Vehicle High-speed Drive Motor Vibration Fixture  
Design and Simulation Analysis  

Yu-cheng FU, Zhi-tao CAI, Bin WANG, Xin HUANG and Shan REN  
China Automobile Technology and Research Center  

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Abstract. The new energy vehicle drive motor has a trend of high rotating speed. The vibration test of high speed motor has a close influence on NVH performance, so the vibration fixture design of high speed and high torque motor is very important. Taking the drive motor vibration fixture of electric vehicle as the main object of study, and analyzing the dynamic characteristics of vibration fixture. The vibration fixture is modelled by computer aided design, three-dimensional modeling. According to the mode of the test fixture on the vibration table, the finite element analysis was used for modal analysis of the fixture. Optimizing the structure design, and improving the first natural frequency of vibration fixture. Finally, get a vibration fixture structure with natural frequency far away from the frequency of excitation signal to ensure the drive motor vibration test smoothly. The problem of sample failure and damage caused by resonance is solved.

Introduction  

In recent years, under the strong policy support of the new energy vehicle industry, the electric vehicle industry has been developing rapidly with the MIIT issued to passenger cars the average fuel consumption down to 5.0 L/100 km in 2020. The domestic automaker companies focus on this market, its electric car sales also has a higher market share gradually, such as BAIC EV series and BYD e6 and QIN has gradually into ordinary consumers families. In the meantime, foreign auto companies have also stepped up the domestic distribution of electric vehicles and hybrid vehicles, and its many models have come to China to seize the market share, such as TOYOTA corolla hybrid, BMW i3 and GM volt. As one of the three core components of electric vehicles, the importance of driving motor is undoubtedly obvious. The electric vehicles, especially hybrid vehicles, the motor is installed in a limited and narrow space. The work environment is quite harsh, such as strong vibration, impact, dust, high temperature and high humidity compared with traditional industrial motor. Therefore, the vibration test of the drive motor as one of the important contents to evaluate the motor system, which is of great significance to the study of electric vehicle NVH performance and the comprehensive performance of the vehicle.

Electric and hybrid vehicle motor will be affected by certain vibration during the use process. Therefore, the random vibration test of motor will be carried out to verify the environmental adaptability of the product after the design and production of motor structure. If the random vibration test proves that it cannot meet the requirements of environmental adaptability. In that way, the secondary design and production of the product structure shall be carried out. A lot of manpower and material resources are wasted. As a component connecting the vibration table and the tested part, the design of the vibration fixture affects the result of the vibration test directly. Therefore, this paper uses Nastran simulation analysis to conduct the design stage of vibration fixture. It makes the fixture design more reasonable and simulates the dynamic characteristics of actual structure more realistically. Improving the product reliability, and reducing the research cost and time.

According to the standard GB/T 28046.3-2001, the installation position of electric and hybrid motors are different. The random vibration frequency of the motor system for new energy vehicles is divided into 10-1000Hz and 10-2000Hz. At present, the resonant frequency of the moving coil which used for electromagnetic vibration table exceeds 2000Hz. When the vibration fixture is installed on the vibration test bench, the whole system resonance frequency is reduced. If the vibration fixture is not designed properly or installed not well, the test results will be affected.
During the vibration test, the table size of the vibration test bench is limited, meantime the specification and number of fixed threaded holes on the bench is also limited. The tested part is generally installed on the table test bench through vibration fixture. The vibration fixture is used as the intermediate part between the vibration test bench and the tested part. Firstly, the vibration and energy are transferred to the fixture, and then to the part under test. Therefore, the fixture becomes a very important link in the vibration test. The accuracy of the test and the reliability of the test results are directly related to the design, manufacture and installation of the test fixture. The connection mode of fixture and vibration table is determined by the vibration table. However, the connection of the DUT and fixture is more complicated due to the different structure of the test sample. Then different types of motor have different dynamic characteristics, and the fixture installation and connection requirements are also different. So the dynamic characteristics of the fixture must be tested through a random vibration test.

**Vibration Fixture Design**

The driving motor system vibration test study is to fix the tested sample on the vibration test table and put it in the normal installation position of the vehicle. Measure the vibration resistance of the motor and inverter after vibration test. Check it up whether or not some parts of motor are damaged and fasteners are loose under test. Frequency sweeping sine vibration and random vibration are simulate the vibration of electric vehicle motor system in the actual road driving. And sine vibration is used to simulate the steady state of real vehicle at high speed, one of the other random vibration is used to simulate the irregular vibration of vehicle in bad road driving. This paper mainly studies the fixture design and analysis of vehicle high-speed motor in the vibration test. The research plan mainly includes the following contents:

1) According to the lab vibration table parameters, the motor fixing, select the fixture type, consider the weight of the fixture, the resonance frequency and other factors to determine the fixture structure and processing size.

2) Selection of fixture. Formula

\[ f_0 = \frac{1}{2\pi} \sqrt{\frac{K}{M}} \]

The natural frequency \( f_0 \) is improved by increasing the fixture structural stiffness \( K \) or reducing the fixture weight \( M \). The characteristics of common fixture materials are shown in Table1. The vibration fixture should be made of material with high stiffness, large damping and light weight. So this the vibration fixture has little influence on force, wider frequency response bandwidth and good transmission force parameter performance. Therefore, the vibration fixture has little influence on whole test. Based on actual needs and cost considerations, now the lab is using aluminum.

3) The test fixture is modeled in 3d. And analyze its dynamic characteristics by using the finite element analysis software Nastran. Optimize the fixture structure, improve the first order natural frequency, and finally obtain a vibration fixture structure whose natural frequency is far from the frequency of excitation signal. The high-speed driving motor for vehicles generally adopts the front-end fixation mode, so the design fixture adopts L-type supports to fix the motor connection surface, and the rear end adopts multi-point support structure. Bolted the fixed plate to the support plate.

| material | Young modulus E (N/cm²) | density ρ (N/cm³) | specific stiffness E/ρ (cm) | Thermal Expansion (°C⁻¹) | Sound velocity (Km/s) |
|----------|-------------------------|-------------------|-----------------------------|--------------------------|----------------------|
| Al       | 7.0×10⁶                 | 2.5-2.8×10⁻²      | 2.8-2.5×10⁸                 | 24×10⁻⁶                  | 5.11-5.23            |
| Fe       | 2.0×10⁷                 | 7.0-8.0×10⁻²      | 3.0-2.6×10⁸                 | 18×10⁻⁶                  | 5.05-5.13            |
| Be       | 3.0×10⁷                 | 1.85×10⁻²         | 1.6×10⁹                    | 12×10⁻⁶                  | 12.6                 |
| Mg       | 5.0×10⁸                 | 0.94×10⁻²         | 0.96×10⁸                   | 26×10⁻⁶                  | 4.60-4.90            |
And the front and back parts of the fixture are connected which is regarded as a rigid body during the analysis. The fixture structure is shown as below in Figure 1.

![Figure 1. Original structure drawing of fixture.](image1)

**Vibration Fixture Natural Frequency Analysis**

1) The fixture model is divided into tetrahedral solid mesh.

- Dimension: 6mm, number of elements: 1446020. Analyze the model constraint modal, constrain the six degrees of freedom of the floor threaded holes, and analyze the first five order modal of the structure. Analyze natural frequency of the original structure of the motor fixture is as below:

   - The local modal of reinforcement rib is shown as below in Figure 2. The first order natural frequency of the fixture is 646Hz.

   ![Figure 2. The first order natural frequency.](image2)

   - The second order natural frequency, similar to the mention earlier, the local modal of reinforcement rib is shown as below in Figure 3. The second order natural frequency of the fixture is 708Hz.

   ![Figure 3. The second order natural frequency.](image3)

   - Further analysis of the whole and local modes of the fixture reinforcing ribs is shown in Figure 4. The third order natural frequency is 859Hz.
Similarly, the local modal of the four order reinforcement rib is analyzed as shown in Figure 5. Its natural frequency is 985Hz.

The fifth natural frequency of the fixture is 1018Hz, as shown in Figure 6. The method is to analyze Y direction bending modal of the whole fixture.

2) The original structure of the fixture was optimized to improve the shape of the reinforcement rib. So that the first three order natural frequencies of the fixture were obviously increased in local modal. The first order natural frequency 646Hz increased to 814Hz, as shown in Figure 7. The second order 708Hz increased to 919Hz, as shown in Figure 8. And the third order 859Hz increased to 1020Hz, as shown in Figure 9. As shown below:
Experimental Verification

Through verify the real fixture vibration, study the acceleration curve and PSD curve of vibration frequency domain. The response frequency of fixture was close to the response frequency of the simulated design, and the resonance frequency point was avoided.

1) The fixture structure is installed on the Japanese EMIC vibration table, and vibration sensors are mounted on the bottom and top. Loading random vibration condition of GB/T28046.3, the frequency is 10Hz-1000Hz, and acceleration rms value is 27.8m/s^2. The intensity curve of random vibration is shown in table 2. Testing the vibration characteristics of the fixture, and measuring the relationship between power spectral density PSD and test frequency f in the vibration process, as shown in figure 10.

| f/Hz | PSD/(m/s^2)^2/Hz |
|------|------------------|
| 10   | 20               |
| 55   | 6.5              |
| 180  | 0.25             |
| 300  | 0.25             |
| 360  | 0.14             |
| 1000 | 0.14             |
Read PSD-f data in Figure 10, that the yellow line is the PSD curve corresponding to the vibration response frequency. The test frequency $f$ has a peak in the region 650Hz-700Hz, and the PSD curve corresponding to 650Hz has exceeded the Plus Alarm curve (Brown line). The vibration frequency of the fixture has obvious resonance, which is basically consistent with the first-order natural frequency and second-order natural frequency of the fixture.

2) Figure 12 shows the vibration test layout after the structural optimization of the support part of the vibration fixture. With the same random vibration conditions as the original fixture test conditions, test the vibration of the optimized fixture. The comparison test results showed that the PSD curves of vibration response did not exceed the Alarm line, and there was no resonance in the test process. Only peaks appeared near the Abort line in the region of 900Hz-950Hz, and the PSD response curve of this frequency band also verified the accuracy of the second order natural frequency analyzed after the fixture structure optimization.
Conclusion
In the vibration test, the influence of fixture structure itself on the test results should be fully considered. In the design of fixture structure, the natural frequency of vibration fixture can be quickly calculated by Nastran finite element analysis, which is of practical reference significance. The test results certify that the natural frequency of the fixture calculated by finite element analysis is basically consistent with the test data obtained from the actual vibration, which further explains the rationality of the fixture design.

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