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Theoretical and experimental results of determination of the peeler-bar parameters of corn-thresher

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Abstract. A new type corn-thresher was developed and tested for farms in Uzbekistan. Unlike to the existent threshers, this corn-thresher peels the husks of corn-cobs and threshes the kernel. At first parameters of the peeler-bars were researched theoretically, then three types of peeler bars were installed symmetrically on the surface of rotor of the corn-thresher and compared experimentally. The corn-thresher works qualitatively and it requires least metal and energy. The weight of corn-thresher is just 350 kg, consumes power amount is 5 KW and the work performance of the thresher in the pure time is 4600 kg/hour. During the theoretical research, the results were determined that, width of the peeler-bar should be bigger or equal than 4.8 cm ($b_p \geq$ 4.8 cm). Also, the distance between peeler-bar and concave should be equal to 38 mm ($S_c = 38$). While we researched experimentally the types of peeler bars, three type of them, namely straight tooth, sloped tooth and fluted bar were tested. Their surface was compared between 36-44 mm distance of peeler-bar and concave. When the distance between sloped tooth peeler-bar and concave was 38-40 mm, we achieved to peeling well the husk of corn-cob, threshing better the kernels than other peelers, the most important was that any grain had not damaged when we analyzed results.

1. Introduction

Nowadays corn is being produced for one of the main plants in many countries. The reason is that, corn is a main forage plant for developing live-stock and poultry-farm over the world. In addition, the productions are produced by the corn for to use of a food-stuffs industry, medicine and at technical aims, those productions are pop-corns, canned-foods, starch, crystallized sugar, spirit and other more production [1]. The corn's first motherland is the North America; it is known that by the conclusive evidences archaeological and botanical scientists' opinion, the first time corn was grown as a cultural plant in the south-western United States of America 3013 years ago.

However, wild corn was once thought to have existed in the Tehuacốn Valley of southern Mexico 7013 years ago and the corn growing was begun for cultural plant in this region 4613 year ago.   Corn has been produced more than 500 million tons at the present day over the world and the United States is the

leading corn-growing country, with more than 40 per cent of the world's production. Most of its crop is grown in the Midwestern region known as the Corn Belt, comprising Ohio, Indiana, Illinois, Iowa, Missouri, Kansas and Nebraska. The other leading corn-growing nations are China, Brazil, Mexico, Russia, Italy, India and other countries [2].

In Uzbekistan corn is grown 31308 hectare area as above mentioned countries [3], this crop indicator is produced as a main corn-crop area but after harvesting wheat crops, again corn is grown as the second crop instead of wheat field in our Republic every year and after wheat harvesting only early-ripening and middle-ripening corn sorts are grown, the early-ripening corn ripens between 70-75 days and middle-ripening corn is ripened between 90-95 days in our Republic.

If we take it into a count growing the corn as the second crop instead of wheat crops, this indicator will raise to 300000 hectares. One of the most important tasks is to grow corn for grain. It is required to harvest ripened crops without losses. Especially if this work is performed by the help of mechanized method and technical instruments we'll achieve seriously decreasing manual labor and material expenses.

Hand operated maize-sheller was created and researched experimentally it. The advantage of corn-sheller is that, it does not use any electrical energy; however its disadvantage is using manual labor. It means it is not mechanized device [4]. Like above mentioned research pedal operated maize sheller was developed. This sheller device also has positive side. Because, it is moved by human's leg-force. However, it is not mechanized sheller too. For using it of course human's energy is demanded [5].

Another type of hand sheller machine was created and researched as well. It was observed how to influence to the capacity of grain shelling. In this research explorers achieved satisfied result when the moisture of the grain was 14.7 per cent. The test crop maize had grain moisture content of 14.7 per cent wet basis. Maize shelling using the developed hand sheller resulted in causing no damage to maize kernels. They also counted economical effect of the sheller [6].

Other scientists observed locally constructed sheller machine. According to their research, main problems faced by machine operators include corrosion of machine parts, separation of kernels from cobs after shelling, packaging of kernels and cobs into bags after shelling and flying over of maize cobs during shelling. The maize shellers were of economic use and highly efficient though no prior design parameters and engineering properties of maize were considered before the fabrication of the machines, engineers are however tasked on the modification of the machine. They achieved their aim in this research [7].

A group of researchers studied development and performance evaluation of a spring-loaded hand operated maize sheller with variable mechanisms in condition of Nigeria. According to their research hand operated maize sheller was tested with corn cobs at 12.6% moisture content and its shelling performances compared. They compared shelling mechanisms such as "spike tooth", "rasp bar" and "star tooth". They achieved 100% shelling efficiency, 13.83 kg/hr shelling capacity and 0% kernel damage. However, 13.83 kg/hr shelling capacity is a very low indicator. It is not suitable for modern farmers' demand who produce the in large hectars [8].

We had to learn and analyze peeling technologies too, because in our research work there is peeling the husks of the pod-corn too. Like this peeling work has been observed too. Only this work was for peeling "cassava plant" differently from ours. This research work was about comparative analysis and performance evaluation of three cassava peeling machines. According to result cassava is posed with inherent characteristics, morphological distributed in numerous cultivars, being these have contributed to the global un-acceptable peeling technique of the tuber. The machines were evaluated at three different speeds, namely at 300, 500 and 700 rpm with 1.0 HP electric motor. The result indicates that up to 91.87% peeling efficiency is achieved in less than 25 seconds using mechanical peeling method [9].

It is a very good result. Before doing our research for peeling the husk of the pod-corn, we learned and analyzed their created method too. Modification and testing of jimma adjustable hand maize sheller was developed [10]. However, in this research work also it was paid attention to create hand operated machine. As we mentioned above it should be adapted mechanized work because of demand of safety of human.

About designing and development as well evaluation of a power operated maize sheller with spiked disk type some research work has been done. The developed power operated maize sheller was tested in

laboratory as well as operations at load for short durations by authors. According to their achieved result, disc speed of operation 60 rpm was quite satisfactory. The shelling capacity of the machine was 100.25 kg grains/hr with shelling efficiency of 99.95 % and cleaning efficiency of 99.37%. The breakage percentage was 0.406 which is well within the prescribed limit for such machines [11]. The shelling efficiency and cleaning efficiency are satisfied. However, its capacity is much lower for large farms.

According to above mentioned observations, the complex of machines and earlier-harvesting technology were created for harvesting corn in Uzbekistan. The researches were performed for creating of the corn-thresher. For determination its parameters and modes operation of the working elements of created corn-thresher, it is necessary to do theoretical and experimental research before reaching conclusion.

2. Materials and Methods

It is a difficult process to peel the husk of the corn-cob that is fed between peeler-bar and concave of the corn-thresher, peeling qualitatively of husks of the corn-cob depends on width, length as well surface of the peeler-bar. Therefore, at first we researched theoretically the parameters of the peeler-bar according to laws of the theoretical mechanics and tested the taken results experimentally. During the observed experiments we used following materials and methods:

As the studying aim of the peeling efficiency the husks of the corn-cob a special experimental device was prepared and it was equipped with the glass where the peeling process of the husk can be observed (Figure 1).

Figure 1. A device for laboratory to observe the peeling process of the corn-**cob**

Different peeling-bars which can remove the husk of the corn-cob were installed on the surface of the thresher-drum of special experimental device that prepared for studying the peeling quality of the husk. For this, peeler-bars were prepared which have different working surface such as straight tooth, sloped tooth and fluted bar (Figure 2).
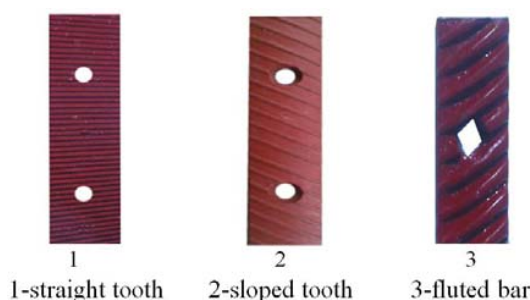

1-straight tooth   2-sloped tooth   3-fluted bar
Figure 2. View of different researched peeler-bars

Table 1. Formulas for counting the work quality indicators of corn-thresher

No.	Indicators	Formulas
1.	Real feeding overall mass, kg/s	$\Pi_{real} = \dfrac{G_{gr.} + G_{th}}{t}$
	Grain	$\Pi_{gr.} = \dfrac{G_{gr.}}{t}$
2.	Work efficiency, t/hour	$W = 3{,}6 \cdot \Pi_{real}$
3.	Grain analyzing, %	
	- unbroken grain (pure grain)	$\Delta g_{ub.gr.} = \dfrac{g_{ub.gr.} \cdot 100}{g_{н}}$
	- empty grain	$\Delta g_{e.gr.} = \dfrac{g_{e.gr.} \cdot 100}{g_{н}}$
	- broken grain	$\Delta g_{b.gr.} = \dfrac{g_{b.gr.} \cdot 100}{g_{н}}$
	- other mixtures	$\Delta g_{o.m} = \dfrac{g_{o.m} \cdot 100}{g_{н}}$
	- cracked grain	$\Delta g_{c.gr.} = \dfrac{g_{c.gr.} \cdot 100}{g_{b.gr.}}$
	- external damaged grain	$\Delta g_{e.d.gr.} = \dfrac{g_{e.d.gr.} \cdot 100}{g_{b.gr.}}$
4.	Overall grain in the sample, %	$\sum g_{s.gr.} = \Delta g_{b.gr.} + \Delta g_{p.gr.}$
5.	Overall pure grain that taken during the repetition of experiment, kg	$\Delta G_{o.p.gr.} = \dfrac{g_{gr.} \cdot \sum g_{s.gr.}}{100}$
6.	Overall grain losses, kg	$\Delta g_{gr.l} = g_{fgr.} + g_{o.k.gr.} + g_{th.k.gr.}$
7.	Grain losses, %:	
	- Amount of fallen free grain on land during the threshing process	$\Delta g_{fgr.} = \dfrac{g_{f.gr.} \cdot 100}{G_{o.p.gr.} + \sum g_{gr.}}$
	- Amount of free grain that came out with pith and husk	$\Delta g_{o.k.gr.} = \dfrac{g_{o.k.gr.} \cdot 100}{G_{o.p.gr.} + \sum g_{gr.}}$
	- Amount of un-threshed grain	$\Delta g_{th.k.gr.} = -\dfrac{g_{th.k.gr.} \cdot 100}{G_{o.p.gr.} + \sum g_{gr.}}$
8.	Overall grain losses, %	$\Delta g_{gr.} = g_{fgr.} + g_{o.k.gr.} + \Delta g_{th.k.gr.}$
9.	Threshing efficiency, %	$\Pi_{o.gr.} = 100 - \Delta g_{th.k.gr.}$

During the laboratory and field experiments the work-quality indicators of the developed corn-thresher were determined by the help of important documents such as OST 70.8.13-83 "Machines for harvesting corn for grain and post-harvesting treatment corn-cob. Program and methods of testing", power indicators Tst 63.03:2001 "Testing agricultural technics. Methods power estimate" [12, 13].

The obtained results during the experiments were analyzed by counting mathematical analyzing methods, the parameters of the working units of developed corn thresher were installed at optimal positions by mathematical planning method of performed experiments.

As estimate criteria of working quality indicators of the corn-thresher we took indicators such as peeling efficiency, threshed grain, grain damaging and cleanliness as well separating efficiency of the grain from husk and pith. Counting methods and formulas of these indicators are presented in Table 1.

While overall parameters and sizes of corn-thresher were being researched, experiments were performed by five times repetition method. Before doing experiments, moisture of corn-cob as well their size-mass indicators were observed by using methodological manual SAUS (State all-union standard) 20915-2011. "Agricultural technics. Methods determination conditions experiment" [14]. In that period the diameter of the pod-corn consisted of average 39.4 mm, diameter of the pith 25.1 mm, and number of the husks on corn-cob average 6.4 pieces. The length of the pod-con was equal to average 317.07 mm, the most rate of the mass of pod-corn belonged to the grain, it consisted of 76.3 per cent, after grain pith and husk included 16.5 and 7.2 per cent respectively.

For determination peeling efficiency of the husk of pod-corn, the corn-cobs fed into corn-thresher were analyzed, un-peeled husks were separated from them and their mass quantity was defined. Then, the husks that were un-peeled by hand and they were added to the husks that peeled by corn-thresher, in this way overall mass of the husk was defined and the peeling efficiency of the husk was defined according to ratio of the percentage of husks that peeled by corn-thresher to overall mass of the husks.

3. Results and Discussions

3.1. Theoretically determination the parameters of the peeling-bars

It is a difficult process to peel the husk of the corn-cob that is fed between peeler-bars and concave through bunker of the corn-thresher (Figure 3), peeling qualitatively of husks of the corn-cob depends on width, length as well surface of the peeler-bar. According to above mentioned opinion, the sizes of the peeling-bar such as width, length and surface are demanded to determine.
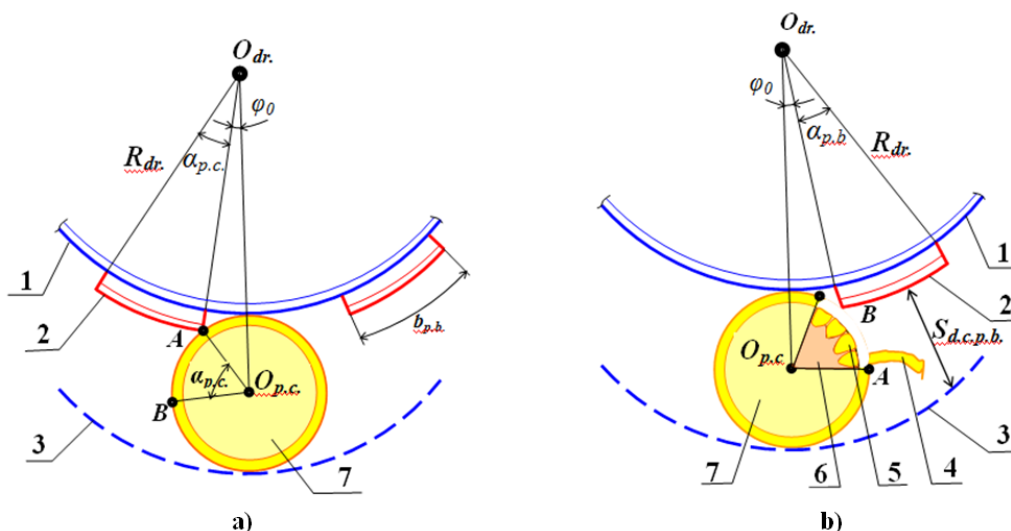

Figure-3. Determination scheme of the crashing surface of pod-corn with peeling-bar: *1-drum, 2-peeler-bar, 3-concave of drum, 4-peeled husk of the pod-corn, 5-kernel, 6-pith, 7-pod-corn*

The husks of the pod-corn covers under the 120^0 angle. For pushing toward the side or peeling of the husks of pod-corn by peeler-bars, they have to influence to the husks of the pod-corn at least 30^0 part (Figure 3, changing process from **a** situation to **b** situation).

From this situation following condition is appeared:

$$\alpha \geq \frac{\pi}{6} \tag{1}$$

It was known that from above counted expression, in threshing apparatus the moving velocity of the pod-corn is much slower than rotation velocity of peeling-bar. Therefore, pod-corn turns around self-axle to $\alpha_{p.c}$ angle that is less than $\alpha_{p.b}$ central angle of the peeling-bar during its movement. According to the difference of the velocities of pod-corn and peeling-bar $\alpha_{p.c}$ can be defined as following.

$$\alpha_{p.c.} = \frac{\alpha_{p.b.} + 2\varphi_0}{\omega_{dr.} - \omega_{r.p.c}} \cdot \omega_{p.c} \tag{2}$$

where $\omega_{dr.}$ – angular velocity of the thresher drum, rad/s;

$\omega_{r.p.c.}$ – angular velocity of the pod-corn during the rotation in threshing apparatus, rad/s;

$\omega_{p.c.}$ – angular velocity of the pod-corn to be rotating around self-axle, rad/s.

Central angle of the peeler-bar is equal to following expression:

$$\alpha_{p.b.} = \frac{b_{p.b.}}{R_{dr.}} \tag{3}$$

where $b_{p.b.}$ – width of the peeling-bar, m;

$R_{dr.}$ – radius of the thresher-drum, m.

According to (3), (2) is formed as following formula.

$$\alpha_c = \frac{\dfrac{b_{p.b.}}{R_{dr.}} + 2\varphi_0}{\omega_{dr.} - \omega_{r.p.c.}} \cdot \omega_{p.c.} \tag{4}$$

From formula (4), (1) is formed as following expression:

$$\frac{\dfrac{b_{p.b}}{R_{dr.}} + 2\varphi_0}{\omega_{dr.} - \omega_{r.p.c.}} \cdot \omega_{p.c} \geq \frac{\pi}{6} \tag{5}$$

From this condition we can define the width of the peeling-bar:

$$b_{p.b.} \geq R_{dr.} \left(\frac{\pi \left(\omega_{dr.} - \omega_{r.p.c.} \right)}{6\omega_{p.c.}} - 2\varphi_0 \right) \tag{6}$$

according to expression (6) at $R_{dr.}$=175 mm; $\omega_{dr.}$ =62,8 rad/s ва $\omega_{r.p.c.}$=14,1 rad/s; φ_0=0,047 rad $\omega_{p.c.}$=68,9 rad/s it was known that the width of the peeler-bar should be $b_{p.b.} \geq 4,8$ cm.

In threshing apparatus maximum pressing of pod-corn is as following expression:

$$h_{max} = D_{p.c} - S_{d.c.p.b.}, \tag{7}$$

Where $D_{p.c}$ – diameter of pod-corn, m;

$S_{d.p.b.c.}$ – distance between peeler-bar and concave, m.

When peeler-bar presses the pod-corn, the kernel enters into pith and halts on hard part of the pith. The next pressing causes to break the kernel. Therefore, there is limited amount of deformation of the corn-

cob $h_{l.d.}$, if it is $h_{max} > h_{l.d}$, it means that, in this situation the kernel breaks, therefore $h_{max} \leq h_{l.d}$ condition should be provided.

From this condition according to above described expression the distance between peeler-bar and concave should be as following

$$S_{d.c.p.b.} = D_{p.c.} - h_{max} \text{ ,}$$

(8)

In expression (8) if we count by using these amounts $D_{p.c.}$ = 40 mm; h_{max}=2 mm, it becomes known $S_{d.c.p.b.}$= 38 mm.

3.2. Studying experimentally the influence of the surface form of peeler-bar to work quality indicators in husk peeling zone of the corn-thresher

The sample device of the corn-thresher for laboratory was created for observing the influence of peeling-bar that has a defined surface according to performed theoretical researches to the work quality indicators of corn-thresher. During the performed experiments the rotation-frequency of the drum consisted of 600 rpm, the number of peeling-bars 6 pieces, the distance between peeling-bar and concave was changed from 36 mm to 44 mm and they were compared.

When straight tooth peeling-bar was researched by changing the distance between peeling-bar and concave from 36 mm to 44 mm, it was known that peeling efficiency of the husks of pod-corn consisted of 99.8, 99.3 and 97.2 per cent when distance between peeling-bar and concave was installed at 36, 38 and 40 mm respectively. The amount of threshed grain decreased from 97.0 per cent to 83.4 per cent; as well it was known that damaging of the grain dropped from 3.1 per cent to 1.5 per cent. However, when the distance between peeling-bar and concave increased from 42 to 44 mm, the peeling rate of the husks was observed to decrease to 96.8 and 96.2 per cent, while the grain threshing at every changing fell to 50.8 and 24.2 per cent respectively. Damaging of the grain did not occur (Table 2).

According to above used method, the sloped tooth peeling-bar was researched too. During that experiment the distance between peeling-bar and concave was changed from 36 mm to 44 mm, the peeling rate of the husks of the pod-corn became 100 per cent at the size of 36 mm of distance between peeling-bar and concave, at 38 mm this portion decreased slightly and consisted of 99.6 per cent.

Table 2. Influence of surface types of peeler-bars to work quality indicators along husk peeling zone of corn-thresher

No.	Work quality indicators, %	Distance between peeler-bar and concave of thresher drum, mm														
		straight tooth,					sloped tooth					fluted bar				
		36	38	40	42	44	36	38	40	42	44	36	38	40	42	44
1.	Husks peeling	99.8	99.3	97.2	96.8	96.2	100	99.6	98.3	97.8	96.7	100	100	99.4	98.7	98.0
2.	Threshed grain	97.0	92.4	83.4	50.8	24.2	97.0	91.8	72.3	28.9	15.0	93.8	97.4	88.1	27.1	25.9
3.	Grain damaging	3.1	2.2	1.5	0	0	2.8	0	0	0	0	7.7	2.6	0	0	0

In this conditions, the amount of threshed grain included 97.0 and 91.8 per cent respectively. Damaging of grain consisted of 2.8 per cent when the distance was installed at 36 mm, while the distances were changed from 38 mm to 44 mm grain damaging was not observed.

When the distance between sloped tooth peeler-bar and concave was installed, the rate of husk peeling decreased and constituted 98.3, 97.8 and 96.7 per cent correspondingly, as if that position of installing the threshing of the grain made up 72.3, 28.9 ва 15.0 per cent in the same order.

When the distance between fluted-bar and concave was researched by changing from 36 to 44 mm, while the distance between peeler-bar and concave changed to 36 mm and 38 mm, it was defined that the husks of the pod-corn was peeled completely, grain threshing rose from 93.8 to 97.4 per cent, grain damaging decreased from 7.7 to 2.6 per cent. However, when the distance between peeling-bar and concave became

40, 42 and 44 mm, the peeling rate of the husks was observed to decrease to 98.0 per cent, while the grain threshing fell to 25.9 per cent. Damaging phenomenon of the grain was not observed.

According to performed theoretical and experimental researches the technological scheme (fig.4) and experimental sample (fig.5) of the corn-thresher were produced. The corn-thresher has following dimensions of: length – 1900 mm; width – 1600 mm; height – 1100 mm [15].

The corn-thresher machine consists of: bunker (1), peeler-bar (2), rotary thresher-drum (3), electric motor (4), grain-auger (5), concave of thresher-drum (6), rasp-bar (7), wheel (8), bottom part of grain-auger (9), sieve-gutter (10), sieve (11), elevator (12), outlet of pith and husk (13), caster-bar (14).
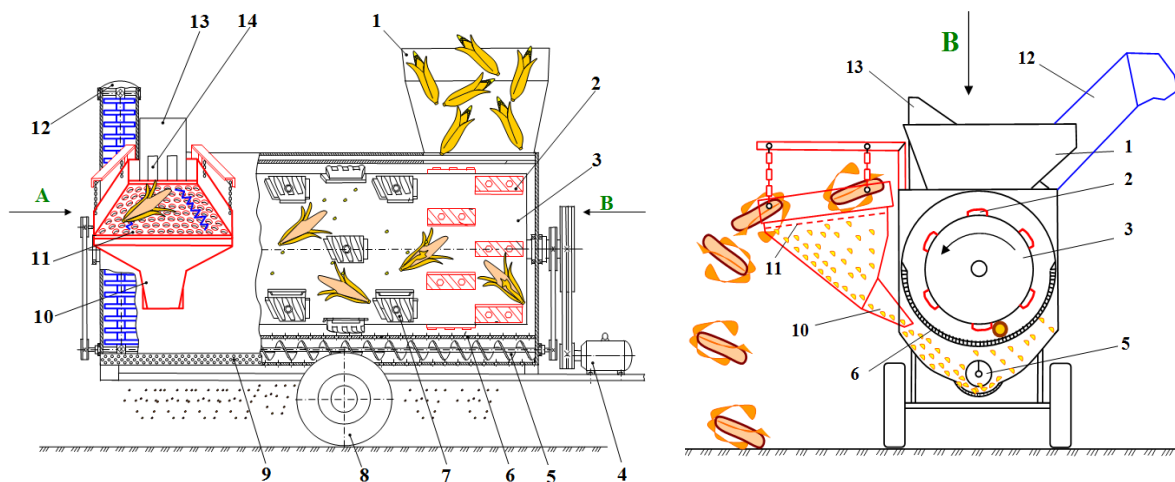

Figure 4. Technological scheme of the corn-thresher

Figure 5. Experimental sample of the corn-thresher

The technological process of the corn-thresher is proceeded in the following manner: The pod-corns are fed to the rotary thresher drum (3) through receiving bunker (1), rotary thresher drum pulls of pod-corn through concave (6) and drum, then the husk is peeled from pod-corn by the help of peeler-bar (2) and the ear-corn are threshed by the help of rasp-bar thresher (7) the rasp-bar threshers were installed on the surface of the rotary drum, the rasp-bar threshers influence mechanically to the ear-corn and thresh along

axis. Then the threshed grains are separated through apertures concave (6) and the separated grains fall on the auger (5), and the auger pushes the grain toward elevator (12) then the grain is unloaded by the elevator in to sack or on a transport vehicle. The separated pith and husk also joined a few quantity un-separated grains together come out from the outlet of pith-husk (13) by the help of the caster bar (14) and they arrived on the surface of sieve (11) the grains are separated by the help of sieve and fall through a sieve-gutter (10) again on the auger (5) it sends the grain toward elevator (12) and the grains are unloaded by the elevator in to sack or on a transport vehicle joining to real mass, the smaller mixtures than grain fall on the land through holes of the bottom part of grain-auger (9). The corn-thresher is moved by the electric motor (2) or a cardan shaft of tractor.

According to above shown technological scheme (Figure 4) of corn-thresher the experimental sample (Figure 5) was prepared it and researched in field testing by many repetitions. Husk peeling efficiency, grain cleanliness and losses as well grain damaging and threshing efficiency were observed of depending on parameters and work regimes of the corn-thresher. The pod-corn was fed 10 kg every experiment into corn-thresher.

The results that achieved during the experiment were analyzed mathematical statistically for determination work quality indicators of the corn-thresher. In table 3 the work quality indicators of the developed corn-thresher are presented that defined during the experiments.

During the experiment of the developed corn-thresher the rate of husk peeling efficiency consisted of 99.8 per cent, while grain threshing-separating efficiency included 99.6 per cent, grain damaging 0.1 per cent, grain cleanliness 99.5 per cent, grain losses 0.6 per cent. These indicators satisfy primary demands.

Table 3. Work quality indicators of the developed corn-thresher

No.	Name of indicators	Amount of indicators	
		In experimental period	According to primary demands
1.	husk peeling efficiency, %	99.8	-
2.	grain threshing-separating efficiency, %	99.6	higher than 99 %
3.	grain damaging, %	0.1	no more than 2 %
4.	grain cleanliness, %	99.5	at least 97%
5.	grain losses, %	0.6	no more than 1%
6.	power use, kW	5.0	-

4. Conclusions

The results of performed research showed that according to theoretical count width of the peeler-bar should be bigger or equal than 4.8 cm ($b_p \geq 4.8$ cm) while the distance between peeler-bar and concave is equal to 38 mm ($S_c = 38$). These indicators were proved to be suitable and depend on the experimental research. Namely, the peeling rate of the husk of pod-corn and grain threshing opportunity by the straight tooth and fluted bars were higher than sloped tooth peeling-bar. However, grain damaging by the straight tooth and fluted bars consisted of more level than sloped tooth peeling-bar. When the distance between sloped tooth peeling-bar and concave became 38-40 mm, we achieved peeling husk well, also qualitative grain threshing and the most attentive result is that any grain was not damaged.

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