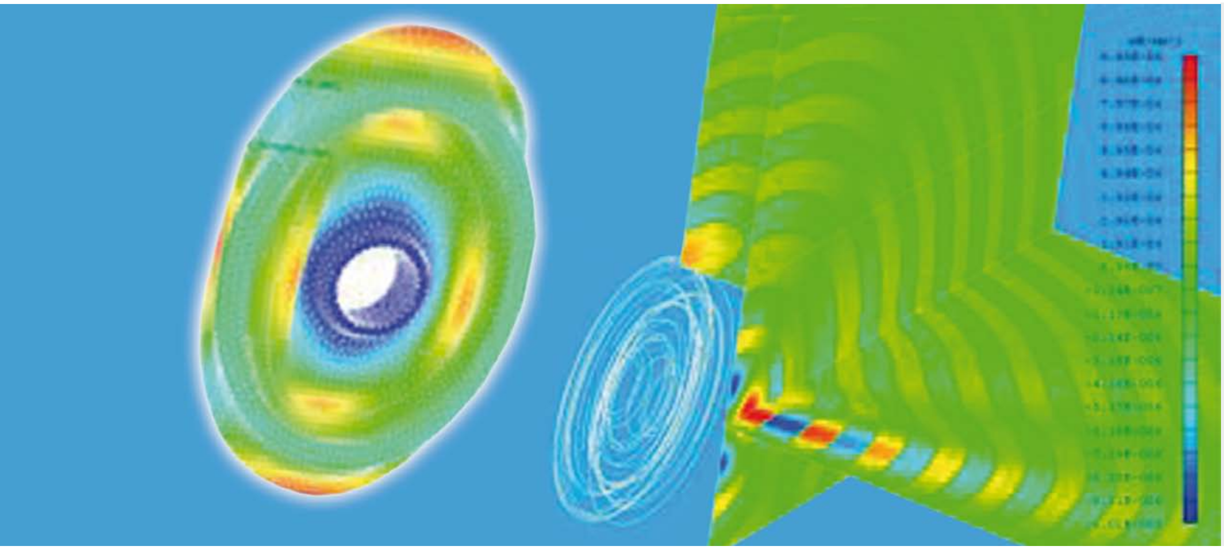
Vibration and Acoustic Characteristics of Railroad Wheels



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As cities become more crowded and congested, reducing rolling noise from railway vehicles such as commuter and freight trains is an important priority in controlling urban noise pollution. Rolling noise consists of both rail noise and wheel noise. This study focused on the wheel noise and its sources including the wheel web and associated parts. A 3-D experimental modal analysis was performed to validate the mode shapes obtained by Finite Element Method (FEM) analysis and the predicted sound power from Boundary Element Method (BEM) analysis. Finally, the acoustic radiation from modified wheel geometries was calculated, showing that wheels with increased rim thickness produced the lowest sound level.

Introduction

Rolling noise is produced by moving railway vehicles and occurs when the rail and wheel interact. It is one of the main noise components. An effective method to reduce this noise is needed, especially for urban areas where noise is already exceeding tolerable limits.

When the wheel rotates, many small asperities over the rail and wheel surfaces produce the vibration loads. Under its influence, the whole structure vibrates, resulting in a rolling noise with a spectral maximum usually between 1 and 2 kHz.

The vibrating plate surface of the wheel is generally the main source of noise and results in sound radiation downward towards the railroad tie (sleeper). However, other wheel components can also have an important effect on the sound distribution and intensity. A complete examination that locates the sources and the directions of wheel-based rolling noise is essential for a proper noise reduction strategy.

In this study the results of FEM vibration analyses were verified by performing 3-D experimental modal analyses for different types of narrow-gauge railway wheels. In addition, the wheels' shape parameters were studied so that the radiation characteristics could be better understood and so that basic data could be acquired to design wheels with less noise.

Narrow-gauge Railway Wheel Shapes

Except for "C-type", typical railway wheels have an offset on the plate for the purpose of reducing heat stress caused by continuous braking and to reduce their weight (Fig. 1). Also, the wheels are classified as "corrugated" or "non-corrugated" with the corrugated wheels having a reinforcing plate located radially and at fixed angles (every 60°). In addition, the corrugated wheel's plate thickness is reduced to further lessen the weight of the wheel. Recently, the new corrugated "NA-Type" wheel, which has about 7% less weight than a conventional "A-Type" wheel, has been used.

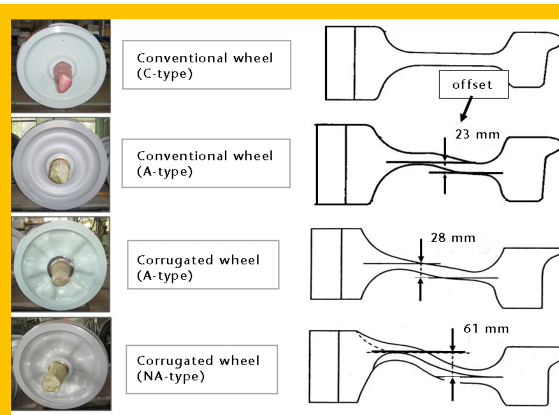

Figure 1: Narrow-gauge railway wheels: profile comparison.

Vibration test: 3-D Experimental Modal Analysis

A wheel set with a connecting axle was placed on a rail in the testing lab. Forced excitations were produced by a shaker in the vertical direction of the tread to simulate excitation from the rail during normal train travel (Fig. 2). The shaker produced random excitation from 250 Hz to 5 kHz, with a force of 20 N (p-p). A non-contact, 3-D scanning laser vibrometer (Polytec PSV-400-3D) monitored the wheel's response recording the vibration velocity vector at each point on a predefined measurement grid generated with the Polytec vibrometer software. The number of measurement points ranged from 450 to 570 points depending on the wheel shape and measurement angle. Internal scanning mirrors move the laser beams to subsequent points on the measurement grid. An integrated laser range finder combined with the scanning mirrors is used to establish the test wheel's geometry and distance from the vibrometers.

The wheel's response was measured including the plates (outer rail side), the rims and the treads. The measurement missed 160° of the wheel due to blockage of the probe lasers by the wheel axle. Also excluded were parts with large curvatures such as the rim because the laser return signal was too small.

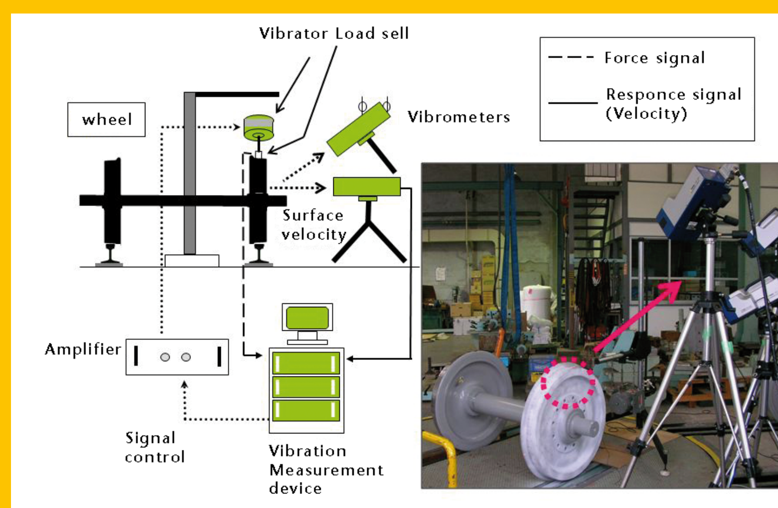

Figure 2: Measurement set up.

Analysis of the Wheel's Sound Radiation

Part-by-part Sound Radiation Power

A structural sound field analysis was done using a low-frequency noise and vibration simulation program (RAYON, ESI Group). In this analysis, the structural response of the wheel acquired from the FEM analysis was used and combined with sound radiation boundary conditions. To determine the sound radiation characteristics, the product of calculated sound pressure and velocity was integrated over the surface to obtain the individual sound power. All wheels were excited in a radial direction from 250 Hz to 5 kHz with a resolution of 25 Hz.

Sound Profile Estimation Based on Wheel Shape

The wheel's stiffness has a significant impact on its sound radiation profile. The plate thickness, rim thickness and plate offset are important shape factors.

Five different shape models were analyzed and compared including radiation sound pressures at six evaluation points and total sound power for the wheel.

Shape Models:

1. Standard model: same plate thickness, rim thickness, and offset as the A-Type wheel
2. Double-thickness plate model

3. Zero-offset plate model
4. Double-thickness rim model
5. Double-offset plate model

Results

3-D Vibration and Sound Radiation Characteristics

In the upper section of Fig. 3 the frequency response functions (FRF) is shown for the 3-D experimental modal analysis on the conventional “A-Type” wheel. In the lower section, the sound power analysis is shown over the circumference of the wheel except for the hub part. In Fig. 4 a similar analysis is shown for the “NA-Type” corrugated wheel.

Both types of wheels present large vibration amplitudes in the X (rail) and Y (vertical) directions in addition to Z (railway tie or sleeper) direction. In the experimental modal and sound power analysis, seven peaks appeared in the frequency range up to 4 kHz for the A-Type wheel and five peaks for the NA-Type wheel. The differences in resonance frequency are probably from differences in shape between simulated and real wheel. The sound power of the NA-Type tends to be higher than the A-Type, and the FRF shows high amplitudes around 1780 Hz. In Figures 5 and 6, the comparison of the deflection shapes is shown at the resonance frequencies found in the experimental modal analysis, FEM analysis, and BEM analysis. The analysis shows that the plate generates out-of-plane vibration in the tie/sleeper direction as expected. In addition, the rim was largely deformed in the radial direction. This behavior of the rim significantly impacts the radiation pattern and can generate high sound power for many wheel designs.

Part-by-part Sound Radiation Characteristics

Regardless of the wheel type, the plate generates the most acoustic radiation; but, the percentage varies greatly with wheel shape. For NA or A-Type wheels, the plate’s contribution to the whole sound power is about 80%. On the other

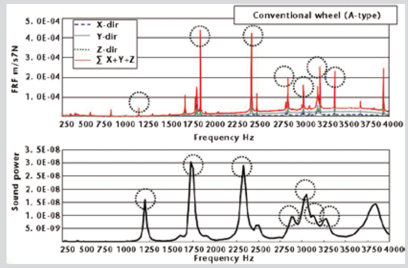

Figure 3: Results of three-dimensional vibration test (Top) and the sound power analysis by BEM (Bottom) on A-Type wheel.

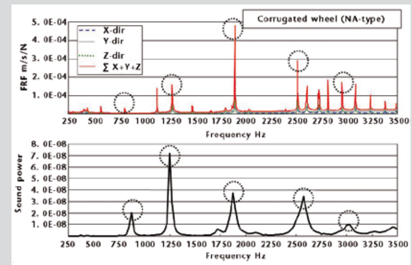

Figure 4: Results of three-dimensional vibration test (Top) and the sound power analysis by BEM (Bottom) on NA-Type wheel.

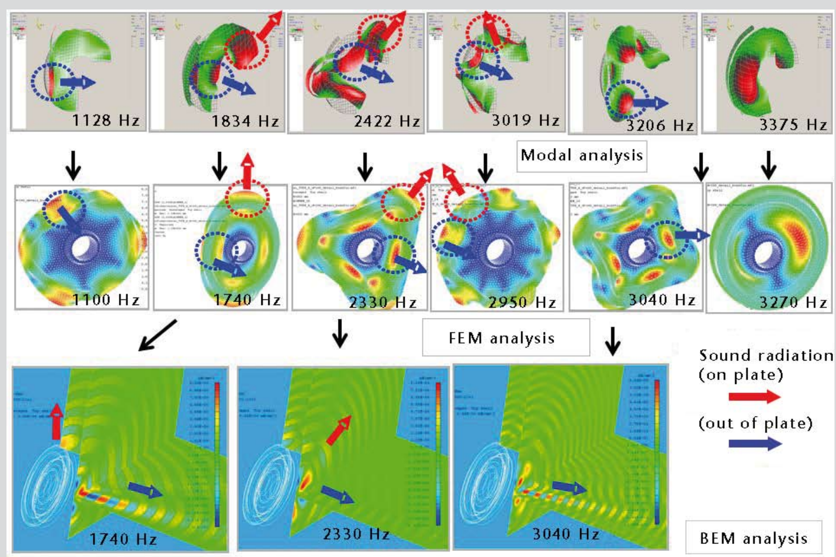

Figure 5: Vibration modes and sound radiation patterns at the resonance frequencies (A-Type).

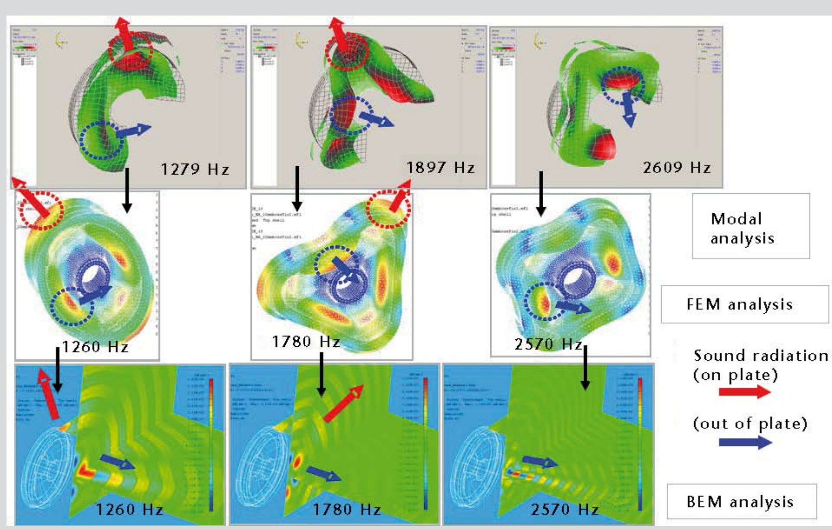

Figure 6: Vibration modes and sound radiation patterns at the resonance frequencies (NA-Type).

hand, for the C-Type, the ratio is a relatively low 50%. Above 3 kHz the percentage from the tread tends to dominate. Also, in some wheels, the radiation peak from the tread corresponded to the overall peak sound power and an increased rim thickness reduced radiated sound power. Clearly, the radiation from both the plate and the tread must be carefully considered.

Conclusion

Combining the 3-D Scanning Laser Vibrometer data with the structural sound field analysis of the railway wheels leads to the following two conclusions:

1. The highest sound power comes from the wheel's plate: 80% for corrugated NA-type wheels with large offsets and 50% for C-type wheels.

2. Regarding wheel shape factors, the rim is an important part of the sound power which decreases with increasing rim thickness.

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The Railway Technical Research Institute (RTRI) conducts basic research and applied engineering for railway technologies covering rolling stock, civil engineering, electrical engineering, information technology, material, environment and human sciences.

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