Energy Saving Design and Optimization of suspension System in Baja Competition for College Students

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Abstract: The suspension design and optimization of Baja car were carried out on the premise of meeting the rules of the race in order to improve the handling stability and ride smoothness of the car. Firstly established the 3 d modelling software UG in suspension system 3 d model, the according to the design of the frame model of hard point ADAMS motion simulation model of motion simulation analysis and optimization selection of parameters, stress suspension system was analyzed by ANSYS, ensure the strength of the car, according to the four-wheel positioning parameters of suspension system and, along with the change of wheel parallel to beat curve using ADAMS/Insight module for parametric curves were optimized. Combined with the design and optimization, the front wheel camber angle changed from 0.81 to 0.68, the caster angle changed from 5.66 to 5.84, the caster angle changed from 6.35 to 6.42, and the front wheel toe angle changed from-1.48 to 0.99, jumping up and down in front wheel track changes reduced from 100 mm to 50 mm, swing arm to connect hard point rise of the front suspension arm Angle smaller, ultimately achieve steering the car light, effectively improve the performance of the car.

Keywords: Baja Racing; Suspension system; ADAMS simulation and optimization; ANSYS analysis; Structural parameter optimization.

1. Introduction
Baja SA E China (BSC Contest for short) is a small off-road vehicle competition for college students sponsored by China Society of Automotive Engineering. The BSC competition requires teams to design and manufacture a single-seat, mid-engine, rear-drive suv using the same type of engine within one year. As one of the most critical components in the chassis, suspension is an important assembly of the whole vehicle. Its main task is to transfer all the forces and torques between the wheel and the frame (or body); It eases the impact load transmitted from the road to the frame (or body), attenuates the vibration of the bearing system caused thereby, and ensures the ride comfort and handling stability of the racing car [1-2].

Worldwide at present, the study of suspension performance is relatively common [3-5], if it is based on the old design scheme to carry out the test and optimization, there is significant waste of resources, on the one hand, on the other hand is difficult to achieve the ideal design in 1 year period, so in this paper, on the premise of meet the tournament rules [6], baja racing suspension system for design and optimization, comprehensive handling car, driving stability, driving comfort design concept, design a set of highly handling, stability, impact resistance, the small cross-country car suspension system.

2. Establish the Three-dimensional Model of Suspension
Determination and 3 D Modeling of Suspension Type: The front suspension uses the double cross arm type independent suspension, this suspension has the good handling, can provide the better lateral support and the lateral rigidity, simultaneously for the driving condition bad Baja car, also can guarantee
the certain stability. The rear suspension adopts oblique single longitudinal arm suspension, and adds two limit pull rods to limit the freedom of the tire, which is similar to the multi-link suspension in structure. The advantages of this suspension form lie in its stable structure, stable limit of rear wheel, and high upper limit of parameter adjustment [7].

Design of Front and Rear Column Wheel Cores: In the case of meeting the strength requirements, the design process is dominated by column, wheel core and swinging arm. The lower swinging arm of the suspension frame adopts 4130 steel pipe with a wall thickness of 2.4mm. The front and rear wheel core columns are made of 7075 aluminum alloy, which can greatly reduce the vehicle weight. In the design of structural modeling, a simple and practical wheel core column is designed mainly considering the processing cost, the convenience of disassembly and assembly and the factors of improving material utilization ratio, as shown in Figure 1 and Figure 2.

![Figure 1. Front wheel core column.](image1)

![Figure 2. Rear wheel core column.](image2)

Design of Swinging Arm: Three aspects should be considered in the design of swinging arm: first, the strength should meet the design requirements; Secondly, we should pay attention to the lightweight optimization design; Finally, design with installation in mind. In terms of material selection, 4130 steel tubes with a wall thickness of 2.4mm are used for the lower arm of the suspension frame, as shown in Figure 3 and Figure 4.

![Figure 3. Front swinging arm.](image3)

![Figure 4. Backswing arm.](image4)

### 3. Suspension Stiffness Check

By ANSYS finite element analysis of the suspension system, the stiffness is a very high performance when racing cars run on various racetracks. Finite element analysis of wheel core column: save the model of wheel core column established by 3D modeling software UG as "stp" file format, and then define the material of wheel core column, including setting Poisson's ratio and elastic modulus, and then apply the working force to the wheel core column, and then mesh it, and finally get the stress diagram [8]. As shown in Figure 5, it can be seen from the figure that the wheel core Mpa meets the driving practice of the real month, and the strength of the column is reliable and participates in the competition.

![Figure 5. Stress diagram of core column.](image5)
4. ADAMS Motion Simulation Model and Parameter Determination
ADAMS software was used to build the motion simulation model. The model was simplified and assumed as follows: (1) each component of the front and rear suspension is rigid body, and no deformation occurs when the wheel is jumping up and down; (2) The wheel is also simplified as a rigid body without considering the deformation of the wheel; (3) The connection between parts shall not consider the clearance, and the friction force between parts shall be ignored; (4) The damping characteristics of front and rear suspension shock absorbers are simplified to linear characteristics. The hard point coordinates of the suspension system are determined by the THREE-DIMENSIONAL model established by UG, and the kinetic model of front and rear suspension is established in ADAMS, as shown in Figure 6 and Figure 7:

![Figure 6. Motion simulation of front suspension Adams.](image)

![Figure 7. Motion simulation of rear suspension Adams.](image)

5. Determination of Four-wheel Positioning Parameters
Four-wheel positioning parameters is to ensure that in the case of steering system can work normally still can make the wheels with automatic correction function \([9\text{-}10]\), taking into account for the front suspension design bigger kingpin inclination and caster Angle, make the wheels with large positive moment back, facilitate correction, isometric double cross arm USES swing arm is expected at the same time make the wheels on the more sensitive response \([11\text{-}12]\). As for the rear suspension, the traditional three-link is abandoned, and the double wishbone of the same length as the front suspension is adopted, and the lateral pull rod is used to limit the left and right swing of the wheel.

5.1 Front Wheel Camber
The camber angle of the front wheel is the clamp between the intersection of the transverse plane of the automobile passing through the center of the front wheel and the plane of the front wheel and the vertical line of the ground. The camber angle of the front wheel can make the tires wear evenly and reduce the load of the outer bearing of the hub, and the general design value is about 1. It can be seen from the solid line in Figure 9 that the angle changes from 1.22 to 0.18, the change amount is greater than 1°/50mm, and the change trend does not meet the design requirements. When the wheel moves upward from the equilibrium position, the angle should decrease, and it is better to decrease to a negative value, so there is still room for optimization.

**Optimization of camber angle of front wheel:**
It can be seen from Figure 8 that after optimizing the parameter curve with ADAMS/Insight module, the camber angle of the wheel changes from 0.81 to 0.68, the change amount is less than 1°/50mm, and the change trend is more in line with the design requirements.
5.2 Caster Angle of Kingpin
The caster angle is the angle between the kingpin axis and the vertical line of the ground in the longitudinal plane of the automobile. The caster angle of the kingpin can make the wheels form a stable moment of righting, so as to ensure the straight running of the automobile. We designed the caster angle to be 6. The caster angle of the suspension kingpin changes as shown in Figure 9. It can be seen from the solid line in Figure 9 that the angle changes from 4.86 to 5.04, and the overall change is less than 1°/50mm, but the distance from the design value is too large to meet the design requirements, so there is still room for optimization.

Optimization of kingpin caster angle:
It can be seen from Figure 9 that after optimization, the kingpin caster angle changes from 5.66 to 5.84, the overall change is less than 1/50 mm, and the distance from the design value is less, which better meets the design requirements.

5.3 Inclination Angle of Kingpin
The angle between the kingpin axis and the vertical line of the ground in the transverse plane of the automobile is called the kingpin inclination angle. In addition to the function of automatically aligning the wheels, the kingpin inclination angle can also make the steering lighter. Generally, the design value is not more than 8, and our design kingpin inclination angle is 7. The variation of kingpin inclination angle of the front suspension is shown in Figure 10. It can be seen from the solid line in Figure 10 that the angle increases from 7.40 to 6.25. The angle value is similar to the design value, but it has a wide range of changes and does not meet the design requirements, so it needs to be optimized. Front wheel front bundle Angle: Through ADAMS/Insight module analysis of the front wheel front bundle Angle from 1.48° to 0.99°, when installing the front wheels, make the center surface of the two front wheels of the race car not in the same plane, eliminate the front wheels on the ground edge sliding phenomenon, reduce tire wear.

Optimization of kingpin inclination angle:
It can be seen from Figure 10 that after ADAMS/Insight module analysis, driver's driving practice for two months and repeated tests, the kingpin inclination angle changes from 6.35 to 6.42, so that the
overall change range is smaller, which better meets the design requirements, reduces the driver's force
on the steering wheel, and reduces the impact of severe and complex track on the steering wheel, thus
achieving the effect of making the driver drive comfortably.

![Figure 10](image1.png)

**Figure 10.** Comparison curve of caster angle of BSC racing car before and after optimization, dotted line is after optimization.

5.4 Front Wheel Toe Angle
The existence of front wheel toe-in can eliminate the adverse effects caused by wheel camber, so that
the wheel will not roll and slip. The ideal toe angle change should be zero to negative toe-in when the
wheel jumps up. The toe angle of the front suspension changes as shown in Figure 11. It can be seen
from the solid line in Figure 11 that the angle changes from -1.99 to -0.61, and the angle of negative toe-
in changes greatly, which needs further optimization.

**Optimization of front wheel toe angle:**
It can be seen from Figure 11 that the optimized front wheel toe angle changes from -1.48 to 0.99, the
change trend remains unchanged, and the overall change quantity becomes smaller, which better meets
the design requirements.

![Figure 11](image2.png)

**Figure 11.** Comparison curve of BSC racing car toe angle before and after optimization, dotted line is after optimization.

6. Structural Optimization of Front Suspension
Suspension optimization: In order to improve the handling of the car, the front suspension at the
beginning of the design first consider the reduction of the tire jumping up and down when the four wheel
positioning parameters change. The front swing arm adopts the upper and lower parallel double fork
arm type, which is 10° lower than that of last season, 60mm higher than the hard point of the lower
swing arm, and 80mm lower than the front suspension wheel base.
In the case that the swing arm Angle becomes slower and the span becomes smaller, the change of wheel
base when the front suspension jumps up and down is reduced from 100mm last season to 50mm.
After the suspension: The rear suspension swing arm also adopts the double-fork arm structure with the
upper and lower parallel, and the overall rear suspension is the five-link independent suspension, so as
to improve the adhesion ability of the racing wheels, enhance the driving stability and the passing ability
of the racing cars.
Swing arm manufacture: The front swinging arm is changed from U-shaped arm to A-shaped arm, and the rear swinging arm is changed from bent arm to straight arm, avoiding hot machining and ensuring the strength of swinging arm.

Figure 12. Front suspension for racing car.

Figure 13. Rear suspension for racing car.

Connecting hard points of front column and swing arm: The tilt Angle of the swing arm of the front suspension is small due to the rise of the swing arm connection hard point. The front column breaks the traditional form to change the wheel mandrel entry type into the upright shaft entry type, and the swing arm connection hard point is raised to the center of the tire. In the case of shortened wheel base and slow swing arm Angle, the swing arm span is reduced, which, on the one hand, increases the strength of the swing arm itself, and on the other hand, reduces the range of change of wheel base when the tire jumps up and down, which is beneficial to the driving stability of the car and reduces the wheel wear.

7. Conclusion
In this paper, a three-dimensional model of suspension system is established in the three-dimensional modeling software UG, and the coordinates of all hard points needed by ADAMS/car to establish the model are determined by measuring the point coordinates of the model in UG and combining with the actual design data, and the simulation test-bed is built on ADAMS/car. The post-processing module Postprocessor is used to analyze the angle change of each wheel positioning parameter; Sensitivity analysis of the optimization target is carried out by using the optimization module Insight, thus completing the optimization process of the front suspension. In suspension design, firstly, all parts are built and assembled in UG, then the required hard point coordinates are determined according to the design data, and finally, the model is completed and the test bench is established on ADAMS/car according to the parts' functions and parts' relationships. Finally, the four-wheel positioning parameters, the front wheel camber angle changed from 0.81 to 0.68, the caster angle changed from 5.66 to 5.84, the caster angle changed from 6.35 to 6.42, and the front wheel toe angle changed from -1.48 to 0.99, the hard point of the swing arm connection is raised, and the shape of the front and rear swing arms is optimized, which finally achieves the effect of making the steering operation of the racing car light and effectively improving the performance of the racing car, and successfully completes the race with excellent results.

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