

Constructive and kinematics parameters of the picking device of blueberry harvester

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Abstract. The article focuses on the selection of constructive and kinematics parameters of the picking device intended for picking lowbush blueberry, cultivated on milled peat fields. The constructive parameters of the picking device are reel radius, the height of the picking device's axis of rotation from the ground, the number of picking rakes (or the displacement angle of neighbouring rakes) and the angle of inclination of rake teeth in relation to the upward direction. The kinematics parameters include the angular speed of the picking reel, the machine velocity and the kinematics number.

Key words: agricultural engineering, blueberry harvester, picking reel, constructive and kinematics parameters.

INTRODUCTION

Lowbush blueberries, the height of which is between 10...60 cm depending on the variety and the berries of which ripen more or less at the same time (Starast et. al, 2005; Strik, 2009), could be harvested most reasonably with a machine, where the functional working unit is a drum or a picking reel (Olt & Käis, 2006). Picking rake contains teeth attached to the axis of rotation (Olt & Arak, 2012). Blueberries do not ripen after harvesting and therefore the berries have to be picked at their full maturity (Albert et al., 2009). Ripened blueberries do not defoliate easily and could thus stay on the bush ca 10 days when ripened (Starast et. al, 2009).

The principle layout of the blueberry harvester has been presented in Fig. 1. It is the so-called rough harvester, i.e. the additives of the blueberry harvester (leaves, pieces of stems and peat, etc) and bruised berries are not separated from the berry mixture. Thus, the technological operations of the blueberry harvester comprise removing the berries harmlessly from the stems and collecting the berries into berry boxes or containers, meant for handling.

Picking reel 3 contains picking rakes 12 that have been attached to the axes between side discs; rake teeth 13 have been rigidly attached to the picking rakes. Berries are separated from the stems with the help of rake teeth 13 that are put into motion through the blueberry stems. The diameter of the rake teeth 13 is 5 mm and their interval from each other on the picking rake 6 is 8 mm.

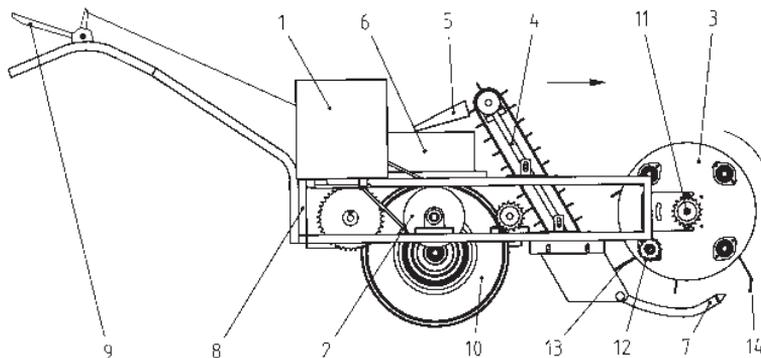


Figure 1. Main assemblies and parts of a motoblock-type harvester (Patent EE05488 B1): 1 – engine, 2 – power transmission elements, 3 – picking reel, 4 – conveyor, 5 – chute, 6 – berry box, 7 – copying unit, 8 – frame, 9 – steering levers, 10 – wheels, 11 – reel shaft, 12 – picking rake, 13 – rake tooth, 14 – hook spring-tine.

MATERIALS AND METHODS

The article studies the constructive parameters of the picking reel of the blueberry harvester: radius r_A , the height of the picking reel shaft from the ground H , (Fig. 2) the number of picking rakes z (or the angle of displacement of neighbouring rakes) and the angle of inclination of the rake teeth of the picking rake γ in relation to the vertical direction, as well as the angular speed of the kinematic parameters' picking reel ω_r , velocity of the machine v_m , and the selection principles of the kinematic indication number λ .

The picking reel 3 is a parallelogram reel, which is characterised by the fact that the rake tooth 13 of the picking rake 12 is located with a permanent (constant) rake angle toward the ground, and, thus, the following condition has to be followed

$$|\omega_r| = |\omega_p|, \quad (1)$$

where: ω_r – the angular speed of the picking reel 3; ω_p – the angular speed of the picking rake 12.

The rake angle γ of the rake teeth 13 of the picking rake 12 can be changed according to need.

The picking rake 12 participates in unitary movement: linear moving with the machine and rotary relative movement around the horizontal axis. According to the scheme presented in Fig. 2, the coordinates of point B, the free tip of the rake teeth of the picking reel are expressed as follows:

$$x(t) = v_m t + r_A \cdot \cos \varphi - l_p \sin \gamma; \quad (2)$$

$$y(t) = 0; \quad (3)$$

$$z(t) = -r_A \cdot \sin \varphi - l_p \cos \gamma; \quad (4)$$

where: v_m – speed of the blueberry harvester; r_A – radius of the picking reel 3 (the distance of the centre-axle A of the picking rake from the axis of rotation O of the picking reel); $\varphi = \omega_r t$ – angle of rotation of the picking reel; ω_r – angular speed of the picking reel; γ – rake angle of the picking rake teeth; $\gamma = \text{const}$; β – the angle characterising the position of the picking rake; $\beta \neq \text{const}$; l_p – length of the picking rake teeth; t – time.

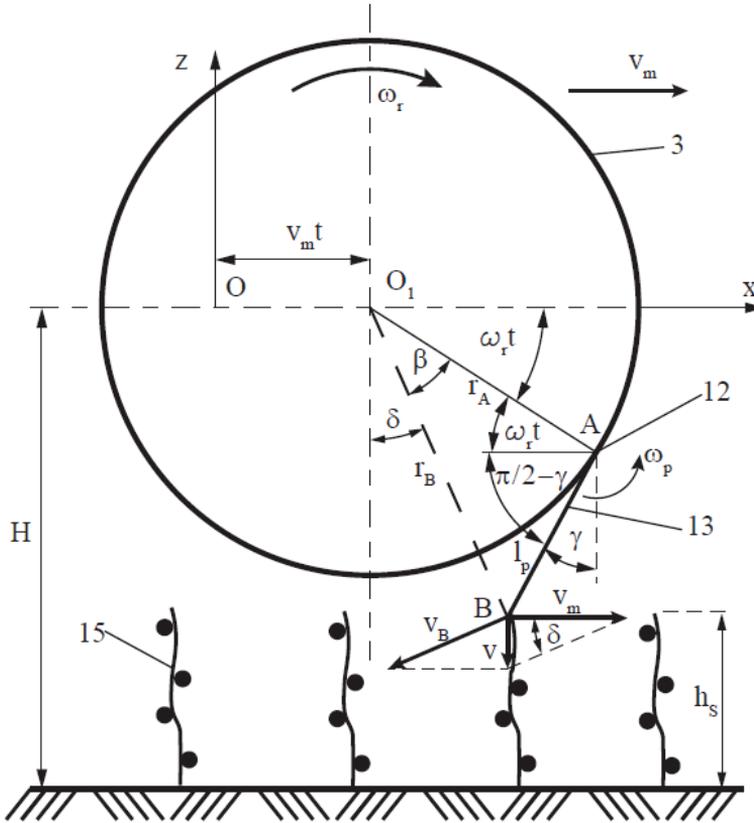


Figure 2. Calculation scheme for compiling equations of the trajectory of picking reel's rakes and for determining the height of the picking reel shaft from the ground: 3 – picking reel, 12 – picking rake, 13 – rake teeth, 15 – blueberry plant.

The trajectory of the picking reel has been studied by Heinloo (2007), but in this case we are not interested in the trajectory of the picking reel and the picking rake. Nevertheless, some important analytical relations for the technological calculation of the picking reel can be indicated with the trajectory equations (2, 3, 4). Firstly, this includes a relation for the selection of the rotational speed of the picking reel. So that the picking of berries could at all occur, the following condition has to be met:

$$v_x = \frac{dx}{dt} < 0,$$

Thus, after differentiation of the first equation (2) according to time t , the result is

$$v_m - \omega_r r_A \sin \omega_r t < 0. \quad (5)$$

Dividing the inequality (5) with the machine velocity v_m and marking $\lambda = \omega_r r_A / v_m$, which indicates the kinematic indication number of the picking reel, the result is

$$\lambda > \frac{1}{\sin \omega_r t}.$$

That is, calculating that the maximum value of sine is 1, then $\lambda > 1$, whereas the value of λ changes practically in the limit of $\lambda \approx 2 \dots 2.5$, and the absolute velocity of the picking reel is expressed as follows:

$$v = v_m \sqrt{1 + \lambda^2 - 2\lambda \sin \omega_r t}, \quad (6)$$

and the angular velocity of the picking reel ω_r is expressed thus:

$$\omega_r = \frac{\lambda \cdot v_m}{r_A}. \quad (7)$$

As this is a motoblock-type machine, the machine velocity v_m is limited with the operator's velocity, that is, $v_m < 1 \text{ m s}^{-1}$. The velocity of the machine prototype is changeable in the interval of $v_m = 0.30 \dots 0.78 \text{ m s}^{-1}$. During tests, most suitable working velocity is $v_{m,opt} = 0.55 \text{ m s}^{-1}$.

The task of the picking reel 3 is to remove blueberries from the stems without any damage. In real working conditions, during the rotation of the picking reel 3, the movement direction of the rake teeth tips has to be vertical, directed top-down, when the rake teeth 13 tips of the picking reel (point B) reach the top of the blueberry plant; in this way the picking rake teeth can penetrate between the blueberry plants 15, that is, at the moment of penetrating between the stems carrying berries the absolute speed vector of the rake teeth tips (Fig. 2) has to be directed vertically top-down. In this case, the height H of the picking reel 3 shaft from the ground is expressed as follows:

$$H = h_s + l_p \cdot \cos \gamma + r_A \cdot \sin \omega_r t \quad (8)$$

where: h_s – the average height of the blueberry plant from the ground to the top, as $\lambda = 2.5$, then it is reasonable to implement the condition $l_p \geq 0.5h_s$.

RESULTS AND DISCUSSION

Analysing equation (8), it is evident that except for the angle $\omega_r t$ all other parameters can be determined. Thus, for the purpose of being able to use the equation (8), an unknown angle has to be expressed $\omega_r t$. This is possible if we express the fictive radius r_B from the triangle O_1AB (Fig. 2), using a cosine sentence as follows:

$$r_B^2 = r_A^2 + l_p^2 - 2r_A l_p \cos \left[\frac{\pi}{2} + (\omega_r t - \gamma) \right]. \quad (9)$$

Considering that

$$\cos \left[\frac{\pi}{2} + (\omega_r t - \gamma) \right] = -\sin(\omega_r t - \gamma) = -\sin \omega_r t \cdot \cos \gamma + \cos \omega_r t \cdot \sin \gamma,$$

the relation (9) can be expressed as follows

$$r_B^2 = r_A^2 + l_p^2 + 2r_A l_p [\sin \omega_r t \cdot \cos \gamma - \cos \omega_r t \cdot \sin \gamma]. \quad (10)$$

Also, the following relation can be drawn from the Fig. 2

$$r_B \cdot \cos \delta = r_A \cdot \sin \omega_r t + l_p \cdot \cos \gamma. \quad (11)$$

by squaring both sides of the relation (11) and formulating from this fictive radius r_B

$$r_B^2 = \frac{r_A^2 \cdot \sin^2 \omega_r t + 2r_A l_p \sin \omega_r t \cdot \cos \gamma + l_p^2 \cos^2 \gamma}{\cos^2 \delta}, \quad (12)$$

where δ – positional angle of the rake tooth tip B.

If we apply a sine law for the triangle formed from velocity vectors (Fig. 2):

$$\frac{\sin \delta}{v} = \frac{\sin \left(\frac{\pi}{2} - \delta \right)}{v_m} \quad (13)$$

and considering relation (6) as well as the fact that $\sin \left(\frac{\pi}{2} - \delta \right) = \cos(\delta)$, then we can express it after the conversions as this

$$\frac{1}{\cos^2 \delta} = \lambda^2 - 2\lambda \sin \omega_r t + 2. \quad (14)$$

When solving together relations (10), (12) and (14), grouping the units and after squaring and converting of both sides, we can formulate the following equation for the angle $\omega_r t$:

$$\begin{aligned} 4\lambda^2 r_A^4 \sin^6 \omega_r t + r_A^2 (\lambda^2 r_A - 4\lambda l_p + 2r_A)^2 \sin^4 \omega_r t + \\ + 4l_p^2 [\cos^2 \gamma (r_A - \lambda^2 r_A + \lambda - 2r_A)^2 + \\ + r_A \sin^2 \gamma] \sin^2 \omega_r t - l_p^4 [(\lambda^2 + 2)^2 \cos^2 \gamma - 1] + r_A^4 = 0. \end{aligned} \quad (15)$$

If we mark
 $\sin^6 \omega_r t = z^3$

$$\sin^4 \omega_r t = z^2$$

$$\sin^2 \omega_r t = z$$

$$\text{and } 4\lambda^2 r_A^4 = a$$

$$r_A^2 (\lambda^2 r_A - 4\lambda l_p + 2r_A)^2 = b$$

$$4l_p^2 [\cos^2 \gamma (r_A - \lambda^2 r_A + \lambda - 2r_A)^2 + r_A \sin^2 \gamma] = c$$

$$l_p^4 [(\lambda^2 + 2)^2 \cos^2 \gamma - 1] + r_A^4 = d,$$

We can write the relation (15) in this form

$$az^3 + bz^2 + cz - d = 0$$

that is,

$$z^3 + \frac{b}{a}z^2 + \frac{c}{a}z - \frac{d}{a} = 0. \quad (16)$$

If we mark $A = b/a$; $B = c/a$ and $C = -d/a$, then the satisfactory result of the equation (16) is expressed in the following form:

$$\sin \omega_r t_1 = \sqrt{z} = \sqrt{K_1 - \frac{K_2}{K_1} - K_3}, \quad (17)$$

where

$$K_1 = \left(\sqrt{\frac{B^3}{27} - \frac{C^2}{4} + \frac{A^3 C}{27} - \frac{A^2 B^2}{108} - \frac{ABC}{6} - \frac{A^3}{27} + \frac{AB}{6} - \frac{C}{2}} \right)^{\frac{1}{3}},$$

$$K_2 = \frac{1}{3} \left(B - \frac{A^2}{3} \right),$$

$$K_3 = \frac{A}{3}.$$

Because in different plantations the height of the blueberry plant h_s (the length of the stems) (Starast et. al, 2005) can differ, then the position of the axis of rotation of the picking device shall be changeable, so as to ensure harvesting without any loss.

Considering the fact that the average height of the blueberry plant from ground to top is $h_s = 0.2$ m and the technical parameters of the picking reel correspond to the ones indicated in Table 1, then the angle of rotation of the picking rake is $\omega_r t = 8^\circ$, and we get the minimum height of the picking reel shaft according to relation (8) as $H_{\min} = 330$ mm.

Table 1. Technical characterisation of the picking reel

Parameter	Symbol	Unit	Value
Radius of the picking reel	r_A	mm	165
Length of the picking rake teeth	l_p	mm	135
Rake angle of the picking rake teeth	γ	degree	30

If we consider that the working speed of the machine is $v_{m,opt} = 0.55 \text{ m s}^{-1}$, then according to the relation (7), the angular speed of the picking reel is $\omega_r = 8.33 \text{ rad s}^{-1}$.

Rake teeth tips B of the picking rake have to reach the ground in their lower position. Deducing from this, we can check the distance of the picking rake axis from the shaft centre r_A with the following relation:

$$r_A \leq \frac{H - l_p \cdot \cos \gamma - d_c}{\cos \beta}, \quad (18)$$

where: d_c is the thickness of the copying unit runner, β – the angle characterising the position of the picking rake; $\beta \neq \text{const}$; $\beta = 0 \dots 360^\circ$.

Thus, if $H = 330 \text{ mm}$, the rake angle of the picking rake teeth is $\gamma = 30^\circ$, the thickness of the runner $d_c = 30 \text{ mm}$ of the copying unit 7 (Fig. 1), the angle characterising the position of the picking rake $\beta = 20^\circ$ if $\omega_r t = \pi/2$ and considering also the fact that the berries may be located close to the ground, then the maximum radius of the picking unit according to relation (19) has to be $r_A \leq 173 \text{ mm}$. The radius of the picking reel of the blueberry harvester prototype (Fig. 3) is 165 mm, which prevents clutching peat pieces and other litter from the ground during the harvesting process.

**Figure 3.** Prototype of the blueberry harvester.

The number of rakes depends both on the kinematics of the picking reel as well as the positioning of its shaft. During design, it would be most reasonable to choose the number of the reel rakes in the limit of $z = 4 \dots 6$ (Landtechnik, 1999). Following from

these recommendations, the number of rakes has been chosen $z = 4$ when designing the prototype of this machine.

CONCLUSIONS

The article has pointed out methodology and explanation for the selection of the most important part of the motoblock-type blueberry harvester - the constructive and kinematics parameters of the picking reel. The constructive parameters of the prototype of the blueberry harvester (Fig. 3) are the following:

- 1) the diameter of the picking reel $2r_A = 330$ mm,
- 2) the height of the axis of rotation of the picking reel from the ground $H = 330$ mm,
- 3) the number of picking rakes $z = 4$.

Kinematics parameters are the following:

- 1) angular speed of the picking reel $\omega_r = 8.33$ rad s⁻¹,
- 2) machine movement speed $v_m = 0.55$ m s⁻¹,
- 3) kinematic indication number $\lambda = 2.5$.

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