

Study of the Dynamic Characteristics of the Suspension as Related to Brake Judder Reduction

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ABSTRACT

The reduction of brake judder requires refined tuning of the dynamic characteristics in the suspension, which as an oscillatory system has a great influence on brake judder. Here, a component model of the suspension is used to calculate its vibration mode and frequency characteristics. This makes it possible to conduct a comparative examination of the influence of the suspension geometry (the main factor in brake judder), bushing characteristics, parts weight, and other such factors by means of simulation. As a result, the values predicted by calculation have been found to correspond closely with the actual measurements, and compliance steer has been confirmed to play a significant role in reducing brake judder.

1. Introduction

The source of brake judder is known to be excitation caused by braking torque fluctuation resulting from uneven wear and rusting of the disk rotor. Countermeasures include reducing disk rotor run-out and improving the grinding characteristics of the friction material, but these efforts still have not eliminated brake judder.

Whereas the source of excitation for the phenomenon is the brakes, the resonance system is the suspension and the transfer system includes the body and steering system. Thus, many parts are involved with the phenomenon and the mechanism by which it occurs is quite complex. Therefore, experimental analysis approaches come to a stop at understanding the phenomenon and are difficult to translate into guidelines for further development, which has made finding a solution to the issue difficult.

Looking at the suspension, which is a resonance system, the dominant mode when brake judder occurs is known to be the mode in which the tires move in a longitudinal manner called compliance vibration of the suspension.

This compliance plays an important role in improving, for example, ride comfort, but it also has the conflicting characteristic that this first order vibration is the main cause of steering shimmy and brake judder vibration.

The focus of this study is to clarify why compliance vibration of the suspension excites the steering system. This issue was approached through vibration testing using actual vehicles and parameter studies using finite element method simulations of the placement of suspension mounting points and the bushing characteristics. The results confirmed that reducing suspension transfer sensitivity and reducing input to the steering system are also effective at reducing brake judder in an actual vehicle.

2. Understanding the Phenomenon

The circumferential acceleration on the steering wheel and the acceleration at various suspension points were measured during actual cruising and frequency analysis was performed to understand the suspension behavior when brake judder occurs. The results showed that the largest component occurs around approximately 15 Hz. Fig. 1 shows a typical example of the time history data and frequency analysis results for the steering wheel.

Fig. 2 shows the vibration mode extracted at the peak gain frequency in order to confirm the suspension behavior at this time. This figure shows that longitudinal vibration of the suspension, that is to say compliance vibration, is the dominant behavior when brake judder occurs.

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The various suspension and brake parts are excited by compliance vibration, and this inertia force mainly occurs as a moment around the kingpin shaft. Axial force is generated on the tie rod as reaction force to support this inertia moment, and this axial force passes through the steering gear box and becomes rotational vibration of the steering wheel.

These test results confirmed that braking torque fluctuation is conveyed through this type of transfer path and becomes steering vibration.

3. Analysis by Simulation

The results of the above running tests clarified that compliance vibration of the suspension has a large influence as a resonance system. Therefore, it was necessary to create a simulation model capable of reproducing these phenomena.

The modeled phenomena were the weight of each part comprising the suspension and brake, the bushing characteristics of the body mounting points, the rigidity of the body mounting points, and the position of each point comprising the suspension link mechanism. Fig. 3 shows the calculation model created from this information.

Note that with the exception of the bushings comprising

each device, the influence of elastic deformation of the suspension parts was considered to be minute, so the model was created using rigid body elements. In addition, part weights were modeled by the dispersed location of concentrated mass at the representative points of each part. This also made it possible to easily express inertia moments that had been difficult to obtain thus far.

This model was used to calculate the vibration mode during compliance vibration and the transfer characteristics from the tire ground contact point to the rack end by performing frequency response analysis using the general-purpose finite element method solver NASTRAN. Relative evaluation with respect to changes in each influencing factor is possible by performing comparative investigations of these results.

4. Example of Application to Development

An example of application to actual development is shown below. Here, the two countermeasure proposals A and B were investigated with respect to the base specifications. The proposal A specifications reduce the spring rate and improve the damping factor of the compliance bushing with respect to the base specifications. The proposal

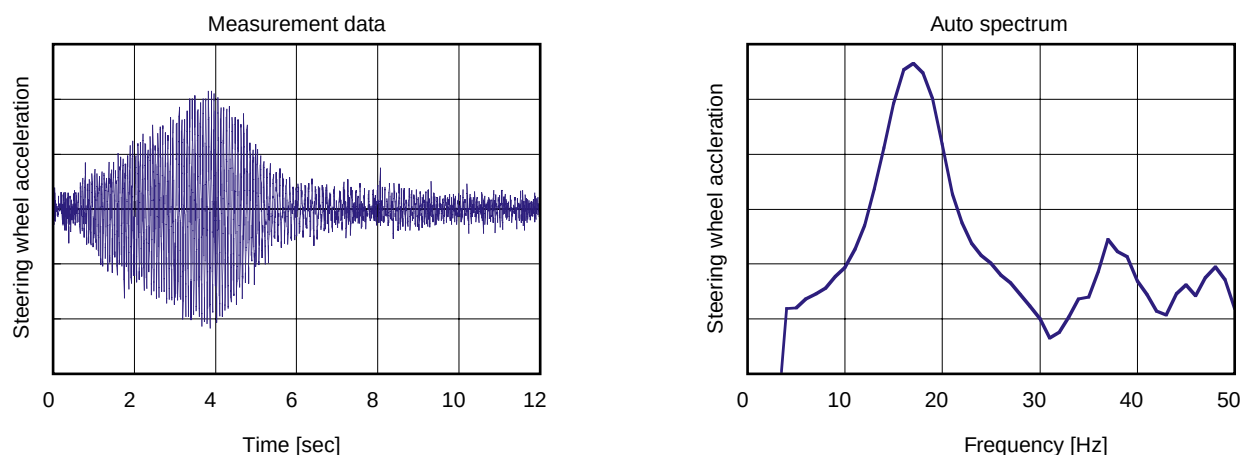


Fig. 1 Example for steering wheel acceleration

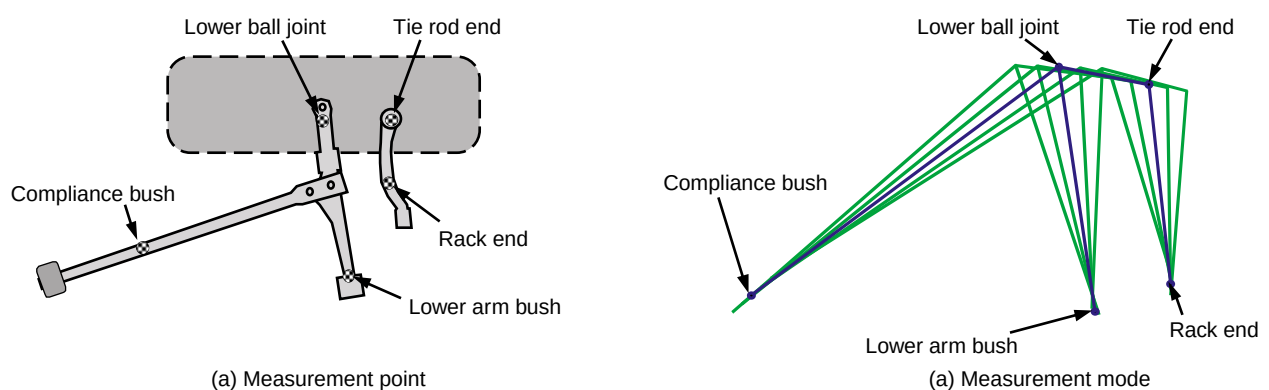


Fig. 2 Compliance vibration: experimental mode

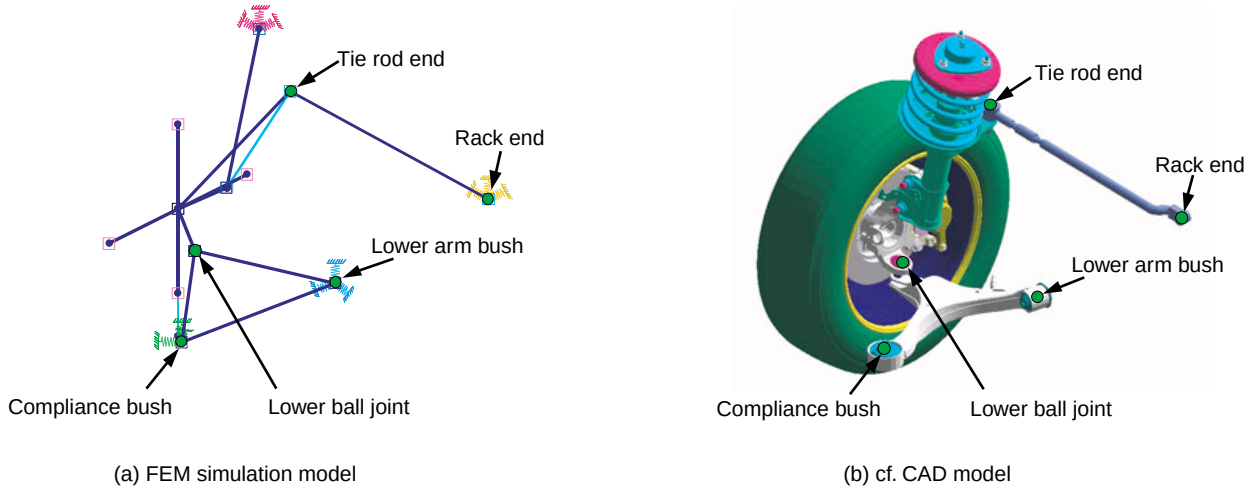


Fig. 3 Suspension component model

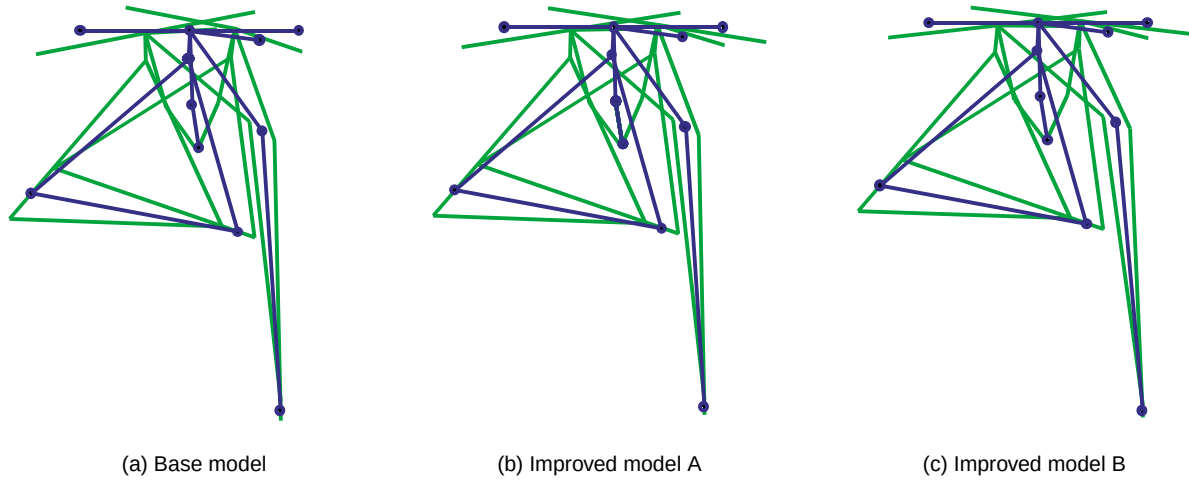


Fig. 4 Simulation result: natural frequency mode

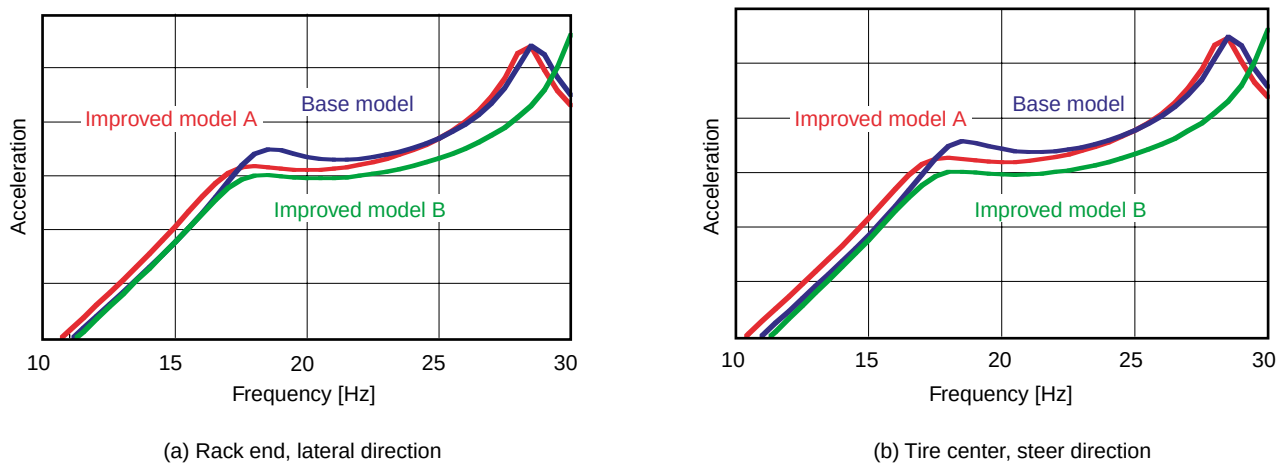


Fig. 5 Simulation result: auto spectrum

B specifications build on the proposal A specs by changing the rack end position to the rear. Fig. 4 and Fig. 5 show the calculation results for each of these specifications.

Proposal A further improves the vibration energy scattering effects due to the compliance bushing by changing the bushing characteristics, and is effective at reducing the peak gain.

In addition, examining the vibration modes for both proposals A and B shows that rotational movement in the tire toe direction, or the so-called compliance steering, due to longitudinal vibration decreases in stages with the addition of each countermeasure item compared to the base specifications. This can also be confirmed from the decrease in the steering direction gain at the tire center in Fig. 5(b).

The moment occurring around the kingpin shaft is generated by the inertia force of the tire, wheel and incidental parts that perform rotational movement, and is a major factor in exciting vibration. Directly reducing this moment is extremely effective in reducing the transfer sensitivity of the suspension.

These results confirmed that each of the countermeasures were improvements over the base specifications, so these improved specifications were verified by actual vehicle tests.

Fig. 6 compares the results of actual measurements and simulations of steering wheel acceleration in the rotational direction. This figure shows an excellent proportional relationship between the calculations and actual measurements, thus confirming the validity of this method.

5. Analysis of the Degree of Contribution of Each Factor

Most of the various suspension-related specifications have an influence on multiple vehicle performances, so it is necessary to set characteristics that achieve a balance between each performance. Accordingly, it is extremely important to know the degree of influence that each factor has on the respective performances.

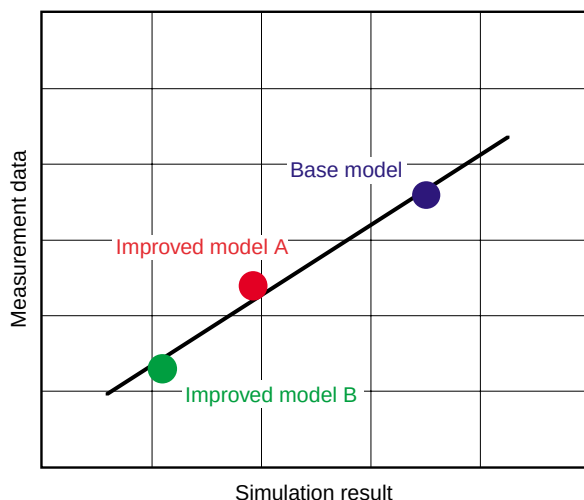


Fig. 6 Acceleration comparison: simulation result and measurement data

Therefore, parameter studies were performed for a number of characteristics that were thought to have a large influence on brake judder, and the degree of contribution was analyzed for each factor. Fig. 7 shows the transfer characteristics from the tire ground contact point to the rack end and the steering direction gain at the tire center as the change in characteristics when each parameter is changed. Here, the calculation results for the base specifications are used as the reference.

These results show that the influence of the compliance bushing characteristics is the largest among the investigated factors. As described in section 4, this is not merely the effect of improved vibration energy dissipation due to a reduced spring rate and improved damping factor; reduced compliance steering due to the spring rate change also has a significant effect. The results of each of these studies indicate a close relationship between the lateral fluctuations in the rack end and compliance steering, and also show a large contribution toward the transfer sensitivity of the suspension.

The results of this study showed that the compliance bushing characteristics also have a large influence on changes in the vibration mode. However, at the stage where each factor can be changed freely, the position of the suspension mounting points has the greatest influence.

However, the suspension geometry has basic characteristics that affect many performances, and investigations are repeated numerous times from the concept stage, so there are many cases where changes are difficult once the specifications have been decided. Therefore, it is important to optimize compliance steering as one of the basic characteristics from the initial development stages.

6. Conclusion

The mechanisms when brake judder occurs were analyzed, and theoretical investigations were carried out using a finite element model which reproduces these phenomenon. The following results were obtained.

- (1) Brake judder can be lessened by reducing the transfer sensitivity during compliance vibration of the suspension which is a vibration resonance system.
- (2) The suspension geometry and the compliance bush characteristics have the greatest influence on the transfer sensitivity during compliance vibration.
- (3) Compliance steering plays an important role as an influence on the vibration mode.
- (4) The simulation method proposed by this study was confirmed to be effective even in actual development.

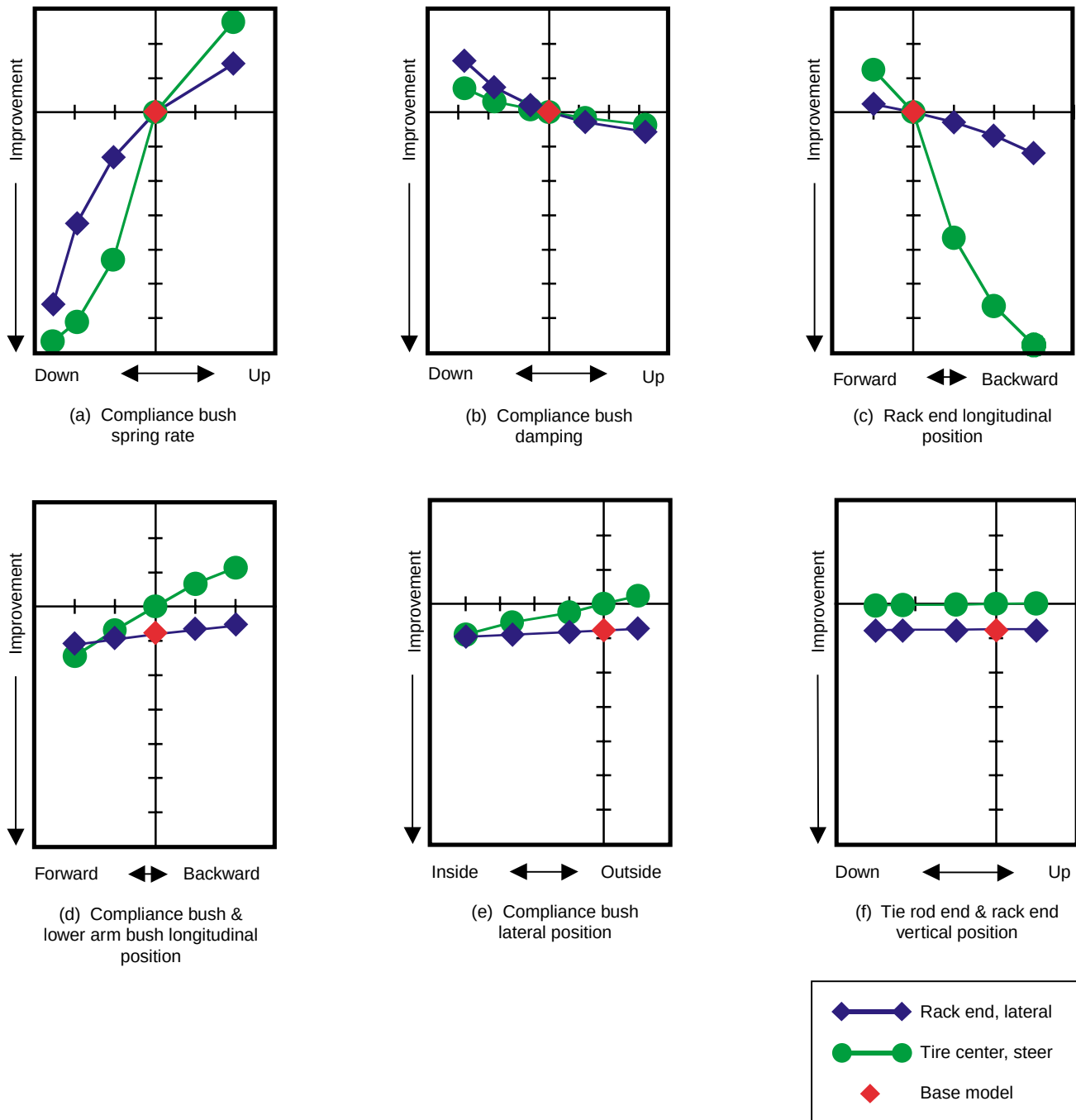


Fig. 7 Parameter study result

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