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Analysis of Suspension and Tire Modal Energy Contributions to Whole Structure Resonance

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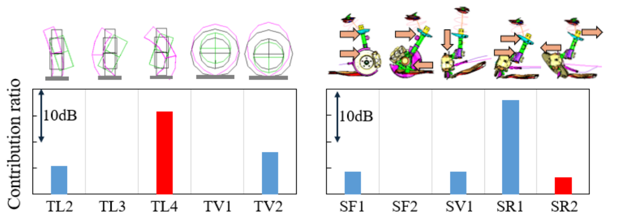
It is necessary to define the required characteristics of both tires and suspensions to efficiently improve road noise performance. However, it is difficult to quantitatively understand the contribution of subsystems to the resonance of a tire-suspension system (hereafter referred to as the whole structure), because the tire and suspension may form complex coupled vibrations. Although several methods have been proposed to extract subsystem eigenmodes that strongly contribute to the whole structure resonance, further analysis of the vibration coupling between the tire and suspension is required to clarify the required characteristics of the tire subsystem.

This paper presents an approach to evaluate the energy contribution of each subsystem mode to a whole structure resonance. The proposed approach analyzes the *kernel* compliance matrix, which represents the subsystem coupling relationship in the FRF-based substructuring method. Using this approach, the coupling mechanism between subsystems can be clarified from two perspectives. First, the proximity of the whole structure eigenfrequencies to those of the subsystems is evaluated. Second, the similarity between the subsystem eigenvectors at the coupling points and an eigenvector of the kernel compliance matrix is evaluated. Consequently, guidelines for subsystem improvement to reduce the whole structure vibration can be obtained.

Focusing on the lateral whole structure resonance with strong coupling between the tire and suspension, the contribution of subsystem eigenmodes to the whole structure resonance was identified (Fig.1). By analyzing two cases using Tire A and Tire B, it was found that the tire lateral bending mode (TL4 in Fig.1(a)) and the suspension lateral vibration mode (SR1 in Fig.1(b)) exhibited large contributions in both cases.

Subsequently, the coupling mechanism of these subsystem modes was analyzed, and differences in the vector ϕ_{TL4}^{Pc} of the tire eigenmode at the hub coupling point between the two tires were observed (Fig.2). The vertical translational degree of freedom z and the rotational degree of freedom about the longitudinal axis θ_x had a particularly large influence. It was confirmed that Tire B showed lower similarity and consequently a lower contribution. These results suggest that the whole structure vibration can be reduced by controlling the z and θ_x components of the vectors of the tire subsystem eigenmodes at the coupling point as in Tire B.

Based on the above assumption, Tires C and D were prepared with equivalent eigenfrequencies of the lateral bending mode but different eigenmode shapes at the hub coupling point. The effect of these differences on the whole structure resonance was then investigated. As a result, Tire D was found to reduce the blocked force at the suspension mounting point, as intended (Fig.3(a)). This tire exhibited lower similarity between the eigenvector of the kernel compliance matrix and the subsystem eigenvectors.Since the standalone axial forces of each tire are equivalent (Fig.3(b)), the difference in the whole structure vibration described above can be attributed to differences in the coupling of the tire subsystem with the suspension subsystem. This result confirms the validity of the proposed guideline.



(a) Tire mode contributions　(b) Suspension mode contributions

Fig.1 Contribution of each subsystem mode

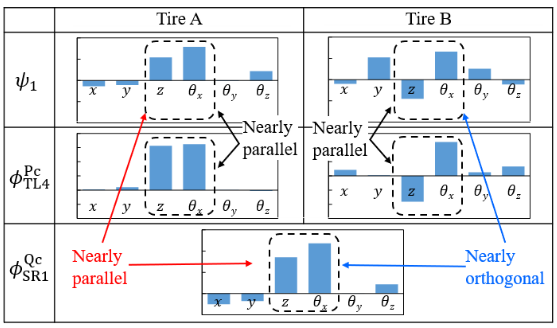
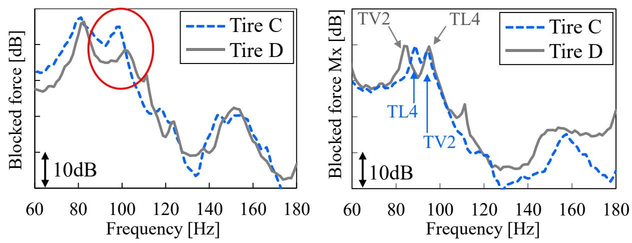


Fig.2 Comparison vector components



(a) Suspension blocked force at lower arm lateral direction　(b) Tire axial blocked force about the x-axis (Mx)

Fig.3 Verification of the effect of tire mode difference

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