

Improvement of Dynamic Spring Characteristics of Engine Mounts with Non-combination Type Dynamic Damper

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ABSTRACT

Cabin noise originating in the power plant has been reduced by utilizing non-combination type dynamic dampers to reduce the absolute value of the complex spring constant (K^*) of the engine mounts in the high-frequency range.

Development first employed simulations, which demonstrated the superiority of the non-combination type to the combination type dynamic dampers. Next, the study focused on how best to exploit the structural characteristics of non-combination type dynamic dampers to enable them to be applied to the rubber parts of the engine mount. Single non-combination type dynamic damper units have been shown to control increases in K^* caused by rubber surging and mount bracket resonance. Cabin noise in a completed vehicle has been also reduced. Finally, it has been confirmed that the targeted durability can be kept even with the use of the dynamic dampers on the rubber parts of the engine mount.

1. Introduction

Customer requirements with respect to the comfort of automotive cabins are continually increasing, and the targets for in-cabin quietness are consequently being raised. At the same time, there are demands for vehicles to be made lighter as a means of responding to environmental issues, and to achieve this the thickness of component panels is being reduced and aluminum and other lightweight materials are beginning to replace steel. Lower weight generally means lower rigidity, and this tends to lead to increases in-cabin noise and vibration. Lightweight damping and soundproofing materials have been developed to prevent this, but preventive measures which concentrate on automotive panels having a large area are rather inefficient from a weight efficiency perspective, and other preventive measures which focus on the sources of noise and vibration can be considered more fundamental.

Of the various forms of in-cabin noise and vibration, the research discussed in this paper targeted those generated by vibration in the power plant, and tested the effectiveness of a lightweight engine mount structure in ensuring the quietness of the cabin by reducing the vibration transmitted to the chassis by the power plant. The results of this research are presented below.

2. Research Goals

One of the factors present in the transfer paths of vibration originating in the power plant to the body panels that causes the amount of vibration to increase is rubber surging in the engine mounts. Rubber surging is resonance generated in the rubber sections themselves. The absolute value of the complex spring constant (K^*), increases in the frequency range of this resonance, increasing the vibration transmissibility from the power plant to the chassis. As a

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result, the level of noise and vibration in the cabin increases. The aim of the research discussed here was to reduce the increase in vibration input caused by rubber surging in the engine mounts with a lighter-weight countermeasure than conventionally used.

To date, when rubber surging has become an issue, various countermeasures have been available, such as positioning plate-shaped objects called intermediate plates in the center of the rubber sections. However, these conventional measures simply shift the frequency of the surging. After this shift in frequency, noise and vibration in the cabin increases correspondingly in the new frequency range. The use of combination type dynamic dampers is also possible, but these have the same effect, causing K^* to peak at frequencies higher and lower than the initial surging frequency⁽¹⁾. Rather than conventional combination type dynamic dampers, this research project therefore utilized improved non-combination type dynamic dampers to attempt to control the increase in K^* caused by rubber surging in the target frequency range.

3. Overview of Non-combination Type Dynamic Dampers

Figure 1 shows the structures of the non-combination type dynamic damper used in this research project and the conventionally used combination type dynamic damper. The non-combination type dynamic damper is a two-part structure, consisting of an added mass covered by an elastic material and a surrounding housing. The added mass of the conventional dynamic damper is connected to the target of vibration reduction by rubber or some other elastic substance. In the non-combination type, the added mass is covered in an elastic material, but this is not connected to the target of vibration reduction. This added mass can move freely in the housing which covers it to prevent it flying off.

In addition to producing the same damping effect by combination type dynamic dampers, this structure enables the vibration response peaks generated as a result of the use of dynamic dampers to be reduced. Figure 2 shows a two degree of freedom spring-mass model with a non-combination type dynamic damper, and Fig. 3 shows the results of a simulation employed to confirm its vibration reduction effect⁽²⁾. Here, the target of vibration control is M1; the base section is excited at a constant amplitude of acceleration and the amplitude of response acceleration in M1 is compared without a damper, with a combination type dynamic damper and with a non-combination type dynamic

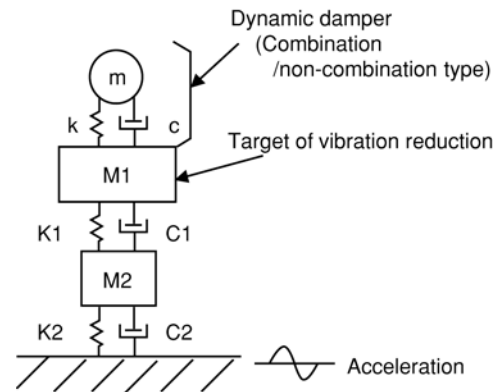


Fig. 2 Analytical spring-mass model of two degrees of freedom

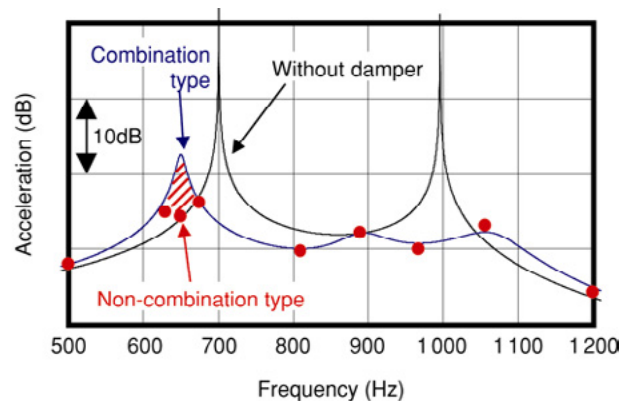


Fig. 3 Comparison of vibration reduction effect

damper. The specifications of the dynamic dampers were established to reduce the peak occurring at around 1 000 Hz when no damper was used. As Fig. 3 shows, in comparison with the effect of the combination type damper in reducing the peak at 1 000 Hz, the use of the non-combination type dynamic damper reduced the peak occurring at around 650 Hz due to the use of the combination type damper, and as a result there is a virtually flat response, without the two peaks occurring when dynamic dampers are not utilized.

4. Application to Engine Mounts

While continuing to investigate the characteristics of non-combination type dynamic dampers, in which the added mass is contained within a housing, research focused on a type of engine mount in current use, and tested the effectiveness of the damper when applied to it. To exclude the effect of the natural vibration of the bracket attached to the chassis, a bush type engine mount with a circular bracket was produced. Tests were conducted with this as the base component. Figure 4 shows a schematic view of this engine mount, and Fig. 5 shows its dynamic spring characteristics. This shape is very commonly used in engine mounts. Measuring K^* in a vertical direction when the engine mount is excited at a constant amplitude of acceleration enables evaluation of the dynamic spring characteristic.

As can be seen in Fig. 5, this engine mount demonstrates rubber surging at around 740 Hz, and K^* peaks in that

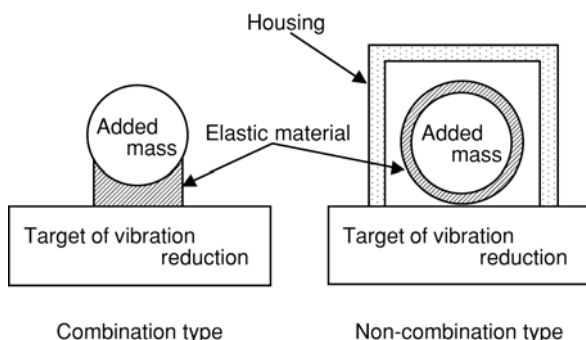


Fig. 1 Examples of dynamic damper structures

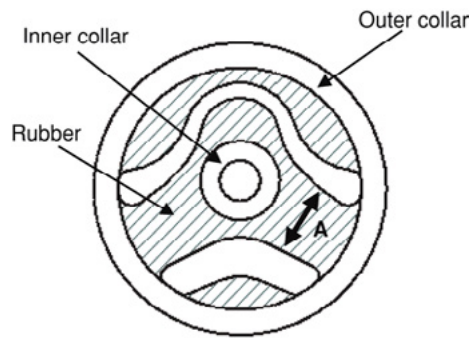


Fig. 4 Schematic view of engine mount

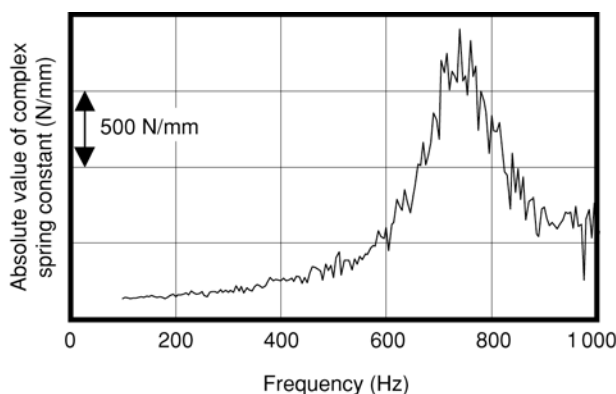


Fig. 5 Absolute value of complex spring constant

frequency range. This rubber surging is thought to be a first-order resonance generated when the inner and outer collars at the ends of the rubber section are fixed. Positioning a non-combination type dynamic damper at the center of the rubber section was judged to be effective in reducing this resonance response. Considerations of ensuring durability in the rubber sections towards displacement generated by the power plant led to the selection of a round pipe housing in which stress would not concentrate, which was vulcanized into the center of the rubber section. The added mass was made cylindrical to match the shape of the space inside the housing, and both ends of the housing were plugged to prevent it from flying out. Because the direction of displacement of the first-order resonance mode of the target rubber section is basically the direction shown as A in the cross-section in Fig. 4, the outer circumference of the added mass was covered in an elastic material. Figure 6 shows a cross-section of the structure of this non-combination type dynamic damper, and Fig. 7 shows the engine mount after application of the damper.

This structure is effective because the added mass is covered in an elastic material and fitted inside a housing rather than being connected to the target of vibration reduction by an elastic material. For example, when rubber is used as the elastic material, a thickness of 3 mm is required in the rubber section to ensure the strength of the metal mold forming the section, and it is not possible to fit a combination type dynamic damper in the same space. The possibility of size reduction is another characteristic of non-combination type dynamic dampers, which is not shared by combination type dynamic dampers.

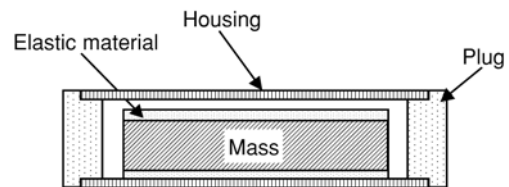


Fig. 6 Section of non-combination type dynamic damper structure

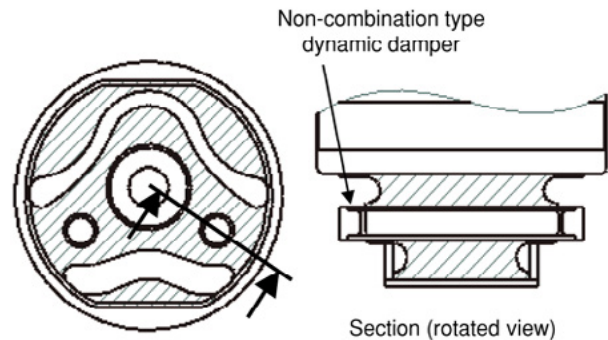


Fig. 7 Non-combination type dynamic damper applied to engine mount

5. Results of Confirmation of Unit Characteristics

5.1. Characteristics of the Bush Type Engine Mount

Unit characteristics were measured using the bush type mount employed to neutralize the effect of the natural vibration of the bracket. Measurements were taken using the mount as shown in Fig. 4 (in isolation) and Fig. 7 (with attached non-combination type dynamic damper). The range of frequencies for evaluation of the dynamic spring characteristics was 100 Hz to 1 000 Hz, the range which is particularly problematic for cabin noise originating in the power plant when the vehicle accelerates. The static spring constant was equivalent in both mounts.

5.1.1. Dynamic spring characteristics

In addition to testing with and without the non-combination type dynamic damper, the type of a damper shown in Fig. 7 without the added mass was used in order to

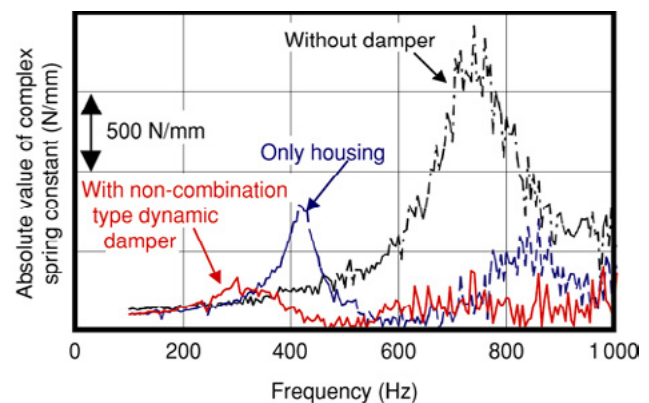


Fig. 8 Comparison of effect of reduction of absolute value of complex spring constant

test the characteristics when a mass is added as when employing an intermediate plate. K^* was measured in a vertical direction. The fixed amplitude of acceleration utilized in the measurement of K^* was the same as used in the previous measurements. Measurement results are shown in Fig. 8. As this graph shows, the peak around 740 Hz is reduced when the housing only is used, but this generates two new peaks, around 420 Hz and 860 Hz. By contrast, the damper with the built-in mass does not generate a noticeable peak and shows a virtually flat characteristic in the target frequency range.

5.1.2. Comparison with hydraulic engine mounts

A comparison was done of the absolute value of complex spring constants in a currently used (bush type) hydraulic engine mount and of the engine mount employing a non-combination type dynamic damper described above. Hydraulic engine mounts are utilized to reduce K^* . A schematic of the hydraulic engine mount used in the comparisons is shown in Fig. 9. When the comparison tests were conducted, the hardness of the rubber in the engine mount employing the dynamic damper was altered to make its static spring constant in a vertical direction to match that of the hydraulic engine mount.

The results of measurements of K^* are shown in Fig. 10. A constant amplitude of acceleration was utilized for excitation when measurements were taken. As can be seen in the graph, the hydraulic engine mount shows peaks at around 460 Hz and 750 Hz, while the engine mount employing the non-combination type dynamic damper demonstrates a flat response with no conspicuous peaks. The engine mount with the dynamic damper reduces K^* to a lower level than the hydraulic mount across virtually the entire frequency range.

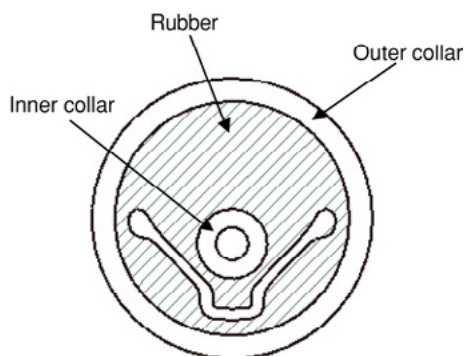


Fig. 9 Hydraulic engine mount

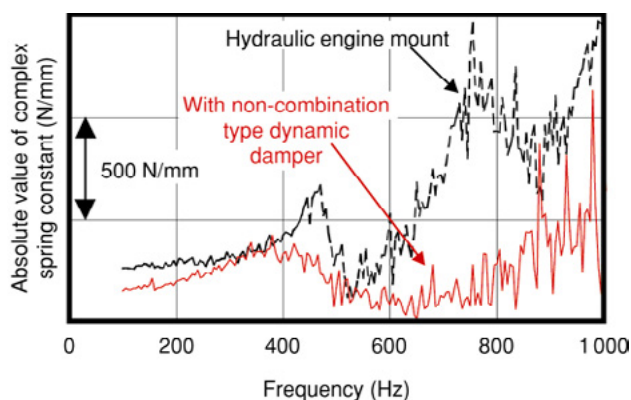


Fig. 10 Effect of reduction of absolute value of complex spring constant

5.2. Dynamic Spring Characteristics of Completed Product

K^* of the bush type engine mount described above was measured in the mount when pressed into the bracket connecting to the chassis, as when used in a vehicle. A comparison was conducted of performance with and without the non-combination type dynamic damper. Figure 11 shows the engine mount with the damper applied. The same type of mount was used in tests without the dynamic damper. The results of measurements of K^* are shown in Fig. 12. The test piece was excited with a constant amplitude of acceleration during these measurements.

The graph shows that when the non-combination type dynamic damper was not used, K^* peaked at around 700 Hz due to rubber surging and at around 1 000 Hz due to resonance in the connecting bracket. However, when the dynamic damper was utilized, the level of both these peaks was reduced, and a virtually flat characteristic was obtained in the target frequency range.

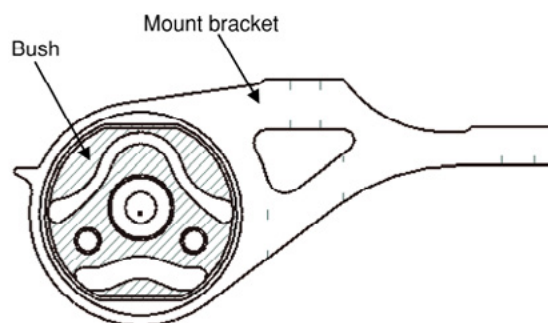


Fig. 11 Engine mount with non-combination type dynamic damper

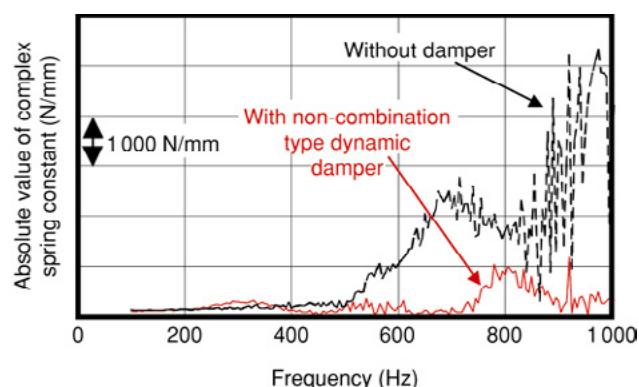


Fig.12 Effect of reduction of absolute value of complex spring constant

6. Results of Vehicle Performance Tests

The engine mounts described above were fitted in a vehicle, and the level of quietness in the cabin was compared with and without the non-combination type dynamic damper. Evaluation criteria were the vibrational acceleration at the engine mount points and sound pressure level in the center of the cabin while the engine was idling. The respective measurement results are shown in Figs. 13 and 14. The horizontal axes of the graphs show the central frequencies in the 1/3 octave band. Figures 12 to 14 show that the

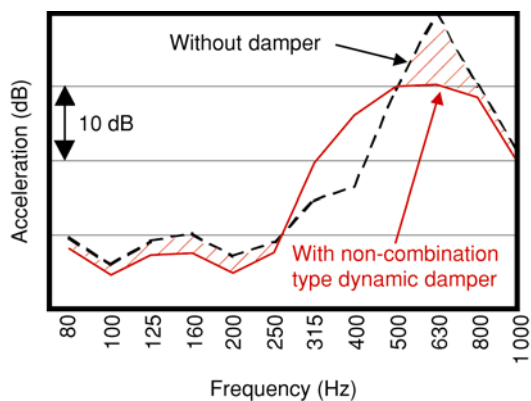


Fig. 13 Effect of reduction of vibration of engine mount point of body side

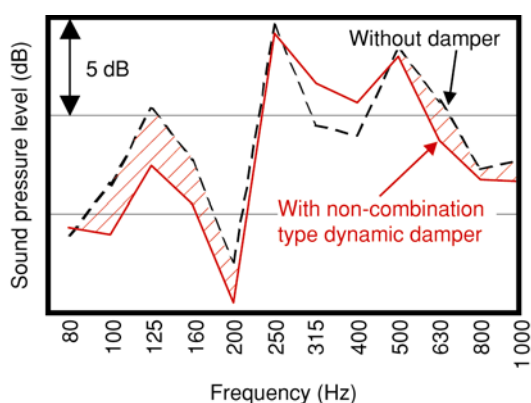


Fig. 14 Effect of reduction of sound pressure of interior noise

vibrational acceleration of the engine mount points has been reduced in the frequency range in which K^* has been reduced, and the sound pressure level in the center of the cabin has consequently been reduced.

7. Results of Unit Durability Tests

To evaluate the durability of the rubber section due to displacement from the power plant when a non-combination type dynamic damper unit is fitted, unit durability tests were conducted using identical excitation conditions to those utilized in current tests of mass production units. Figure 15 shows the appearance of the engine mount after the completion of tests. The tests confirmed that no cracks or similar deviations occurred in the rubber section.



Fig. 15 Engine mount after endurance test

8. Conclusion

Research was conducted on the use of non-combination type dynamic dampers to reduce the level of increase of K^* caused by rubber surging in the engine mounts, in order to reduce noise and vibration in vehicle cabins. Unit tests and vehicle tests were conducted to verify the effectiveness of the dynamic damper. The following outcomes were generated by the research:

- (1) In comparison with a combination type dynamic damper, it was shown that the non-combination type dynamic damper reduced response peaks without increasing vibration in other frequency ranges.
- (2) A structure employing a non-combination type dynamic damper was proposed as a measure to control rubber surging in the engine mount.
- (3) The application of a non-combination type dynamic damper to the rubber section of an engine mount significantly reduced K^* in the target frequency range and produced a virtually flat response characteristic compared to the base product. The non-combination type dynamic damper also achieved superior results to a hydraulic engine mount employing a structure designed to reduce K^* in the target frequency range.
- (4) When the engine mounts fitted with non-combination type dynamic dampers were employed in a vehicle, the vibrational acceleration at the engine mount points was reduced in the frequency range in which K^* was reduced. Consequently, the sound pressure level in the center of the cabin was reduced.
- (5) It was confirmed that unit durability requirements due to displacement originating in the power plant were satisfied even when a non-combination type dynamic damper was fitted to the rubber sections of the engine mount.

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