Design and Simulation of Chopping Device of Straw Returning Machine

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Abstract: In view of the shortages of straw conveying to one side, knife wear in straw returning machine, a new type of straw chopping and returning device was designed in the paper. On the basis of briefly describing its structure and principle, the type, number and arrangement method of chopping knife were designed, the solid models of the knife and chopping device were built by applying Solidworks, and finite element simulation analyses were carried out based on Simulation, the results showed that the safety factors of the adopted knives were all greater than 1.5, and the stress distribution of the knife shaft was uniform when moving knives were arranged according to the work order of the engine, after comparing with the maximum stress of the knife shaft arranged according to the spiral line, the stress distribution of the knife shaft decreased by 8.84%, which was conducive to extending the service lives of the knife and the knife shaft.

1. Introduction

Crop straw contains more mineral elements and organic matter components, straw returning to field could effectively increase soil organic matter and reduce environmental pollution caused by straw burning[1]. It had become an important research content related to the sustainable development of agriculture to carry out the research on the mechanized returning technology of crop straw and the development of matched machines and tools.

At present, straw returning machine generally used single or double moving knife and adopted spiral arrangement method to cut straw. Single knife could effectively avoid the clogging of straw in the chopping device, but the efficiency was low and the qualified rate of length could not be guaranteed. Double knife had high stability in the chopping process, and straw was not easily blocked, however, the threshing drum on the longitudinal axial flow combined harvester rotated clockwise, and the straw was easy to accumulate on one side after threshing, which was not conducive to the chopping of straw[2]. Although the spiral arrangement method of moving knife had the advantages of simple structure and uniform force on the shaft, because the spiral arrangement of moving knife on the same side was consistent, there were usually problems such as the transportation of chopped straw to one side, the uneven wear of the knife and the poor stability of the shaft. In order to eliminate the shortcomings of the existing straw returning machine, a new type of straw chopping and returning device was designed in the paper.
2. Design of Chopping Device of Straw Returning Machine

2.1. Structure and working principle of chopping device

Chopping device was mainly composed of knife shaft, moving knife and fixed knife, as shown in Fig.1, moving knife was hinged with knife holder through the hinge, and knife holder was welded to the moving knife shaft. The solid core journal at each end of the knife shaft was connected with the side plate through a bearing. Fixed knife was fixed on the fixed knife shaft, and the belt pulley was connected with the solid core journal through a spline.

When the straw chopping device worked, harvester power was transferred to the belt pulley through the transmission system and moving knife shaft was driven to rotate with it together, negative pressure was formed at the front end of the chopping chamber, and the straw was inhaled into the chopping chamber, under the support of fixed knives inside the curved cover piece, the straw was chopped with moving knives that were symmetrically and evenly distributed along the length of the knife shaft. Under the combined actions of airflow and centrifugal force generated during the rotation of the knife shaft and moving knives, the chopped straw was moved to the scattering device and distributed evenly on the ground.

2.2. Design of the main components of chopping device

2.2.1. Design of the knife

At present, most of the knife types used on straw returning machines were hammer claw type, L type and straight type. In order to make the knife have good performances of chopping and picking at the same time, a combined moving knife composed of L type knife and straight type knife was designed in the paper. A study by Li Guo found that when the edge of chopping knife was quenched with 65Mn, the wear degree of the knife edge could be significantly reduced [3]. Therefore, the material of the knife designed in the paper adopted 65Mn.

According to the actual chopping requirements of straw, the knife size should be reasonably determined. Alikhashkin had concluded that when the minimum knife front angle was 25°, the wear speed of the knife edge would be greatly reduced [4], hence, the knife edge angle was determined to be 25°. After comprehensive consideration of working stability and chopping effect, the main parameters of the combined knife designed in the paper were listed in Tab.1, the sawtooth structure was adopted in straight type knife.

Tab.1 The main parameters of the combined knife

| Knife type | Technical parameters | Design value |
|------------|----------------------|--------------|
| L type     |                      |              |
|            | Straight line length $l_1$/mm | 100          |
|            | Effective length of blade line $l_2$/mm | 95           |
|            | Width $w_0$/mm          | 50           |
In order to ensure the chopping quality of straw returning machine, reasonable number of knife was very important. When the knife shaft speed and working width were the same, there was an optimal value for the number of the knife which was usually measured in a density range\(^5\), That was

\[ N = C \times L_C \]  

(1)

In the formula, \( N \): blade number, slice; \( C \): blade arrangement density, slice/mm; \( L_C \): knife shaft length, mm. The normal range of density for L type knife was 0.02~0.04 pieces/mm.

According to the requirements of the manufacturer, the shell length of straw returning machine was determined to be 1800mm, in order to facilitate arrangement of the combined moving knife, the working width of the device was determined to be 1730 mm, and the density of the combined knife was set at 0.0208 pieces/mm, then 36 pieces of L type moving knife and 18 pieces of straight type moving knife were set to constitute 18 groups of the combined knives.

In order to further improve the quality of chopping straw, a row of fixed knives were installed in the curved cover piece of straw chopping device, which made the combined moving knife form chopping support. The fixed knife was an ordinary straight knife, the length×width×thickness were set to be 170mm×50mm×4mm, left and right ends of the knife were equipped with chopping edge, and the width of the fixed knife slot was set to be 6 mm, the fixed knife was fixed through the fixed knife shaft and the fixed knife slot.

### 2.2.2. Arrangement Design of the knives

In order to eliminate the shortcomings of spiral line arrangement method of the knife, a new type of the knife arrangement method was designed: the knife shaft was divided into \( m \) sections along the length direction, and \( n \) knife holders were arranged in each section, the \( i \)th knife holder between each section was arranged in staggered symmetry at an interval of \( 360^\circ/m \) in work order of the engine, the initial phase difference of knife holder arrangement between each section was:

\[ \theta_i = 360^\circ / m \]  

(2)

In the formula, \( m \): section number of knife shaft.

In each section, each knife holder was distributed in equal angle along the circumferential direction of the knife axis, and the phase difference of adjacent knife holder was as follows:

\[ \theta_2 = 360^\circ / n \]  

(3)

In the formula, \( n \): knife number in each section.

Each knife holder was evenly spaced along the knife shaft so that the knife shaft was loaded uniformly. Taking 18 groups of combined moving knife as an example, its specific arrangement method on the knife shaft was shown in Fig.2, and the alternating arrangement was adopted between the fixed knife and moving knife.
2.2.3. Design of knife shaft
The influences of chopping quality and force balance were considered in the design of knife shaft, under the premise of ensuring the shredding effect, and after considering comprehensively the quality of the whole machine and the strength of the knife shaft, it was determined that the knife shaft was hollow structure, the outer diameter was 100mm, the wall thickness was 10mm, and the material was Q235A carbon structural steel, which had good toughness and plasticity, excellent welding performance and hot workability, and was convenient for the welding of knife holder.

3. Solid modelling of chopping device

3.1. Blade modelling
The models of L type knife, straight type knife and fixed knife were established by applying Solidworks according to the main parameters of the combined moving knife designed in Tab.1, the model of combined moving knife obtained after assembling the L type knife and straight type knife was shown in Fig.3.
Fig. 4. Overall assembly diagram of chopping device

4. Simulation and stress analysis of chopping device

4.1. Simulation pre-processing of the knife

In order to ensure stable work of the knife for a long time, it was necessary to carry out finite element analysis to obtain the stress analysis diagram and safety factor of the knife.

Because the main role in chopping process was L type knife and fixed knife, it was necessary to analyze the static stress of these two types of knives. The setting of straw chopping pressure was the key to the force reality of the knife in the simulation result, and the chopping pressure should be added according to chopping mechanical characteristics of the straw. Taking chopping wheat straw as an example, the models of L type knife and fixed knife were opened, and the knife material was set to be 65Mn spring steel, according to the mechanical property parameters of wheat straw \(^6\), the shear strength of wheat straw was 6.5 MPa, so the parameter value was set at 6.5 N/mm\(^2\) when the pressure was applied.

Mesh refinement diagrams of L type knife and fixed knife were obtained after choosing to generate the grid option and setting finely in the grid setting option.

4.2. Finite Element Analysis of the knife

According to the actual working conditions of the knife, after the pressure (P=6.5 MPa) was applied in perpendicular direction of the knife slant, simulation results showed that the yield strength of L type knife was 430 MPa, a maximum stress on the knife was 267.1 MPa, and the safety factor was 1.61, as shown in Fig.5(a), the yield strength of fixed knife was 430 MPa, a maximum stress on the knife was 250.2 MPa, and the safety factor was 1.72, as shown in Fig.5(b).

![Fig. 5 Stress diagram of the knife](image)

(a) L type knife  
(b) fixed knife

Fig. 5 Stress diagram of the knife

From the stress diagram of L type knife and fixed knife, it could be seen that the forces of the knives were concentrated near the confined parts, that was, there was a large stress concentration in the hinge connecting part, and the processing steps should be optimized in production to avoid the stress exceeding the rated safety limit.
4.3. Finite Element Simulation Analysis of Chopping Device

After the finite element simulation of a single knife and the analysis of its stress during chopping straw, it was necessary to simulate the whole chopping device, and compare and analyze the stress effects of the common and new knife arrangement methods on the knife shaft. In order to simplify the simulation process, it was determined that the finite element analysis of chopping straw was carried out under ideal conditions, and the speed of the knife shaft was set at 2400 r/min in the simulation.

4.3.1. Simulation Analysis of Chopping Device with Spiral Line Arrangement of Moving Knife

At present, most of moving knife in straw returning machine adopted spiral line arrangement method, the material of knife shaft was set as Q235A, the materials of moving knife and other parts were set as 65 Mn, a load was applied to each group of moving knife, and the load was the shear force 6.5MPa of wheat straw. When dividing grids of the knife axis and moving knife, the default grid density was selected in the paper, and the grids were divided according to the curvature.

After applying the set speed of the knife shaft to drive, the simulation results were shown in Fig.6. It could be seen from the stress distribution of the knife shaft that the maximum stress appeared at the welding position between the knife holder and the knife shaft, which was up to 225.1 MPa and lower than the yield strength 235 MPa of the knife shaft material, and the stress close the end of knife shaft was larger, but within the normal range of the result.

4.3.2. Simulation Analysis of Chopping Device with New Arrangement of Moving Knife

For the new arrangement method of moving knife designed in the paper, the stability of the knife shaft could be determined according to its influence on the stress of the knife shaft during chopping. the material of chopping device and applied load of moving knife were the same as the setting of spiral line arrangement method. the global contact was selected between the material part contact, after clicking to generate this example and the stress distribution diagram obtained by simulation was shown in Fig.7.

We could see from Fig.7 that the stress distributions on the knife shaft were uniform and the maximum stress also occurred at the welding position between the knife holder and the knife shaft, which was up to 205.2 MPa and lower than the yield strength 235 MPa of the knife shaft material.
5. Results & Discussion
When selecting safety factor, we should choose it from the angle of safety and economy, under static load analysis in general, the safety factor of rigid material could be chosen as 1.5\textsuperscript{[7,8]}, because the maximum stresses of L type knife and fixed knife were less than the allowable stress 286.67 MPa of the material, and the safety factors were more than 1.5, the designs of L type knife and fixed knife met the requirements.

When adopting spiral line arrangement method of moving knife, the vibration of chopping device was small, but the straw would accumulate on one side of the shell when working, which would easily cause the device to be blocked. Compared with the spiral alignment method, the maximum stress on the knife shaft decreased by 8.84\% after adopting the new arrangement method of moving knife. This arrangement method made the knife shaft run smoothly, which was beneficial to prolong the service lives of the knife and the knife shaft, and improve the effects of straw chopping and scattering.

6. Conclusions
(1)The combined moving knife composed of L type knife and straight type knife had good performances of chopping and picking, the maximum stresses of L type knife and fixed knife were 267.1MPa and 250.2MPa respectively after applying a pressure of 6.5MPa vertically on the slant of the designed L type knife and fixed knife, and the safety factors were 1.61 and 1.72 respectively, This met the design requirements.

When the working width of chopping device was 1730 mm, 36 pieces of L type knife and 18 pieces of straight knife could be arranged on the knife shaft according to the selected density of 0.0208 pieces/mm, which could constitute 18 groups of combined knives, the center distance of the adjacent moving knife was 100 mm.

(3) When the pressure of 6.5MPa was perpendicularlly applied to the slant of L type knife and the rotation speed of knife shaft was set at 2400r/min, the maximum stresses of the knife shaft both appeared at the welding positions of the knife holder and the knife shaft in accordance with the commonly used spiral line and the engine work order proposed in this paper, and reached 225.1MPa and 205.2MPa respectively, compared with the spiral line arrangement method of moving knife, the maximum stress on the knife shaft decreased by 8.84\% when moving knives were arranged in engine work order, which indicated that the new arrangement method was more reasonable.

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