

Prediction Technique for Gear Noise Transfer in Engine Mounting Systems

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ABSTRACT

Prediction methods using finite element method (FEM) analysis were investigated to construct technology for predicting the aggravation of gear noise and other high frequency vibrations due to engine mount transfer in the initial development stages. Engine mounts are normally comprised of rubber clasped between metal brackets on the power plant and chassis sides. Coupled vibration including these metal parts is a problem for high frequency vibration transfer. This study showed the mount vibration transfer characteristics are a composite of the response characteristics of each metal part, and that simple evaluation by the response level can be used to predict the aggravation of noise in the cabin. In addition, modeling the chassis frame and case to which the metal fittings are joined, and modeling the clamping rigidity of the joints using spring elements, made it possible to accurately calculate the frequency response (error of resonance frequency: approximately 5%).

1. Introduction

Reducing transmission gear noise is an important issue from the viewpoint of improving automobile product appeal. Routes for gear noise into the front seat are divided into structural-borne noise, such as through the engine mounts and cables, and airborne noise radiated from the transmission case. Currently, gear noise transferred from the engine mounts is a large contributing factor. Many development man-hours are spent to coping with this problem. Research thus far has shown that there is little attenuation of vibration in engine mounting systems due to resonance of the metal fittings on the power plant and chassis sides which encase the mount rubber. This results in vibration which is transferred at certain frequencies, thus aggravating gear noise in the front seat. However, it was difficult to quantitatively predict the amount of aggravation in advance. Accurate prediction techniques are desired due to recent trends toward shorter development periods and reduced numbers of prototypes. Therefore, this study investigated the following items.

- (1) Methods of evaluating the appropriateness of the transfer level by calculating the gear vibration transferred through the engine mounts.
- (2) Model creation techniques for simple and accurate calculations.

2. Investigation of Calculation Evaluation Methods

2.1 Analysis of Gear Vibration Transfer

Gear meshing vibration is transmitted through the transmission case. Part of this vibration is transmitted to the chassis through the brackets fixing the transmission, the rubber and the metal fittings fixing the rubber. Therefore, the problem is thought to be the total transfer characteristics of the transmission case, mounting system and chassis frame. Fig. 1 shows a comparison of the condition where gear vibration is transmitted at the peak vibration while cruising

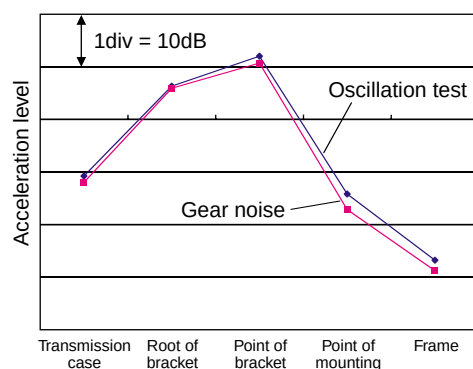


Fig. 1 Mode shape of mounting system

and the vibration mode where the tip of the transmission side bracket is excited by hammering excitation. In addition, Fig. 2 shows an example mounting system layout.

The graph shows the size of the gear vibration component while cruising at each point and the response at that same

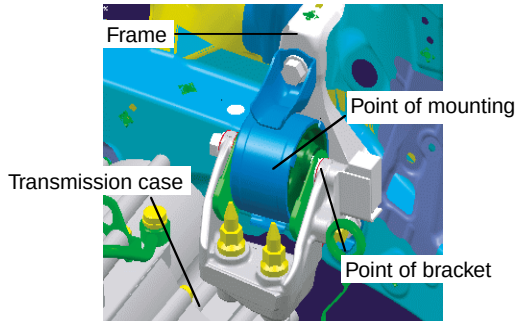


Fig. 2 Layout of a mounting system

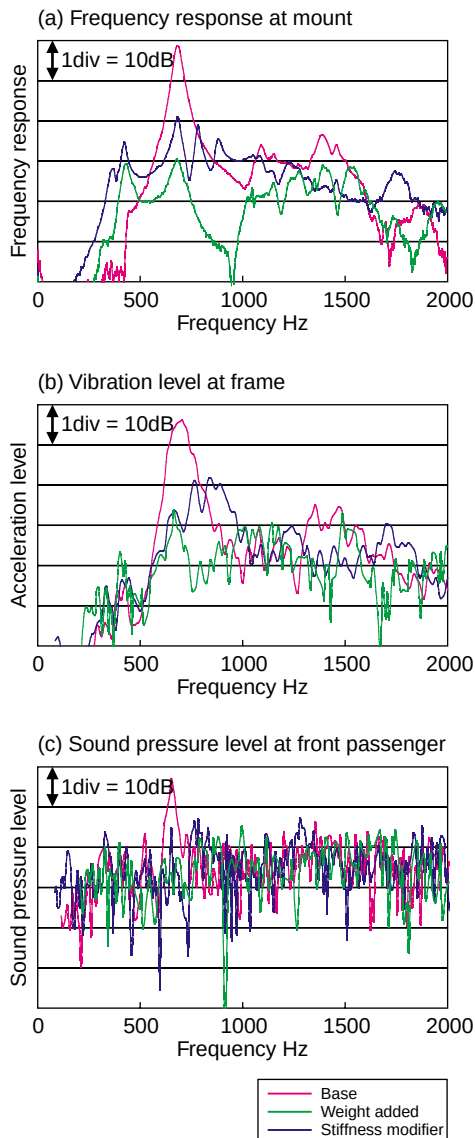


Fig. 3 Sound and vibration level reduction effect of improvement of frequency response

point when the tip of the power plant side is excited. These results show that hammering-induced coupled vibration and gear vibration transfer while cruising have almost the same mode. In addition, Fig. 3 shows the hammering-induced frequency response (chassis side tip response to transmission side tip excitation), the gear vibration level on the chassis side while cruising, and the gear noise level in the front seat.

These graphs compare three different types of mounting system specifications: the base specifications without countermeasures, specifications with weight added to change the resonance frequency, and specifications with the bracket stiffness changed. The metal bracket and mount fittings resonate with the base specifications resulting in sharp peaks in each of noise, vibration and frequency response measurements. However, the resonance frequency is shifted for each of the countermeasure specifications. The frequency response is improved and the sound and vibration peaks decrease. This indicates that there is a correlation between the frequency response characteristics of the mounting system and gear noise, and that gear vibration transfer can be evaluated by this response level. Therefore, frequency response characteristics (chassis side tip response to transmission side tip excitation) were calculated through simulations.

2.2 Simplification of the Model

As stated in 2.1. above, there is a correlation between the mount vibration while cruising and the gear noise in the front seat. The problem with this gear vibration is thought to be the vibration mode of the total transfer route. However, modeling the entire system is impractical due to system resources and other limitations, thus it was decided to calculate the chassis and transmission sides separately with the rubber as the boundary. First, the coupled condition of the metal bracket and mount fittings was analyzed through hammering excitation tests. Fig. 4 shows a comparison of the discrete responses for the transmission (a) and chassis (b) sides, the overall response characteristics due to the mounting tip response to bracket tip excitation (d), and the composite of the discrete responses (c).

This comparison shows that the total response characteristics due to transmission bracket tip excitation (d) exhibit features of the discrete metal bracket and mount fitting responses (a) and (b), and closely match the composite (combined) characteristics (c) of the two discrete responses.

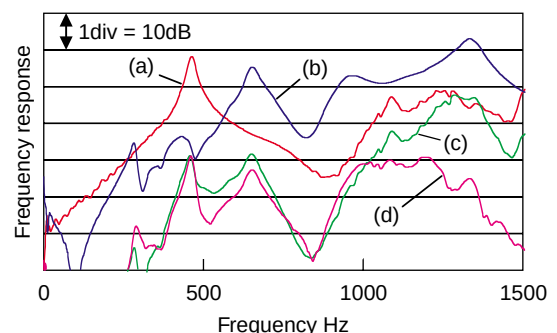


Fig. 4 Analysis of frequency response

In other words, the attenuation of the rubber has comparatively flat characteristics with respect to frequency, and the rubber stiffness is also sufficiently low compared to the metal fittings, so the metal fitting modes on the transmission and chassis sides are independent. Therefore, it can be assumed that only the load is transmitted between the metal fittings, which means that simple prediction of the total frequency response characteristics is possible by calculating and combining the frequency response characteristics (point inertance) of the discrete metal bracket and mount fittings.

2.3 Composite Inertance Calculation Results

Fig. 5 shows the results (hereafter “composite inertance”) obtained by calculating and combining the discrete bracket and metal fitting inertance for the three specifications described in Fig. 3 of section 2.1. Like sound, vibration and hammering-induced frequency response, the peak level relationship for composite inertance also showed the largest peak for the base specifications, with lower peaks for each of the countermeasure specifications. In addition, it was confirmed that gear noise also decreased when the calculated composite inertance was lower.

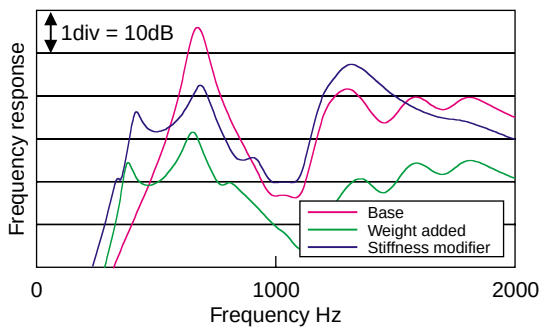


Fig. 5 Total frequency response function

2.4 Judgment Criteria for Composite Inertance Level

As described above, aggravation of gear noise can be predicted by the composite inertance level. Therefore, in actual development target levels can be established for each characteristic by considering the chassis acoustic characteristics, excitation source size and required performance based on the composite inertance level of the mounting systems for mass production models developed thus far.

3. Bracket Frequency Response Analysis

3.1 Difference in Results due to Boundary Conditions

When performing eigenvalue analysis and response analysis, calculations can be performed with sufficient accuracy as shown in Fig. 7 in the discrete free-state (unclamped and with no added objects) shown in Fig. 6.

However, in the mounted condition (joined to the case and chassis frame), the results vary widely according to the clamping conditions and other factors. Fig. 8 shows a



Fig. 6 Bracket model

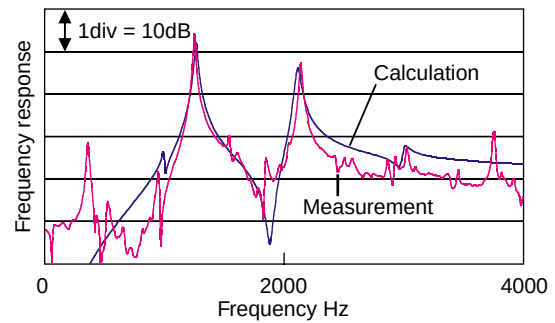


Fig. 7 Frequency response of bracket

Solver : CATIA FEM
Auto mesh : CATIA FEM
Mesh size : 5 mm ~ 10 mm
Damping ratio : 0.05

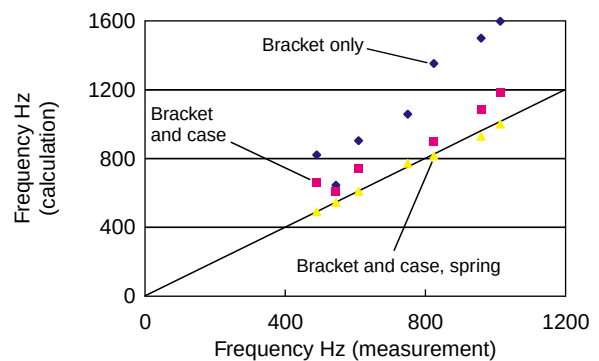
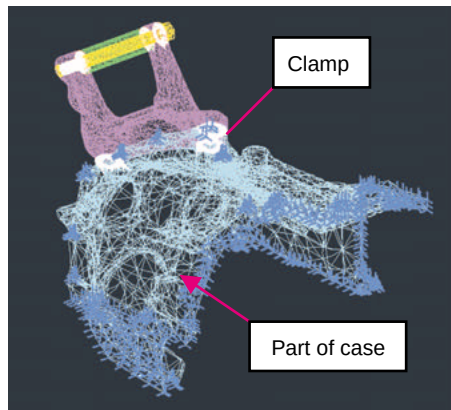


Fig. 8 Resonance frequency

comparison of the calculation results and the actual measured resonance frequency due to hammering excitation. This graph shows the values under three types of clamping conditions for each of the discrete bracket (mount clamping), bracket and case, and case and bracket coupled by spring element models.

These results show that the model consisting of only the metal bracket fitting does not match with the measured values, so the case and chassis frame must be modeled as shown in Fig. 9, or the joint must be modeled in order to obtain accurate results (error: 5% or less).

(1) Case and bracket



(2) Frame and mounting

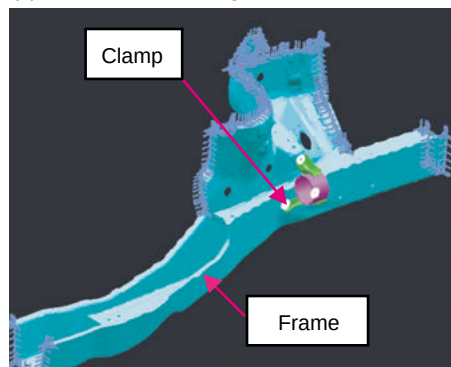


Fig. 9 FE model

that a thick plate and test piece were joined with contact elements and downward pressure was applied over the approximate area of the washer diameter. Fig. 11 shows the thickness of the clamped plate and the contact diameter. As shown in this figure, the plate deforms into a bowl shape and the contact area becomes smaller as the plate thickness decreases. Accordingly, these calculations showed that for a steel plate approximately 2 mm thick, even if the drawing shows a wide contact area, the range coupled by the spring elements is approximately the diameter of the clamping washer.

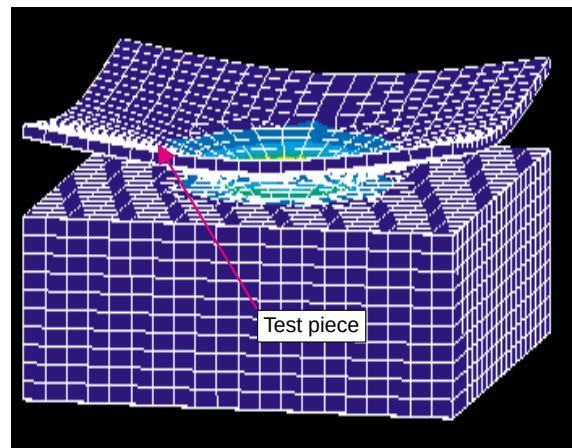


Fig. 10 FE model of contact analysis

3.2 Bolt Clamping Conditions

3.2.1 Spring Coupling Concept and Spring Constants

The mount and bracket fittings are bolted to the chassis frame and the transmission case. These types of joints are generally said to have lower stiffness than normal structures.⁽¹⁾

This study created a model assuming that springs equivalent to the bolt stiffness and clamping portion stiffness exist on the contact surface. The static stiffness k of the bolt clamping portion was assumed to be $k = k_t + k_c$, where k_t is the bolt spring constant and k_c is the clamped portion spring constant. Using an approximation formula⁽²⁾, k_t and k_c were calculated as approximately 10^5 to 10^6 N/mm (determined by the material characteristics and shapes of the bolt and clamping portion).

3.2.2 Differences due to Spring Coupling Range and Plate Thickness

When the contact surface of the bolt clamping portion is modeled using spring elements, the coupling range is also important. The actual contact surface area and the contact surface on the drawing may differ according to the clamping portion shape. Therefore, contact analysis was performed using finite element method (FEM) analysis using simple shapes, and the clamped portion thickness and clamped contact area were investigated. Fig. 10 shows the model used for the calculations.

The calculation analyzed the contact condition assuming

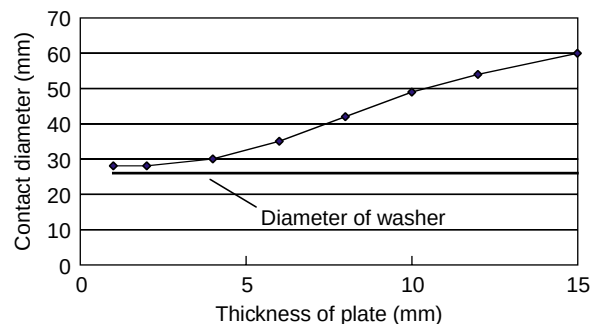


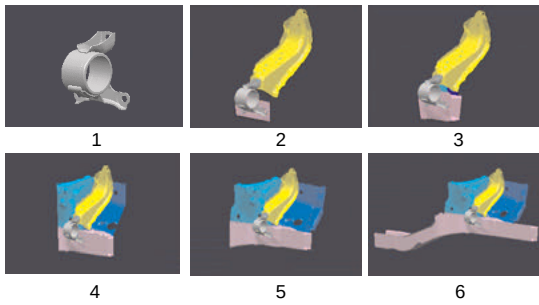
Fig. 11 Diameter of contact surface

3.3 Extent of Modeling

Fig. 12 shows the extent of modeling and a comparison of the calculated resonance frequency and the actual measurements for each model.

This figure shows that the calculation for the discrete metal fitting (model 1) produces a resonance frequency that is too high as mentioned previously, but that if even a small part of the chassis frame is modeled (model 2), the results approach the actual measurements. Thus, this study performed calculations for models 4 and higher in Fig. 12, which is thought to be a sufficient extent of modeling.

(1) Extent of FE model



(2) Comparison of resonance frequency

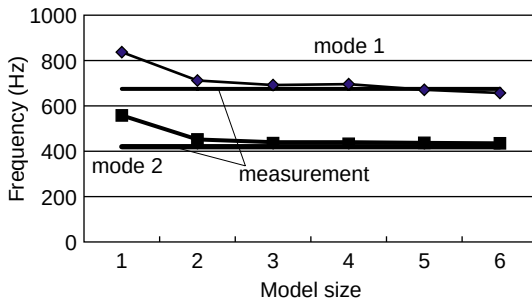
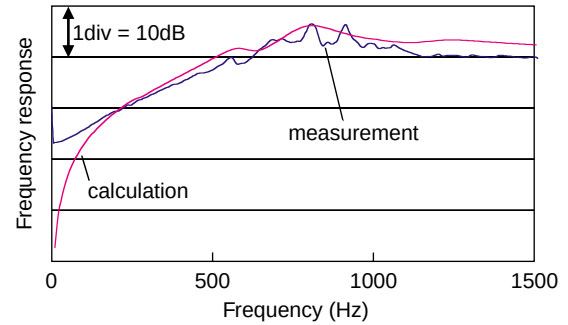


Fig. 12 Relationship of resonance and model size

(1) Example 1



(1) Example 2

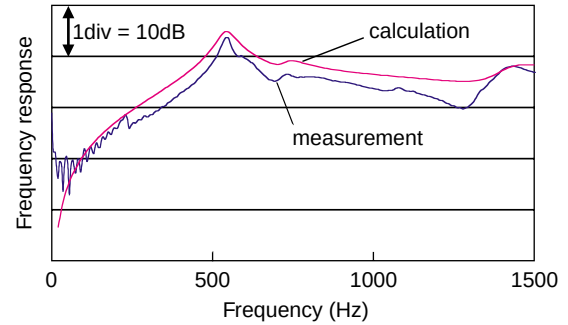


Fig. 13 Comparison between calculation and measurement for frequency response

3.4 Response Analysis Results

Fig. 13 shows an example comparison of the analysis results under the above conditions and actual measurements due to hammering. In addition, Fig. 14 shows an example of eigenvalue analysis results.

As shown in these figures, the calculated point inertance of the metal bracket and mount fittings matches closely with the hammering excitation test results using actual vehicles. Thus, a composite inertance such as shown in Fig. 5 can be accurately calculated using either of these results. In addition, it was confirmed that analysis can be performed in approximately one day by creating a mesh and calculating directly from the CATIA 3D model which is the product drawing. Therefore, the mount transfer characteristics can now be accurately predicted and optimized at an early timing.

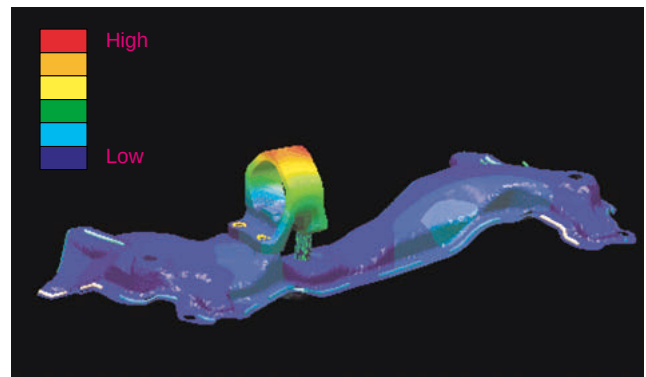


Fig. 14 Displacement of mounting at resonance frequency

4. Conclusion

This study yielded the following results.

- (1) Gear vibration transfer by the engine mounts can be simply evaluated by the composite value level of the response analysis results for the discrete metal bracket and mount fittings in the engine mounting system.
- (2) The necessary know-how was obtained to enable comparatively simple yet sufficiently accurate calculations (error: 5% or less) by creating models to the necessary extent and spring elements for the bolt clamping portions.
- (3) The traditional problem of gear noise peaks at certain speeds is mostly due to structural-borne noise transferred through the engine mounts and other elements as

described in this study. The transfer characteristics of each part can be predicted and development efficiency can be vastly improved in the future by using the prediction technique proposed in this study from the initial development stages.

CAE is progressing and we are approaching an environment where virtually anyone can perform FEM analysis. However, despite this it is surprisingly difficult to apply FEM analysis to real noise and vibration problems at actual development sites and achieve satisfactory results. The contents of this study may not be high level in terms of vibration science and calculation technology, but they are

reported as an example of an application which can contribute to reducing man-hours at development sites amidst the need to shorten development periods. It is the authors' hope that these results will prove a useful reference in improving development efficiency using simulations in the future.

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