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A STUDY ON THE TRANSFER CHARACTERISTICS OF IN-WHEEL MOTOR SYSTEM BASED ON EV PLATFORM

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ABSTRACT

The In-Wheel motor system is mounted directly on the inside of the tire where the road load comes in and increases the unsprung mass, which has a critical effect on the NVH performance of the vehicle. Although the evaluation of the In-Wheel motor at the component and vehicle level is performed respectively, performance at the system level is difficult to predict due to the absence of a test system. In this study, two types of test system are developed to verify the integrated platform performance at the level of the drive unit + suspension system in order to predict the characteristics of vehicles assembled with the in-wheel motor system. So, the dynamic performance difference is analyzed by the load transfer ratio between the suspension system in which the EV motor and the in-wheel motor are assembled.

Keywords: *In-Wheel Motor System, Suspension system, Dynamic Performance, Load Transfer Ratio.*

1. INTRODUCTION

Recently, according to the global interest in eco-friendliness, electrification is being carried out at a rapid pace in the automobile industry. Representatively, the strengthening of CO_2 regulations and tax benefits for eco-friendly cars require automobile manufacturers to develop low-emission and high-energy-efficient vehicles.[1] Following this trend, various types of motors are being developed for the purpose of driving automobiles. This study deals with the contents of the direct drive type In-Wheel system. In the direct drive type In-Wheel system, the motor and brake system are mounted directly inside the wheel of the vehicle and directly drive the wheel without a drive shaft. Compared to existing vehicles, it has the advantage of a simple path and structure for transmitting power.[2] Since the motor support structure is designed in a small space inside the wheel and the motor is directly coupled to the suspension system, there is a disadvantage in that the excitation force of the motor is directly transmitted to the vehicle body.[3][4]. And the road load also comes in directly and increases the unsprung mass, which has a critical effect on the NVH performance of the vehicle. In order to predict this problem in advance, it is necessary to study not only the component and vehicle level, but also the system level as the intermediate stage. [5] In this study, an integrated platform evaluation system for drive unit + suspension system + tire level was developed to analyze the NVH characteristics in order to analyze the NVH characteristics of the suspension system applied to the in-wheel system.

2. TEST SYSTEM I : ROLLER BENCH

In order to simulate the driving conditions of an actual vehicle, a roller bench test device was built as an integrated platform consisting of a drive unit + suspension system + tire, and the system was configured as shown in Fig. 1. The load transfer characteristics of the suspension system level were verified by utilizing the input load from the roller-tire patch surface, which implements the same surface friction coefficient as the asphalt road, and the output load of the vehicle body mountings. In addition, the roller base height was adjusted to generate a pre-load of the actual vehicle. The input force can be measured from the wheel force transducer (WFT) mounted on the tire and the output force

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can be measured from the force sensor mounted on the vehicle body jig mount to obtain the load transfer ratio at the ratio of the two loads. This load transfer ratio can be defined as a characteristic of the system.

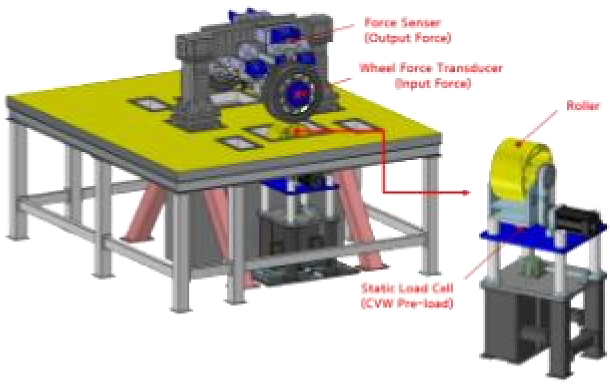

Figure . Roller Bench Test System.

2.1 Input Force

In this study, the roll bench system was operated by a test mode that simulated run-up 0 to 100 kph based on the actual vehicle drive mode. Analyzing the characteristics of the input load shown in Fig. 2, the 1st and harmonics are generated under system conditions, which does not occur in In-Wheel single-component dynamo evaluation, due to unbalance of tire deformation caused by pre-load. In addition, the tire resonance mode moves from 190 Hz to 200 Hz according to the sweep speed, and In-Wheel motor (64 pole 60 slots) mounted directly inside the tire generates 32nd/60th/64th order and sideband components by electromagnetic force of motor.

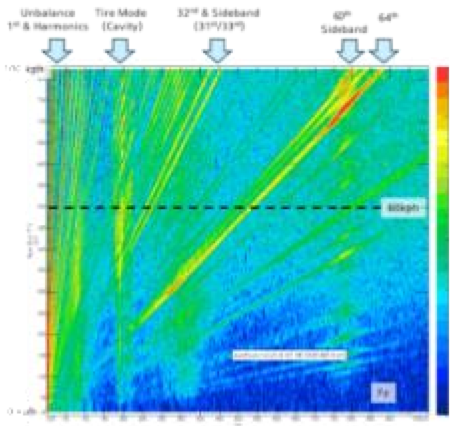

Figure 2. Input Force of Tire Wheel Center in In-Wheel Motor System

2.2 Output Force

In order to obtain the output force of the suspension system, the dynamic force sensor was directly mounted on four body mounts (Shock Absorber, Spring, Member FR/RR Mount). Finally, the Z-direction load, which is the most dominant force according to the mounting direction, was selected as the representative value.

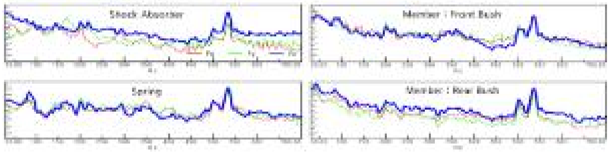

Figure 3. Output Force of Tire Wheel Center in In-Wheel Motor System

2.3 Load Transfer Ratio

It is possible to define the load transfer ratio of the system by the measured input/output force. Using this quantitative value, the contribution of transfer path of the suspension system the vehicle body transfer path can be analyzed on target frequency band.

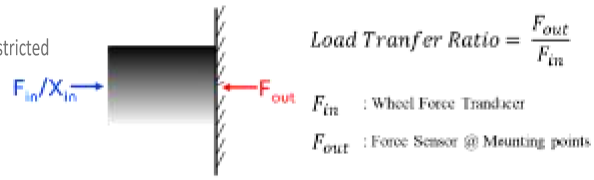

Figure 4. Definition for the Load Transfer Ratio

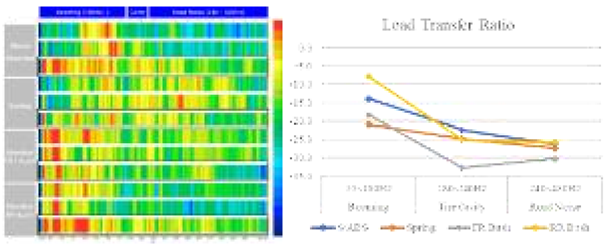

Figure 5. Load Transfer Ratio on Mounting Points at Roller Bench Test.

To define the load transfer characteristics of the frequency band, it is classified and analyzed into three bands according to the noise pattern: booming noise below 180 Hz, tire cavity between 180 and 240 Hz, and road noise band up to 500 Hz based on frequency range.

First, in the booming noise band (180 Hz ↓), the transmission is large in the order of rear bush > shock absorber > front bush > spring.
Second, the contribution can be found in the order of shock absorber > rear bush ≒ spring > front bush in the tire cavity band (180 Hz ~ 240 Hz).
Lastly, in the road noise band (240 Hz to 500 Hz), it can be seen that a large amount of load is transmitted in the order of rear bush ≒ shock absorber ≒ spring > front bush.
Comprehensively looking at contributions across all frequency bands, the suspension system can determine that the transfer paths to the member rear bush and shock absorber are dominant.

2.4 Analysis of Dynamic Characteristics for Suspension System

In addition to the load, the vibration transfer phenomenon of each system component was verified. As shown in Fig. 6, the vibration is amplified in the suspension arms compared to the input part equipped with the in-wheel motor. In addition, when the vibration is transmitted to the member after the suspension bushes, the vibration is reduced again.
A mode map of dynamic characteristics of the suspension system was constructed to analyze the contribution of load transfer by components in more detail. As shown in Fig. 7, it can be seen that the resonance mode of each component element occurs at frequencies where the load transfer ratio peaks. Particularly, the global mode of the suspension system is the main cause in a band of 100 Hz or less, and that the load transfer ratio is deteriorated by the individual modes of the members/arms and the mode coupling between parts more than 100 Hz. This mode map is meaningful in that it has established a process of selecting an improvement target by checking the cause parts of the problem frequency in the future.

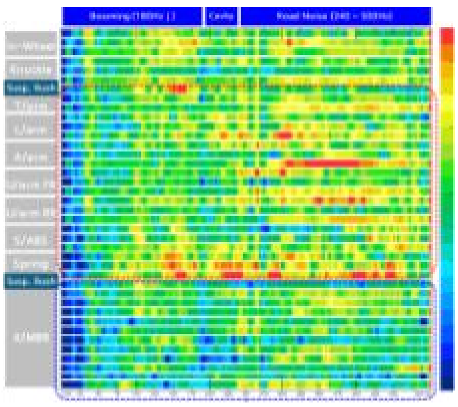

Figure 6. Vibration Transfer characteristics of components

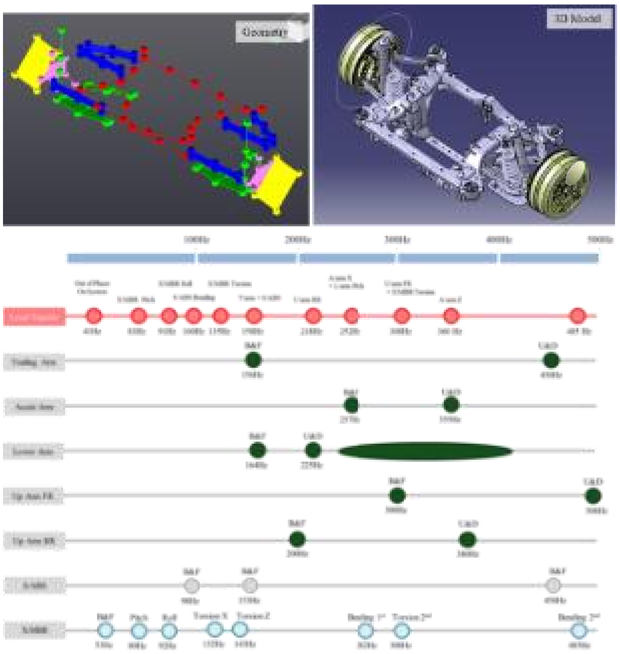

Figure 7. Geometry and Mode Map for the In-Wheel System

2.5 Comparison between In-Wheel and EDU System

The test results were analyzed to compare In-Wheel type and the EDU system, which are currently mass-produced electric vehicles. In-wheel shows different characteristics in input load and load transfer ratio because there is a structural difference in which the motor is rigidly fastened directly to the inside of the tire and the EDU type is fastened to the member by mount bushes. Due to these structural differences, it was verified that tire components (180 to 220 Hz) and unbalanced components due to pre-load are equally generated at the input load, but motor/gear order components are not generated in the EDU type at 500 Hz or less, as shown in Fig. 7.
As shown in Fig. 8, by quantitatively comparing the load transfer ratio of the two systems, it can be seen that the In-Wheel motor system has a superior load transfer ratio compared to the EDU system in all frequency range and transfer paths. In other words, it can be predicted through system level evaluation that In-wheel system's road noise is better than EDU system in real vehicles.

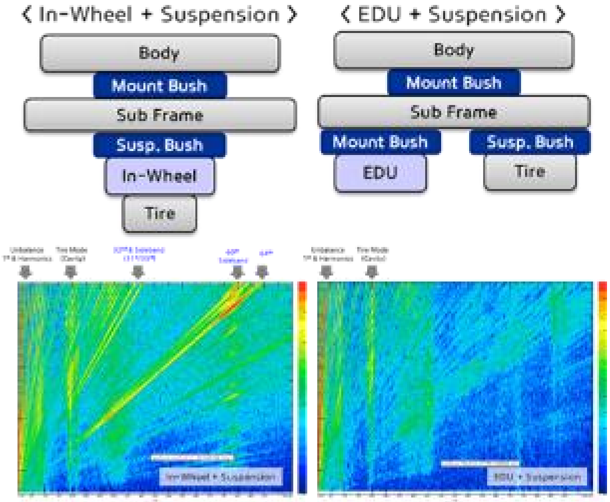

Figure 8. Comparison between In-Wheel and EDU System

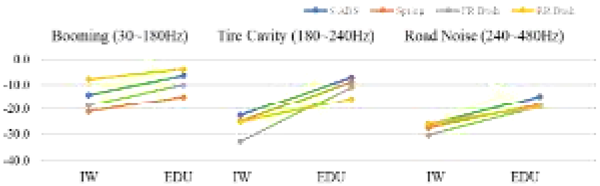

Figure 9. Result of Load Transfer Ratio between In-Wheel and EDU System at Roller Bench Tester

3. TEST SYSTEM II : LINEAR ACTUATOR

The second evaluation system developed is a linear actuator type as shown in Fig. 10. In this test system, a large-capacity excitation motor of 1 ton was newly developed and applied to control the static pre-load and the dynamic force at the same time. Compared to the roller bench type, it is evaluated as a system that combines only the drive unit + suspension system excluding the tire, so the difference is that it reflects the original characteristics of the suspension.
In the linear excitation test, sweep the LH/RH vertical axis to the 30 to 300 Hz in both the in-phase and out-of-phase to obtain the load transfer ratio. Based on this linear actuator system, the load transfer ratio can be compared for two drivetrain types, In-Wheel and EDU, and the results are shown in Fig. 11.

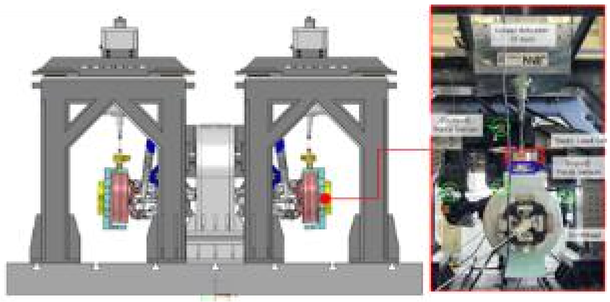

Figure 10. Linear Actuator Test System

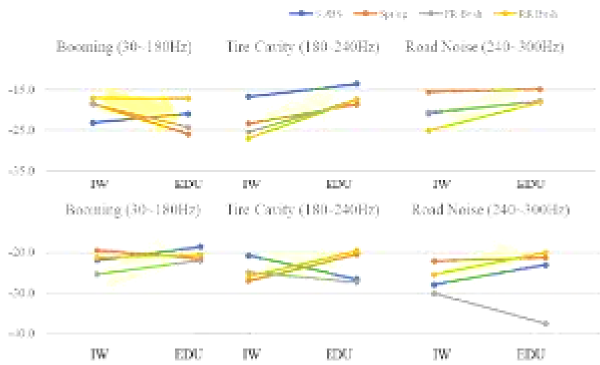

Figure 11. Result of Load Transfer Ratio between In-Wheel and EDU System at Linear Actuator Tester

Overall, the In-Wheel system has a superior load transfer ratio than the EDU system, just like the previous roller bench test. However, when the linear actuator tester is in-phase excited, the result is opposite to the roller bench test in which the In-Wheel type is inferior only in the booming noise band (30 ~ 180 Hz). When the test results are compared in detail in the frequency domain, the load transfer ratio in the 140 ~ 180 Hz band is amplified in the In-Wheel type, which can be judged as the effect of the boundary conditions of the two excitation systems. Although there are differences in boundary conditions such as whether tires are mounted or not, or excitation conditions such as roller/linear exciters, it can be seen that each test has independent characteristics at the same time.

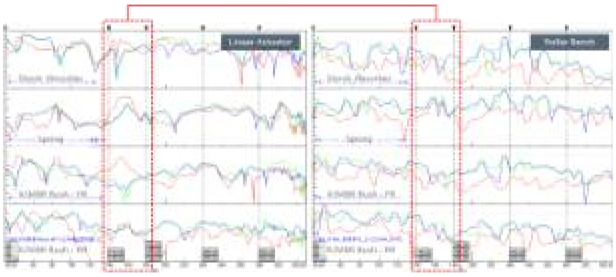

Figure 12. Comparison between Linear Actuator and Roller Bench Test System

4. CONCLUSION

So far, we have introduced the development of an evaluation system for verifying system-level NVH performance for the In-Wheel motor. In addition, the NVH performance of the system level due to the difference in the drive unit (In-Wheel vs EDU) was extracted and compared with a quantitative value called the load transfer ratio. And a mode map was constructed to analyze the causative component for selecting the target component when improving performance. Using this study, we laid the foundation for verifying the performance of the integrated platform level including the drive unit and suspension system.

5. REFERENCES

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