Stress Relaxation of a Sport Utility Vehicle Chassis Using a Dynamic Force Counteracting Approach

Wenlin Wang[1,2], Zhichao Hou[2], Zirong Zhou[1] and Siyuan Cheng[3]

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

[2]*State Key Laboratory of Automotive Safety and Energy, Tsinghua University, Beijing 100084, China.*

[3]*Jiangling Motors Co., Ltd, Nanchang 330001, China.*

Abstract. Structural failures in a Chinese sport utility vehicle (SUV) Land-wind X6 chassis were reported in recent years, thus, it is meaningful to conduct trouble-shooting and effective optimization to improve the chassis. Stress relaxation of the Land-wind X6 chassis using a novel dynamic force counteracting approach was carried out in this study. Finite Element Analysis (FEA) model of the chassis was firstly established and theoretical modal analysis was performed using the FEA model, experimental modal analysis was followed to validate the theoretical modal analysis and the FEA model. Further static and local stress analyses demonstrate that irrational designs between the longitudinal beams and the suspension components lead to inadequate stiffness and excessive stress concentrations which would cause fatigue and structural failure when the SUV chassis is subject to complex and severe excitations. A novel dynamic forces counteracting approach was introduced to optimize the chassis structure, FEA results show that excessive stress concentrations were obviously eliminated and the chassis stiffness, especially the torsional stiffness was greatly improved after optimization, followed industrial implementation also verifies that the FEA-based study and product optimization performed in this work are successful and significant.

1 1. Introduction

Sport Utility Vehicle (SUV) is one of the most popular personal vehicles for it has both excellent off-road capability and considerable road ride comfort. However, a SUV chassis is prone to be in failure when subject to severe excitations on rough terrains for a long time in service, in some extreme cases, some of the chassis structures might facture and lead to safety risks.

Land-wind SUV series have shared considerable markets both in China and abroad in recent years, however, chassis structural failures in some Land-wind X6 vehicles were reported. As shown in Figure 1, fatigue-induced cracks or even fractures were found both in the welded mounting brackets (left side F_{11} and right side F_{12}) for the anchor arms of the front suspension torsion bars and in the welded mounting brackets (left side F_{21} and right side F_{22}) for the front suspension control arms. Thus, structural failure trouble-shooting and optimization should be conducted to improve the SUV chassis.

Finite Element Analysis (FEA) approaches are commonly used in modern vehicle structural development. The FEA modelling and stress analysis [1] was instructive in vehicle structural strength improvement [2,3], weight reduction [4,5] and fatigue life prediction [5–7]. During the modelling and analysis process, both theoretical and experimental modal analyses [8,9] were often performed to capture the response nature of a structure, and the test results [9] were usually used to validate that of the theoretical modal analysis and the established structural FEA model. FEA-based design optimizations were also carried out to relax stress [10], improve strength [11] and durability [12] of automotive structures.

Figure 1. Structural failure in a Chinese SUV Land-wind X6 chassis.

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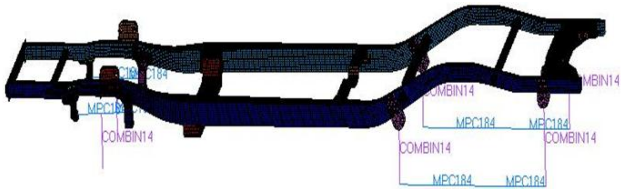


Figure 2. FEA model of the Land-wind X6 chassis.

This study first established the FEA model of the Land-wind X6 chassis and theoretical modal analysis was performed using the FEA model, experimental modal analysis was followed and the test results were used to validate that of the theoretical modal analysis and the FEA model.

Further static and local stress analyses were performed in the structural failure trouble-shooting, based on the trouble-shooting, structural optimization of the chassis was conducted using a novel dynamic force counteracting approach, both FEA evaluation and industrial implementation prove that the Land-wind X6 chassis performance has been greatly improved and the former structural failure has been removed.

2 Finite element modelling and experimental validation

2.1 Finite element modelling

A full FEA model of the Land-wind X6 chassis, as shown in Figure 2, was built using the softwares of HyperMesh and ANSYS, based on 3-D Unigraphics model of the chassis. The chassis is made up of 16MnL steel with Density of 7.8e-6 kg/mm^3, Elastic Modulus of 2.17e+5 MPa, Poisson's Ratio of 0.3, Yield Stress of 350 MPa and Tensile Strength between 510–610 MPa.

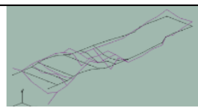
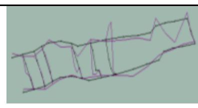
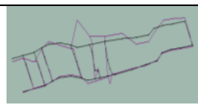
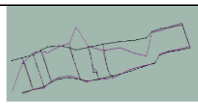
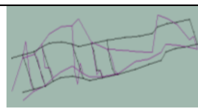
2.2 Modal analysis and experimental validation

Theoretical modal analysis was performed using the above FEA model, experimental modal analysis was also conducted by establishing a test system with the chassis supported by two automotive tires, a 16-channel Chinese DH5920 data acquisition system, a data analysis system, 16 accelerometers and the input hammer. In the experiments, the response datum of 48 key points was collected.

Table 1 compares of the theoretical and the experimental modal analysis results of the first five modal orders. Table 1 demonstrates that considerable motion amplitudes occur at the front part of the chassis, so stiffness especially the torsional stiffness of the chassis is obviously inadequate, however, the modal shapes obtained from FEA and test agree with each other.

The relative errors of modal frequencies between theoretical modal analysis and test are very small except for one outlier of 13.6%, which is also tolerable and feasible in engineering. Therefore, the theoretical modal analysis results are experimentally validated, and it is also concluded that the established FEA model of the Land-wind X6 chassis is correct and effective.

Table 1. A comparison of theoretical and experimental modal analysis results

Modal Order	FEA Result	Test Result	Relative Error
1	 f_1=27.43 Hz	 f_1=26 Hz, Damping ratio 2.87%	5.5%
2	 f_2=31.54 Hz	 f_2=36.5 Hz , Damping ratio 0.61%	13.6%
3	 f_3=46.50 Hz	 f_3=43.5 Hz , Damping ratio 0.46%	6.9%
4	 f_4=56.48 Hz	 f_4=57Hz, Damping ratio 0.33%	0.9%
5	 f_5=64.01 Hz	 f_5=64 Hz, Damping ratio 0.49%	0.02%

3 Failure analysis and structural optimization

3.1. Failure analysis of the chassis

Static analysis using the above validated FEA model shows that the static stiffness is not a direct and leading factor contributing to failure, but the torsional stiffness of the chassis is obviously inadequate.

Local stress and its distribution were analyzed in detail at the areas of F_{11}, F_{12}, F_{21} and F_{22}, the results illustrate that complex stress concentrations occur at the welded joint areas between the mounting brackets and the longitudinal beams of the chassis, the five maximum local stresses reach 404.41 MPa, 446.34 MPa, 485.34 MPa, 549.88 MPa and 744.78 MPa respectively, because yield stress of the chassis steel is 350 MPa, so the maximum overload coefficient reaches 2.13. Further analysis verifies that structure designs at the areas of F_{11}, F_{12}, F_{21} and F_{22} are irrational because the dynamic stresses at the two sides of chassis seem to have no way to be relieved.

Thus, weak stiffness and irrational structural design of the chassis lead to structural failure when the SUV is frequently subject to complex and severe excitations.

3.2 Structural optimization using a dynamic force counteracting approach

If link the left and right brackets at the areas of F11 and F12 using a cross member, as demonstrated by Figure 3, the dynamic forces F_{left} and F_{right} produced by the torsion bars due to suspension motions would pull the cross member and counteract each other instead of pulling the longitudinal beams, so stress concentrations at the areas of F_{11} and F_{12} would be relieved effectively. So it would be when link the left and right control arm brackets at the areas of F_{21} and F_{22} by adding cross members.

Structural optimization was carried out on the Land-wind X6 chassis using the above dynamic force counteracting approach. As illustrated by Figure 4, one cross member was added to link the welded mounting brackets for the left and right anchor arms of the front suspension torsion bars, and another two cross members were added to link the welded mounting brackets for the left and right front suspension control arms.

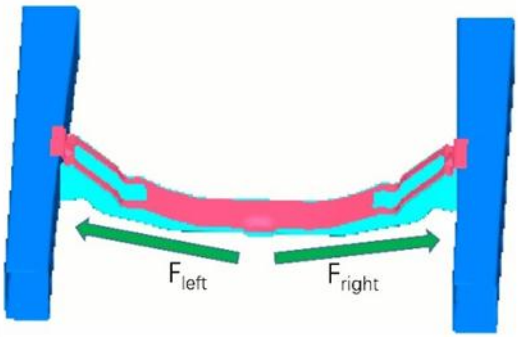


Figure 3. The mechanism of dynamic forces counteracting by linking the left and right brackets using a cross member.

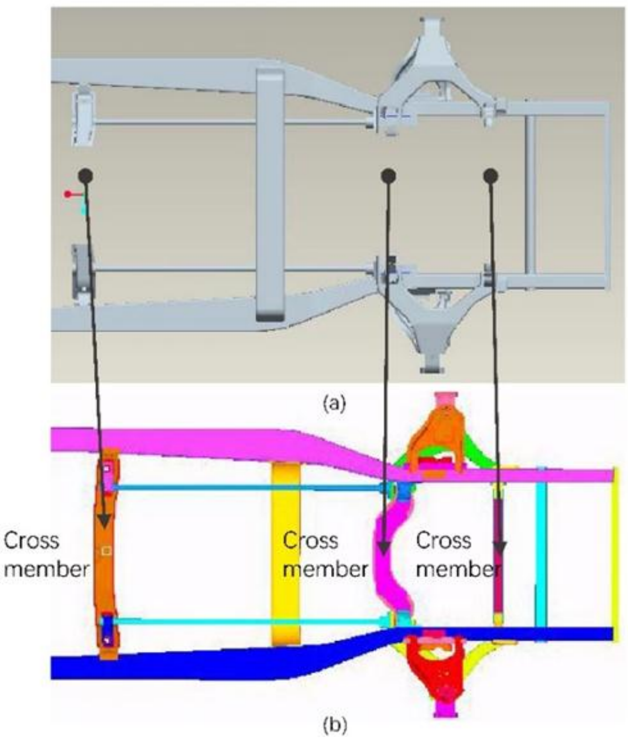


Figure 4. Structural optimization of the Land-wind X6 chassis: (a) Before optimization and (b) After optimization.

4 The effects of structural dynamics improvement

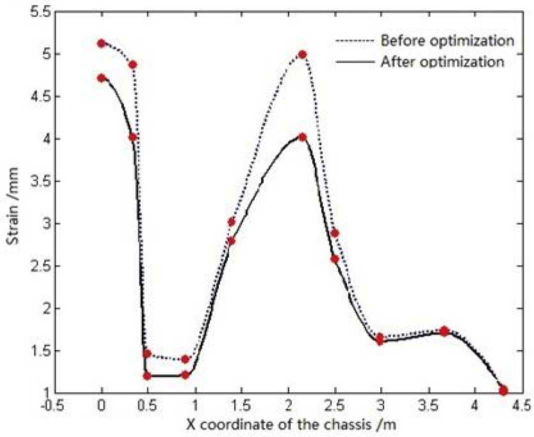
4.1. FEA results

Structural dynamics improvement of the chassis was firstly evaluated by FEA, and the main results are shown in Figures 5 and 6, the key indices of the chassis performance before and after optimization are also listed in Table 2.

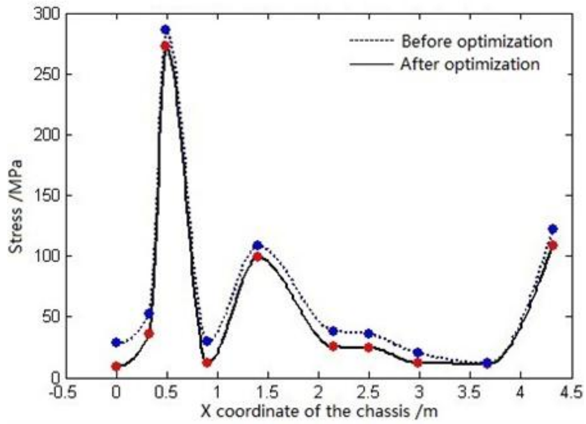
Table 2. Key indices of the chassis before and after structural optimization

Key Indices	Before Optimization	After Optimization	Effect
Bending stiffness (Nm^2)	1.56 e+6	1.62 e+6	↑ 3.8%
Torsional stiffness (Nm/deg)	346.3	701.8	↑ 102.6%
Maximum strain under a full load of bending (mm)	5.1	4.7	↓ 7.9%
Maximum stress under a full load of bending (MPa)	286.3	272.3	↓ 4.9%
Maximum left-and-right height difference under a full load of torsion (mm)	13.3	12.2	↓ 8%
Maximum stress under a full load of torsion (MPa)	238.9	199.9	↓ 16.3%
Maximum local stress at F_{11} or F_{12} (MPa)	446.3	251.1	↓ 43.8%
Maximum local stress at F_{21} or F_{22} (MPa)	549.9	203.3	↓ 63%

When the chassis is subject to a full load of bending, Figure 5 and Table 2 combine to illustrate that the chassis strains are considerably reduced after optimization, the maximum strain is cut by 7.9%. Obvious reductions of the peak strains at the front suspension and at the chassis center indicate that bending stiffness of the chassis is improved and with an improvement of 3.8%; The chassis stresses are also reduced after optimization although the chassis has an eligible bending stiffness before optimization, the maximum stress is cut by 4.9%.



(a)



(b)

Figure 5. Performance of the chassis before and after optimization when it is subject to a full load of bending: (a) Strain and (b) Stress.

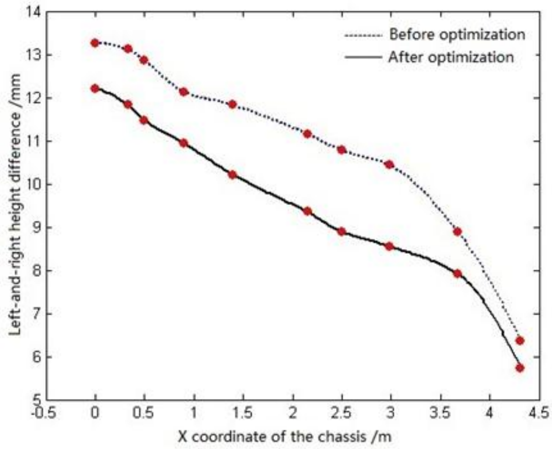
When the chassis is subject to a full load of torsion, Figure 6 and Table 2 combine to illustrate that both the left-and-right height differences and stresses are greatly reduced after three cross members were added to the chassis, the maximum left-and-right height difference is cut by 8%, and the maximum stress is cut by 16.3%, the whole torsional stiffness of the chassis is greatly improved by 102.6%.

Dynamic forces counteracting at the structures and large scale improvement of the chassis stiffness, especially the torsional stiffness, directly eliminate the excessive stress concentrations, the maximum local stresses at F_{11} and F_{12} (or F_{12} and F_{22}) are significantly reduced by 43.8% and 63%, and the maximum local stresses 251.1 MPa and 203.3 MPa are both much smaller than the yield stress of 350 MPa.

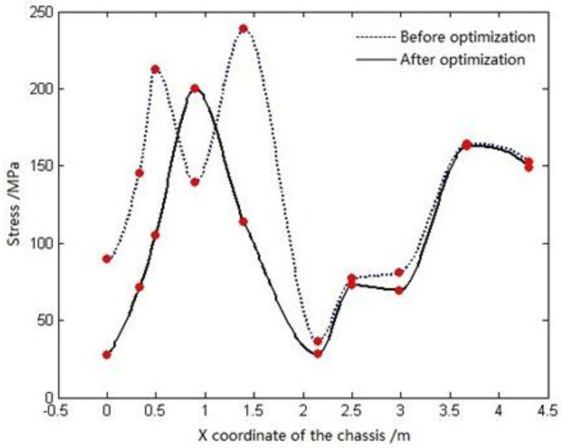
4.2. Industrial Implementation Effects

The above FEA-based structural optimization scheme was implemented in industry, the Land-wind X6 chassis was optimized and upgraded with some other considerations, the resulting structure is the current Land-wind X7 and X8 chassis in service.

Market response verifies that the former structural failure has been removed and the optimized chassis has got an excellent performance both in strength and durability.



(a)



(b)

Figure 6. Performance of the chassis before and after optimization when it is subject to a full load of torsion: (a) Left-and-right height difference and (b) Stress.

5 Conclusions

• Experimental modal analysis was performed to validate the theoretical modal analysis, so the established FEA model is correct and effective and becomes the basis of further FEA-based works.

• The structural designs between the longitudinal beams and the suspension components of Land-wind X6 chassis are irrational, the irrational designs lead to inadequate stiffness and excessive stress concentrations which would cause fatigue and structural failure when the SUV chassis is subject to complex and severe excitations.

• By means of the novel dynamic forces counteracting approach, excessive stress concentrations between the longitudinal beams and the suspension components were obviously eliminated, and the chassis stiffness, especially the torsional stiffness was greatly improved.

• Both FEA assessment and industrial implementation effect verify that the FEA-based study and product optimization performed in this work are successful and significant.

• Further studies should be carried out in the concept of low-stress chassis and concrete design methodologies for chassis development, the concept and methodologies would make the stresses be eliminated before any prototype or product being produced.

6 Acknowledgements

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