

Extension of a Tire/Road Noise Model Accounting for Two Peaks of Accelerated Pass by Noise Level

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Road traffic noise needs to be accurately understood and predicted for further noise reduction. In particular, tire/road noise accounts for a large proportion of vehicle noise from electric vehicles. In the previous study, the authors defined the increase in tire/road noise caused by driving torque during acceleration as tire torque noise and proposed a source model based on the elastic energy associated with tread block deformation. Since the maximum acceleration pass-by noise level often appears after the vehicle passes the microphone, the previous model mainly considered tire torque noise generated at the trailing edge of the tire. However, acceleration pass-by noise exhibits two peaks; therefore, this study extends the model to include tire torque noise generated at the leading edge.

Figure 1 shows the vehicle pass-by noise during coasting and full-throttle acceleration. During full-throttle acceleration, two peaks appeared before and after the vehicle passed the microphone. Tire proximity noise also increased at both the leading and trailing edges during acceleration. These results suggest that the first peak is mainly associated with tire torque noise generated at the leading edge, whereas the second peak is mainly associated with that generated at the trailing edge. Frequency analysis of tire proximity noise and tire vibration also showed an increase in tread block vibration at the leading edge during acceleration.

At the trailing edge, tread block vibration is considered to be excited when the tread block, which undergoes shear deformation in the contact patch, is released from the road surface. At the leading edge, vibration is considered to be excited by rapid deformation when the tread block comes into contact with the road surface. Although the excitation mechanisms differ between the two sides, the elastic energy U was adopted as a common explanatory variable representing the magnitude of tread block deformation caused by the driving force. The trailing-edge tire torque noise model is shown in Equation (1).

In this study, four all-season tires and two summer tires were added to the four passenger-car tires used in the previous study, resulting in a total of ten test tires. Tire torque noise corresponding to the second peak was extracted from the Pass-by noise test results and compared with the elastic energy calculated using FEM. The measured values for the additional six tires also lay close to the regression line of the previous model, and the coefficient of determination for all ten tires was $R^2 = 0.914$,

$$L_{p_TRQ_out} = 9.89 \log_{10}(U/U_0) + 34.3 \quad \cdots (1)$$

$$L_{p_TRQ_in} = 9.89 \log_{10}(0.7U/U_0) + 34.3 \quad \cdots (2)$$

where U is the elastic energy associated with tread-block deformation and $U_0 = 1 \text{ J}$ is the reference elastic energy.

Figure 2 shows the relationship between tire torque noise and elastic energy at the leading edge. Regression of the measured values gave a logarithmic slope of 9.30, which was close to 9.89 for the trailing-edge model. Therefore, the same logarithmic slope was used for both sides, and the sound pressure level difference at the same elastic energy was identified as the correction amount ΔL_{in} . As a result, $\Delta L_{in} = -1.53 \text{ dB}$ and an equivalent correction factor of $\gamma = 0.7$ were obtained. The leading-edge tire torque noise model is shown in Equation (2). The red solid line in Figure 2 represents the estimated values obtained using Equation (2), and the coefficient of determination between the estimated and measured values was $R^2 = 0.845$. Here, γ is an equivalent correction factor for the sound pressure level difference between the leading and trailing edges and does not represent the physical ratio of elastic energy actually stored on the two sides.

The extended model was also applied to urban driving conditions with a speed limit of 40–50 km/h. Considering tire torque noise generated at the leading edge increased the overall vehicle sound power level by approximately 0.4 dB for the passenger-car case and 1.2 dB for the SUV case. Under the calculation conditions used in this study, reducing the equivalent tread-block stiffness from 4524 N/mm to 2371 N/mm increased tire torque noise by approximately 2.7 dB, while increasing the vehicle mass from 1615 kg to 2631 kg increased it by approximately 4.0 dB.

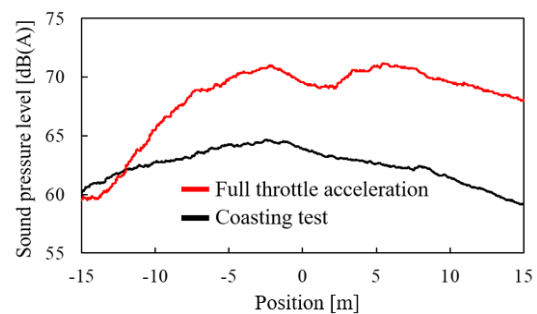


Fig. 1 Measured vehicle pass-by noise levels

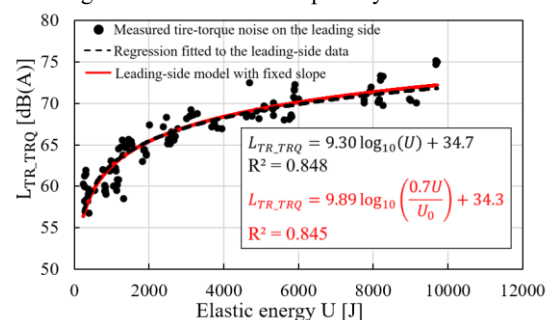


Fig. 2 Relationship between tire torque noise and elastic energy on the leading edge