KINEMATICS OF THE WORKING UNIT OF THE BLUEBERRY HARVESTER

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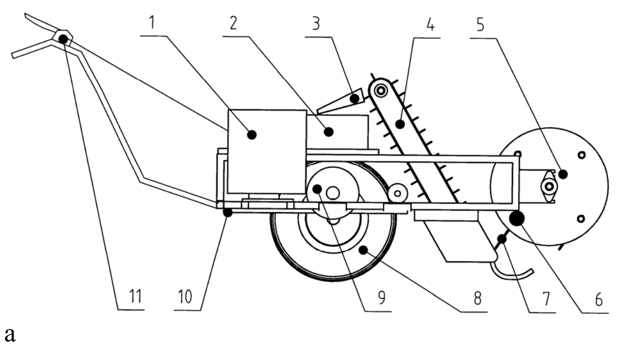
ABSTRACT. *The height of the plant of lowbush blueberry is in the range 10–60 cm and berries ripen more or less at the same time (Starast* et al.*, 2005). It is appropriate to harvest blueberries with machines. The functional working unit of the machine is a picking-reel and the working elements are four picking rakes. A picking rake consists of rake teeth fixed on a rotating shaft. In this case we study the rough blueberry harvester. The task of the blueberry harvester is to pick berries undamaged and to transport them into a container. The harvester is without a sorting line and because of that the berries and additives are not separated. The apparatus parameters of the picking reel are: reel radius r, reel height H, number of rakes z, teeth length of the picking rake* l_p *and angle of inclination γ.*

Keywords: *blueberry harvester, picking reel, picking rake, rake teeth, kinematics parameter.*

Introduction

As a result of peat production there are 3000 ha unusable peat fields in the fens of Estonia. The unused peat fields are suitable for berry farming, cultivating blueberry, cowberry and cranberry. Farmers are interested in picking machinery which makes it possible to manage bigger fields. For example blueberries have to be picked during 10 days when ripe because blueberries do not ripen after harvesting, although a ripe blueberry can stay on bush for 10 days. The harvest work lasts for 1–2 weeks usually and only short time help is needed.

In Estonia, lowbush blueberries "North" and "Northblue" are common (Starast *et al.*, 2005). The characteristics of the lowbush blueberry in Estonia are given in the literature (Starast *et al.*, 2003). The mean values of lowbush blueberry characteristics are used in kinematics synthesis of the harvester: blueberry stalk height 350 mm, rhizome stalk number 6, length 130 mm and diameter of a blueberry 7.5 mm. The principle scheme of the blueberry harvester is shown in Figure 1.



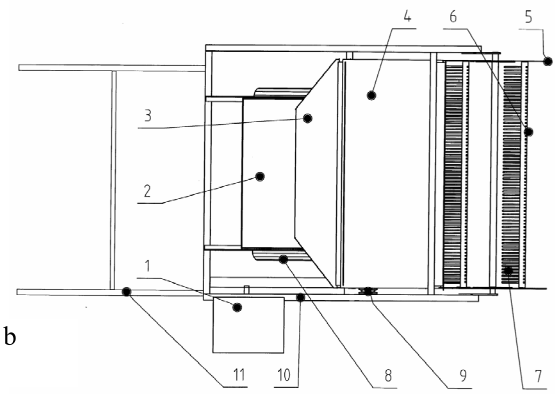


Figure 1. The blueberry harvester assembly and parts: a – front; b – top; 1 – engine; 2 – berry box; 3 – chute; 4 – conveyor; 5 – picking reel; 6 – picking rake; 7 – rake teeth; 8 – wheels; 9 – power transmission elements; 10 – frame; 11 – levers with steering mechanics

Material and Methods

The working unit of a berry harvester is a rotating picking reel with picking rakes. This paper focuses on the synthesis and analysis of the kinematics characteristics of a picking reel. By construction the reels can be the parallelogram reels with alterable inclination angle or copying reels. Parallelogram reels are cheaper because of their robust and simple design.

Mechanically the picking reel is a kinematics chain, composed (Figure 2) of kinematics links, where picking rake 4 is fastened to the central shaft 1 by link 2 (circular disc). The picking rake and link 2 have been joined together with bearing 3. The teeth 5 of the picking rake have been fastened into the drilled holes of the rotating shaft.

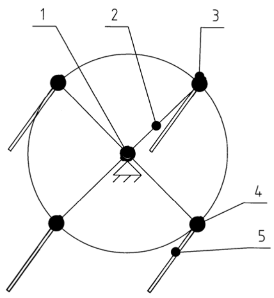


Figure 2. The schema of the parallelogram reel: 1 – center of the reel shaft; 2 – link (circular disc); 3 – bearing; 4 – picking rake; 5 – teeth

The rotating picking rakes are connected with each other and with the central axle by flexible kinematic elements. This paper will not elaborate on the construction and work of the blueberry harvester, focusing, however, on the kinematics synthesis of the reel-rake-tooth.

Results and Discussion

The kinematics schema of the reel is shown in Figure 3. The work of the picking reel can be investigated by the modelling trajectories of the kinematics links (points A, B, C, D) and the teeth tips (points A', B', C', D') (Reintam, 1972).

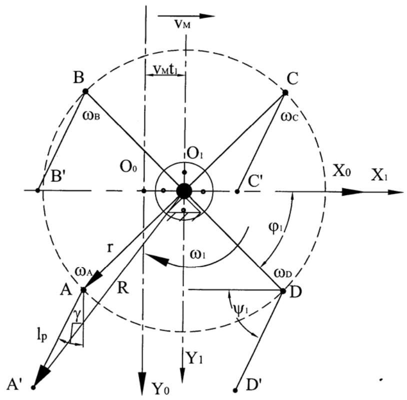


Figure 3. The kinematics schema of the reel

Displacements in cartesian co-ordinates at time t_1 (Figure 4) of the rakes (AA', BB', CC', DD') (Figure 3) are calculated by equations 1 and 2:

$$X = R \cdot cos(\varphi_1) + v_M \cdot t_1, \quad (1)$$

$$Y = R \cdot sin(\varphi_1), \quad (2)$$

where R – length of the link ($R = OA' \neq const$);
φ_1 – rotation angle of the reel at time $t_1 = 0$;
v_M – velocity of the blueberry harvester in the standing reference frame $O_0X_0Y_0$.

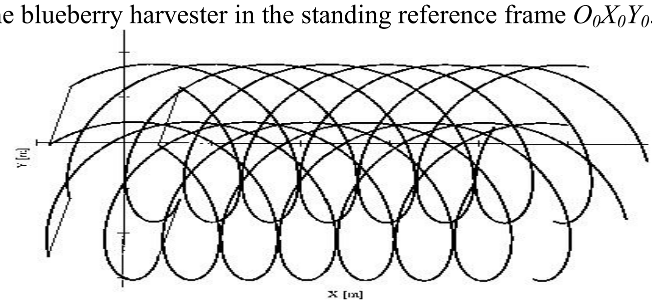


Figure 4. Displacements of the end points of the rakes

Velocity of the blueberry harvester $v_M\, t_1$ and the rotation of the reel $v_H = \omega_1\, R$ is a complex movement (Figure 4) in the standing reference frame $O_0X_0Y_0$ and in the moving reference frame $O_1X_1Y_1$.

The trajectories (Figure 4) determined by the radius of the reel $r = \overline{OA}$ and the length of the teeth $l_p = \overline{AA'}$ (Figure 7), are two cycloids distanced from each other (Figure 4). The rotation speed of the reel can be quite slow, but the absolute velocity of the rake tip has to be higher than the moving speed of the blueberry harvester $v_H > v_M$, and the moving directions have to be opposite.

The character of the cycloid may vary, depending on the kinematics parameter $\lambda = \frac{\omega_1 \cdot R}{v_M}$ (λ has to be more than 1) and the radius of the rake R (Olt, 2002). The number of the rakes z, can be evaluated:

$$z = \frac{2 \cdot \pi \cdot R}{s \cdot \lambda}, \tag{3}$$

where s – step of the reel.

The condition of the motion is function $f(\lambda, R)$ of the cycloid of the teeth, specifying the blueberry harvester's kinematic, dynamic, construction and technological parameters and its field performance.

The key kinematics parameters of the reel are λ and r (Figure 3). The trajectories of the tips of the teeth are shown in Figure 5, if changing the value of the kinematics parameter λ (λ = 1.9; 2.0; 2.2), when r= *const*. If the kinematics radius of the reel is r = 0.175 m; 0.18 m; 0.2 m and λ = *const*, the trajectories are shown in Figure 6.

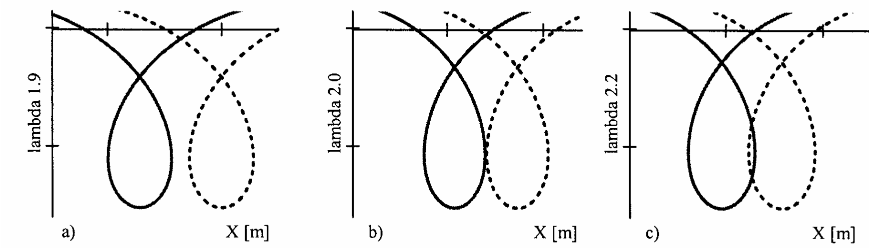


Figure 5. The trajectories of the teeth tips changing the kinematics parameter λ: a) λ = 1.9; b) λ =2.0; c) λ = 2.2

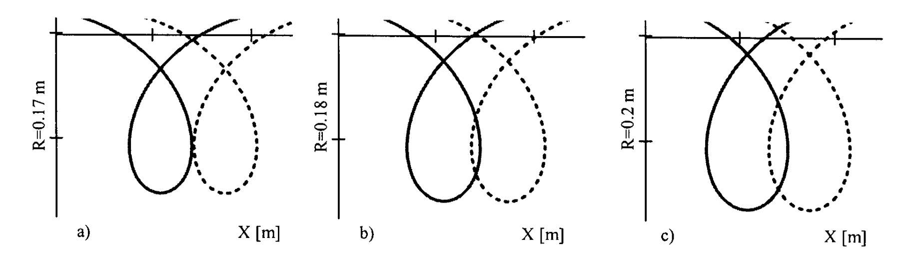


Figure 6. The trajectories of the teeth tips changing the kinematics radius: a) R = 0.17 m; b) R = 0.18 m; c) R = 0.2 m

The task of the reel is to catch and pull off berries from the bush and to throw them onto the conveyor. The movement of the rake and the teeth should not deform the berries or pull the stalks from the ground. But it should pick most of the berries, including those placed on stalks close to the ground or standing up high. The direction of the pull-off of the berries by the teeth is equal to the direction of the absolute velocity vector of the teeth tips and is perpendicular to the teeth (Figure 7).

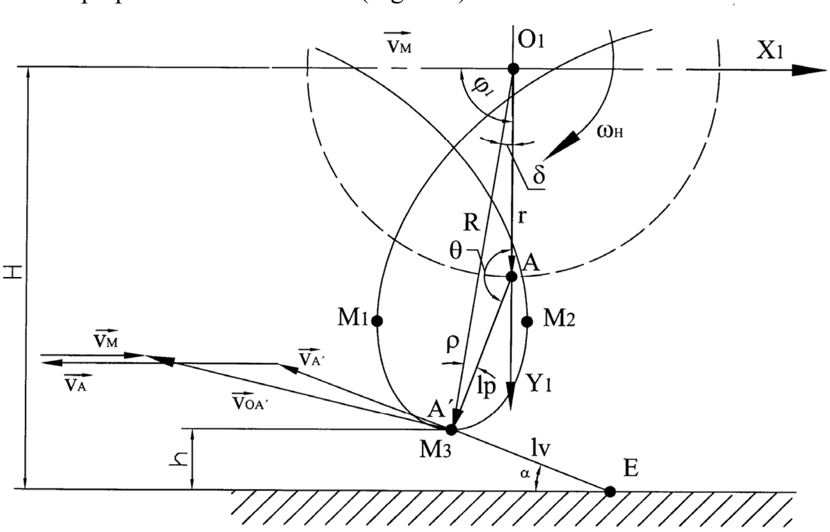


Figure 7. The diagram of the absolute velocity vector of the tooth tip

The velocity vectors of the tooth tip are derivatives of functions (Equations 1 and 2) and are expressed mathematically:

$$v_X = \frac{dx}{dt}, \quad (4)$$

$$v_Y = \frac{dy}{dt}. \quad (5)$$

Therefore, the absolute velocity vector of the tooth tip can be evaluated:

$$v = v_X + v_Y, \quad (6)$$

and angles between them:

$$\cos\alpha = \frac{v_X}{v}, \quad (7)$$

$$\sin\alpha = \frac{v_Y}{v}. \quad (8)$$

The absolute velocity of point A' at time t_i is calculated and shown graphically in Figure 8.

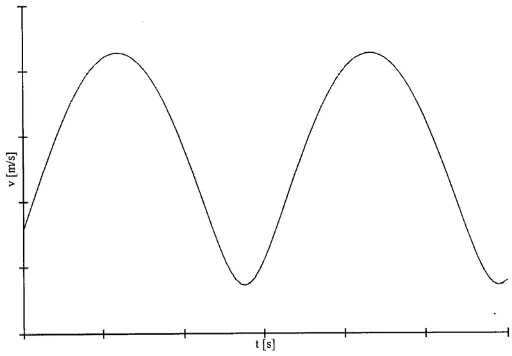


Figure 8. The diagram of the absolute velocity of the tip of the picking teeth

The constructive parameters of the working unit are (Figures 3 and 7): reel radius r, height of the reel centre H, number of the rakes z (or displace angle of the nearest rakes), and angle of inclination γ between the rake teeth and the vertical direction.

By a simplified method, the height of the reel centre H (Figure 7) can be expressed as follows:

$$H = l_v \cdot \sin\alpha + l_p \cdot \cos\gamma \cdot r \cdot \sin\varphi, \quad (9)$$

where l_v – length of a stalk;
l_p – length of a tooth;
r – kinematics radius of the reel;
α – inclination angle of a stalk at the moment when a berry is pulled off;
γ – inclination angle of a tooth;
φ – rotation angle of the reel.

As the height of the plants (length of stalks l_p) and the extent of the lodge (angle α) may differ according to plantations, the height of the reel centre has to be adjustable, to prevent losses at harvesting work.

Conclusions

To summarize, mechanized blueberry harvesting with the mechanical blueberry harvester is a complicated technological process. During the picking of berries, all stalks, leaves and berries are caught together and pulled through the rake, which may damage the berries. The complex movement of the rake and the height of the reel centre have to be investigated experimentally to find out the optimum constructive parameters of the harvester.

The most important conclusions of the research:

1. The trajectory of the tooth tip is a cycloid that varies according to the ratio of the traversing movement of the blueberry harvester and the circumferential velocity of the reel v_H/v_M subject to, $v_H > v_M$. Then the $\lambda > 1$.

2. The effective work and the absolute velocity of the rake tooth is maximum in point M_3 and minimum in point A' (Figure 7).

3. The trajectory of the tooth tip can be changed by changing the kinematics parameter of the reel λ or the radius of the reel r.

4. With the change of radius r, the values of the geometrical characteristics (reel height, distance) of the blueberry harvester have to be changed.

5. The number of rakes z depends on the values of kinematics characteristic λ and radius R.

6. Theoretically, the direction of the pull-off of the berries by teeth is equal to the direction of the absolute velocity vector of the teeth tips and is perpendicular to the teeth (Figure 7).

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