtained by various Approaches (in the Case of Open End)

B. Comparison of Natural Acoustic Frequencies obtained by Various Approaches (In the Case of Open End)

Fig.9 shows the comparison of the natural acoustic frequencies obtained by T.T.M. ("Anal." in the figure), acoustic mode ("Cal." in the figure) and the sound speed obtained by the present experiment ("Ave." in the figure), respectively. From this figure, it can be seen that these results obtained by three different methods are coincident with each other.

Three different methods are as follows.

(1) Eigen value analysis by T.T.M.

(2) Method obtained by $f=c/\lambda$, λ is obtained by acoustic mode.

(3) Present method. Natural acoustic frequency is obtained by $f=c_a/2\Delta l$. Where c_a is the apparent sound speed and Δl is the distance between two microphones. c_a can be obtained the time difference measured by two microphones.

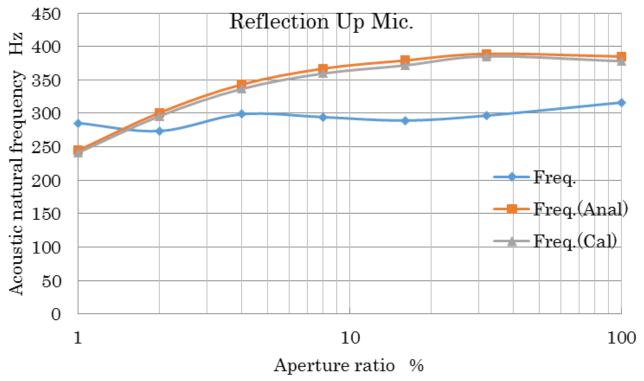

Fig.10 Comparison of Natural Acoustic Frequency Obtained by various Approaches (in the Case of Closed End)

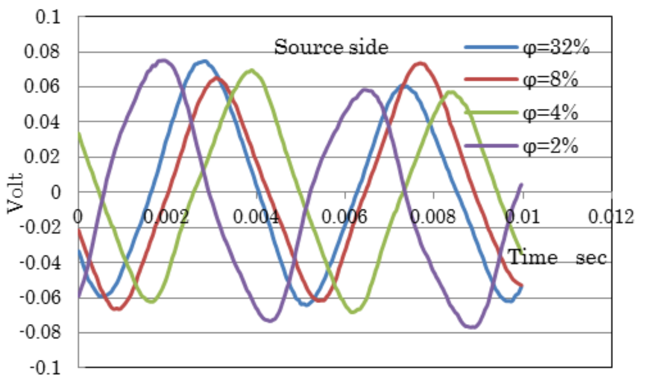

Fig.11 Sound Pressure Wave Form at Source Side

C. Effect of Boundary Condition on Evaluation of Sound Speed

Next, the experimental result performed in the same manner in the case of closing the end of ant-speaker side is shown by the blue colour in Fig.10. From this result, it can be seen that the natural acoustic frequency is independent of the aperture ratio. Because the apparent sound speed did not change by changing the aperture ratio. In reality, as the natural acoustic frequency becomes lower with decreasing the aperture ratio, the correct frequency can't be obtained by the experimental method described above.

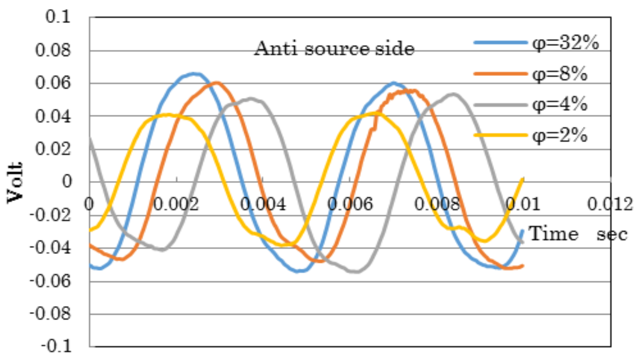

FIG.12 Sound Pressure Wave Form at Anti-Source Side

D. On the Pressure Wave at the Backward and Forward of the Perforated Plate

Fig.11 and Fig.12 show the sound pressure wave forms at the backward and the forward of the perforated plate respectively in the cases of the aperture ratios being 2%, 4% , 8% and 32%, The sound pressure at the speaker side (Source side) is considered to become larger with decreasing the aperture ratio but it does not appear clearly. This is considered to become the sound pressure uniform like the diffused sound field. Because the microphone's position is near to the speaker. On the other hand, in the anti-speaker side (Anti-source side), the pressure drop generates at the perforated plate and it is larger with decreasing the aperture ratio. Then it is reasonable that the sound pressure at the microphone's position becomes smaller with decreasing the aperture ratio. It appears clearly in Fig.12.

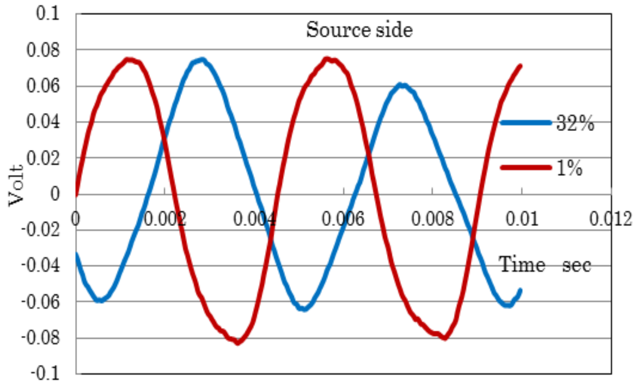

FIG.13 Sound Pressure Wave Form at Source Side

Fig.13 and Fig.14 show the sound pressure forms at the speaker side and the anti-speaker side respectively in the cases of the aperture ratios being 1% and 32%.

In the case of 32%, both wave forms are the same and like the sine waves both the speaker side and the anti-speaker side. On the contrary, in the case of 1%, the wave form at the speaker side is comparatively the sine wave but lose shape at the anti-speaker side. And the amplitude of the sound pressure at the anti-speaker side becomes smaller than that at the speaker side. From these fact, the perforated plate can be considered to have a roll of the flow passage reactance. Namely, it plays the roll of the inertia effect acoustically.

From experimental and analytical results described above, it is concluded that the natural acoustic frequency of the duct decreases with decreasing the aperture ratio and the boundary condition at the perforated plate is accredited "open" at aperture ratio being over 16%.

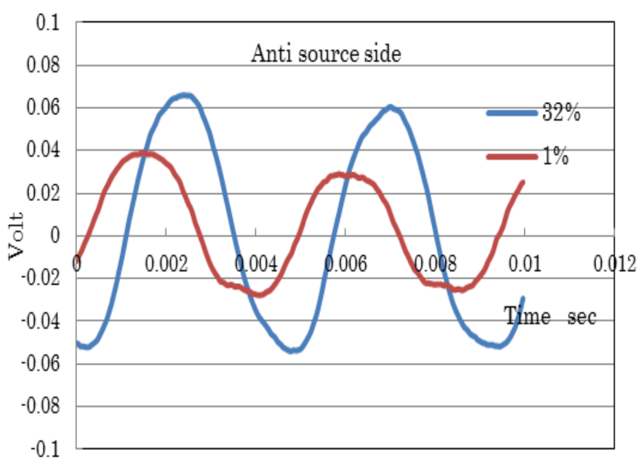

FIG.14 Sound Pressure Wave Form at Ant-Source Side

V. Conclusions

The apparent sound speed was evaluated and the natural acoustic frequency was calculated on the basis of it in order to examine the effect of the aperture ratio of the perforated plate on the natural acoustic frequency.

(1) The natural acoustic frequency obtained by the present method coincided with those obtained by other methods such as T.T.M and the consideration of the mode.

(2) The fact that the natural acoustic frequency becomes lower with decreasing the aperture ratio can be explained by the lowering the apparent sound speed.

(3) When the aperture ratio becomes over 16%, it is not necessary to consider the perforated plate acoustically.

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