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Finite Element Analysis and Structural Optimization of an Outer Steering Tie Rod

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Abstract – **The outer tie rod of automobile steering plays an important role in the automobile steering system, which directly affects the handling stability, sensitivity and driving safety of automobile steering. In order to ensure that the outer steering tie rod products can meet many performance requirements, ensure the stability of product performance and improve production efficiency, the structure of the outer steering tie rod must be optimized. The main research contents are as follows: the main product performance requirements of the outer steering tie rod include the pull-out force of the outer steering tie rod and the swing angle of the ball pin, which should meet the two product requirements of the outer steering tie rod, it requires designers to control the product performance in the product design stage. In this paper, the three-dimensional model and finite element model of the outer steering tie rod are established to simulate the product performance. By comparing with the pull-out force test and ball pin swing angle test results, the rationality of the three-dimensional model and finite element establishment is proved. The orthogonal test is designed for range analysis, and the main influencing factors affecting the pull-out force of the outer steering tie rod and the ball pin swing angle are determined, the optimal size combination is obtained to improve the stability of product performance.**

Keywords – **Steering Outer Tie Rod, Hydraulic Test, Orthogonal Test, Finite Element Analysis.**

I. INTRODUCTION

The steering rod is a very important component in the automobile steering system. The strength and quality of the steering rod directly affect the steering sensitivity and handling stability of the automobile. Sleepongsom [1] proposed a multi-objective optimization design method for rack and pinion steering mechanism. In the previous optimization of rack and pinion steering mechanism, there is often only one optimization objective to minimize the steering error, and the minimization of turning radius is often ignored. Sleepongsom puts forward multi-objective optimization analysis. The optimized steering structure can meet the minimization of steering error and turning radius at the same time. Neider Romero [2] and others use continuous genetic algorithm to globally optimize the multi link steering mechanism. The genetic algorithm can solve the nonlinear problem and solve the established equation with natural coordinates. The final optimization goal is to minimize the structural error of the multi link steering mechanism. The program established in this paper is not only used for the multi link mechanism, it can also be applied to other mechanisms to find the comprehensive optimal solution. Ruidong Guo [3] analyzed the failure of the ball pin fracture in the automobile steering system. By testing the mechanical properties of the material, metallographic test, hardness test and chemical composition analysis, it is concluded that the main cause of the ball pin fracture is fatigue fracture, and the uneven quenching treatment leads to the uneven thickness of the quenching hardening layer. It provides a reference idea for the failure analysis of ball pin fracture in the future. Du Heng [4] studied the pull rod in the steering system of heavy vehicles. Heavy vehicles generally use the electro-hydraulic power steering system. The hydraulic drive system in the electro-hydraulic power steering system will affect the force of the steering mechanism. Then, the pull rod force model is established based on the Lagrange equation, and the key factors affecting the force of the pull rod are obtained. Aravindaraj E [5] designed the existing pull rod structure through ANSYS and analyzed its load reason. In order to avoid the failure of the pull rod due to overload, the original pull rod was optimized by changing the material and structure. Zhenbo Ji [6] and others carried out fracture analysis and structural optimization design of 42CrMo steering tie rod. Firstly, by means of chemical composition analysis and hardness test, it is determined that the fatigue fracture of the tie rod is due to the local stress concentration of the tie rod. After that, the orthogonal test was designed by using ANSYS Workbench. The test results were analyzed by variance. According to the test results, the structure of the tie rod was optimized to solve the problem of stress concentration.

Based on the correct three-dimensional model and finite element model of the outer steering tie rod, this paper optimizes the size of the outer steering tie rod ball pin sleeve. Firstly, the main dimensions affecting the pull-out force of the outer steering tie rod and the swing angle of the ball pin are selected as the design variables. Taking the maximum pull-out force of the outer steering tie rod and the maximum swing angle of the ball pin as the optimization objective, the orthogonal test is designed to determine the optimal size combination.

II. FINITE ELEMENT ANALYSIS OF PULL-OUT FORCE OF OUTER STEERING TIE ROD

A. *Material Model*

The object of finite element analysis is the outer steering tie rod, which simulates the pulling process of ball pin from ball pin sleeve. The outer steering tie rod assembly includes ball pin, ball pin sleeve, dust cover, ball bowl and base plate. In order to simplify the calculation, the base plate and dust cover are omitted, and the base plate and dust cover have no impact on the simulation process. Therefore, it is removed in the simulation process, and only the finite element model of ball pin, plastic ball bowl and ball pin sleeve is established.

Table 1. Stiffener material properties.

Rebar Material	**Young's Modulus /GPa**	**Poisson's Ratio**	**Density/Kg/m³**
Ball Pin	205	0.277	7850
Ball Pin Set	209	0.269	7890
Ball Bowl	2.6	0.38	1380

B. *Finite Element Model*

When the ball pin is pulled out of the ball pin sleeve, the ball pin will contact with the ball pin sleeve and the ball bowl, and the ball bowl will also contact with the ball pin sleeve. Therefore, the contact type should be defined. In this paper, face-to-face contact is adopted. When selecting the master-slave surface, the one with high stiffness should be defined as the master surface and the one with low stiffness as the slave surface [7]. Therefore, the ball pin and the ball pin sleeve are defined as the main surface, and the ball bowl is defined as the slave surface. Tied adhesive contact is adopted between the ball bowl and the ball pin sleeve to simulate the fixed state of the ball bowl in the ball pin sleeve. The corresponding setting dynamic friction coefficient is 0.1 and static friction coefficient is 0.15.

Fully restrain the bottom of the ball pin sleeve, and apply a forced displacement in the Y direction to the ball pin, with the forced displacement of 15mm, so as to ensure that the ball pin can be pulled out of the ball pin sleeve. Set the output variable, output reforce to view the pull-out force, output d3plot file to view the stress displacement cloud diagram, and define the calculation time and time interval. The set finite element model is shown in Figure 1. Finally, the set finite element model is exported to K file, and the K file is imported into LS DYNA solver for solution.

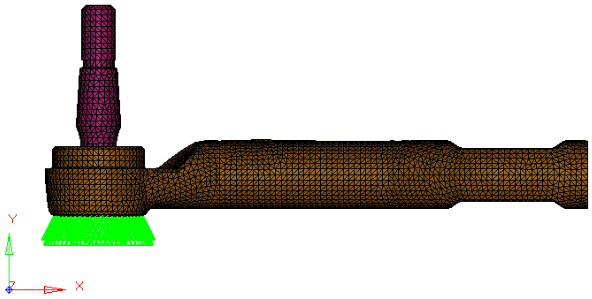
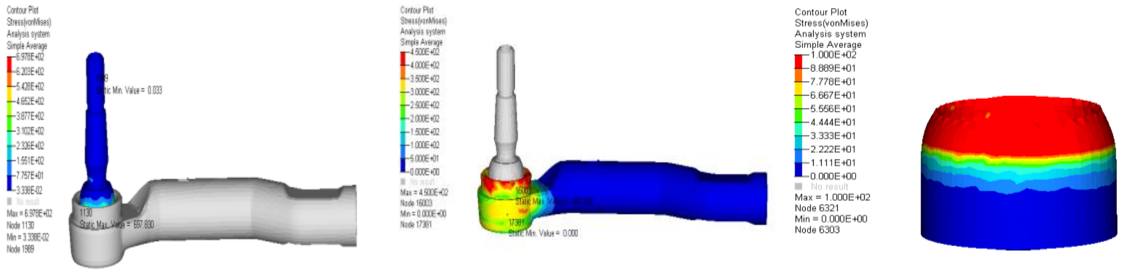


Fig. 1. Finite element model of the steering outer tie rod.

C. *Model Post-Processing*

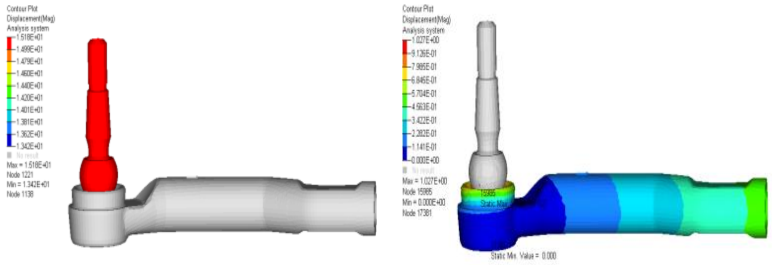
According to the solution results, view the Mises stress displacement nephogram of the outer steering tie rod. As shown in figure 2, the Mises stress nephogram of ball pin, Mises stress nephogram of ball pin sleeve, displacement nephogram of ball pin and ball pin sleeve and Mises stress nephogram of ball bowl are shown respectively.



(a) Mises stress cloud diagram of ball pin.

(b) Mises stress cloud diagram of ball pin sleeve.

(c) Ball Bowl Mises stress cloud diagram.



(d) Ball pin displacement cloud diagram.

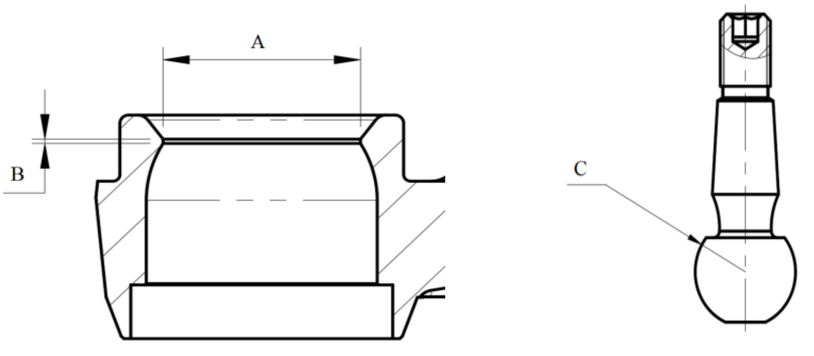
(e) Cloud diagram of ball pin sleeve displacement.

Fig. 2. Mises stress and displacement cloud diagram.

According to the Mises stress nephogram of ball pin and ball pin sleeve, when the ball pin is pulled out of the ball pin sleeve, the maximum stress of the ball pin is 697mpa and the maximum stress of the ball pin sleeve is 450MPa. According to the Mises stress nephogram of the ball bowl, the maximum stress of the ball bowl is 100MPa, the maximum stress values of the ball pin sleeve and the ball bowl have reached the yield limit of each material, and the maximum stress value of the ball pin occurs at the maximum diameter of the ball head, that is, the place where the ball pin contacts the ball bowl when it is pulled off; The maximum stress of the ball pin sleeve occurs at the bowl mouth, and the simulation results are the same as the actual stress results; The maximum stress of the ball bowl occurs at the mouth of the ball bowl. Due to the extrusion of the mouth of the ball bowl during the extraction of the ball pin, some grids at the mouth of the ball bowl are extruded and deformed. According to the displacement nephogram of the ball pin and the ball pin sleeve, the maximum displacement of the ball pin is 15.18mm, the whole is pulled out for 15mm, the maximum displacement of the ball pin sleeve is 1.02mm, which occurs at the bowl mouth. The bowl mouth is permanently deformed at the ball bowl because it is squeezed by the ball pin, and the rod at the right end of the ball pin sleeve is slightly deformed, because only the base part of the ball pin sleeve is restrained when restraint is applied, the simulation results show that there is slight jitter, so there will be slight deformation.

III. ORTHOGONAL EXPERIMENTAL DESIGN

Based on the correct finite element model and three-dimensional model, this chapter will carry out the orthogonal test for the structural optimization design of the outer steering tie rod. It mainly studies the optimization of the combination of the bowl size, step size and outer steering tie rod ball pin size of the outer steering tie rod ball pin sleeve. The factors affecting the pull-out force of the outer steering tie rod and the swing angle of the ball pin may include the bowl size of the ball sleeve, the inner diameter of the ball sleeve, the step size of the ball sleeve, the size of the ball pin and the depth of the ball pin. It can be seen from the product structure and processing experience, the main factors affecting the pull-out force of the outer steering rod and the swing angle of the ball pin are the bowl size a and step size B of the outer steering rod ball pin sleeve, and the ball head size c of the ball pin, as shown in figures 3.



(a) Size of the pin sleeve for the steering outer tie rod.

(b) Ball pin size for steering outer tie rod.

Fig. 3. The main factors.

A. *Analysis of Orthogonal Factors*

The purpose of this test is to investigate the primary and secondary order and optimal size combination of the influence of the bowl size and step size of the outer steering rod ball pin sleeve and the ball pin ball joint size on the pull-out force of the outer steering rod and the swing angle of the ball pin. In order to make the optimized outer steering tie rod meet both the pull-out force requirements and the ball pin swing angle requirements, the inspection indexes of this test are the maximum pull-out force and the maximum swing angle to evaluate the optimized outer steering tie rod size. Select the following three factors to formulate the factor level table. The above factors are analyzed by $L_{16}(4^{15})$ orthogonal test, and the test factor level table is shown in Table 2.

The above orthogonal test factor design table is expanded orthogonally, and the grip is characterized by the friction force in the driving direction. The results of the orthogonal test are analyzed as shown in Table 4.

Table 2. Test factor level table.

Level	**Factors**		
	A **Bowl size/mm**	**B** **Step size/mm**	**C** **Ball pin size/mm**
1	22.0	0.6	23.95
2	22.5	0.8	24.00
3	23.0	1.0	24.05
4	23.5	1.2	24.10

Table 3. Results of orthogonal test.

No.	**Orthogonal Test Influencing Factors**			**Maximum Pull-Out Force /KN**	**Maximum Swing angle of Ball Pin /°**
	Bowlsize (mm)	**Step Size (mm)**	**Ball Pin Size (mm)**		
1	1（22.0）	1（0.6）	1（23.95）	26.316	26.8
2	1（22.0）	2（0.8）	2（24.00）	26.853	26.3
3	1（22.0）	3（1.0）	3（24.05）	26.524	25.8
4	1（22.0）	4（1.2）	4（24.10）	27.892	25.4
5	2（22.5）	1（0.6）	2（24.00）	24.204	28.4
6	2（22.5）	2（0.8）	1（23.95）	24.781	28.5
7	2（22.5）	3（1.0）	4（24.10）	25.322	27.7
8	2（22.5）	4（1.2）	3（24.05）	26.078	27.0
9	3（23.0）	1（0.6）	3（24.05）	23.604	28.6
10	3（23.0）	2（0.8）	4（24.10）	25.130	28.6
11	3（23.0）	3（1.0）	1（23.95）	23.245	28.5
12	3（23.0）	4（1.2）	2（24.00）	25.861	28.4
13	4（23.5）	1（0.6）	4（24.10）	19.691	29.0
14	4（23.5）	2（0.8）	3（24.05）	20.111	28.9
15	4（23.5）	3（1.0）	2（24.00）	20.413	28.8
16	4（23.5）	4（1.2）	1（23.95）	20.618	28.7

According to the orthogonal test simulation results in table 3, the range analysis is carried out for the maximum pull-out force simulation results and the maximum swing angle of the ball pin, and the range value is obtained. The magnitude of the range reflects the influence of various factors on the maximum pull-out force of the outer steering rod and the maximum swing angle of the ball pin. Finally, the influence of three factors on the pull-out force of the outer steering rod and the maximum swing angle of the ball pin and the optimal size combination are determined. In the process of range analysis, $K_1K_2K_3K_4$ represents the sum of test indexes corresponding to the four levels of factor A, B and C respectively. Take the bowl size of factor A as an example and the maximum pull-out force as an index for range analysis. The four tests containing the first level of factor A are divided into one group, that is, tests 1, 2, 3 and 4 are divided into one group, which is recorded as the first group. In this group of tests, the four levels of factor B and factor C appear once respectively. Add this set of test data and record it as *K1. K1* reflects the four effects of the first level of factor A and the four levels of factor B and factor C. Similarly, *K2*, *K3* and *K4* can be obtained. Therefore, when factor A is compared with *K1K2K3K4*, it can be considered that the effects of the other two factors are the same, $\bar{K}1$ $\bar{K}2$ $\bar{K}3$ $\bar{K}4$ respectively represents the mean value of *K1K2K3K4*. The difference between $\bar{K}1$ $\bar{K}2$ $\bar{K}3$ $\bar{K}4$ is caused by different levels of factor A. calculate the first group of tests of factor A, and the calculation formula is shown in formulas (1) and (2).

$$K_1 = x_1 + x_2 + x_3 + x_4 = 26.316 + 26.853 + 26.524 + 27.892 = 107.585 \tag{1}$$

$$\bar{K}_1 = \frac{K_1}{4} = \frac{107.585}{4} = 26.896 \tag{2}$$

In the above formulas (1) and (2), x_1, x_2, x_3 and x_4 are the maximum pull-out force values corresponding to the first group of tests of factor A, *K1* and $\bar{K}1$ are the sum and mean value of the first group of test data of factor a respectively. Similarly, the $K_2K_3K_4$ value of factor a can be calculated and the mean value can be obtained, and then the maximum value and the minimum value of the mean value can be selected to obtain the R value, and R is the range [8]. Similarly, factor B and factor C can be calculated in the same way, and the final calculation results are listed in table 4; The range analysis is carried out for the maximum swing angle of the outer steering tie rod ball pin. The calculation method is as described above, and the results are listed in table 5.

It can be seen from table 4 that in the process of analyzing the maximum pull-out force of the outer steering tie rod, the factors affecting the maximum pull-out force peak are bowl size, step size and ball pin size in turn. There is a negative correlation between the bowl size and the maximum pull-off force of the outer steering rod. The smaller the bowl size is, the greater the pull-off force of the outer steering rod is; The step size and ball pin size are positively correlated with the maximum pull-out force of the outer steering tie rod. The greater the two values are, the greater the pull-out force of the outer steering tie rod is. Because the target is the maximum pull-out force of the outer steering tie rod, the greater the value is required, the better. According to the average value of each level, the maximum pull-out force is taken as the objective function, the optimal scheme is $A_1B_4C_4$. Under the condition of optimal size combination, HyperWorks and SolidWorks are used to simulate and analyze the maximum pull-out force and swing angle of the outer steering tie rod. The results are shown in table 6.

It can be seen from table 5 that in the process of analyzing the maximum swing angle of the ball pin of the outer steering tie rod, the factors affecting the maximum swing angle of the ball pin are bowl size, step size and ball pin size in turn. The bowl size is positively correlated with the maximum swing angle of the ball pin. The larger the bowl size is, the greater the swing angle of the ball pin is; The step size and ball pin size are negatively correlated with the maximum swing angle of the ball pin. The smaller the step size and ball pin size, the greater the swing angle of the ball pin. Because the optimization objective is the maximum swing angle of the ball pin, the larger it is required, the better. From the average value of each level, taking the maximum swing angle of the ball pin as the objective function, the optimal scheme is $A_4B_1C_1$. Under the condition of optimal size combination, HyperWorks and SolidWorks are used to simulate and analyze the maximum pull-out force and swing angle of the outer steering tie rod. The results are shown in table 6.

It can be seen from table 6 that only the maximum pull-off force of the outer steering tie rod is used as the objective function to optimize the component size, and its maximum pull-off force is 28kN, which meets the pull-off force requirements of the product. However, the maximum swing angle of the ball pin is only 25.5°, which is less than the minimum swing angle of 26° required by the product, so it does not meet the optimized maximum swing angle index of the ball pin; Only the maximum swing angle of the outer steering tie rod ball pin is used as the objective function to optimize the component size. The maximum swing angle of the ball pin can reach 29.5°, which meets the swing angle requirements of the product. However, the maximum pull-out force of the outer steering tie rod is only 17kN, far less than the 25kN required by the product, so it does not meet the pull-out force requirements of the optimized outer steering tie rod. Therefore, only taking the maximum pull-out force of the outer steering tie rod or the maximum swing angle of the ball pin as the objective function, the results can only meet the requirements of a single optimization objective, and can not meet the requirements of two optimization objectives at the same time. Therefore, it is necessary to introduce the weighted objective function for multi-objective optimization [9], so that the maximum pull-out force of the outer steering rod and the swing angle of the ball pin can reach the optimal state after optimization, so as to meet the requirements of the optimization of the outer steering rod.

Table 4. Difference analysis of maximum force.

Factors	**Bowl size/mm**	**Step size/mm**	**Ball Pin size/mm**
K_1	107.585	93.815	94.960
K_2	100.385	96.875	97.331
K_3	97.840	95.504	96.317
K_4	80.833	100.449	98.035
$\overline{K}_1$	26.896	23.454	23.740
$\overline{K}_2$	25.096	24.219	24.332
$\overline{K}_3$	24.460	23.876	24.079
$\overline{K}_4$	20.208	25.112	24.509
R	6.688	1.658	0.769

Table 5. Difference analysis of maximum force.

Factors	**Bowl size/mm**	**Step size/mm**	**Ball pin size/mm**
K_1	107.585	93.815	94.960
K_2	100.385	96.875	97.331
K_3	97.840	95.504	96.317
K_4	80.833	100.449	98.035

Factors	Bowl size/mm	Step size/mm	Ball pin size/mm
$\overline{K}_1$	26.896	23.454	23.740
$\overline{K}_2$	25.096	24.219	24.332
$\overline{K}_3$	24.460	23.876	24.079
$\overline{K}_4$	20.208	25.112	24.509
R	6.688	1.658	0.769

Table 6. Simulation results of optimal size combination.

Parameter Combination	Maximum Pull-Out Force/KN	Maximum Swing Angle of Ball Pin/°	Compliance with Product Requirements
$A_1B_4C_4$	28	25.4	No
$A_4B_1C_1$	17	29.5	No

B. *Multi Objective Optimization Analysis*

In order to make the optimized pull-out force of the outer steering tie rod and the swing angle of the ball pin meet the optimization requirements at the same time, the objective function of the pull-out force of the outer steering tie rod W_r (x) and the swing angle of the ball pin T_r (x) is constructed. Because the larger the pull-out force of the outer steering tie rod and the swing angle of the ball pin, the better, the value direction is the same in the optimization process, and the dimensionless values of W_r (x) and T_r (x) are taken to construct the objective function F_1 (x).

$$F_1(x) = z\ \omega_1 W_r(x) + \omega_2 T_r(x) \tag{3}$$

In equation 3, ω_1 and ω_2 are weights, which respectively represent the importance of the pull-out force of the outer steering tie rod and the swing angle of the ball pin in the objective function F_1 (x). Control their influence on the objective function F_1 (x) to meet $\omega_1 + \omega_2 = 1$. Both performances are equally important for the structural optimization of the outer steering tie rod, so $\omega_1 = \omega_2 = 0.5$. When calculating the formula, select the dimensionless relative value of W_r (x) and T_r (x) for calculation. The minimum value of pull-out force W_r (x) of outer steering tie rod is required to be 25 and the minimum value of ball pin swing angle T_r (x) is required to be 26. Replace the minimum values required by the two into equation (3) to calculate, and the minimum value required by objective function F_1 (x) is 25.5. According to the calculation results in table 3, the value of objective function F_1 (x) is obtained as shown in table 7, and the range analysis of the value of objective function F_1 (x) in table 7 is carried out. The results are shown in table 8.

Table 7. Results of the tests

Number	A Bowl size(mm)	B Step size(mm)	C Ball pin size(mm)	F_1 (x)
1	1（22.0）	1（0.6）	1（23.95）	26.558
2	1（22.0）	2（0.8）	2（24.00）	26.577
3	1（22.0）	3（1.0）	3（24.05）	26.162

Number	**A** **Bowl size(mm)**	**B** **Step size(mm)**	**C** **Ball pin size(mm)**	**F_1 (x)**
4	1（22.0）	4（1.2）	4（24.10）	26.646
5	2（22.5）	1（0.6）	2（24.00）	26.302
6	2（22.5）	2（0.8）	1（23.95）	26.641
7	2（22.5）	3（1.0）	4（24.10）	26.511
8	2（22.5）	4（1.2）	3（24.05）	26.539
9	3（23.0）	1（0.6）	3（24.05）	26.102
10	3（23.0）	2（0.8）	4（24.10）	26.865
11	3（23.0）	3（1.0）	1（23.95）	25.873
12	3（23.0）	4（1.2）	2（24.00）	27.131
13	4（23.5）	1（0.6）	4（24.10）	24.346
14	4（23.5）	2（0.8）	3（24.05）	24.506
15	4（23.5）	3（1.0）	2（24.00）	24.607
16	4（23.5）	4（1.2）	1（23.95）	24.659

It can be seen from table 8 that the factors affecting the change of objective function $F_1 (x)$ in the optimization process of outer steering tie rod are bowl size, step size and ball pin size in turn. Since the objective function $F_1 (x)$ is defined by the combination of the pull-out force of the outer steering tie rod and the swing angle of the ball pin, the greater the value is required, the better. According to the average value of each level, taking $F_1 (x)$ as the objective function, the optimal scheme is $A_2B_4C_2$. Under the condition of optimal size combination, HyperWorks and SolidWorks are used to simulate and analyze the maximum pull-out force and swing angle of the outer steering tie rod. The results are shown in table 9.

It can be seen from table 9 that when the component size is optimized by using the weighted objective function $F_1 (x)$ of the pull-out force of the outer steering tie rod and the swing angle of the ball pin, the maximum pull-out force is 27.5kN, which is 12% higher than that before optimization and meets the 25kN required by the product; The swing angle of the ball pin is 28°, which is 3% higher than that before optimization, meeting the product requirements of 26°. Finally, the optimized size combination of the outer steering tie rod is qualified and meets the application requirements of the outer steering tie rod in the actual working process.

Table 8. $F_1(x)$ Difference analysis.

Factors	**Bowl size/mm**	**Step size/mm**	**Ball pin size/mm**
K_1	105.943	103.308	103.731
K_2	105.993	104.589	104.617
K_3	105.971	103.153	103.309

Factors	Bowl size/mm	Step size/mm	Ball pin size/mm
K_4	26.486	25.827	25.933
$\bar{K}_1$	26.498	26.147	26.154
$\bar{K}_2$	26.493	25.788	25.827
$\bar{K}_3$	24.529	26.244	26.092
$\bar{K}_4$	1.969	0.456	0.327
R	26.498	26.147	26.154

Table 9. Comparison of results before and after optimization.

Outer Steering Tie Rod	Before Optimization	After Optimization	Rate of Change /%
Maximum pull-out force	24KN	27.5KN	+12.0
Swing angle of ball pin	27°	28°	+3.0

IV. CONCLUSION

Based on the finite element simulation, this paper takes the bowl size, step size and ball pin size of the outer steering tie rod as the optimization variables, and the maximum pull-out force of the outer steering tie rod and the maximum swing angle of the ball pin as the optimization objectives. The orthogonal test design is used to optimize the size combination of the outer steering tie rod.

According to the designed orthogonal test table, the corresponding three-dimensional model and finite element model are established to obtain the ball pin swing angle and the pull-out force of the outer steering tie rod respectively. The range analysis is carried out on the test results. When only the pull-out force of the outer steering tie rod is taken as the optimization objective, the optimal size combination can not meet the requirements of the ball pin swing angle; When only the ball pin swing angle is taken as the optimization objective, the optimal size combination can not meet the requirements of the pull-out force of the outer steering tie rod. Therefore, it is difficult to find a group of size combinations to meet two optimization objectives at the same time when only a single objective is taken as the optimization objective. Therefore, using two objective functions to construct a weighted objective function for size combination optimization can obtain the best size combination, and the pull-out force of the outer steering rod and the swing angle of the ball pin are effectively optimized within the qualified range. The research conclusions can provide reference for the next step of tire grip performance research.

REFERENCES

[1] S. Sleesongsom, S. Bureerat. Multi objective optimization of a steering linkage [J]. Journal of Mechanical Science and Technology, 2016, 30(8): 81-91.

[2] Neider Romero, Elkin Florez, Luis Mendoza. Optimization of a multi-link steering mechanism using a continuous genetic algorithm [J]. Journal of Mechanical Science and Technology, 2017, 31(7): 83-88.

[3] Ruidong Guo, Song Xue, Ailin Deng. Failure analysis of the balance ball pin in the car steering system [J]. Engineering Failure Analysis, 2018, 94: 232-238.

[4] Du Heng, He Yongyao, Chen SM. Study on tie rod force characteristics in electro-hydraulic power steering system for heavy vehicle [J]. Proceedings of the Institution of Mechanical Engineers, Part D: Journal of Automobile Engineering, 2021, 235(2-3): 564-579.

[5] Aravindaraj E. Natrayan L. Santhosh M.S. Kumar M.S. Design and analysis of connecting tie rod assembly for automotive application [J]. IEEE/CAA Journal of Automatica Sinica, 2018, 5(2): 15-20.

[6] Bo-zhen Ji, Bao-zhu Jian, Jian-jun sun. Fracture analysis and optimization design of 42CrMo tie rod [J]. Forging technology, 2015, 40 (12): 136-140.

[7] Tao Xu. Simulation study of hydraulic reinforcement subsidy on broken casing [J]. Petroleum machinery, 2020, 48 (01): 117-123.

[8] Shu-jian Zhu, Jian Li. Simulation and optimization of hydro forming in t-tee based on orthogonal test method [J]. Forging technology, 2018, 43 (09): 75-82.

[9] [9] Jin-zhong Li, Jie-wu Xia. Research progress of multi-objective simulated annealing algorithm and its application [J]. Computer engineering and science, 2013, 35 (08): 77-88.

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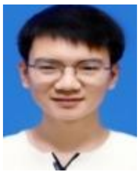

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