Comparative experimental study on working performance of air-blowing and air-suction cotton-boll separation device

Chen Changlin, Kong Fanting, Shi Lei*, Xie Qing, Zhang Yutong, Sun Yongfei, Huang Mingsen

(*Nanjing Research Institute for Agricultural Mechanization, Ministry of Agriculture, Nanjing 210014, China*)

Abstract: Some cotton bolls, cotton stalks, cotton leaves and other impurities are always collected with cotton during cotton mechanization harvesting. And then all of them are put into the postposition cleaning device. Cotton-boll separation device is added on stripper cotton harvester during cotton mechanization harvesting due to the immature cotton bolls, which can easily dye the cotton and cause the decline of cotton quality. In order to improve separating efficiency, decrease immature cotton bolls dying the cotton, and solve other problems, two kinds of cotton-boll separation device, i.e., air-suction separation device and air-blowing separation device were developed based on their main elementary structures, working principle and the difference between suspending velocities of different materials. The inner airflow velocities and pressures distributions of two kinds of cotton-boll separation devices were numerically simulated by using ANSYS Fluent software, and then the simulation results were analyzed. The suspending velocities of different materials and performances of cotton-boll separation device experiments were carried out and the simulation results were compared with the experiment results. The experimental results showed that: the average error between simulation and experimental results were less than 5%, which is valuable and has great meaning in the research of cotton mechanization harvesting. Air-suction cotton-boll separation device is better than air-blowing cotton-boll separation device. The airflow of air-suction cotton-boll separation device get together in the stable zone of negative pressure formed during cotton conveying process. The suspending velocity of cotton was low enough to separate seed cotton from cotton fluid cluster. Air-suction cotton-boll separation device can improve more than 20% of cotton-boll separating rate and reduce 5% of cotton loss rate than air-blowing cotton-boll separation device.

Keywords: cotton, boll, air-blowing, air-suction, experiment

Citation: Chen, C. L., F. T. Kong, L. Shi, Q. Xie, Y. T. Zhang, F. Y. Sun, and M. S. Huang. 2017. Comparative experimental study on working performance of air-blowing and air-suction cotton-boll separation device. International Agricultural Engineering Journal, 26(3): 75–81.

1 Introduction

Cotton is one of the most important economic crops in China and is also an important raw material in the textile industry. In recent years, shortage of labor issue is becoming increasingly acute that seriously restricts the development of cotton industry in China. Promoting the mechanization of cotton harvesting has become the inevitable tendency of cotton industry sustainable development. The perennial planting area of cotton is 4222.33 thousand hectares and the mechanization harvesting area is 661.16 thousand hectares (Ye et al., 2011), but mechanization harvesting rate just is 15.7% (Ding et al., 2012).

Manual picking was widely adopted by the cotton farmer due to the lack of suitable cotton harvester. The reduced number of cotton picking worker leads to a higher labor cost and lower cotton price in recent years. An amount of cotton has been left in the field and the economy of the cotton declines very seriously. The cost of stripper cotton harvester remarkably decreased with the constant innovation, it means that the market of

Received date: 2017-06-12 **Accepted date:** 2017-07-07

* **Corresponding author**: **Chen Changlin**, Nanjing Research Institute for Agricultural Mechanization. Tel.: 86-025-58619528, Email: njsccl@163.com.

stripper cotton harvester has a great potential for development. While only a small amount of stripper cotton harvester are used in South America and the horizontal spindle type cotton harvester were widely used in the main cotton field of American and other countries. Researchers have studied different methods for designing and optimizing a new field cleaning device with improved cleaning performance and processing capacity (Barker et al., 1991; Baker et al., 1999; Baker et al., 2000; Whitelock et al., 2007; Lu, 2013). There are little breakthroughs in the study of machine-mounted seed cotton pre-treatment apparatus.

EMA-SA-0030 type stripper cotton harvester, developed by Auros Company in Argentina, was introduced by Nanjing Research Institute for Agricultural Mechanization, Ministry of Agriculture in 2009. The practical experiment proved that cotton trash content which has been processed by its machine-mounted seed cotton pre-treatment apparatus was too high to meet the need of the cotton harvesting in China. This research group has improved machine-mounted seed cotton pre-treatment apparatus and also developed two kinds of cotton-boll separation devices on the basic of the problems found during the pre-experiments (Huang et al., 2016; Price et al., 1996). Cotton-boll separation device is key part of stripper cotton harvester and one of innovative subjects. Optimization and improvement of this device is convenient for improving efficiency of following cleaning work (Tian et al., 2017), collecting the bolls and increasing income of cotton farmer (Krifa et al., 2013).

2 Working principle of cotton-boll separation device

2.1 Suspending velocity of material

Suspending velocity is one of main material aerodynamics characteristic (Brashears et al., 1995), which is the important basic design parameter for pneumatic conveying, pneumatic separation and other devices (Carlos et al., 2009). Not only the airflow, but also the gravities and disturbance resistances affected cotton-impurity mixtures when the cottons were moving in pipeline.

Material and the airflow can be uniform and in a straight line with the same speed while the material's resultant force is zero and material is in equilibrium. That means the velocity of airflow is the suspending velocity of material. The material will downward at a finite speed when air force is less than the force keep material upward. The resistance force of material will increase with the increasing descent velocity.

When the length of pipeline is under ideal condition, there is always a moment that velocity of material is in equilibrium. At that time the velocity is called "settlement velocity of material". Settlement velocity has different meanings with suspending velocity although they are equal in number. So they are uniformly called "critical speed of material". The theoretical value of material's acting force affected by airflow can be calculated with following formula derivation.

$$P = k\rho A v^2 \qquad (1)$$

where, k is the aerodynamic drag factor which is affected by material shape, surface properties and Reynolds number; ρ is air density, kg/m^3; A is the maximum cross-section area of material in direction of perpendicular to relative velocity, m^2; and v is relative speed between material and airflow, m/s.

The kinematic equation used to calculate material which is affected by vertical airflow field is:

$$m\frac{d_v}{d_t} = P - G \qquad (2)$$

where, m is materials quality, kg; G is material suffered gravity, N.

By the knowledge of hydromechanics we can know that: when material is affected by vertical airflow field and keeps in equilibrium,

If the material is in the state of suspend: $\frac{d_v}{d_t} = 0$

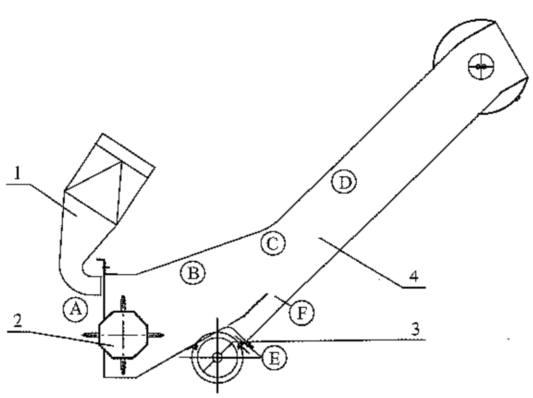
If the material is in the state of moving upward: $\frac{d_v}{d_t} > 0$

If the material is in the state of moving downward: $\frac{d_v}{d_t} < 0$

Cotton-boll separation device separate the boll from cotton by use of difference suspend velocities between closed boll, light impurities and other materials.

2.2 Elementary structure and working principle of cotton-boll separation device

Air-blowing cotton-boll separation device and seed cotton convey device is shown as Figure 1, which mainly consist of centrifugal fan, accelerating duct, cotton picked roller, air-lock valve for cotton gather, feeding duct and so on, where A, B, C, D, E, F represent wind pressures and wind speed measurement areas. Parameters of air-blowing cotton-boll separation device is shown in Table 1. Working principle of air-blowing cotton-boll separation device refers to separating the boll from cotton cluster using different masses of seed cotton and boll. Wind-force was produced by high-speed centrifugal fan and further speeded up by accelerating duct over work. That can push the cotton with cotton picked roller and diffuse rapidly. Under the push of flow power, light cotton kept moving upwards until entering into the following seed cotton pretreatment device. Heavy boll being along the baseplate moved over backwards under the resultant force of gravity, inertia force and airflow thrust. The wind pressure damped when passed the baseplate. Some bolls fell down to air-lock valve because their gravities were larger than the wind thrust that achieves a separation.



1. Accelerating duct 2. Cotton picked roller 3. Air-lock valve 4. Feeding duct

Figure 1 Air-blowing cotton-boll separation device

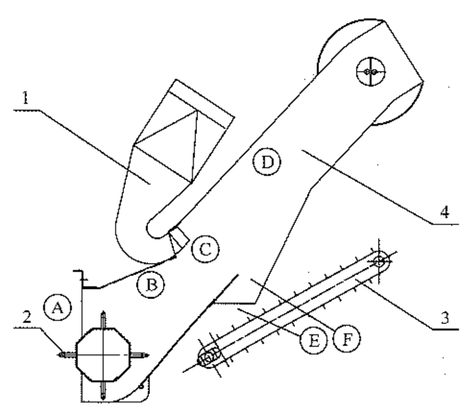
Table 1 Parameters of air-blowing cotton-boll separation device

Name	Units	Targeted value
Diameter of cotton picked roller	mm	250
Linear speed of cotton picked roller	m/s	2-2.2
Lifting difference in height of cotton boll	mm	>270
Flow of fan	m^3/h	>10000
Feed quantity of seed cotton	kg/s	0.5-0.8

Air-blowing cotton-boll separation type was also called air-assisted separation type which usually can be seen in heavy impurity separator of cotton processing line (Gillum et al., 2001) and achieves the function of soil block, carpolite and other heavy impurities separating (Whitelock et al., 2007).

2.3 Elementary structure and working principle of air-suction cotton-boll separation device

Air-suction cotton-boll separation device which includes centrifugal fan, Accelerating duct, cotton picked roller, opening boll collecting and transfer part, feeding duct and other parts is shown as Figure 2 and their mainly parameters are shown in Table 2, where A, B, C, D, E, F represent wind pressure and wind speed measurement area. The working principle of air-suction cotton-boll separation is based on the theory of gas-solid two-phase flow. The cotton becomes loose, diffusion and layering under the push of cotton picked roller. Wind-force was produced by high-speed centrifugal fan and further speeded up by accelerating duct over work. Then negative pressure which exerted a strong pull on seed cotton was formed at diffusion zone. Because of obviously different suspend velocities of seed cotton and boll, two different materials can be separated.



1. Accelerating duct 2. Cotton picked roller 3.Opening boll convey 4. Feeding duct

Figure 2 Air-suction cotton-boll separation device

Table 2 Parameters of air-suction cotton-boll separation device

Name	Units	Targeted value
Diameter of cotton picked roller	mm	250
Linear speed of cotton picked roller	m/s	2.2-2.5
Lifting difference in height of cotton boll	mm	>320
Flow of fan	m^3/h	>10000
Feed quantity of seed cotton	kg/s	0.5-0.8

3 Simulation analysis based on ANSYS

3-D solid models of two kinds of cotton-boll separation devices have been designed by using ProE software. Inner airflow velocities and pressures distribution of cotton-boll separation device under the action of strong airflow have been simulated respectively by ANSYS Fluent software. Based on proper grid partition and parameters, i.e., relative pressure of all the exits of zero and inlet velocity of 40 m/s, and other boundary conditions, the results of simulation analysis can be obtained.

3.1 Simulation analysis results of air-blowing cotton-boll separation device

Simulation analysis results of air-blowing cotton-boll separation device are shown as Figure 3 and Figure 4.

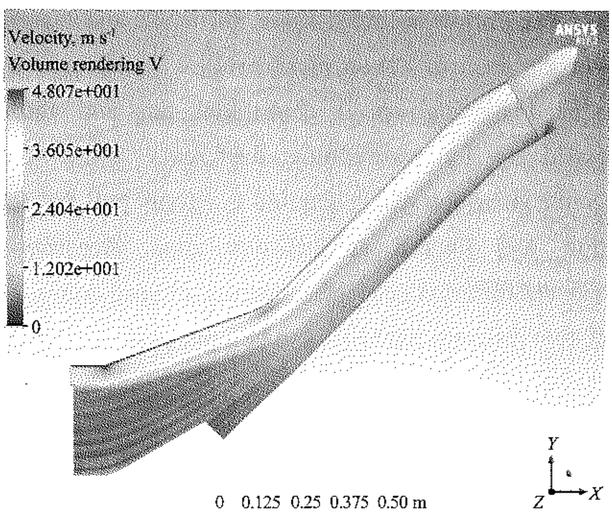


Figure 3 Velocity distribution of air-blowing cotton-boll separation device

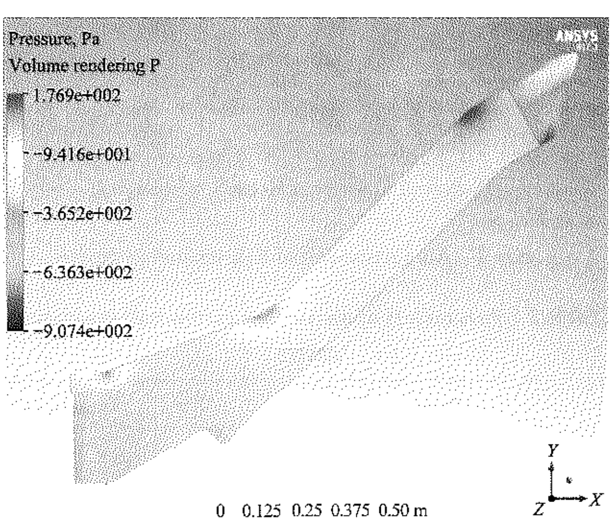


Figure 4 Pressure distribution of air-blowing cotton-boll separation device

By analyzing the simulation diagram that can be get to know: flow velocities of air-blowing cotton-boll separation device from top to bottom taper off in the same section, flow spread quickly and difficult to aggregated along the direction of feeding duct.Pressure has sudden changed in some bending positions and it would easily arose the vortex, which would generated interference and had the impact on movement direction of seed cotton.

3.2 Simulation analysis results of air-suction cotton-boll separation device

Simulation analysis results of air-suction cotton-boll separation device as is shown in Figures 5 and 6.

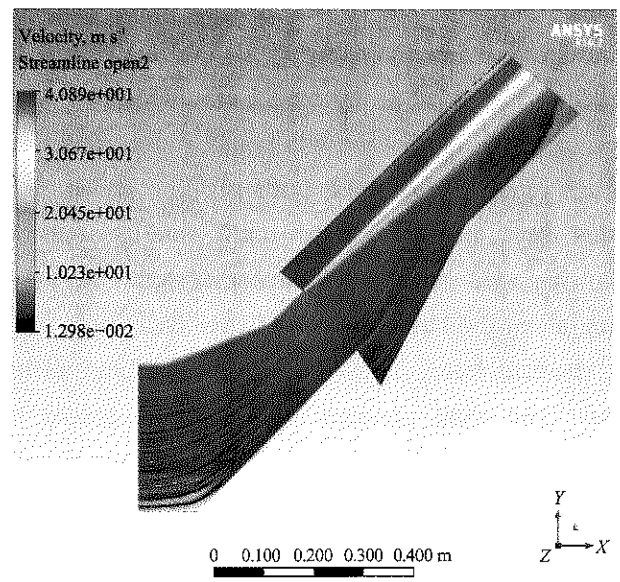


Figure 5 Velocity distribution of air-suction cotton-boll separation device

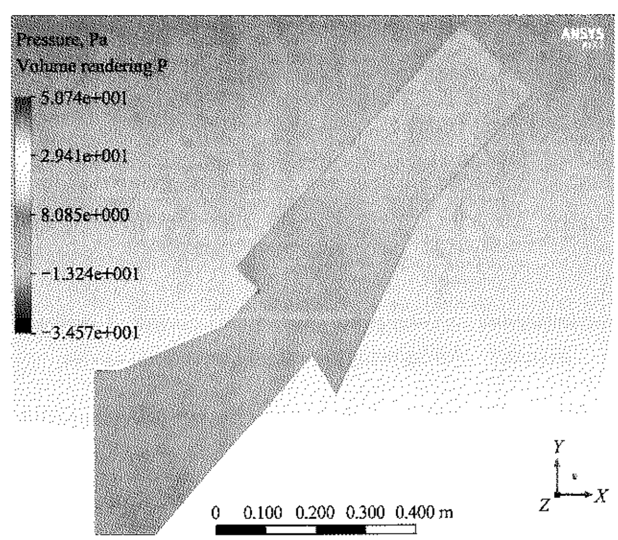


Figure 6 Pressure distribution of air-suction cotton-boll separation device

The internal flow velocity of air-suction cotton-boll separation device was faster than the internal flow velocity of air-blowing cotton-boll separation device. The flow obviously stratified and got together. Meanwhile, air-suction cotton-boll separation device had more negative pressure, thus achieving the cotton-boll separation and seed cotton transfer easier.

4 Experimental verification

4.1 Experiment of suspending velocity

The cotton fluid units always contain seed cottons, cotton stalks, cotton bolls, cotton leaves and other materials which were harvested by stripper cotton harvester. Suspending velocities of different materials can be respectively measured by using suspending velocity test-bed, and the experiment results were shown in Table 3.

Table 3 Suspending velocities of materials

Material	Suspending velocity, m/s
Single seed cotton	2.9-3.6
Seed cotton per boll	4.1-5.0
Lateral branch	6.2-6.7
Main stem	8.2-10.3
Bracteole	4.9-7.0
Closed boll	11.0-13.2
Ajar boll	6.2-7.8
"ginned cotton" control group	1.6-2.9

As the experimental results shown in Figure 7, the ascending sequences of different materials' suspending velocities are: closed boll>main stem>ajar boll>bracteole>lateral branch>seed cotton per boll> ginned cotton. Although it is found that suspending velocity of the same kinds of material is also affected by moisture content, their own sizes and other factors in the experiment. There are obvious difference suspend velocities between closed boll and light impurities, it means that they can be easily separated by airflow acting force under the same experimental condition.

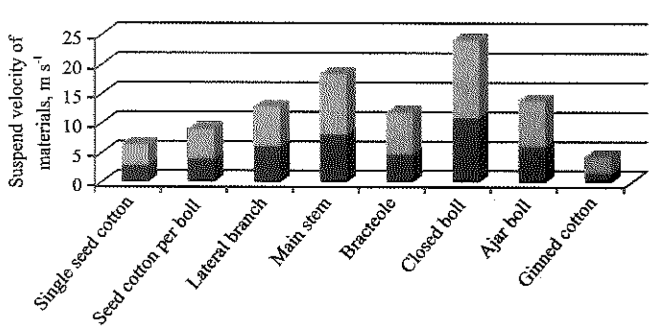


Figure 7 Interval distribution of suspending velocities

4.2 Experimenting of cotton-boll separation device

Two kinds of cotton-boll separation devices were respectively driven by high speed centrifugal fan which shaft power is 40 kW. The rated speed is 3800 r/min, the measured air volume is 13000 m^3/h and the wind pressure is 3.7 kPa. In the experiment, high speed airflow was produced by centrifugal fan and entered into cotton-boll separation device from the front of device. A, B, C, D, E, F and other experimental points had been set in the device.

Pressure measuring equipment was GM520 type barometer which was manufactured by Benetech Technologies Co Ltd. Its ranges are –35-35 kPa and accuracy is 0.001 kPa. Wind speed measuring equipment was AVM-07 type anemograph which was manufactured by TES Electrical Electronic Corp. Its ranges are 0-45 m/s and accuracy is 0.01 m/s. Wind speeds and wind pressures distribution had been measured and their change rules were researched. The experiment results were shown as Table 4 and Table 5.

Table 4 Wind speeds and wind pressures of air-blowing cotton-boll separating device

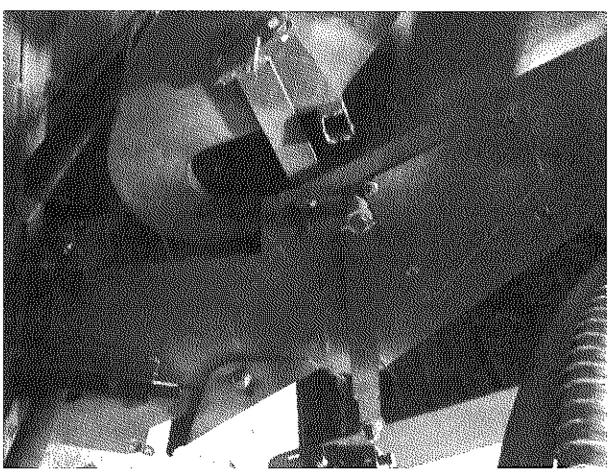
Item	Parameters of each measuring point					
	A	B	C	D	E	F
Wind pressure, kPa	–0.34	0.36	0.3	0.21	–0.03	–0.15
Wind speed, m/s	12	42	36	28	9	11

Table 5 Wind speeds and wind pressures of air-suction cotton-boll separating device

Item	Parameters of each measuring point					
	A	B	C	D	E	F
Wind pressure, kPa	–0.07	–0.09	–0.14	0.51	–0.09	–0.18
Wind speed, m/s	2.35	2.5	5.5	44	9	13

The error between simulation and experimental results of air-blowing cotton-boll separation device was about 4.7%. The error between simulation and experimental results of air-suction cotton-boll separation device was about 3.5%. It can be assumed that the simulation model was reasonable and requirement of practical inspection could be fulfilled. Through the comparison of wind speeds and wind pressures value between two kinds of cotton-boll separating devices, it can be found that, wind speeds of all experimental points which had been set in air-blowing cotton-boll separating device were greater than the suspending velocities of the testing materials which cannot separate the cotton and boll easily. The wind speed at experimental point C, which was set in air-suction cotton-boll separating device, was between the suspending velocities of cotton and impurities that make it easy to separate the cotton and boll.

The quantitative mixture composed of picking cotton with machinery and cotton boll that was feeding in the front of device when ran the performance tests. The percentage of the mass of bolls in separated cotton to feed quantity in the front of device that cotton-boll separating rate. And the percentage of the mass of cotton drop out with bolls at experimental point E to the total amount of falling materials that is cotton loss rate. Prototype structure of air-suction cotton-boll separation device was shown in Figure 8.



1. Accelerating duct 2. Opening boll convey 3. Feeding duct

Figure 8 Prototype structure of air-suction cotton-boll separation device

The cotton-boll separating rate was 76% and loss rate of seed cotton was 5% by using air-blowing cotton-boll separation device. The results showed that: part of boll and seed cottons were lifted up with cotton picked roller, which was too late to disperse and then pushed to the following feeding duct directly. The flow direction, speed and pressure at the bottom of device were instantaneously affected by the undispersed fluid cluster. Some cottons discharging from boll exit with boll that caused the cotton loss.

Cotton-boll separating rate was 99% and loss rate of seed cotton was 0 by using air-suction cotton-boll separation device. The results showed that, the cotton fluid cluster can be dispersed and layered sufficiently and a stable zone of negative pressure was formed at separating zoon and boll exit.

5 Conclusion and discussion

Based on the simulation analysis of software ANSYS and combined experimental results of two kinds of cotton-boll separation devices, the conclusions can be drawn as follows:

(a) Average error between simulation and experimental results was less than 5%. It could be assumed that the simulation model is reasonable and requirement of practical inspection can be fulfilled.

(b) Flow velocity of air-blowing cotton-boll separation device from top to bottom taper off in the same section, flow spread quickly and difficult to aggregate along the direction of feeding duct. Pressure has sudden changes in some bending positions and easily arises the vortex, which would generate interference and have the impact on movement direction of seed cotton. Simulation and experimental results both verificated that the boll could not be easily separated from cotton cluster unit by using air-blowing cotton-boll separation device.

(c) A stable zone of negative pressure was formed at boll exit and separating zoon that facilitated to separate seed cotton from cotton fluid cluster, reduced seed cotton loss and improved the recycling efficiency of seed cotton.

(d) The combination property of air-suction cotton-boll separation device is obviously better than air-blowing cotton-boll separation device. Air-suction separation device improved more than 20% of cotton-boll separating rate and reduced 5% of cotton loss rate than air-blowing separation device

[References]

[1] Barker, G. L., R. V. Baker, and J. W. Laird. 1991. *GINQUAL: a cotton processing quality model. Agricultural Systems*, 35(1): 1–20.

[2] Baker, R. V., and A. D. Brashears. 1999. Effects of multiple lint cleaning on the value and quality of stripper harvested cotton. *World Journal of Surgery*, 26(3): 335–341.

[3] Baker, R. V., and A. D. Brashears. 2000. Combined effects of field cleaning and lint cleaning on stripper harvested cotton. In *Proceedings Beltwide Cotton Conferences, San Antonio, USA*, 2000: 1616–1621.

[4] Brashears, A. D., and K. D. Hake. 1995. Comparing picking and stripping on the Texas highplains. In *Proc. Beltwide Cotton Conf., San Antonio, TX.*1995: 652–654.

[5] Carlos, B. A., and D. B. Kevin. 2009. Harvesting and seed cotton cleaning of a cotton cultivar with a fragile seed coat. *Engineering and Ginning*, 13(2): 158–165.

[6] Ding, Z. F., W. X. Wang, S. N. Jia, and Y. G. Wang. 2012. Separation system design of all-harvest cotton picker. *Machinery Design and Manufacture,* 3(3): 25–26.

[7] Gillum, M. N., C. B. Armijo, and D. D. Mc Alister. 2001. Optimization the speed of the cleaning cylinder on the Batt-Less lint cleaner. *Journal of Electronic Packaging*, 44(3): 487–492.

[8] Huang, M. S., S. Lei, Y. T. Zhang, C. L. Chen,Y. F. Sun, Q. Xie, and T. F. Kong. 2016. *Optimization experiments of machine-mounted seed cotton pre-treatment apparatus for cotton stripper harvester. Transactions of the Chinese Society of Agricultural Engineering,* 32(21): 21–29. (In Chinese with English abstract)

[9] Krifa, M., and G. Holt. 2013. Impacts of gin and mill cleaning on medium-long staple stripper-harvested cotton. *Transactions of the ASABE*, 56(1): 203–215.

[10] Lu, W. D. 2013. The problem met in extending machine pickup cotton technology and its countermeasures. *China Fiber Inspection*, 2013(9): 31–31. (In Chinese with English abstract)

[11] Price, J. B., and R. V. Baker. 1996. Cleaning experiences with stripper-harvested cottons. In *Beltwide Cotton Conferences*.

[12] Tian, J , X. Zhang, W. Zhang, H. Dong, X Jiu., and Y Yu. 2017. Leaf adhesiveness affects damage to fiber strength during seed cotton cleaning of machine-harvested cotton. *Industrial Crops and Products,* 2017(107): 211–216.

[13] Whitelock, D. P., C. B. Armijo, G. R. Gamble, and S. E. Hughs. 2007. *Survey of seed-cotton and lint cleaning equipment in U.S. roller gins. Journal of Cotton Science,* 29(11): 128–140.

[14] Ye, W., and H. X. Zhang. 2011. Simulation research on cotton harvester about positive wind power conveying system based on Floworks. *Journal of Jiamusi University (Natural Science Edition),* (29)3: 252–255.