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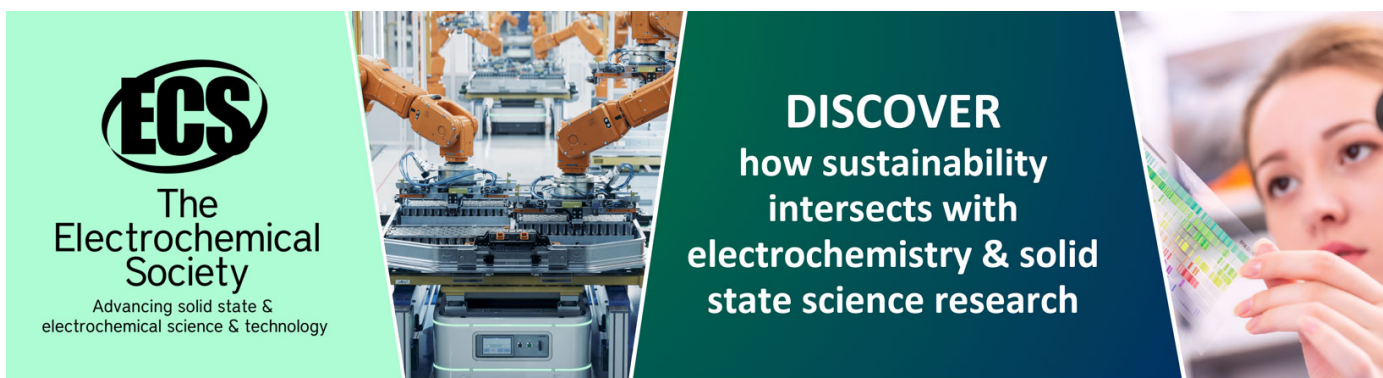
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Structural Optimization for Stiffness and Stochastic Fatigue Life Improvement of a Sport Utility Vehicle Chassis

Wenlin Wang^{1,*}, Bao Huang^{1,2}, Jianming Du² and Siyuan Cheng³

¹School of Mechanical Engineering, Dongguan University of Technology, Dongguan 523808, China.

²College of Mechatronics and Control Engineering, Shenzhen University, Shenzhen 518060, China

³Jiangling Motors Co., Ltd, Nanchang 330001, China

*Corresponding Author: E-mail: pianowwl@163.com

Abstract. To further improve the structural dynamic performance of the Land-Wind X-6 chassis, structural optimization was performed: An X-shape cross member with high stiffness is added to the chassis, in addition, the cross member connecting the two torsion bar attachments is also strengthened. Extensive Finite Element Analysis (FEA) demonstrates that the inadequate torsion stiffness has been greatly increased by 102.6% after optimization, and the adequate bending stiffness has also been slightly improved by 3.8%, in addition, the level of local stresses on the chassis has been considerably declined; After optimization, the fatigue life coefficient when the vehicle is running on A-class concrete road at a speed of 110 km/h has been improved by about 40.36%, and that when the vehicle is running on D-class macadam road at a speed of 60 km/h has been improved by about 33.43%. Followed industrial implementation, field test result and product feedback information verify that the structural optimization performed in this study is effective and significant.

1. Introduction

Structural fatigue and fracture usually occur in the chassis system of a sport utility vehicle (SUV) although the fatigue strength allowance of the chassis system is well-designed in the product development process, and many trouble-shooting works indicate that the reason might due to the unpredictable actual load spectrum under severe in service conditions.

Finite Element Analysis (FEA) based approaches [1] are usually used in automotive structural development, fatigue life prediction and optimization. Vijayan et al. [2] used FEA modelling in the structural analysis of automotive chassis when considering the cross-section and material, Lee et al. [3] and Radziński et al. [4] respectively used the stress relaxation approach and the experimental modal analysis approach in the automotive structural strength improvement, Thomas [5] characterized cut-edges in structural improvement and fatigue life prediction, Kang et al. [6] and Song et al. [7] both put efforts in structural durability improvement by optimizing the suspension elements.

Wang et al. [8] performed static and local stress analysis in the structural failure trouble-shooting of the Chinese Land-wind X6 chassis by establishing and validating the FEA model of the chassis, and based on the findings, Wang et al. [9] optimized the chassis using a novel dynamic force counteracting approach, and the preliminary industrial implementation proved the effectiveness of their research. However, the stiffness and the stochastic fatigue life of the chassis still needs to be improved.



This study continues the research of literatures 8 and 9 in furthering the structural optimization of Land-wind X6 chassis for its stiffness and stochastic fatigue life improvement. An X-shape cross member with high stiffness is added to the chassis and the cross member connecting the two torsion bar attachments is also strengthened. Extensive FEA analyses indicate that the inadequate torsion stiffness of the chassis has been greatly increased, the adequate bending stiffness has also been slightly improved, the level of local stresses on the chassis has been considerably declined, and the stochastic fatigue life has also obviously improved. Followed industrial implementation verifies the effectiveness of the structural optimization.

2. Structural optimization

Figure 1 shows the loading and calculation approach in stiffness FEA analysis of the chassis. So referring to figure 1(a), the bending stiffness K_{bending} of the chassis can be formulated by

$$K_{\text{bending}} = \frac{Fa^3}{48f} \quad (1)$$

where F is the load, a is the automotive wheel-base and f is the vertical deflection of the chassis.

Similarly, referring to figure 1(b), the torsion stiffness K_{torsion} of the chassis is formulated by

$$K_{\text{torsion}} = \frac{L^2 \pi}{180} \cdot \frac{F}{h} \quad (2)$$

where L is the arm of load and h is the twist deflection of the chassis.

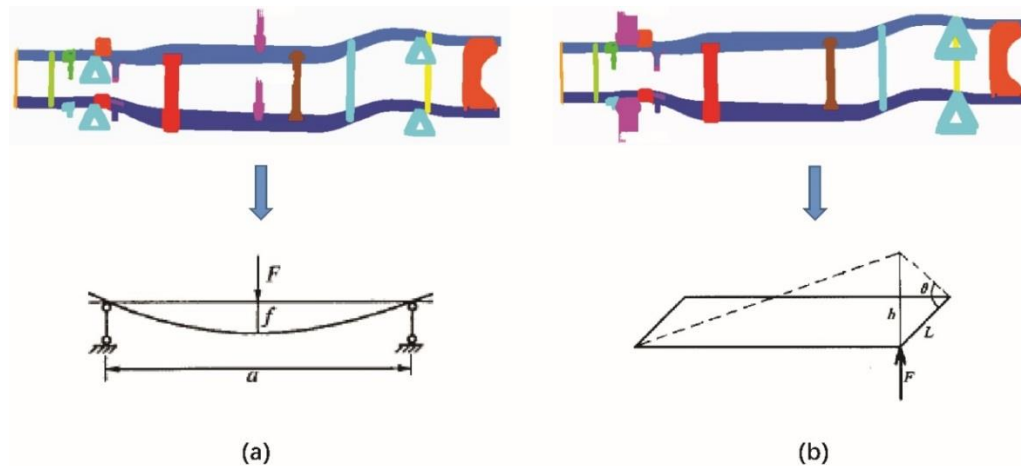


Figure 1. The loading and calculation approach for FEA stiffness analysis: (a) the bending stiffness and (b) the torsion stiffness.

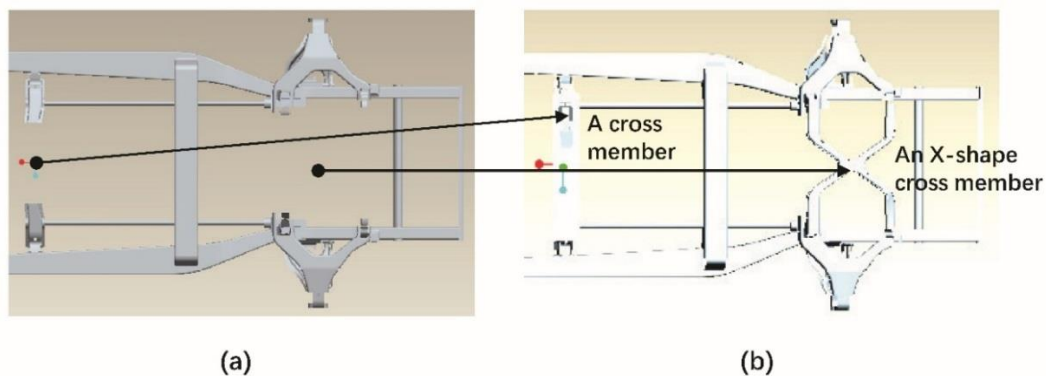


Figure 2. Structural optimization of the Landwind X6 chassis using a strengthened cross member and an X-shape cross member: (a) before optimization, (b) after optimization.

Assisted by FEA stiffness analysis, structural optimization of the Landwind X6 chassis using a strengthened cross member and an X-shape cross member is performed, as shown in figure 2. The current optimization is different from the initial structural refinement performed in [9]: An X-shape cross member with high stiffness is added to the chassis, in addition, the cross member connecting the two torsion bar attachments is also strengthened.

3. Structural dynamics improvement

3.1. The effectiveness of stiffness and local stress improvement

Figure 3 compares the FEA-based stiffness analysis results of the chassis before [9] and after the structural optimization. Figure 3(a) shows that under full load conditions the maximum vertical deflection drops from 0.561 mm to 0.542 mm after optimization, which leads to the bending stiffness of the chassis increases from $1.56 \times 10^6 \text{ N m}^2$ to $1.62 \times 10^6 \text{ N m}^2$, i.e., a 3.8% improvement after optimization.

Figure 3(b) illustrates that under full load conditions the maximum twist deflection drops from 49.36 mm to 24.36 mm after optimization, which leads to the torsion stiffness of the chassis greatly increases from 346.3 N m/° to 701.8 N m/°; i.e., a 102.6% improvement after optimization.

Thus, after adding an X-shape cross member and strengthening the cross member connecting the two torsion bar attachments, the inadequate torsion stiffness of the chassis has been greatly increased, and the adequate bending stiffness has also been slightly improved.

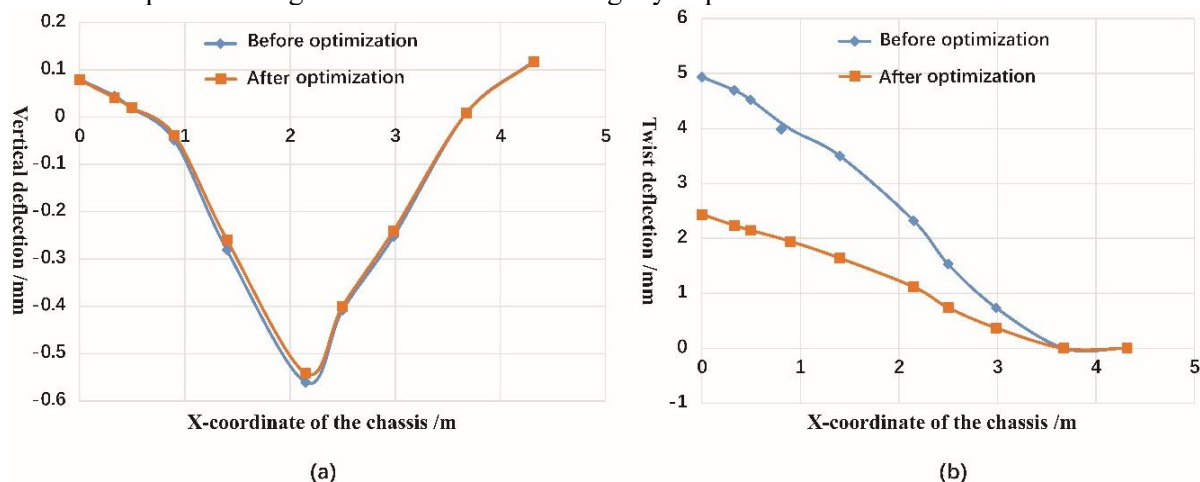


Figure 3. (a) A comparison of vertical deflections of the chassis before and after structural optimization under full load conditions; (b) A comparison of twist deflection of the chassis before and after structural optimization under full load conditions.

Figure 4 compares the local stress distribution of the chassis before and after structural optimization under full load conditions, and it demonstrates that the local stresses have been globally and greatly reduced. Particularly, the maximum local stress in the torsion bar attachment reduces from 446.34 MPa to 251.068 MPa, the maximum local stresses in the arm attachments respectively reduce from 404.41 MPa, 485.34 MPa and 549.88 MPa to 110.339 MPa, 190.766 MPa and 203.311 MPa. Thus, an obvious reduction of the local stresses on the key suspension components indicates that the original structural design imperfections of the chassis have been overcome.

3.2. The effectiveness of stochastic fatigue life improvement

Transient response FEA results show that after optimization a 1σ maximum stress of 120.652 MPa occurs at the attachment of the third cross member and the beam, when the vehicle is running on A-class concrete road at a speed of 110 km/h. Figure 5 shows the stochastic response spectrums at the point with 1σ maximum stress, it indicates that both of the displacement and the velocity responses at

17.5 Hz and between 35-40 Hz are larger and obvious for those frequencies are tightly related to the bending and twisting natural frequencies of the chassis.

Similar analysis is performed when the vehicle is running on D-class macadam road at a speed of 60 km/h, the 1σ maximum stress is 185.647 MPa.

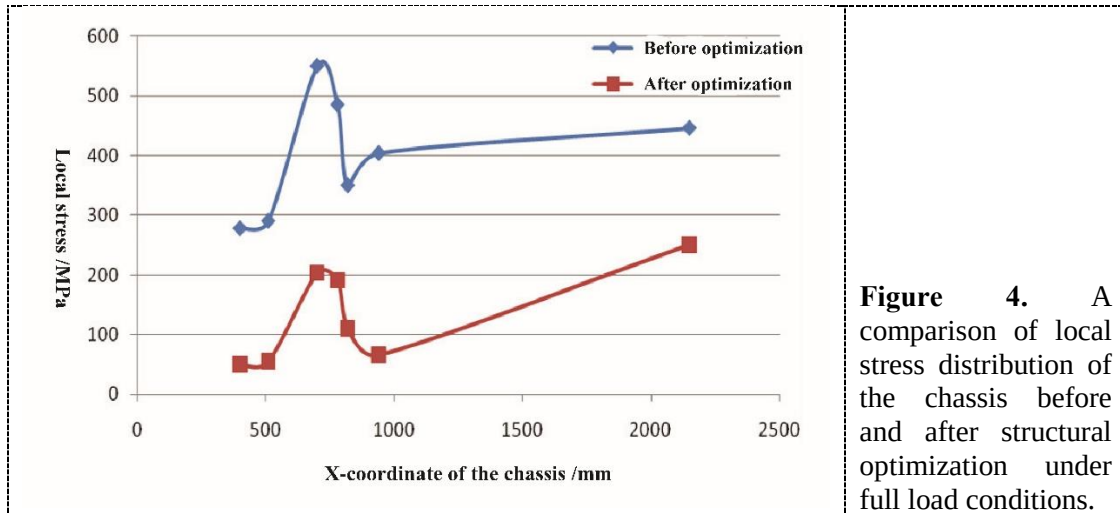


Figure 4. A comparison of local stress distribution of the chassis before and after structural optimization under full load conditions.

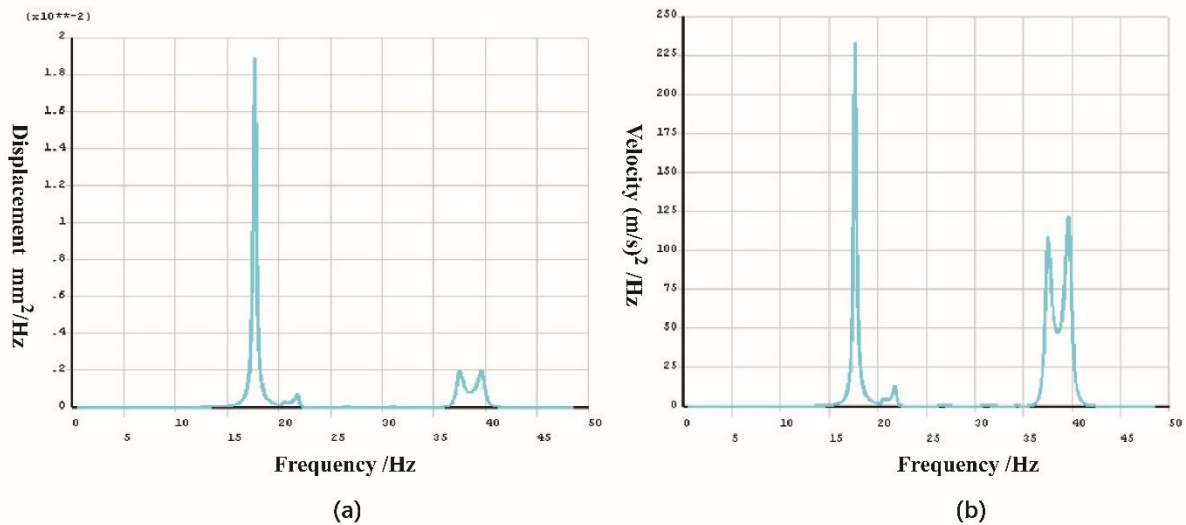


Figure 5. (a) Displacement response spectrum and (b) Velocity response spectrum at the point with 1σ maximum stress when the vehicle is running on A-class concrete road at a speed of 110 km/h.

Miner has proposed the linear fatigue cumulative damage law [10] as

$$\frac{n_1}{N_1} + \frac{n_2}{N_2} + \dots + \frac{n_n}{N_n} = 1 \quad (3)$$

where n_1 , N_1 are respectively the actual cycle number and the damage cycle number of a component when it undergoes the first level of stress, and so on.

Thus, the fatigue life coefficient of the chassis under stochastic vibrations can be calculated by using the three-region estimation approach [11], which is based on the Gaussian distribution and Miner fatigue cumulative damage law. The fatigue life coefficient is formulated by

$$D = \frac{n_{1\sigma}}{N_{1\sigma}} + \frac{n_{2\sigma}}{N_{2\sigma}} + \frac{n_{3\sigma}}{N_{3\sigma}} \quad (4)$$

where $n_{1\sigma}$, $n_{2\sigma}$ and $n_{3\sigma}$ are respectively the cycle numbers when the stresses fall within the scopes of 1σ , 2σ and 3σ ; $N_{1\sigma}$, $N_{2\sigma}$ and $N_{3\sigma}$ are respectively the allowed cycle numbers corresponding to the stress scopes of 1σ , 2σ and 3σ , $N_{1\sigma}$, $N_{2\sigma}$ and $N_{3\sigma}$ can be obtained by looking up the S-N curve of a particular material in the materials handbook. For this research, the chassis is made of 16Mn.

Calculating by equation 4, the fatigue life coefficients of the chassis under different stochastic vibrations conditions are obtained. When the vehicle is running on A-class concrete road at a speed of 110 km/h, the fatigue life coefficient after optimization decreases from 0.4841 to 0.2887, which means that the fatigue life after structural optimization and under that vibration condition has been improved by about 40.36%.

Similar analysis shows that when the vehicle is running on D-class macadam road at a speed of 60 km/h, the fatigue life coefficient after optimization decreases from 0.8356 to 0.5562, which means that the fatigue life after structural optimization has got a 33.43% improvement.

3.3. A summary

After adding an X-shape cross member and strengthening the cross member connecting the two torsion bar attachments, the dynamic performance of the new chassis has been greatly improved, the concrete indices are summarized in Table 1.

Table 1. A comparison of performance indices of the chassis before and after structural optimization

Performance indices	Before optimization	After optimization	Change
Maximum stress under full bending load (MPa)	286.3	272.3	↓ 4.9%
Maximum stress under full torsional load (MPa)	238.9	199.9	↓ 16.3%
Bending stiffness of the chassis (N m ²)	1.56×10 ⁶	1.62×10 ⁶	↑ 3.8%
Torsion stiffness of the chassis (N m/°)	346.3	701.8	↑ 102.6%
Maximum local stress around the attachment of arms (MPa)	549.88	203.311	↓ 63%
Maximum local stress around the attachment of torsion bar (MPa)	446.34	251.068	↓ 43.75%
Fatigue life coefficient on A-class road (concrete)	0.4841	0.2887	↓ 40.36%
Fatigue life coefficient on D-class road (macadam)	0.8356	0.5562	↓ 33.43%

4. Conclusions

- Structural optimization was performed on the Land-Wind X-6 chassis: An X-shape cross member with high stiffness is added to the chassis, in addition, the cross member connecting the two torsion bar attachments is also strengthened.
- After optimization, the inadequate torsion stiffness has been greatly increased by 102.6%, and the adequate bending stiffness has also been slightly improved by 3.8%, in addition, the level of local stresses on the chassis has been considerably declined.
- After optimization, the fatigue life coefficient when the vehicle is running on A-class concrete road at a speed of 110 km/h has been improved by about 40.36%, and that when the vehicle is running on D-class macadam road at a speed of 60 km/h has been improved by about 33.43%.

- Followed industrial implementation, field test result and product feedback information verify that the structural optimization performed in this study is effective and significant.

Acknowledgements

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