

Design of Floating Seat for Control of Seat Resonance Frequencies

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ABSTRACT

A method of seat design that makes it possible to control resonance frequencies of the seat in order to reduce seat vibration when the vehicle is idling and when it is in motion has been proposed. The research discussed in this paper made it possible to reduce vibration by controlling the resonance frequencies by replacing the structures of the seat-mounting unit with floating structures using rubber bushings. It was also shown that partly replacing the mounting unit with floating structures makes it possible to control the resonance frequencies of the entire seat. Compared to a design that replaces the entire seat-mounting unit with floating structures, this design makes it possible to optimally position floating structures for each type of seat. The issue of balancing vibration reduction with strength and durability and crash safety performance due to fitting the floating structures to the seat-mounting unit was addressed using stopper structures optimized for each type of input. The use of the floating structures in an actual vehicle realized a lighter-weight seat configuration than the use of conventional vibration countermeasures.

1. Introduction

Automotive seats are a part with which a vehicle occupant's body is constantly in contact, from entering to exiting the vehicle, making them an important part that affects the commercial appeal of the vehicle. From the perspective of vibration performance, identifying how to reduce the vibration felt by vehicle occupants through the seat when the vehicle is idling and when it is in motion is an important issue in the development process. Measures that reduce the vibration input from the mounting points of the seat⁽¹⁾ and measures that reduce the vibration response of the seat itself by adding inertia masses or adopting dynamic dampers are employed to address this issue. Measures against vibration by the use of dynamic dampers are widely used, however this increases the weight of the entire seats. Currently, the automotive industry is seeking to reduce the weight of all the parts that compose vehicles in order to increase fuel efficiency and reduce CO₂ emissions. For seats as for other parts, it is necessary to restrain increasing mass even if this enhances vibration performance. Against this background, the research set out to balance the reduction of the weight of the seat with vibration performance.

In order to reduce vibration of the seat, an effective method is to attempt to ensure that the resonance frequencies of the seat do not coincide with the frequencies of the input vibration, thus reducing the vibration response of the seat to the target frequencies. However, in order to

control the seat's resonance frequencies without increasing weight, it is necessary to reduce the stiffness of the seat bottom, and this has made the achievement of a balance with strength and durability performance and crash safety performance an issue. The present research added rubber bushings provided with stopper structures to sections of the seat-mounting unit structure, making it possible to realize a balance between control of the seat's resonance frequencies and strength and durability performance and crash safety performance.

2. Development Goals

The phenomena that represent issues in the area of seat vibration are vibration while the vehicle is idling and vibration while the vehicle is in motion. As Fig. 1 shows, vibration while idling is a phenomenon that occurs because the resonance frequencies in the longitudinal and lateral directions of the seat are close to the frequencies of vibration input from the engine.

As Fig. 2 shows, vibration while the vehicle is in motion occurs because the torsion mode frequencies of the body and the lateral resonance frequencies of the seat are close to each other when random frequency input is imparted from the suspension to the body. Because the body mode that excites the longitudinal vibration of the seat is rarely close to the range of the resonance frequencies of the seat, longitudinal vibration of the seat is seldom an issue.

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In order to respond to these issues, it is necessary to conduct design keeping the longitudinal and lateral resonance frequencies of the seat away from the vibration frequencies of the input and body modes that are factors in the occurrence of the issues. Conventionally, the method adopted has been to reduce the seat's resonance frequencies by adding inertia masses⁽²⁾. In many cases the control of the seat's resonance frequency using inertia masses is inadequate, and dynamic dampers are also widely used. Both of these methods increase the weight of the seat. Figure 3 shows the results of an analysis of the optimization of the thickness of sections of the seat in order to obtain the necessary resonance frequencies without increasing the weight of the seat. In this analysis, the longitudinal resonance frequency was varied from 19 Hz to 15 Hz, and the lateral resonance frequency was varied from 18 Hz to 16 Hz. As the figure indicates, using a conventional seat structure, it would be necessary to reduce the thickness of the base of the seat by half in order to obtain the necessary resonance frequencies. This would represent an issue in terms of achieving a balance with strength and durability performance and crash safety performance.

This research therefore sought to develop a method of

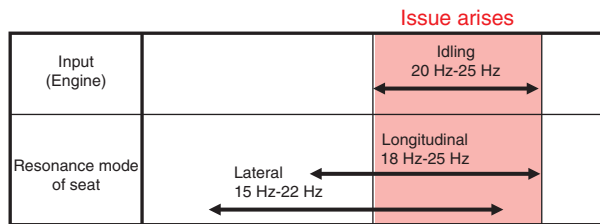


Fig. 1 Frequency of vibration when vehicle is idling

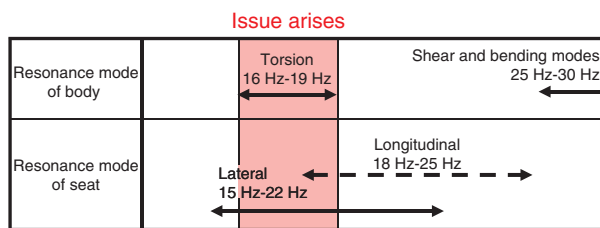


Fig. 2 Frequency of vibration when vehicle is in motion

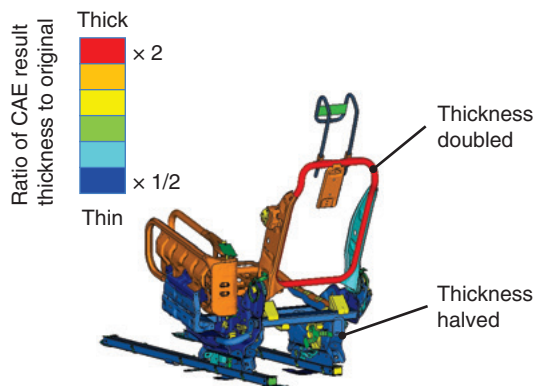


Fig. 3 CAE result for reducing resonance frequency of seat

seat design that would realize the following three goals:

- (1) Make it possible to control the seat's resonance frequencies;
- (2) Realize a balance with strength and durability performance and crash safety performance; and
- (3) Realize a reduction in weight against a seat using inertial mass or dynamic dampers.

3. Floating Seat Design Method

In this research, the target seat design method was realized by replacing the mounting structure of the seat with rubber bushings provided with stopper structures. These rubber bushings will be termed "floating structures," and seats to which they have been applied will be termed "floating seats" below.

3.1. Concept of Positioning of Floating Structures

The resonance frequencies demanded from the seat differ depending on the resonance frequencies of the body modes of the specific vehicle and the engine speed set for idling. The basic structure of the seat also differs depending on the seat of the specific vehicle, and the resonance frequencies of the longitudinal and lateral eigenmodes change respectively. As a result, there are vehicles in which the resonance frequency in the longitudinal direction represents an issue, and vehicles in which the resonance frequency in the lateral direction represents an issue. The verification regarding the number of floating structures employed and the positions in which they are employed was performed to realize the control method for optimal resonance frequencies in response to the specific vehicle body and seat. Figure 4 shows changes in resonance frequencies when all of the mounting points of the seat are replaced with floating structures, when only the rear mounting points are replaced with floating structures, and when only the mounting points on the outer sides of the seat are replaced with floating structures. The seat using the



	Conventional	Floating structure		
		All	Rear	Outer side
Longitudinal resonance mode	23 Hz	16 Hz (-7 Hz)	17 Hz (-6 Hz)	18 Hz (-5 Hz)
Lateral resonance mode	19 Hz	13 Hz (-6 Hz)	17 Hz (-2 Hz)	16 Hz (-3 Hz)

Fig. 4 Differences in resonance for different floating structure positions

floating structures for all the points reduce the resonance frequencies the most in both longitudinal and lateral directions. Comparison of a seat using floating structures for the two mounting points at the rear of the seat and a seat using floating structures for the two mounting points at the outer sides of the seat showed that the former had a greater resonance frequency reduction effect in the longitudinal direction and the latter had a greater effect in the lateral direction.

Figure 4 indicates that even when only some floating structures are employed, it is possible to reduce its resonance frequencies. It also indicates that it is possible to realize optimal designs in relation to the necessary characteristics by changing the positioning and number of the floating structures in accordance with the longitudinal or lateral directions in which the reduction of the resonance frequency is desired.

3.2. Specific Structure

Three characteristics are demanded of the floating structures: To possess a spring constant making it possible to realize the desired seat resonance frequencies in the small amplitude area required for vibration performance; To continue to satisfy the spring constant following strength and durability tests; and To avoid the seat from being displaced during crash safety tests. Figure 5 shows the actual structure of the floating seat. Figure 5(a) shows the rubber bushing that helps to realize the desired seat resonance frequencies. The seat resonance frequencies are controlled by adjusting the spring constant. Figure 5(b) shows a stopper structure that helps to prevent the rubber bushing from breaking under the input experienced during strength and durability tests. This helps to retain the desired seat resonance frequencies even after strength and durability tests. Figure 5(c) shows a stopper that helps to ensure that the floating structure itself will not break even in the event that rubber parts (a) and (b) break in response to the large input associated with a crash. It was verified that the structures displayed no issues even as a result of the input associated with crash safety performance tests.

In addition, the example of the specific layout for the floating structures is shown in Fig. 6. The floating structures can also be fitted in the seat-body assembly area as shown in (a), or fitted inside the mounting structure of the seat as shown in (b). It is possible to realize the optimum positioning for the specific seat structure to achieve a balance with other mechanisms.

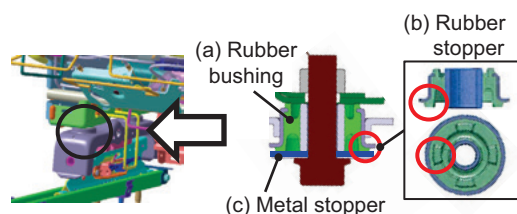


Fig. 5 Parts of floating structure

3.3. Method of Setting Spring Constant

The floating structure spring constant necessary for the realization of the seat resonance frequencies demanded by seat vibration performance was set after conducting frequency analysis by means of CAE using FEM. The seat resonance frequencies are affected by the stiffness of the seat frame and mounting section. CAE is therefore used in modeling the structure of the seat unit and the mounting section as shown in Fig. 7 by considering the body as a rigid body. With regard to the coupling of the seat to the vehicle body, constraint conditions were applied in the actual bolt-coupling sections. In addition, the rubber bushing was analyzed by setting the spring constant to six-degree-of-freedom. The spring constant of the rubber bushing was varied and a parameter study conducted, making it possible to determine the characteristics that would produce the optimum resonance frequencies.

A variety of methods have previously been employed in predicting resonance frequencies when a seat is occupied⁽³⁾. The method adopted in this research was to estimate the change in the resonance frequencies between unoccupied and occupied seats in advance, following which an analysis was conducted for an unoccupied seat.

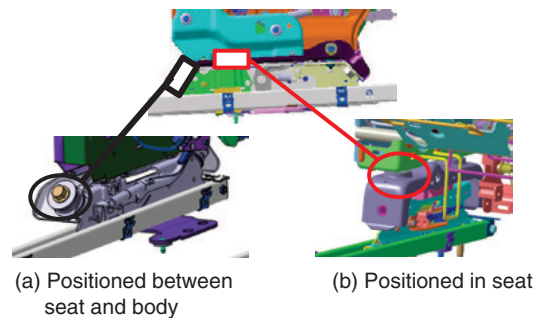


Fig. 6 Layout of floating structure

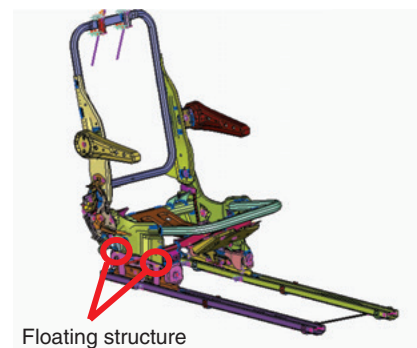


Fig. 7 Model for calculation of seat resonance frequencies

4. Results of Actual Vehicle Tests

This chapter will discuss the results of verification that used an actual SUV mounted with a 4-cylinder engine.

4.1. Setting of Resonance Frequency Target

The resonance frequency target was a frequency that would make it possible to achieve a 5-dB reduction in vibration, equivalent to the reduction achieved by conventional measures. Considering a damping ratio of 1.4 using a one-degree-of-freedom model of displacement excitation, it would be necessary to realize a resonance frequency 0.91 times the input frequency in order to obtain a 5-dB vibration reduction. The engine speed during idling was set at 720 rpm and the frequency of the main vibration input from the engine was 24 Hz. The resonance frequency of the body torsion mode was 18 Hz. During the vehicle development process, the resonance frequency target with the seat occupied was set at 16 Hz or less for the lateral direction and 21.5 Hz or less for the longitudinal direction, and the seat was designed on this basis.

4.2. Applied Structure

CAE prediction of resonance frequencies using a seat model with a conventional configuration showed that no reduction of the resonance frequency in the longitudinal direction was necessary, but a reduction of 4 Hz was required in the lateral direction. The configuration shown in Fig. 8, in which two floating structures are employed at the mounting points on the outer sides of the seat, was therefore employed due to its effectiveness in reducing resonance frequency in the lateral direction. As Table 1 shows, the mass increase against a conventional structure has been limited to approximately 0.07 kg.

4.3. Setting of Spring Constant of Floating Structure

The spring constant was set based on frequency analysis results obtained using CAE. The actual use environment in which seat vibration becomes an issue is when the seats are occupied, and the effect of the occupant on the resonance frequencies of the seat therefore cannot be ignored. Based on the change in resonance frequencies of a similarly shaped seat, in this research the change in resonance frequencies when the seat was occupied against resonance frequencies when it was unoccupied was estimated at plus 4.0 Hz in the longitudinal direction and plus 0.5 Hz in the lateral direction. This meant that the resonance frequency targets for CAE were 17.5 Hz in the longitudinal direction and 15.5 Hz in the lateral direction. Figure 9 shows changes in the resonance frequencies of the seat when the spring constant of the floating structures is changed using the CAE analysis. In the figure, the value in the horizontal axis is the spring constant for the vertical direction of the vehicle, however spring constants of other degrees of freedom were also changed in the same ratios. The results show that for the longitudinal mode, even when the spring constant is high, the resonance frequency is sufficiently low in relation to the target. A spring constant of 420 N/mm was therefore set in order to realize the target for the lateral mode. The shapes of the actual rubber bushing and rubber stopper were designed based on this spring constant and strength and durability

Table 1 Comparison of mass between conventional and floating seat

Part name	Conventional seat [kg]	Floating seat [kg]
Cushion side frame	0.70	0.80
Foot member	1.14	0.60
Foot bracket (Include floating structure)	0.62	1.02
Bracket	-	0.11
Total	2.46	2.53

performance and crash safety performance. These were employed in the actual vehicle under development, and tests of strength and durability performance and crash safety performance showed that a similar level of performance as the conventional structure was maintained.

4.4. Effect of Floating Structures

This section will discuss results for resonance frequencies and vibration performance in actual vehicle tests. Figure 10 shows the results for resonance frequencies. All the measurements were made under the condition that a seat is occupied. The broken lines in the figure show the resonance frequencies for seats in which a rigid body had been used for the seat-mounting unit. These results make it possible to verify the effect of the floating structures in controlling resonance frequencies. The resonance frequency of the longitudinal mode has been reduced by 2 Hz, and that of the lateral mode by 3 Hz. The effect of reduction in the lateral direction is greater than in the longitudinal direction, verifying the effect of employing floating structures for the

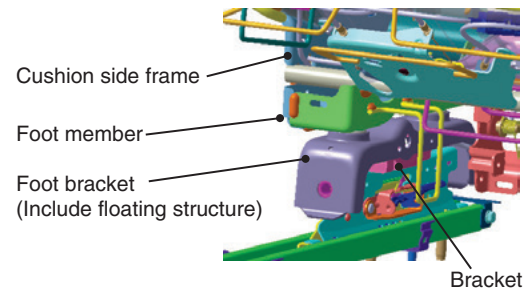


Fig. 8 Structure of floating seat

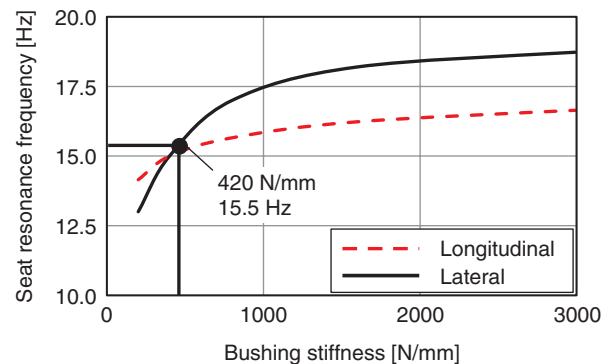


Fig. 9 Relationship between seat resonance frequencies and bushing stiffness

two mounting points on the outer sides. In addition, the targets for a lateral direction resonance frequency of 16 Hz or less and a longitudinal direction resonance frequency of 21.5 Hz or less when the seat is occupied were realized.

Vibration performance will be discussed next. Figure 11 shows results for seat vibration in the lateral direction while the vehicle is in motion. The effect of the body torsion mode is significant and lateral vibration of the seat is an issue, but the floating structures achieve a 5-dB reduction in vibration against a seat using rigid supports, realizing the targets set for the method.

Figure 12 shows results for seat vibration in the longitudinal direction while the vehicle is idling. Regarding vibration while idling, the resonance frequencies of the seat do not coincide with vibration frequencies input from the engine, even when the floating structures are not used, however their use results in a further reduction of 3 dB for vibration.

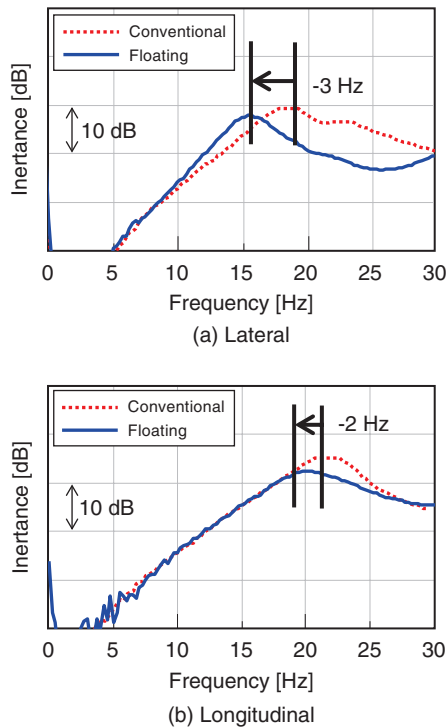


Fig. 10 Resonance frequencies of floating and rigid seat

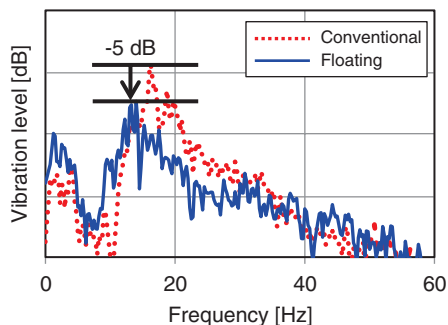


Fig. 11 Results for vibration when vehicle is in motion

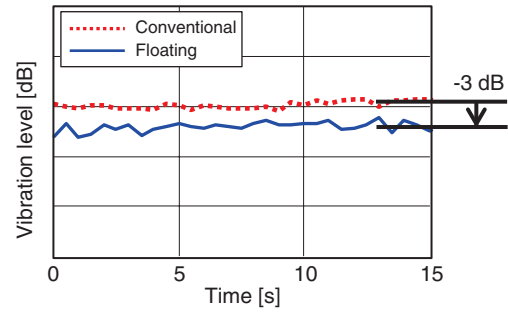


Fig. 12 Results for vibration when vehicle is idling

5. Conclusion

The following outcomes were obtained in relation to the three goals of the research discussed in this paper.

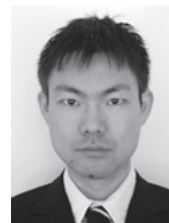
- (1) Seat resonance frequencies were controlled by fitting floating structures to sections of the seat-mounting unit.
- (2) In order to achieve a balance between vibration reduction and crush durability performance and crash safety performance, the use of stoppers in the floating structures made it possible to maintain a similar level of performance to a conventional support structure.
- (3) The use of the method made it possible to reduce the weight of the seat by 0.88 kg per foot against the conventional similarly shaped seat employing dynamic dampers.

Target vibration performance was realized through the application of this method to a seat fitted in an actual vehicle. The developed floating seat will be used in vehicles to be developed in the future.

References

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