Research on Vibration Fatigue Life of Commercial Vehicle Stent Based on PSD Spectrum

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Abstract. The battery frame stent structure is a significant part for a commercial vehicle, which often suffers from fatigue damage. In order to solve this problem, the principle of structural vibration fatigue analysis is discussed and the vibration fatigue of the battery frame stent structure is studied in this paper. Prompting acceleration of the stent and strain time history of the dangerous points are obtained by carrying out the load collection test under specific road conditions. Through the analysis of the strain at the dangerous points, the maximum stress and weak parts are obtained, which provides a reference for the fatigue life analysis. The fatigue damage distribution of stent is got out by carrying out stent vibration fatigue analysis based on Dirlik model and acquired prompting acceleration PSD spectrum. After user feedback, the predicted position and life are more consistent with the actual situation.

1. Introduction
The battery frame stent is an important structural component for carrying a battery on a commercial vehicle. In the development and testing process, the problem of cracking on the vehicle body stent often appeared. Sometimes the stent structure on the vehicles delivered to the market appeared fatigue failure under specific use conditions. When looking for the reason of the failure, it is often found that the stress of the stent under static normal working conditions is far below the fatigue limit of the material, so which is not due to static fatigue. In addition, the strength of the stent in the extreme working conditions also meets the performance requirements, which indicate that the reason of the stent failure is not due to excessive structural load.

The time-domain load spectrum is collected on the road causing the failure, which is converted to the frequency domain load spectrum. Measuring and analysing the natural frequency and mode shape of the stent structure through experiments and CAE software. Based on the analysis results, it can be found that the frequency of the input load is consistent with or close to the natural frequency of a certain order, which causes the structure to resonate at an input frequency, resulting in a larger structural response that accelerates structural fatigue damage. Therefore, the main reason of the stents’ failure is vibration fatigue damage, which must be studied by vibration fatigue analysis.

Vehicles are always working in a vibrating environment. Roads, engines and high-speed wind resistance are the sources of vibration. Structural vibrations transmitted to the vehicle body can be reduced through some methods. For example, the vibration isolation, the powertrain and the body stent are connected by a rubber bushing or a hydraulic suspension, the vehicle chassis and the body are connected by a rubber bushing, the cooling module is connected with the body through a rubber
bushing, etc. For example, the vibration damping, the front and rear wheels are equipped with a damper to attenuate the Z-direction vibration load transmitted to the vehicle body. The aforementioned rubber bushings and hydraulic suspension also have a certain function of attenuating the vibration load energy. For example, the decoupling of various systems and input loads is considered to avoid resonance in the early stage of vehicle development. Although many methods for controlling structural vibration are considered in the development of vehicles, it is still common that the vibration fatigue failure appeared on vehicle stent structures during development because of the road complexity and the vehicle lightweight requirements. It is necessary to study the vibration fatigue assessment method and analysis standards for the stent to meet the vehicle lightweight requirement. Some scholars have conducted a series of studies on the vibration fatigue of vehicle structures\cite{1-9}. The battery frame stent of commercial vehicles is taken as the research object in this paper. Aiming at the problem of structural fatigue failure, the vibration fatigue life of battery frame stent is studied. After analysis, the predicted life is consistent with the actual use.

2. Vibration load test of battery frame stent

Arranging the acceleration sensor at the connection between the battery frame stent and the frame, arrange the strain gauge at the theoretical danger point of the battery frame stent, and adopt 32-channel data acquisition when the heavy truck is fully loaded, it travels on the specified various road surfaces. As shown in Figure 1.

![Figure 1](image1.png)

Figure 1. The layout of battery frame vibration load test.

The acceleration signal and strain signal are obtained under the test road condition based on the test. The strain signals of the three channels of the right-angle strain flower are synthesized by the formula (1) to obtain the Von Mises stress.

\[
\sum = \sqrt{\sigma_{\text{max}}^2 - \sigma_{\text{min}}^2} \sigma_{\text{max}} + \sigma_{\text{min}}^2
\]  

(1)

\[
\sigma_{\text{max}} = \frac{E}{2} \left[ \left( \frac{\varepsilon_1 + \varepsilon_3}{1 - \nu} \right) + \left( \frac{1}{1 + \nu} \right) \sqrt{\left( \varepsilon_1 - \varepsilon_3 \right)^2 + \left(2\varepsilon_2 - (\varepsilon_1 + \varepsilon_3)\right)^2} \right]
\]  

(2)

\[
\sigma_{\text{min}} = \frac{E}{2} \left[ \left( \frac{\varepsilon_1 + \varepsilon_3}{1 - \nu} \right) - \left( \frac{1}{1 + \nu} \right) \sqrt{\left( \varepsilon_1 - \varepsilon_3 \right)^2 + \left(2\varepsilon_2 - (\varepsilon_1 + \varepsilon_3)\right)^2} \right]
\]  

(3)

E and \(\nu\) are the elastic modulus and Poisson's ratio of the material respectively.

The signal obtained from the test is shown in Figure 2. Based on Figure 2, it can be found that the stress at point A reaches a maximum of 260MPa, and the stress at point B reaches a maximum at 160MPa under the specified road conditions. In the fatigue analysis, the fatigue life near A should be focused on. The excitation signal of the frame to the stent is mostly concentrated below 25 Hz, which is a low frequency load, and a peak appears near 5 Hz, which is generated for the road surface excitation.
3. Frequency response analysis of battery frame stent

In order to obtain the stress distribution of the structure under unit excitation at different excitation frequencies, it is necessary to analyze the frequency response. By means of the battery frame stent mainly suffer from the gravity of the battery, unit load of 1g and the Z-axis negative direction are set in this analysis. The analysis frequency is 1-100Hz, and the analysis step is 1Hz. Figure 3 shows the stress response of the structure under a unit load of 5 Hz.

4. Vibration fatigue analysis of battery frame stent

4.1. Vibration fatigue theory

Fatigue life estimation is evaluated by fatigue cumulative damage. The theory of Miner’s linear cumulative damage are widely accepted by the theoretical and engineering circles, which is simple, easy to use, and can predict the mean value of fatigue life. The structure life estimation method is divided into time domain method and frequency domain method. In this paper, the frequency domain method is used to describe the response stress information in the frequency domain with the spectral parameters of the response power spectral density (PSD), and then the structural fatigue life is estimated basing on the fatigue performance curve of the material and the cumulative damage theory. The peak of the road load spectrum is usually a Gaussian random distribution of width, so the fatigue
life estimation is based on the Dirlik rain flow amplitude distribution model. Many studies indicate that the Dirlik formula has high accuracy.

Firstly, the power spectral density of the unit stress is obtained by frequency response analysis and power spectrum analysis, and the frequency domain fatigue life can be calculated. The analytical formula of the Dirlik method is \( N(S) = EPT_p(S) \), the number of stress cycles for the stress amplitude \( S \) in the time length \( T \) is \( N(S) \).

The formula for extracting the probability density function from the power spectral density of the stress is

\[
p(S) = \left( \frac{\theta}{\sqrt{2\pi}} \right) e^{-\frac{S^2}{2\theta^2}}
\]

Where \( P(S) \) is the probability spectral density function of the stress amplitude, \( S \) is the stress amplitude.

\[
D_i = \frac{2(1-x_i^2)}{x_i^2 (2y_i^2)} ; \quad D_2 = \frac{y_i - x_i D_3 - D_2}{1-x_i - D_2} ; \quad D_3 = 1 - D_1 + D_2 ; \quad Z = \frac{S}{2\sqrt{m_0}} ; \quad Q = \frac{1.25S(x_i D_2 - D_4 R)}{D_1} ; \quad R = \frac{y_i - x_i D_3}{1-x_i - D_3} ; \quad \gamma = \frac{m_0}{\sqrt{m_0 m_i}} ; \quad \gamma_m = \frac{m_0}{\sqrt{m_0 m_i}}.
\]

Where \( m_n \) is the \( n \)th moment of the power spectral density

\[
m_n = \int_{0}^{\infty} e^{i\omega} G(\omega) d\omega = \sum_{k=1}^{m} e^{i\omega G(\omega_k)} d\omega
\]

According to the material S-N curve and the stress probability spectral density function, the damage \( D \) accumulated in the \( T \) period under the probability spectral density \( P(S) \) can be deduced as shown in Eqn.(6)

\[
D = \frac{EPT}{\theta} \int_{0}^{\infty} S d\rho(S) = \frac{EPT}{\theta} \sum_{i=1}^{q} S_i^2 \rho(S_i)
\]

When the time is 1, \( D \) is equal to the damage in the unit time. \( E(P) \) is the expected peak-to-valley number per second, \( T \) is time; \( b \) is the fatigue strength index of the S-N curve, \( k \) is the cyclic intensity coefficient of the S-N curve, \( S_i \) is the \( i \)th stress amplitude.

**4.2. Battery frame vibration fatigue life assessment**

The stent excitation PSD spectrum obtained by the test is applied in fatigue life assessment of the stent and the material is selected from the S-N curve of Q345. Based on the vibration fatigue theory, the fatigue life of the stent structure is analyzed. The results are shown in Figure4.
potential dangerous point with a calculated life of 1.57E5 km. According to user feedback, the predicted position and life are more consistent with the actual situation.

5. Conclusion
1) Footnotes should be avoided whenever possible. In this paper, the spectrum analysis is applied to the fatigue life analysis, which is more convenient to solve the problem that the large-model, long-period, multi-sampling points are difficult to solve in the time domain, and the simulation method is used to replace the test for improving the efficiency.

2) The stress state of the structure is determined by testing the stress history time of the dangerous point, which provides a reference for fatigue life assessment.

3) The vibration fatigue life simulation of the battery frame stent is carried out basing on the Dirlik model, and the results are compared with the weak fatigue life of the actual structure. After user feedback, the predicted position and life are more consistent with the actual situation.

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