Design of Straw Guiding Device for Straw Returning Machine

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Abstract: Burying straw into the field is the most direct and effective method for straw utilization. This research enables deep soil fertilization and interval deep loosening. To enhance the efficiency of deep straw burial and returning, as well as the straw cleaning rate, a concave straw guiding device was designed and installed on a side-sweeping type straw returning machine. Based on relevant literature and design requirements, theoretical analysis and calculations were performed for the concave straw guiding plate. The calculated range for the guiding plate deflection angle (β) was $0° \le \beta \le 32.08°$, and the range for the guiding device inclination angle (θ) was $25.89° \le \theta \le 66.8°$. Considering practical processing and installation constraints, the deflection angle β was selected as 30° within the specified range, and the inclination angle θ was set at 45°.

Keywords: Straw Returning; Straw Guiding Device; Mechanism Analysis; Performance Test

1. Introduction

In the process of deep burial and returning straw to the field after cutting and crushing, the guiding device is the main factor affecting the deep burial and returning of straw to the field. However, little research exists on the movement law of straw on the guiding device, so it is impossible to directly choose the most reasonable guiding device, resulting in easy accumulation of straw during the process of deep burial and returning straw to the field[1]. The straw cut and crushed by the side-sweeping deep-burial machine can fall into the deep ditch opened by the machine along with the guiding plate. The original guiding device cannot guide the crushed straw into the deep ditch properly, resulting in blockage at the end of the guiding plate[2]. In view of the above problems, this study will analyze the movement law of straw on the guiding device, which has important academic value, but also lays a solid theoretical foundation for the design of the guiding plate in the future, and plays an important role in the quality of deep burial and return of straw to the field.

The straw guiding device must meet the following design requirements: It should be structurally sound to satisfy operational demands and structural integrity; it must work seamlessly with the side-sweeping deep-burial tillage machine, effectively guiding straw flow during operation; and it should adapt to complex field conditions, ensuring optimal passage of crushed straw[3-5].

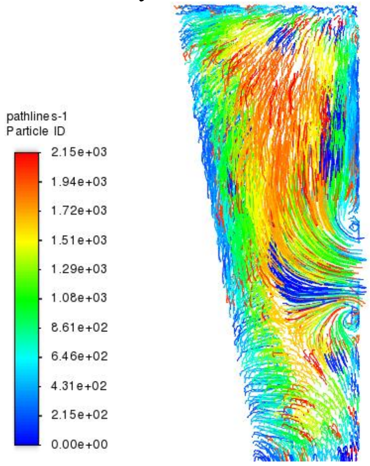
The concave flow guiding device was designed in this paper, the force analysis of straw soil and the straw guiding device was carried out, and the effect of the straw guiding device was simulated by 3D-modeling software to determine the structural parameters of the flow guiding device. This study provides theoretical support for the practical application and design of straw returning machine.

2. Determine the Straw Guiding Mode

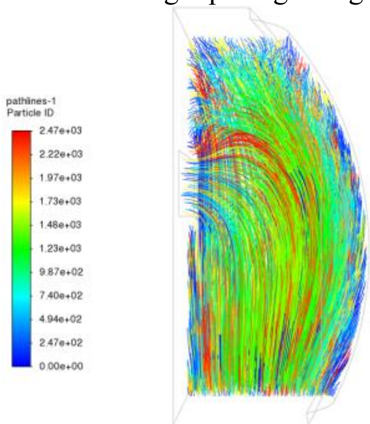
The straw guiding device was simplified by using 3D-modeling software, and the processed model was extracted in Space claim to complete the establishment of the flow field model as shown in Figure 1. Then the mesh division was started in mesh, and the boundary was defined and bar construction was set according to the requirements.

The influence of installing different shapes of flow guiding devices on the gas flow field was analyzed using fluent. The inlet wind speed was defined as 1 m/s, with other boundary conditions remaining unchanged. Motion trajectory line diagrams and vector diagrams were obtained for three different shaped flow guiding devices and no bottom installation of flow guiding devices.

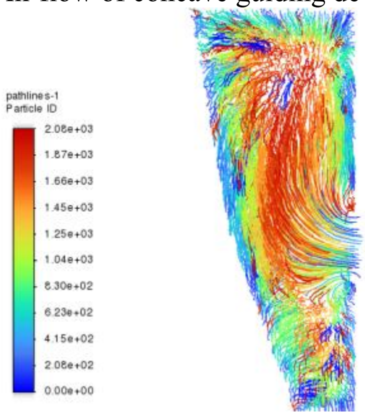
The pressure distribution patterns of different shaped guiding devices were analyzed under identical conditions. Results showed that concave-shaped guiding devices enable gas to flow downward, effectively conveying straw into the single-shovel chamber. Figure 1 demonstrates that straight-plate guiding devices generate maximum upward pressure during gas movement, failing to exert downward force on straw. Comparative tests revealed that the concave-shaped configuration achieves superior operational efficiency.



(a) Air flow of straight plate guiding device



(b) Air flow of concave guiding device



(c) Air flow of folding plate guiding device

Figure 1. Air Flow of Different Guiding Devices

Based on the above analysis, this paper selects concave flow guiding device for optimization design under the condition of meeting mechanical design requirements.

3. Design of Straw Guiding Device

The straw guiding device of the side-sweeping deep-burial tillage machine serves as a critical component. Its primary function is to channel the shredded straw from the cutting blade into deeper soil layers. The shredded straw is propelled along the vertical direction perpendicular to the guiding plate's tangent line, effectively reducing collision frequency between straw and guiding plates while minimizing operational resistance and energy loss. This mechanism optimizes the mechanical properties of straw utilization through lateral cutting and dispersion[6]. According to the requirements of agricultural machinery design manual, the structural parameters of the guiding plate are designed theoretically to ensure that the crushed straw can slide smoothly into the soil.

During the operation of the side-sweeping deep-burial tillage machine, the blade cuts and crushes the straw, which is then thrown toward the guiding plate. Guided by the guiding device, the straw follows a predetermined trajectory to a designated location before being buried into the soil by the automatic soil covering mechanism on the machine[2].

A modular drainage device housing with a curved design (Figure 2) has been developed which compose of an automatic soil covering shovel, straw guiding panels, sliding rail fixing device and sliding rails. The device features detachable components connected via bolts to the outer casing of the straw guiding rails and panels, while rectangular spacer strips are installed on the casing. This innovative design enables adjustable positioning when mounted on straw guiding rails and panels, significantly reducing maintenance costs.

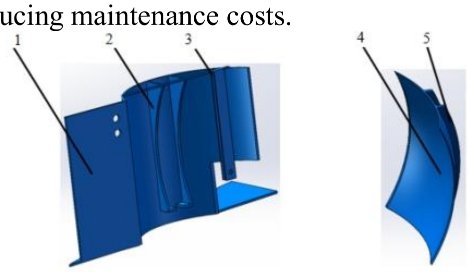


Figure 2. Straw Guiding Device

1. Automatic soil covering shove
2. Sliding rail fixing device
3. Fixing crossbeam
4. Concave guiding plate
5. Sliding rails

4. Analysis and Test of Straw Guiding Device

4.1 Analysis of Straw Guiding Mechanism

Taking crushed straw as the research object, a coordinate system was established, in which x-axis represents the horizontal direction perpendicular to y-axis, y-axis represents the opposite of the forward of the deep-burial straw returning machine, and z-axis represents the plane perpendicular to xoy. As shown in Figure 3, v is the forward speed of the deep-burial straw returning machine, measured in meters per second(m/s); F_f is the frictional force exerted on the crushed straw sliding along the curved surface of the guiding plate, measured in newtons(N); θ is the angle between the tangent direction of the guiding plate and the horizontal plane, measured in degrees (°); β is the installation tilt angle of the guiding plate relative to the returning machine's forward direction. The frictional force F_f caused by the gravitational pull G acting on the shredded straw sliding along the guiding device, combined with the centripetal force F_c generated by the curved surface of the guiding plate, determines the straw's position in the deep furrow through x-directional motion. The differential equation governing x-directional motion is:

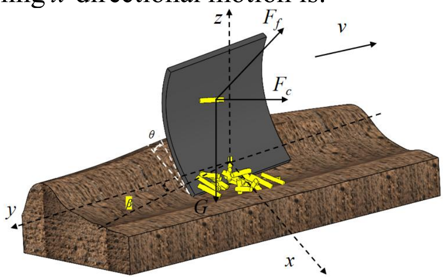


Figure 3. Guiding Mechanism Analysis

$$\frac{d^2x}{dt^2} = \mu g\sin\beta\cos\theta + \frac{\mu\cos\beta\cos\theta}{\rho}\left(\frac{ds}{dt}\right)^2 \quad (1)$$

μ is friction coefficient between corn stalk and concave guiding plate;

s is sliding displacement of chopped and crushed straw on concave guiding plates, m;

ρ is curvature radius of concave guiding plate, m.

$$s = \frac{x}{\sin\beta\cos\theta} \quad (2)$$

Substituting equation 2 into equation 1 yields:

$$\frac{d^2x}{dt^2} = \mu g\sin\beta\cos\theta + \frac{\mu\cos\beta}{\rho\sin^2\beta\cos\theta}\left(\frac{dx}{dt}\right)^2 \quad (3)$$

In order to simplify the calculation process, the method of substitution is used to solve it:

let $p = \frac{dx}{dt}$, $q_1 = \mu g\sin\beta\cos\theta$, $q_2 = \frac{\mu\cos\beta}{\rho\sin^2\beta\cos\theta}$. By carrying it into the calculation, the expression of velocity v_x along the x direction of the cut and crushed straw on the concave guiding plate can be obtained as:

$$v_x = p = \sqrt{\frac{e^{\frac{q_2(x-c)}{2}} - q_1}{q_2}} \quad (4)$$

In equation 4, the unknown constant c needs to be solved. At the same time, considering the feasibility of practical application and convenient processing and production, the curved shape of concave flow guiding plate is set as a parabolic function, and its expression equation is $y=ax^2$. By selecting the cut and crushed straw, point M (x_m, y_m) is the left limit position of the concave guiding plate. The value of the horizontal coordinate x_m at the left limit position of point M is -200 mm, the vertical coordinate of the left extreme position is 600 mm. Substituting the coordinate value of the left limit point M into the equation yields the coefficient a=0.03.

When the machine moves forward, the straw is cut and crushed by the blade and thrown to the concave guiding plate under the action of inertia, and slip is generated when it is in contact[5,7]. According to the actual production needs, Q235 steel with friction coefficient μ 0.6 is selected as the material of the guiding plate. When the shredded straw is in contact with the concave flow guiding device at point N (point N is located at installation angle β=45°, and the inclination angle of concave flow guiding plate is θ=45°), the coefficient q_1=2.94 can be obtained; According to equation 5, the radius of curvature ρ of the concave baffle at the contact point N is obtained to be 330 mm, so that the coefficient q_2=0.0036 can be obtained.

$$\rho = \frac{1}{k} = \frac{(1+y'^2)^{\frac{3}{2}}}{|y''|} \quad (5)$$

The moment of contact between the cut and crushed straw and the concave guiding plate is regarded as an ideal state (that is, air resistance and the interaction force between the cut and crushed straw are ignored). Due to inertia, there are still velocities in y direction and z direction at the moment of contact, and the velocity in x direction is 0. By putting the parameters into equation 5, it is calculated that the constant c is 189.71. Therefore, the x-direction velocity of the cut and crushed straw on the concave guiding plate can be determined as shown in equation 6.

$$v_x = \sqrt{\rho\left[\frac{\tan\beta\sin\beta\cos\theta}{\mu}e^{\frac{\mu\cot\beta}{2\rho\sin\beta\cos\theta}(x+c)} - g\sin^2\beta\tan\beta\cos^2\theta\right]} \quad (6)$$

v_x is the speed of straw returning direction, m/s;

g is acceleration of gravity, m/s^2.

4.2 Parameters of Guiding Plate

In order to ensure that the cut and crushed corn stalks can smoothly slide into the inner part of the shovel ditch along the concave guiding plate. The results show that the installation angle β and inclination angle θ of concave guiding plate are the parameters affecting the effect of straw guiding device. According to the theoretical analysis, when installing the concave guiding device, the x-axis direction should be consistent with the working width of the single automatic furrow opening and covering shovel designed in the first generation straw deep-burial and returning machine, so as to ensure that the cut and crushed straw can fully contact the concave guiding plate during the operation of the machine. According to the national standard GB/T24675.6-2009, the length of the cut and crushed straw should be less than or equal to 10 cm. Based on all the above analysis, it can be concluded that the range of the deflection angle of the concave guiding plate is $0° \le \beta \le 32.08°$.

The range of installation angle of concave guiding plate is brought into equation 6, and the value range of inclination angle of concave guiding plate is calculated to be $25.89° \le \theta \le 66.8°$. According to the actual situation, within the scope of meeting the design requirements, the appropriate deflection angle β of the guiding plate is selected for easy installation, and the inclination angle θ of the guiding device is 45°.

4.3 Performance Test of Guiding Device

4.3.1 Test objective

In order to verify whether the working performance of straw guiding device of the second generation side-sweeping deep-burial tillage machine can meet the design requirements, the test factor was selected as the forward speed of the machine. Other test conditions were the same as above.

4.3.2 Test of concave straw guiding device

The working effect of the straw guiding device refers to the operation efficiency of cutting and crushing the corn straw, which slides down to the bottom of the ditch through the concave guiding plate. That is, the ratio of the mass of the straw sliding down to the bottom of the ditch per unit area to the total mass of the straw per unit area, which can be calculated by equation 7[8]:

$$\xi = \frac{M-m}{M} \times 100\% \tag{7}$$

m is mass of straw remaining per m^2, kg;

M is the total amount of straw per m^2, kg;

ξ is straw guiding rate, %.

4.3.3 Results and analysis of test results

The performance test results of the concave straw guiding device show that the average width of straw fall is 273 mm, and the coefficient of variation of straw fall width is 4.12%. The straw guiding rate is 95%. The results indicate that, based on actual requirements, the design of the concave straw guiding device meets practical needs.

5. Conclusion

Deep burial of straw in the field can achieve deep soil fertilization and intermittent deep loosening of the soil, thereby rapidly increasing soil organic matter content. During the deep burial of straw, straw scattered on the soil surface is collected by a side-sweeping shredding device and placed into trenches opened by a trenching and soil-covering blade. To ensure that all shredded straw is efficiently directed into the trenches, a straw guiding device was designed. The use of a curved surface guiding structure achieves a high efficiency in transporting straw to the bottom of the trenches, with a straw guiding rate of 95%, meeting the technical requirements for straw deep burial and return to the field guiding operations.

Acknowledgments

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