STUDY OF THE AERODYNAMIC NOISE CHARACTERISTICS OF BLUFF BODIES AS A PANTOGRAPH MEMBER

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ABSTRACT
Reduction of the aerodynamic noise generated by pantographs is a matter of great important for further speedup of the high speed trains. In general, pantographs are composed of some kind of bluff bodies. Therefore, the method to reduce the aerodynamic noise generated by bluff bodies is demanded. In this paper, we will present the noise reduction effect of cylinder by equipping intermittent holes first. Then, we will discuss the noise reduction mechanism by estimating the approximate noise source strength. Finally, we will show the results of applying this method to an elliptic cylinder.

INTRODUCTION

Preservation of the environment is a matter of great importance for Shinkansen (Japanese high-speed railway). Reduction of way side noise has strongly been required. As far as the present Shinkansen is concerned, the contribution of aerodynamic noise is dominant when compared with other kinds of noises, such as rolling noise, concrete structure noise and so on. A pantograph is one of the main aerodynamic noise sources of train sets. So, researches to develop a so-called low noise pantograph have been continued. The low noise pantograph is constructed to a configuration as simple as possible to reduce noise sources. The shapes of its members should be aerodynamically-smoothed to lower the aerodynamic noise.

At present, some types of low noise pantographs have already been come into use (Fig. 1). They considerably contribute to the reduction of way side noise. The currently maximum speed of Shinkansen is 300km/h. In order to survive in the keen competition with other transport facilities, we have to continue researches on speed-up.

Fig. 1 Example of Low noise pantograph (Type PS207 of JR-East)

Fig. 2 presents a contour map of the aerodynamic noise distribution of the low noise pantograph PEGASUS[1)]. This measurement was performed at the large scale anechoic wind tunnel of RTRI (Maihara Wind Tunnel) using an X-array microphone system[2)]. It is clear that the panhead generates larger aerodynamic noise than the articulated system does. In other words, the main noise source of a low noise pantograph is the panhead.

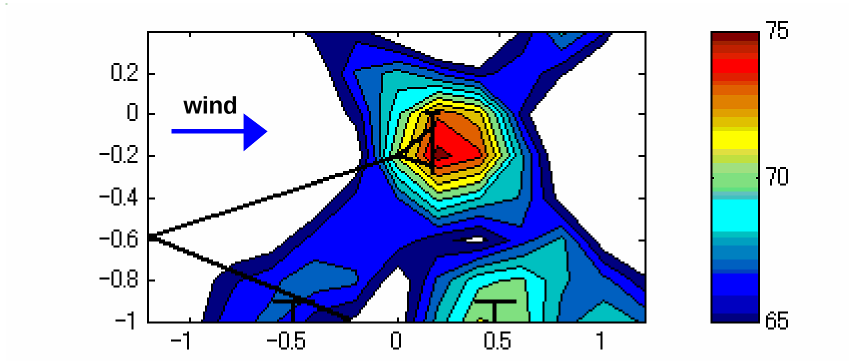


Fig. 2 Contour map of aerodynamic noise generated by a low noise pantograph (PEGASUS[1] 2500kHz band)

It is well-known that a streamline body like an aerofoil generates lower aerodynamic noise than bluff bodies. Therefore, the shape of the panhead of the low noise pantograph is smoother than that of the traditional panhead. But the stability of the aerodynamic force acting on the panhead is also strongly demanded in the high speed region. If a large aerodynamic force acts on the panhead, the contact force is not able to be in the suitable range. So, completely streamlined members are difficult to apply as a panhead. Thus, measures to reduce aerodynamic noise generated from the bluff body are the main subject to reduce the noise of pantograph.

REDUCTION OF AERODYNAMIC NOISE GENERATED BY CYLINDER

The most typical bluff body is a cylinder. In general, a cylinder generates remarkable narrowband noise, namely Aeolian tone. Since this noise level is very high, some kinds of measures to prevent generation of this noise have been proposed. In the case of low noise pantograph, horns of the panhead are made of cylindrical members. To prevent the generation of the Aeolian tone, the horn is equipped with intermittent holes. Our research has clarified that not only the Aeolian tone but also the broadband noise are reduced by this measure. We think that it is useful to clarify this phenomenon in order to reduce the noise of bluff bodies. Therefore, we investigated the mechanism of this phenomenon experimentally first.

Equipment and Models for Wind Tunnel Testing

We performed wind tunnel testing by using a small scale anechoic wind tunnel of RTRI. This wind tunnel is of the Gottingen-type having an open-type test section for aerodynamic noise measurement. The nozzle size is 480mm x 400mm and the maximum wind velocity is 300km/h (83.3m/s). Fig. 3 shows the experimental apparatus. The test model is set at the test section that has end walls (450mm x 600mm). The coordinate system is defined as shown in Fig. 3.

Fig. 4 shows the test models. There are four types of models, that is, (a) simple cylinder, (b) cylinder with a spiral wire of diameter 6mm, (c) cylinder with intermittent holes (20mm x 5mm R2.5mm at the corner of each holes), and (d) cylinder with a continuous slit (thickness : 5mm). The diameter of each models is 25mm.

The Aerodynamic noise is measured by a non-directional 1/2 inch microphone which is located at x=0mm and z=-1000mm. The flow velocity at the region of wake of the models is measured

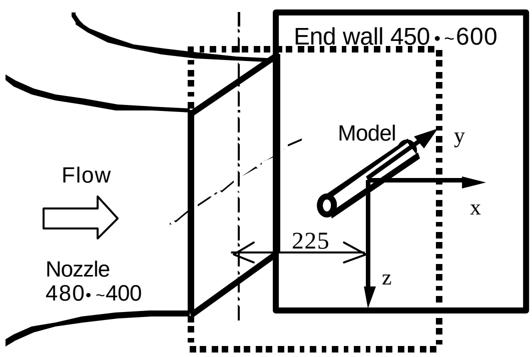


Fig. 3 Experimental apparatus

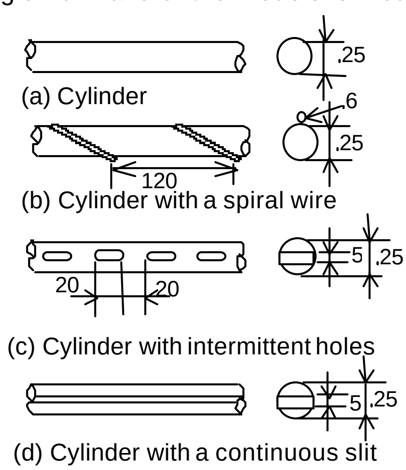


Fig. 4 Cylinder models

by a hot wire anemometer.

Aerodynamic Noise Characteristics
Fig. 5 presents the experimental results of aerodynamic noise of these models at the wind velocity of 200km/h (55.6m/s), as a function of Strauhal number. The diameter of the cylinder (0.025m) is set as the characteristics width *D*. The Reynolds number is $9.2.10^{4}$.

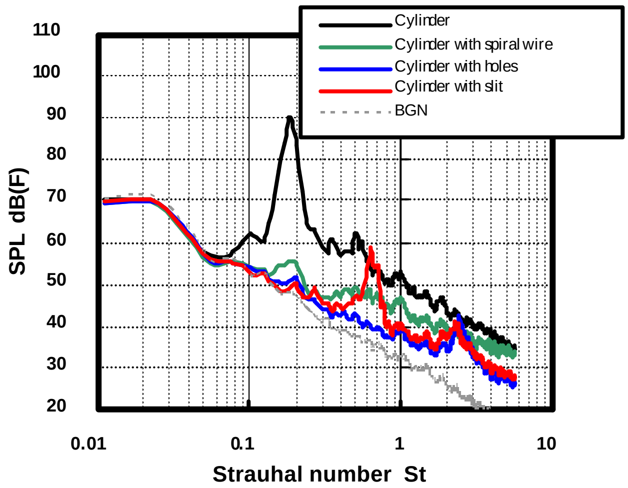


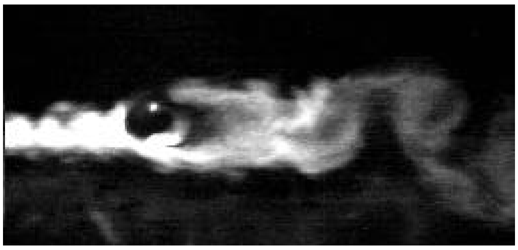
Fig. 5 Aerodynamic noise of cylinder models at 200km/h

The simple cylinder generates a remarkable Aeolian tone in the neighborhood of S_t =0.18. In contrast, the cylinder with a spiral wire, the cylinder with holes, and the cylinder with a slit hardly generate such a peaky noise at S_t =0.18. In this sense, these models have the almost equivalent noise reduction effect on the Aeolian tone. On the other hand, the effects to decrease broadband noise are not the same. The cylinder with a spiral wire generates distinctly higher level of broadband noise where S_t is 0.3 or over than the cylinder with holes and the cylinder with a slit do. In the range where S_t is 0.5 or over, the broadband noise of the cylinder with a spiral wire becomes almost at the same level as that of the simple cylinder independent of the wind velocity. The cylinder with a slit and the cylinder with holes have similar noise characteristics except for a narrowband noise in the neighborhood of S_t =0.65. Broadband noise of them is reduced from that of the simple cylinder. We can observe a narrowband noise in the vicinity of S_t =2 in the both cases. This frequency is unchangeable irrespective of wind velocity. So this noise is caused by the resonance in the slit or the holes. The frequency of this noise is determined by the length of slit or holes into the flow direction.

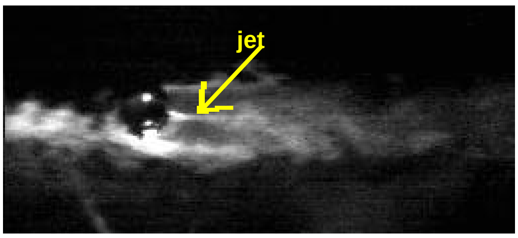
These results suggest that the characteristic of the broadband noise is greatly different, even if the effect of decreasing Aeolian tone is almost equivalent.

Flow Pattern
Fig. 6 presents the results of visualization of the flow around the models by a smoke method. The wind velocity is 4.2m/s. We can easily observe the remarkable Karman vortex street in the wake of the simple cylinder. However, in stead of the Karman vortex street, a notable jet emitted from a hole is recognized in the wake of the cylinder with holes. In the case of the cylinder with a slit, the jet is unstable and interacts with the separated shear flow on both sides of the wake.

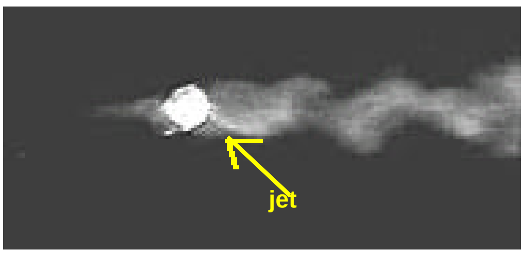
Fig. 7 shows the flow fluctuation measured by a hot-wire anemometer. In the case of the simple cylinder, flow fluctuation is particularly large in the region where Karman vortexes are separated from the surface of the cylinder. On the contrary, a comparatively large flow fluctuation area is located limitedly in the jet and in the separated shear flow in the vicinity of *x*=3*D* in case of the cylinder with holes. The absolute value of flow fluctuation in the wake of the cylinder with holes



(a) Simple cylinder

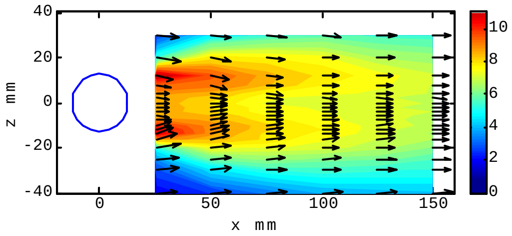


(b) Cylinder with intermittent holes

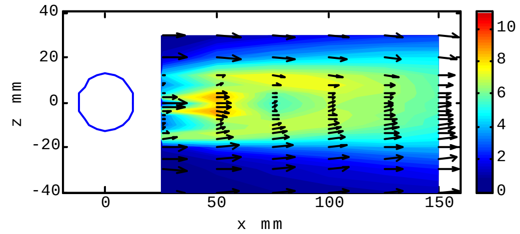


(c) Cylinder with a continuous slit

Fig. 6 Visualization of the flow field in the wake of models



(a) Simple cylinder



(b) Cylinder with holes

Fig.7 Distribution of the standard deviation of the flow velocity at 100km/h (unit•F m/s)

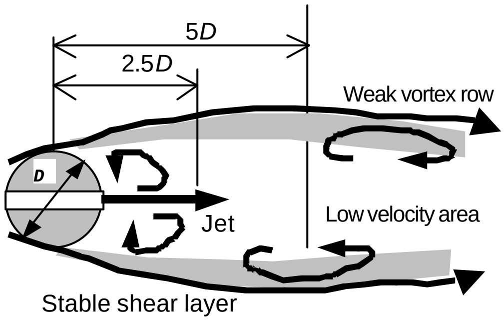


Fig.8 Construction of the flow in the wake of the cylinder with holes

becomes lower than that of the simple cylinder. This is because large scale vortexes such as Korman vortex does not appear in case of the cylinder with holes.

Fig. 8 describes an outline of the flow pattern near the cylinder with holes. Large momentum is supplied by the jet to the wake. Therefore, the interaction between both shear flows decreases. In addition, the interference between the jet and the separated shear flow is hardly generated, because the jet emits out intermittently into the span-wise direction. As a result, the shear flow of the wake is much stabilized, and generation of the Karman vortex street is suppressed. The cylinder with a slit has an almost similar flow pattern. However, 2-dimensional jet tends to interact with the separated shear flow. So, this instability induces the generation of the narrow band sound at S_t =0.65.

Estimation of noise source strength

The aerodynamic noise is essentially generated by the motion of the vortexes passing near the body. However, the direct measurement of the vorticity is difficult in general. Then we attempt to estimate vorticity approximately by using a W-type hot wire probe which consists of two parallel I-type hot wire probes separated at a distance of 1.4mm. That is, we can evaluate

$$\tilde{w} \approx \frac{\partial|\mathbf{u}|}{\partial z} = \frac{|\mathbf{u}(x,y,z+\Delta z)| - |\mathbf{u}(x,y,z)|}{\Delta z} \qquad (1)$$

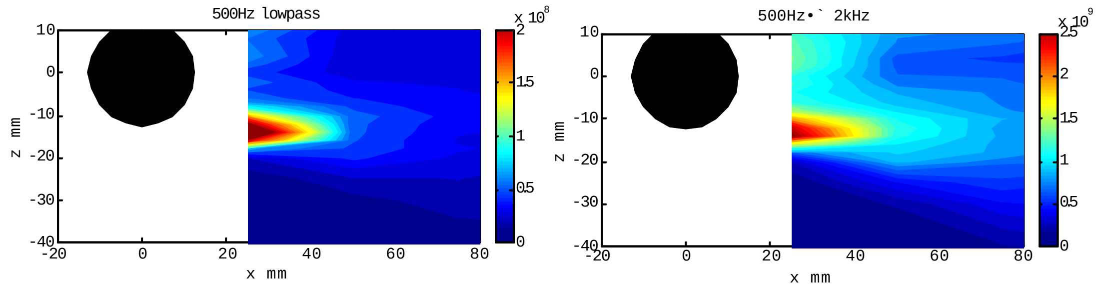
as an approximate value of $w_y = \frac{\partial u}{\partial z} - \frac{\partial w}{\partial x}$.

If the sound source can be regarded as compact, the aerodynamic noise in the far field radiated from a rigid body is expressed by Howe's theory as follows;

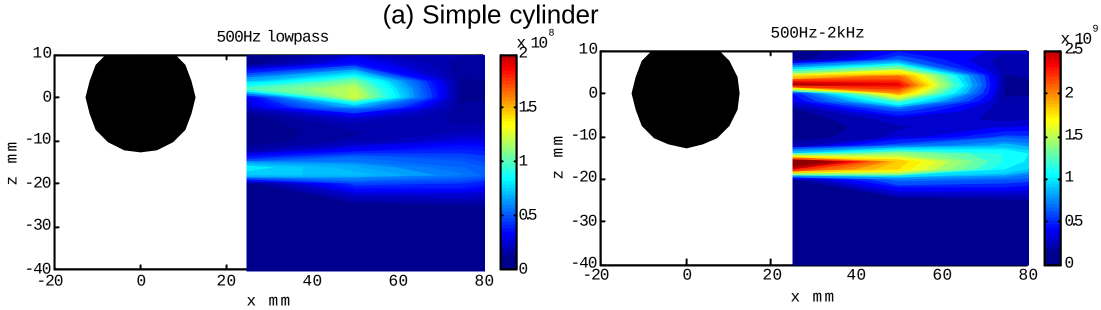
$$P_a = -\frac{r_0 x_j}{4p c_o |\mathbf{x}|^2} \frac{\partial}{\partial t} \int \left\{ \mathbf{\grave{u}}(\mathbf{y}, t - \frac{|\mathbf{x}|}{c_0}) \times \mathbf{u}(\mathbf{y}, t - \frac{|\mathbf{x}|}{c_0}) \right\} \frac{\partial Y_i}{\partial \mathbf{y}} d\mathbf{y} \qquad (2)$$

where ñ$_0$ is the flow density; c_0 is the sound velocity; ***x*** is the position vector of the observing point; ***ù*** is the vorticity; and ***Y*** is the velocity potential satisfying the boundary condition on the body surface. So, we can obtain an outline of the distribution of the noise source strength by the following quantity.

$$Q(\mathbf{y}, t) = \frac{1}{T} \int_0^T \left(\frac{\partial}{\partial t} \{ \tilde{w} \times |\mathbf{u}| \} \right)^2 dt \qquad (3)$$



(a) Simple cylinder



(b) Cylinder with intermittent holes

Fig. 9 Distribution of approximate noise source strength

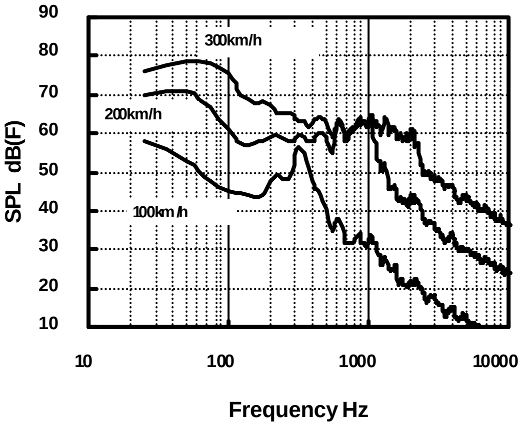
Of course, this quantity Q does not present the exact noise source strength. But we can consider the mechanism of noise generation mechanism roughly by using this quantity. Note that the effect of the term $\partial Y_i / \partial \mathbf{y}$ in the equation (2) presents the radiation efficiency of the sound by the solid surface. In general, as the noise source is closer to the object surface, the radiation efficiency becomes higher.

Fig. 9 presents the evaluation result of distribution of Q at 100km/h (27.8m/s). These data are evaluated by dividing into two frequency ranges, that is, under 500Hz and 500~2kHz. In the former frequency range, the influence on the Aeolian tone can mainly be discussed. In the latter case, the influence on the broadband noise can be discussed. In the frequency range of under 500Hz, we can guess that a strong noise source exists in the separated shear flow near the body surface in the case of the simple cylinder. The value of Q in the wake of the cylinder with holes is lower. In the frequency range of 500~2000kHz, the maximum values of Q in the two cases do not differ from each other. However, the distribution of value Q is not similar. In the case of the cylinder with holes, the region with a high Q value is located in the very narrow area. As mentioned above, the noise source near the body surface has large radiation efficiency. So, total contribution of the noise source of the cylinder with holes to noise radiation becomes lower than that of the simple cylinder. In this way, we think that extreme localization of the noise source distribution is important for aerodynamic noise reduction. Cancellation of noise source strength is also effective to reduce aerodynamic noise. In a stable shear flow, considerable cancellation of the noise source will occurs. This is another reason to reduce broadband noise of the cylinder with holes.

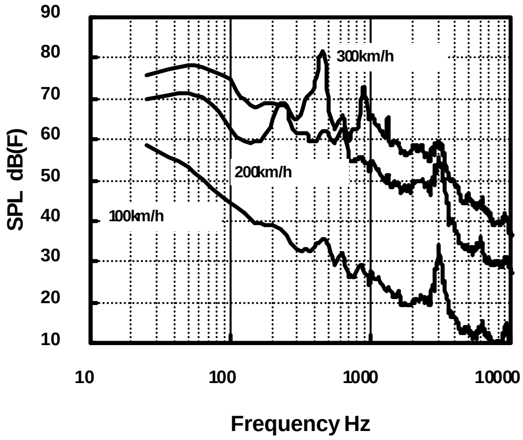
From these discussions, we think that it is very important to stabilize the boundary layer of the bluff body for the purpose of noise reduction. Equipping with intermittent holes can realize such flow stabilization.

APPLICATION TO ELLIPTIC CYLINDER

In order to confirm whether this idea is effective for other kinds of bluff bodies, the aerodynamic noise generated by elliptic cylinders is measured by the same way as that for cylinders. The testing model is an elliptic cylinder with a cross section of 25 x 50mm with and without intermittent holes. The configuration of hole is the same as that of the cylinder model shown in Fig. 4. Fig. 10 presents the measurement result of aerodynamic noise characteristics of the elliptic cylinder with and without holes. At 100km/h (27.8m/s), we can observe that not only the Aeolian tone but also the broadband noise reduce when intermittent holes are equipped. The narrowband noise observed at 3kHz is caused by the resonance in the hole.



(a) Elliptic cylinder without hole



(b) Elliptic cylinder with holes

Fig. 10 Aerodynamic noise characteristics of elliptic cylinder models

However, as the wind velocity becomes higher, the effect on noise reduction becomes lower. Conversely, a different narrowband noise which can not be observed in the case of the elliptic cylinder without holes is generated at 300km/h. It is likely that this phenomenon occurs for the following reasons. When the frequency of the Aeolian tone and that of the resonance tone emitted from holes are close to each other, strong instability is induced. In this condition, the method to use intermittent holes becomes ineffective for noise reduction.

These results suggest that equipping intermitted holes is effective to reduce aerodynamic noise of not only a cylinder but also an elliptic cylinder. However, this method is ineffective under the condition that the frequency of Aeolian tone is close to the frequency of resonant noise generated by the hole. The frequency of the resonance tone depends on the scale of the body. To prevent this instability, we must study the effect of the configuration of holes.

CONCLUSIONS

(1) When the cylinder is equipped with intermittent holes, not only the generation of the Aeolian tone but also that of the broadband noise are suppressed. In contrast, the aerodynamic noise level of the cylinder with a spiral wire approaches that of the simple cylinder in the high frequency range, although the generation of the Aeolian tone is suppressed.

(2) The shear flow around the cylinder with holes is stabilized by the jet emitted from holes. Then the area where strong noise source exists near the body surface is extremely localized. Furthermore, cancellation of noise source tends to occur in the case of the stable flow pattern. Therefore, remarkable noise reduction can be realized.

(3) Reduction of the aerodynamic noise is possible for the elliptic cylinder where intermittent holes are equipped, too.

(4) This noise reduction method is ineffective under the condition that the frequency of Aeolian tone is close to the frequency of resonant noise generated by the hole. To prevent this instability, we must study the effect of the configuration of holes.

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