Design and Analysis of 4LZ-8 Wheat Harvester Head

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Abstract—In this paper, the parameter design of the header of the 4LZ-8 wheat harvester is established, and the three-dimensional model of the header is established. The header frame is selected as the main analysis object. The force analysis and static analysis of the header frame are carried out to detect whether it meets the stiffness requirements. In order to reduce the loss caused by vibration during harvesting, the pre-stressed modal analysis is performed on the designed header on the basis of statics to obtain the natural frequency and main vibration mode of the header frame, and then the vibration frequency is analyzed. The results show that the probability of resonance of other parts of the header with the header frame is relatively low, which meets the requirements for use.

1. INTRODUCTION (HEADING 1)
With the adjustment of my country's agricultural structure and the internationalization of the agricultural product market, rural land will gradually develop towards intensive management, the agricultural production model will gradually become large-scale, and the market demand for large and medium-sized combine harvesters will continue to increase. Therefore, all domestic combine harvester companies have increased investment in research and development of large and medium feed models[1-4].

The header of the harvester is the first process to complete the harvesting task. Its main function is to harvest and transport rice and wheat. Therefore, the header must first ensure the quality of the harvest. The wheat grains should be reduced during harvest. At the same time, the damage caused by the harvest and the damage to the grain should be minimized. The vibration of the combine harvester often causes parts Failure and deformation affect the reliability of the combine harvester [5-7]. At the same time, in addition to the large vibration loss of the header during the field harvest of the machine, the complex vibration will also reduce the driver's comfort. Therefore, as the most vibrating working part of the combine harvester, the finite element analysis of the header is very necessary [ 8-10].

Experts and scholars at home and abroad have done a lot of research on the vibration of the header, but most of them are modal analysis of the header under restraint conditions. This paper makes the analysis results more accurate by conducting modal analysis under prestressed conditions.
2. PARAMETER DESIGN OF MAIN COMPONENTS

2.1 Cut width
Cutting width is one of the most important parameters of the harvester, and its calculation method cutting width B is determined as follows:

\[ B = 10000q \times \frac{\beta_0}{M \times \nu_m} \]  \hfill (1)

In the formula: B——Cutting pair of harvester (m).
q——Feed amount (kg/s)
\( \beta_0 \)——The ratio of the weight of wheat grains cut to the weight of straw
M——Wheat yield per unit area (kg/hm²)

By consulting the data and field tests, \( \beta_0 = 0.55 \), M=8840 (kg/hm2), the average working speed \( \nu_m \) of the grain harvester is about 1.8 (m/s), and the cutting width of the 4LZ-8 wheat harvester is calculated as 2750mm.

2.2 Determination of main performance parameters of reel
According to the function to be completed by the reel wheel, the diameter of the reel wheel can be determined according to the following two principles:

1). In order to allow the dial to be inserted into the grass, its horizontal split speed should be zero when it enters the grass; 2). The reel dial supports the straw so that the cutter should act slightly above the center of gravity of the straw, that is, 1/3 of the cut part, because if it is being dialed at the center of gravity, the cut straw will be thrown out. If the platform is below the center of gravity, the straw will be tilted in front of the header.

According to the above two conditions, it can be determined:

\[ R = (L - h) \times \frac{1}{3} + R \sin \varphi_1 \]  \hfill (2)

In the formula: R——Reel radius length
\( \varphi_1 \)——Entry angle
L——Wheat's natural growth height
h——Stubble height from harvest

By consulting the literature, it can be concluded that the entry angle \( \varphi_1 \) and the ratio of the speed of the reel wheel to the traveling speed \( \lambda \) have the following relationship:

\[ \sin \varphi_1 = \frac{1}{\lambda} \] \hfill (3)

In this situation, it can be concluded that the radius of the reel is:

\[ R = \frac{\lambda(l - h)}{3(\lambda - 1)} \] \hfill (4)

Through the harvesting test of other harvesters and field measurement, L=700mm, h=138mm, and the speed ratio \( \lambda = 1.6 \), the diameter of the wheel is calculated to be 1000mm, and through the calculation of other components, the figure is obtained 1 shows the model.

Figure 1. 3D model of 4LZ-8 wheat harvester header
3. STATIC ANALYSIS OF HEADER FRAME

3.1 Force analysis of header frame

The header frame is used as the supporting part of the header structure of the harvester. Its strength and rigidity have a greater impact on the header efficiency. Therefore, the header frame part is selected from the header, and the static analysis is performed to analyze the header. The displacement of the frame determines whether the stiffness meets the requirements [11-12].

The table frame mainly adopts a welded structure, which is mainly subjected to the gravity generated by the reel wheel, the gravity generated by the feeding auger and the cutting device in a static state, so the simplified mechanical model is shown in FIG. 2. Because the header frame and the bridge are welded, the connection between the frame and the box can be fixedly constrained [13]. At the same time, G1 and G2 respectively represent the gravity of the cutting device and the feeding auger, while \(F_1x, F_1y, F_2x\), and \(F_2y\) are the reeling device and the cutting machine due to gravity Two points of force at the hinge point of the connection point of the frame. By setting the material density \(\rho=7.85\times10^6\text{kg/mm}^3\), the weights of the reel, feeding auger and cutting device are 180kg, 120kg and 75kg respectively, and the following mechanical calculation formula:

\[
F = mg
\]  
(5)

Equilibrium state equations for parallel forces:

\[
F_1x = F_2x = F_1y \tan 20°
\]  
(6)

\[
F_1y - G3 - F_2y = 0
\]  
(7)

\[
\sum M(A) = G_3 x_1 - F_2x y_2 - F_2y x_2 = 0
\]  
(8)

\[
\sum M(B) = G_3 (x_1 + x_2) - F_1y x_2 - F_1x y_2 = 0
\]  
(9)

Obtain the force of the reel on the header frame \(F_1x = 1166\text{N}, F_1y = 3202\text{N}, F_2x = 1166\text{N}, F_2y = 1438\text{N}\), feeding auger acting on the header machine. The force \(G2 = 1176\text{N}\) on the rack and the force \(G1 = 735\text{N}\) of the cutting device acting on the header frame.

![Figure 2. The mechanical model of the stand at rest](image)

3.2 Static finite element analysis of header frame

The material of header frame is structural steel Q235, add this material in ANSYS Workbench, and set the yield strength \(\sigma_s\) to 235MPa, the density \(\rho\) to \(\rho=7.85\times10^6\text{kg/mm}^3\), and set the Young’s Modulus \(E=200\text{GPa}\), Poisson’s Ratio \(\mu = 0.3\) [14]. In order to ensure the accuracy of the analysis, tetrahedral
meshing is performed. Since the mesh accuracy has little effect on the displacement cloud and does not produce too much error, in order to control the calculation time, the overall mesh accuracy is set to 100mm, and the position accuracy of the larger local force is set to 20mm, and in order to make the grid division more uniform and complete, here the Transition is adjusted to the Slow mode to ensure the uniformity of the grid division [15].

Through the analysis of ANSYS Workbench, the displacement cloud diagram shown in Figure 3 can be obtained. The maximum displacement is at the position where the cutting board is installed with the cutting device. The maximum displacement under static conditions is 0.15795mm, and the deformation is very small, which can meet Stiffness requirements.

![Displacement cloud diagram of rack](Image)

**Figure 3. Distortion cloud diagram of rack**

### 4. MODAL ANALYSIS OF HEADER FRAME

#### 4.1 Fundamental of finite element modal analysis

For modal analysis, only the characteristics of the structure itself are considered, independent of external effects, and damping is generally not considered. The dynamic equation of the structure is simplified to:

\[
[M][\dot{\mu}] + [K][\mu] = 0
\]  

(10)

If let \(\mu = \{\phi_i\}\cos(\omega_i t)\), substitute the structure free vibration finite element equation to get:

\[
([K] - \omega_i^2[M])\{\phi_i\} = 0
\]  

(11)

The above formula is a homogeneous linear equation system, and the conditions for its non-zero solution are:

\[
\det([K] - \omega_i^2[M]) = 0
\]  

(12)

The above formula is the basic equation for structural frequency eigenvalue analysis. By solving this eigenvalue problem, the natural vibration frequencies and modes of each order of the structure can be obtained. For modal analysis that considers the effect of stress stiffening, only the above frequency eigenvalues The stress stiffness term can be added to the stiffness matrix of the equation, which is still an eigenvalue problem.

#### 4.2 Finite Element Modal Analysis

The stress generated by the mechanism under constant load will greatly affect the natural frequency. In this paper, the pre-stressed modal analysis is carried out on the header frame. Therefore, when performing modal analysis on the frame, the static analysis structure obtained from the static analysis of the frame under static conditions must be transferred to the modal analysis. In Workbench Obtain the natural frequency and deformation area of the first 6 order modules of the header frame as shown in Table 1.
TABLE I. THE 6TH ORDER NATURAL FREQUENCY AND VIBRATION MODE OF HEADER FRAME

| Order | Natural frequency (HZ) | vibration mode |
|-------|------------------------|----------------|
| 1     | 43.159                 | Base plate bending vibration |
| 2     | 61.159                 | Floor wave vibration |
| 3     | 81.766                 | Base plate bending vibration |
| 4     | 102.87                 | Floor wave vibration |
| 5     | 112.69                 | Floor wave vibration |
| 6     | 117.11                 | The bottom plate wave vibration and the side plate vibration |

Finite element analysis shows that the first 6th order modal frequency of the header frame is 43.159–117.11 Hz, and the following characteristics can be obtained from the modal vibration mode of the header frame: the first to fifth order modes of the header frame, the maximum deformation is located at the position where the cutter is installed on the bottom plate of the header. The first and third orders are all bending vibrations, and the second, fourth and fifth orders are all wavy vibrations. The cutter is installed on the bottom plate of the cutting table. During the wheat harvest process, due to the uneven distribution of the wheat stalks and the influence of the ridge, the cutter is subjected to random loads. When the frequency of the load is close to the 1-5 order frequency, it will cause violent vibration at the front end of the bottom plate, thereby affecting the service life of the cutter; In the sixth-order modal header frame, not only the bottom plate is oscillating in a wave shape, but also the side plates of the frame are deformed. The reel is installed on the side plate of the header. When this deformation occurs, the cross beam of the reel will also produce bending vibration with the side plate of the header, which will further affect the rigidity of the side plate of the header. Here, due to the problem of the picture frame, only the third and sixth order vibration modes shown in FIG. 5.

![Figure 4](image-url)
4.3 Header vibration result analysis

The other parts of the header of the header frame are mainly inspired by the rotation of the reel, the rotation of the agitator, and the reciprocating motion of the cutter. When the external excitation received by the header frame is equal to or close to its natural frequency, the component will resonate, causing the component to vibrate in a larger amplitude. Therefore, in order to verify whether the header is reliable, it should be verified whether the external excitation received by the header is equal to or close to its natural frequency.

The rotating speed of the reeling wheel is about 20r/min during harvesting, about 170r/min during harvesting and about 500r/min for the cutter crank, which is substituted into the formula:

$$f = \frac{n}{60}$$  \hspace{1cm} (13)

The rotation frequency of the reel is about 0.33Hz, the rotation frequency of the auger is about 2.83Hz, and the reciprocating frequency of the cutter is about 8.33Hz. When the mechanical structure resonates, the excitation frequency has the following relationship with the natural frequency:

$$0.8f_a < f < 1.2f_a$$  \hspace{1cm} (14)

$f$ is the natural frequency of the structure, and $f_a$ is the excitation frequency.

According to the analysis of this formula, other parts of the header and the header frame will have a lower probability of resonance, which meets the requirements of use.

5. CONCLUSION

1) Parameter design of the header of the 4LZ-8 wheat harvester, and finally the harvester's cutting width is 2750mm and the diameter of the reel is 1000mm.

2) By establishing the mechanical model of the header, the corresponding mechanical calculation formula is established. Obtain the force of the reel on the header frame $F_{1x}=1166N$, $F_{1y}=3202N$, $F_{2x}=1166N$, $F_{2y}=1438N$, The force of the feed auger acting on the header frame $G_2=1200N$ and the force of the cutting device acting on the header frame $G_1=750N$. The static analysis of the header frame is completed, and the maximum displacement is obtained at the position where the cutting device is installed on the bottom plate of the header, and the maximum displacement under static conditions is 0.15795mm.

3) Through the modal analysis of the header frame, the 6th-order modal frequency is 43.159~117.11 Hz, and the maximum deformation is at the position where the cutter is installed on the bottom plate of the header. And by analyzing the external excitation frequency, it is concluded that the other parts of the header and the header frame have a low probability of resonance, which meets the requirements of use.

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REFERENCES

[1] Qian Liu, Qizhi Yang. The evolution of my country's agricultural production model in the transition period[J]. Rural Economy, 2013(12):46-48

[2] Qiang Wang, Juanzhi Zhang. The Road of Agricultural Development in my country—— Corporatization of Production Mode[J]. Inner Mongolia Agricultural Science and Technology,2012(04):4-6.

[3] Haiying Cheng. The structure and inspection adjustment of the vertical header of the semi-feed combine harvester[J]. Friend of Farmers Getting Rich,2016(11):189.

[4] Congling Zhu, Zhisheng Cheng, Hongyuan Wang, etc. Research on the vibration of the header of the combine harvester[J]. Journal of Agricultural Machinery, 2004,35(4):59－61,69.
[5] Xiaohui Li. Virtual assembly of cutting head and bridge of harvester and motion simulation of cutting mechanism[D]. Hebei University of Technology, 2015.

[6] Ma Lina, Junyi Wei, Xiaomao Huang, Wangyuan Zong, Guangchao Zhan. Vibration analysis of the header of the 4LL-1.5Y crawler rape combine harvester[J]. Journal of Anhui Agricultural University, 2019, 46(04): 723-727.

[7] Zhichao Hou, Jianghua Gao, Le He. Vertical vibration characteristics of human in sitting position and its three-degree-of-freedom model parameters[J]. Journal of Harbin Engineering University. 2011(09)

[8] Zhiyong Chang, Wei Liu, Jin Tong, Li Guo, Heng Xie, Xiao Yang, Haifeng Mu, Donghui Chen, Design and Experiments of Biomimetic Stubble Cutter, Journal of Bionic Engineering, Volume 13, Issue 2, 2016, Pages 335-343.

[9] Xiaomin Wang, Daxing Fang, Yongxiang Li. Vibration characteristics of 4LL–1.5Y combine harvester header [J]. Journal of Hunan Agricultural University (Natural Science Edition), 2018, 44(04): 435-441.

[10] Zhuohuai Guan, Chongyou Wu, Qing Tang, etc. Finite element modal analysis and experiment of threshing drum of combine harvester [J]. Agricultural Mechanization Research, 2016, 38(8): 136–140.

[11] Zhipeng Gao, Lizhang Xu, Yaoming Li, etc. Vibration test and analysis of track-type rice-wheat combine harvester under field harvesting conditions [J]. Journal of Agricultural Engineering, 2017, 33(20): 48–55

[12] Xiaomin Zhang. Design and Research on the Head of the Millet Combine Harvester [D]. Shanxi Agricultural University, 2017.

[13] Fangsi Zhou, Lijun Li, Yibin Ouyang. Lightweight Research of Weeder Frame Based on ANSYS[J]. Journal of Forestry Engineering, 2017, 2(6): 103–109.

[14] Zhong Tang, Hongda Wang, Xiyao Li, Xinda Chen, Biao Wu, Yaoming Li. Structural design and modal analysis of the header of the track-type combine harvester [J]. Agricultural Mechanization Research, 2020, 42(01): 25-30.

[15] Shuqian Cao, Wende Zhang, Longxiang Xiao. Modal analysis of vibration structure-theory, experiment and application [M]. Tianjin: Tianjin University Press, 2014.