

# Development of Prediction Method for Evaluation of Transmission Case Noise Radiation Characteristics

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## ABSTRACT

A method has been developed for predicting the sound radiation characteristics of transmission cases in order to reduce gear whine noise radiating from transmissions. Normal components of frequency response vectors on the transmission case surface calculated using an FE model of the case are used to predict sound radiation characteristics. To study the validity of the method, the correlation between sound pressure level, the level of vibration of the case surface during operation, and the predicted sound radiation characteristics was investigated. Results showed a good correlation between the figures and enabled equations of correlation between them that were unaffected by shape or type of transmission to be obtained, indicating that this method is sufficiently accurate for studying case specifications at the design stage.

This method enables the design of transmission cases fulfilling performance requirements for gear whine noise using only an FE -model of the case. The employment of the method in the development process commenced with the development of 2004 model year LIFE AT.

## 1. Introduction

Radiation noise from the transmission is dominant in the high frequency range of 1 kHz or more for gear whine noise inside the cabin. In this high frequency radiated noise range, there are occasions where the case surface vibration mode becomes an issue, and countermeasures such as adding ribs or increasing wall thickness have been implemented. On the other hand, studies have been made into the effect that weight reduction through the elimination of ribs or of reducing wall thickness has on radiated noise. In these cases, the method conventionally used to make predictive studies of case noise radiation characteristics was to build full models from inputs such as excitation force, internal structure, case, and acoustic fields, to outputs<sup>(1),(2)</sup>.

However, with radiation noise in the high frequency range, there are many peaks generated from case surface localized resonance modes. In these cases, it is believed that the effect of frequency response characteristics is the dominant factor in radiated noise level. In addition, if it were possible to make independent predictive evaluations of the case noise radiation characteristics, it would be possible to set the specification for the case by itself, effectively reducing the design study period.

Therefore, this development project aimed to establish a prediction method for evaluation of case noise radiation characteristics which allows designers to create the rib and shape layout necessary to achieve the performance requirements for gear whine noise using the case FE model at the design stage.

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Table 1 Size of FE -model

| Number of nodes | Number of elements |
|-----------------|--------------------|
| 544,571         | 301,433            |

※ Element type : Isotropic tetrahedral element with midside nodes.  
(consisting of 10 nodes for a element)

## 2. FE Model and Noise Radiation Characteristics Prediction

The transmission case FE model was created from the CATIA-3D model using the automatic meshing function. The mesh size index was set for mesh count per unit volume and for mesh quality according to the accuracy verification from the experimental modal analysis results. Figure 1 shows an example of the components of a transmission case assembly model, and Table 1 shows that model's size.

Concerning each component's connection surface boundary conditions, non-adaptive meshes were connected by interpolated elements. The optimal connecting conditions were established from verifications with experimental modal analysis results.

From the concept of meshing transmission error, the excitation force was set to be a frequency spectrum of fixed displacement against frequency, and was input to each case bearing support part according to the ratio of divided load against meshing reaction force. In addition, eigen mode analysis was carried out in advance. Then, to represent the eigen mode shape, the case surface was divided into very small radiation surfaces, and those representative points were established as the evaluation points. From the results of combining frequency responses by each excitation force, the vibration level along the normal vector direction of each evaluation point was determined, and these were taken as the values of noise radiation characteristics predictions.

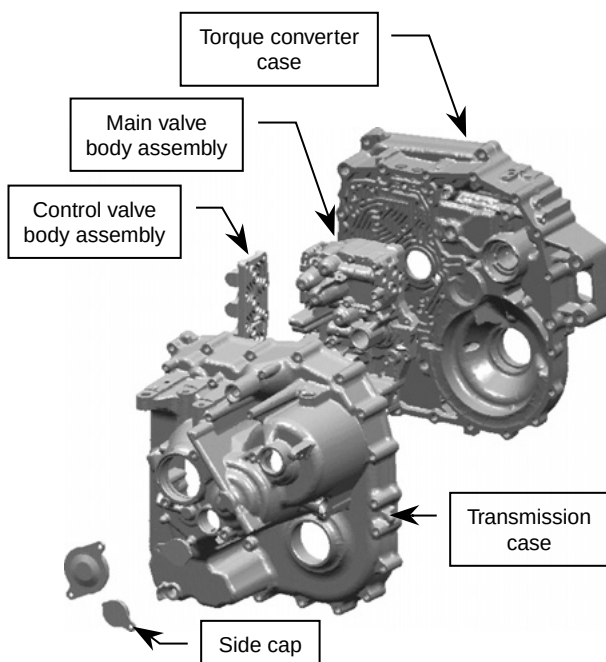


Fig. 1 Components of case model for analysis

## 3. Verifying the Correlation between Radiated Noise and Case Surface Vibration during Operation, and Noise Radiation Characteristics Predictions

In order to determine specifications at the design stage using noise radiation characteristics predictions, it is necessary to have a correlation between the noise radiation characteristics predictions and the radiated noise level during operation. In order to confirm that correlation, first, an analysis was made of the correlation between radiation noise and case surface vibration during operation. Figure 2 shows the results of correlation analysis of radiation noise peak values as measured on four types of transmissions and the maximum values of case surface normal vector direction vibration. Regardless of the type of transmission, it was confirmed that the correlation between radiation noise and case surface vibration could be expressed with a single equation of correlation for the peak values.

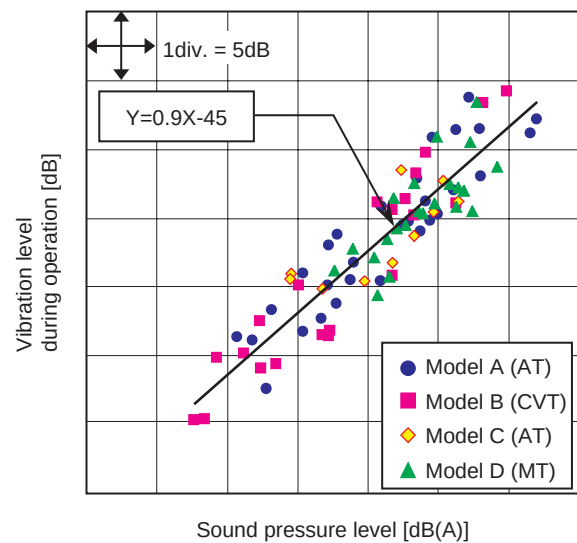


Fig. 2 Correlation between sound pressure level and vibration level

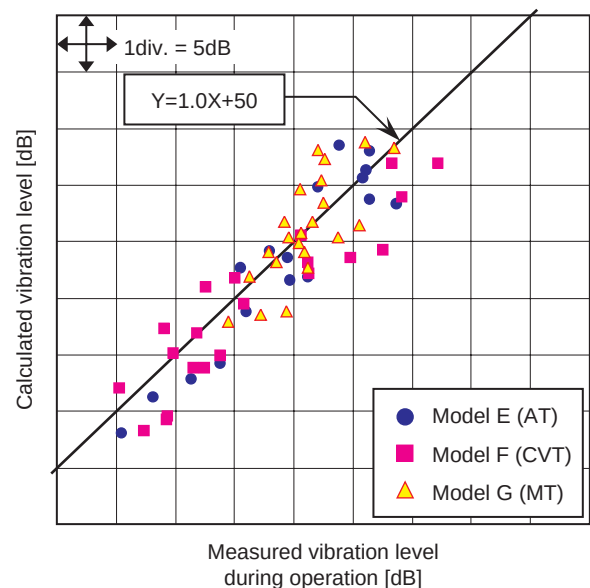


Fig. 3 Correlation of vibration level (measured vs. calculated)

Next, analysis was carried out to correlate case surface vibration during operation with noise radiation predictions for the case eigen mode that matched that vibration mode during operation. The values used in the correlation analysis were the maximum values in each mode, with the same evaluation points on the case surface. The results are given in Fig. 3. For three different types of transmissions, the correlation could be expressed with the same linear equation of correlation.

From the results above, the noise radiation characteristics predictions had sufficient linear correlation with the noise radiated during operation, with no effect from the transmission type. It can be used as an index to set specifications at the design stage.

#### 4. Establishing Target Values for Noise Radiation Characteristics Predictions

By applying the two equations of correlation shown in Figs. 2 and 3 to the previously set targets for measured radiation noise during operation, the target values for noise radiation characteristics predictions are established (Fig. 4). The target for measured noise radiated during operation can help establish the values incorporating the specification, such as completed vehicle quietness targets and gear whine noise frequency characteristics, etc. Therefore, the prediction targets of noise radiation characteristics, too, can incorporate required performance according to specification.

#### 5. Examples of Actual Applications

Figure 5 shows the results of applying this method to the 2004 model year LIFE AT case. The abscissa is indicating frequency, while the ordinate is indicating case vibration evaluation points, comparing each area. The color represents the level of difference

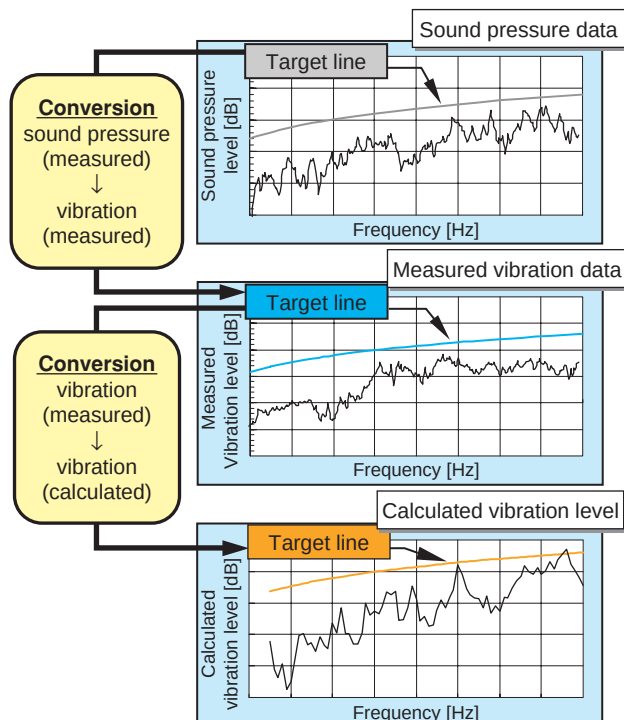


Fig. 4 Conversion of target line

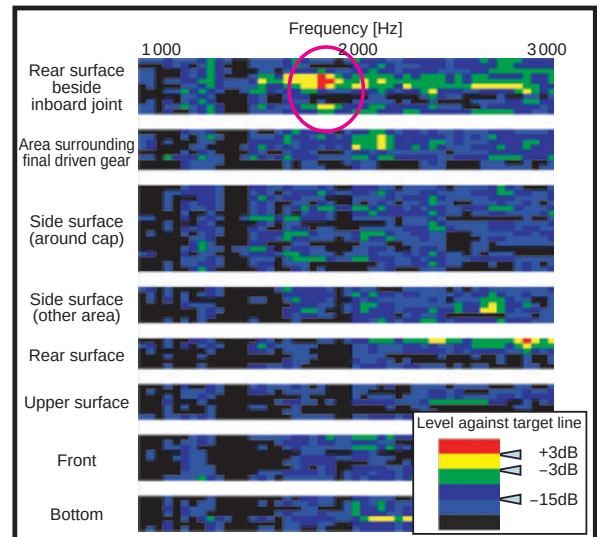


Fig. 5 Evaluation map for vibration level of original structure (calculated)

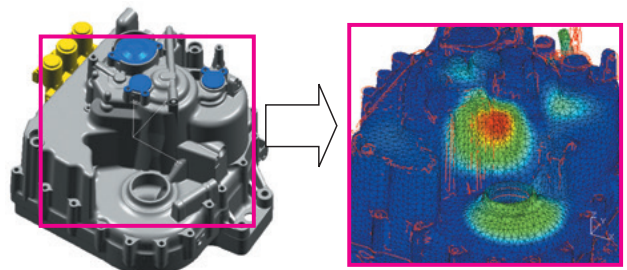


Fig. 6 Target mode shape

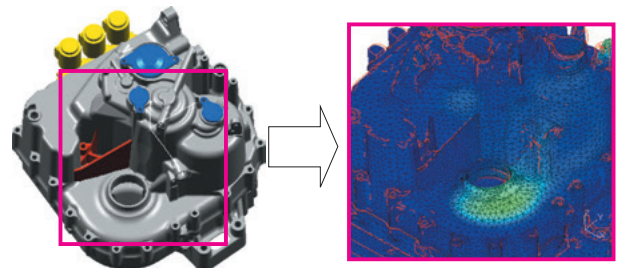


Fig. 7 Modified mode shape

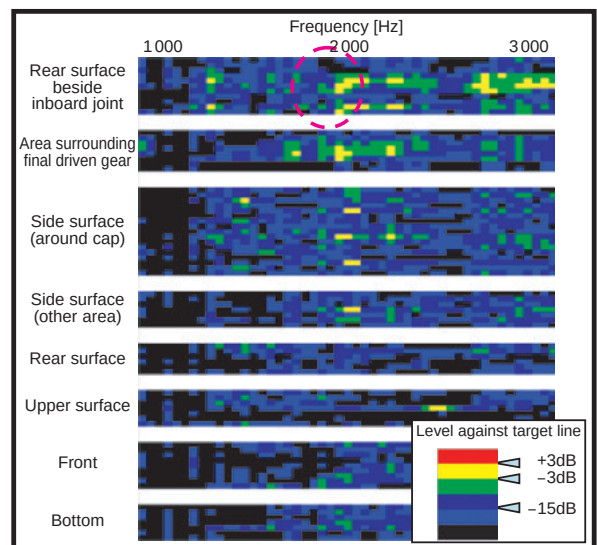


Fig. 8 Evaluation map for vibration level of modified structure (calculated)

from the judgment criteria of the noise radiation characteristics prediction. For this case, it was detected that there is an area of the case rear surface across the drive shaft inboard joint that exceeds the reference value in the range from 1 900 to 2 000 Hz, so countermeasures were studied for that area. Figure 6 shows the vibration mode subject to countermeasures.

Using this method, one or two models of countermeasures using additional parts, such as ribs, can be analyzed in a single day. Additional weight and reductions in radiation noise for a variety of countermeasure configurations were compared and studied. Figure 7 shows the configuration adopted and its vibration mode. The mode subject to countermeasures is clearly shown to be suppressed extremely well. In addition, Fig. 8 shows the results of that noise radiation characteristics predictive evaluation. The countermeasure specification has a 6 dB reduction effect in the subject mode, with a weight increase of 150 g. No increasing in other modes is expected. Figure 9 shows the results as confirmed through incorporation of this specification in an actual transmission. In the actual transmission, there was a radiation noise reduction of 6 to 8 dB, confirming its correspondence to predicted noise radiation characteristics.

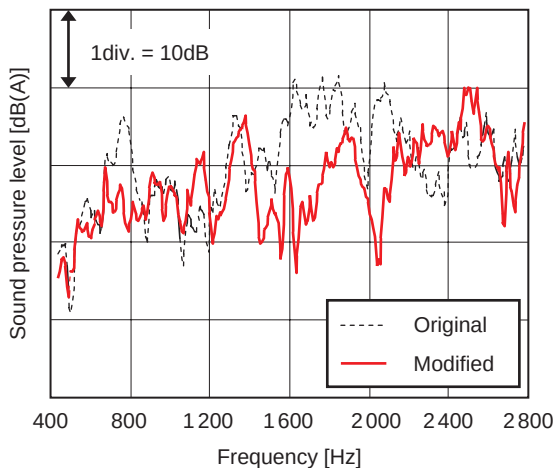


Fig. 9 Comparison of sound pressure level (original vs. modified structure)

## 6. Conclusion

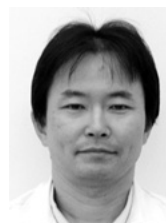
In order to reduce gear whine noise in the high frequency range, studies were made of a method to predict and evaluate transmission noise radiation characteristics. The following results were achieved.

- (1) This method uses normal vector direction components of case surface vibration as determined from case FE model frequency response characteristics. It was confirmed that regardless of the type of transmission, the values of noise radiation characteristics predictions have good linear correlation with radiated noise levels during operation.
- (2) By using the equation of correlation obtained from the results above, it is possible to convert the radiation noise targets during operation into the prediction targets of case noise radiation characteristics. This makes it possible to have case specification design incorporating quality required concerning gear whine noise, for the case by itself.
- (3) This method was applied in the development of the 2004 model year LIFE AT, and its effectiveness proved.

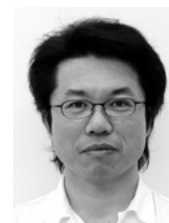
## References

- (1) Sumi, K., Yamamoto, K., Gielen, L.: Development of Hybrid Model for Powerplant Vibration, SAE 1999-01-1656 (1999)
- (2) Kano, M., Hajika, T.: Useful Method to Calculate the Radiation Noise of Transmission, 2004 JSAE Annual Congress Proceedings No. 66-03, 20035523

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