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Acoustic and Flow Noise Characteristics of Duct with Expanded Part and Some Holes

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***Abstract*— Noise from an air conditioning duct of a rail vehicle is annoying for passengers especially when the rail vehicle is in a resting state. Then the noise reduction is very important from the point of view of keeping the car room comfortable and is one of the differentiating techniques. This paper described experimental results of flow noise characteristics. The air conditioning duct has some holes to ventilate the car room. I have studied the acoustic characteristics of the flow noise of the straight duct and the bending duct previously. In this study, the flow noise characteristics generated from the air conditioning duct have been studied experimentally by using the duct with expanded part and four holes. As a result, it was clarified that the noise increasing due to expanding is about 10dB and the effect of the absorbent is 3dB ～4dB in the existing of the flow .**

***Index Terms*— Aerodynamic Acoustics, Measurement, Duct, Flow Noise, Railway Vehicle, Air Conditioning**

I. INTRODUCTION

An air conditioning equipment is usually set in a rail vehicle in order to keep comfort. However, the noise it creates is offensive to the ear especially when the rail vehicle is in a resting state. Therefore, noise reduction is so important to keep the compartment comfortable, and is one of the differentiating techniques of rail vehicles.

The air conditioning equipment consists of a fan and ducts with holes. Noise sources are fan noise generated from the fan itself, flow noise generated from bended and expanded parts of the ducts which are made out of necessity, and flow noise generated from open holes in the ducts that is released directly into the compartment. However, the present situation cannot clarify which source is dominant.

Therefore in this study, I will grasp a degree of contribution of each source to the compartment noise by regarding a duct with holes as an air conditioning duct. There are many studies related to the noise generated from ducts [1]～[9]. However, studies on the acoustic characteristics and generated flow noise from ducts with open holes like air conditioning ducts are small in number.

In a previous papers [10][11], I studied acoustic characteristics of a straight and a bending ducts with holes and clarified the difference of acoustic characteristics between ducts with and without holes. In this paper, flow noise characteristics of the duct with holes will be studied and the absorbing effect in existing flow will be also examined experimentally by using the expanded duct with four holes. Moreover the effect of noise reduction of some devices will be confirmed.

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II. EXPERIMENTAL METHOD

A. Experimental Setup and Purpose

Figure1 shows the two experimental setups. One is the duct without holes and the duct end open (call “Duct A”). Another is the duct with four holes and the duct end closed (call “ Duct B”).The expanded duct is connected to a nozzle of a low noise wind tunnel. The cross sectional area of the nozzle is 200mm ×200mm. A speaker is set at the position of 75mm from the nozzle exit. Four microphones are set at positions of 0.64m, 1.25m, 1.85m and 2.4m from the left end of the duct as shown in Fig.1 in Duct A. These measuring positions are named by P1, P2, P3 and P4. The time sound pressure data obtained by these microphones are inverted to frequency data by FFT analyser. Measuring points of Duct B will be described later.

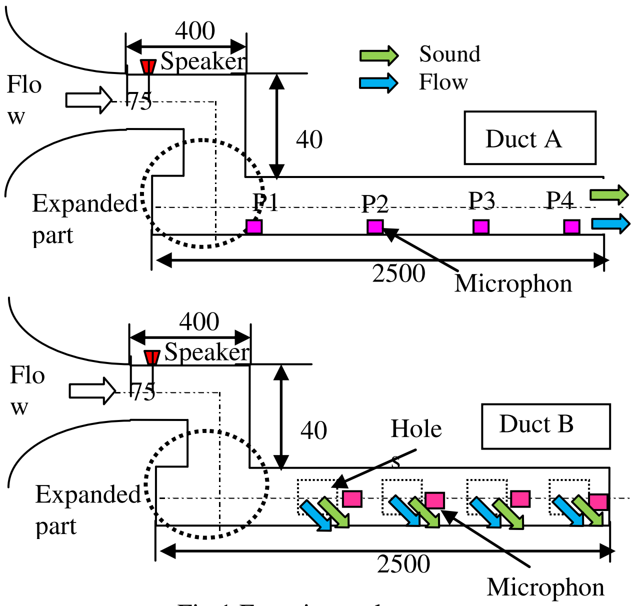


Fig.1 Experimental setup

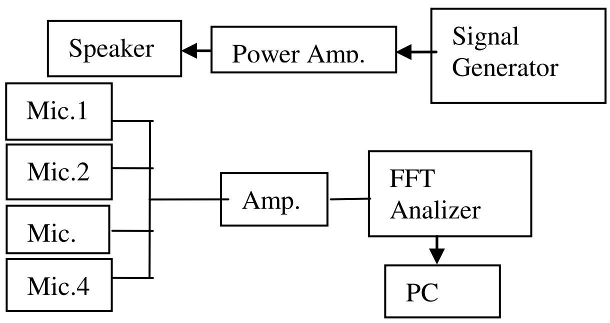


Fig.2 Measuring block diagram

B. Experimental Method

The speaker is set at the position of 75mm apart from the nozzle exit of the wind tunnel and the sin wave is swept from the signal generator. The output of each microphone is derived to the FFT analyzer via the noise measuring system and it is inserted to the PC after tracking processing. The frequency range is 200Hz～5000Hz and the frequency resolution is 12.5Hz. The sweeping time is 500s. The measuring block diagram is shown in Fig.2.

The experimental parameters are as follows.

(1) Open area size:

・0mm×0mm (0square)･･･named “Without holes”

・50mm×50mm (50Square),

・75mm×75mm (75Square),

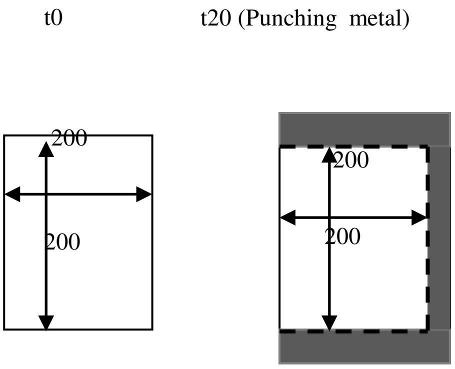
・100mm×100mm (100Square)

(2) Acoustic absorption treatment : (See Fig.3)

・absorbing material with 20mm thickness and specific weight is 48kg/ m[3] (denoted by “t20”)

・no absorbing material (denoted by “t0”)

Where absorbing material is the glass wool and applied to the duct as shown in Fig.3.



Fig,3 Kind of absorbing treatment of duct

III. ACOUSTIC EXPERIMENTAL RESULTS AND DISCUSSIONS

A. Acoustic Characteristics of Expanded duct

Figure 4 and Fig.5 show the sound pressure level (Overall value) at four measuring points for without the absorbent and for with the absorbent respectively. The parameter is the hole’ area and those are 0square (0□), 50square(50□), 75square (75□) and 100square(100□). Where 50square means the area 50mm×50mm. The measuring points are as shown in Fig.1 in the case of without holes and at oblique 45 degree and 100mm apart from holes in the case of with holes as shown in Fig.6.

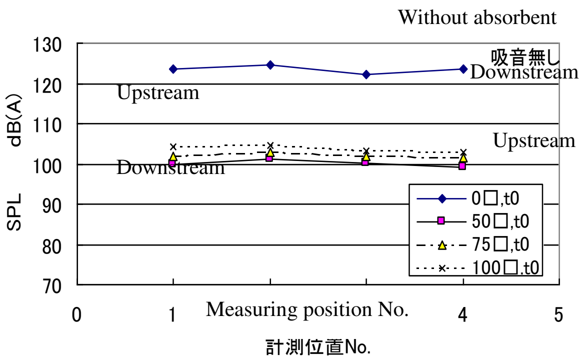


Fig.4 SPL at each measuring point (without absorbent)

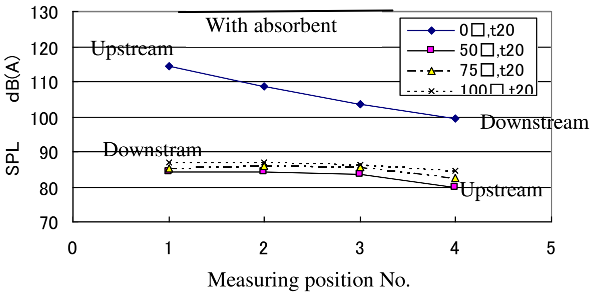


Fig.5 SPL at each measuring point (with absorbent)

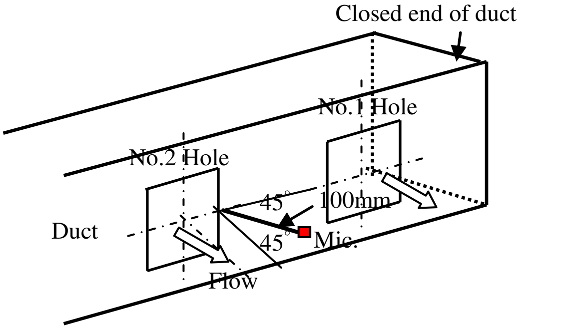


Fig.6 Measuring position of duct(B)

In the case of without absorbent, the difference among SPL at four measuring positions can’t be seen. On the other hand, in the case of with absorbent, the SPL decreases linearly with increasing distance from the noise source in the duct without holes (-14.8dB/1.8m). This is the same as the straight duct of -15dB/1.8m [10].

In the duct with holes (Duct B), the SPL becomes larger with increasing the hole’s area independent of existence or non-existence of absorbent. In the case of with absorbent, only the SPL at the measuring position No.4 is small. This position is most far from the noise source.

B. Reduction Effect of Absorbent (Evaluation with O.A. Value)

Figure 7 shows the reduction effect due to the absorbent by indicating hole’s area as a parameter. From Fig.7 the reduction effects are different at measuring points in the case of the duct without holes (Duct A) and it becomes larger with increasing the distance from the noise source. This result is the same as the case of the straight duct [10]. On the other hand, the reduction effects are the same at any measuring position independent of the hole’s area in the case of the duct with holes (Duct B). The reduction effect is about 17dB. .

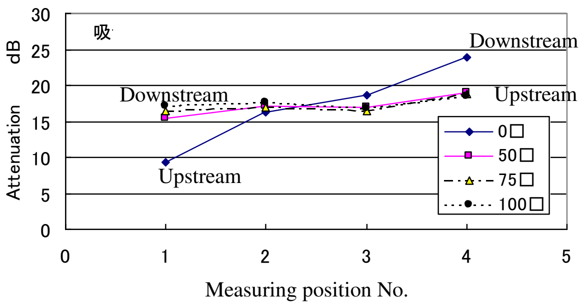


Fig.7 Attenuation at each measuring point (with absorbent)

C. Reduction Effect of Absorbent (Evaluation with Octave Analysis Value)

Fig.8 shows the sound pressure level at four measuring points as shown in Fig.1 at each 1/1 octave center frequency in the case of duct A (without holes). The black symbol and the red symbol indicate the results of without/with absorbent respectively. The frequency characteristics of SPL at each measuring point are all the same and it has the peak at 2kHz. The noise reduction effect of the absorbent becomes larger with increasing the distance from the noise source. The noise reduction effect is defined by the difference of the SPL in the cases of without/with absorbent.

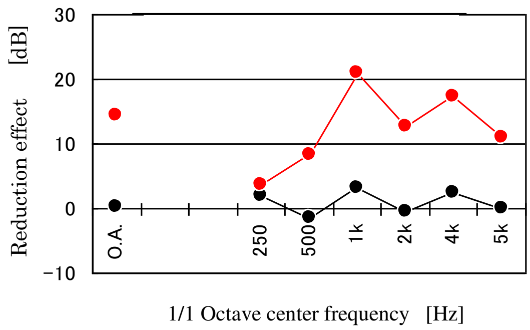


Fig.9 Distant attenuation of duct A with/without absorbent

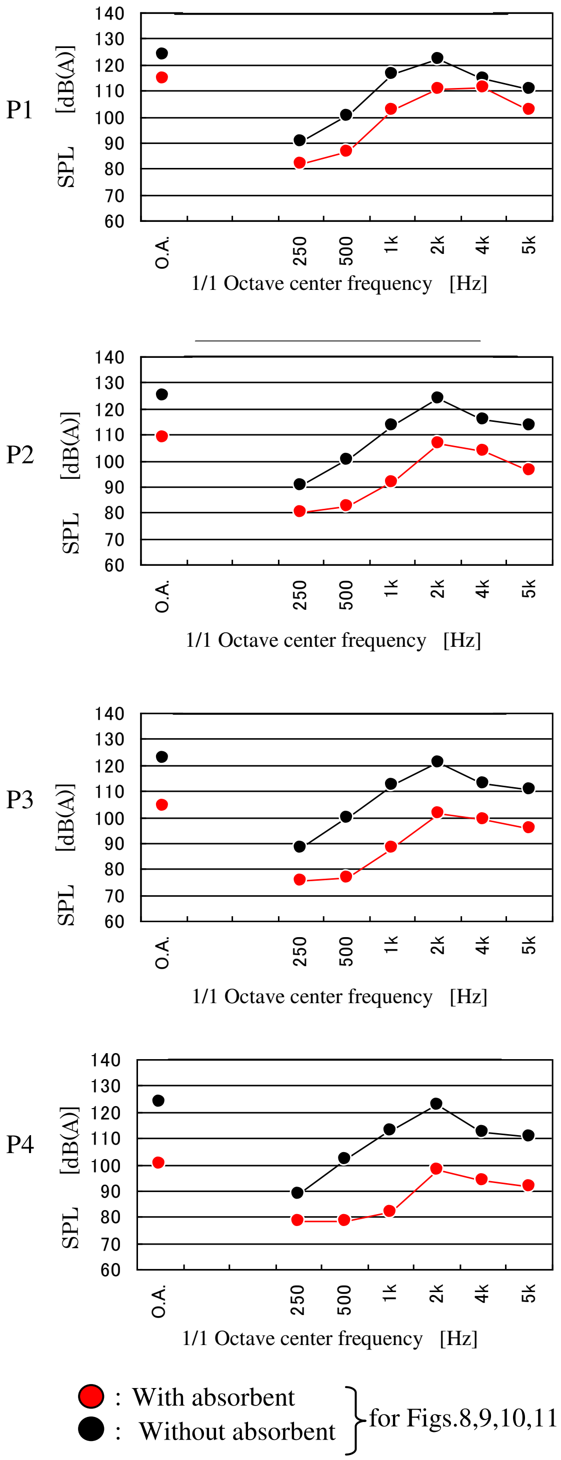


Fig.8 Octave band analysis results of duct A without holes

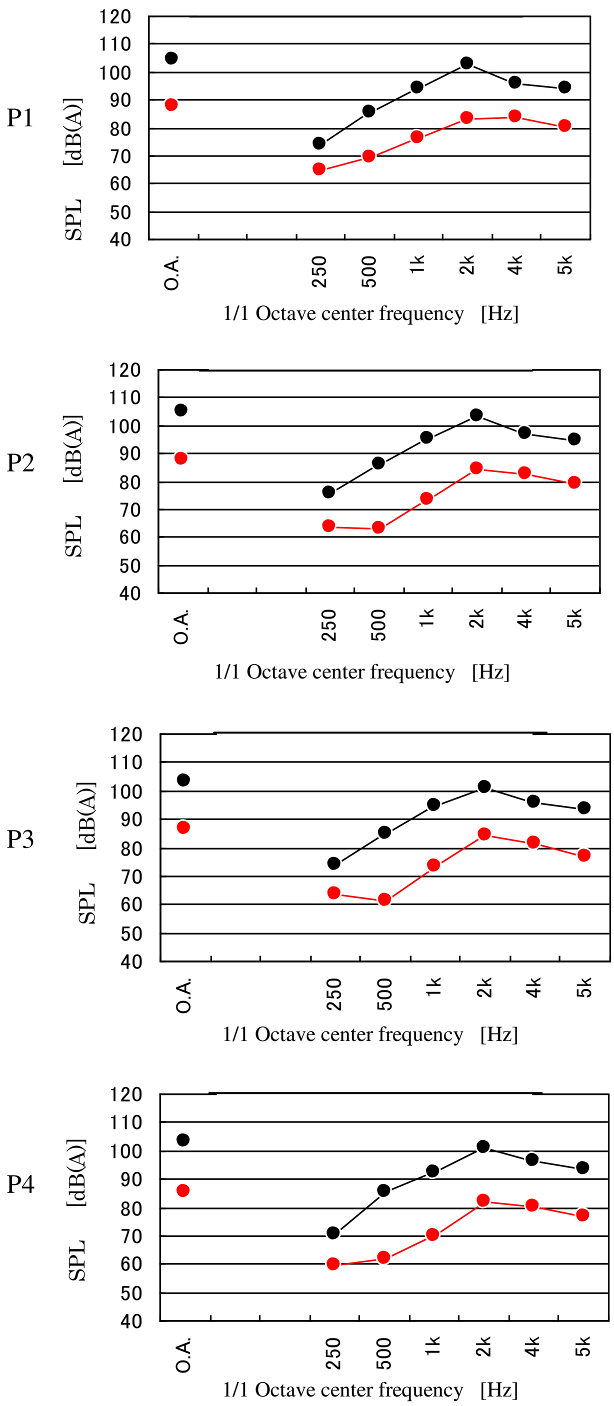


Fig.10 Octave band analysis results of duct with holes

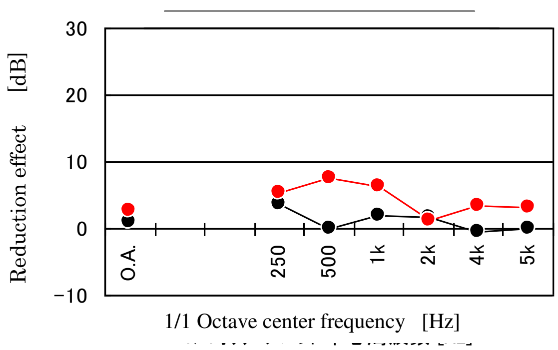


Fig.11 Attenuation of ducts with/without absorbent

Fig.9 shows the difference of the SPL at the measuring point P1 (Most upstream) and P4 (Most downstream). This difference corresponds with the distance attenuation of the duct. According to this result, the distance attenuation almost does not appear in the case of without absorbent (Black symbol). On the other hand, in the case of with absorbent (Red symbol), 15dB O.A. noise reduction was obtained and the peak at 1kHz can be seen in the frequency characteristics of the sound pressure level.

Fig.10 shows the Octave Band Analysis results of the duct B (with holes). This result is the case of 100Square . The same frequency characteristics of SPL can be seen in any measuring position and the SPL has the peak at 2kHz in the frequency characteristics of the sound.

Fig.11 shows the distance attenuation of the duct B. Red and Black circles in these figures indicate results in the cases of with and without absorbent respectively.

IV. EXPERIMENT OF FLOW NOISE CHARACTERISTICS

A. Experimental Setup

The experimental setup is the same as that shown in Fig.1. But the measuring points are different from those of duct A (without holes) and it is the positions of 100mm apart from the duct end exit and oblique 45 degree direction. In the case of the duct B (with holes), the measuring points are the positions of 100mm apart from hole edge and oblique 45 degree direction as shown in Fig.5. This was described before.

B. Experimental Procedure

The total pressure tube is set at 100mm downstream from the nozzle exit of the low noise wind tunnel. The rotating speed of the fan is adjusted watching the digital manometer until realizing the test total pressure.

After the total pressure being adjusted, the noise and the flow velocity are started to measure. The output of each microphone is inserted to the FFT analyzer via the noise measuring system. After frequency analyzing, the data are inserted to the personal computer. The frequency range is 200Hz～5000Hz and the frequency resolution is 12.5Hz. The experimental parameters are as follows.

(1) Test total pressure: 50, 170, 430, and 750Pa

(2) Kinds of duct: three kinds of duct as shown in Fig.12.

(a) With Guide and Airfoil, without absorbent・・・(Black)

(b) Without Guide and Airfoil, without absorbent (Red)

(c) Without Guide and Airfoil, with absorbent ・ ・ (Blue)

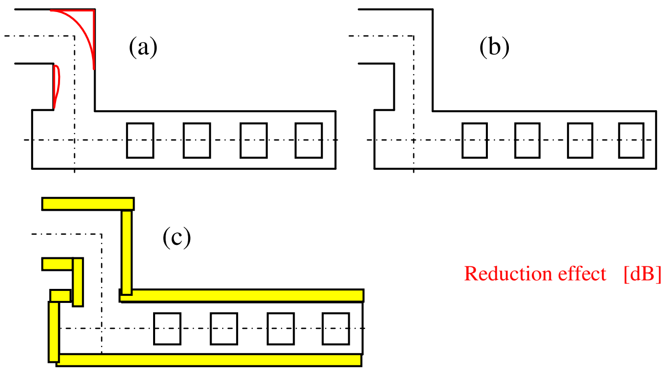


Fig.12 Three types of ducts tested

The configurations of guide and airfoil are shown in Fi.13.

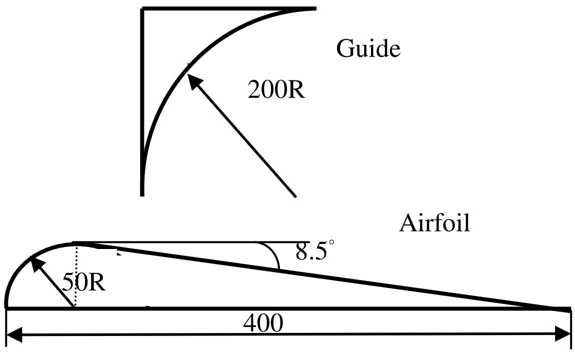


Fig. 13 Configurations of guide and airfoil

V. FLOW NOISE EXPERIMENTAL RESULTS AND CONSIDERATIONS

A. Duct A (without holes and duct end open)

Fig.14 shows the relation between the root velocity and the SPL of three types of duct. Fig.15 shows the relation between the root velocity and the root total pressure.

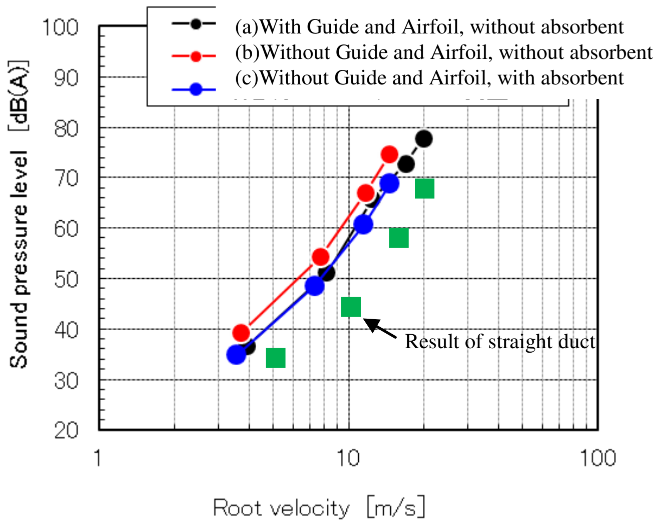


Fig.14 Relation between root velocity and SPL

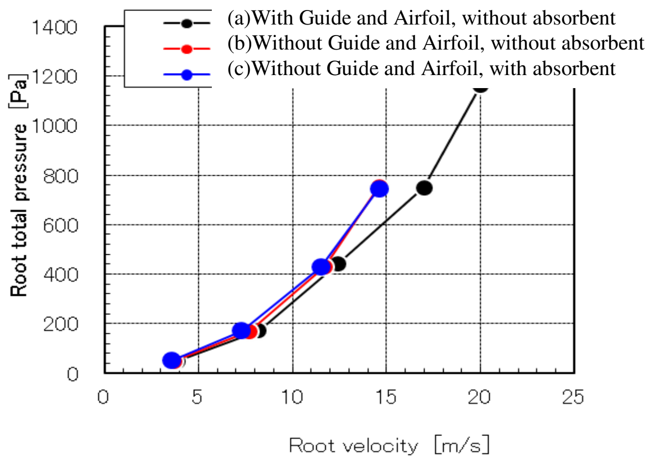


Fig.15 Relation between root velocity and root total pressure

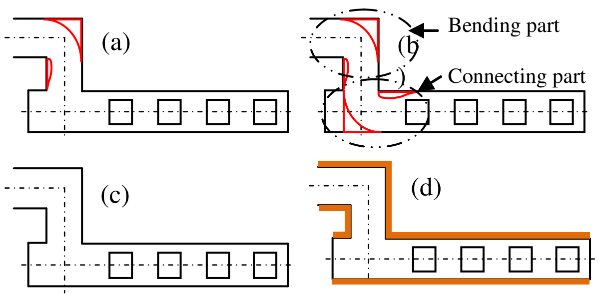


Fig. 16 Three kinds of duct tested

The data of the straight duct is shown by ■ in Fig.14 (5m/s: 29dB, 10m/s: 40dB, 15m/s: 56dB, 20m/s: 64dB). The following findings can be obtained from this figure.

(1) Noise increasing of about 20dB can be seen due to the bending and expanding by comparing with the straight duct.

(2) From the fact that the noise increasing of 10dB ～15dB was obtained in the past research by comparing the bending duct with the straight duct, the noise increasing due to expanding is estimated by 5dB～10dB.

(3) The noise reduction due to absorbent is about 3dB～4dB and this value is the same as that obtained by experimental results of the straight duct and the bending duct [10] , [11]..

B. Duct B (with holes and duct end closed)

The experiment was conducted by using four ducts as shown in Fig.16. These ducts are as follows.

(a) Guide and Airfoil at bending part, without absorbent (Black)

(b) Guide and Airfoil at bending part and connecting part, without absorbent (Red)

(c) Nothing of devices and without absorbent (Blue)

(d) Nothing of devices, with absorbent (Yellow)

The hole's area is three kinds of 50square, 75square and 100square.

Fig.17 shows the SPL at four measuring points described before. Fig.17 (a) is the result at measuring point No.1 and its position is most downstream. And (d) is No.4, most upstream.

The hole's area of 50Square is shown as one example.

From Fig.17, the following findings can be obtained.

(1) The SPL is large at upstream and small at downstream.

(2) The noise reduction effect of the absorbent is about 0dB ～3dB and large at downstream and is not at upstream all.

(3) The separation protecting devices like guide and airfoil give the reduction effect of 3dB and this value is the same at any hole position. Especially, Setting the device at the connecting part gives strong effect and the bending part gives nothing effect at all.

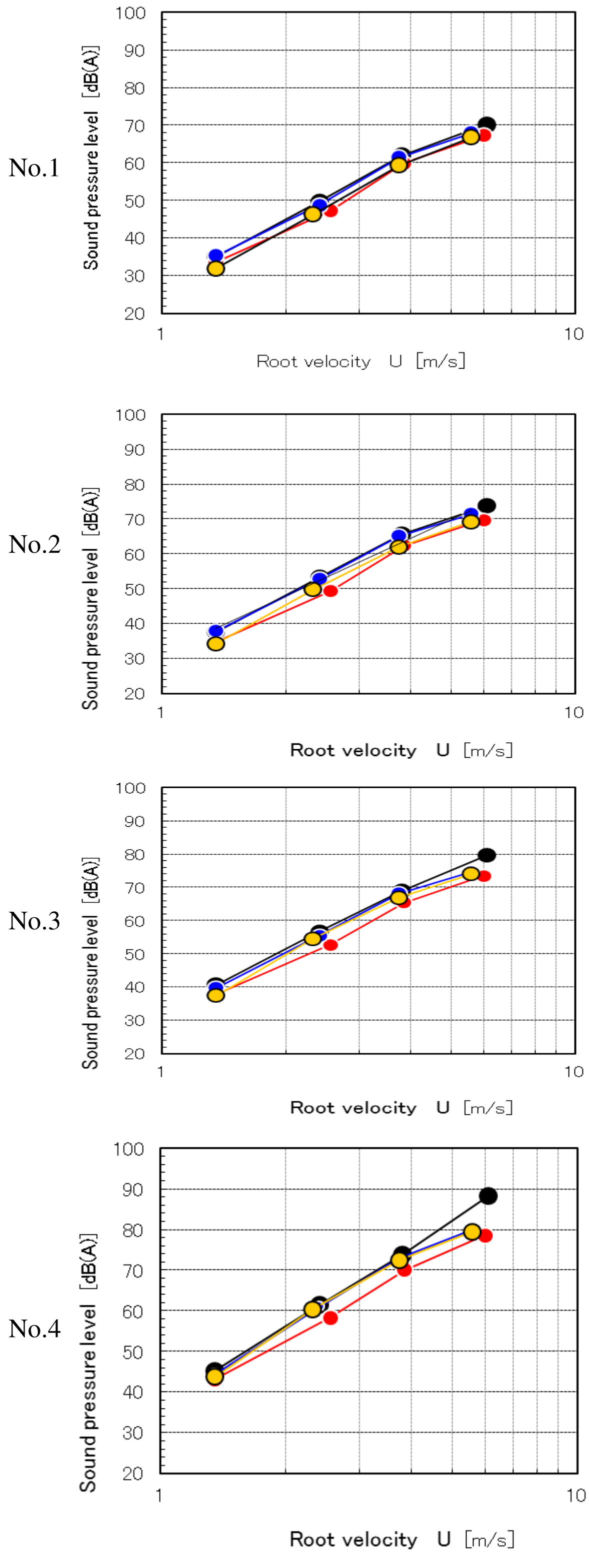


Fig.17 SPL at each measuring point (50square)

Above features can be said in other hole's area but omit due to space limitation. However the effect of the difference of hole's area on the SPL is interested. Then the

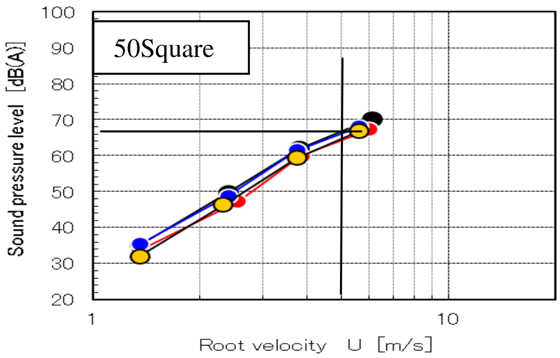
SPL at the measuring position No.1, this point is the most downstream, is shown in Fig.18 about three hole's area such as 50Square, 75Square and 100Square.

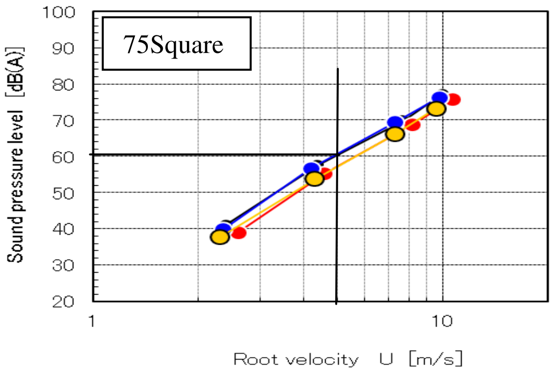
The following findings can be obtained from these figures.

(1) The SPL becomes smaller with increasing hole's area.

(2) The SPL indicated by blue (without countermeasure) is the maximum and by red (with device) the minimum. However setting the device at the bending part does not give the reduction effect at all.

(3) The noise reduction effect of the device (Red) is the same as that of the absorbent (Yellow).





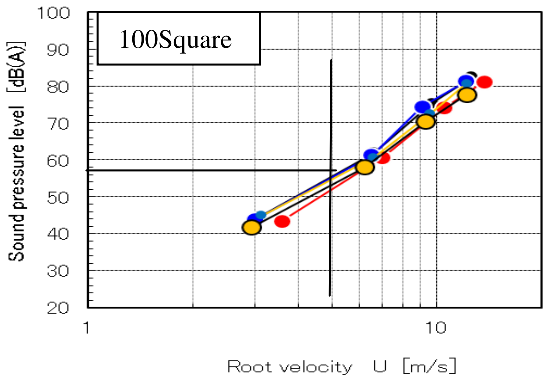


Fig.18 SPL in each hole's area(Measuring position No.1)

Above finding (1) can be said on the condition of the same root velocity. The reason is that the flow velocity passing through the hole is smaller with increasing the hole's area and the sound power is proportional to the sixth power of the flow velocity and the hole's area like $\rho U^6 S/c^3$. Where U is the flow velocity, S is the area, ρ is the air density and c is the sound speed. Then the SPL due to the flow becomes smaller with increasing the hole's area on the same root velocity condition.

VI. Conclusions

The Acoustic and flow noise characteristics of the ducts with expanded part and four holes like air conditioning ducts were examined experimentally. As a result, the following findings could be obtained:

(1) The effect of the absorbent is larger with increasing distance from the sound source and its frequency characteristics are the same in both upstream and downstream in duct A (without holes).

(2) In duct B (with four holes, end closed), the SPL in any hole is the same value and the same frequency characteristics. Namely inner of the duct is regarded as the diffuse sound field and the effect of the absorbent is about 17dB.

(3) The noise increasing due to expanding is about 10dB in the existing of the flow.

(4) The effect of the absorbent is 3dB ～4dB in the case of existing of the flow. This fact is not the result of the acoustic experiment at all in existing of only flow noise.

(5) The noise effect of the separation protecting device is the same as that of the absorbent.

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He worked in Kawasaki Heavy Industry Co. Ltd. as an Mechanical Engineer for 33 years. After that he became a Professor of The University of Tokushima in 2004. He had been studying the vibration and noise control, above all he studied the flow induced vibration and noise problems. He has authored or co-authored over 100 technical journal and over 50 conference papers. He is a fellow of JSME (Japan Society of Mechanical Engineers) now. He is a Professor of Tokushima Bunri University. He teaches a mechanical field subjects for students.