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Application of Finite Element Algorithms for Formula Racing Steering Wheels

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Abstract: - The steering wheel of a Formula Student car has an important influence on the driving and handling stability of the car. The steering wheel of the racing car must have good mechanical and stable performance, taking into account lightweight and economic performance. Due to the small riding space of the car, the size of the steering wheel is not required to be too large. In this case, it is very difficult to meet its harsh stress state and control its vibration and noise. Based on the general requirements of the competition rules of the Formula Student racing competition, this paper constructs the geometric model of the steering wheel of the racing car by using the computer 3D design software CATIA. ANSYS software was used to conduct finite element analysis of the mechanical properties of the metal skeleton of the steering disc. Magnesium alloy, a light material with excellent mechanical properties, was selected, and combined with the actual working conditions of the steering disc, especially the force under extreme conditions, the computer simulation results showed that the force distribution and displacement of the steering disc met the design requirements. Considering that the noise and vibration of the steering wheel will have a great impact on the racer, the modal analysis of the steering wheel is carried out by using ANSYS software, and the analysis results show that there is no resonance or instability.

Keywords: Finite Element Algorithms; Steering wheel; Modal analysis; NVH.

I. INTRODUCTION

Formula Student Competition (FSAE) requires students to organize teams to independently design, manufacture, and debug a Formula car every year. In the process of design and manufacturing, in addition to testing the team's engineering practice ability, it also considers the team’s engineering management, commercial marketing, cost control, investment promotion, and other all-round capabilities. Each Formula car is the result of wisdom and engineering invested by a group of aspiring young people for a whole year, and it is also a true portrayal of the spirit of craftsmanship. The event closely follows the development path of the industry, deeply promotes cooperation in all aspects of production, teaching, and research, and trains much-needed talents for the industry. Committed to building a new generation of automotive talents, Whampoa Military Academy has received support and recognition from all walks of life [1].

To effectively solve the big vibration problem of an MPV steering wheel when the engine speed reaches 2500r/min, WANG Ya-yun and SUN Fu-hua systematically analyzed the vibration transmission path combined with the problem phenomenon, and used data acquisition equipment to confirm that the vibration was transmitted to the steering wheel through the right suspension of the engine second-order excitation. By adjusting the engine calibration strategy to avoid the vibration frequency of the steering wheel, and optimizing the steering wheel rim to reduce the first-order modal amplitude of the steering wheel body. Subjective evaluation and real car tests show that after the implementation of the optimization scheme, the steering wheel vibration is significantly reduced, the problem is effectively solved, and the NVH performance of the car is improved [2].

Miriam Fandakova, Michal Pal cak, and Pavol Kudela propose a method for creating a 3D virtual model of a steering wheel in a car and realizing a real-size assembly in the model space. Focus on solving the theoretical knowledge of steering wheel modeling problems, size specifications, the number of assembled parts, and the selection of a suitable 3D CAD application. It also describes a variety of non-standard software with specific functions, which have made significant contributions to the work of more attractive designs [3].

From the perspective of human body size and psychological and behavioral characteristics of the elderly, Weng Guowei et al. designed the ring steering wheel structure with Solidworks software based on the design concept of humanization, emotion, and green design, and carried out mechanical analysis and modal analysis of the ring wheel mechanism of the elderly mobility scooter by using ANSYS finite element analysis. The results show that the designed indexes meet the working requirements [4].

People like Dana Boheme discussed the design, modeling, and manufacturing process of a multi-purpose steering wheel for a formula racing car. This multi-functional steering wheel can adjust the lateral control of the car by changing its parameters. The design of the steering wheel is aimed at comfort, practicality,

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manufacturability, and economy. The design and manufacturing process of the main modular die is given in consideration of the production process and the selection of suitable materials. The steering wheel of the Formula Student electric racing car SGT-FE18 uses pre-impregnated carbon fiber fabric-reinforced polymer (CFRP) curing technology under high pressure and the design of the composite layer, the bending test of the material is carried out, and the custom internal parts via 3D printing technology are used to install the electrical components and mechanical control components [5].

ZHAO Shaohua and HUANG Qin analyzed the stiffness, strength, mode, and fatigue life of a steering wheel by finite element analysis technology, to assist the design of the steering wheel. The commonly used finite element analysis software HyperMesh, NASTRAN, and Ncode were used to carry out corresponding finite element analysis of a steering wheel, and the analysis results were compared with the relevant design standards of automobile enterprises. The results showed that the steering wheel met the design requirements [6].

HE Ya-nan et al solved the steering wheel skeleton simulation analysis and structure optimization problems through LS-DYNA software and CATIA software. LS-DYNA software simulation analysis method is used to analyze the bending characteristics of the digital model, spline sleeve push-out analysis, head object impact analysis, and upper body dummy impact analysis. The surface creation method of CATIA software was used to optimize the structure of the 3D model with simulation failure. The results show that LS-DYNA and CATIA software solve the problem of the steering wheel skeleton structure. It is feasible to use LS-DYNA and CATIA together to solve the design problems of the steering wheel skeleton structure in the early stage [7].

Sumit S. Naygaonkar and Sandeep R. Desai measured and analyzed the vibration of agricultural tractors by surveying the drivers of agricultural tractors, found the current situation of serious vibration of the steering wheel of agricultural tractors, and put forward suggestions to reduce the degree of vibration. The main purpose of this work is to minimize the vibration of the steering wheel of agricultural tractors, thereby reducing the adverse effect on the driver's hands. Through a survey of agricultural tractor drivers, we found information on the degree of steering wheel vibration they experienced. Through the measurement of the tractor’s vibration value, the vibration problem experienced by the driver when driving the tractor is confirmed. In this study, the root cause of steering wheel vibration was found by measuring steering wheel vibration. According to the cause analysis, a tuned mass damper was installed on the steering wheel to reduce the vibration amplitude at the steering wheel of the tractor to solve the problem [8].

Sumit Someshwar Naygaonkar and Sandeep Rangao Desai conducted a trial analysis of steering wheel vibration in agricultural tractors to reduce arm vibration syndrome (HAVS). The Mahindra 575 DI tractor was selected for further research and development because the maximum vibration acceleration of the Mahindra 575 DI tractor was found when the vibration amplitude of various tractors was measured. The researchers designed an experimental test device to reduce steering wheel vibration, that is, after setting a tuned mass damper between the steering gearbox and the shaker, the vibration level was effectively reduced [9].

II. Steering performance requirements for Formula Student racing cars

Formula Student drivers drive cars that can avoid obstacles at high speeds, enter and exit corners, and steer hard to ensure driving safety. The race track adopts sharp turns with small turning radius and obstacle barrels with different spacing, and the steering wheel must ensure light weight and good mechanical properties to meet the mechanical performance requirements. The rules require cars to use a purely mechanical steering system and prohibit power steering. The driver's arm force is the only source of control of the steering wheel, which drives the other steering gears to complete the steering action of the car. The technical state of the steering wheel of a racing car has a great impact on the safety of the vehicle and the workload of the racer. The steering wheel is the key component of car steering, is to ensure the basis of car steering, straight, and sometimes even affects the life safety of the racer. The steering disk must be a close round or oval shape, with no inward concave parts, but it can have a certain flat part of the outside, and can not use unconventional steering disk or split steering disk. No matter what Angle, the top of the steering wheel should be lower than the top of the front ring.

It can be seen that the steering efficiency of the car is high, and it is necessary to use a small steering wheel Angle and a small rack stroke to achieve the desired steering wheel Angle. And the free travel of the steering disk can not be too large, and the operation needs to be agile when steering, to achieve sharp steering. The jitter generated by the Vibration excitation transmitted by the chassis will be directly fed back to the driver. If the jitter is too large, it will not only affect the NVH (Noise Vibration Harshness) performance of the vehicle, and reduce the driving comfort, but also affect the normal running of the car. It interferes with the driver's operational stability and becomes an unsafe factor in driving.

The design of the steering wheel of a racing car must start from the two aspects of mechanical properties and NVH, taking into account light weight and economy. Due to the particularity of the small riding space of the racing car, its size is required not to be too large. In this case, it is very difficult to meet its harsh stress state and control its vibration and noise.

III. Geometric modeling of steering disk

The steering disc assembly is composed of a magnesium and aluminum alloy skeleton, polyurethane foam, plastic parts, and electronic components, among which the magnesium and aluminum alloy skeleton is the main bearing structure, which determines the mechanical properties of the steering disc assembly and is the main structure of the steering disc modal optimization. The steering wheel skeleton is generally divided into spoke plates, spokes and wheel edges, as shown in Figure 1.

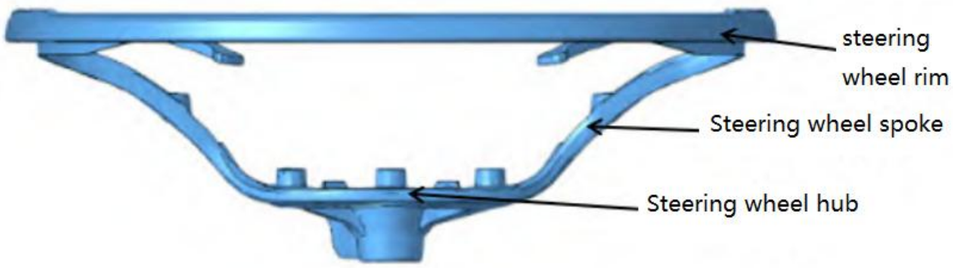


Figure 1: Skeleton structure of steering wheel

According to the design rules of the racing car, the three-dimensional model of the steering disc assembly is designed using CATIA, as shown in Figure 2. In the process of modeling, the three-dimensional diagram of each part is drawn first, and the final assembly is put together.

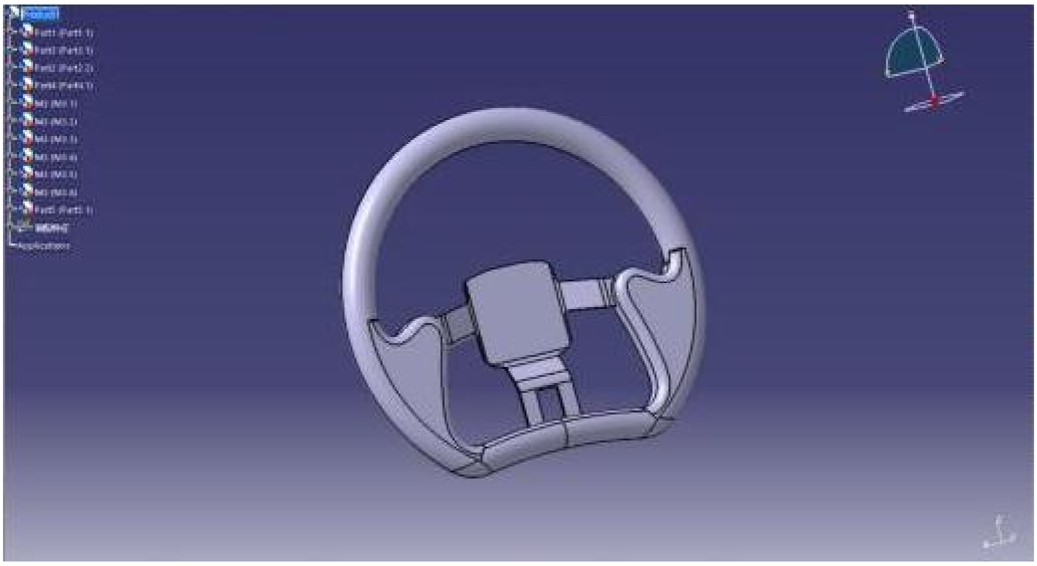


Figure 2: Overall 3D diagram of the steering wheel

IV. ANSYS simulation analysis

A. *Static analysis*

The purpose of this static analysis is to evaluate the stability and safety of the steering wheel during use, determine its bearing capacity and deformation, and put forward corresponding improvement suggestions according to the analysis results.

a) Material conditions

The light material AM60B magnesium alloy is used as the frame material of the steering disc, which is light and has excellent mechanical properties. Table 1 shows the detailed parameters of AM60B magnesium alloy material.

Table 1: Parameter Settings of AM60B magnesium alloy

argument	Value
Density (kg/m^3)	1790
Modulus of elasticity (MPa)	4.5×10^4
Poisson's ratio	0.35
Yield limit (MPa)	130
Elongation (%)	8
Strength limit (MPa)	230

b) Load conditions

The CATIA model was converted and imported into ANSYS software. The model was pre-processed, and then the properties of magnesium alloy were defined. The mesh division platform in ANSYS was used to divide the mesh. Considering the running speed and calculation accuracy of the computer, tetrahedral mesh with a side length of 3mm is used. The boundary conditions of finite element analysis are Loads and constraints. With fixed constraints, we use the torque loads provided by Mechanical in ANSYS, click Static Structural(A5), then select the center point of the steering wheel, and click loads to select the Moment. The load condition considered in this analysis is the maximum torque of the steering wheel during use, and its value is 40N·m, input it, then select Solution, then click Insert, Stress, Equivalent in the sequence, and then click Solution again, right mouse button Solve. The result is shown in Figure 3.

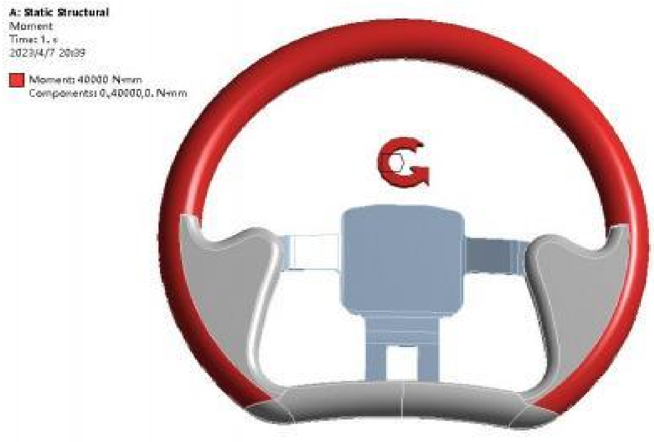


Figure 3: Applying torque

c) Analysis method

In this analysis, the steering disc is divided into finite elements by the finite element method, the node displacement equation and the element stiffness matrix are established, the global stiffness matrix is assembled, and the boundary conditions are applied to solve the static characteristics of the steering disc such as displacement, stress, and strain.

d) Analysis results

According to the analysis results, it can be seen from Figure 4 that 0.53767mm generated by the steering disk under the force action is the maximum displacement. As can be seen from FIG.5, 96.831MPa is the maximum stress; As can be seen from Figure 6, 4.8416e-4 is the maximum strain. The analysis results show that the steering disc has sufficient stability and safety under the load condition, and no obvious deformation and failure phenomenon is found.

According to the results of static analysis, the steering disc has sufficient stability and safety during use, but it is still necessary to pay attention to the selection of appropriate materials and sizes during design and use, and take appropriate installation and use conditions to reduce the stress and strain of the steering disc and extend its service life.

B. Modal analysis

The purpose of this modal analysis is to evaluate the vibration characteristics and natural frequency of the steering wheel during use, determine its natural frequency and vibration mode, and put forward the corresponding improvement suggestions according to the analysis results.

a) Analysis method

In this analysis, the finite element method was used to divide the steering disc into a finite number of small elements, establish the node displacement equation and the element stiffness matrix, assemble the global stiffness matrix, and apply boundary conditions to solve the natural frequency and vibration modes of the steering disc [10][11][12].

b) Analysis Process

The CATIA model was converted and imported into ANSYS, and the model was pre-processed, and then the properties of magnesium alloy were defined and contacts were established. The mesh division platform in ANSYS was used to divide the mesh, and the tetrahedral division method was used to establish a 3mm tetrahedral mesh. The material properties are shown in Table 1. By clicking the mouse, select the Insert that appears, select Fixed Support, select Tools in the toolbar, then select the center point of the steering wheel, and click Apply. Then click Insert in the menu, click Displacement, select the Line tool, select the whole steering wheel, then click Apply, enter zero in the Z Component, and finish the configuration. Click Solution, Insert, Deformation, and Total in the directory respectively, and then click Solve in the menu to solve.

After solving, click Total Deformation in the model, select the modal values of each order appearing on the computer screen, and then select Create Mode Shape Results (as shown in Figure 7). Six Total Deformations will appear in the directory. Then click Solution and right-click Ecaluate All results. The corresponding vibration modes are shown in Figure 5 below.

Table 2: First six frequencies of steering wheel

The number of modal orders	1	2	3	4	5	6
natural frequency	22.924Hz	25.673Hz	35.424Hz	63.363Hz	75.624Hz	115.32Hz

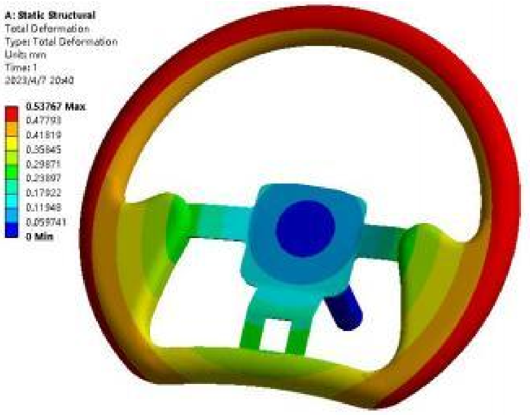


Figure 4: Displacement cloud image

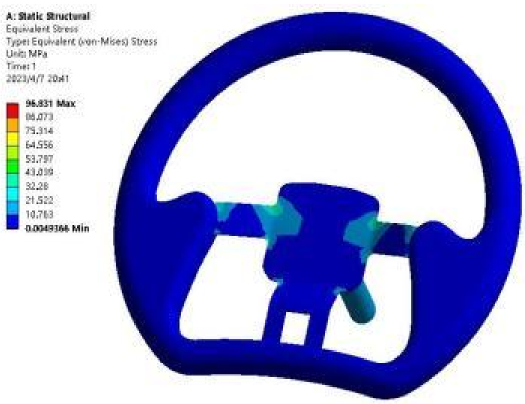


Figure 5: Stress cloud image

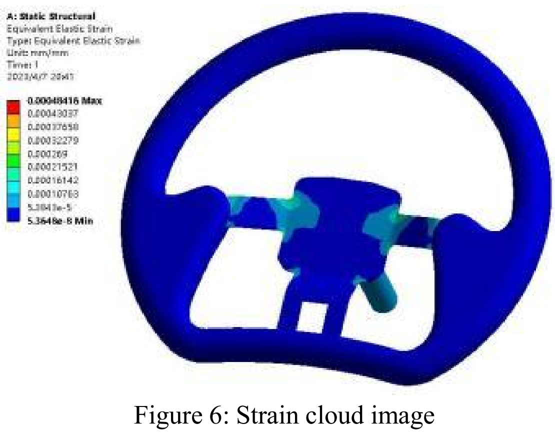
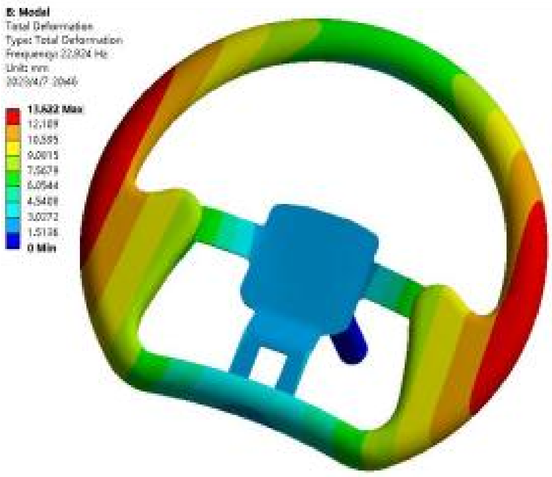
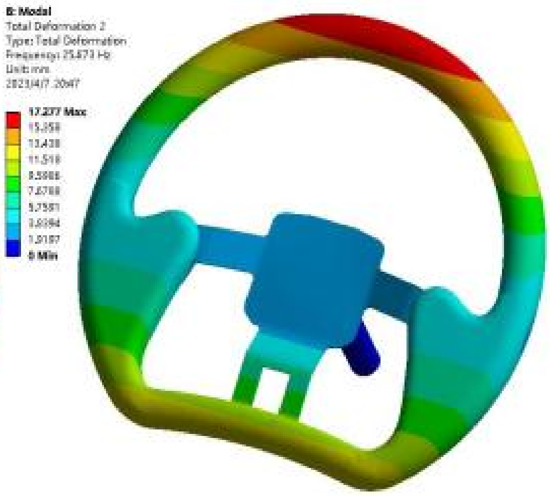


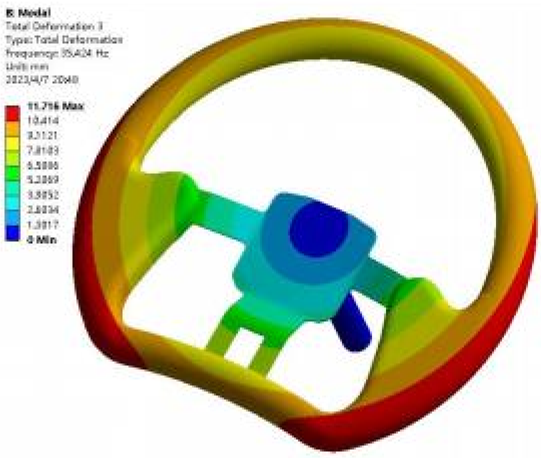
Figure 6: Strain cloud image



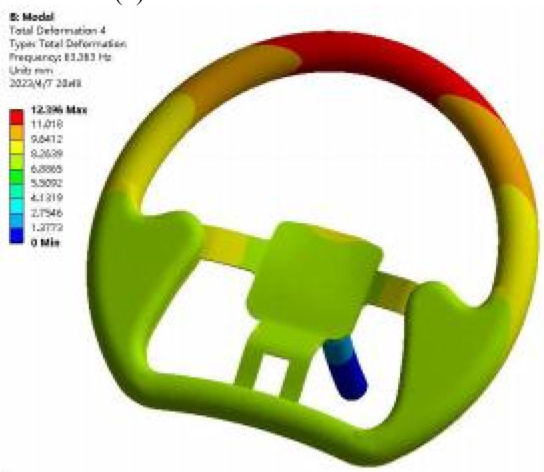
(a) Formation drawing of the first order



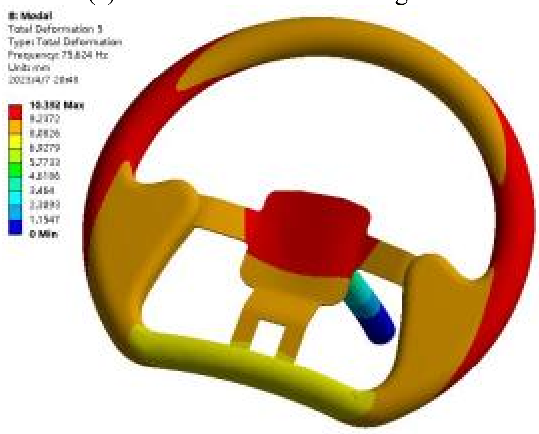
(b) The second formation chart



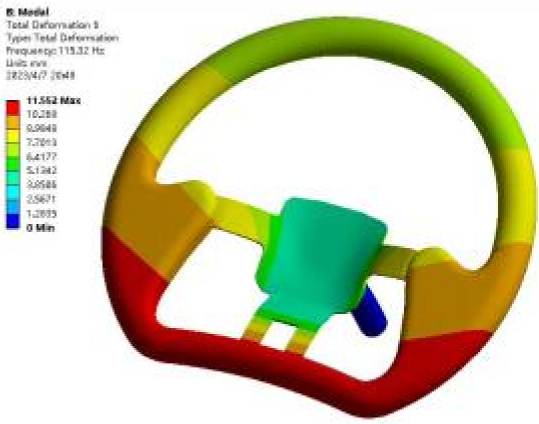
(c) Third-order formation diagram



(d) Fourth-order formation chart



(e) Formation chart of the fifth order



(f)Sixth order formation chart

Figure7: Modal formation diagram

According to the results of the modal analysis, the natural frequency and vibration modes of the steering wheel meet the design requirements, and no obvious resonance and vibration instability are found. However, it is still necessary to pay attention to the selection of appropriate materials and sizes in the design and use process, and to take appropriate installation and use conditions to reduce the vibration and noise of the steering disc and improve its comfort.

V. CONCLUSION

In this paper, a series of studies are carried out around the steering wheel of a Formula Student racing car, and its material, size, and shape are determined within the scope of competition rules. The three-dimensional modeling of the steering wheel was carried out by CATIA software, and the static and modal finite element analysis of the steering wheel under various working conditions was carried out by ANSYS software. The analysis results showed that the steering wheel made of magnesium alloy was not only light in weight, but also had good mechanical properties, which was suitable for the material selection of racing car design and laid the foundation for the manufacture of formula racing cars in the later stage.

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