Static and dynamic performance analysis of scissor seat of combine harvester

Hao Song, Liyou Xu*, Xiaoliang Chen, Weizhen Wei and Kui Liu

1School of Vehicle & Traffic Engineering, Henan University of Science & Technology, Luoyang, Henan, 471003, China

*Corresponding author’s e-mail: xlyou@haust.edu.cn

Abstract. This paper takes the scissor type seat of a domestic combine harvester as the research object, uses CATIA software to carry out three-dimensional modeling of the seat, and then imports the seat model into ANSYS Workbench software for static analysis and modal analysis, so as to judge whether the scissor type seat of the combine harvester meets the design requirements. The results of static analysis show that the maximum stress of the seat under the two different loads is less than the yield strength of the material, and the overall strength of the seat meets the design requirements. The modal analysis results show that the first six natural frequencies of the seat completely avoid the sensitive frequencies of the human body, which basically guarantees the working comfort of the driver. This study provides a theoretical basis for the structural design and optimization of combine seat.

1. Introduction

China is a traditional agricultural country. As a mechanical equipment that can harvest agricultural products quickly and efficiently, combine harvester has developed rapidly in China. The working environment of combine harvester in the field is relatively bad, and it will produce large vibration. As a connecting device connecting the driver and the vehicle body, the structure of the seat directly affects the ride comfort and safety. The scissor seat is widely used in combine harvesters because of its high stability and reliability [1]. Because the scissor seat of combine harvester is closely related to comfort and safety, it is of great significance to judge whether the structure of the seat meets the design requirements.

In ANSYS Workbench software, static analysis is mainly used to analyze structural changes, such as displacement, stress and strain. Modal analysis is the basis of dynamic analysis. It is mainly used to analyze the vibration characteristics of structures, such as natural frequency and natural vibration mode. In this paper, the static analysis and modal analysis of the scissor seat of the combine are carried out to determine whether the scissor seat meets the design requirements.

2. Establishment of three-dimensional model of seat

Because ANSYS Workbench software lacks convenience compared with CATIA in establishing complex three-dimensional model, CATIA software is used to establish the three-dimensional model of scissor seat of combine harvester in this paper.

The scissor seat of combine harvester is mainly composed of base frame, cushion frame and sponge pad. Its connection methods mainly include welding and bolt connection. The scissor seat has adjustment functions in four directions, namely, up and down movement in the vertical direction and back and forth movement in the horizontal direction. The up and down movement along the vertical
direction is adjusted by rotating the screw pair composed of screw and nut, and the back and forth movement along the horizontal direction is adjusted by moving the horizontal slide rail.

The movement diagram of the seat in the vertical direction is shown in Figure 1. During adjustment, the screw pair composed of rotating screw nuts drives two points A and C to move in the groove, and two points B and D rotate in the limit hole. The length of shear rod AD and BC is fixed and rotates around point O. Some research results show that when the shear rod length and inclination change within the seat size range, it has little impact on the seat damping performance [2]. However, because the scissors seat is equipped with a set of screw and nut adjusting devices, which bear a part of tensile stress. After comprehensive consideration, the seat state with the smallest included angle $\alpha$ between scissors bars is selected for modelling, in order to make the stressed state of the seat in the most unfavorable position.

Finally, considering that the main stressed parts of the scissor seat under external load are the base frame and cushion frame, but in addition, the seat also contains some connecting mechanisms and surface skins that are not required in finite element analysis, which have little impact on the strength and stiffness of the seat, and a large number of analysis nodes and elements will be added during analysis [3], in addition to improving comfort, Basically, it does not bear the externally applied load, so the seat model can be reasonably simplified [4]. The simplified scissor seat model of combine is shown in Figure 2.

3. Establishment of finite element model of seat

For finite element analysis, a reasonable finite element model is the basis of the analysis, which determines the success or failure of the analysis. Therefore, it is necessary to pre-process the seat model imported into ANSYS Workbench. After the model is imported, it is checked that there are no wrong modeling places such as edge and corner protrusions and gaps between faces. Since the material used for the scissor seat is Q235 steel, the performance parameters of Q235 steel need to be added and applied to the seat model. The performance parameters of Q235 steel are shown in Table 1.

| Name       | Density (g/cm³) | Elastic modulus (GPa) | Poisson's ratio | Tensile strength (MPa) | Yield strength (MPa) |
|------------|-----------------|-----------------------|----------------|------------------------|---------------------|
| Q235 steel | 7.85            | 210                   | 0.25-0.33      | 370-500                | 235                 |

After the seat material is set, the connection mode needs to be set. Through preliminary observation, the scissor seat connection mode mainly includes welding and bolt connection. For the welding and bolt connection between two parts, the rigid element connection method is used to simulate [5].

The number and accuracy of meshing directly affect the accuracy of simulation results and calculation time [6]. For the scissor seat, the size of the grid element set in this paper is 5 mm. When dividing the grid, the multi area grid control method is combined with the automatic grid control.
method. Finally, the finite element model of the scissor seat is divided into 345264 nodes and 170742 elements. After successful mesh generation, check the mesh quality through the check mesh quality tool. The quality of the divided mesh unit is 0.78, the aspect ratio is 2.4394, the Jacobian is 0.98, the warpage factor is $9.694 \times 10^{-15}$ and the inclination is 0.435. After comparing the grid quality metrics, the quality of the divided grid is better and can be used for subsequent operations.

4. Static analysis of seat structure

As a connecting device connecting the driver and the vehicle body, the scissor seat of the combine transmits various forces and moments during the operation of the combine. If the seat structure is deformed, it will directly affect the driving safety. Therefore, the seat must have appropriate strength and stiffness.

In the static analysis of seat structure, the finite element equation can be written as:

$$[K][u] = [F]$$  \hspace{1cm} (1)

Where, $[K]$ is the stiffness matrix, $[u]$ is the displacement vector and $[F]$ is the static load.

According to the national standard GB 10000-1988 human body size of Chinese adults, the weight with the percentile of 99 in the population aged 18~60 is 83 kg. Therefore, in this paper, a weight of 100 kg is applied on the contact plane between the driver and the seat, and a fixing constraint is applied to the bolt hole at the bottom of the seat. After the load and constraint are applied, the seat is solved. The solution results of deformation and stress distribution of the seat are shown in Figure. 3~4.

![Figure 3. Schematic diagram of deformation (a).](image)

![Figure 4. Stress distribution diagram (a).](image)

It can be seen from the results that under the weight of 100 kg, the maximum deformation of the seat is 1.588 mm, the deformation is mainly concentrated in the center of the seat cushion, and there is basically no deformation in other parts of the seat. The maximum stress point of the seat is at both ends of the slide rail at the bottom of the seat, and the maximum pressure is 153.15 MPa, which is less than 235 MPa of the yield strength of Q235 steel. Therefore, the overall strength of the seat meets the requirements of daily use.

In addition, according to the provisions of the national standard GB 15083-2019 strength requirements and test methods for automobile seats, seat anchorages and head restraints, a load passing through the center of mass, horizontally forward and not less than 20 times the weight of the seat itself needs to be applied to the seat. After measurement, the weight of the scissor seat is 13.12 kg. Therefore, the multi-point restraint method is used to apply 2600 N load to the seat. The solution results of deformation and stress distribution of the seat are shown in Figure. 5~6.
Figure 5. Schematic diagram of deformation (b).

Figure 6. Stress distribution diagram (b).

It can be seen from the results that under a load passing through the center of mass and moving forward horizontally, which is not less than 20 times the weight of the seat itself, the maximum deformation of the seat is 0.5368 mm, and the deformation is mainly concentrated at the seat cushion. The maximum stress point of the seat is at both ends of the slide rail at the bottom of the seat, and the maximum pressure is 109.01 MPa, which is less than 235 MPa of the yield strength of Q235 steel, which meets the requirements of the national standard.

Based on the results of the shear seat of the combine under two loads, the maximum deformation point is concentrated at the seat cushion; The maximum stress points are at both ends of the slide rail at the bottom of the seat and are less than 235 MPa of the yield strength of Q235 steel. Therefore, the overall strength of the seat meets the design requirements.

5. Seat modal analysis

The scissor seat of the combine and the driver can be regarded as a multi degree of freedom vibration system. Most of the vibration during the operation of the combine will be fed back to the driver by the seat. Therefore, the modal analysis of the combine seat is mainly used to determine whether the excitation frequency of the seat avoids the sensitive frequency of the human body, so as to ensure the comfort of the driver at work.

5.1. Modal analysis theory

When solving the seat vibration mode, the finite element multi degree of freedom vibration equation can be written as:

\[
[M]\{\ddot{u}\} + [C]\{\dot{u}\} + [K]\{u\} = \{f(t)\}
\]  

(2)

Where, \([M]\) is the seat mass matrix, \([C]\) is the seat damping matrix, \([K]\) is the node acceleration, \(\{\ddot{u}\}\) is the node velocity and \(\{f(t)\}\) is the load function varying with time.

When \([C] = 0\), it is an undamped free vibration system, and equation (2) can be rewritten as:

\[
[M]\{\ddot{u}\} + [K]\{u\} = 0
\]  

(3)

Suppose the solution of equation (3) is:

\[
\{u(x, y, z, t)\} = \{\varphi(x, y, z)\} \sin \omega (t - t_o)
\]  

(4)

Where, \(\{\varphi(x, y, z)\}\) is the amplitude, \(\omega\) is the angular frequency of simple harmonic motion, \(t\) is the time variable and \(t_o\) is the time constant determined by the initial conditions.

Substituting equation (4) into equation (3) can obtain:

\[
[K - \omega^2 M]\{\varphi(x, y, z)\} = 0
\]  

(5)
In equation (5) \( \{\varphi(x, y, z)\} \) the necessary and sufficient conditions for \( (x, y, z) \) to have a nonzero solution are:

\[
|K - \omega^2 M| = 0
\]  

(6)

5.2. Modal analysis solution

The finite element model of the seat in the above static analysis is directly transferred to the modal analysis module. After solving, the first six vibration modes of the seat can be obtained as shown in Figure 7~12.

According to relevant research, the sensitive frequency range of human body to vertical vibration is 4~12.5 Hz, and the sensitive frequency range to horizontal vibration is 0.5~2 Hz. Compared with the first six natural frequencies of the seat shown in Table 2, it can be seen that the scissor seat completely avoids the sensitive frequencies of the human body and basically ensures the working comfort of the driver.

6. Conclusion

In this paper, the static analysis of the scissor seat of a domestic combine harvester was carried out. Assuming the force of the seat in two different cases, it was obtained that the maximum pressure on the seat was less than the yield strength of the material. Therefore, it can be considered that the overall strength of the seat meets the requirements and the structure is more reasonable. Then the modal analysis of the seat was carried out. The results show that the first six natural frequencies of the scissor seat of the combine completely avoid the sensitive frequencies of the human body, and basically ensure the working comfort of the driver.
References

[1] Xu X M, Zhu S H. (2006) Theoretical Analysis on the Vibration Characteristics of One Kind of Scissors Linkage Driver's Seat. China Mechanical Engineering., 17(8):802-804.

[2] Wang L J, Yan J G, Hou Z F, et al. (2019) Influence analysis for structural parameters of scissor type seat on seat's vibration characteristics. Mechanical & Electrical Engineering Magazine., 36:368-373.

[3] Yang F, Xu H X, Zhu Q Q, et al. (2017) Method of optimizing the comfort of tractor seat with finite element simulation. Journal of Chinese Agricultural Mechanization., 38:47-52.

[4] Ye F, Xu Z M, Zhai X C.(2019) Analysis and research on strength simulation of an automobile seat. Mechanical & Electrical Engineering Magazine., 36:1188-1193.

[5] Xu Z W, Sheng Z Q, Zhang H H, et al. (2009) Car Seat Backrest Static Strength Experiment and Simulation. Applied Mechanics and Materials., 16:178-182.

[6] Zhang, X J, Wang, C L, Guo, K H, et al. (2017) Dynamics modeling and characteristics analysis of scissor seat suspension. Journal of vibration and control., 23:2819-2829.