RESEARCH ARTICLE OPEN ACCESS

Study on the Influence of the Shape of Leaf Spring on the Stress and the Kinematic Characteristics

Zhuo Xu, Liang Hong, Xiao Lian Wang, Chun Shu Ding
Engineer, Medium & Heavy Vehicle Development Department 1, Commercial Vehicle Development Institute, CHINA FAW CORPORATION LIMITED JIEFANG BUSINESS DIVISION, Changchun, 130011, P.R. China.
Corresponding auther: Zhuo Xu

ABSTRACT
This paper is based on a novel shape of asymmetric few-leaf spring, which is used in the traditional parabolic leaf spring. By means of experiments and finite element method,we compared the stressdistribution and kinematic characteristics of the leaf spring before and after the shape change. Analysis results show that under the conditions of same stiffness and hard point layout, especially under braking conditions, kinematic characteristics of the few-leaf spring can be optimized by changing its shape, and the stress distribution conforms to the stress design principle of parabolic leaf spring.
Keywords: leaf spring; leaf shape; finite element method; kinematic characteristics; stress distribution;

Date of Submission: 07-06-2018 Date of acceptance:22-06-2018

I. INTRODUCTION

Leaf spring is the important part in suspension system, which is basically a laminated structure that absorbs energy. Leaf springs are the oldest form of suspension systems that are still being used in commercial vehicles, military vehicles, construction vehicles, etc. due to its simple structure, good reliability, low cost and convenient maintenance[1-3]. Leaf spring is a kind of elastic component of automobile suspension, which is installed between the frame and wheel, passing all the torque and force between the wheel and the frame, easing the impact of the road surface to the body and ensuring the riding comfort. At the same time, the leaf spring is also a guiding mechanism, which simplifies the suspension structure of the vehicles.

Due to the gradual reduction of fossil fuels and the need for ecological protection, fuel economy has become an important indicator of the vehicle, and the weight of the vehicle becomes an important factor. Therefore, the taper leaf spring was born. In the past, the main form of spring is multiple-leaf spring[4-6], and the stiffness of the leaf spring is increased by adding more leaves with the same thickness. Multiple-leaf spring possesses simple structure, easy manufacturing process and low cost, but it is heavy in weight. Along with the development of lightweight, taper leaf spring gradually rise[7-8], its structure characteristics is thicker in the middle and thinner at both ends, generally separated by anti-friction pads to each leaf. The function of multiple-leaf spring is realized by means of fewer taper leaf springs, so it is called few-leaf spring[9], and is used for the front suspension system. The few-leaf spring generally shows parabolic or trapezoidal section[10-12], due to theirunique cross section, the stress distribution of the leaf spring is more uniform after stress, and prolongs the service life. The taper leaf spring has been used in vehicles in developed countries such as Europe and America. In the mid-1950s, Rockwell in America had begun to develop the taper leaf spring, and by the 1960s it had begun to put on display. At the same time, General Motors Corporation began to study the use of taper leaf in the Chevrolet D sedan. By the end of the 1970s, the use ratio of taper leaf spring in the three major U.S. auto companies had reached 60%. In the early 1960s, British steel company also began to study the application technology of the few-leaf spring, and the proportion of usage the taper leaf spring was increasing year by year. In the mid-1960s, Japan also applied a taper leaf spring technology to the vehicles, and then began to create a factory to produce the taper leaf spring. Since then, the taper leaf spring has been widely used in Japan. Nowadays in these developed countries, the taper leaf spring has replaced the application of traditional multiple-leaf spring in the vehicles.

Nowadays, due to the rapid development of computer technology, CAE method-computer aided engineering analysis, is widely used in the analysis of leaf spring[13-16]. Due to the high efficiency of computer operation, CAE method can be integrated use of finite element method, difference method and boundary element method in computer. CAE technology can be applied for simple modeling and nonlinear analysis of leaf spring according to the actual working condition, and a series of data such as stress, strain and contact force can be obtained, therefore, it's the most widely used and the most advanced technology currently.

Design research for leaf spring is mainly include two aspects: reliability and performance[17-18], and focus on the stiffness, stress and interleaf friction, material and process[19-22], while less attention focus onthe shape of leaf spring. Currently the most manufacturers still adopts parabolic few-leaf spring, but there are a few manufacturers try to adopt the new structure of leaf spring. The change of the shape of the leaf spring is very likely to improve the performance of the suspension system, however, these performance data have not been studied in-depth and reported. In this paper, inspired by a special asymmetric leaf spring structure, the stress distribution and kinematics characteristics of a special structure leaf spring are studied. By means of finite element simulation method, the finite element calculation results are checked with test results. Based on the correct and reliable finite element model, we simulated the vertical loading and braking condition of the leaf springs, and the shape is changed without changing the initial position of leaf eye and the central holes. By contrast analysis, the shape of leaf spring show the positive influence on the stress, stress distribution and kinematic characteristics, which provides a new way for the design of leaf spring.

II. BENCH TEST OF LEAF SPRING

1.1 Test subjects and test conditions.

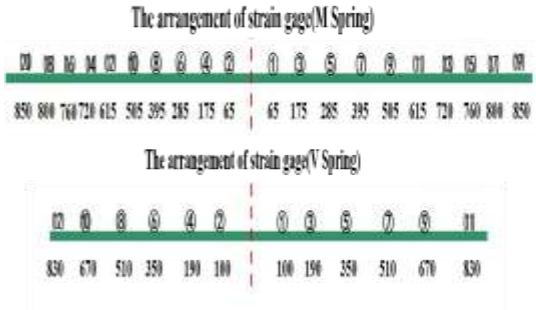
The leaf springs for test can be divided into two different springs, one is symmetrical parabolic spring (M spring), and the other is asymmetric special shaped spring (V spring). In the subsequent comparison with finite element method, M spring is the main object for contrast, and V spring is theauxiliary contrast object.

The test status is shown in Figure 1, and the stress test of leaf spring with different static load is carried out on the MTS linear actuator. The front and rear of the spring eye are fixed by dowel with bracket, the front bracket is fixed, and the rear bracket can move horizontally. The arrangement of strain gage is shown in Figure 2, and 20 strain gage are arranged symmetrically around the M spring, and 12 strain gage are arranged in the first part of the V spring.

Figure 1 The test status

There aretwo kinds of loading conditions for the test, the first is static test, with ladder loading from 0 to 2 tons, 3.5 tons, 4.5 tons, and recording the strain of leaf spring. Then apply dynamic loading at the frequency of 2 Hz and 4 Hz respectively by MTS linear actuator sine wave signal and record the strain of the leaf spring, the frequency of each actuator displacement amplitude were 0.5 mm, 1.5 mm and 2.5 mm, 5 mm, 10 mm.

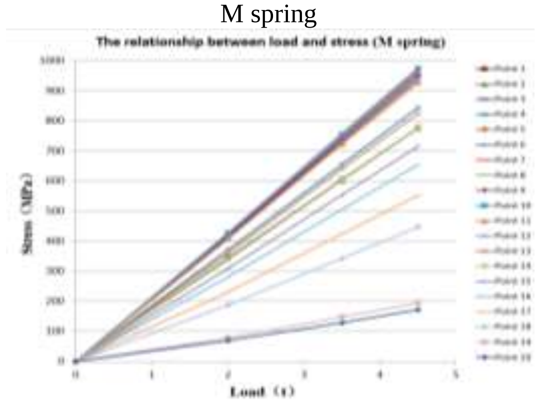
Figure 2 The arrangement of strain gage



1.2 Bench test results

According to the results of stress measurement (Figure 3) under different loading at static loading conditions, the stress of each measuring point of M spring is linear with the load.

Figure 3 The relationship between load and stress of M spring



It can be seen from the statistical results of maximum stress in dynamic loading condition (Figure 4 and Figure 5) that the stress and amplitude of each measuring point of M spring are in linear relationship. For M spring and V spring, the stress is linearly dependent with the load, and the stress is linear with the amplitude.

The stress distribution for M spring can be seen in Figure 6, and V spring shown in Figure 7. The strain gage cannot be arranged in the center position of the leaf spring, so the stress value cannot be collected. Therefore, the stress of the center values as 0 MPa according to the ideal state. By comparing Figure 5 and 6, the stress distribution is different due to different leaf shapes.

Figure 4 The relationship between amplitude and stress of M spring (2Hz)

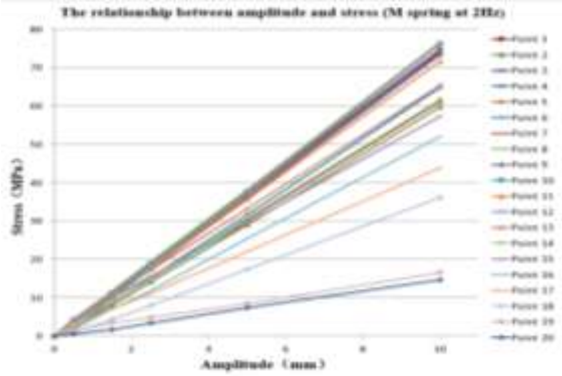


Figure 5 The relationship between amplitude and stress of M spring (4Hz)

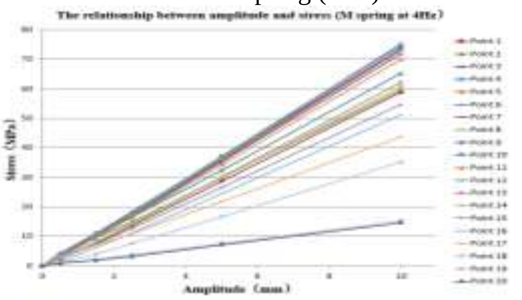


Figure 6 Stress distribution of M leaf spring

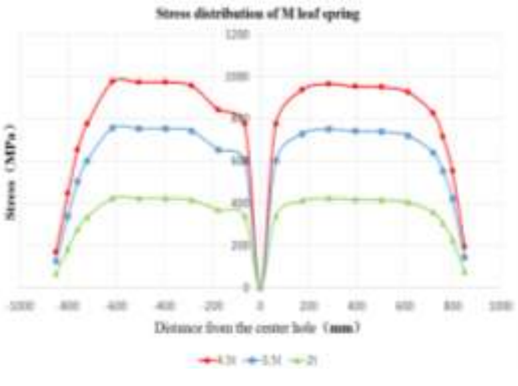
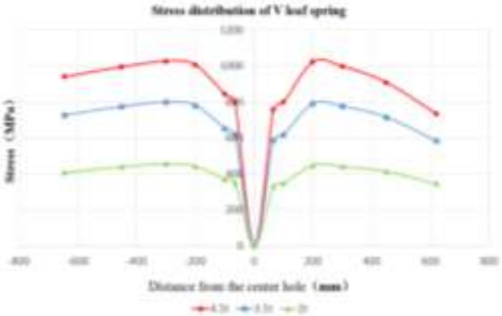


Figure 7 Stress distribution of V leaf spring



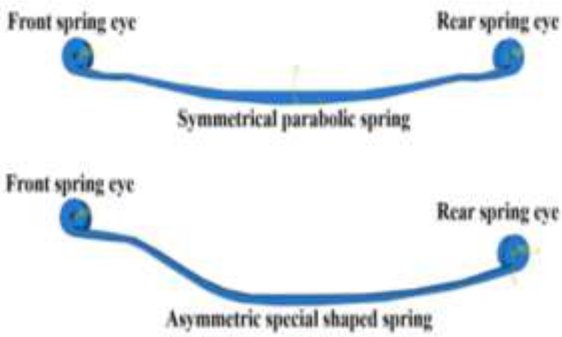
III. THE ESTABLISHMENT AND VERIFICATION OF FINITE ELEMENT MODEL FOR LEAF SPRING

In this paper, two sets of the finite element model is set up, the first is in conformity with the loading conditions of test bench, for contrast verification the models. The second is the finite element model in line with the vehicle driving condition based on the correct finite element modeling method, which is used for analyzing the influence of leaf shape on stress, stress distribution and kinematic characteristics of leaf spring. In order to verify the shape effect, other interference factors are minimized, and the finite element model is established with a model of single leaf spring.

2.1 The establishment of contrast model with test bench

Leaf spring geometric model is established by reverse method form actual spring. Two kinds of leaf spring model is set up : the symmetric parabolic single leaf spring model (M spring) and asymmetric special shaped few-leaf spring model (V spring), the finite element model as shown in Figure 8. On the boundary condition, the front spring eye can be rotated around the y axis, and rear spring eye can be rotated around the y axis and can move along the X direction, which is consistent with the bench test model. The basic parameters of the finite element model are shown in Table 1.

Figure 8 Finite element model used to compare with the result of the test



The cause of the inconsistent of 2 t loading on V spring with 4.5 t loading on the bench test is due to the difference of test object. V spring in test bench is two piece, while the simulation object is a single leaf spring, so the stiffness are twice as large. It is verified by the test bench test, the stress of the same leaf spring is linearly dependent on the load and amplitude, so the stress under different loads is different but the distribution trend is almost the same. Therefore, the test results of V spring and bench test can be used to analyze the correctness of the model.

Table 1 basic parameters of finite element model.

	Symmetric parabola shape single leaf spring	**Asymmetric few-leaf spring model**
Young's modulus	$2.\times10^5$ N/mm^2	$2.\times10^5$ N/mm^2
Poisson ratio	0.3	0.3
yield strength	1300MPa	1300MPa
load	4.5t	2t

2.2 Finite element model validation

Since the M spring is a single spring, in this paper, the M spring is the main contrast object and V spring is the auxiliary contrast object. The results of stress distribution on M spring is compared with the test results and shown in Figure 9, blue curve show the M spring tensile stress distribution along the spring length direction which calculated from simulation, and the red curve show the M spring stress distribution form the test. The two curves fit well, the distribution trend is the same, and the finite element simulation value is slightly smaller than the experimental value. Besides, combine the simulation results and the experimental results of V spring for auxiliary comparison which shown in Figure 10, and the stress trend in the box area is almost the same. Therefore, the finite element method used in this paper has reference value.

Figure 9 Finite element results compared with the simulation results (M spring)

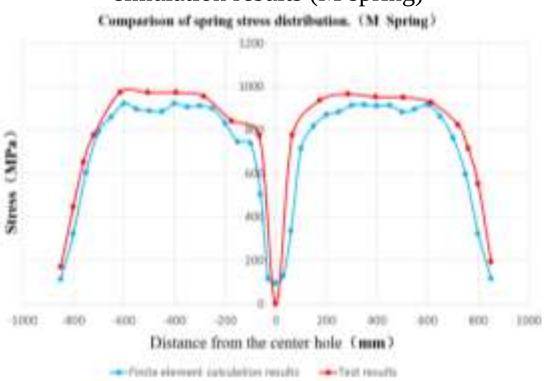
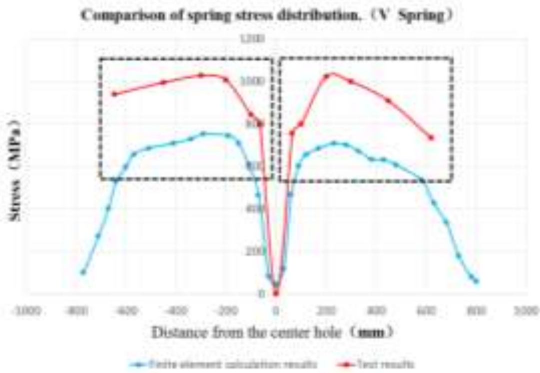


Figure 10 Finite element results compared with the simulation results (V spring)



IV. THE ESTABLISHMENT OF FINITE ELEMENT MODEL FOR LEAF SPRING ANALYSIS

The finite element model is verified and proved that it is feasible to analyze stress distribution based on finite element method. The finite element model established in the paper is in accordance with the model of the bench test condition, which is different from the actual suspension system model, and the main difference is the boundary condition of the rear spring eye. On vehicle, rear spring eye of the leaf spring connect with the back pedestal through the rings, and the actual trajectory is circular arc with the radius of the distance between the two holes on the rings. By adding the rings to the above finite element model, the real vehicle condition can be satisfied.

3.1 The modeling principles for three-dimensional model of leaf shape analysis

By changing the leaf shape, we contrastive analysis the influence of shape on leaf spring stress and kinematic characteristics, at the same time to ensure that the finite element model of leaf spring has the same stiffness, high arc height, fixed position of the front spring eye and the rear spring eye. The method used in this paper is based on the same leaf spring, and only the shape of first half segment changed, at the same time, the stiffness can be guaranteed consistency by vertical loading detection. The principles of model for different leaf shape are shown in Figure 11, and the green is the 3D model of V spring, and the red is the model for the leaf shape analysis of the asymmetrical parabolic few-leaf spring (VP spring). In this paper, we establish two sets of comparison models, one is V spring and the VP spring, and another group is based on the symmetric parabolic few-leaf spring (P spring) and the special shaped few-leaf spring with adjustment of the first half (PT spring). The leaf shape of P spring and PT spring is shown in Figure 12.

Figure 11 The contrast model for V spring before and after leaf shape changed

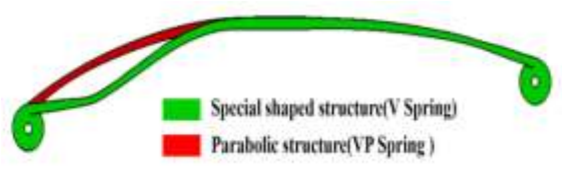
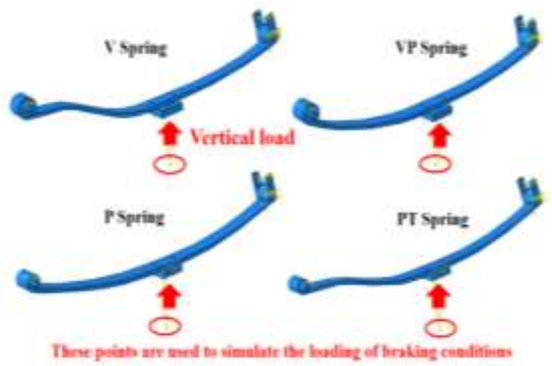


Figure 12 The contrast model for P spring and PT spring

3.2 The establishment of the simulation model for working condition of real vehicle

In chapters 2, the ring is added based on the finite element model which verified through bench test, making the boundary conditions of rear spring eye in line with the working condition of real vehicle, and the simulation models for V spring, VP spring, P spring, and PT spring are set up as shown in Figure 13. The boundary condition of the front spring eye is constant, and the rear spring eye is connected with the bottom of the ring with the hinge, and the boundary condition of the upper end of the ring is the same as the boundary condition of the front spring eye. In the real vehicle, the leaf spring is clamped with front axle with U-bolt, so rectangular structure is bounded below the central flat section of leaf spring. Simulate the tension between the leaf spring and the front axle, and apply the vertical load on the bottom of the rectangular structure. Furthermore, the braking condition is simulated, coupling the inner point of the red circle with the rectangular structure, applying the concentrated load at that point and applying torque to the flat section of the leaf spring.

Figure 13 The simulation model conforms to the real vehicle condition



V. ANALYSIS OF THE RESULTS OF DIFFERENT LEAF SPRING

In this paper, by changing the leaf shape, the analysis model is established for difference shape comparison. Two sets of simulation model for V spring with the VP spring and P spring with PT spring is built up by changing the leaf shape with the same and constant leaf eye position, arc height, material properties and stiffness. Meanwhile, the vertical loading, braking mode is simulated for analysising the influence of shape change on stress and kinematic characteristics of the leaf spring.

4.1 Analysis of the influence of kinematic characteristics

4.1.1 Vertical loading condition

The simulation results of V spring and VP spring are shown in Figure 14. The stress distribution in the second half of V spring and VP is similar, and the first half is different. The displacement of the center position was measured and the results are shown in Table 2, Z displacement for V spring is 122 mm, the VP spring is 115 mm, therefore their stiffness is close to each other from Z displacement measurement result. From the kinematics analysis, assuming that the V spring with the VP spring have the same parabolicshape, V spring shows slightly larger Z displacement than the VP spring, and the X displacement of the V spring center position should be slightly larger than the VP spring as stretch of the surface. While, due to the change of the structure, X displacement of V spring is reduced 6 mm compared with VP spring under vertical loading conditions, it follows that this particular structure can effectively reduce the center position movement of the leaf spring in suspension system under the vertical loading. Besides, when the single wheel beats, the front axle swinging can be inhibited which show a positive effect on kinematic characteristics of the suspension system.

Figure 14 The simulation results of V spring and VP spring under vertical load

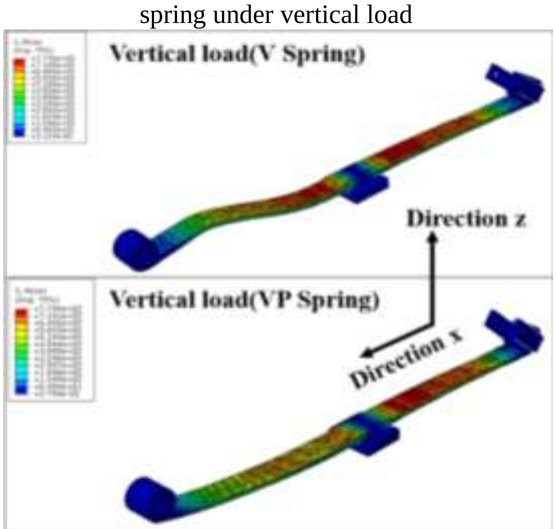


Table 2 The displacement of the center position at the vertical loading condition

Center position on leaf spring	X displacement(mm)	Z displacement(mm)
V spring	-43	122
VP spring	-49	115

In order to verify the influence of the special leaf shape on the kinematic characteristics of the suspension system, the simulation results of P spring and PT spring is in comparison as the supplementary verification. P spring is a traditional symmetric parabolic few-leaf spring, and PT is modified into a special shape at the first half based on the P spring. The simulation results of P spring and PT spring are shown in Figure 15. Table 3 shows the displacement values of center position on leaf spring, the Z displacement of PT spring is slightly larger than the P spring, and the stiffness is slightly smaller. For example, P spring and PT spring have the same parabolic structure, X displacement of PT spring should be larger than P spring, but as the structures changed, the X displacement of PT spring is 3 mm shorter than P spring. If increase the stiffness value of PT spring up to the same value as the P spring, the above X displacement will be reduced more compared to P spring. As shown in Figure 16, the model of stiffness enhanced PT spring is established, the simulation calculation results show that the Z displacement is 120 mm, implying the enhancement of stiffness. And the X displacement is 6 mm shorter than P spring with vertical loading, proved that the special structure can effectively improve kinematic characteristics of suspension system under the vertical loading, reduce the influence of suspension system on steering system in the driving process, and therefore improve the driving stability of vehicle.

Figure 15 The simulation results of P spring and PT spring under vertical load

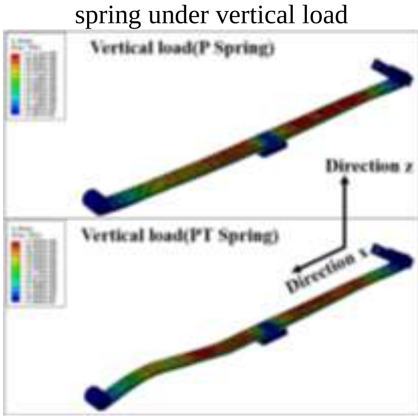


Figure 16 Thestiffness enhanced PT spring

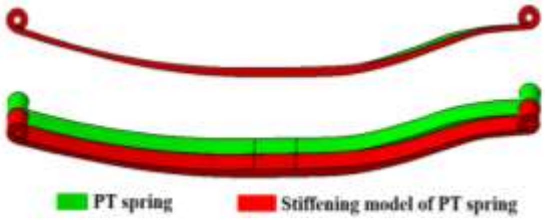


Table 3 The displacement of the center position of P spring and PT spring at the vertical loading condition

center position on leaf spring	X displacement(mm)	Zdisplacemen(mm)
P spring	-36	124
PT spring	-33	134
Stiffness enhancedPT spring	-30	120

4.1.2 Braking condition.

The simulation results of V spring with VP spring, P spring with PT spring under braking conditions are shown in Figure 17, and the high stress area under braking conditions is concentrated in the second half of the leaf spring. In kinematic characteristics, from the measurement results of center position displacement (table 4), the X displacement of V spring is -54 mm, VP spring is -66 mm, their X displacement difference is 6 mm under vertical loading conditions. While under braking conditions, the difference of X displacement increase to 12 mm, implying the change of structure is more obvious to the optimization of kinematic characteristics at braking condition. Therefore, compared with parabolic few-leaf spring, this special leaf shape can effectively reduce the backward movement of the suspension at braking condition.

Figure 17 The simulation results of braking condition

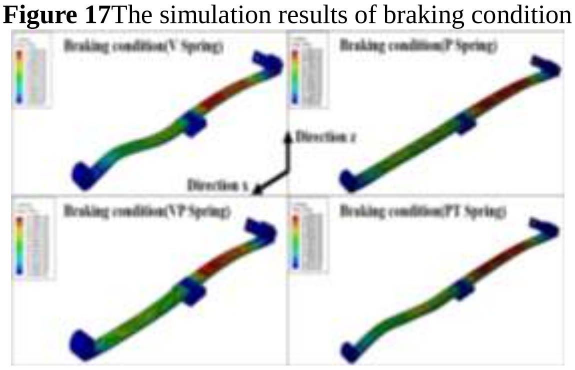


Table 4 The measurement results of center position displacement of V spring and VP spring.

center position on leaf spring	vertical loading		vertical loading + braking condition	
	X (mm)	Z (mm)	X (mm)	Z (mm)
V spring	-43	122	-54	160
VPspring	-49	115	-66	160

Table 5 The measurement results of center position displacement of P spring and PT spring

center position on leaf spring	vertical loading		vertical loading + braking condition	
	X (mm)	Z (mm)	X (mm)	Z (mm)
P spring	-36	124	-43	158
PT spring	-33	134	-37	163
Stiffness enhanced PT spring	-30	120	-34	152

The displacement measurement is verified by P spring, PT spring which based on shape changed P spring, and PT spring with stiffness enhanced (Table 5). PT spring with shape optimization has smaller X displacement than P spring under the vertical loading and braking condition although the P spring with the lower stiffness value. Through enhancing the stiffness of PT spring, the spring shows a smaller X displacement, especially in the braking condition. The results show that the special leaf shape can greatly reduce the forward and backward movement, front axle deflection and improve the vehicle steering stability at driving, braking condition, Therefore, the kinematic characteristics of vehicle suspension systems can be optimized through optimizing the slice structure.

4.2 Stress analysis

4.2.1 Vertical loading condition.

The stress distribution of V spring and VP spring are shown in Figure 18. The VP spring is the parabolic spring with equivalent stress zones on both ends, and V spring also has the obvious equivalent stress zone at the first half, while the second half has no obvious stress zone due to the special leaf shape. The stress distribution increases rapidly from the center of the leaf spring to the spring eye, and then decreases gradually after reaching the maximum stress point. The simulation results of P spring, PT spring and stiffness enhanced PT spring are shown in Figure 19, the stress distribution is close at the second half, and the P spring has the equivalent stress zones at the first half, while PT and stiffness enhanced PT spring both show no obvious stress zone. Therefore, shape change has influence on the stress distribution; the special structure is not obvious to stress optimization under the vertical loading condition.

Figure 18 The stress distribution of V spring and VP spring

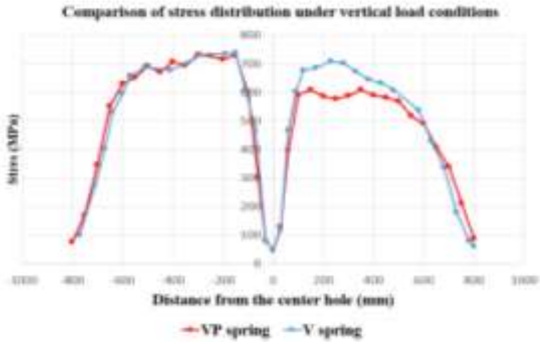
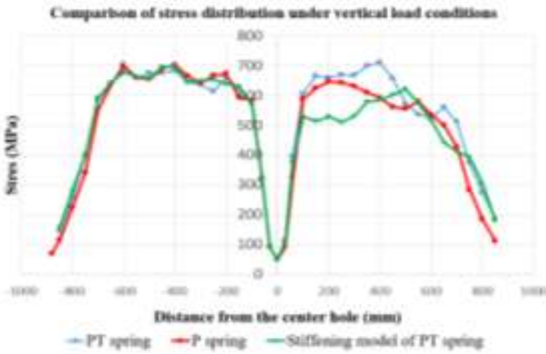


Figure 19 The stress distribution of P spring, PT spring and stiffness enhanced PT spring



4.2.2 Braking condition

The simulation results of V spring and VP spring under braking condition are shown in Figure 20, the stress is reduced in the first half of the leaf spring, and the second half is obviously increased. As seen from the simulation results of two springs during, the stress distribution is almost the same at the second half, and the main difference is at the first half. The VP spring is a parabolic structure, and at the braking condition the stress at the first half is increased from the center to the spring eye, which reaches the peak near the spring eye, while, the stress peak is in the weak area with thin thickness of the leaf spring. Combined the stress results of P spring with the shape changed spring, as shown in Figure 21, P spring has parabola structure, similar with the VP spring under the braking condition, with the peak stress near the spring eye, and the peak stress on PT spring and its stiffness strengthened spring appears in the middle of the first half. But overall stress is reduced in the first half at braking condition, the special shape has obvious effects on stress distribution at the first half under braking conditions, and its distribution is more reasonable than traditional parabolic spring. But the overall stress is reduced at first half at vertical loading condition, so this structure change on the stress distribution does have a positive impact; however, the reliability improvement of leaf spring is not great.

Figure 20 The stress distribution of V spring and VP spring

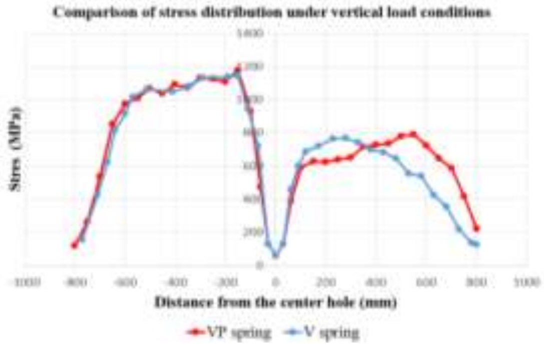
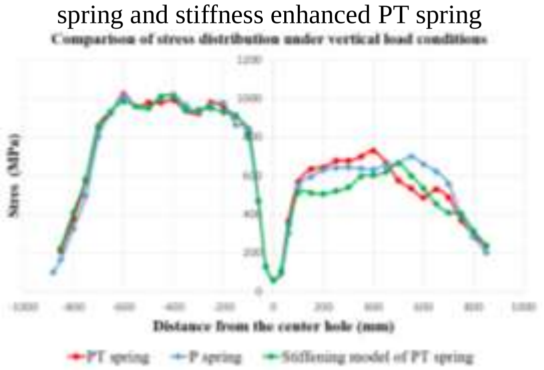


Figure 21 The stress distribution of P spring, PT spring and stiffness enhanced PT spring



VI. CONCLUSIONS

This paper mainly studies the influence of leaf shape on stress and kinematic characteristics. The finite element model is established for leaf shape and kinematic characteristics analysis, which proved feasible by experiments. V spring and P spring with two different design ideas is commonly applied to the vehicle, V spring has asymmetrical special structure, P spring has symmetrical parabolic structure. The author inspired by the special structures, and changes the structure of V spring and P spring, and analysis the influence of leaf shape on stress distribution and kinematic characteristics. The conclusions are as follows:

(1) The change in structure show obvious optimization on kinematic characteristics of suspension system, and forward and backward displacement can be effectively reduced through shape adjustment, therefore the displacement of front axle connected with the leaf spring and angle of front axle swing is reduced. So driving stability is improved caused by rough road and optimize the kinematics characteristic of the suspension system. In the braking condition, due to the structure of the leaf spring, the overall backward displacement of the suspension system is greatly reduced, and the stability of the suspension system structure is improved.

(2) Under vertical loading condition, the structure has influence on the stress distribution of leaf spring. In this article, the stress distribution on the special shaped leaf spring has no obvious equivalent stress zone, which is different from the traditional parabolic shape structure.

(3) Under braking conditions, the stress distribution of leaf spring can be optimized through the structure change. From the results of simulation analysis, the optimized stress distribution can reduce the stress of the thin section of the end of spring eye, and improve the life span of the thinnest area.

REFERENCE

[1]. Hou, J.P., Cherruault, J.Y., Nairne, I., Jeronimidis, G. and Mayer, R.M. (2004) 'Evolution of the eye-end design of a composite leaf spring for heavy axle loads', Composite Structures, Vol. 78, No. 3, pp.351–358.

[2]. Amrute, A.V., Karlus, E.N. and Rathore, R.K. (2013) 'Design and assessment of multi leaf spring', International Journal of Research in Aeronautical and Mechanical Engineering, Vol. 1, No. 7, pp.115–124.

[3]. Saini, P., Goel, A. and Kumar, D. (2013) 'Design and analysis of composite leaf spring for light vehicles', International Journal of Innovative Research in Science, Engineering and Technology, Vol. 2, No. 5, pp.309-311.

[4]. Krishan, K. and Aggarwal, M.L. (2012) 'A finite element approach for analysis of a multi leafspring using cae tools', Research Journal of Recent Sciences, Vol. 1, No. 2, pp.92–96.

[5]. Li, Q. (2004) 'A contact finite element algorinthm for the multi-leaf spring of vehicle suspension systems', Journal of Automobile Engineering, Vol. 218, No. 3, pp. 305-314.

[6]. Kim, T., Moon, W. and Kim, S. (2004) 'Influences of leaf shapes on performance of progressive multi-leaf springs', International Journal of Vehicle Design, Vol. 34, No.1, pp. 65 – 83.

[7]. Duan L., Song, C.X., Yang, S.K., Fan, S.Q. and Lu, B.W. (2016) 'High-precision modeling and simulation of the taper leaf spring of tandem suspension of commercial vehicles', Journal of Mechanical Science and Technology, Vol. 30, No. 7, pp 3061–3067.

[8]. Zhou, S.T., Huang, H.W., Ouyang, L.G. and Xiang, T.M. (2013) 'Analysis and computation

of taper leaf spring based on FE contact analysis', Advanced Materials Research, Vol. 705, pp.516-522.

[9]. Meng, X.Y., Wang, Z.B. and Gao, W. (2014) 'New material research and application for few piece leaf spring of heavy vehicles', Advanced Materials Research, Vol. 1015, pp.679-683.

[10]. Rahman, M.A., Siddiqui, M.T. and Kowser, M.A. (2002) 'Design and non-linear analysis of a parabolic leaf spring', Journal of Mechanical Engineering, Vol. 37, No. 1, pp.47–51.

[11]. Dewangan, R.K., Patnaik, M. and Yadav, N. (2012) 'Minimization of stress of a parabolic leaf spring by simulated annealing algorithm', International Journal of Engineering Research and Applications, Vol. 2, No. 4, pp.457-460.

[12]. Kong, Y.S., Omar, M.Z., Chua, L.B. and Abdullah, S. (2014) 'Fatigue life prediction of parabolic leaf spring under various road conditions', Engineering Failure Analysis, Vol. 46, pp.92-103.

[13]. Nenggen, D. and Jian, M.J. (2003) 'Finite element analysis on the hysteresis behavior of leaf springs', Automotive Engineering, Vol. 25, No. 1, pp.12–15.

[14]. Carello, M., Airale, A. G., Ferraris, A., Messana,A. and Sisca, L. (2017) 'Static design and finite element analysis of innovative CFRP transverse leaf spring', Applied Composite Materials, Vol. 24, No. 6, pp.1493–1508.

[15]. Bakir, M., Ozmen, B. and Donertas, C. (2018) 'Correlation of simulation, test bench and rough road testing in terms of strength and fatigue life of a leaf spring', Procedia Engineering, Vol. 213, pp.303-312.

[16]. Rajesh, N.H. and Sreekumar, M. (2016) 'Design and simulation of a novel hybrid leaf spring with embedded cylindrical structures', International Journal of Heavy Vehicle Systems, Vol. 23, No. 2, pp.131-154.

[17]. Subramanian, C. and Senthilvelan, S. (2010) 'Effect of reinforced fiber length on the joint performance of thermoplastic leaf spring', Materials & Design, Vol. 31, No. 8, pp.3733-3741.

[18]. Brouwer, D.M.,Meijaard, J.P. and Jonker, J.B. (2013) 'Large deflection stiffness analysis of parallel prismatic leaf-spring flexures', Precision Engineering, Vol. 37, No. 3, pp.505-521.

[19]. Singh, H. and Brar, G. S. (2018) 'Characterization and investigation of mechanical properties of composite materials used for leaf spring', Materials Today: Proceedings, Vol. 5, No. 2, pp.5857-5863.

[20]. Kong, Y.S. bdullah,S.A., Omar,M.Z. and Haris, S.M. (2016) 'Failure assessment of a leaf spring eye design under various load cases', Engineering Failure Analysis, Vol. 63, pp.146-159.

[21]. Kouters, M.H.M., Slot, H.M., Zwieten, W. and Veer, J. (2014) 'The influence of hydrogen on the fatigue life of metallic leaf spring components in a vacuum environment', International Journal of Fatigue, Vol. 59, pp.309-314.

[22]. Kat, C.J., Johrendt, J.L. and Els, P.S. (2017) 'Methodology for developing a neural network leaf spring model', International Journal of Vehicle Systems Modelling and Testing, Vol. 12, No.1/2, pp. 94 – 113.

Zhuo Xu "Study on the Influence of the Shape of Leaf Spring on the Stress and the Kinematic Characteristics " International Journal of Engineering Research and Applications (IJERA) , vol. 8, no.6, 2018, pp.13-21