Influence of Bogie Components on Aerodynamic Bogie Noise Generated from Shinkansen Trains

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Aerodynamic bogie noise generated from Shinkansen trains is the main source of the noise when they are running at above 300 km/h and noise reduction is important for preserving the quality of the environment around railway lines. In order to reduce bogie noise effectively, it is important to evaluate the contribution of the bogie components to the aerodynamic bogie noise. The purpose of this paper is to estimate their contributions at the measurement point close to the track by a wind tunnel test. Both the noise contribution of each component and the measures to reduce the aerodynamic noise are investigated by arranging the component in the bogie model.

Keywords: aerodynamic noise, wind tunnel test, Shinkansen, lower part noise

1. Introduction

In a previous study, it was shown that noise generated from the lower part of a Shinkansen train (hereinafter referred to as lower part noise) became especially dominant at speeds above 300 km/h [1]. A method has been proposed to quantitatively evaluate aerodynamic noise generated from the bogie section (referred to as aerodynamic bogie noise) through wind tunnel tests, in which flow distributions parallel to the sleeper direction at the inlet of the bogie section are suitably modelled [2]. By using this method, it was estimated that the aerodynamic bogie noise becomes dominant especially under 500 Hz to the total lower part noise. In order to effectively reduce aerodynamic bogie noise therefore, it is important to estimate the contribution of each noise source around the bogie section to total aerodynamic bogie noise. However, it is difficult to estimate the contributions by numerical simulations because it is necessary to consider the complex bogie components inside the bogie cavity. One of the possible approaches to estimate the contribution of each part to the total aerodynamic bogie noise is to evaluate the changes in noise level when removing each part from the bogie model in a wind tunnel test [3 - 5].

In this paper, the contribution of each bogie component and the cavity structure to total aerodynamic bogie noise was estimated experimentally using a 1/7 th scale train model in wind tunnel tests at a speed of 320 km/h. The aerodynamic bogie noise at the wayside of the track was estimated using a 2-D microphone array installed in the wind tunnel. A detailed bogie model was used in the wind tunnel tests to simulate aerodynamic bogie noise generation. The contributions of the bogie components, e.g. wheels, axle, gear case, motors, guide, brake and axle box, to the noise level was evaluated by removing each component one by one. Next, two countermeasures were investigated: a deflector and a cavity under cover. The noise reduction achieved by these countermeasures was estimated by using the proposed estimation method in [2].

2. Estimation methods for aerodynamic bogie noise

2.1 Outline of the wind tunnel test

In order to evaluate the influence of bogie components on the aerodynamic bogie noise level, a wind tunnel test was conducted in the Large-Scale Low-Noise Wind Tunnel of RTRI (MWT) as shown in Fig.1. A schematic layout of the test section is shown in Fig. 2 [6]. The experimental setup was composed of a 1/7 th scale train model installed on a stage, with a width of 5.5m and length of 7 m, and two-dimensional microphone array beside the model. The coordinate system has the x axis along the rail, z axis vertical, and y axis orthogonally crossing the x and z axes with the origin at the center of the bogie cavity on the ground. A detailed bogie model was installed inside the bogie cavity located below the train body. The distance between the car and the ground plate was 57 mm (400 mm in actual size). The plate had a width of 1.1 m and length of 5.6 m. Acoustic barrier was installed beside the train body to reduce the
noise from the strut of the train body.

The aerodynamic bogie noise was measured under the flow conditions of the middle car of the Shinkansen train by using the 2-D microphone array. This is because the noise generated from the bogie section of the train model was too small compared with the noise generated from other parts. Finally, the A-weighted sound pressure level at the measurement point, i.e. 2 m away from the nearest rail and 0.4 m above the rail head (actual measurements), was estimated based on the 2-D SPL (Sound Pressure Level) distribution. Details regarding the flow adjustment and the estimation procedure can be found in Reference [2]. The flow velocity at the inlet of the nozzle was 320 km/h which corresponded to the running speed of an actual Shinkansen train.

Dimensions in this report are shown on a scale of 1:7 and frequencies are shown in A-weighted actual frequencies, unless otherwise specified.

2.2 Components of the bogie section

The bogie components are illustrated in Fig. 3. A detailed bogie model was installed inside the bogie cavity with a width of 400 mm (bottom surface level of the train car), height of 114 mm and length of 571 mm (1/7 th scale). Both sides of the cavity were fully covered during the noise measurement. The influence of these bogie components, e.g. wheel, axle, gear case, motor, guide, brake and axle box, on the total aerodynamic bogie noise was evaluated by removing each component one by one. The lists of the conditions in these experiments are shown in Table 1. All components were attached in Case St-1 (standard condition), while all bogie components were removed in Case A-1 (hereinafter referred to as empty cavity condition). Cases B-1, B-2 were measured with wheels and axles attached, while Case B-3 and C-1 to C-4 were measured with them removed.
2.3 Contributions of the bogie components to the total aerodynamic noise

The contributions of each bogie component to total aerodynamic bogie noise was evaluated by the difference in SPL in a range from 125 Hz band to 1 kHz band (hereinafter referred to as noise reduction level, $\Delta L_{O.A.}$) between the level under standard condition and conditions where certain bogie components had been removed. In this study, the noise contribution of each bogie component was calculated using the following equations.

\[
\Delta L_{O.A.} = 10 \log \left( \frac{10^{\frac{L_{O.A.}}{10}}}{10^{\frac{L_{O.A.}}{10}}} \right) \times 100
\]

Here, the subscripts indicate the bogie condition shown in Table 1 (e.g. $L_{A-1}$ indicates the overall of SPL in the case A-1). In this paper, it is assumed that the flow conditions are unaffected by the removal of bogie parts.

2.4 Influence of the bogie components on the aerodynamic bogie noise

The frequency spectra of the aerodynamic bogie noise in Case B-1 (without guides), Case B-2 (without gear cases) and Case B-3 (without wheels, axles and gear cases) were compared with the SPL under standard condition, i.e. Case St-1, as shown in Fig. 4. Noise reduction level ($\Delta L_{O.A.}$) shown in parenthesis. For the influence of the wheels, gear boxes and axles which are exposed to relatively fast flow, $\Delta L_{O.A.}$ of Case B-3 is about 1.5 dB although $\Delta L_{O.A.}$ is about 5 dB in Case A-1 (with empty cavity condition). And $\Delta L_{O.A.}$ in Cases B-1 and Case B-2 are 0.7 and 0.6 dB, respectively. These results suggest that bogie components except wheels and gear cases have considerable contribution to the total aerodynamic bogie noise.

The spectra in Case B-3 are lower in wider bands. These trends are remarkable in the range 200 Hz to 400 Hz. Nonetheless, the change in SPL at around 500 Hz is almost undetectable when components are removed. This implies that the noises in these bands are generated by other bogie components. The spectrum in Case A-1 (empty cavity condition) is composed of 2 remarkable frequency components, i.e. around the 125 Hz band and between 250 and 800 Hz.

| Table 1 | Bogie component configurations |
|---------|-------------------------------|
| Case    | Bogie | Wheel | Axle | Gear case | Motor | Guide | Brake | Axle box |
| St-1    | ○     | ○     | ○    | ○         | ○     | ○     | ○     | ○        |
| A-1     | ×     | ○     | ○    | ○         | ○     | ○     | ○     | ○        |
| B-1     | ○     | ○     | ○    | ○         | ○     | ×     | ○     | ○        |
| B-2     | ○     | ○     | ×    | ○         | ○     | ○     | ○     | ○        |
| B-3     | ○     | ×     | ×    | ×         | ○     | ○     | ○     | ○        |
| C-1     | ○     | ×     | ×    | ○         | ×     | ×     | ○     | ○        |
| C-2     | ○     | ×     | ×    | ×         | ×     | ×     | ○     | ○        |
| C-3     | ○     | ×     | ×    | ×         | ×     | ×     | ×     | ○        |
| C-4     | ○     | ×     | ×    | ×         | ×     | ×     | ×     | ×        |

Legend ○: On the bogie, ×: Removed

Here, the 1/3 Octave bands are shown in Fig. 5 (e.g. $L_{A-1}$ indicates the overall of SPL in the case A-1). In this paper, it is assumed that the flow conditions are unaffected by the removal of bogie parts.

Fig. 4 Influence of the gear case or guide on aerodynamic bogie noise

Fig. 5 Influence of the Motor or brake on aerodynamic bogie noise
The influences of the motor and the brake are shown in Fig. 5. Noise reduction level ($\Delta L_{O.A.}$) is also shown in parenthesis. $\Delta L_{O.A.}$ of Case C-1 (without wheels, axles, gear cases and guides) is approximately 2 dB, whereas those of Cases C-2 and C-4 are 3 dB and 4 dB, respectively. Furthermore, it should be noted that noise component around 500 Hz decreases significantly by removing the brake.

2.5 Contribution ratio of each bogie component to total aerodynamic bogie noise

The contribution ratio of each bogie component to aerodynamic bogie noise is shown in Fig. 6. Here, “others” in Fig. 6 contains the axle box ($r_{ax} = 1 \%$). The estimated contribution of the bogie parts indicates that the bogie components inside the cavity contribute to total aerodynamic bogie noise besides the wheels which are exposed to the flow under the train. The cavity structure itself represents a share of around 30 % of the noise.

3. Fundamental study on the countermeasures for noise reduction

3.1 Outline of measures to reduce noise

In order to reduce the noise generated from these bogie components, the quantitative noise reducing effect of two basic measures was examined, e.g. a deflector and cavity under cover. The basic ideas of these measures are intended to inhibit flow into the cavity.

(1) Deflector

In order to deflect flow to the ground, triangular prisms (hereinafter referred to as deflectors) were installed along both edges of the bogie cavity as shown in Fig. 7. The length in the sleeper direction of the deflector, $W$, shown in Fig. 8 was set at lengths of 100, 75 and 50 % of the width (400 mm) of the bogie cavity. Furthermore, the influence of the bogie equipment on noise reduction was also examined with the deflector installed. The length of the deflector are shown in Table 2.

(2) Cavity under cover

In order to prevent the flow inside the bogie cavity, the lower part of the bogie cavity was covered as shown in Fig. 9 and Fig. 10. The effect of the area covering the lower part of the bogie cavity was examined by changing the width of the cover to 100, 75 and 37.5 % of the width of the bogie cavity (400 mm). The size of the gap around the wheels was 105 mm in $x$ direction and 24 mm in $y$ direction. The influence of the gap between the lower edge of the side cover and that of the under cover was investigated by adjusting the gap.

| Case | Bogie condition | Length W [mm] |
|------|----------------|---------------|
| St - 2 | Standard | 200 |
| D - 50 | Standard | 300 |
| D - 75 | Standard | 400 |
| D - 100 | Cavity | 400 |
| D - 100C | Cavity | 400 |
3.2 Effects of noise reduction measures

Figure 11 shows the noise reduction effect of the deflector. Noise reduction level (ΔL_{O.A.}) is also shown in parenthesis. When the deflector length was 37.5 and 75 % of the cavity width, there was no noise reduction effect. However, the noise level above the 315 Hz band was reduced by covering the entire area while noise was reduced up to approximately 4 dB by covering the side gap. However, the noise reduction obtained using this measure was smaller than Case D-100C where the deflector was installed along the edges of the cavity. This could be because noise was generated around the wheels exposed to the flow under the train body. Furthermore, noise was generated around the bogie equipment and downstream cavity edge due to flow into the cavity.

Figure 12 shows the effect of the floor cover on the noise reduction level. Noise reduction level (ΔL_{O.A.}) is also shown in parenthesis. When the deflector length was 37.5 and 75 % of the cavity width, there was no noise reduction effect. However, the noise level above the 315 Hz band was reduced by covering the entire area while noise was reduced up to approximately 4 dB by covering the side gap. However, the noise reduction obtained using this measure was smaller than Case D-100C where the deflector was installed along the edge of the cavity. The limited noise reduction is assumed to be due to noise generated around the wheels and the separation of flow at the cover edge.
4. Conclusions

In order to estimate the contribution of each bogie component to total aerodynamic bogie noise, a wind tunnel test was conducted in which flow conditions at the inlet of the bogie section were simulated reproducing field test conditions. Results showed that besides the wheels which are exposed to the outer flow, bogie equipment inside the bogie cavity, such as the motor and the brake, also influence aerodynamic bogie noise.

Based on these results, two noise reduction measures against the aerodynamic bogie noise were examined. The first one was to install various length of deflector along the edges of the cavity, while second measure was to add different sized under covers beneath the cavity. When the deflectors were installed on a bogie cavity, noise was reduced by 8 dB. However, noise was only reduced by approximately 3 dB when the deflectors were installed with bogie equipment in the cavity, and by 4 dB when the cavity is fully covered by the side covers and the under covers. In future work, flow condition around the bogie section and more practical noise reduction methods will be investigated in detail.

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