ISSN 2706-655X Vol.5, Issue 4: 52-57, DOI: 10.25236/IJFET.2023.050409

Optimization of Blade Structure for a Straw Returning Machine

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Abstract: *To address the problem of insufficient impact resistance and easy damage of blades in straw returning machines, which affects the efficiency of straw crushing, an optimization design of the blade structure for straw returning machines was carried out to enhance the strength of the blades. Based on the geometric dimensions of the physical L-shaped blade for straw returning, a mathematical model was established using simulation software. Reinforcement was added to the blade to optimize the structural design. By comparing and analyzing the internal stress of the blade before and after optimization, the optimal bending angle of the blade was determined. When the applied load varies within a certain range, a comparative analysis of the deformation of the tool before and after optimization was conducted, and the results showed that the deformation of the blade after optimization was significantly reduced. Therefore, the L-shaped blade for straw returning with the optimal bending angle and reinforcement has stronger impact resistance, better environmental adaptability, higher efficiency in straw crushing, and extended service life.*

Keywords: *straw returning, blade structure, static analysis, optimal design*

1. Introduction

Currently, China's policy no longer allows the direct burning of straw in the fields, and most rural areas no longer need straw as fuel for cooking or heating. Therefore, the treatment of straw has become an urgent problem that needs to be solved. Ecological circular agriculture is a sustainable agricultural production, and it is also an agricultural model that focuses on new technologies and pursues maximum yield. Returning straw to the fields is an important component of ecological circular agriculture[1]. Circular agriculture has been advocated in various regions of China for a long time, and three principles have been listed, namely, "reduction", "reuse", and "recycling". The "recycling" principle requires the secondary utilization of agricultural and sideline products to transform them into usable resources rather than worthless waste [2]. Returning straw to the field is a production method that enhances soil fertility and has gained widespread attention around the world. This approach not only eliminates air pollution caused by burning straw, but also has the effect of increasing fertilizer and efficiency[3]. Therefore, the technology of returning straw to the field has emerged as the best solution for handling the problem of straw.

Currently, there is relatively little research on straw returning machines in China, and the focus is mainly on the structural design of the machine's main shaft and the optimization of motor parameters. There is very little research on the optimization design of blades. Blades play an important role in straw crushing work, and they are closely related to the quality and efficiency of straw crushing. Using finite element analysis software Ansys Workbench, not only can the geometric structure of the blades for straw returning machines be optimized, but also the stress analysis of the blades can be obtained. Based on this, parameter adjustments can be made to improve the working efficiency and reliability of the straw returning machine.

2. Overview of Straw Returning Machine

Straw returning machine is a type of machinery that ploughs the field while returning straw to the field, achieving secondary utilization of straw. It can cut and crush the crop straw and stubble left between fields, and then spread or turn it into the soil. The main structure of the straw returning machine consists

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of a power system, a transmission system, a cutting and crushing system, and other major components. The main components of the cutting and crushing system include the box body, main shaft, and blades.

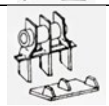
Since the 1960s, China has been exploring straw returning technology. Many agricultural colleges and institutes have conducted many trials of reduced tillage and no-till farming, and have developed a series of straw returning implements, effectively improving the efficiency of straw returning. However, there has been little research on the basic theoretical aspects of the working mechanism and material improvement of straw returning machines. After more than half a century of development, although some achievements have been made in straw returning technology in China, most of them are only applicable to plains and cannot be used for straw returning in mountainous areas. Currently, domestic straw returning machines have complex models and styles, and the quality of straw returning cannot be guaranteed. The automation and intelligence level of straw returning is also low. At the same time, the adaptability of straw returning blades to complex terrain is poor, and the working stability is poor. A standard and standardized production system for blades has not yet been formed[4-5].

3. The important role of straw returning blades

Straw returning blade is a key component of straw returning machine, and its operating environment is relatively harsh, requiring frequent direct contact or friction with debris such as stalks, soil, and even stones. Moreover, the rotating speed of the shaft that installs the straw returning blade is relatively fast, so in order to crush the straw, the blade needs to bear a lot of pressure[6].

In order to enhance the adaptability of straw returning blades for crushing various crop straws, multiple types of straw returning blades with different designs have been developed domestically in recent years. Among them, hammer-claw type blades, straight blade type blades, and L-shaped blades are widely used. Their characteristics are shown in Table 1.

Table 1: Characteristics of common straw returning blades

Blade type	Picture	Material	Power consumption
Hammer-claw blade		Cast steel	High
L-shaped blade		High manganese steel	Centered
Straight blade		High manganese steel	Relatively high

Hammer-claw type blades can crush various types of crop straws, such as corn, wheat, and cotton straws, but they have poor adaptability to terrain. Straight blade type tools have good crushing effect, but they have a higher stubble height and are more complicated to process. L-shaped blades have good crushing effect on brittle straws and can effectively reduce the entanglement of straw fibers on the shaft. However, it is susceptible to hard objects and can easily break when encountering stones [7].

Among the three types of straw returning blades, the L-shaped blade has the highest economic efficiency and higher crushing efficiency. Its scope of application and power consumption are better than hammer-claw type blades, and the cutting height and production cost are better than straight blade type cutters.

4. Method of blade optimization

Optimization design is a design method that compares multiple design options and selects the best solution to achieve the optimal design goal and effect. It is based on the optimization theory in mathematics, creating an objective function for the performance goals that the design needs to achieve, and seeking the optimal design solution based on meeting the given constraints.

When conducting optimization design for blade structure, Ansys Workbench is the most commonly used finite element analysis software. Ansys Workbench software has universality and openness, and can interact with other CAD software, third-party solvers, or product data management programs and other tools in real-time data exchange, thus achieving an efficient workflow. Compared with other traditional

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optimization methods, using Ansys Workbench software is more convenient and accurate. Users can develop various modules and formulate calculation plans according to their needs, thereby improving the efficiency and quality of model analysis[8].

This article's optimization of the straw-returning blade includes two aspects: firstly, setting up reinforcing ribs on the straw-returning tool, and secondly, selecting the bending angle of the straw-returning blade. When using the finite element analysis software Ansys Workbench for optimization design of the straw-returning blade, the following steps are included: (1) Establish a straw-returning blade model with reinforcing ribs and a normal-returning blade model, compare the deformation of the two models through static analysis. (2) Change the bending angle of the straw-returning blade with reinforcing ribs, set up 4 groups of simulation data, and compare the deformation of the models through static analysis. (3) Perform statistical analysis on the simulation data and obtain the optimal bending angle for the straw-returning blade with reinforcing ribs.

5. Optimization design of straw returning machine blades

The L-type blade is generally hinged on the tool holder, and there is a certain overlap in the rotation trajectory between adjacent tools. The rotation direction of the blade is opposite to the walking direction of the chopper. Some L-type blades are machined with two-sided edges that can be replaced, which can reduce production cost. In order to balance the axial force of the cutter arbor and the throwing blade to improve the crushing effect of the straw, the L-shaped blade is generally symmetrically arranged in a Y-shaped style. The L-shaped blade consists of a side cutting edge and a tangent cutting edge. When working in the field, the tangent cutting edge cuts across the straw, and the side cutting edge gradually cuts in along the direction of the straw.

The work of the L-type tool on the straw is mainly focused on the impact crushing, with cutting as a supplement. During operation, the use of sliding cutting action can reduce cutting resistance by 30% to 40%. Therefore, this type of blade does not require very high sharpness of the cutting edge, but it does require high impact resistance. The purpose of this optimization design is to reduce blade wear, blade change time, and overall usage cost.

5.1 Optimization design of overall blade structure

When using high manganese steel as the material, straw returning blades have good crushing ability and lower processing costs, but they are afraid of hard objects such as stones when working. If there is a collision, the blades are easily damaged. In order to improve the impact resistance of L-shaped cutting tools, the angle at the bending point of the tool can be changed and a "blade ridge", namely a reinforcing rib, can be added to the tool. The distance between the reinforcing rib and the center of the blade installation circular hole is set to 12mm to ensure the normal installation of the blade. This can improve the strength and impact resistance of the blade, thereby reducing the degree of fragmentation when the tool is damaged. Figure 1 shows a comparison diagram of the L-shaped straw returning blade before and after optimization. The upper part of the blade is 11cm long, the lower part is 6.25cm long, and the overall horizontal length of the blade is about 15cm to ensure its effective cutting range.

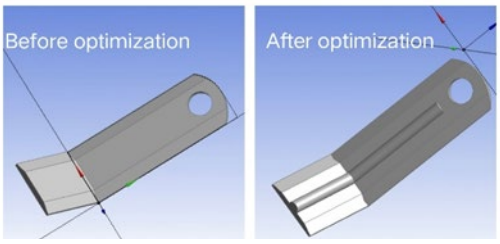

Figure 1: Comparison of L-shaped straw returning blade before and after optimization

The cutting edge of the straw returning blade is the first location to wear out, and to extend its lifespan, NIWC material can be sprayed and welded onto it. The reinforced layer formed by spraying and welding NIWC alloy powder has excellent wear resistance, which can be used to repair and strengthen the cutting tools of the straw returning machine. Selecting a blade angle of 30 ° can not only ensure its self-grinding performance, but also improve the overall crushing efficiency of the straw returning machine and increase its economy[9].

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5.2 Selection of blade bending angle

The bending angle of the blade has a significant impact on the deformation and power consumption. When the bending angle is too large, the blade tip will first come into contact with the straw, and the resistance of the tool will increase, which will accelerate the deterioration of the tool and easily lead to the deformation of the blade. On the contrary, when the bending angle is too small, the bending point will first come into contact with the straw, which is prone to entanglement and reduces the crushing efficiency.

Numerous studies in relevant literature have shown that bending angles ranging from 125 ° to 130 ° are optimal [10]. When conducting simulation analysis of blade bending angles, 124 °, 127 °, 130 °, and 133 ° were selected as experimental data. At the same time, in order to make the deformation more obvious, a pressure of 5KN can be applied to the side of the cutting tool. The deformation of the cutting tool under the same load conditions for different bending angles is shown in Figure 2. From the simulation results, the deformation is smallest when the bending angle is 130°. Therefore, the cutting tool bending angle of 130° is used in this optimization design.

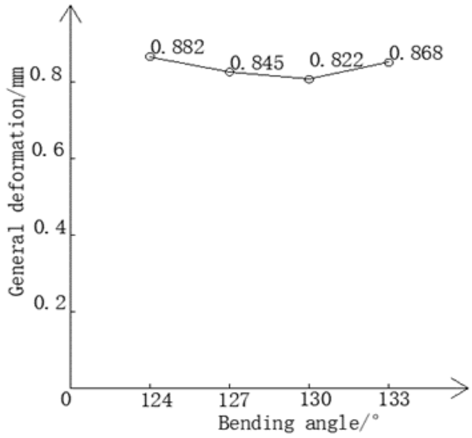

Figure 2: The impact of bending angle for L-shaped straw returning blade

5.3 Static analysis of L-shaped straw returning blades

When the straw returning machine is working, the returning blades rotate rapidly. At this time, the straw returning blade is not only subjected to the force transmitted by the blade holder and the friction force between the blade and the straw, but also to the reaction force when colliding with the stone[11]. Therefore, when optimizing the design of straw returning blades, the first consideration should be how to reduce these stresses or improve the blade's ability to resist deformation.

The basic process of static analysis using ANSYS software can be followed step by step. A mathematical model can be established using an L-shaped blade as the research object, and geometric parameters of commonly used L-shaped blades, such as length, width, thickness, bending angle, etc., can be selected as simulation parameters. On this basis, reinforcement ribs can be added and the bending angle can be optimized to 130° to obtain the optimized structure of the L-shaped cutting tool.

Add the same load was added to the same part of the blade model before and after optimization, as shown in Figure 3. When performing static analysis, pressure A was added at the cutting edge where the blade is most likely to collision with hard objects, and the variation range of the added pressure is 400N-800N. A fixed support B was added at the circular hole on the blade. The deformation degree of the blade was simulated and recorded, and on this basis, the data which could support the optimal design of the straw returning blade was obtained.

Figure 4 shows a comparison of the total deformation of the straw returning blade before and after optimization. The red color represents the maximum deformation, while the blue color represents the minimum deformation. From the figure, it can be seen that the optimized straw returning blade has a smaller range for larger deformation and a more uniform stress distribution. Figure 5 is a comparison line chart of the deformation of the straw returning blade under load. From the figure, it can be seen that the deformation of the blade before optimization is significantly higher than that of the optimized blade under the same load, and the fluctuation of the deformation is relatively large. This indicates that the

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blade before optimization is more prone to deformation.

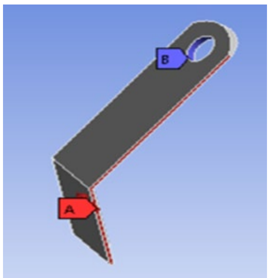

Figure 3: Schematic diagram of load-bearing of L-shaped straw returning blade

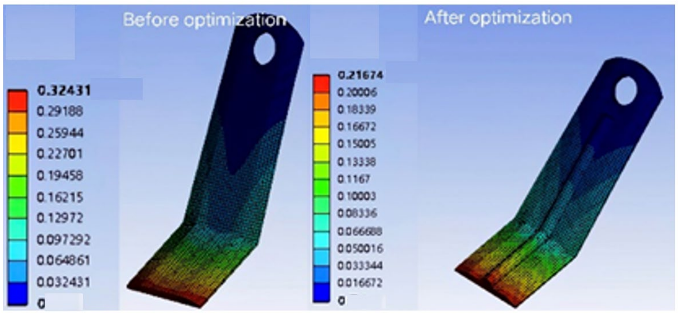

Figure 4: Comparison chart of total deformation for L-shaped straw returning blade before and after optimization

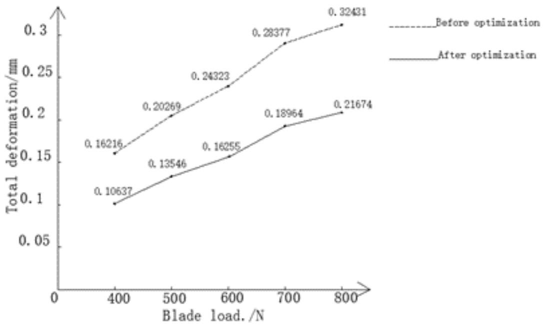

Figure 5: Comparison line chart of deformation for straw returning blade

Table 2 shows the deformation of the straw returning blade before and after optimization under different loads. The data indicate that the deformation of the optimized blade decreased by approximately 33.17%. Therefore, the optimized blade has better toughness and impact resistance, which can extend the service life of the straw returning blade.

Table 2: Comparison of deformation of straw returning blade

Load(N)	Deformation before optimization(mm)	Deformation after optimization(mm)	Rate of change (%)
400	0.16215	0.10837	33.167%
500	0.20269	0.13546	33.169%
600	0.24323	0.16255	33.170%
700	0.28377	0.18964	33.171%
800	0.32431	0.21674	33.169%

6. Conclusion

As a vulnerable component of the straw returning machine, the straw returning blade has a short service life due to the harsh working conditions and severe wear in the field. Frequent replacement of the blade is very troublesome and can increase costs. Therefore, it is necessary to optimize the structure of

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the straw returning blade.

On the basis of the model built based on the actual blade, additional reinforcement was added, and the optimal bending angle of the tool was determined to be 130 ° through static analysis. Finally, by comparing the total deformation cloud map of the straw returning blade before and after optimization, it was found that the deformation of the optimized blade decreased significantly. This optimization design can solve the problem of weak impact resistance and easy damage of L-shaped cutting tools, and provide theoretical support for the optimization design of straw returning machine cutting tools.

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