Analysis Technologies for Noise and Vibration of EV Motor

Taikai Mise

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Abstract

There is a growing global interest in environmental protection. In the automotive industry, electrification like pure Electric Vehicles (EVs) and hybrid EVs is in progress. A vital issue for these electrified vehicles is vibration and noise. So far, we have taken measures against noise[1] from the motor by analysis. In this case, however, extensive knowledge and experience are required to set parameters. It was necessary for a full-time person selected from experts to combine high-accuracy measurement and a time-consuming model. As a method of not requiring such a full-time dedicated person to perform the matching, we introduced a measurement evaluation method, an optimization method, and a noise analysis method. In doing so, we realized the reduction of the motor noise and a shorter development period.

1 Preface

For the verification of the structure design, we adopted the Finite Element Method (FEM) to conduct vibration and noise analysis by using an electromagnetic force as the vibrating force. While vibration analysis was carried out, some issues arose during the work[2] to make adjustments according to the result of the experimental mode analysis by changing the analytical parameter of the stator core. The issues were as follows:

(1) Due to the lack of consideration of the accelerometer positioning arrangement, the structure was not able to hold the accelerometer. We could not fully grasp the natural vibration mode of the structure. As a result, the analytical accuracy was compromised.

(2) The search for the optimal value of analytical parameters took time which delayed verification.

(3) Due to the lack of professional experience and expertise and experience for factor analysis, adequate measures could not be taken.

In order to solve these issues, we adopted a method to determine an adequate accelerometer positioning layout, a method to short-cut the searching time for the analytical parameter, and a method to identify a noise generating point by organizing the analytical results. This paper introduces these methods.

2 Acquisition of an Accurate Measurement Method

To extract a natural vibration mode attributable to motor noise and acquire quality data, it is essential to consider adequate positioning layout of an appropriate number of accelerometers. The contents of this process are described below.

Fig. 1 shows the vibration modes of the stator core. Although the stator core is an important structure in determining the magnetizing direction, the evaluation on accelerometer positioning layout had been qualitative with regard to the bending vibration[1] (n = 2, 3, 4, ···). XXn means the node diameter number is the natural vibration mode. We since have come to a method to make quantitative evaluation on positioning layout.

Fig. 2 shows an accelerometer positioning layout of the stator core FEM. Accelerometers (blue

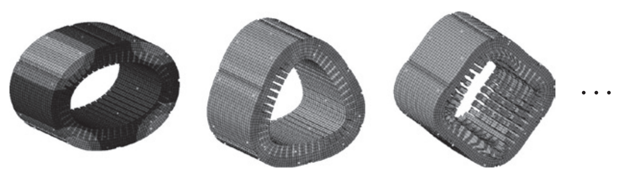


Fig. 1 Vibration Modes of Stator Core

A part of the vibration modes of the stator core when measured in accelerometer positions determined by a pretest is shown.

points) are mounted on the FEM model. Since we reached a method to make quantitative evaluation on positioning layout, the below explains this point.

Fig. 3 shows the evaluation matrix for the accelerometer positioning layout. The axes of abscissas and ordinates of matrix are used to align the natural modes of the eigenvalue analysis results from the analysis. The matrix inside is given by the MAC value[(2)] (modal assurance criterion) of an expression corresponding to the natural vibration mode of the stator core. If two eigenvectors in the matrix completely coincide with each other, such state is indicated by 1 (shown in red). If two eigenvectors cross each other, then such a state is indicated by 0 (shown in blue). If there are many greens and yellows close to red in (a), such an accelerometer positioning layout indicates an insufficient separation between neighboring natural vibration modes. In other words, if the accelerometer positioning layout is properly adjusted, yellows and greens in (b) decrease, which means highly accurate measurements can be made.

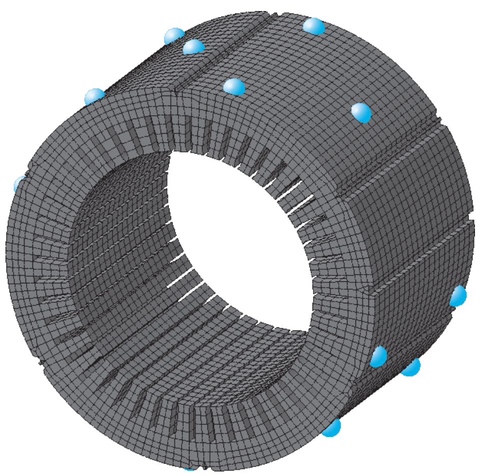


Fig. 2 **Accelerometer Positioning Layout of the Stator Core FEM**

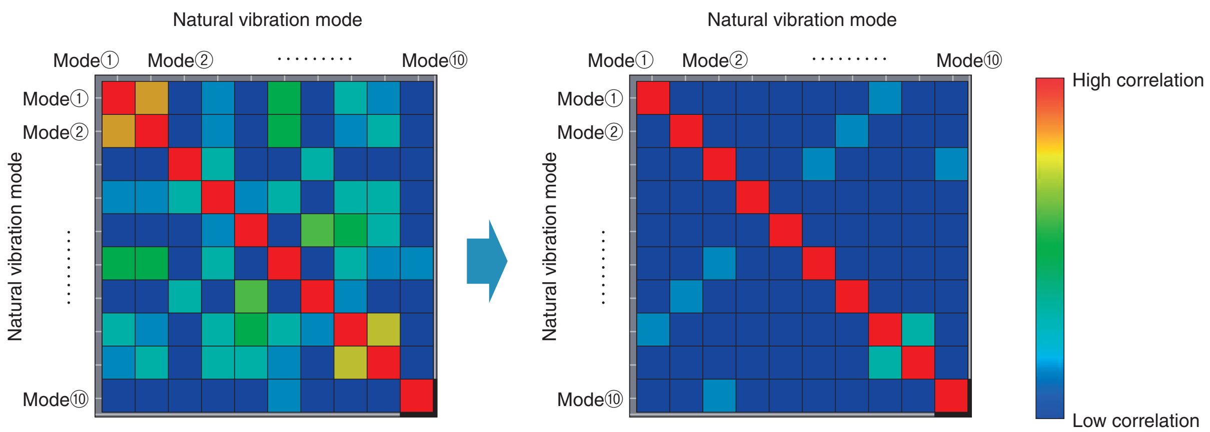
Blue points on the FEM show accelerometer positions during the measurement.

3 Acquisition of Efficient Search Method for Analytical Parameters

When matching the analytical models, it is necessary to adjust the analysis parameter values when automation is made by using a general-purpose optimization software for the analytical parameter adjustment. If there is a sizable gap between initial parameter values and optimal target values, a considerably long time to search the analytical parameters is required. As a result, we adopted a method described below to substantially reduce the time required for searching analytical parameters.

3.1 Selection of Analytical Parameters by Experimental Design Method

There are more than 50 analytical parameters for the stator core. As such, it is a large combination and is time consuming when all the parameters are targets of matching. Accordingly, we adopted the Design Of Experiment (DOE) method to compute analytical parameter sensitivity and selected highly sensitive parameters. Among the analytical parameters, we selected highly sensitive parameters against the (1) natural frequency of the eigenvalue



(a) Initial position (before improvement)

(b) Position after adjustments (after improvement)

Fig. 3 **Evaluation Matrix for Accelerometer Positioning Layout**

The result of an evaluation is shown by (a) initial positions of accelerometers and (b) accelerometer positions after the layout adjustment.

Table 1 Relationship between Analytical Parameters and the Result of Eigenvalue Analysis

The relationship between analytical parameters (longitudinal elastic modulus, transverse elastic modulus, and Poisson's ratio) after execution of DOE and the result of eigenvalue analysis (frequency, MAC) is shown.

	Frequency 1	Frequency 2	MAC1	MAC2
Longitudinal elastic modulus 1	0.01	0.01	0.2	0.3
Longitudinal elastic modulus 2	0.4	0.3	0.7	0.8
Transverse elastic modulus 1	0.3	0.2	0.2	0.2
Transverse elastic modulus 2	0.01	0.01	0.25	0.2
Poisson's ratio 1	0.01	0.8	0	0
Poisson's ratio 2	0	0.01	0	0

analysis result and the (2) natural vibration modes.

Table 1 shows a relationship between analytical parameters and the result of eigenvalue analysis. In case an analytical parameter shows a high sensitivity in the result of eigenvalue analysis, such data is highlighted in blue. In other non-highlighted cases, low sensitivity is indicated. Among many analytical parameters for the stator core, we selected highly sensitive parameters as targets of matching.

By applying adjustments to the selected analytical parameters, we determined the values of the initial parameters getting closer to the optimized parameter values. By this method, the time consumed for a wide-area search by general-purpose software was reduced by 2/3.

3.2 Optimization Method by General-Purpose Software

After initial parameters are selected by this above-mentioned method, the parameter matching process is then carried out by using the optimization method of general-purpose software. Table 2 shows the MAC values and frequency differences between the analysis and measurement. Since the MAC values are above 0.7 and the frequency difference is within 5%, these figures show that accurate analytical parameters were acquired. Fig. 4 shows the FEM analysis results and the response acceleration of the measurement results. We compared the result of FEM analysis and a transfer function of measurement. The result shows the peak position of the natural vibration frequency was reproduced.

Table 2 MAC Values and Frequency Differences between Analysis and Measurement

Based on the result of the eigenvalue analysis with analytical parameters for model adjustment, the table shows the difference in MAC values and frequencies between analysis and measurement.

Vibration mode	MAC value	Frequency difference (%)
1	0.98	0
2	0.98	−1.6
3	0.85	−0.3
4	0.72	−0.6

※The MAC value by vibration is defined as unity (1) in the case of complete coincidence.

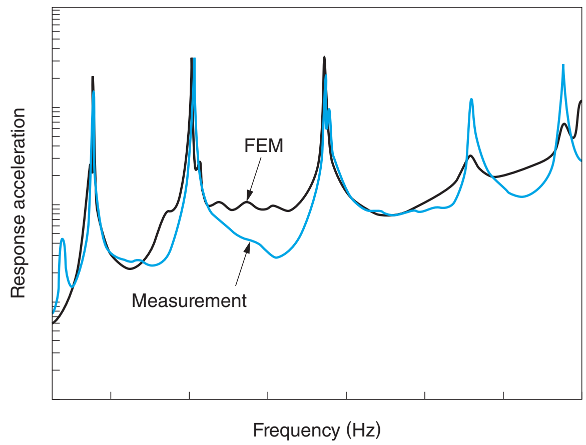


Fig. 4 FEM Analysis Results and Response Acceleration of the of Measurement Results

The graph shows the result of the comparison of transfer function between FEM analysis and measurement.

4 Acquisition of a Method to Identify Noise-Generating Points

In order to take countermeasures against malfunction relating to noise, it is necessary to identify noise generating points. For this purpose, contribution analysis was carried out. Contribution analysis here refers to a method where noise level of each component of the motor is calculated and analyzed in the same graph.

Fig. 5 shows the graph of noises from the entire motor and its components. It shows the relationship between frequency and noise level. We compared the noises between the entire motor and each part (Parts 1, 2, 3). In doing so, we identified noise generating parts and their frequencies.

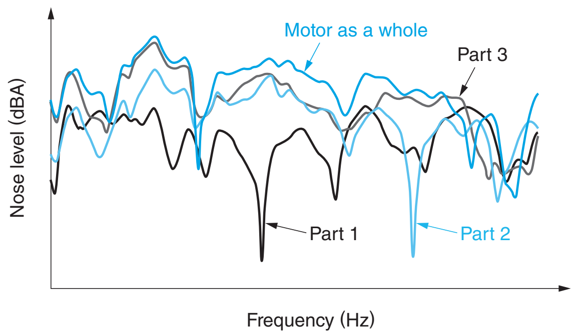


Fig. 5 **Graph of Noises from the Entire Motor and its Components**

The relationship between frequency and noise level of the motor as a whole and its respective parts is shown.

5 Postscript

For our EV motors, we realized acoustic analysis with accuracy by increasing the accuracy level of the analytical models. Through efficient acquisition of analytical parameters, we substantially reduced the analysis time. By increasing the speed and simplifying the analysis, we will apply such acoustic analysis into the upstream stage of our design.

《**References**》

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