Effect parameters of vertically spindle cotton picker machines on the mechanical damage of cotton seeds during machine harvesting

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Abstract. The article describes the influence of factors as a suction and injection method of transporting raw cotton from a harvesting machine to the mechanical damage of cotton seeds. The influence of the rotation speed and design of the fan impeller, as well as the width of the working slit of the harvesting apparatus on the formation of an undesirable defect, that is, mechanical damage to cotton seeds are examined. Recommendations are proposed to reduce the mechanical damage to cotton seeds.

Rotating the spindle together with the drum, the cotton is transported to the pick-up area, where due to the spindle reversal due to the epicycle mechanism of its drive, the bulk of the cotton is discharged from the spindle surface, and part of the cotton windings is removed by brush pullers rotating in the same direction ( while the linear speed of the brushes is 4 times greater than the peripheral speed of the spindle) and under the action of centrifugal force, the cotton from the surface of the puller is dumped into the slotted receiving chamber of the harvester apparatus.

1. Introduction

Cotton is grown on irrigated lands mainly between 60 sm and 90 cm row-spacing in Uzbekistan. Depending on the climatic and biological characteristics, the agro-technology of cultivation, and the state of soil conditions, plant productivity varies from 2.5 to 5 t/ha. Mechanized harvesting is based on a system of machines for collecting the opened part of the crop, where it is recommended to use both horizontal-spindle (with a high cotton yield of more than 36 q/ha) and vertical-spindle (with medium and low cotton yield) cotton-picking machines. In the field of development, creation, and production of cotton-picking machines, Uzbekistan and the USA remain the main world centers of this high-tech equipment.

In recent years, Israel, China, India, Australia, the Russian Federation, Argentina, and Turkey have been actively involved in this work, where new patents for technical solutions are being created mainly for spindle and stripper cotton pickers, and are protected by a patent for a multi-row pneumatic cotton picker. From materials, obtained through open press and Internet sites in the field of mechanization of cotton harvesting, it was determined that based on market demand and the requirements of environmental standards for soil impact in the United States, China (under a U.S. license), multi-row cotton harvesting machines are developed and produced (from 3 to 6-row spindle
and 8-12-row strippers) with an ejection pneumatic conveying system using Jetartrole technology, and in Uzbekistan, machines are manufactured with both suction and discharge pneumatic conveying system, and a discharge system for transporting the cotton collected by the apparatus to the storage bin [1 – 13].

At the same time, for the above cotton pneumatic conveying systems, the urgent problem of preserving the natural quality of seeds and fiber remains. It should be noted that the mechanical damage to the seeds includes: change with damage to the peel, through which the seed core (through piercing of the peel, shell) crushing, cracking is visible [14]. During the cotton harvesting machine, the appearance of mechanical damage in the seeds of raw cotton significantly increases the strength in fibers and ultimately reduces its textile properties [4, 21].

2. Methods
Analysis of the design of the pneumatic conveying system and the results of experiments with determining the quality of seeds during operation of a vertically spindle cotton picker machine. Methods for studying seed damage at different values of the working gap in the harvesting machine are based on well-known STATE STANDART 21820.076.

3. Results and discussion
For conducting field experiments, modern semi-mounted cotton-picking machines equipped with vertical-spindle-type harvesting machines shown in Figure 1 were used.

The principle of operation and the sequence of work processes occurring in cleaning machines and machines in the slots are described in detail in [4, 5, 20, 21]. Here we briefly dwell on the basics of the stages of the working process in a vertical spindle apparatus.

Developed on the basis of the invention of L.M.Rosenblum [15], the technological process in the apparatus of a modern vertically spindle cotton picker proceeds as follows: the cotton plant is fed into the working chamber by special brush guides, where, due to the opposite movement of the rotary motion machine, the spindle drums run around the bushes, compressing them to sizes of the green cotton box and transport them to the narrowest part of the working gap (22-40 mm).

At the same time, the teeth of the spindles (a vertically mounted gear cylinder on 2 supports with a drive roller), directed in the direction of their rotation (due to a hypo cyclic drive), are injected into the slices of the opened box, capturing them wound on the cylindrical surface of the spindle.

![Figure 1. Semi-trailed cotton picker machines](image)

Rotating the spindle together with the drum, the cotton is transported to the pick-up area, where due to the spindle reversal due to the epicycle mechanism of its drive, the bulk of the cotton is inertia (up to 75-80%) discharged from the spindle surface, and part of the cotton windings is removed by brush pullers rotating in the same direction (while the linear speed of the brushes is 4 times greater than the peripheral speed of the spindle) and under the action of centrifugal force, the cotton from the surface of the puller is dumped into the slotted receiving chamber of the harvester apparatus. Further, the
cotton from the receiving chamber of the apparatus is carried away by the suction airflow created by the fan.

The cotton passing through the fan with the subsequent discharge air flow is transferred to the hopper of the machine. Spindles, rotating in orbit together with the drum, enter the working chamber of the apparatus, and the spindle rollers interacting with the direct rotation belt (hypocyclic drive) change the direction of rotation and the collection process is repeated. In [17], the results of tests of cotton-picking machines of vertically spindle types in real field conditions with the assessment of damage to cotton seeds during transportation to the hopper of machines were summarized. At the same time, the fact of increased damage to seeds in the suction-discharge flow of the cotton pneumatic conveying system than in the injection system was ascertained, as can be seen from table 1. The power expenses for one fan of the pneumatic conveying system are also shown here.

Cotton harvesting machines for the general cotton harvest 14XV-2.4, 17XV-1.8, XN-3.6, XNP-1.8 were produced at the “Tashselmash” plant in the early 70-80s, and special machines were vertically spindle type for the collection of long-fiber cotton XBN-1.2A (XBN-1.8) and replaceable cotton XVB-1.8 (XVA-1.2) were produced at the request of cotton farms. The last two models of machines were equipped with a discharge pneumatic conveying system.

**Table 1.** Mechanical damage to seeds of long and medium fiber cotton during harvesting by various brands of machines

| Rand of vertical spindle machines * | 14XV-2.4 | XBN-1.2A | XVB-1.8 | 17XV-1.8 | XN-3.6 | XNP-1.8 |
|-----------------------------------|---------|---------|---------|---------|-------|-------|
| Damage to seeds, in% (from the hopper of the machine) |        |         |         |        |       |       |
| - medium fiber                    | 1.2±1.3 | 0.1±0.7 | 0.1±0.73| 1.3     | 0.52±4.2 | 1.58±3.26 |
| - long fiber                      | 3.8±6.6 | 0.35±0.7| -       | -       | -     | -     |
| Power consumption per fan (kW)    | 4.58    | 12.5    | -       | 5.75    | -     | 6.0    |

Note - in machines 14XV, 17XV, XN, XNP pneumatic systems of suction type; in machines CVI, CVB pneumatic systems of the discharge type.

More energy-saturated machines XBN-1.2A and XVB-1.8 ensured the reduction of mechanical damage to cotton seeds to the requirements of regulatory materials (STATE STANDART 22587) due to the rational choice of high-speed operating modes. The influence of the linear velocity of a dust-type fan is studied in [18]. Table 2 shows the results of experiments conducted on the example of medium-fiber cotton of machine harvest.

**Table 2.** Influence of fan peripheral speed on damage to cotton seeds

| n, rpm | 3, rot. m/s | Damage to cotton seeds |
|--------|------------|-----------------------|
|        |            | crushing | damage | overall |
| 1270   | 34.5       | -        | -      | -       |
| 1285   | 35.0       | -        | 0.2    | 0.2     |
| 1300   | 35.4       | -        | 0.9    | 0.9     |
| 1330   | 36.2       | 0.2      | 1.7    | 1.9     |
| 1350   | 36.7       | 0.4      | 2.3    | 2.7     |
| 1360   | 37         | 0.4      | 2.5    | 2.9     |
At a linear peripheral speed of the fan rotor of 34.5 m/s, damage to the seed cotton was not observed, but already at a speed of 35.0 m/s, damage at the level of 0.2% begins to be detected, up to a peripheral speed of the rotor of 35.4 m/s (its rotation speed 1300 rpm) fan rotor seed damage was within acceptable limits. The linear peripheral speed of 36.2 m/s (or angular rotation speed of 1330 rpm) and higher leads to a significant increase in damage, exceeding the permissible value (STATE STANDARD 22587) by 1.9 times and with min crushing of seeds reaches 0.4%, and the total damage was 2.9%, which is 2.9 times more than the permissible value.

The limit value of the linear speed of the rotor of the dust-type fan according to the results of experiments should be up to 34.5 m/s. It allows, under given conditions, to preserve the natural quality of cotton and seed. It should be noted that according to the translated data, the initial moisture content of cotton is absent, which also affects the damage to seeds.

In [17], by the example of the suction-discharge design of a pneumatic conveying system for machines of the type 17XV-1.8, 14XV-2.4, and others, researchers differentially studied the damage to seeds in the corresponding areas:

AB - the receiving chamber of the cleaning apparatus, BV - in the suction pipe with geometrical bends, VG - in the inside of the fan with a blade rotor, HD - in the discharge pipe and IDE - in the hopper of the machine. The total value of the damage is obtained in the form:

\[ \sigma_{OB} = \sigma_{AB} + \sigma_{BV} + \sigma_{VG} + \sigma_{GD} + \sigma_{E}, \]

where \( \sigma_{OB} \) is the total number of mechanical damage, %;
\( \sigma_{AB} = 0.2 \pm 0.4\% \) is the mechanical damage on the AB site;
\( \sigma_{BV} = 0.1 \pm 0.2\% \) is the mechanical damage on the BV site;
\( \sigma_{VG} = 0.8 \pm 1.2\% \) is as well on the VG site;
\( \sigma_{GD} = 0.1 \pm 0.2\% \) is as well on the GD site;
\( \sigma_{E} = 0.2 \pm 0.4\% \) is the mechanical damage in the hopper of machines.

*Figure 2. The scheme of the pneumatic conveying system of cotton machines of type XB (a) and mechanical damage to seeds in its sections (b)*.

AB is the section of the cleaning apparatus and the receiving chamber; BV is the pneumatic conveying suction pipe; VG is the fan; DG is the discharge pipeline pneumatic transport; DE is the hopper zone.
The authors concluded that the minimum and maximum values of seed damage are equal 
\[ \sigma_{\text{min}} = 1.4\% \quad \text{and} \quad \sigma_{\text{max}} = 2.4\% \]
and in some experiments, it reached 3.5\% \[17\]. Note that they are associated with the impact processes of cotton seeds on the walls of pipelines and fan blades in these areas. The largest value - 50 \% ... 57\% of damage is installed inside the fan. Therefore, to eliminate this negative situation in GSKB for cotton growing machines, together with SRIMA, universal cotton-picking machines with a pneumatic system were developed and tested. But because of complexity and low reliability, they did not find the application.

In \[18\], the suction - discharge system is improved by developing a special design of a centrifugal fan with an open (hollow) central rotor with blades. And this design required the use of special large diameter bearings for the rotor, which halted its use in real production. But it should be noted that seed damage did not exceed the permissible norm. At various stages of the design of cotton-picking machines, mainly dust-type centrifugal fans of dust type were used because of their simplicity of construction and not the complexity of manufacturing and operation.

To adapt them to cotton picking with minimal damage to cotton seeds, several significant changes were introduced into the fan design. Table 3 shows the kinematic and geometric parameters of these fans, as well as the results of their work under real conditions with the determination of damage to the cotton change \[20\].

| Fan type                                      | Tumber of rotation. Impellers, rpm | Outer diameter of Impeller, mm | Rotation speed of impeller, m/sec | Number of lobe, piece | Moisture of cotton, % | Capacity by cotton, kg/hour | Damage of cotton seed, % |
|-----------------------------------------------|-----------------------------------|-------------------------------|----------------------------------|-----------------------|------------------------|----------------------------|--------------------------|
| Central suction fan with separating disk of machine CXM-48 | 2150                              | 330                           | 39.4                             | 6                     | 7.9                    | 750                        | 0.60                     |
|                                               | 2250                              |                               | 41.2                             |                       | 9.3                    |                            | 1.83                     |
|                                               | 2450                              |                               | 44.8                             |                       | 8.0                    |                            | 1.20                     |
| Side suction fan of machine SCHM-48M          | 2450                              | 400                           | 51.3                             | 8                     | 9.7                    | 700                        | 1.32                     |
| Side suction fan XBC-1.2                      | 2400                              | 400                           | 50.2                             | 8                     | 10.0                   | 700                        | 2.28                     |
|                                               | 2650                              |                               | 55.6                             |                       |                        |                            | 2.53                     |
| Dust type central suction fan SAGI             | 1150                              | 500                           | 30.1                             | 8                     | 8.0                    | 720                        | 6.1                      |
|                                               | 1250                              |                               | 32.7                             |                       |                        |                            | 8.4                      |
| Centrifugal fan With angular elliptical entrance | 1250                             | 500                           | 32.7                             | 12                   | -                      | 720                        | 0.8                      |
|                                               | 1370                              |                               | 35.8                             |                       |                        |                            | 2.0                      |
| Centrifugal fans with central hollow rotor     | 1250                              | 600 700                       | 39.3                             | 12                   | -                      | 750                        | 0.2                      |

Due to the simplicity of manufacture and ease of use, the penultimate 5th variant of the translated 6 types of fans is widely used in modern vertically spindle cotton pickers as a suction - pressure system for pneumatic transport of cotton into the hopper of a machine (see figure 1).
It can be seen from the table that in the first three fan options, to provide the required performance, the angular rotor speed varied between 2150 and 2650 min\(^{-1}\) and the linear peripheral speed of the impeller periphery changed from 39.4 to 55.6 m/s. During the testing of these fans in a cotton picker under real field conditions, the moisture content of the cotton varied from 7.9% to 10.0%, and the damage to the cotton seeds varied from 0.6% to 2.53% (see table 3). Here you can see that with an increase in the humidity of the cotton, seed damage increases, and if with a humidity of cotton of 7.9, the damage to the fan with a central suction and with a separating disk was 0.6%, then at a moisture content of 9.3% the damage was already 1.83%.

This pattern is also observed for fans with lateral air intake, where at a moisture content of cotton of 9.7%, seed damage was 1.32%, at a moisture content of 10% they were 2.28%, i.e. growth was more than 1.72 times. A fan of the Central Agro-Hydrodynamic Institute (CAHI) with central air intake even with an angular rotation speed of 1150 min\(^{-1}\) and a cotton humidity of 8%, the damage reached 6.1%.

This phenomenon is since the developers of the fan expected to use the negative pressure that appears in the center of the rotor with the blade. Due to the longer residence time of the cotton fan, this phenomenon was recorded. And for a fan with a close-lying elliptical corner, a section of the main cylinder (see Fig. 2) has cotton – air mixture that interacts less with the rotor blade.

Less energy consumption (more than 2 times, according to the results of extensive comparative tests, see table 1), the suction - injection pneumatic conveying system allowed them to equip modern semi-trailer machines of the MX-1.8 MX-2.4 type (see figure 1). But at the same time, the problem of reducing the damage to seeds of harvested cotton remains relevant and requires an innovative solution.

In this direction, we studied the effect on the damage to cotton seeds of a change in the working gap between the drums of the harvester at a given fan rotor speed. Since in previous studies this factor was not considered, that is. The experiments were conducted on a modern 4-row cotton harvesting machine type MX-2.4.

The agro-technical conditions of the experiments were tested as follows: cotton variety - Sultan, plant height - 91 cm, width 34 cm, percent opening of bolls - 73%, number of leaves on one plant, pieces., Total - 5, including dry - 2 pieces., semi-dry - 1 pc., green - 2 pieces., the yield on open cotton in the logging plot - 29.1 c / ha. The plant standing density is 103 thousand pieces/ha. The results of field trials of the MX-2.4 cotton picker machine are presented in Table 4.

| Brand of machine | Frequency of fan, rpm | Open cotton yield, q/ha | Width of working gap between front drums, mm | Width of working gap between rear drums, mm | Moisture of cotton, % | Damage of cotton seed, % |
|------------------|----------------------|-------------------------|---------------------------------------------|---------------------------------------------|----------------------|------------------------|
| MX-2.4           | 1480                 | 29.1                    | 36                                          | 30                                          | 1.8                  | 2.3                    |
|                  |                      |                         | 34                                          | 30                                          | 7.2                  | 3.8                    |
|                  |                      |                         | 32                                          | 28                                          |                      |                        |

An analysis of the results of studies of the pneumatic conveying system of the suction - discharge type of a cotton picker showed that to reduce damage to cotton seeds at the agro-demand level (up to 1%), changes were made to the fan design. Instead of a diametrical peripheral or central inlet of the air-cotton mixture, centrifugal fans with lateral central or secondary elliptical designs were developed. Centrifugal fans with an axial hollow vane rotor have also been created.

This complication of the design to a certain extent solved the problem of damage, but at the same time required additional costs. The limiting values of 35 m/s of the linear velocity of the peripheral points of the fan rotor blades were determined. The effects of individual sections of the suction - injection pneumatic transport system on seed damage were studied. But at the same time, the influence...
of changes in the working gap of the harvesting apparatus on damage to the seeds of harvested cotton remained open.

Using a new one-time method for harvesting cotton using modern vertical spindle machines, we carried out experiments to determine the width of the working slit of the harvester for seed damage during the suction-injection pneumatic system. Reducing the working gap from 36-30 mm to 32-28 mm vertically spindle apparatus with paired working drums increases seed damage up to 3.4 times, ceteris paribus.

Reserves to reduce the damage to cotton seeds are to ensure the moisture content of the cotton being harvested up to 9%, increase the working gap at the first pass of the machine and reduce the rotation frequency of the fan rotor.

4 Conclusions
To ensure agro-technical indicators of vertically spindle cotton pickers at the one-time gathering at the level of regulatory requirements, the working slot of the harvester at the first pass of the machine should be at the level of 34-36 mm for the front pair of drums and 30-28 mm for the rear pair of drums. Changes in the location of the suction pipelines and a decrease in the rotor speed of the fan rotor are reserves to reduce the quality of cotton and seeds.

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