Vibration Fatigue Analysis of Interface Enclosure with Cantilever Structure for Charging Commercial Electric Vehicles

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Abstract. The interface enclosure for charging commercial electric vehicle (CEV), which is an alternative to the fuel filler of internal combustion engine vehicle, was studied. It supplies the power and the communication signal for charging between the power supply (EVSE) and the battery. It should be long to match the exterior of the vehicle for easy charging, and it requires space between the vehicle frame and the enclosure to connect the charging cable. In order to design the interface enclosure with the cantilever structure which is vulnerable to vibration, analysis-based design through vibration fatigue analysis was conducted, and the reliability of analysis results was reviewed through experiments.

1. Introduction

Recently, the need for zero emission vehicles (ZEVs) is increasing due to the strengthening of greenhouse gas (GHG) regulations and the seriousness of particulate matter (PM). In particular, carbon dioxide emissions of trucks, which account for most road freight transport, have more 2.5 times than ones of passenger cars. Therefore, it is essential to develop the commercial electric vehicle (CEV). As the battery price, which has burdened the vehicle price, continues to decline, commercial electric vehicles are being developed mainly for vans, buses, and logistics service vehicles that do not have long distances per day. The electric vehicle supply equipment (EVSE) monitors the charging environment through communication (PLC or CAN) with the battery electric vehicle (BEV) and provides power to charge the battery through charging inlet. When converting an internal combustion vehicle (ICV) to an electric vehicle (EV), passenger cars and commercial vehicles of 1 ton or fewer install the charging inlet to the vehicle frame. However, medium and heavy trucks require additional parts to mount the charging inlet to the understructure frame. As the demand for electric vehicles increases, the need for high-capacity and rapid charging is increasing. Structural stability of the enclosure to protect the charging circuit from the harsh road driving environment is becoming more important for high voltage charging. In this paper, the interface enclosure that is installed to the lower frame of a commercial electric vehicle for protecting the inlet circuit was studied. It is designed to stably protect the circuit inside the enclosure...
by various vibrations generated while driving the vehicle. Vibration fatigue analysis, which performs durability analysis in the frequency domain, was used to secure sufficient mechanical stability of the interface enclosure with the cantilever structure, which is vulnerable to vibration. The reliability of the analysis results was verified through the resonance-point search test, the experimental stress analysis, and the random vibration test.

2. Results and Discussion

2.1. Vibration fatigue analysis

Random vibration in mechanical engineering means that future behavior cannot be accurately predicted with non-deterministic motion. Vibrations generated by vehicles on the road, rocket launches, and airplane wings during turbulence are not repetitive and unpredictable [1,2]. The data acquired through the accelerometer is difficult to predict and not repeatable. Therefore, a random vibration test is needed to reflect the reality. Structural responses to random vibrations are generally handled using statistical or probabilistic approaches. Random vibration is more realistic than sinusoidal vibration because it excites not only the resonant frequency but also all frequencies at the same time. FFT is excellent for analyzing vibrations when there is a finite number of dominant frequency components, whereas power spectral density (PSD) is used to characterize arbitrary vibration signals [3]. The random vibration analysis uses the modal superposition technique as the basis for the harmonic response. It is scaled and combined to the input power spectral density to obtain the dynamic response and the equivalent PSD projected onto the critical plane [4]. The vibration exciter applies random accelerations over a bandwidth of approximately 20 to 2000 Hz [5]. Most signals have a bell-shaped, symmetrical probability density function(PDF). Gaussian signal has 3 kurtosis with a probability of 99.73% at 3\( \sigma \). The vibration fatigue analysis is estimated through the process shown in figure 1.

![Figure 1. Vibration fatigue analysis process](image)

2.2. Modal analysis

Natural frequencies and mode shapes are important parameters that characterize the dynamic responses of test parts during vibration test [6]. The model of interface enclosure for modal analysis as shown in figure 2 was simplified. It was set to match weight of the actual enclosure using a distributed mass. In addition, simulation conditions for bolt connection were implemented by using point mass. It was analyzed up to 10th mode using the pre-stress condition. To verify the result of the modal analysis, it
was compared with the resonance-point search test of figure 3. Table 1 shows the simulation results and vibration test results. The 1st mode shape in the X-axis direction was predicted at 44 Hz, and the fundamental natural frequency measured by the resonance-point search test was 42 Hz. Analysis results were similar to vibration test results.

Table 1. compare modal analysis with resonance-point search test

|                | Modal analysis | Resonance-point search test |
|----------------|----------------|-----------------------------|
| **x-axis**     |                |                             |
| (Fr-Rr)        | 1st mode 44.0Hz | 42.56Hz, 16.9G/G            |
| **y-axis**     |                |                             |
| (Rh-Lh)        | 2nd mode 61.1Hz | 56.4Hz, 10.3G/G             |
| **z-axis**     |                |                             |
| (vertical)     | not present within 100Hz | 100.3Hz, 9.9G/G           |

2.3. Random vibration analysis

The purpose of random vibration analysis is to determine the response of a structure to a random vibration load. The frequency of the time history is captured along with statistics and used as a load in random vibration analysis. For historical reasons, this spectrum is referred to as the power spectral density. The load profile of input in the x-axis (front-rear direction of the vehicle), y-axis (left-right direction of the vehicle), and z-axis (up-down direction of the vehicle) was power spectral density. A
solution of modal analysis is coupled with the initial conditions for random vibration analysis. The simulation results were evaluated at the 3 sigma level, and were compared with results acquired by attaching a Rosette strain gauge to the surface of the charging interface enclosure. As shown in figure 4, the signals of strain gauge were combined for the three axes, and the stress were converted. The results of experimental stress test were compared with the results of random vibration analysis. Test results were similar to simulation results. Based on the results of random vibration analysis, a vibration fatigue test was conducted. Each axis was excited for 35 hours and the cracks were checked. If there was no crack in all axes, an additional vibration test was conducted on the z-axis for 35 hours. Changes in the vibration profile were examined, such as increase in amplitude or shift of resonance frequency, etc. It was confirmed that the vibration profile was not changed during test as shown in figure 5, and bolts were not loosed.

![Figure 4. Compare strain gauge test with random vibration analysis](image)

![Figure 5. Vibration profile according to additional Z-axis excitation in vibration fatigue test](image)
3. Conclusions

Interface enclosure was designed for charging commercial electric vehicles. It has a cantilever structure due to design constraints. It was designed to have sufficient vibration durability through vibration fatigue analysis, and the reliability of analysis results was reviewed through the resonance-point search test, the experimental stress analysis, and the random vibration test.

1. Considering the PSD data of random vibration, the fundamental natural frequency of enclosure should be designed higher than 40Hz to avoid severe resonance. Through modal analysis, the enclosure was designed so that the first mode shape occurred above 40Hz. As a result of the analysis, the first mode shape occurred at 44 Hz. The fundamental natural frequency of 42 Hz was confirmed in the resonance-point search test.

2. Random vibration analysis was performed for the fatigue analysis of structures caused by external excitation. Since the time history deviating from ±3σ is probabilistically within 0.3%, the equivalent stress was estimated using the ±3σ scale factor. In order to evaluate the results of the vibration fatigue analysis, an experimental stress analysis was performed using a strain gauge. It was confirmed that the analysis result reflects the measured stress result well.

3. A charging interface enclosure with cantilever structure was designed through analysis-based design. As a result of the random vibration test, there was no damage to the interface enclosure and no loosening of bolts was found. Reliability was verified by comparing analytical and experimental techniques. It is expected that reliable design can be secured by applying the vibration fatigue analysis when design changed in the future.

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References
[1] Hu J 1995 J. Ind. Electron. Soc. 38 34-40
[2] Li R S 1999 J. Electron. Packag. 123 394-400
[3] Lin J S and Yim K S 2000 Application of random vibration test methods for automotive subsystems using power spectral density (PSD) SAE Tech. Pap. 2000-01-1331
[4] Teixeira G M, Jones D and Draper J 2014 Random vibration fatigue-A study comparing time domain and frequency domain approaches for automotive applications SAE Tech. Pap. 2014-01-0923
[5] Lambert R G 1976 Shock Vib. Bull. 46 55-72
[6] Yu D, Al-Yafawi A, Park S and Chung S 2010 Proc. 60th Electron. Comp. Techn. Conf. (ECTC): IEEE 188-193