Extraction of grains from ears of grain crops by grinding when opposite moving the conveyor and deck

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Abstract. When combine harvesters work, about half of the engine power is spent on extracting grain from ears of grain crops. The high energy costs for extracting grain from ears are due to the need to drag straw through a threshing device, the small displacement between the drum or rotor and deck, as well as to extract grain from ears of grain crops mainly by impact. Upon impact, grain damage also occurs. Therefore, the task was to develop a combine harvester that extracts grains from the ears of grain crops by grinding. For modeling, the assumption was made that the spike fell on the deck, after which it was clamped between the working branch of the conveyor and the deck strictly perpendicular to the direction of movement of the conveyor branch. The conveyor belt moves uniformly, and the deck oscillates. The movement of the conveyor and deck from the initial position is considered in the opposite direction. To efficiently remove single grains from the ears, when the conveyor belt and deck are moved in opposite directions, it must rotate 360°. As a result of the simulation, the kinematic parameters of the process were detected during the opposite movement of the conveyor and deck. The following are determined: the speed of the belt of the upper conveyor, the angular speed of the drive shaft of the upper conveyor, the period of oscillation of the deck, the movement and the angle of rotation of the ear located between the working branch of the conveyor and the deck, when they are counter-moving. The simulation will then allow us to consider the movement of the ear during the movement of the conveyor and deck from the starting position and, based on the calculations, to identify the structural and kinematic parameters of the conveyor and deck.

1. Introduction
When combine harvesters work, about half of the engine power is spent on extracting grain from ears of grain crops [1-5]. The large energy costs for extracting grain from ears are caused by the need to drag straw through a threshing device, the small displacement between the drum or rotor and deck, as well
as the extraction of grain from ears of grain crops mainly by impact [6,8,11]. On impact, grain damage also occurs [7,9,10]. Therefore, the task was to develop a combine harvester that extracts grains from the ears of grain crops by grinding.

Attempts to create such a combine harvester, undertaken earlier, were unsuccessful due to the lack of the theory of extracting grains from ears of grain crops by grinding [12,14,15,16]. To create a theory of grain extraction by grinding, it is necessary to simulate the process [13,17,18,19,20]. The upper part of the triticale “Tornado” with an ear is taken for the modeling process. The average grain size of this crop is $2 \times 3 \times 8$ mm. The number of grains in the triticale ear is from 50 to 90.

2. Methodology and results of theoretical research

When the ear falls on the deck, it is clamped between the working branch of the upper conveyor and the deck [10] strictly perpendicular to the direction of movement of the branch of the upper conveyor (figure 1).

In a top view, grains in an ear are arranged in six rows. Let us combine the center of the ear with the picket “initial position” and designate the corner points of the ear as $A, B, C, D, E, F$. The ribbon of the upper conveyor moves uniformly (to the right in the figure 1). The deck can be motionless or oscillate. Let us consider the option in which the deck oscillates. Assume that the deck, making fluctuations, began to move counterclockwise (to the left in the figure 1). An ear will roll between the working branch of the upper conveyor and the deck. The distance between the belt of the upper conveyor and the deck is assumed to be constant, equal to the thickness of the ear. Moving the conveyor belt and deck oppositely, we analyze the movement of the ear.

In order to efficiently remove the grains from the ears, when the belt of the upper conveyor and the deck are moved in the opposite direction, it must make a revolution, that is, to turn at least $360^\circ$. Assume that the ear does not crumple, then it will rotate relative to points $D, C, B \ldots$ from one position to another (figure 2). We will determine from the figure the angles of rotation of the ear from one position to another and the movement of the center of the ear.

The movement of the spike when it is rotated $360^\circ$ will be 44.94 mm. Accordingly, in stages $7.21+8.05+7.21+7.21+8.05+7.21$. From the figure, the rotation angles at stages are $59.78^\circ+60.44^\circ+59.78^\circ+59.78^\circ+60.44^\circ+59.78^\circ$.
From figure 3 we will determine the total movement of the belt of the upper conveyor and deck when moving in the opposite direction and with the 360° rotation of the ear.

![Figure 3](image-url)

**Figure 3.** The total movement of the belt of the upper conveyor and deck when moving in the opposite direction.

From the figure, the total movement of the belt of the upper conveyor and the deck in the opposite direction $14.4+16.1+14.4+14.4+16.1+14.4 = 89.8$ mm.

When moving in the opposite direction, the total movement $s_b$ of the working branch of the upper conveyor and deck is:

$$s_b = s_c + s_d,$$  \hspace{1cm} (1)

where $s_c$ – movement of the working branch of the upper conveyor; $s_d$ – movement of the deck.

From the structural layout [10] we take the amplitude of the deck oscillations $A_d = s_d = 60$ mm. The movement of the deck when moving in the opposite direction should exceed the movement of the belt of the upper conveyor, so that in the case of passing motion the ear rotates in the opposite direction to the greatest possible angle for quick extraction of grains from the ear [5,6]. Then the movement of the belt of the upper convey or $s_c$ is half of the period of oscillation of the deck:

$$s_c = 0.5A_d,$$  \hspace{1cm} (2)

$s_c = 30$ mm; $s_b = 90$ mm.

The speed of movement of ears in the space between the working branch of the upper conveyor and the deck should be at least twice the speed of movement of the working branch of the inclined conveyor, otherwise the upper parts of the plants will accumulate in front of the upper conveyor and deck: $v_{uc} \geq v_c; v_{uc} \geq 1.66$ m/s.

The belt speed of the upper conveyor:

$$v_{uc} = \frac{s_c}{\tau_{d,0.5}},$$  \hspace{1cm} (3)

where $\tau_{d,0.5}$ – is the half of the deck oscillation period.

If $v_{uc} = 1.66$ m/s, then the half deck oscillation period is:

$$\tau_{d,0.5} = \frac{s_c}{v_c}; \tau_{d,0.5} = 0.018 \text{ s},$$

and the deck oscillation period $\tau_d = 0.036 \text{ s}$.

The angular speed of the drive shaft of the upper conveyor:

$$\omega_{uc} = \frac{v_{uc}}{r_{uc}},$$

where $r_{uc}$ – the radius of the drive shaft of the upper conveyor; we will accept $r_{uc} = 0.05$ m.

$$\omega_{uc} = \frac{1.66}{0.05} = 33.2 \text{ rad/s}.$$  

Movement of the working branch of the conveyor at any time $t$:

$$s_c = 1.66t.$$  \hspace{1cm} (4)
and the average ratio of the angle of rotation of the ear $\varphi$ and the movement of the working branch of the conveyor:

$$\varphi = 12s_c,$$

as $360 \div 30 = 12$ deg/mm.

We will accept the crank drive of the deck [2]. Since the ear makes a full revolution in half a turn of the crank, on average for half of the deck oscillation period $\alpha = 2\varphi$, or

$$\alpha = 6s_c.$$

where $\alpha$ – crank angle (figure 4).

The movement of the deck at any time can be determined from figure 4. Semicircle radius $r = 30$ mm, equal to half of the deck movement.

![Figure 4](image)

Figure 4. Scheme for determining the movement of the deck.

Deck movement

$$s_d = r(1 - \cos \alpha),$$

or for the construction in question

$$s_d = 0.03(1 - \cos \alpha).$$

Half of the deck oscillation period $t_d_{0.5} = 0.018$ s, and the period of time the deck moves from one position to another

$$t = \frac{t_d_{0.5}\alpha}{180^\circ},$$

or for the construction in question

$$\alpha = 9997t;$$

$$s_d = 0.03(1 - \cos 9997t).$$

![Figure 5](image)

Figure 5. The ear in position 1 when the working branch of the conveyor and the deck move in the opposite direction.
At the stage of rotation of the ear from the initial position to position 1 (figure 5), the movement of the working branch of the upper conveyor and deck when moving in the opposite direction $s_b = 14.4$ mm.

We have a system of equations:

\[
\begin{align*}
    s_c &= 1.66t \\
    s_d &= 0.03(1 - \cos 9997t) \\
    s_c + s_d &= 0.0144.
\end{align*}
\]

Hence $t_{0-1} = 0.004$ s; $s_c = 6.8$ mm; $s_d = 7.4$ mm; $\alpha \approx 41.2^\circ$. Ear movement when the upper conveyor and the deck move in the opposite direction $s_e = -0.41$ mm, angle of rotation of the ear $\varphi = 59.78^\circ$.

Carrying out similar constructions and calculations, we will obtain at the stage of rotation of the ear from position 1 to position 2 the total movement of the working branch of the conveyor and deck $s_b = 30.5$ mm, $t_{0-2} = 0.0068$ s; $s_c = 11.3$ mm; $s_d = 18.8$ mm; $\alpha \approx 68.1^\circ$, ear movement $s_e = -3.97$ mm, $\varphi = 120.21^\circ$. At the stage of rotation of the ear to position 3: $s_b = 44.9$ mm, $t_{0-3} = 0.009$ s; $s_c = 15$ mm; $s_d = 30$ mm; $\alpha = 90^\circ$, $s_e = -7.49$ mm, $\varphi = 180^\circ$. At the stage of rotation of the ear to position 4: $s_b = 59.3$ mm, $t_{0-4} = 0.0112$ s; $s_c = 18.7$ mm; $s_d = 41.2$ mm; $\alpha = 111.9^\circ$, $s_e = -11$ mm, $\varphi = 239.78^\circ$. At the stage of rotation of the ear to position 5: $s_b = 75.4$ mm, $t_{0-5} = 0.0139$ s; $s_c = 23.8$ mm; $s_d = 52.6$ mm; $\alpha = 138.8^\circ$, $s_e = -13.93$ mm, $\varphi = 300.21^\circ$.

3. Discussion
The use of modeling of the extraction of grains from ears of grain crops by grinding allowed us to calculate the kinematic parameters of the process.

The modeling will also allow us to consider the movement of the ear during the opposite movement of the conveyor and the deck and, based on the calculations, to identify the structural and kinematic parameters of the conveyor and deck.

4. Conclusion
In order to reduce engine power spent on extracting grain from ears of the grain crops, as well as to reduce damage to the extracted grains, it is proposed to carry out this process by grinding.

For this, an appropriate theoretical model was developed that allows simulating the process of extracting grains. The upper part of the triticale “Tornado” with an ear is taken as a model. During the simulation, the most difficult conditions for the implementation of the technological process were considered, under which it was believed that the ear fell on the deck, after which it was clamped between the working branch of the conveyor and the deck strictly perpendicular to the direction of movement of the conveyor branch. It was taken into account that the conveyor belt moves uniformly, and the deck oscillates, while their relative movement is opposite, and the grain of the ear rotates at least 360°.

As a result of modeling, kinematic parameters of the process are revealed. So, when the conveyor and deck move in opposite directions, the following are determined: the belt speed of the upper conveyor, which should be less than 1.66 m/s, the angular velocity of the drive shaft of the upper conveyor – 33.2 rad/s, the oscillation period of the deck – 0.036 s, and also the movement and spike rotation angle for 6 calculated positions. The data of the results of theoretical calculations will allow the analysis of the structural and kinematic parameters of the conveyor and deck, their selection and optimization based on subsequent power parameters.

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