Advance Journal of Food Science and Technology 6(1): 144-148, 2014
DOI:10.19026/ajfst.6.3045
ISSN: 2042-4868; e-ISSN: 2042-4876

Submitted: September 28, 2013 Accepted: October 14, 2013 Published: January 10, 2014

Research Article

Optimization Analysis on Parameters of Cleaning Sieve of Rape Combine of "Bi Lang 4LZ(Y)-1.0"

[1, 2]Wu Mingliang, [1, 2]Tang Lun, [1]Guan Chunyun and [1, 2]Tang Chuzhou
[1]Hunan Agricultural University, Changsha,
[2]Hunan Provincial Engineering Technology Research Center for Modern Agricultural Equipment, Hunan, 410128, China

Abstract: Against the phenomenon of high impurity rate and cane and pod shell are difficult to discharge at the end of the sieve for rape combine of "Bi Lang 4LZ(Y)-1.0". This study take cleaning sieve of rape combine of "Bi Lang 4LZ(Y)-1.0" as study object, analyzed the movement of materials on sieve, established the virtual prototype model of the cleaning sieve of this rape combine, taken materials and cleaning sieve all at the best motion state as constraint conditions and optimized the structure and kinematics parameters of the cleaning sieve by utilizing ADAMS software. Optimization results shown that when angle θ between sieve surface and level is 9°, vibration angle ε is 28°, crank radius R is 12 mm, crank angular velocity ω is 32 rad/sec, the cleaning sieve has the best transmission performance and meet the requirements of the best state of motion (the cane and pod shell always maintain the upward trend and rapeseed could upward and downward). The conclusion could provide a theoretical basis for improving and optimization design for rape combine.

Keywords: ADAMAS, cleaning sieve, optimization analysis, slider-crank mechanism

INTRODUCTION

Rape is the major oil crops of the world, plays a very important role in agricultural development. Rapeseed production in China is very large, rape planting area in 2007 is 5642 thousand hm^2, accounting for 23.32% of the world, has become the fifth advantage crops after the rice, wheat, corn and soybean, but mechanization level of rapeseed production is relatively low in our country, both in the planting and harvesting is particularly prominent, seriously hampered China's rapeseed production (Chen, 2008; Bai, 2009; Wu, 2008).

Cleaning device is one of the key components of the rape combines; its work performance would have a major impact on cleaning effectiveness and efficiency of the harvesters. Currently the cleaning device of rape combines are basically converted from rice and wheat combine harvester, or the type of cleaning device use either in rice, wheat and rape, cleaning effect is not satisfactory (Gao *et al*., 2000). Therefore, the study of cleaning device of rape has great significance.

In recent years, domestic institutions of higher learning carried out extensive studies on the rape combine and the research for the cleaning device mainly have: the movement rule of materials on the screen under the different conditions of motion and structure parameters, experimental research of cleaning effect of cleaning sieve at the different form of screen surface structure and composition and optimizing the structural parameters and motion parameters of cleaning sieve by utilizing virtual prototyping software etc., (Ma *et al*., 2007; Cheng and Wang, 1999). Chen cuiying etc., utilizing ADAMS software take the maximum displacement between seed and short stem on the surface of sieve as optimization objective, make optimizing for the cleaning sieve, get the best working parameters, but did not consider the stem, pod shells and other impurities whether can be smoothly discharge outside, or whether the cleaning sieve have optimal transmission performance. In this study, take materials and cleaning sieve all at the best motion state as constraint conditions and maximize minimum transmission angle as optimization objective in the process of cleaning sieve working, optimize the structure and motion parameters of cleaning sieve by utilizing ADAMS software, so as to improve the performance of cleaning sieve.

MATERIALS AND METHODS

The composition and working principle of cleaning mechanism: Now the widely used combine harvester in China, the majority cleaning method were dual-fan

Corresponding Author: Wu Mingliang, Hunan Agricultural University, Changsha, Hunan, 410128, China

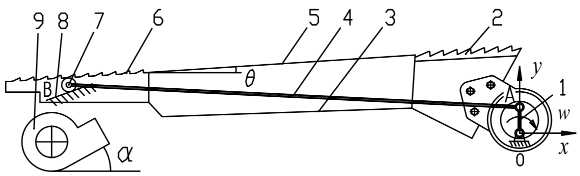

Fig. 1: Structure schematic of cleaning device
1: Crank; 2: Separator riddle; 3: Down sieve; 4: Link; 5: Up sieve; 6: Concave plate; 7: Slider; 8: Slide rail; 9: Fan

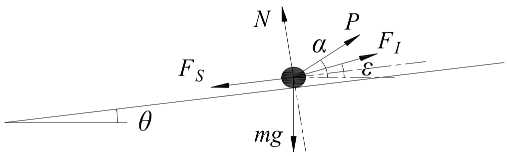

Fig. 2: Force analysis graphics of material upward

plus double vibration screen (Sun *et al*., 2006). Cleaning sieve commonly adopted slider-crank mechanism and crank-rocker mechanism two types of drive mechanism. The rape combine of "Bi Lang 4LZ(Y)-1.0" adopts slider-crank mechanism and the structure diagram of cleaning device is shown in Fig. 1.

The angular velocity of crank *OA* is ω = 31.41 rad/sec clockwise rotation, crank radius *R* = 15 mm, link *AB* = 1020 mm, up sieve is fish scale sieve of which the length is 640 mm, width is 960 mm, down sieve is woven screen of which the sieve pore is 6×6 mm, length is 490 mm, width is 960 mm, the angle θ between sieve surface and level is 5°, the angle between slide rail and level is 20°, vibration angle ε is 20°, the angle α between fan outlet and level is 25°.

Because of the vibration and excitation action on sieve surface which generated by slider-crank mechanism or crank-rocker mechanism, the threshed mixtures falling from the concave plate sieve move to up sieve when cleaning sieve was working, at this moment the materials on the up sieve would slide up and down or leap along sieve surface, with the action of the fan, rapeseeds and a little of impurities would fall into down sieve. Meanwhile, short stem, pod shell and other impurities would be push forward to separator riddle, finally discharged outside the machine through separator riddle and the materials fell into the down sieve would be cleaned once again, the rapeseed fall from down sieve would enter into collection box through screw feeder, the other little of impurities would be discharge outside from sieve tail and achieved the separation of grain and impurities (Li *et al*., 2007).

Kinetic analysis of single particle materials on up sieve: Motion rules of the material on the sieve surface would directly affect the cleaning effect and efficiency of cleaning sieve. Did dynamic analysis for materials on the sieve surface is the basic starting point to master the motion rules of the material.

As the movement of material groups on the sieve surface was complex, ignored the interaction between material particles, only studied the single particle materials and at the condition of the length of the crank was far less than link, approximately consider the cleaning sieve's motion as straight reciprocating motion (Dong, 2006).

Taken rotation center *O* of crank *OA* as the origin of coordinates, level to the right as the positive direction of *x*-axis, vertical upward as the positive direction of *y*-axis, established coordinate system is shown in Fig. 1. Taken crank located in the positive direction of *y*-axis as the initial phase of the time and displacement and did analyze in accordance with defined coordinate system and the rule of trigonometric functions, so the displacement *S* and acceleration a of any points on the sieve surface were (Ma *et al*., 2007):

$$S = R\sin\omega t \quad (1)$$

$$a = -R\omega^2\sin\omega t \quad (2)$$

Materials upward along sieve surface: When the crank located at 1, 2 quadrant, acceleration a was negative, direction to the left, the direction of inertial force materials suffered on screen surface was right, motion trend toward right, friction direction toward left. Then, the force of the materials on the sieve surface were gravity mg, support force *N*, friction force *FS*, wind force *P* and inertia force *FI*, shown in Fig. 2, assuming the acceleration of materials relative to screen slide upward was *a*1 and designated upward along the screen was positive, then:

$$ma_I = P\cos(\alpha - \theta) + F_I\cos(\varepsilon - \theta) - mg\sin\theta - F_S \quad (3)$$

In Eq. (3), $P = mgv^2/v_p^2$, $FI = mR\omega^2\sin\omega t$, $FS = N\tan\varphi$, $N = mg\cos\theta - P\sin(\alpha - \theta) - FI\sin(\varepsilon - \theta)$. *v* denotes flow velocity relative to materials, *vp* denotes suspension velocity of materials, φ denotes friction angle between materials and screen surface.
Then simplified and ordered formula (3):

$$a1 = gv^2/v_p^2 \times [\cos(\alpha - \theta) + \sin(\alpha - \theta)\tan\varphi] + R\omega^2\sin\omega t \times [\cos(\varepsilon - \theta) + \sin(\varepsilon - \theta)\tan\varphi] - g\sin\theta - g\cos\theta\tan\varphi \quad (4)$$

When $gv^2/v_p^2 \times [\cos(\alpha - \theta) + \sin(\alpha - \theta)\tan\varphi]$ $R\omega^2\sin\omega t \times [\cos(\varepsilon - \theta) + \sin(\varepsilon\theta)\tan\varphi] > g\sin\theta + g\cos\theta\tan\varphi$, $a1>0$, materials upward along screen surface, then, crank located at 1, 2 quadrant, $0 \le \sin\omega t \le 1$.

Because of cleaning sieve played a decisive role on the movement state of threshed mixtures and the

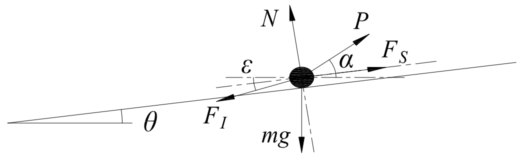

Fig. 3: Force analysis graphics of material downward

motion state of cleaning sieve mainly decided by the crank radius and rotate speed. Therefore, defined the cleaning index K_1, definite $K_1 = R\omega^2/g$, then by simplifying and ordering formula (4) obtained the requirement of materials upward along sieve surface:

$$K_I \geq \{\sin(\varphi + \theta) - v^2/v_p^2 \times \cos[\varphi - (\alpha - \theta)]\}/\cos[\varphi - (\varepsilon - \theta)] \quad (5)$$

By measuring the material's suspension speed, obtained rapeseed, short stem and pod shell's suspension speed vp were 6.78, 6.9 and 5.74 m/sec, the best flow speed was greater than the suspension speed of light debris, the value is vq = 3.8 m/sec. The friction angle φ between rapeseed, short stem and pod shell with the sieve surface were 17°, 41° and 39°. As the material's speed on the cleaning sieve was much smaller than air flow speed, using air flow velocity vq approximately instead of the velocity of flow relative to materials (Ma *et al*., 2007). Finally, took various parameters value substituted into formula (5), obtained the conditions of upward movement along sieve surface of rapeseed, short stem and pod shell were:

$K_1r \geq 0.09$, $K_1s \geq 0.49$ and $K_1p \geq 0.3$

Material downward along sieve surface: When the crank located at 3, 4 quadrant, acceleration a was positive, direction to the right, the direction of inertial force materials suffered on screen surface was left, motion trend toward left, friction direction toward right. Then, the force analysis graphics of material downward is shown in Fig. 3, assuming the acceleration of materials relative to screen slide downward was a_2, then:

$$ma_2 = F_S + P\cos(\alpha - \theta) - F_I\cos(\varepsilon - \theta) - mg\sin\theta \quad (6)$$

In Eq. (6), $FI = -mR\omega^2\sin\omega t$, $N = mg\cos\theta - P\sin(\alpha - \theta) + FI\sin(\varepsilon - \theta)$.

In a similar way, defined the cleaning index K_2 of materials downward along sieve surface, then by simplifying and ordering Eq. (6), obtained the requirement of materials downward along sieve surface:

$$K_2 \geq [\sin(\varphi - \theta) + v^2/v_p^2 \times \cos(\varphi + \alpha - \theta)]/\cos(\varphi + \varepsilon - \theta) \quad (7)$$

Took parameter's value substituted into Eq. (7), obtained the conditions of downward movement along sieve surface of rapeseed, short stem and pod shell were:

$K_2r \geq 0.51$, $K_2s \geq 1.31$ and $K_2p \geq 1.34$

Material's leap: Normal reaction of sieve surface to material was zero when materials leap, namely $N = 0$. When materials upward along sieve surface, the normal reaction of sieve surface to material was:

$$N = mg\cos\theta - P\sin(\alpha - \theta) - F_I\sin(\varepsilon - \theta) \quad (8)$$

Defining the cleaning index K_3 of materials upward and leap, obtained the conditions of materials upward and leap was:

$$K_3 = \frac{R\omega^2}{g} \geq \frac{v_p^2\cos\theta - v^2\sin(\alpha - \theta)}{v_p^2\sin(\varepsilon - \theta)} \quad (9)$$

When materials downward along sieve surface, the normal reaction of sieve surface to material was:

$$N = mg\cos\theta - P\sin(\alpha - \theta) + F_I\sin(\varepsilon - \theta) \quad (10)$$

In a similar way, defining the cleaning index K_4 of materials downward and leap, when $\varepsilon > \theta$, Eq. (10) identical greater than zero, considering materials couldn't leap when downward; when $\varepsilon < \theta$, obtained the conditions of materials downward and leap was:

$$K_4 = \frac{R\omega^2}{g} \geq \frac{v_p^2\cos\theta - v^2\sin(\alpha - \theta)}{v_p^2\sin(\theta - \varepsilon)} \quad (11)$$

Took parameter's value substituted into Eq. (9), obtained the conditions of rapeseed, short stem and pod shell upward and leap along sieve surface of were:

$K_3r \geq 3.48$, $K_3s \geq 3.45$ and $K_3p \geq 3.26$

Because the vibration angle ε is greater than the angle θ in this study, according with the analysis forenamed, considered that the materials couldn't leap when materials downward.

In the process of cleaning and separation of threshed mixture, the best state of the material movement should be the short stem and pod shell always maintain the upward trend and rapeseed could upward and downward. This helps to ensure impurities rapidly discharged from the sieve tail, while could guarantee rapeseed have a very good passage probability and obtain a better cleaning effect. In summary, the results from the above analysis can be drawn, when the cleaning index $0.51 \leq K < 1.31$ could meet the conditions that the short stem and pod shell always maintain the upward trend and rapeseed could upward and downward.

Then, took the crank radius R = 15 mm and angular velocity ω = 31.41 rad/sec substituted into the cleaning index K, the value of K was 1.51, did not meet the above analysis results, which could lead to the high impurity rate and threshed mixtures difficult to discharge at the end of the sieve. To this end, would create virtual prototype model of cleaning sieve and optimization analysis through ADAMS software.

RESULTS AND DISCUSSION

Virtual prototype modelling and optimization of cleaning sieve:

Geometric modelling: When create Kinematics model for rigid objects with ADAMS, did not over-pursue the details of component parts of geometry was fully consistent with the actual, just ensure that relative size of every movement components was correct could get satisfactory simulation results. The virtual prototype geometric model is shown in Fig. 4.

Design variables: Angle θ between sieve surface and level, vibration angle ε, crank radius R and angular velocity ω:

$$X = \{x_1, x_2, x_3, x_4\}^T = \{\theta, \varepsilon, R, \omega\}^T \qquad (12)$$

Constraints:

The best motion condition of material cleaning and separation: According to the preceding analysis, to achieve effective separation of grain and impurities should met: the short stem and pod shell always maintain the upward trend and leap and rapeseed could upward, downward and leap. Namely satisfied with the following constraints:

$$\frac{\sin(17°+\theta)-0.28\times\cos[17°-(25°-\theta)]}{\cos[17°-(\varepsilon-\theta)]}-\frac{Rw^2}{9.8}\le 0 \qquad (13)$$

$$\frac{\sin(41°+\theta)-0.3\times\cos[41°-(25°-\theta)]}{\cos[41°-(\varepsilon-\theta)]}-\frac{Rw^2}{9.8}\le 0 \qquad (14)$$

$$\frac{\sin(39°+\theta)-0.44\times\cos[39°-(25°-\theta)]}{\cos[39°-(\varepsilon-\theta)]}-\frac{Rw^2}{9.8}\le 0 \qquad (15)$$

$$\frac{\sin(17°-\theta)+0.28\times\cos[17°+(25°-\theta)]}{\cos[17°+(\varepsilon-\theta)]}-\frac{Rw^2}{9.8}\le 0 \qquad (16)$$

$$\frac{Rw^2}{9.8}-\frac{\sin(41°-\theta)+0.3\times\cos[41°+(25°-\theta)]}{\cos[41°+(\varepsilon-\theta)]}<0 \qquad (17)$$

$$\frac{Rw^2}{9.8}-\frac{\sin(39°-\theta)+0.44\times\cos[39°+(25°-\theta)]}{\cos[39°+(\varepsilon-\theta)]}<0 \qquad (18)$$

The best motion condition of cleaning sieve working: In order to make the materials down from the concave plate shaking loose and layer as quickly as possible and reduce the residence time of impurity in the end screen, the ideal movement way of sieve surface should be met: the amplitude of vertical direction at sieve surface's feed-side is larger than the amplitude of vertical direction at discharge-side (Ma *et al*., 2007). Using ADAMS, establish measurement of amplitude of vertical direction at sieve surface's feed-side and discharge-side MEA_Y_ru and MEA_Y_pai, then, should have:

Fig. 4: Virtual prototype geometric model of cleaning sieve

$$\text{MEA\_Y\_pai} - \text{MEA\_Y\_ru} < 0 \qquad (19)$$

Other constraints: crank radius 5 mm≤R≤25 mm; crank angular velocity 29.32 rad/sec≤ω≤37.7 rad/sec; angle between sieve surface and level 1°≤θ≤9°; vibration angle 10°≤ε≤50°

Parameter optimize: The merits of Cleaning sieve's motion would significantly impact the vibration of the whole harvester and the wear of parts. Transmission angle was an important parameter is for measuring institutional transmission performance merits and efficiency height, the transmission angle more greater, the more favorable for institution to transfer force (Deng *et al*., 2006).

Therefore, under the condition of materials and cleaning sieve at the best motion condition, took maximize minimum transmission angle for the optimal target in course of the cleaning sieve motion, did optimization design for cleaning sieve and both can guarantee a good cleaning rate and can improve the transmission performance of cleaning sieve.

Using ADAMS software, establish the measurement of cleaning sieve's transmission angle FUNCTION_MEA_1 and so the optimization objective function is:

$$F(X) = \text{MAX}\ \{(\text{FUNCTION\_MEA\_1})_{\min}\} \qquad (20)$$

Optimization results: When angle θ is 9°, vibration angle ε is 28°, crank radius R is 40 mm, crank angular velocity ω is 32 rad/sec, meet the requirement of the materials and cleaning sieve have the best state of motion. At this point, the minimum transmission angle of maximum value 30.2°, while the minimum transmission angle before optimize is 22.5°, increased 34.3%, optimization results more obvious.

CONCLUSION

According to the problems of cleaning sieve of rape combine of "Bi Lang 4LZ(Y)-1.0" in the process of working, established the virtual prototype model of the cleaning sieve by using ADAMS software, took maximize minimum transmission angle for the optimal target, optimized the structure and motion parameters of cleaning sieve. Optimization results shown that: when angle θ between sieve surface and level is 9°, vibration angle ε is 28°, crank radius R is 12 mm, crank angular velocity ω is 32 rad/sec, satisfied with the short stem and pod shell always maintain the upward trend and leap and rapeseed could upward, downward and leap and made cleaning sieve had a good transmission performance.

The field experiment shown that cleaning rate was higher than before and did not occur the phenomena that threshed mixture was difficult to discharge at the sieve tail.

ACKNOWLEDGMENT

Project 2010BAD01B06 supported by National Science and Technology Pillar Projects (); Technology System of Modern Rape Industrial.

Project 2009FJ1006-2 supported by Science and Technology Agency Key projects of Hunan.

REFERENCES

Bai, R., 2009. Agricultural mechanization and doubling farmers income [J].Chinese Agric. Mechan., 1: 10-12.

Chen, Z., 2008. Technology progress of rape harvest mechanization [J]. Agric. Mach. Qual. Superv., 3: 9-14.

Cheng, F. and J. Wang 1999. Test study on the flow field above surface of the air and screen cleaning mechanism [J]. T. Chinese Soc. Agric. Mach., 15(1): 55-58, (In Chinese).

Deng, C., D. Tao and J. Gao, 2006. Dynamic characteristics and factors affecting performance of air-stream cleaning windmill [J]. T. Chinese Soc. Agric. Eng., 22(4): 121-125, (In Chinese With English abstract).

Dong, G., 2006. The air-and-screen cleaning mechanism prototyping modeling and simulation [D]. M.A. Thesis, Zheng Jiang Jiangsu University, China.

Gao, H., W. Li and H. Li, 2000. Prospects of China agricultural mechanization facing the 21st century [J].T. Chinese Soc. Agric. Eng., 16(2): 9-12, (In Chinese).

Li, Y., Z. Zhao and J. Chen, 2007. Nonlinear motion law of material on air-and-screen cleaning mechanism [J]. T. Chinese Soc. Agric., 23(11): 142-146.

Ma, X., Y. Li and L. Xu, 2007. Simulation research of air flow field in air-and-screen cleaning device for combine harvester [J]. J. Agric. Mech. Res., 1: 81-82, (In Chinese).

Sun, J., Y. Li and L. Xu, 2006. Technique analysis on the research of cleaning mechanism of rape combined harvester [J]. J. Agric. Mech. Res., 6(6): 62-64, (In Chinese with English abstract).

Wu, C., 2008. Full mechanization technical way of rape in China [J]. Agric. Mach. Qual. Superv., 3: 15-21.