Screening model and optimization of grains group by queuing theory on air-and-screen cleaning device

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Abstract: In order to develop screening models of grains group on air-and-screen cleaning device, the grains group separating through sieve process and state transition were analyzed by stochastic queuing theory. The models of accumulation grains thickness, grains group separating through sieve hole and losing grain rate of cleaning sieve were developed by stochastic queuing theory. The optimal sieve holes were predicted by controlling the minimum of operating costs and grain losing costs of cleaning sieve. Grains distribution under the cleaning sieve was obtained by performing a cleaning test to verify the predictive value of grain separation and loss process models. The results showed that when the separating capability of one sieve hole was 1.5 Grains per second (Abbreviated as: Gs/s) with grains group feed rate 36.0 Gs/s, the cleaning loss rate of losing grain model was 0.037 Gs/s (grains losing ratio was 0.103%); and the cleaning loss rate of cleaning experiment was found to be 0.042 Gs/s (grains losing ratio was 0.117%) with the relative error 11.97% to model predictive value. The rate of grains group separating through sieve holes and losing grain on cleaning sieve were demonstrating supported by cleaning experimentally of air-and-screen cleaning device. The modeling of grains group separating through sieve hole and losing grain ratio were useful for designing the structural and variable components of the air-and-screen cleaning device.

Keywords: Grains group, queuing theory, cleaning process, sieve hole, cleaning sieve

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1 Introduction

Separating grains from the mixture material on cleaning device was an important step for combine harvester. But the more cleaning efficiency and the lesser grain losses ratio demanded much bigger cleaning device (Tang et al., 2013). From an economic point of view, grain losses in cleaning process resulted in a direct loss of income for the farmer (Craessaerts et al., 2010). Energy consumption by huge and complex cleaning device also resulted in a higher harvesting costs (Liao et al., 2015). So, minimizing grain loss and simplifying structure size were the design requirements of cleaning device. The mixture ingredients separating through cylinder concave were grains, chaff and shredded leaves, short straw. The function of cleaning device was separating grains from the mixture material.

Improvements in modern combine harvesters including new threshing and separation devices have resulted in higher crop yield prompting many researchers to carry out studies to design new cleaning device prototypes (Shen et al., 2016). Structure and parameter design of new cleaning device was based on agricultural machinery manual, past experience, paper data or foreign prototypes (Gu et al., 2014; Cui et al., 2015). But the grain yield, water content of straw and stem characteristics were difference from the state being years ago. So the design theory and design parameters of cleaning device applied to cleaning Chinese crops should be developed. For improving cleaning efficiency and minimizing cleaning loss, many researchers investigated the influence of different cleaning device settings such as fan speed, screen lip angle, oscillating frequency and amplitude (Su et al., 2016).

Several mathematical models using empirical,

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statistical, and physical approaches have been developed in the last decades (Craessaerts et al., 2008). Physical interpretation of cleaning and grain segregation along sieve length was used to describe the cleaning process by Miu et al. (2003); Zhao et al. (2010) simulated the cleaning process of particle flow on vibrating plate based on the soft-ball dry contact model. Ren et al. (2015) established a cleaning results relationship curve affected by airflow velocity in cleaning shoes. Based on experimental data and modeling analysis, non-optimum working regimes can be distinguished from the optimum. Above cleaning investigation was macroscopic method taking cleaning process as an overall without intuitive process model. More physical insight into the cleaning process could be gained by developing physical and statistical models.

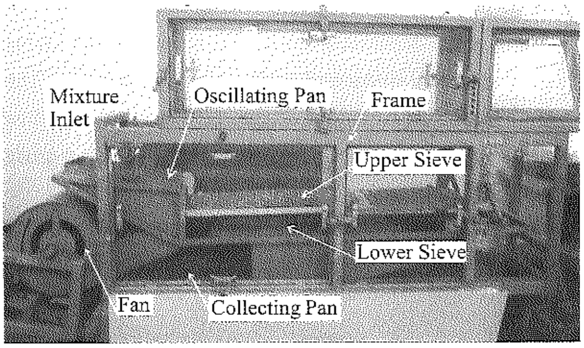
A disadvantage was that the coefficients in these mathematical functions were influenced by crop properties, adjustments, and design parameters. Some researches tried to create a deeper insight into certain aspects of the cleaning process, but the common drawback of most standard modeling was that most of these mathematical models were regression models or simulation models. The general applicability of a regression model was very limited. Li et al. (2013) presented mathematical investigation of particulate motion on an inclined screening chute using the Discrete Element Method (DEM). After that, Jiao et al. (2008) developed a two-dimensional DEM emulator, and investigated three typical penetrating behaviors in cleaning process by the emulator. Li et al. (2014) simulated discrete grain separating process on sieve based on the DEM software to improve efficiency and reduce grain loss. Above investigation methods were discrete motion of particles. These EDEM cleaning simulation could display characteristics parameters of single grain. In EDEM cleaning simulation process, the grains group behavior was obviously. But there was not widely accepted cleaning theory and model (Craessaerts et al., 2007a, 2007b; Liu et al., 2015; Joernsgaard and Halmoe., 2003).

In this paper, the separation and loss model of grains group were developed by the queuing theory. The numbers of sieve holes was optimized using the queuing separating model, and rice grain cleaning tests were performed to verify the queuing separation model. These models of grains group separating through sieve holes and losing grain rate of cleaning sieve could be used to optimize the structure of the cleaning device and monitor the grain loss in harvesting.

2 Materials and methods

2.1 Air-and-screen cleaning device

Air-and-screen cleaning device was an important component of combine harvesters. Cleaning device on a combine harvester consists of mixture inlet, oscillating pan, cleaning sieve, collecting pan, fan and boom cleaning sieves and fan. The structure of air-and-screen cleaning device was shown in Figure 1.

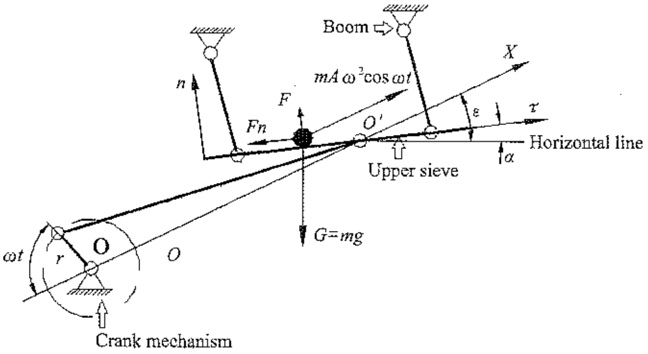


1. Mixture inlet 2. Oscillating pan 3. Upper cleaning sieve 4. Frame
5. Boom 6. Fan 7. Collecting pan 8. Lower cleaning sieve

Figure 1 Structure of air-and-screen cleaning device test bench

The structure size of upper cleaning sieve was approximately 650 mm long, 200 mm wide, with sieve holes diameter of 8-12 mm. Mixture material was fed onto upper cleaning sieve from oscillating pan. Then grains were separating from the mixture material on upper cleaning sieve. The fan speed, sieve holes diameter, oscillating frequency and oscillating amplitude of this air-and-screen cleaning device could be changed or replaced. The screening process of this air-and-screen cleaning device was coupled simulation using a commercial Computational Fluid Dynamics code (CFD$^{®}$ 2015) and a commercial three-dimensional DEM code (EDEM$^{®}$ 2.5,) (Tang et al., 2015; Li et al., 2012). Preliminary findings were based on a fan speed of 800 rpm, sieve holes diameter at 8 mm.

A variable-frequency motor was used to drive the cleaning device. Mechanical oscillations of the cleaning sieve resulted in the transport of all materials along the sieve length. When the cleaning device was loaded with grains, chaff, shredded leaves and short straw, the reciprocating oscillation carries out the upper sieve. This was done by the up and down action of the grain, which pushes it into the sieve hole. The reciprocating oscillation of the upper and lower sieve includes the sieve, boom, four-bar linkage and crank mechanism. The structure and diagrams of oscillating sieve was shown in Figure 2. The motion analysis of oscillating sieve was also introduced by Li et al. (2012).



Note: ω was the rotation velocity of crank mechanism, rad/s; t was working time, s; r was the crank radius, mm; O was coordinate origin; G was gravity, N; n was the direction perpendicular to the sieve surface; Fn was friction between grain and sieve; A was the amplitude of oscillating sieve, mm; O' was endpoint of bar linkage; X was the direction of x-axis; F was the comprehensive force, N; ε was angle of horizon line and x-axis; τ was angle of horizon line and sieve surface.

Figure 2 Mechanism diagrams of oscillating sieve

According to Figure 2 when the upper sieve was reciprocating moving with the rotation of crank mechanism, the grain started moving on the upper sieve. There was relatively motion between upper sieve and grains. So, the motion rule of grains group was different from the upper sieve. The motion of oscillating sieve was promoting the grains group separating through sieve holes.

2.2 Statistical analysis

Analysis of variance to discriminate significant differences between the group mean values was performed on all subjects. The data was presented as mean result (M) ± standard deviation (SD). The mean of the data was analysed statistically, using a factorial design with the SPSS software (version 13.0, SPSS Inc., CA, USA). The mean results were compared by least significant difference (LSD) post-hoc test at the 5% significance level ($p<0.05$).

2.3 Ingredients of mixture material

Ingredients of mixture material separating through cylinder grid concave seriously affected the cleaning results. The ingredient of cleaning mixture material on oscillating sieve was well correlated with cleaning loss. It has been a well-known fact that crop properties (like moisture, grain/straw ratio) vary within different fields. There was a need for homogenous units and uniformly cultivated. The cleaning mixture includes grain, chaff and straw (rice varieties: Wu japonica rice 13#). The morphological characteristics of cleaning mixture material were shown in Figure 3.

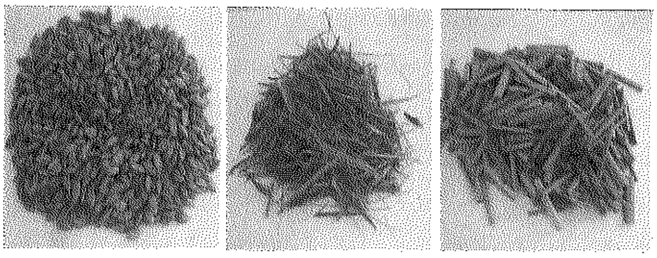

a. Grains group b. Chaff c. Short straw

Figure 3 Sample morphological of rice cleaning mixture

The rice grain was spherical or ellipsoid, about long 6 mm with a radius of 1.6 mm. The short straw was cylindrical, about 30 mm long with a diameter of 4 mm diameter. And the mass ratio of the mixture was short straw 9%, chaff 13%, and grain 78%. Moisture content of straw and chaff was 49.09% (SD = 6.04) and 36.74% (SD = 4.29) respectively. Moisture content of grains group was 22.56% (SD = 2.02). The average mass of grains per 1000 was 28.5 g (SD = 3.46) (Number of test groups was 10).

2.4 Grains group separating of queuing theory

The cleaning results can be expressed in terms of cleaning loss, cleaning efficiency, and grain purity ratio on collecting pan. The cleaning results were influenced by two categories: promoting grains group into the sieve holes, and hindering the grains group separating through the sieve holes. These separating behaviors helped to shorten cleaning time and helped to maintain homogenous through grain quality. Grains group separating through sieve hole and some grains loss blown outside sieve tail was random.

2.4.1 Characteristic factor of queuing separation

In the cleaning process of cleaning device, there were continuous and large amounts of grains on oscillating sieve. Based on the research results of grains movement on oscillating sieve (Li et al., 2012), the grains group separating through sieve process and screening model were analyzed by stochastic queuing theory. The following assumptions have been made:

(a) The amount of grain getting into the sieve hole was independent and undisturbed within the same time.

(b) The probability of grain getting into the sieve hole was random.

(c) Two or more than two grains getting through the sieve hole was impossible within the same hole.

2.4.2 Modeling of queuing separation

Based on stochastic probabilistic model, Kendall presented the Kendall Symbol' *M*/*M*/*S*/*d*/∞/*R*' of queuing theory (Kendall, 1953). The state transition diagram of *M*/*M*/*S*/*d*/∞/*R* was shown in Figure 4. Let the feeding rate of cleaning grain group was λ, and the separating service capability of one sieve hole was μ.

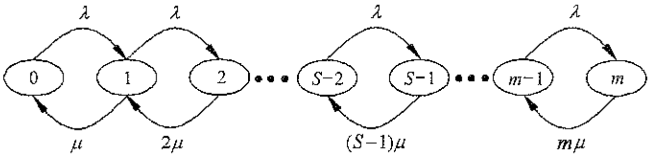


Figure 4 State transition of separating through sieve hole

According to Figure 4, the state transition separations was {0, 1, 2, …*m*}, the state of grains group separating through sieve hole of "0," where the sieve was idle. The state of "*k* (1≤*k*≤*S*)" means that the number of separating grain number was *k* (the numbers of idle sieve holes was *S*-*k*.). E.g. when the state transition of grains group was at state of "1", the state of "1" would change to the state of "0" ("1"→ "0"). The separating service capability of one sieve hole was μ. If the grains group separated through sieve hole at the state of "*k*", there would be several sieves separating grains, changing the state of "*k*" to "*k*-1"("*k*"→"*k*-1"). If the sieve was at stable rate, and there was no loss, the capability of grain group spreading was greater than the rate of feed. Let the probability of grain separating through sieve hole state "*i*" was *Pi*, the expectations number of feeding grain $E(\lambda_i)$ and the expectations number of separating grain through the sieve hole $E(\mu i)$ could be described as follows:

$$E(\lambda_i) = \lambda_{(i-1)}P_{(i-1)} + \mu_{(i+1)}P_{(i+1)} \tag{1}$$

$$E(\mu_i) = \mu_i P_i + \lambda_i P_i \tag{2}$$

If the state of grains group separating through sieve hole was a stable state (the losing grain was 0), the equation of sieve stable state could be described as follows:

$$\mu_i P_i + \lambda_i P_i = \lambda_{(i-1)}P_{(i-1)} + \mu_{(i+1)}P_{(i+1)},\ 2 \leq i \leq S-1 \tag{3}$$

When the grains group separating through sieve hole, the state was "0"; there were $\mu P_1 = \lambda P_0$ and $(S\mu)Ps = \lambda P_{(S-1)}$. According to Equation (1) to Equation (3), the probability of every state of grains group separating through sieve hole could be described as follows:

$$P_i = \frac{\lambda_{(i-1)}}{\mu_i}P_{(i-1)} = \frac{\lambda^S}{\mu(2\mu)\cdots(S-1)\mu(S\mu)}P_0 \tag{4}$$

If there were *k* grains in one column of sieve holes with the maximum number of sieve holes *S*, the probability P_k (the derivation process was described by Lu (1984)) of grain separating through sieve hole could be described as follows:

$$P_k = \frac{1}{k!}\left(\frac{\lambda}{\mu}\right)^k P_0,\ k \leq S \tag{5}$$

$$P_k = \frac{1}{S^{(k-2)}S!}\left(\frac{\lambda}{\mu}\right)^k P_0,\ k > S \tag{6}$$

2.4.3 Indicators of queuing separation

Models of queuing separation need to be solved in order to evaluate the quality and efficiency of grain group separating through sieve holes, and to obtain the optimal parameter combination. The feeding rate of grain group was λ, with $1/\lambda$ being the interval between two feeding grains. The separating service capability of one sieve hole was μ, and then $1/\mu$ was the interval between two separating grains.

Due to $\sum_{k=0}^{\infty} P_k = 1$, then

$$\sum_{k=0}^{s} P_k + \sum_{k=s+1}^{\infty} P_k = 1 \tag{7}$$

By substituting Equation (5) and Equation (6) into Equation (7), Equation (7) could be solved as:

$$\sum_{k=0}^{s} P_k + \sum_{k=S+1}^{m} P_k = P_0 \sum_{k=0}^{s} \frac{1}{k!}\left(\frac{\lambda}{\mu}\right)^k + \frac{P_0}{S!}\left(\frac{\lambda}{\mu}\right)^S \frac{1}{1-\rho} = 1 \tag{8}$$

$$\rho = \frac{\lambda}{S\mu} \tag{9}$$

where, ρ was the intensity coefficients of grain group separating through sieve hole. The Equation (8) could be solved as P_0:

$$P_0 = [\sum_{k=0}^{S} \frac{(S\rho)^k}{k!} + \frac{S^S}{S!}\frac{\rho(\rho^S - \rho^m)}{1-\rho}]^{-1} \tag{10}$$

According to Equation (9) and Equation (10), the grains group state transition of separating through sieve hole could be described as follows:

(a) If $\rho<1$, grains group on oscillating sieve were waiting for separating through sieve holes, the state of grains group separating through sieve hole was stable state.

(b) If $\rho=1$, grains group on oscillating sieve were waiting for separating through sieve holes was zero, the state of grains group separating through the sieve holes was saturation.

(c) If $\rho>1$, grains group on oscillating sieve were waiting for separating through sieve holes was increasing, the state of grains group separating through the sieve holes was congested. Grains group not separating through sieve holes would be losing.

Using the same method (Bauerlen, 2006; Mecitc, 2006), the accumulation grains group thickness L_q (the derivation process was described by Lu (1984)) on oscillating sieve waiting to separating through sieve holes could be solved as:

$$L_q = \frac{(S\rho)^S \rho P_0}{S!(1-\rho)^2}[1-\rho^{(m-S)} - (m-S)\rho^{(m-S)}(1-\rho)] \tag{11}$$

The losing grains rate of oscillating sieve P_m (the derivation process was described by Lu (1984)) which was not separating through sieve holes could be solved as:

$$P_m = \frac{S^s}{S!}\rho^m P_0 \tag{12}$$

2.4.4 Sieve holes number optimization

By increasing the number of sieve holes, the separating capability was improved. Utilizing the separation model optimizes the number of the sieve holes. In order to optimize the number of sieve holes, two aspects were taken into consideration: cost and grain loss. Let the cleaning objective function of oscillating sieve was Z, then cleaning objective function of oscillating sieve could be described as follows:

$$Z = C_s \times S + C_w \times L_q \tag{13}$$

where, C_S was operating costs, due to the number of sieve openings S, which were equipment wear, equipment maintenance, labor costs, etc. C_W was the grain losing costs, due to the accumulation grain thickness L_q, the grain was losing in separating the sieve holes.

According to Equation (13), the accumulation grain thickness $L_q(S)$ was a function of sieve holes number S. Objective function of oscillating sieve $Z(S)$ was only a function of sieve holes number S. Because Equation (13) was not a continuous function, objective function $Z(S)$ could be solved by the Marginal Analysis.

If the objective function $Z(S)$ was minimum $Z(S^*)$, the $Z(S^*)$ could be described as follows:

$$\begin{cases} Z(S^*) \le Z(S^*+1) \\ Z(S^*) \le ZS^* - 1 \end{cases} \tag{14}$$

By substituting Equation (13) into Equation (14), the Equation (14) could be solved as:

$$\begin{cases} C_s \times S^* + C_w L_q(S^*) \le C_s \times (S^*-1) + C_w L_q(S^*-1) \\ C_s \times S^* + C_w L_q(S^*) \le C_s \times (S^*+1) + C_w L_q(S^*+1) \end{cases} \tag{15}$$

Let $L_q(+1)=L_q(S^*)=L_q(S\text{-}+1)$ and $L_q(-1)=L_q(S^*-1)$ $-L_q(S^*)$. The Equation (14) could be solved as:

$$L_q(+1) \le \frac{C_s}{C_w} \le L_q(-1) \tag{16}$$

3 Results and Discussion

In order to calculate the indications of cleaning capability and cleaning loss, let feeding rate of grains group λ was 4.5-225 grains per second (Abbreviated as: Gs/s). Because grain proportion 78% of mixture and average mass 28.5 g of grains per 1000 grains, the feeding rate of cleaning mixture material was 0.16-8.22 kg/s. Let the separating service capability of one sieve hole μ was 1.5 Gs/s, the maximum number of sieve holes S was 30; the sectional grains number of waiting separating on oscillating sieve d was 90. The cleaning losing grains rate Pm which was not separated through the sieve hole was calculated by Equation (12). The intensity coefficients ρ of grains group separating through sieve holes could be calculated by Equation (10). The cleaning capability indicators with cleaning loss were shown in Table 1.

Table 1 Cleaning capability indicators by queuing model

No.	Feeding rate λ Gs/s	Cleaning grain intensity coefficient ρ	Grain loss rate P_m Gs/s
1	4.5	0.1	0
2	9.0	0.2	0
3	13.5	0.3	0
4	18.0	0.4	0
5	22.5	0.5	0
6	27.0	0.6	0
7	31.5	0.7	0
8	36.0	0.8	0.01
9	40.5	0.9	0.21
10	54.0	1.2	1.67
11	67.5	1.5	33.33
12	90.0	2.0	50.00
13	225.0	5.0	80.00

According to Table 1, the feeding rate increased with the grain intensity. Due to the increasing of grain feeding rate, the grain doesn't have the opportunity to separating through the sieve holes. The accumulation grains group thickness on oscillating sieve pan increased. If the feeding rate was less than 40.5 Gs/s, the cleaning grain intensity coefficient ρ was less than 1. If $\rho<1$, grains group on oscillating sieve were waiting for separating through sieve holes, the state of grains group separating through sieve hole was stable state. When the feeding rate was 54 Gs/s (the grain intensity was 1.2 in Table 1), the cleaning loss rate was 1.67 Gs/s. If the feeding rate was more than 54 Gs/s, then cleaning grain intensity coefficient was $\rho>1$. If $\rho>1$, grains group on oscillating sieve were waiting for separating through sieve holes was increasing, the state of grains group separating through the sieve holes was congested. Grains group not separating through sieve holes would be losing. So, the feeding rate was more than 54 Gs/s, the sieve holes would be congested. In order to decrease the cleaning loss rate, increasing the number of sieve holes would increase the opportunity for grain separation. If the number of sieve holes were unlimited, the structure and institutions of cleaning device would be huge. If the holes were too little, cleaning loss would be much greater. Based on minimum of operating costs and grain losing costs, the optimal numbers model was developed shown in Equation (16).

The cleaning separation and loss process models were developed by the Kendall Symbol of queuing theory in this paper. According to the stochastic queuing theory cleaning modeling, in ideal conditions as the short straw would remain on sieve pan, where the grain would separating through the sieve and into the grain bin. The grains group run outside sieve tail was reported as grain loss. The losing grain rate of oscillating sieve was shown in Equation (12), using the stochastic queuing theory model. Many probability models were applied to design and optimize cleaning device, but grains group cleaning loss model and state transition model was not reported.

For each feeding rate value, an optimal interval $[L_q(+1)\ ,\ L_q(-1)]$ could be obtained by Equation (15). Because C_S/C_W was a known value, and C_S/C_W could be any value. If C_S/C_W being different values, objective function $Z(S)$ was different. But the relative size was certain. The C_S/C_W value was based on the operating costs and losing costs. The value of C_S/C_W was a variable, and any value was the same results for the design of oscillating sieve. In this paper, let C_S/C_W being 0.8.

The C_S/C_W value indicated that the optimal number of sieve holes could be calculated by Equation (16). The results of optimal sieve holes, with different feed rate were shown in Table 2.

Table 2 Optional variable of sieve holes by queuing model

No.	Feed rate λ Gs/s	Cleaning grain intensity coefficient ρ	Optimal interval $[L_q(+1), L_q(-1)]$	Objective value Z	Optimal sieve hole S^*
1	4.5	0.1	[0.26 , 1.17]	21.77	5
2	9.0	0.2	[0.68 , 2.60]	37.36	8
3	13.5	0.3	[0.44 , 1.14]	51.99	12
4	18.0	0.4	[0.66 , 1.59]	66.38	15
5	22.5	0.5	[0.43 , 0.88]	80.58	19
6	27.0	0.6	[0.56, 1.09]	94.23	22
7	31.5	0.7	[0.68 , 1.26]	143.94	25
8	36.0	0.8	[0.78 , 1.36]	162.60	28
9	40.5	0.9	[0.52 , 0.84]	134.82	32
10	54.0	1.2	[0.77 , 1.07]	172.32	40
11	67.5	1.5	[0.75 , 0.94]	291.95	47
12	90.0	2.0	[0.79 , 0.91]	892.07	53
13	225.0	5.0	[0.61 , 0.86]	1968.89	59

Based on the Equation (13), the objective function $Z(S)$ could be obtained. The objective function $Z(S)$ was index, which could be used to solved Optimal sieve hole S^* by Equation (14). According to Table 2, when the cleaning grain intensity coefficient ρ was less than 1, the state of grains group separating through sieve hole was stable state. Then the optimal interval $[L_q(+1), L_q(-1)]$ was [0.52, 0.84]. If the oscillating sieve needs to be a stable state (the losing grain was minimum), the capability of separating grains group were more than that of the feeding rate (shown in Table 2). As feeding rate increases, the need for sieve holes increases. The optimal numbers of sieve holes at each feeding rate was shown in Table 2.

The cleaning grains group feeding rate was 4.5 Gs/s (mixture material feeding rate was 0.16 kg/s) at each column (Continue to feed 3 minutes). Then the total cleaning grains group feeding rate was 49.5 Gs/s (mixture material feeding rate was 1.81 kg/s), there were 11 sieve holes of each sieve columns. The cleaning loss rate of feeding rate 4.5 to 225 Gs/s were test. Based on the optimal sieve hole, the cleaning loss rate predictive and test results with optimal number of sieve holes were shown in Table 3.

Table 3 Grain loss rate of each column sieve hole

Sieve holes S^*	Feeding rate λ Gs/s	Sieve cleaning loss rate Gs/s	
		Predictive value	Test results M±SD
5	4.5	0.021	0.034±0.014
8	9	0.059	0.045±0.018
12	13.5	0.031	0.042±0.012
15	18	0.038	0.045±0.016
19	22.5	0.028	0.058±0.018
22	27	0.032	0.054±0.014
25	31.5	0.034	0.046±0.012
28	36	0.037	0.042±0.013
32	40.5	0.029	0.046±0.012
40	54.0	0.031	0.074±0.006
47	67.5	0.061	0.182±0.048
53	90	0.159	0.364±0.116
59	225	0.607	0.864±0.102

According to Table 3, when the feeding rate was 36.0 Gs/s, the grain intensity was 0.8 (shown in Table 2), while the cleaning loss rate was 0.042 Gs/s. Because grains group feeding rate was 36 Gs/s with 3 seconds. The total losing grains divided by total feeding grains, then grains losing ratio was 0.117%. When the feeding rate was 36.0 Gs/s, the optimum number of sieve holes was 28 (shown in Table 2). This resulted in the sieve loss being 0.042 Gs/s (grains losing ratio was 0.117%), when compared to the calculated results 0.037 Gs/s (grains losing ratio was 0.103%), and the error being 11.97%. When compared to the test results in Table 3, the results of modeling agree well with that of experiments. This shows that the separation modeling of material motion on oscillating sieve of air-and-screen cleaning device was feasible.

Where the grain loss was less than 0.042 Gs/s (grains losing ratio was 0.117%), the total grain loss was 1.32 Gs/s (the width of oscillating sieve was 0.6 meter). According to estimates (Craessaerts et al., 2010), even in optimum settings, it was very difficult to reduce total cleaning loss below 1%-2% (Craessaerts et al., 2007a, 2007b). However, total grain cleaning losses in Germany remained 4%-6%. Spengler stated that if total losses could be diminished to 5%, this would offer an increasing in turnover of 20 k$ per year, for each combine (Spengler et al., 2003).

The cleaning efficiency and capability of air-and-screen cleaning device was typically expressed in terms of cleaning loss. From the experimental and model results, there was some deviation between some model predictive data and experimental data. These models also can be seen as a tool for researchers and designers who want to simulate and optimize the cleaning process. These modeling of queuing and separating through oscillating sieve could be used to investigate the losses sensor installed at the tail of oscillating sieve to predict the grain losing. The predicting of grain cleaning loss by separation and loss process model of air-and-screen cleaning device was very useful, and it could be applied to other crops such as barley, corn, oats, and rapeseed.

5 Conclusions

For developing screening model of grains group on air-and-screen cleaning device, the accumulation grain thickness on oscillating sieve, losing grains rate of oscillating sieve, state transition of separating through sieve hole, intensity coefficients of grain group separating through sieve hole were developed by queuing theory. Based on minimum of operating costs and grain losing costs, the optimal numbers model was developed.

(1) If oscillating sieve needs to be a stable state, the capabilities of separating grains group were more than that of the feeding rate. If intensity coefficients ρ more

than 1, grains group on oscillating sieve were waiting for separating through sieve holes. The state of grains group separating through the sieve holes was congested.

(2) When the feed rate was 36.0 Gs/s, the separating service capability of one sieve hole was 1.5 Gs/s, the maximum number of sieve holes was 30, and then the cleaning loss rate at each sieve column is 0.042 Gs/s (grains losing ratio was 0.117%). Then compared to the calculated results 0.037 Gs/s (grains losing ratio was 0.103%), and the error being 11.97%.

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Abbreviations used:

Kendall Symbol 'M/M/S/d/∞/R'(Poisson Distribution of feeding grain method (*M*)/ Negative *Exponential Distribution* of grain separating through the sieve hole (*M*)/ maximum sieve hole number (*S*)/ sectional grain number of waiting separating grain on sieve (*d*)/ unlimited amount of feeding grain (∞)/ the rule of separating through the sieve of losing or waiting method (R)); SD (standard deviation).

Parameters: ω (rotation velocity of crank mechanism); t (working time); r (the crank radius); O (coordinate origin); G (gravity); n (direction perpendicular to the sieve surface); F_n (friction between grain and sieve); A (amplitude of oscillating sieve); O' (endpoint of bar linkage); X (direction of x-axis); F (comprehensive force); ε (angle of horizon line and x-axis); τ (angle of horizon line and sieve surface); λ (feed rate of cleaning mixture); μ (separating service capability of one sieve hole); i (grain separating through the sieve state); P_i (probability of grain separating through sieve hole); S (grains in one column with the maximum number of sieve hole); ρ (intensity coefficients of grain separating).