DOI: 10.61782/fa.2023.0691

forum acusticum 2023

Numerical Simulation for Durability Evaluation of Bearing Brackets of Electric Vehicles considering the Driving Environments

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ABSTRACT

Electric vehicles have differences in dynamic properties, vibration characteristics compared to engine vehicles. For this reason, the test criteria of dynamic environment of an electric vehicle must be determined differently from an engine vehicle. The bearing bracket supporting the driving shaft is an important device for transmitting power to the wheels. This study modeled the structural behavior of the bearing bracket applied on base excitation considering the driving environments and predicted its structural durability. A numerical model based on the finite element method was simulated to perform the modal analysis. The predicted mode shapes and modal frequencies that affect the decreased durability were investigated. The transfer function was calculated by using effective mode vectors. To simulate the actual driving environments, the displacement signal of electric vehicle was measured and set as the boundary condition of base excitation. Explicit time analysis was performed to calculate time signal of dynamic loads during driving test. And, the durability life of bearing bracket was predicted by using the cumulative damage law through the numerical results of dynamic loads. The proposed methodology of durability life prediction can be utilized to design a mounting structure of an electric vehicle device and evaluate its dynamic stability.

Keywords: *Durability life, Finite element method, Bearing bracket, Electric vehicle*

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1. INTRODUCTION

The driving shaft of an electric vehicle is an important device that transmits the driving force from the driving part of a vehicle to the wheels. For the power of the electric motor to be transmitted to the wheels, the designs of the driving system and bearing bracket for mounting the shaft are essential. For a successful dynamic environmental test, vibration durability should be analyzed during component development. This study developed a numerical model for predicting the durability of a driving shaft system, and the mode shape and dynamic stiffness of the bearing bracket were investigated. A single unit test of the bearing bracket was performed to verify the accuracy of the numerical analysis model. Finally, the durability of the bearing bracket was predicted using the vibration measurement data of the electric vehicle.

2. DYNAMIC CHARACTERISTIC ANALYSIS

A numerical simulation based on the finite element method was performed for the vibration analysis of an inner shaft system. The finite element equation is expressed as

$$\begin{bmatrix} \mathbf{M}_{00} & \mathbf{M}_{01} & \mathbf{M}_{02} \\ \mathbf{0} & \mathbf{0} & \mathbf{0} \\ \mathbf{0} & \mathbf{0} & \mathbf{0} \end{bmatrix} \begin{Bmatrix} \ddot{\mathbf{d}}_0 \\ \ddot{\mathbf{d}}_1 \\ \ddot{\mathbf{d}}_2 \end{Bmatrix} + \begin{bmatrix} \mathbf{K}_{00} & \mathbf{K}_{01} & \mathbf{K}_{02} \\ \mathbf{0} & \mathbf{I}_{11} & \mathbf{0} \\ \mathbf{0} & \mathbf{0} & \mathbf{I}_{22} \end{bmatrix} \begin{Bmatrix} \mathbf{d}_0 \\ \mathbf{d}_1 \\ \mathbf{d}_2 \end{Bmatrix} = \begin{Bmatrix} \mathbf{0} \\ \mathbf{u}_1 \\ \mathbf{u}_2 \end{Bmatrix}, \quad (1)$$

where $\mathbf{d}_0$, $\mathbf{d}_1$ and $\mathbf{d}_2$ are the displacement matrix of the driving shaft system, electric motor and speed reducer, respectively; $\mathbf{M}$ and $\mathbf{K}$ are the global mass and stiffness matrices of the driving shaft, respectively; $\mathbf{I}$ is the identity matrix; and $\mathbf{u}_1$ and $\mathbf{u}_2$ are the measured displacement signals of the electric motor and speed reducer, respectively. The mode shape and modal frequencies were calculated using the global mass and stiffness matrices to investigate the dynamic stiffness of the bearing bracket. Torsional and bending modes of the bearing bracket with a large displacement of the bearing bracket were estimated as shown in Figure 2. For a simple harmonic analysis, the displacement and force matrices were assumed to be frequency response terms. The finite element equation in the frequency domain was obtained using equation (1) to calculate the dynamic stiffness of the bearing bracket of the driving shaft. An experimental test was performed to verify the numerical dynamic stiffness and modal frequencies.

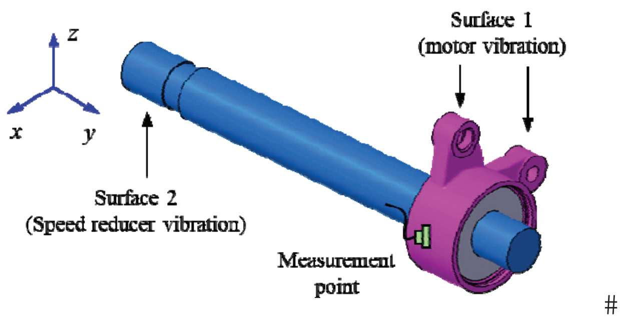

Figure 1. Schematics of the driving shaft system considering driving environments

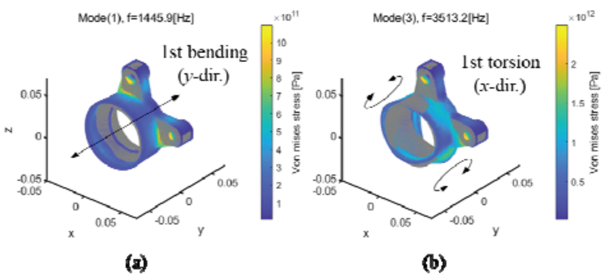

Figure 2. Numerical results of modal analysis of bearing bracket for driving shaft: (a) 1st bending mode, (b) 1st torsional mode.

3. DURABILITY EVALUATION

A time analysis for the total driving shaft system was performed using the modal shape and frequencies of the bearing bracket to predict the durability evaluation of the driving shaft. The measured displacement signal of the electric vehicle was used to model the dynamic environments as shown in Figure 3. Explicit direct integration of equation (1) was performed when calculating the stress time history on the bearing bracket as shown in Figure 4. Miner's rule was applied to the predicted stress data using a finite element model to calculate the damage index of the bearing bracket. Miner's rule is expressed as follows:

$$D = \sum \frac{n_i}{N_i}, \qquad (2)$$

where D is the damage fraction of life consumed by exposure to the cycles at varying stress levels. Generally, structural failure occurs when the damage fraction reaches 1. In addition, n_i is the number of cycles at stress level i and N_i is the fatigue life cycle at stress level i. To predict the durability life of the bearing bracket for 10,000 h in a dynamic environment, we calculated the damage fraction of bearing bracket under three times of input vibrations using the SN curve. The damage fractions of bearing bracket subjected to vibration in all directions are predicted to be less than 1 as shown in Table 1. Based on the simulation results of the finite element model for the driving shaft system, it is predicted that the bearing bracket of the driving shaft will remain structurally safe against road vibration. Also, the bending and torsional modes of the bearing bracket are important factors determining the structural durability life.

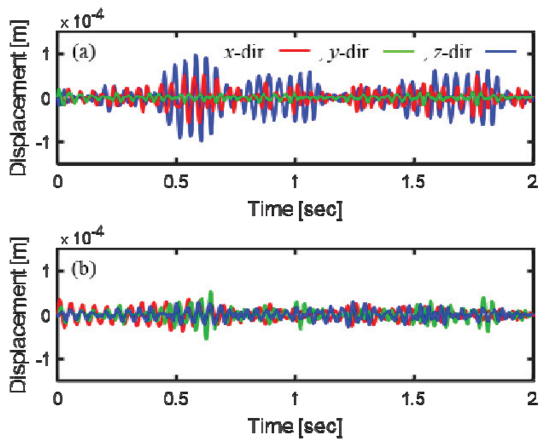

Figure 3. Displacement time signals of electric vehicle: (a) motor, (b) speed reducer

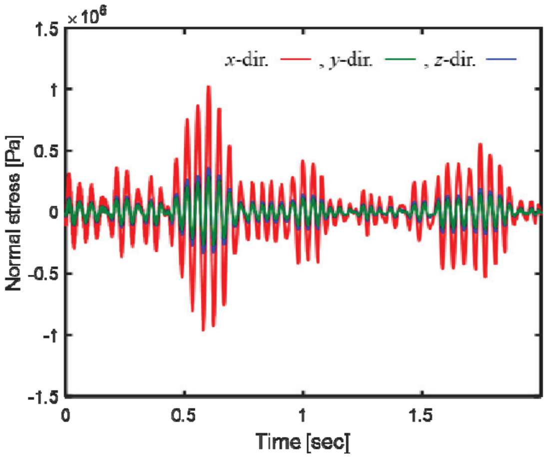

Figure 4. Predicted normal stress time history of bearing brackets for electric vehicle

Table 1. Predicted damage fraction of bearing bracket subjected to road excitation

Direction of axis	Damage fraction
x-dir.	0.214
y-dir.	0.002
z-dir.	0.121

4. CONCLUSION

This research developed a durability evaluation for verifying a driving shaft system applied to a dynamic environment caused by road vibration. Using a finite element model of the driving shaft system, we predicted the displacement responses to base excitation and verified its dynamic characteristics based on the experimental results. The displacement responses of the bearing bracket at the modal frequencies of torsional and bending vibrations were estimated to be large and their mode shapes were important factors for determining the durability life. The time responses while driving were calculated using the explicit direct integration method to evaluate the structural durability. As a result of applying the cumulative damage law under dynamic environments of 10,000 h, the bearing bracket of the driving shaft system was predicted to be safe. This numerical methodology can be used to predict the durability and fatigue life of vehicle part devices in harsh dynamic environments.

5. ACKNOWLEDGMENTS

Following are results of a study on the "Leaders in INdustry-university Cooperation 3.0" Project, supported by the Ministry of Education and National Research Foundation of Korea.

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