Simulation Analysis on Airflow Field of Plot Harvester

Yingchun Xiao[1, a], Shuang Wang[1], Min Liao[1], Jian Liang[1] Junfu Zhang[2]

[1]School of Mechanical Engineering, Xihua University, Chengdu 610039, China

[2]Key Laboratory of Fluid and Power Machinery, Ministry of Education, Xihua University, Chengdu 610039, China

[a]350416226@qq.com

Keywords: Plot harvester, Air-and-screen, Airflow field, CFD Simulation analysis, Fisheye sieve.

Abstract. Airflow field play an important role on the cleaning performance of the air-and-screen cleaning device of the plot harvester, and an unreasonable airflow field can lead to poor cleaning quality. In order to understand the cleaning chamber airflow distribution and improve the cleaning quality of the cleaning device, the orthogonal experiment method is used for the numerical simulation on the plot harvester. The workbench is utilized to extract geometric model flow and mesh division on condition that the original shape and size of the fisheye sieve are kept. By means of CFD software FLUENT, the plot harvester airflow field is simulated and analyzed by changing the cross flow fan angle, the clear inclination of sieve and the cross flow fan speed . Test results show that the effective separation parameter is: the cross flow fan speed is 12m/s, the cross flow fan angle is 20 °, and cleaning sieve angle is 6 °.

1. Introduction

The cleaning room is used as the screening environment to separate the impurity and grain, and the cleaning quality is directly related to the distribution of the airflow field in the chamber. For the plot harvester, in addition to the requirements of the low loss rate of cleaning and high cleaning rate of grain, the plot harvester with excellent performance is also required to keep a low grain residue. A lot of researches have been carried out about the main influence factors-vibration amplitude and frequency, eccentric wheel speed, scaly sieve angle etc.[1, 2] The CFD software has been used to analyze the airflow field of the cleaning device. [3, 4] But at present the airflow field simulation on fisheye sieve is scarce, and fisheye sieve, compared with other kinds of sieves (scaly sieve, plane punching sieve, knitting sieve) differs greatly. In recent years, CFD software FLUENT has been widely used in the field of agricultural equipment research, and has been recognized by researchers at home and abroad. [5-7] By means of the airflow field simulation in place of the testing device, the research and development cycle can be shortened, the cost saved, and thus manpower and material resources reduced. Therefore, the plot harvester airflow field was simulated by the software FLUENT. The airflow field analyzed with different structure parameters by orthogonal test method, the distribution and the effective separation parameters are obtained.

2. Airflow field mathematical model

Gas dynamics differential control equations[8]:

Continuity equation:

$$\frac{\partial \rho}{\partial t}+\frac{\partial}{\partial x_i}(\rho u_i)=0 \tag{1}$$

Navier-Stokes equation:

$$\frac{\partial}{\partial t}(\rho u_i)+\frac{\partial}{\partial x_i}(\rho u_i u_j)=-\frac{\partial p}{\partial x_i}+\frac{\partial}{\partial x_i}\left(\mu\frac{\partial u_i}{\partial x_j}-\rho\overline{u_i^{'}u_j^{'}}\right)+S_i \tag{2}$$

© 2016. The authors - Published by Atlantis Press

In order to close (1), (2) equation, the RNG $k-\varepsilon$ turbulent model control equation is adopted. The RNG $k-\varepsilon$ turbulence model is more suitable for large eddy current field, which can reflect the complex flow field distribution more clearly.

$$\frac{\partial}{\partial t}(\rho k)+\frac{\partial}{\partial x_i}(\rho k u_i)=\frac{\partial}{\partial x_j}[(\mu+\frac{\mu_t}{\sigma_k})\frac{\partial k}{\partial x_j}]+G_k+G_b-\rho\varepsilon-Y_M+S_k \tag{3}$$

$$\frac{\partial}{\partial t}(\rho\varepsilon)+\frac{\partial}{\partial x_i}(\rho\varepsilon u_i)=\frac{\partial}{\partial x_j}[(\mu+\frac{\mu_t}{\sigma_\varepsilon})\frac{\partial \varepsilon}{\partial x_j}]+C_{1\varepsilon}\frac{\varepsilon}{k}(G_k+C_{3\varepsilon}G_b)-C_{2\varepsilon}\rho\frac{\varepsilon^2}{k}+S_\varepsilon-Re \tag{4}$$

Where,

$$Re=\frac{C\mu\rho\eta^3(1-\frac{\eta}{\eta_0})}{1+\beta\eta^3}\frac{\varepsilon^2}{k}$$

$$\mu_t=\rho C_\mu\frac{k^2}{\varepsilon},\ G_k=\mu_t(\frac{\partial u_i}{\partial x_j}+\frac{\partial u_j}{\partial x_i})\frac{\partial u_i}{\partial x_j}$$

$$G_b=\beta g_i\frac{\mu_t}{Pr_t}\frac{\partial T}{\partial x_i},\ Y_M=2\rho\varepsilon M_t^2$$

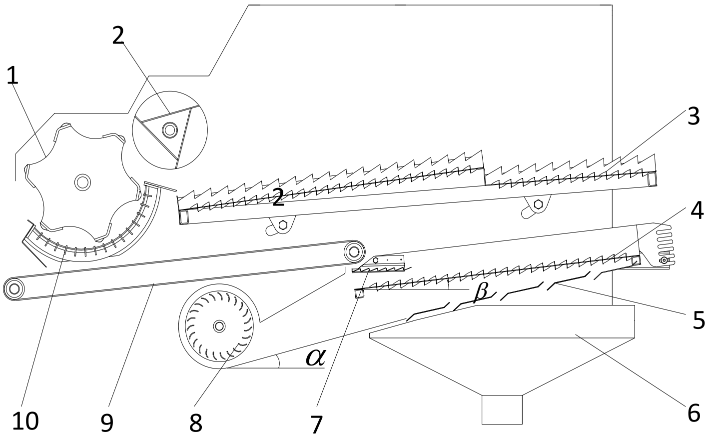
Where,

μ_t -Turbulent viscosity; G_k -Turbulent kinetic energy induced by the mean velocity gradient; G_b -Turbulent kinetic energy induced by the buoyancy effect; Y_M -Effect of compressible turbulent expansion on the total dissipation rate; σ_k -Turbulent kinetic energy corresponding to the Prandtl number; σ_ε -Dissipation rate corresponding to the Prandtl number; S_i, S_k, S_ε -Source term; β -Thermal expansion coefficients; M_t -Mach number.

3. Physical model and calculation model

As shown in figure 1, it's the plot harvester separating cleaning system structure diagram, where α is cross flow fan angle and β is cleaning sieve angle. The cleaning device is composed of several parts, including grain rod roller, concave beater, straw shaker, cleaning sieve, air deflector, grain collector, oscillating grain pan, cross flow fan, conveyer belt and concave grate. After crops threshing through grain rod roller threshing device, most of the wheat grains and draft stem fall on the conveyor belt and are conveyed to the cleaning sieve by oscillating grain pan. However, long straw and a small number of wheat grains are thrown by the concave beater to the straw shaker. By reciprocating motion of the oscillating grain pan, it can effectively separate the wheat grains and the broken ears from the long straws. The wheat grains and the broken ears, through the fisheye sieve hole, fall down to the cleaning sieve after the oscillations of straw shaker while the long straws are thrown to the outside. Meanwhile, the broken ears are blown away with the help of the cross flow fan, and the wheat grains and slight impurities fall to the grain collector.

Because of the complexity of the clearing room, considering that the straw shaker is responsible for the long straw throwing work mostly, and the requirement of airflow between the cavity and straw shaker is low in the cavity. According to the characteristics of the axial uniform distribution of the cross flow fan air outlet,[9] when the consistency between the computation domain and the actual flow field is guaranteed the calculation domain model is simplified. The cleaning chamber cavity region along the axial width of the cross flow fan is reduced, at the same time, the region between the straw shaker and wall was canceled. As shown in Figure 2, A, B, C three points respectively represent the fisheye sieve hole center which is located in a certain section. CREO software is used to create geometric model, and workbench to extract geometric model flow and mesh division. The simplified model of the chamber cavity model is created. In order to vividly simulate airflow through fisheye sieve as much as possible, the original shape and size are retained, where height is 12mm, and length is 25 mm.[10]



1. Grain rod roller 2.Concave beater 3.Straw shaker 4. Cleaning sieve 5. Air deflector
6. Grain collector 7.Oscillating grain pan 8.Cross flow fan 9.Conveyer belt 10.Concave grate

Fig. 1 The plot harvester separating cleaning system structure diagram

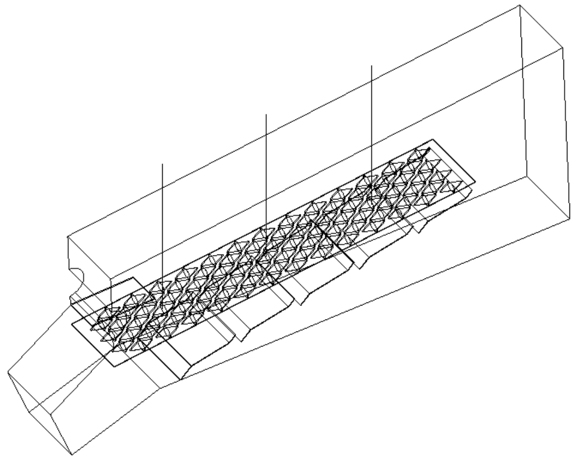


Fig. 2 Computational domain model of the clearing room

4. Solution algorithm and initial boundary condition

The solution is based on the pressure-based of the SIMPLEC separation algorithm, meanwhile, in order to get higher accuracy and less numerical value, second order upwind discretization scheme is adopted. Working environment is set as a standard atmospheric pressure; external boundary conditions: The air outlet of the cross flow fan is defined as the velocity inlet boundary, cleaning sieve tail export is defined as the outflow boundary, other settings are retained default values.[11]

5. Analysis on airflow field in the cleaning chamber

5.1 Test principle

According to the theory of air cleaning, we make use of the difference of the aerodynamic characteristics of the grain mixture to separate. When the updraft speed of fisheye sieve exceeds the floating speed of impurities, and less than the floating speed of grain, it can separate the grain from the mixture effectively. As shown in figure 3, the inclined airflow with velocity v is acting on the material at θ angle with the sieve surface, the material floating speed v_l needs to be overcome by vertical upward flow velocity v_y, satisfied v_y=vsinθ, v_y>v_l.

According to the floating speed of several different of materials in Table 1, if we want to be able to separate the impurities effectively, we need to ensure 6m/s < v_y < 8.9m/s. In the process of moving on the sieve surface, the grain mixture is changed from thick to thin, so, it is important to ensure the sieve surface front airflow velocity 7~8 m/s, central airflow velocity of 5~6 m/s and the rear airflow velocity of 1~2 m/s.[10]

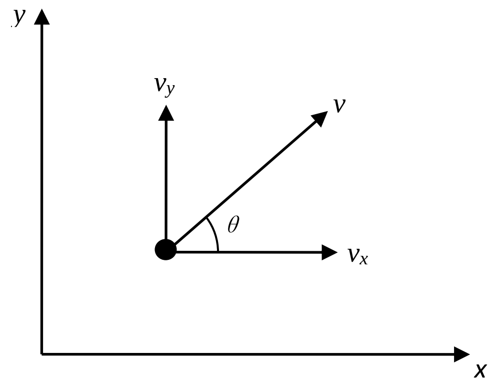


Fig. 3 Vector diagram of airflow velocity

Table 1 Floating speed of several different materials

Category	Floating speed /m•s^{-1}	Density /g•cm^{-3}
Wheat	8.9～11.5	1.22
Light weed	4.5～5.6	1.02
Rice wheat husk	0.6～5	0.4
Short stalk	5～6	
Threshed ear of wheat	3.5～5	

5.2 Design and results of orthogonal experiment

In order to investigate the sieve surface along the length direction of fisheye sieve center airflow velocity on A point, B point and C point. The cross flow fan speed, the cross flow fan angle and the cleaning sieve angle three parameters are selected as influencing factors and orthogonal experiment are carried out with three factors and three levels. [12]The orthogonal experiment table is shown in Table 2.

Table 2 Factors and levels of orthogonal experiment

Levels	factors		
	Cross flow fan speed X/ m•s^{-1}	Cross flow fan angle Y/(°)	Cleaning sieve angle Z/(°)
1	10	15	2
2	12	20	4
3	15	25	6

According to the $L_9(3^4)$ orthogonal experiment table, 9 groups of representative combinations are arranged to carry out simulation tests in the fluent, the test groups and results are shown in table 3.

Table 3 Groups and result of simulation

Test number	Factors			A point airflow velocity	B point airflow velocity	C point airflow velocity
	Cross flow fan speed	Cross flow fan angle	Cleaning sieve angle			
	X/ m•s^{-1}	Y/(°)	Z/(°)	/ m•s^{-1}	/ m•s^{-1}	/ m•s^{-1}
1	10	15	2	5.11	5.38	1.95
2	10	20	4	5.73	6.32	1.68
3	10	25	6	5.86	7.02	1.32
4	12	15	4	5.91	7.15	1.95
5	12	20	6	7.25	8.14	1.53
6	12	25	2	5.96	6.78	2.50
7	15	15	6	9.39	10.20	2.01
8	15	20	2	7.32	8.09	2.92
9	15	25	4	7.91	9.33	2.30

5.3 Test data analysis

As shown in figure 4～6, according to the results of simulation, the speed of A, B, C three points are expressed as the change of the three factor and three level with the chart. It can be seen from Figure 4 that the airflow velocity change of the cross flow fan has obvious influence on the airflow velocity of A, B and C three points. With the airflow velocity increasing, the velocity of the cross flow fan presents an upward trend. As shown in figure 5, the influence of the cleaning sieve angle on the airflow velocity of each point is different. The airflow velocity of A and B have an upward trend with the increase of the sieve surface inclination, however, the airflow velocity of C has a decreasing trend. As shown in figure 6, when the cross flow fan angle is changed, because of the air deflector and the sieve cleaning position has not changed, the airflow velocity of three points changes little.

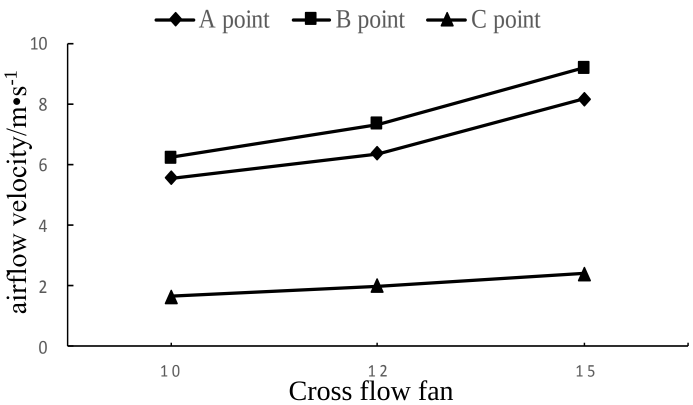


Fig.4 Effect of cross flow fan speed on airflow velocity

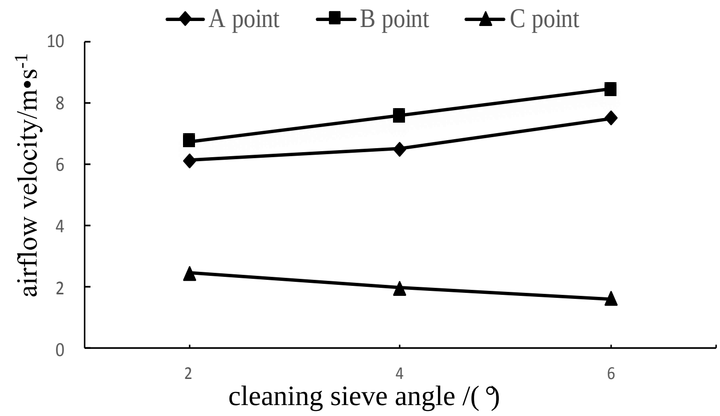


Fig.5 Effect of cleaning sieve angle on airflow velocity

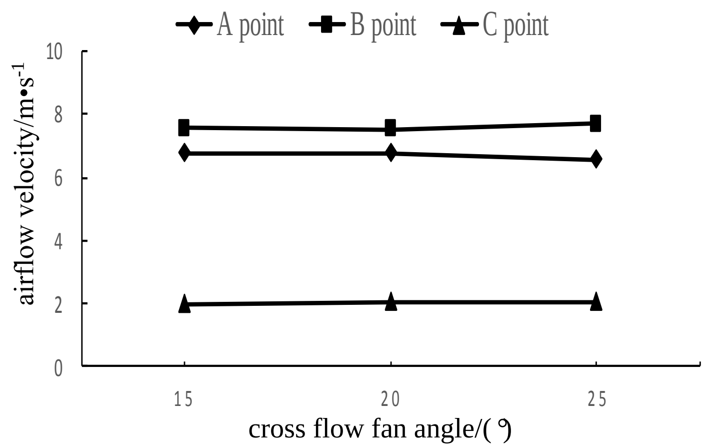


Fig.6 Effect of cross flow fan angle on

According to the test data obtained in table 3 and the requirement of three part airflow velocity of sieve, combined with the floating speed of grain, the combination of test parameters to meet the requirements of the cleaning is determined by $X_2Y_2Z_3$- the cross flow fan speed is 12m/s, the cross flow fan angle is 20°, the cleaning sieve angle is 6°. As shown in Figure 7, the airflow field velocity vector diagram for the parameter combination $X_2Y_2Z_3$.

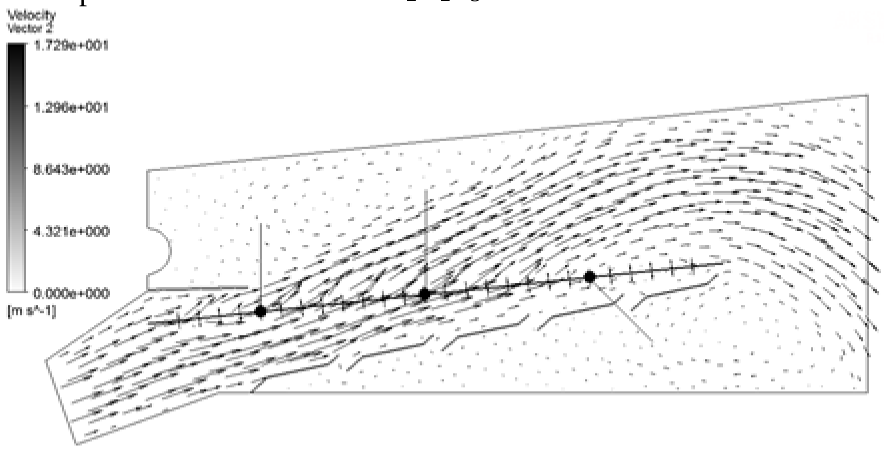


Fig. 7 Airflow field velocity vector diagram of the cleaning room

As shown in figure 7, under the condition of parameter combination for $X_2Y_2Z_3$, the airflow field is relatively smooth, at this point, the A point at a speed of 7.25 m/s, B points at a speed of 8.14 m/s, C points at a speed of 1.53 m/s. Due to the change direction of the front of the sieve surface affected by the Oscillating grain pan. A point y direction of the velocity components is less than B point y direction of the velocity components, and B point speed is less than the floating speed of wheat grains, it can effectively separate the miscellaneous and wheat grains.

6. Conclusion

(1) Simulation on cleaning chamber flow field is carried out by means of CFD software FLUENT, and distribution of the whole cleaning room airflow field is conducted. The three flow velocity of the surface A, B, C is respectively calculated.

(2) Orthogonal simulation experiment with three factors and three levels is utilized. The test results show that: the cross flow fan speed is12m/s, the cross flow fan angle is 20°, the cleaning sieve angle is 6°, which are the best parameter combination in the experiment.

(3) The analysis focuses on cross flow fan speed, cross flow fan angle, cleaning sieve angle. Other factors that affect the distribution of the airflow field (such as the air deflector angle) are not analyzed, but the ideas and theoretical basis can be provided for the further design improvement.

Acknowledgments

This work was financially supported by the Research Project of Application Basis of Sichuan Province (2014JY0055), the Science and Technology Support Project of Sichuan Province (2015NZ0055), the Research Project of Key Laboratory of Fluid and Power Machinery (Xihua University), Ministry of Education (JYBFX-YQ-1), the Innovation Fund of Postgraduated, Xihua University (ycjj2015079).

References

[1]. Yifeng Zhang, Shujuan Yi. Experiment research on multi factors of air-and-screen cleaning device of vertical axial flow[J]. Machinery Design & Manufacture, 2012(02):30-32.

[2]. Wei Tian, Shujnan Yi, Li Zhang. Experimental Research on the Air-and-screen Cleaning Device Parameters[J]. Journal of Heilongjiang Bayi Agricultural University, 2010, 22(04):77-79.

[3]. Hua Li, Meina Zhang, Wenqing Yin, et al. Optimization of Airflow Field on Air-and-screen Cleaning Device Based on CFD[J]. Transactions of the Chinese Society for Agricultural Machinery, 2013, 44(z2):12-16.

[4]. Quan Zhou, Yaoming Li, Hongchang Li. Impact of the Main Structural Parameters on the Airflow Field the Air and Screen Cleaning Mechanism[J]. Journal of Agricultural Mechanization Research, 2012, 34(03):29-32.

[5]. Gebrehiwot M G, Baerdemaeker J D, Baelmans M. Effect of a cross-flow opening on the performance of a centrifugal fan in a combine harvester: Computational and experimental study[J]. Biosystems Engineering, 2010, 105(2):247-256.

[6]. Hongchang Li, Yaoming Li, Fang Gao, et al. CFD–DEM simulation of material motion in air-and-screen cleaning device[J]. Computers & Electronics in Agriculture, 2012, 88(2):111-119.

[7]. Panneerselvam R, Savithri S, Surender G D. CFD modeling of gas–liquid–solid mechanically agitated contactor[J]. Chemical Engineering Research & Design, 2008, 86(12):1331-1344.

[8]. Fang Li, Yaoming Li. Optimization and Simulation Research of the Airway of Tangential - axial Combine Harvester Cleaning Room[J]. Journal of Agricultural Mechanization Research, 2015(02):75-78.

[9]. Xiaoqiang Du, Menghua Xiao, Xiaoqin Hu, et al. Numerrical simulation and experiment of gas-solid two-phase flow in cross-flow grain cleaning device[J]. Transactions of the Chinese Society of Agricultural Engineering, 2014(03):27-34.

[10]. Chinese Academy of Agricultural Mechanization Sciences. Agricultural Machinery Design Manual (down) [M]. China Agricultural Science and Technology Press, 2007.

[11]. Pengfei Li, Minyi Xu, Feifei Wang. FLUENT GAMBIT ICEM CFD Tecplot[M]. POSTS & TELECOM PRESS, 2011.

[12].Qiyi Tang, Mingguang Feng. DPS DATA PROCESSING SYSTEM-Experiment Design, Statistical Analysis and Data Mining[M]. Science Press, 2006.