Experimental Study and Structure Optimization on Cleaning Device of Combine with Single Axial-flow

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ABSTRACT: This paper is aimed to find out main factors influencing material movement through analyzing its motion equations under the effect of the airflow. Orthogonal experiment was used to research the effect of four parameters on cleaning performance indicators (loss and impurity rate). The results show that the optimal working parameters are as follows: the fan rotation speed is 1400rpm, the wind plate I, II angle are 30° and 15°, and the fin-type chaffer scales is 24.5mm. Under this circumstances, the loss and impurity rate are 0.32% and 0.31%. The Fluent software was applied to simulate the airflow field of cleaning room, the results indicated that the airflow velocity in the back of screen surface is still lower than the front when parameters are optimal, and a return sieve plate was designed. Field experiment results demonstrated that when the installation angle of plate is 30°, the loss rate is 0.20% and the impurity rate is 0.17%.

Keywords: single axial-flow; force analysis; working parameter; optimization; return sieve plate

1 INTRODUCTION

Combine is a harvest machine that can complete the process of cutting, conveying, threshing separation, cleaning, set grain, etc. Recently, the threshing roller of combine with single axial-flow is relatively long and grain breakage rate is relatively low, so it has received tremendous attention to the market [6-7]. Cleaning device is one of the most important working parts for combine, which influences the operation performance of machine and the harvest performance of grain (loss rate and impurity rate) directly [1-3]. At present, the cleaning device of combine with single longitudinal axial flow is adopted to the air-and-screen cleaning device mostly [3].

Thanks to the combine with single axial-flow is equipped with vertical cylinder, the airflow produced by the fan at the back of screen surface is smaller than that is in the front. In addition, the rate of impurity of material falling from the back of roller is higher and the grain with the stem is thrown outside easily. Therefore it can cause rain losses and poor cleaning effect [7]. In order to solve the weakness of the air-and-screen cleaning device, parameter and structure optimization are conducted.

In recent years, air-and-screen cleaning device was studied by many scholars on the different levels. Cheng et al. researched on the main parameters of air-and-screen cleaning device by use of experimental system [8-9]; Joe Lee et al. put forward a list of parameters which is contribute to cleaning device, according to the characteristics of rapeseed rotor [10]; Xu and co-workers performed the theoretical research on half-and-half feeding amount united harvest machine cleaning device [11]. To date, the research above mainly focused on analyzing the main parameters for cleaning device, which were only by adjusting the working parameters, and could not attain a good and efficient effect for the tail material.

In this work, an experiment about combine with single axial-flow named turion was carried out, which was based on loss rate and impurity rate as performance indicators. It is aimed to analyze the equations of motion of materials under the effect of airflow to find out the main factors that influencing the material movement. Also, orthogonal experiment was used to research on the effect of parameters on cleaning performance indicators. Besides, the software of Fluent was applied to simulate the air flow field of cleaning room, in order to improve the structure of this device. What’s more, the best structural parameters were at-
tained through the deficiency of the analysis of the field test.

2 AIR-AND-SCREEN CLEANING DEVICE

2.1 The structure and working principle of air-and-screen cleaning device

Air-and-screen cleaning device is mainly composed of fan, vibrating screen, graining auger, gleanings auger, return sieve plate and other components, as shown in Figure 1. When it works, cleaning sieve and shaking board keep reciprocating movement, and materials are conveyed to screen from three shaking boards continuously. Besides, it is scattered, layered and penetrate screen under the role of vibrating screen and airflow which produced by fan. Finally, the cleaned grains are transported to bin by graining auger, and the other gleanings are conveyed to cleaning room for a second cleaning by gleanings auger [4-5].

Figure 1. The structure of cleaning device.

2.2 Equations of materials motion under the effect of airflow

Air cleaning system is mainly related to the different aerodynamic characteristics of materials. A single material is viewed as a particle, when the state of motion of materials is analyzed, its movement can be analyzed. What’s more, the force of a single material follows the equation [12-14]:

\[
p = m k \rho v^2 = m \frac{g}{V_p} v^2
\]  

(1)

Here, \( p \) is the force, which is produced by airflow, acting on a single material, \( m \) is the quality of material, \( k \rho \) is flotation coefficient, \( v_p \) is flotation velocity, and \( v \) is relative velocity that airflow is relative to the particles.

The force \( p \) caused by airflow mainly depends on relative velocity, and \( v \) is relative to the particles, which can be seen from formula (1). The velocity of movement is a single material in the airflow, as shown in Figure 2. Where, \( v_0 \) is the initial speed that a material enters into cleaning room from upper shaking board. Moreover, the angle between initial speed and horizontal is \( \theta \), \( u \) is the speed of airflow, and \( w \) is the velocity that airflow relative to a material. \( V \) is the relative speed (equal and opposite from \( w \)) which is between airflow and a material, and \( \alpha \) is the angle between airflow speed \( u \), horizontal \( v \) and horizontal form an angle of \( \beta \).

Figure 2. Analysis diagram of velocity that single material in the airflow.

The synthesis theorem of velocity vector is used to describe airflow and relative velocity of particle, and \( v \) is given by the follow equation.

\[
v = u - V
\]  

(2)

Therefore, the force \( p \) on a single material can be determined by formula (1) and (2). The diagram of the stress focusing on particle is shown in Figure 3. Where, \( G \) is the gravity of a single material, and \( p \) is airflow force on a single material.

Figure 3. Stress analysis diagram of a single material.

So, differential equation of mechanics of a single material in airflow is able to combine from formula (2).

\[
m \frac{dV_y}{dt} = m \frac{g}{V_p} v^2 \cos \beta = m \frac{g}{V_p} V y
\]

(3)

\[
m \frac{dV_x}{dt} = m \frac{g}{V_p} v^2 \cos \beta - g = m \frac{g}{V_p} v x - g
\]

According to the vector diagram in Figure 1, \( u \) is disintegrated to horizontal and vertical direction.

\[
u_x = u \cos \alpha
\]

\[
u_y = u \sin \alpha
\]

(4)
Then, \( v_x, v_y \) can be represented as,

\[
\begin{align*}
    v_x &= u \cos \alpha - V_x \\
    v_y &= u \sin \alpha - V_y
\end{align*}
\]

Additionally, put formula (5) and (6) into (3) and (4) respectively, and eliminate \( m \).

\[
\begin{align*}
    \frac{dV_x}{dt} &= \frac{g}{V_x^2} (u \cos \alpha - V_x) \sqrt{(u \cos \alpha - V_x)^2 + (u \sin \alpha - V_y)^2} \\
    \frac{dV_y}{dt} &= \frac{g}{V_y^2} (u \sin \alpha - V_y) \sqrt{(u \cos \alpha - V_x)^2 + (u \sin \alpha - V_y)^2}
\end{align*}
\]

In addition, the initial conditions are given by,

\[
\begin{align*}
    V_{x0} &= V_0 \cos \theta \\
    V_{y0} &= -V_0 \sin \theta
\end{align*}
\]

It can be concluded from formula (7) and (8) that the state of motion of material in airflow has to do with its own floating speed \( v_0 \), airflow speed \( u \), direction angle of airflow \( \alpha \), the initial speed (material entering into cleaning room) \( v_0 \), and direction angle. Where, the speed of airflow \( u \) depended on rotational speed of fan. Direction angle of airflow is decided by the angle of wind plate I and the angle of wind plate II. The initial speed that material enters into cleaning room and direction angle \( \theta \), is connected with the state of motion of vibrating screen.

3 PERFORMANCE EXPERIMENT ON FIELD

In order to find out the optimal working parameters of combine with single axial-flow in the process of actual working, the field performance tests were carried out.

3.1 Experimental material

Experiment was carried out in the city of Danyang. The variety of rice was “Zhenjiang rice 18”. Most of characteristics of rice were measured by the method of field experiment about mechanical harvest [15]. The measure results are shown in Table 1.

3.2 Experimental program

In this paper, the effect of four parameters, including the fan rotation speed, the scales of fin-type chaffer, the angle of wind plate I and the angle of wind plate II on cleaning performance indicators were researched mainly. Besides, four factors three levels orthogonal experiment were applied to analyze the cleaning performance test of rice in combine. The cutting width is 2m, and the distance of test is 20m. Orthogonal experiment is shown in Table 2.

3.3 The analysis results of field performance test

The program shown in Table 2 was chosen to conduct the field experiment. Among them, the measurement of performance test was the grain impurity and the cleaning loss. The final cleaning performance index was the average of impurity rate and loss rate (comprehensive performance) [16]. The results of field orthogonal test are shown in Table 3.

As shown in Table 3, the primary and secondary factors that influence the cleaning performance are A,
D, B, C, and the optimal combination of cleaning performance is A3D2B3C1. At that time, the fan rotation speed is 1400 rpm, the angle of wind plate I is 30°, the angle of wind plate II is 15° and the scales of fin-type chaffer is 24.5mm. Compared with other groups of orthogonal combination, the rice loss rate and impurity rate are lower. According to the above data, the parameters of combine were re-adjusted so that the optimal scheme can be acquired finally. The loss rate is 0.32% and the impurity rate is 0.31% under this condition.

4 NUMERICAL SIMULATION AND ANALYSIS OF CLEANING DEVICE

4.1 Simulation conditions

In order to seek a lack of cleaning device, considering of the time and cost, numerical simulation are used to simulate interior airflow field of cleaning device. Because actual air-and-screen cleaning device is both large and complex, the structure of cleaning device is simplified. The width of cleaning device is set 200mm, and the length and height are consistent with the real elements. The three-dimensional (3D) model is shown in Figure 4.

![Figure 4. Three-dimensional (3D) model of the cleaning device.](image)

Then, the Gambit is used to mesh the 3D model. Due to the size of the cleaning room is difference, unstructured grid and hybrid grid technique was used to analyzed in order to improve the quality of the mesh[17]. The total numbers of grid of the cleaning device are 845972 finally.

After that, the mesh is imported into Fluent. The surface of the vibrating screen is viewed as a stationary wall, the working pressure is set to an atmospheric pressure (101325 Pa), the inlet boundary is set to velocity inlet with a value of 10 m/s, the outlet is set to free boundary, and others keep default settings [18].

4.2 The analysis results of numerical simulation

When the fan rotation speed is 1400 rpm, the angle of wind plate I is 30°, the angle of wind plate II is 15° and the scales of fin-type chaffer is 24.5mm. The distribution of airflow in cleaning room is shown in Figure 5.

![Figure 5. Velocity vector diagram of airflow.](image)

Table 3. Characteristics of measured rice.

<table>
<thead>
<tr>
<th>i</th>
<th>j</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>y*</th>
<th>y1</th>
<th>y2</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>The fan rotation speed (rpm)</td>
<td>The angle of wind plate I (°)</td>
<td>The angle of wind plate II (°)</td>
<td>The scales of fin-type chaffer (mm)</td>
<td>Comprehensive performance (%)</td>
<td>Loss rate (%)</td>
<td>Impurity rate (%)</td>
</tr>
<tr>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
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<tr>
<td>3</td>
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<td>0.68</td>
<td>0.53</td>
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<td>1</td>
<td>2</td>
<td>3</td>
<td>1</td>
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<td>2</td>
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<td>3</td>
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<td>0.41</td>
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<td>3</td>
<td>1</td>
<td>2</td>
<td>2</td>
<td>0.50</td>
<td>0.45</td>
<td>0.55</td>
</tr>
</tbody>
</table>

Optimal level: A3, B3, C1, D2
Primary and secondary factors: A, D, B, C
Optimal combination: A3, D2, B3, C1
flow velocity in the last nine fin-type chaffer is higher than it in the first. Contraposing these conditions, the structure of cleaning device is improved.

5 CLEANING DEVICE STRUCTURE IMPROVEMENT

5.1 The structure and working principle of improved cleaning device

On the basis of the above cleaning device, the return sieve plate is installed at the back of the vibrating screen. It makes grains fall from the back of concave screen cleaning at the role of the return sieve. Furthermore, it avoids grains being blown to the outside directly. At the same time, it makes materials migrate to the middle of vibrate screen with high cleaning ability. The operating performance of machine is improved under these circumstances. The improved structure is shown in Figure 6.

![Figure 6. The improved structure of cleaning device.](image)

(1) fan device; (2) upper shaking board; (3) middle shaking board of the wobble plate; (4) fin-type chaffer; (5) lower shaking board; (6) woven sieve; (7) tail sheet; (8) return sieve plate; (9) graining auger; (10) gleanings auger; (11) driving mechanism of vibrating screen

5.2 The design of return sieve plate

The return sieve plate is composed of return plate and woven screen. According to the distribution features of airflow in the cleaning room, the return plate is designed to 440×850mm (the front-end of it located above of the second fin-type chaffer). The aperture of woven screen is 350×850mm (the front-end of it located above of the ninth fin-type chaffer). Return sieve plate structure is shown in Figure 7.

![Figure 7. Return sieve plate structure.](image)

5.3 The analysis results of field performance test

The parameters of field experiment are equal to the optimal parameters. For the sake of seeking the best installation angle of return sieve plate, installation angle of 20°, 30°, 40° were selected for field test respectively.

<table>
<thead>
<tr>
<th>Return sieve plate installation Angle (°)</th>
<th>Loss rate %</th>
<th>Impurity rate (%)</th>
<th>Comprehensive performance</th>
</tr>
</thead>
<tbody>
<tr>
<td>20</td>
<td>0.29</td>
<td>0.11</td>
<td>0.20</td>
</tr>
<tr>
<td>30</td>
<td>0.20</td>
<td>0.17</td>
<td>0.185</td>
</tr>
<tr>
<td>40</td>
<td>0.17</td>
<td>0.22</td>
<td>0.195</td>
</tr>
</tbody>
</table>

Table 4 shows that the cleaning performance is better when the installation angle is 30°. Under the condition of the optimal working parameters, the grain loss rate and impurity rate were 0.20%, 0.17% respectively. The results confirmed that the cleaning performance is improved.

6 CONCLUSION

In order to find out the optimal parameters of cleaning room, orthogonal experiment was carried out to research on the effect of four parameters of cleaning performance indicators (loss rate and impurity rate), including the fan rotation speed, the scales of fin-type chaffer, the angle of wind plate I, the angle of wind plate II. The experiment results show that the optimal working parameters of cleaning room in the process of practical working, the fan rotation speed is 1400 rpm, the angle of wind plate I is 30°, the angle of wind plate II is 15° and the scales of fin-type chaffer is 24.5mm. Under the above mentioned circumstances, the loss rate is 0.32% and the impurity rate is 0.31%.

On the basis of simulating the airflow field of cleaning device by Fluent software, the structure of the cleaning device is improved, the test results show that the performance of cleaning device is advanced after it is improved. In addition, when the installation angle of return sieve plate is 30°, the cleaning performance is better (loss rate is 0.20%, the impurity rate is 0.17%).

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