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Modal Analysis of Formula Racing Frame

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Abstract: Taking the equation racing car frame as the research object, the 3D modeling software was used to establish the model of the racing car frame, and the free mode analysis of the frame was conducted through the finite element analysis software. The natural frequency of the frame was within the range of 30-120Hz, avoiding the possibility of resonance, indicating that the structural design of the frame was reasonable. In addition, the vibration mode of the frame was analyzed. This provides a certain idea for further optimization research of the frame.

1. Introduction

For Formula Racing, the frame serves as the carrier of the racing car, bearing the entire weight of the car[1]. During the race, whether the structure of the car frame is reasonable will affect the performance of the car. It is of great significance to model and analyze the free mode of the car frame, establish a reasonable car frame model, avoid the possibility of resonance, and ensure the reliability and safety of the car[2].

2. Establishment of Finite Element Model for Racing Frame

2.1 Selection of frame geometric modeling and materials

Build a model of the racing frame using 3D modeling software, and the established racing frame is shown in Figure 1:

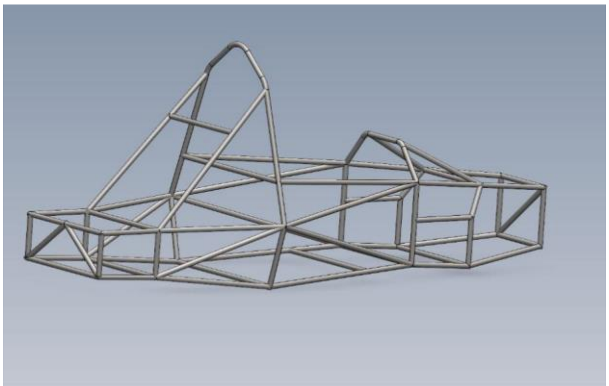


Figure 1: 3D Model of the Vehicle Frame

The material used for racing frames is usually 4130 steel, and the material properties typically include elastic modulus, density, and Poisson's ratio. The material properties of 4130 steel are shown in Table 1:

Table 1: Frame material properties

Material name	Elastic modulus (GPa)	Density (kg/m3)	Poisson's ratio
4130 steel	211	7850	0.29

2.2 Frame finite element model

Import the established model into the finite element analysis software, set material properties, and then select an automated meshing method to divide the frame into grids. The grid size is selected as 5mm, and the divided grid model is shown in Figure 2. There are 74148 grid nodes and 73224 grid units.

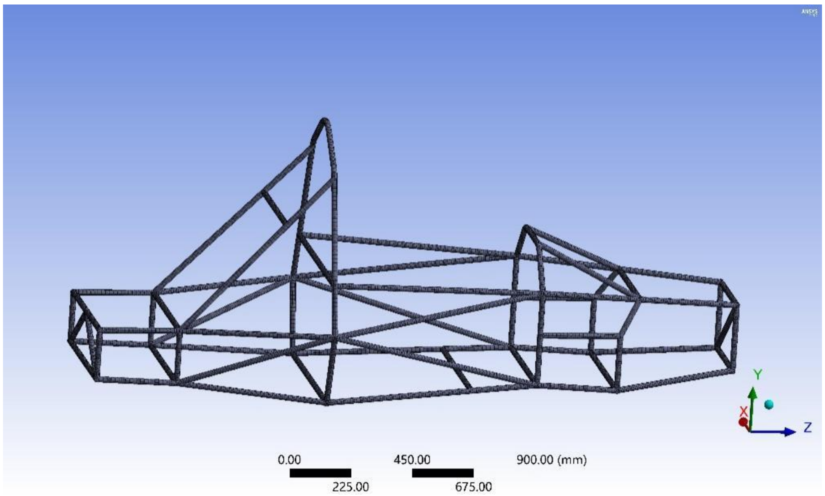


Figure 2: Finite Element Model of Vehicle Frame

3. Modal analysis

3.1 Free modal analysis theory

Modal analysis is a structural dynamics analysis method based on structural vibration theory, used to determine the vibration characteristics of a structure, study the natural frequency, vibration mode, and damping characteristics of the structure during free vibration, and then analyze and predict the vibration response of the structure[4].

According to vibration theory, the differential equation of motion of the system is:

$$M\ddot{x}(t) + C\dot{x}(t) + Kx(t) = P(t)$$

Where: M-system's mass matrix, C-damping matrix, K-stiffness matrix; $\ddot{x}(t)$ - displacement vector of the system, $\dot{x}(t)$- velocity vector, x(t) - acceleration vector; P (t) - Excitation force array. Due to the small damping C of the frame vibration system, it can be ignored. A modal model is established using free vibration, where P(t)=0. Therefore, the above equation can be simplified as:

$$M\ddot{x}(t) + Kx(t) = 0$$

3.2 Free modal analysis steps

Free mode analysis is a structural analysis method, which is used to determine the free vibration frequency and mode shape of the structure. The following are the general steps of free modal analysis:

Defining a structural model: Firstly, it is necessary to define the geometric shape and materials of the structure, which typically involves using modeling software to construct a structural model.

Establish mass matrix and stiffness matrix: determine the mass and stiffness of each node in the structural model, and then use this information to build the mass matrix and stiffness matrix, which describe the physical characteristics of the structure.

Solving the characteristic equation: The characteristic equation is an equation about the free vibration frequency, which contains information about the mass and stiffness matrices. By solving the characteristic equation, the free vibration frequency and corresponding vibration mode of the structure can be determined.

Calculation of vibration mode: Once the free vibration frequency is solved, the stiffness matrix and corresponding eigenvectors can be used to calculate the vibration mode of each node.

Analysis results: Finally, it is necessary to analyze the results, determine the inherent characteristics and free vibration modes of the structure, and evaluate whether these characteristics meet the design requirements.

Generally speaking, free mode analysis is an important structural analysis method, which can be used to evaluate the inherent characteristics of structures and optimize the design of structures.

4. Modal Calculation and Result Analysis of Vehicle Frame

Modal analysis of the frame can obtain the natural frequency and vibration mode of the frame, in order to understand the dynamic characteristics of the frame and provide a basis for the design and optimization of the frame. Usually, the excitation frequency caused by the road surface is below 30Hz, and the excitation frequency caused by the engine is above 120Hz. Therefore, it is required that all modes of the frame avoid this frequency to avoid the possibility of resonance.

4.1 Calculation Results of Frame Natural Frequency

The free mode of the racing car frame is analyzed through the finite element analysis software. The first nine natural frequencies are shown in Table 2:

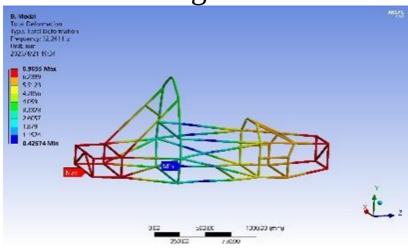
Table 2: Frame natural frequency

order	frequency/Hz
1-3	0
4	32.241
5	53.621
6	79.423
7	94.003
8	97.683
9	104.69

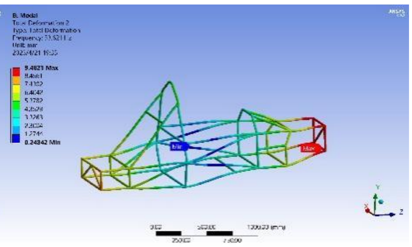
The modal analysis results of the racing frame indicate that the natural frequency of the frame is between 30Hz and 120Hz, effectively avoiding the possibility of resonance.

4.2 Frame vibration mode analysis

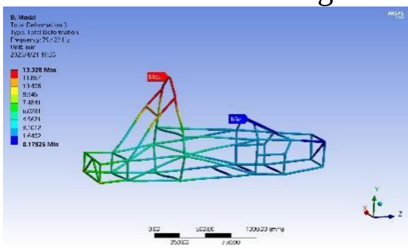
From the vibration mode diagram of the frame in Figure 3, it can be seen that the fourth order frame vibration mode exhibits overall lateral bending; The vibration mode of the 5th stage frame is vertical rotation as a whole; The vibration mode of the 6th stage frame is lateral rotation at the front; The vibration mode of the 7th stage frame is the overall occurrence of lateral bending and rotation; The vibration mode of the 8th stage frame is lateral bending at the rear; The vibration mode of the 9th stage frame is vertical bending at the rear.



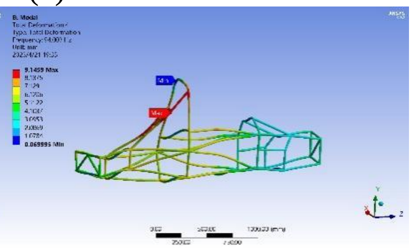
(a) 4th order vibration mode diagram



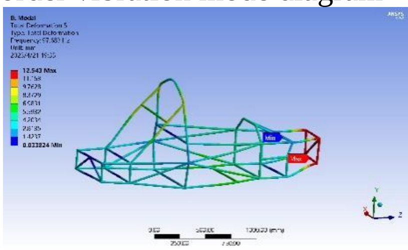
(b) 5th order vibration mode diagram



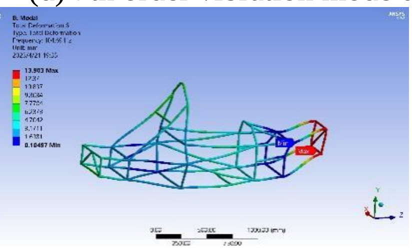
(c) 6th order vibration mode diagram



(d) 7th order vibration mode diagram



(e) 8th order vibration mode diagram



(f) 9th order vibration mode diagram

Figure 3: Frame vibration mode diagram

5. Conclusion

The frame model of the equation racing car is established, the free mode analysis of the frame is carried out, and the first nine natural frequencies and vibration modes of the frame are analyzed. The results show that the frame will not resonate, and the structural design of the frame is reasonable, which provides some ideas for further research of the racing car frame.

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