Determination of stripping zones and axle spacing between the cylinders in two-cylinder stripping reaper (header)

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Abstract. Stripping devices become an alternative to harvester-threshers in the harvesting season. The research objective is improvement of harvesting operations, including the introduction of the method of soya stripping. The research showed that the use of a single-cylinder stripping device was not optimal, for harvesting losses exceeded agricultural norms. It was decided to use a two-cylinder scheme. The implementation of this design solution reduced the grain loss rate, but still it was not enough to achieve compliance with the requirements of classical soybean harvesting. For high-quality soybean stripping, it is necessary to calculate the zones of stripping and axle spacing between the first and second stripping cylinders, as well as the profile of the stripping combs. Schemes presented are calculation of the stripping zones and determination of the axle spacing between the cylinders, taking into account their positional relationship in the stripping reaper.

1. Introduction
When studying the possibility of stripping of agricultural plants, morphological features of the structure of stems and productive parts are of particular importance. The research [1] considers eccentric swinging stripping device for harvesting the ground cherry C. humilis. The results of the experiment with 3 factors showed that the optimal values of the selected parameters are: rotation speed of 11.26 rpm, feed rate of 0.227 m/s and comb turning angle of 5°. The rate of fruit gathering and damage amounted to 95.21% and 4.56%, respectively.

The research is carried out into improvement of the efficiency and reduction in damage during harvesting of L. barbarum [2] by developing a portable vibro-comber type brush harvester. The analyses of the findings showed the best ratio of the selected parameters: the speed of rotation of the comber type brush – 64.52 rpm, the speed of rotation of the cylinder-29.68 rpm, the style of the comber type brush-II. The results of field experiments showed that the completeness of the gathering amounted to 89.12%, and the damage rate - 6.24%.

The research paper presents the findings of investigations on the development and substantiation of the parameters and modes of operation of the working bodies of the machine for harvesting seeds of forage grasses [3]. Analytical dependences that characterize the capture conditions and the length of the ridges were found, and the coefficient of influence of ridges on the ears of plant stems was determined.
The article [4] provides the theoretical justification for the optimal layout of the stripping device for harvesting grain crops; the parameters of the stripping combs; substantiation of their height, width of the gap between the combs and optimal slope of the combs.

When analyzing foreign sources, special attention should be paid to the fact that the problem of crops stripping (in particular legumes) is poorly studied. Basically, the improvement of soybean harvesting consists in the following: creating a mathematical model for estimating the loss of soybean seed yield depending on the changing height of the cut, used for harvesting, and sowing density [5]. Series of field tests were conducted to study the influence of various key operating parameters on the quality of soybean harvesting, and an attempt was made to systematically determine the optimal combination of parameters [6].

The comparison of soybean harvesting was carried out between different cultivation systems that depend on the height of the lower bean attachment and the length of the plant [7]; to improve the quality of the harvesting process, the quality of soybean harvesting was assessed using combine harvesters with different reapers and rates of movement [8]. The main mechanical properties of green soybean seeds and beans were studied (elastic modulus of various parts of green soybean seeds, bean envelope, bean, Poisson's ratio of seeds) [9]; the physical and physiological properties of soybean seeds were assessed at three rates of movement of the combine harvester using statistical control over the technological process [10].

The shape of the comb used for grain crops stripping is not suitable for soybean stripping. A special feature of soybean plants is that the beans are located along the entire height of the plant, starting from 8 to 12 cm from the field surface. In plants of grain crops (wheat), the ear is weakly attached to the stem at the upper point and is easily stripped with a comb and carried away by the air flow created by the stripping cylinder. Losses during harvesting of soybeans by the stripping method amount to 12 - 18 % on average. The main problem is the impact of the stripping comb on the soybean, which leads to its opening and flight of the lower beans and grains of the plant forward in the direction of movement.

**The purpose of the research** is to determine the stripping zones for soybean stripping with the help of cylinders, to determine axle spacing between cylinders in the two-cylinder reaper (header).

2. Materials and methods
The goal was achieved using a mathematical tool, using trigonometric formulas, which, in comparison with the use of the graphical method, eliminates calculation errors.

3. Results
It is necessary to determine the lower level of stripping of soybean stalk with cylinders of the stripping header (reaper).

When designing two-cylinder reaper, it is necessary to determine the diameter and positional relationship of the cylinders. One of the criteria is the height of stripping with the first (upper) cylinder, which owing to ΔH does not coincide with the lower point of the radius of the stripping combs along the surface normal (figure 1).

To determine the parameter ΔH, we use figure 2, where CD is the plant stalk, r is the radius of the cylinder (the minimum radius for the separation of soy beans), and R is the radius of the stripping cylinder at the ends of the stripping combs.

Forward movement of the stripping cylinder: from right to left, rotation – clockwise. The position of the CD stem is the extreme vertical; in this position the section A₂A₃ shall be combed. The stem passes through the lower point B₂ of the stripping cylinder in the position C₁D₁ at the angle β.

Let us compare the vertical position of points A₂ and B₂:

\[ B₁B₂ = R − R \cdot \sin \alpha = R(1 − \sin \alpha) \]  

(1)

where \( \alpha = \arccos(\frac{r}{R}) \);
when the ratio is \( r/R = 0.75; \ \alpha = 41.4°; \ B₁B₂ = 0.339R; \)
when the ratio is $r/R = 0.5; \alpha = 60^\circ; B_1B_2 = 0.134R$; when the ratio is $r/R = 0.25; \alpha = 75.5^\circ; B_1B_2 = 0.032R$

We find the lower point of combing with the help of the first (upper) cylinder using the analytical method (figure 2).

**Figure 1.** Scheme for determining the zones of the upper and lower cylinders

**Figure 2.** Diagram for the determination of $\Delta N$
We consider the triangle $\triangle AOA_2$: $OA = r$, $OA_2 = R$. By increasing the angle $\alpha$ with a certain step up to $90^\circ$, the triangle $\triangle AOA_2$ will be transformed and at $\alpha=90^\circ$ it will take the position of the triangle $\triangle AOB_2$.

We consider two intermediate arbitrary positions of the triangle $\triangle AOA'_2$ and $\triangle AOA''_2$. Using the cosine theorem, we find the distances $AA'_2$ and $AA''_2$:

$$AA'_2 = \sqrt{r^2 + R^2 - 2rR \cdot \cos \alpha'}$$  \hspace{1cm} (2)

$$AA''_2 = \sqrt{r^2 + R^2 - 2rR \cdot \cos \alpha''}.$$  \hspace{1cm} (3)

We consider the triangle $\triangle AA'_2A''_2$.

Considering the arc $A'_2A''_2$ to be a line segment with a certain assumption, its magnitude is determined by the formula:

$$A'_2A''_2 = \frac{\pi R}{180} \cdot (\alpha' - \alpha'').$$  \hspace{1cm} (4)

Using the theorem of cosines, we find angle $\angle AA'_2A''_2$:

$$\angle AA'_2A''_2 = \arccos\left[\left(\frac{AA'_2}{2}\right)^2 + \left(\frac{AA''_2}{2}\right)^2 - \left(\frac{A'_2A''_2}{2}\right)^2\right]/2\left(\frac{AA'_2}{2}\right) \cdot \left(\frac{AA''_2}{2}\right).$$  \hspace{1cm} (5)

Using the above formulas, changing the angle $\alpha$ and taking into account that $\angle AA'_2A''_2$ is an increment of the angle $\beta$, we find that for the variant $R = 150$ mm, $r = 75$ mm, the angle $\beta$ changes from $63,44^\circ$, $AA_2$ – from $167,71$ to $129,9$ mm, and $\Delta AA_2$ respectively $37,81 \div 0$ mm.

Let's determine where the point $A_2$ (the lower point of combing of the stem in the CD position) will move when the stem position is $C_1D_1$. The movement of the stem relative to the original position can be described by two movements: rotation relative to point $A$ and linear movement of point $A_2$ along the line $C_1D_1$.

The diagonal $AB_2$ is equal to:

$$AB_2 = \sqrt{r^2 + R^2}$$  \hspace{1cm} (6)

$$\beta = \arctg \frac{R}{r}. $$  \hspace{1cm} (7)

The distance $AA'_2$ is:

$$AA'_2 = R \cdot \sin \alpha + H_0 \left(\frac{1}{\sin \beta} - 1\right)$$  \hspace{1cm} (8)

where $AA'_2$ is the position of point $A_2$ on $C_1D_1$.

$H_0 \left(\frac{1}{\sin \beta} - 1\right)$ – travel x (figure 3)

$$x = \frac{H_0}{\sin \beta} - H_0 = H_0\left(\frac{1}{\sin \beta} - 1\right)$$  \hspace{1cm} (9)
We compare $AB_2$ and $AA_2'$. Set $R = 150$ mm, $r = 75$ mm, $H_0 = 550$ mm: $r/R = 0.5$; $\beta = 63.43^\circ$; $AB_2 = 167.7$ mm; $AA_2' = 194.4$ mm; $AA_2' > AB_2$, i.e. the combed part of the stem is below the point $B_2$.

Thus, when the stripping cylinder approaches the field surface, the maximum combing will tend to occur at the lower point of the cylinder $B_2$, and when this distance increases - at the point $A_2$ of the vertically standing stem (figure 2). The figure shows that due to the inclination of the stem, the lower level of the main cylinder and the height $h$ of the combs above the field surface do not coincide.

The lower level of combing $h$ with the help of the main cylinder is determined by the formula (10):

$$h_{\text{comb}} = \frac{h}{\sin \beta} = \frac{h}{\sin(\arctg \frac{R}{r})}. \quad (10)$$

To determine the position of the main cylinder above the surface of the field in accordance with a given lower level of the combing associated with the location of the lower beans on the plant stem, use the formula (11):

$$h = h_{\text{comb}} \sin \beta = h_{\text{comb}} \sin \left( \arctg \left( \frac{R}{r} \right) \right). \quad (11)$$

Using formulas (5) and (9), setting the step of changing the angle $\alpha$ in $2^\circ$, for $H_0 = 550$ mm, we make table 1.

The numbers in the first column of table 1 show the increase in amount of combing, by turning the combed plant on the angle $\beta$ and the second column is the reduction in the combing due to the "pulling" of the stem. The value of their difference will show the value of the additional stem combing against the stem combing in the vertical position.

Numbers with negative values indicate that the part of the stem that is combed in a vertical position, at these angles of inclination of the stem, is outside the outer radius of the combs of the combing drum. The maximum difference adds the largest amount of combing to the combing of the stem in an upright position. In this case, the maximum combing will be $129.90 + 5.49 = 135.49$ mm with the angle of inclination of the stem of about $82^\circ$ (table 1).
Table 1. The value of additional combing.

| Angle $\beta$, ° | Increasing the combing by turning $\Delta AA_2$, mm | Reduction of combing due to «pulling» $x$, mm | Difference, mm |
|------------------|-----------------------------------------------|---------------------------------------------|----------------|
| 63.44            | 37.81                                         | 64.90                                       | -27.09         |
| 65.05            | 35.45                                         | 56.65                                       | -21.20         |
| 66.68            | 33.06                                         | 48.95                                       | -15.83         |
| 68.32            | 30.64                                         | 41.80                                       | -11.16         |
| 69.98            | 28.19                                         | 35.20                                       | -7.01          |
| 71.67            | 25.72                                         | 29.15                                       | -3.43          |
| 73.38            | 23.22                                         | 24.20                                       | -0.98          |
| 75.11            | 20.70                                         | 19.25                                       | 1.45           |
| 76.87            | 18.16                                         | 14.85                                       | 3.31           |
| 78.65            | 15.61                                         | 11.00                                       | 4.61           |
| 80.46            | 13.03                                         | 7.70                                        | 5.33           |
| 82.30            | 10.44                                         | 4.95                                        | 5.49           |
| 84.17            | 7.84                                          | 2.75                                        | 5.09           |
| 86.08            | 5.24                                          | 1.10                                        | 4.14           |
| 88.02            | 2.62                                          | 0.55                                        | 2.07           |
| 90               | 0                                             | 0                                           | 0              |

In further calculations, it is necessary to determine the axle spacing in the two-cylinder header.

The presented scheme allows you to calculate the distance of installation of stripping cylinders for high-quality soybean combing. For reasons of minimizing losses and improving the composition of the combed soy grain heap, the upper cylinder combs the tops of plants, about 1/3 of the stem (the height from the field surface to the stripping combs is 40 – 60 cm, depending on the height of the stem), the lower cylinder - 2/3 of the stem.

In this case, the angle of inclination of the stem will be $\alpha = \arcsin \left( \frac{2}{3} \right)$, or about 42°, which does not exceed the angle of bent fracture of the stem, equal to about 20°, obtained experimentally. We accept the condition that the stalk after combing with the help of the first cylinder should take a vertical position before combing with the second cylinder. On the basis of this, we consider the diagram (figure 4).

![Figure 4. Diagram for determining the axle spacing between the stripping cylinders: l – height of the soybean stalk; $H_{01}$ – height of the first stripping cylinder; $H_{02}$ – height of the second stripping cylinder; $O_1$ – center of the first stripping cylinder; $O_2$ – center of the second stripping cylinder; $R_1$ – radius of the first stripping cylinder; $R_2$ – radius of the second stripping cylinder; $a$ – axle spacing; $h$ – distance from the combs of the second stripping cylinder to the field surface]
We consider the triangle $\text{AO}_1\text{O}_2$, the angle and adjacent angles.

We determine the angles:

$$\xi = \arctg \frac{H_{02}}{R_2} = \arctg \left( \frac{h}{R_2} + 1 \right)$$  \hfill (12)

$$\lambda = \arcsin \frac{H_{01}}{l + R_1} = \arcsin \left( \frac{1 - R_1}{l + R_1} \right)$$  \hfill (13)

$$\mu = 180^\circ - \xi - \lambda$$ \hfill (14)

We determine the angle of inclination of the $\delta$ plane passing through the axes of the cylinders to the field surface at the maximum value of the stem height $l_{\text{max}}$:

$$\delta = \arcsin \frac{O_1B}{a} = \arcsin \frac{H_{01} - H_{02}}{a}.$$ \hfill (15)

The angle $\theta = \xi + \delta$

We consider an arbitrary triangle $\text{AO}_1'\text{O}_2$, where the point $O_1'$ lies on the line $\text{O}_1\text{O}_2$.

We determine the dependence of the axle spacing with the help of the cosine theorem:

$$O_1'A = \sqrt{AO_2^2 + O_1'O_2^2 - 2(AO_2)(O_1'O_2)\cos \theta}.$$ \hfill (16)

Denoting $O_1'A = l + R_1$, $AO_2 = \frac{R_2}{\cos \xi} = C$, $O_1'O_2 = a = y$, we square both parts of the equation and get the reduced form of a quadratic equation.

The real root of the equation or substituting values:

$$y^2 - Dy + E = 0$$

where $2C \cdot \cos \theta = D$,

$$[C^2 - (l + R_1)^2] = E.$$  \hfill (17)

Real root of the equation:

$$y_1 = \frac{D}{2} + \sqrt{\left(\frac{D}{2}\right)^2 - E}.$$  \hfill (17)

Or substituting the value:

$$a = C \cdot \cos \theta + \sqrt{[C^2 \cdot \cos^2 \theta - C^2 + (l + R_1)^2]}. \hfill (18)$$

4. Discussion

Taking the values $R_1 = 175$ mm (at the ends of the combs), $R_2 = 330$ mm, $H_{01} = 850$ mm, $H_{02} = 350$ mm, $l_{\text{max}} = 1000$ mm, $l_{\text{min}} = 600$ mm, we get the maximum and minimum axle spacing $y_{\text{max}} = 1400$ mm, $y_{\text{min}} = 800$ mm.

Thus, in a two-cylinder reaper, when adjusting the axle spacing along the $O_1\text{O}_2$ line for the radii of the stripping cylinders and plant heights set by us, the adjustment range should be at least 600 mm.

When calculating the diameter of the main (second) stripping cylinder, initially taken as $2/3$ of the length of the stem, it is necessary to make a clarifying calculation to comply with the following inequality:

$$H_{02} + R_2 \sin \alpha \geq H_{01} - R_1 + \Delta H.$$  \hfill (19)
where \( H_{01} \) and \( H_{02} \) – heights of the axes of the corresponding cylinders relative to the field surface, \( R_1 \) and \( R_2 \) – radii of the stripping cylinders at the ends of the combs, \( \alpha \) is from the diagram in figure 2, where \( \alpha = \arccos \left( \frac{r}{R} \right) \), \( \Delta H \) - difference between the lower point of the upper (first) cylinder and the level of the stem combing of the upper cylinder (figure 1), determined by the above method. If there is nonfulfillment of this inequation, the cylinder diameter must be adjusted.

5. Conclusion
Using the presented formulas and calculation methods, it is possible to determine the diameters and axle spacing of two-cylinder reapers for stripping soya of various varieties having certain morphological features.

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