

NUMERICAL SIMULATION AND EXPERIMENT ON AIRFLOW FIELD OF CORN SEED HARVESTER CLEANING DEVICE

玉米籽粒收获机清选装置气流场数值模拟与试验

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ABSTRACT

To better analyze the distribution law of airflow in the wind sieve type cleaning device, this study took the cleaning device of Yafeng 4YZL-6S corn seed harvester as an example and conducted numerical simulation and comparative analysis of the airflow field inside the cleaning device under the sieve plate opening scales of 12, 16 and 20 mm using CFD software. The numerical simulation showed that the distribution of airflow velocity above the sieve surface was uniform at a sieve plate opening scale of 16 mm. Airflow velocity measurements were performed on the test prototype using an anemometer to verify the accuracy of the numerical simulation results. The simulation test results were supplemented by field trials, which showed that when the speed of the cleaning fan was 1200 r/min and the sieve plate opening scale was 16 mm, the impurity rate in the field harvest of the operating machinery was 1.03% and the loss rate was 1.91%. The operating effect met the standard of mechanized corn grain harvesting. This paper can provide a reference for the design and working mechanism research of corn seed harvester cleaning devices.

摘要

为了更好地分析风筛式清选装置中气流的分布规律,本研究以亚丰 4YZL-6S 玉米籽粒收获机清选装置为例,运用 CFD 软件对筛片开度分别为 12、16 和 20 mm 的清选装置内部气流场进行了数值模拟和对比分析。数值模拟结果表明:当筛片开度为 16 mm 时,筛面上方气流速度分布均匀。使用风速仪在试验样机上进行了气流速度测量,验证了数值模拟结果的准确性。通过田间试验对模拟试验结果进行了补充,田间试验结果表明:当清选风机转速为 1200r/min,筛片开度为 16 mm 时,作业机具田间收获的含杂率为 1.03%、损失率 1.91%,作业效果符合玉米籽粒机械化收获标准。本文可为玉米籽粒收获机清选装置设计和工作机理研究提供参考。

INTRODUCTION

Currently, combine harvesters commonly used wind-sieve-type cleaning devices for corn cleaning operations. The device used the blowing effect of airflow and the vibration effect of the sieve to complete the cleaning work together, which had the advantages of high cleaning efficiency, low grain loss rate and good cleaning effect (Xu, 2019). The airflow distribution in the cleaning chamber can affect the cleaning effect, and the study of it has practical application significance. The traditional cleaning research mainly adopted the method of experiment plus experience, which had the disadvantages of large measurement errors, tedious test processes and inaccurate data, etc. Calculated fluid dynamics CFD numerical simulation software was used to analyze the distribution pattern of the airflow field in the cleaning room, which can save research time and accurately derive the movement pattern of airflow, which had been widely used in recent years (Mekonnen et al., 2010).

Many scholars had conducted numerical simulation analyses of the cleaning device. Some scholars used CFD software to simulate the worm wall of different fans and obtained the conclusion that different positions of the worm wall affect the airflow field inside the fan and change the airflow distribution inside the cleaning chamber (Casarsa L et al., 2011). Some scholars invented a constant pressure concave screen of a combine harvester and modeled the threshing device by using the method of data acquisition and testing (Alan et al., 2015). What's more, some scholars conducted a numerical simulation of the mixed airflow field generated by the fan and detaching drum in the longitudinal axial flow cleaning device, improved the fan structure, compared the airflow field before and after the improvement, and verified the rationality of the improved fan through field tests (Tong et al., 2016). Some scholars used FLUENT software to analyze the

airflow field of four fan models in the cleaning device and studied the transverse airflow distribution law of the four fan models (Wang *et al.*, 2017). In addition, some scholars studied the airflow field distribution and the optimization of fan parameters for the multi-duct cleaning device with the centrifugal fan speed, the number of blades of the impeller, and the fan outlet angle as the research factors (Ning *et al.*, 2019). Some scholars have constructed a mathematical model of the linkage structure of the cleaning system of a grain combine harvester by deriving the coordinates, velocity, and acceleration of each node of the cleaning system (Badretdinov *et al.*, 2019; Badretdinov *et al.*, 2020).

Our team conducted theoretical analysis and optimization of the operation process of the corn seed harvester cleaning device in the early stage (Zhao *et al.*, 2022). To further reveal the influence law of airflow field on the performance of the cleaning device, established CFD mode for the cleaning device of Yafeng 4YZL-6S corn seed harvester. The distribution of the airflow field in the cleaning chamber under different sieve plate opening scales was compared and conducted to check the reliability of the simulation model. This paper can provide a reference for further optimization research of corn seed harvester cleaning devices.

MATERIALS AND METHODS

Overall structure and working principle of cleaning device

As shown in Fig.1, the cleaning device of the corn seed harvester is mainly composed of a shaking plate, crank-link mechanism, fish scale sieve, tail sieve, miscellaneous auger, grain auger, adjustment device of the air-regulating plate, and cleaning fan.

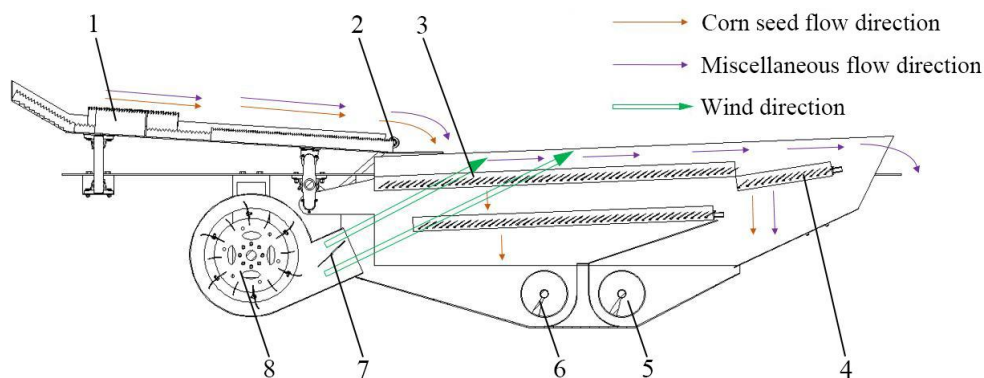


Fig. 1 – Schematic diagram of the structure of the cleaning device

1. Shaking plate; 2. Crank-link mechanism; 3. Fish scale sieve; 4. Tail sieve; 5. Miscellaneous auger; 6. Grain auger; 7. Adjustment device of the air-regulating plate; 8. Cleaning fan

The working principle of the cleaning device is: after the completed threshing operation, the corn threshed mixture is discharged from the holes of the separation concave plate and falls onto the shaking plate. After shaking and bouncing on the shaking board, it will fall evenly on the upper fish scale screen. Light impurities are distributed in the surface layer of the corn threshed mixture, which is directly discharged from the machine after the action of the centrifugal fan. The remaining corn threshed mixture passes through the upper fish scale sieve and falls into the lower fish scale sieve, where the impurity content is less, and clean corn kernels are obtained after further screening by the lower fish scale sieve. The screened seeds slide down the sloping board into the grain auger. The grain auger first collects the seeds to one side and then transports them to the seed collection device. The unclean material from the tail sieve falls into the miscellaneous auger. It enters the threshing unit for the second threshing and cleaning after the action of the miscellaneous auger and the elevator.

Cleaning fan

The cleaning fan is a worm shell centrifugal fan, mainly by the blade, blade connection seat, fan shaft, volute, adjustment device, and damper adjusting plate. Its structure is shown in Fig.2. Compared to the widely used four-blade agricultural centrifugal fan, the six-blade centrifugal fan can provide higher air velocity, air pressure and gas flow. And it can be used for harvests with high material volumes, high water content and high seed content (Cheng *et al.*, 2019). Its main structural parameters are shown in Table 1.

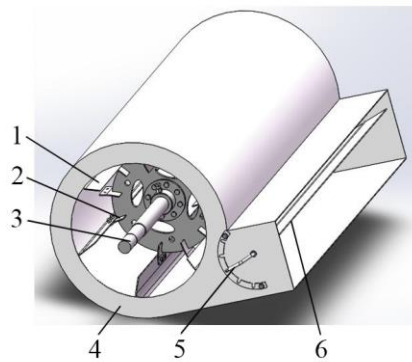


Fig. 2 – Fan structure diagram

1.Blade; 2. Blade connection seat; 3. Fan shaft; 4. Volute; 5. Adjustment device; 6. Damper adjusting plate

Table 1

Centrifugal fan basic parameters

Parameters	Value
Number of blades	6
Outer diameter of impeller /mm	410
Inner diameter of impeller /mm	205
Air inlet diameter/mm	328
Air outlet height/mm	205

Fish scale sieve

As shown in Fig.3, the cleaning sieve is a double-layer fish scale sieve. The fish scale sieve has a similar shape to the fish scale, which has the advantages of strong cleaning ability and high applicability. In addition, the fish scale sieve can well reduce the penetration rate of the threshed mixture and the sieve holes are not easily blocked (Li, 2012). Its structural parameters are shown in Table 2.

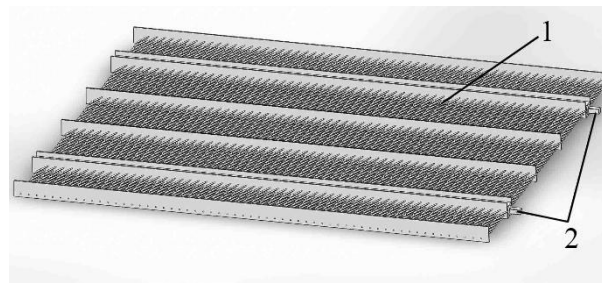


Fig. 3 – Fish scale sieve structure diagram

1.Fish scale sieves; 2. Fish scale sieve adjustment mechanism

Table 2

Centrifugal fan basic parameters

Parameters	Value
Upper fish scale sieve size (LxW)/mm	1500 × 1250
Lower fish scale sieve size (LxW)/mm	1300 × 1250
Upper fish scale screen tilt angle / (°)	5
Lower fish scale sieve tilt angle / (°)	5

Simulation modeling of cleaning airflow field

Based on the model of the 4YZL-6S corn seed harvester cleaning device, the cleaning device was reasonably simplified while retaining the main working parts (Jiang, 2015). In the width direction, 300 mm were selected for the study, SolidWorks was used to establish a three-dimensional flow channel model, saved in igs format, the established model was shown in Fig.4. The length of the model for setting the flow channel of the cleaning device was 2386 mm, the width was 300 mm and the height was 890 mm. The

distance between the front end of the upper fish scale sieve and the front end of the cleaning chamber was 447 mm, and the distance between the front end and the upper end of the cleaning chamber was 413 mm. The distance between the front end of the lower fish scale sieve and the front end of the cleaning chamber was 717 mm, the distance between the front end and the upper end of the cleaning chamber was 529.5 mm, and the two fish scale sieves are parallel to each other. The angle of inclination of the air inlet of the cleaning device was 20° .

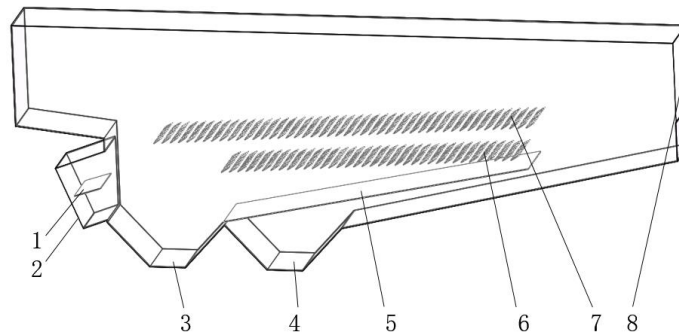


Fig. 4 – Three-dimensional model of cleaning device

1. Damper adjusting plate; 2. Air inlet; 3. Seed auger conveying tank; 4. Miscellaneous auger conveying tank; 5. Grain slide; 6. Lower fish scale sieve; 7. Upper fish scale sieve; 8. Air outlet

The saved .igs file of the cleaning device flow channel model was imported into the Mesh module in Ansys Workbench to divide the mesh. The quality of the mesh division determined the speed and accuracy of the calculation, and a reasonable mesh division was a prerequisite for a successful numerical simulation (Xu *et al.*, 2014). The size of this cleaning device was large, and the flow of internal airflow was complicated, so a tetrahedral unstructured mesh was used for the simulation calculation, and the total number of divided meshes was 6441166. The mesh division was shown in Fig.5.

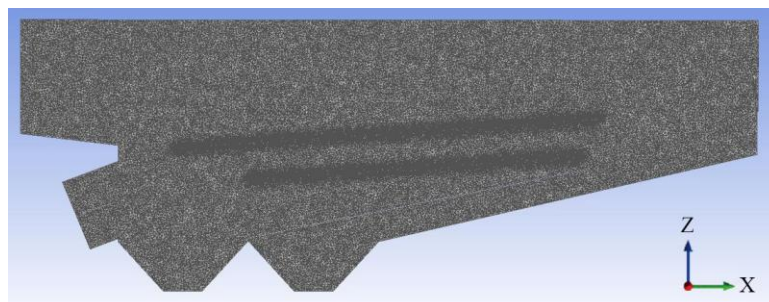


Fig. 5 – Grid division of cleaning device

The divided mesh model was Imported into FLUENT, and it was checked whether the divided mesh met the requirements by the Check command in Setup. And only when the minimum volume was positive, the next step of the solution set could be performed. The dynamic coordinate system method was adopted and the impeller part of the airflow field model was set as the dynamic coordinate system, whose center of rotation was the impeller axis center and the speed was set to 1200 r/min. After setting each boundary condition reasonably, the solution method was set as the pressure-based SIMPLE algorithm, and the model was adopted as the Standard $k-\varepsilon$ model. The number of iteration steps was set to 2800, and the convergence residual was 0.001. By varying the tilt angle of the sieve, three airflow field models were established with sieve plate opening scales of 12, 16 and 20 mm, respectively.

RESULTS AND ANALYSIS

Analysis of numerical simulation results

The monitoring window was set to outlet mass flow rate. When the number of iteration steps was 2,000, the exit mass flow rate reached a steady state, indicating that the variable reached convergence. After the solution was completed, the post-processing was carried out by CFD software, and the plane of $z=200$ mm in the width direction perpendicular to the sieve plane was selected as the study object, and the velocity vector diagram of the cleaning device was obtained as shown in Fig.6, and the velocity cloud diagram was shown in Figure 7.

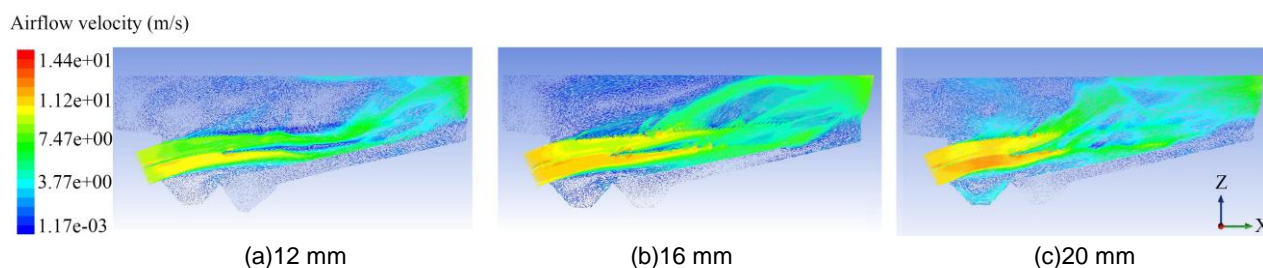


Fig. 6 – Velocity vector diagram

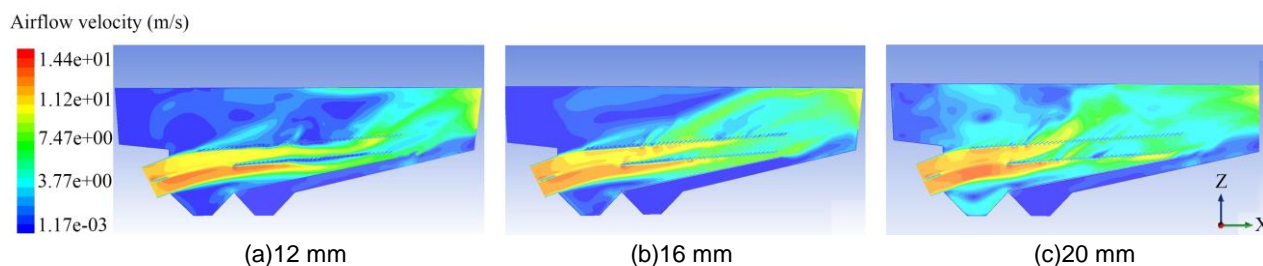


Fig. 7 – Velocity cloud diagram

Compared with the simulation results under different sieve plate opening scales in the figure, it can be seen that when the sieve plate opening scale was 12 mm, the airflow was obstructed by the fish scale sieve and blown to the rear outlet of the cleaning device, and the airflow direction was almost parallel to the sieve surface. The middle position of the vibrating sieve formed a large area of low air-speed area, the sieve surface airflow speed was low and could not blow the seeds and miscellaneous residues in this area to the back of the cleaning room in time, the airflow was not effectively used and did not meet the actual cleaning needs (Jiang et al, 2015).

When the sieve plate opening scale was 16 mm, the sieve had a good inflow effect on the airflow, the gas flow line even ran through the sieve, and there was no vortex between the sieves. The airflow in the middle and rear sections was effectively directed above the sieve surface and high airflow velocity was maintained in these areas. The overall airflow in the cleaning chamber was more uniform, which helped to separate the corn and impurities concentrated in front of the sieve, and the airflow speed at the outlet was increased, which could blow the impurities out of the machine quickly.

When the sieve plate opening scale was 20 mm, because the sieve plate opening scale was too large, it would be made too much high-speed airflow back-guided to the top of the sieve, which could result in the miscellaneous residue being blown to the top of the cleaning room, which could not be effectively excluded, finally causing a decrease in the seed cleaning rate.

Compared with the analysis of the airflow field distribution in the cleaning room under the effect of different sieve plate opening scales, it can be seen that although reducing the sieve plate opening scale could increase the air speed in the X direction, the airflow speed in the Z direction generated by the fan was smaller, which was not conducive to blowing impurities out of the cleaning room. However, when the sieve plate opening scale was too large, it would cause the airflow velocity in the Z direction to become larger. Compared with the simulation results of three different sieve plate opening scales, it can be seen that when the sieve plate opening scale was 16 mm, the air velocity distribution of the airflow field was optimal, which not only produced sufficient airflow in the X direction, but also took into account the airflow in the Z direction, and at the same time, the area of low-speed airflow in the middle of the vibrating sieve was small, which could be met the requirements of the cleaning operation (Zhu, 2019).

Airflow field test verification

In order to ensure that the air velocity distribution law obtained from the simulation had a reference value, the air velocity at the inlet cross-section position of the cleaning device was measured using the cloth point method under the condition of no corn threshed mixture (Ma, 2015). The velocity measurement points were shown in Fig.8, with the lower left end of the air inlet section as the coordinate origin, to the right for X-positive, up for Z-positive, and each measurement point was evenly distributed.

Adjusted the speed of the centrifugal fan to 1200 r/min, refer to GB1236-1985 "Ventilator Aerodynamic Performance Test Methods" to the measurement point at the inlet cross-section for speed testing (Zhang, 2022). Each speed measurement point was tested three times and the average value was taken. Since the

results of the numerical simulation were given in the form of the distribution range, but the test was the airflow velocity at a certain point, in order to compare and analyze the simulation results and test results more accurately, after using TECPLOT software to extract the data of each test point in the simulation results, the measured and simulated values of airflow velocity at each test point were shown in Table 3.

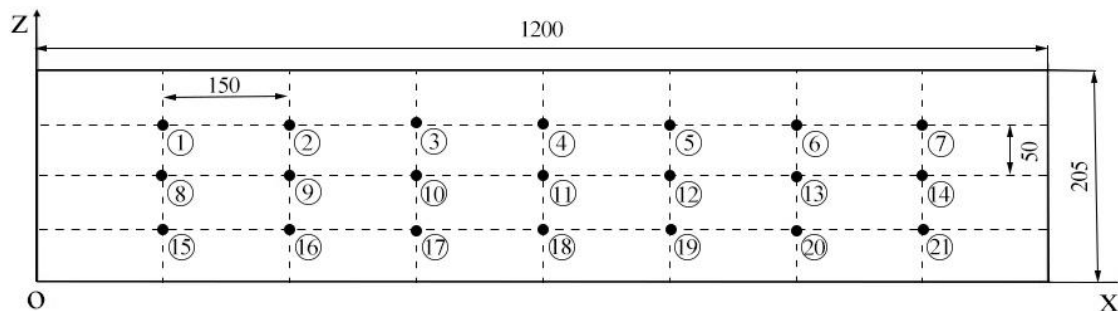


Fig. 8 – Locations of Anemometer Measuring Points at the Wind inlet of cleaning device

Table 3

Airflow speed comparison								
No.	Measured value(m/s)	Simulated values(m/s)	No.	Measured value(m/s)	Simulated values(m/s)	No.	Measured value(m/s)	Simulated values(m/s)
1	11.3	11.7	8	10.5	10.7	15	10.8	11.0
2	12.0	12.3	9	12.2	12.6	16	12.8	13.1
3	13.8	14.0	10	14.1	14.2	17	13.2	13.7
4	13.5	13.6	11	13.9	14.0	18	13.5	13.9
5	13.6	14.1	12	14.0	14.3	19	13.7	14.0
6	11.9	12.3	13	12.4	12.6	20	12.3	12.7
7	11.4	11.7	14	10.8	11.0	21	10.5	10.9

As can be seen from Table 3, the simulated values follow the same trend as the measured values, but the simulated values were slightly larger, the experimental results are consistent with the findings of some scholars (Xu et al., 2010; Wang et al., 2017; Zhu 2019; Ning 2019). The main factors that caused the errors were:

1. The interference of machine vibration and other factors that would cause the inaccuracy of the measured values.
2. In the numerical simulation, the model was created on the basis of simplicity and smoothness, and ignored some of the actual working conditions and flow field energy losses, which caused the simulation values to be large.

The error between the simulated and experimental values at each measurement point was less than 5%, and the overall change trend was consistent, which indicated that the numerical simulation of the flow field in the clearing device of the 4YZL-6S corn seed harvester was reasonable.

Field trials

From the previous numerical simulation and verification test of the airflow field of the cleaning device, the distribution law of the airflow velocity under different sieve plate opening scales was obtained, and the sieve plate opening scale that could produce the ideal flow field was determined to be 16 mm. In order to obtain stable data, the analysis of the airflow velocity above the cleaning sieve was carried out in the stationary state of the mechanism, which had certain limitations, so it was necessary to verify the preliminary study by field trials to investigate whether the actual cleaning effect under the mechanism dynamics meets the demand of cleaning operation.

As shown in Fig.9, the field validation trial was conducted from August 23 to 25, 2022, at the experimental field of Shandong University of Technology, Nanding Town, Zibo City, Shandong Province. The harvested corn variety was Dika 517, the length range was 15~18 cm, the radius range was 4.3~4.8 cm, the mass weight of 1000 grains was 409 g, and the average moisture content of harvested seeds was 30.8%. The test was conducted by Chinese National Standard GB/T 21962-2020 "Corn Harvesting Machinery" (Du et al., 2022).



Fig. 8 – Test site

During the test, the forward speed of the harvester was 2.5 km/h, and the end of harvesting in the test area was the signal for the end of the single test. After the end of the single test, the grain mouth discharge of not less than 2000 g of samples was extracted, and measured according to the five-point sampling method, clean sample bags were used for bagging number. The working parameters of the test machine were set according to the working condition of the simulation test, and the electronic scale with an accuracy of 0.001 g was used to measure the results after the completion of multiple operations, and the results were averaged, and the impurity rate Y_1 and loss rate Y_2 of the operating machine were calculated according to the following formula. As shown in Fig.10, the operation inside the cleaning device was observed through a high-speed camera during the test.

Impurity rate Y_1 :

$$Y_1 = \frac{m_z}{m} \times 100\% \quad (1)$$

Loss rate Y_2 :

$$Y_2 = \frac{m_s}{m} \times 100\% \quad (2)$$

where, m is the total mass of the sample, g; m_z is the mass of impurity in the sample, g; m_s is the mass of corn grains in the sample, g.

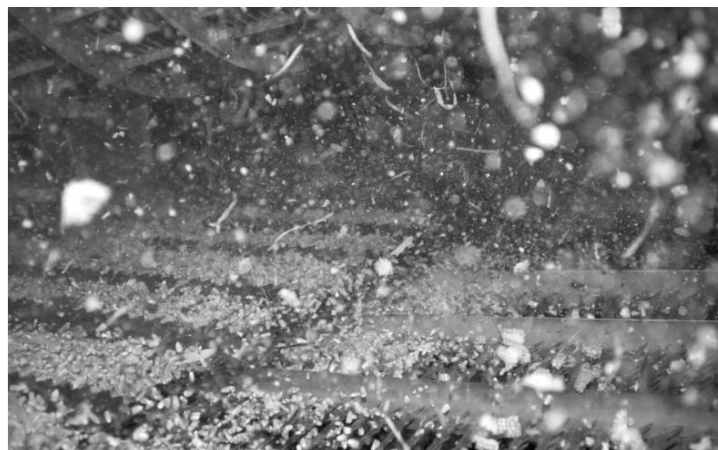


Fig. 10 – Operation inside the cleaning device

According to the test standard, combined with the characteristics of corn cultivation in North China and the requirements of corn mechanized harvesting, the impurity rate in corn seed combine harvester should not exceed 2.5% and the loss rate should not exceed 4%. The values of each index were calculated from equations (1) to (2), and the results were shown in Table 4.

During the test, the machine ran smoothly, the failure rate was zero, the stubble height met the test index. From Table 4, it can be seen that the impurity rate and loss rate were small, and all test indexes had met the requirements of relevant standards.

Table 4

Results of field trials		
Test index	Impurity rate/%	Loss rat/%
Standard value	≤2.5	≤4
Test result	1.03	1.91

CONCLUSIONS

Through numerical simulations and validation tests, the following conclusions were drawn:

1. The numerical simulation results of the airflow field of the cleaning device show that when the sieve plate opening scale was 16 mm, the sieve had a better infusion effect on the airflow. The airflow can pass through the sieve coherently, and there was no eddy flow between the sieves. The overall airflow in the cleaning room was more uniform, and the airflow speed at the outlet had increased, so that impurities could be blown out of the machine quickly.

2. By comparing the measured and numerical simulation results, it can be seen that the airflow velocity distribution was consistent under the same working parameters, and the numerical simulation can be verified as real and reliable.

3. The results of the field cleaning performance test showed that under the working conditions of a fan speed of 1200 r/min and a sieve plate opening scale of 16 mm, the impurity rate was 1.03% and the loss rate was 1.91% after the operation of the cleaning device. The cleaning effect had met the standard of corn grain mechanized harvesting.

ACKNOWLEDGEMENT

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