A Virtual Reality Technology–Based Method for the Study of the Working Process of a Blueberry Harvester's Picking Reel

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ABSTRACT

A virtual reality technology–based method for the study of the working process of a blueberry harvester's picking reel is presented. The virtual model of this reel, which is the assembly of projections of rakes on the plane, perpendicular to the axis of the picking reel, is composed. The model is used for creating a video clip visualizing the motion of the reel. A series of frames from the video clip illustrates the motion of the virtual model. For several values of parameters the motion of a rake of the picking reel and the quality of picking berries with the reel are studied in detail. The obtained results and the computer program, realizing the virtual reality technology–based study of the working process of a blueberry harvester's picking reel, can be useful for designers of berry harvesters.

Keywords: Virtual reality technology, modeling, agricultural machinery, berry harvester.

1. BACKGROUND OF THE STUDY

Numerous abandoned peat fields, which suit for growing various berries, occur in fens all over the world. That is why berry harvesters of different types are highly needed in the world market of agricultural machinery. Addresses of main producers of berry harvesters are available on the internet. If a fen cannot carry a tractor, small harvesters are needed. A small harvester of Maine Blueberry Equipment Company (USA) is shown in Fig. 1.

Figure 1. A small blueberry harvester of Maine--Blueberry Equipment Company (USA)

The possible principal scheme of blueberry harvester (Fig. 2) was presented by Olt, Käis (2006).
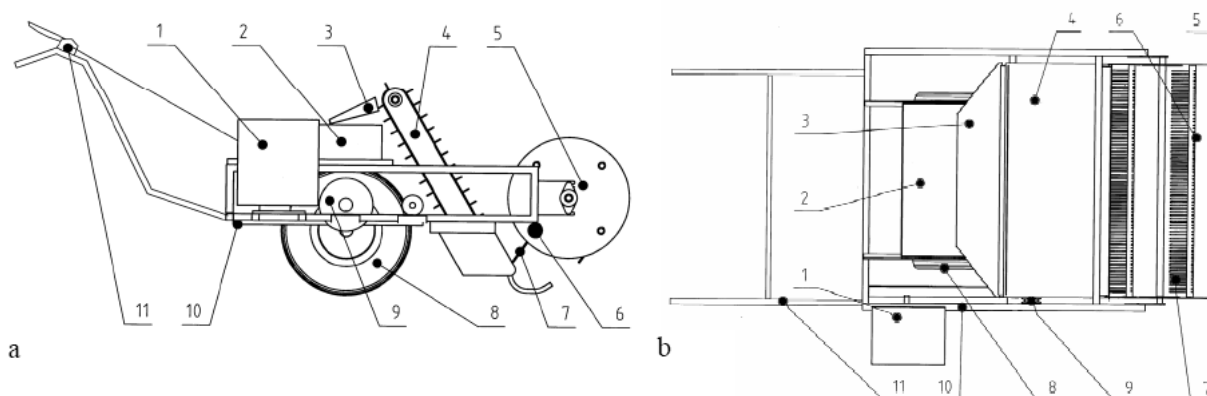

Figure 2. Possible principal scheme of a blueberry harvester: 1- engine, 2 - berry box, 3 - chute, 4 - conveyor, 5 - picking reel, 6 - picking rake, 7 - rake teeth, 8- wheels, 9 - power transmission elements, 10 - frame, 11 - levers with steering.

2. CREATION A TWO–DIMENSIONAL VIRTUAL MODEL OF THE PICKING REEL

An overview of state-of-the-art virtual reality technology is presented by Burdea, Coiffet (2003). In machinery the application of this technology requires the creation of a virtual model of the real object on the computer screen and the study of the working process of this model. It is not always necessary to create a three–dimensional virtual model of a real object for scientific study, but one to three virtual projections would suffice. Results on applying virtual reality technology–based methods in teaching engineering mathematics and in the studies of the working processes of elements of agricultural machinery can be found in Heinloo, Saks (2003), Heinloo, Leola, Veinla (2005), Heinloo, Olt (2006), Heinloo, Tärgla (2006), whereas Heinloo, Leola, Veinla (2005) used one virtual projection and Heinloo, Olt (2006) - three virtual projections of the studied objects.

This paper uses a virtual reality technology–based method on the worksheet of the Computer Package Mathcad to specify the parameters of the picking reel of a small blueberry harvester (Figs. 1, 2).
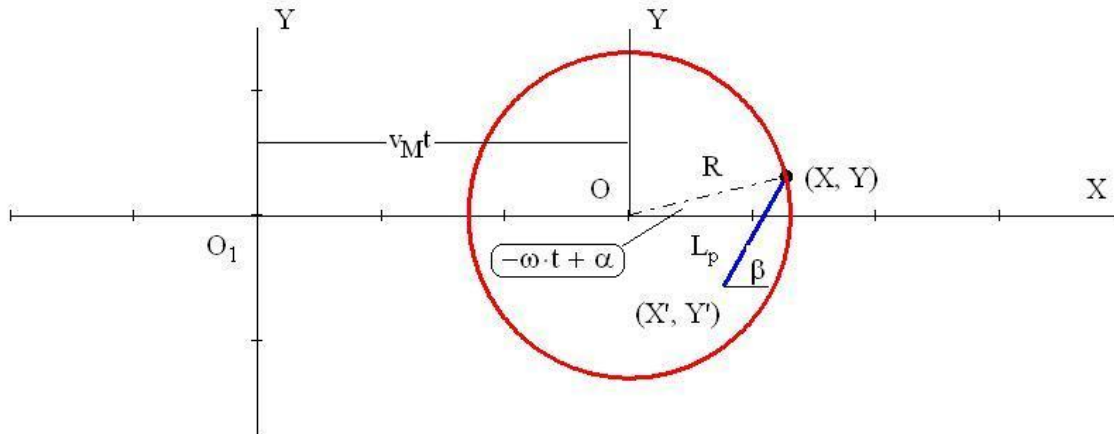
Figure 3. Coordinate systems and parameters of the reel (See text for explanation of symbols)

The picking reel (Figs. 1, 2) is composed of two disks connected by rakes. We suppose that the rakes and the reel are allowed to rotate around their axes so that the rakes are keeping prescribed orientation because special planetary transmission is used. Below we will employ the movable co-ordinate system OXY, rigidly connected to the frame of the harvester, with origin O on the axis of the reel, and the rectangular co-ordinate system O_1XY, immovable relative to the berry field, shown in Fig. 3 together with the projection of the picking reel in the direction of its axis. The projection of a rake in Fig. 3 is a line segment.

Coordinates $X(t)$ and $Y(t)$ of the pivots of the rake in the co-ordinate system OXY can be determined in dependence on time t by the formulae

$$X(t) = R\cos(-\omega t + \alpha) + v_M t, \tag{1}$$

$$Y(t) = R\sin(-\omega t + \alpha). \tag{2}$$

Coordinates of the free endpoint of the rake can be determined by the formulae

$$X'(t) = X(t) - L_p \cos\beta, \tag{3}$$

$$Y'(t) = Y(t) - L_p \sin\beta. \tag{4}$$

Here v_M is the velocity of the harvester, R - the distance of the joint of a tooth from the axis of the reel, ω - angular velocity of clockwise rotation of the reel, α - initial angle of the rake to the x-axis of the rectangular co-ordinate system Oxy, L_p - length of the rake's tooth, t - time, β - permanent inclination angle of the rake to the x-axis. The invariability of the angle β of rakes might be guaranteed by using planetary transmission from the shaft of the reel to the pivots of the rake.

To image rake's tooth on the computer's screen let us define the following vectors:

$$p_x(t) = \begin{pmatrix} X(t) \\ X'(t) \end{pmatrix}, \quad p_y(t) = \begin{pmatrix} Y(t) \\ Y'(t) \end{pmatrix}. \tag{5}$$

In computations we suppose that in formulae (1) - (4) the reel parameters have permanent values: $v_M = 2.4$ m/s, $\omega = 14$ 1/s, $\beta = \pi/3$, $\alpha = \pi/4$.

Let us compose the following functions as programs of Mathcad:

$$P_y(t) = \begin{vmatrix} A \leftarrow \text{augment}(p_y(t,\alpha_0), p_y(t,\alpha_1)) \\ \text{for } i \in 2..Z-1 \\ \quad A \leftarrow \text{augment}(A, p_y(t,\alpha_i)) \end{vmatrix} \qquad P_x(t) = \begin{vmatrix} A \leftarrow \text{augment}(p_x(t,\alpha_0), p_x(t,\alpha_1)) \\ \text{for } i \in 2..Z-1 \\ \quad A \leftarrow \text{augment}(A, p_x(t,\alpha_i)) \end{vmatrix}$$

$$y(t) = \begin{vmatrix} A \leftarrow \text{augment}(Y(t,\alpha_0), Y(t,\alpha_1)) \\ \text{for } i \in 2..Z-1 \\ \quad A \leftarrow \text{augment}(A, Y(t,\alpha_i)) \end{vmatrix} \qquad x(t) = \begin{vmatrix} A \leftarrow \text{augment}(X(t,\alpha_0), X(t,\alpha_1)) \\ \text{for } i \in 2..Z-1 \\ \quad A \leftarrow \text{augment}(A, X(t,\alpha_i)) \end{vmatrix}$$

where Z is the number of rakes in the virtual model, $\alpha_i = i\dfrac{2\pi}{Z}$ (i = 0, 1,…, Z - 1) and the function of Mathcad "augment(a, b)" puts two vectors a and b side by side.

Figure 4 shows two virtual models of the reel at the initial position together with the movable co-ordinate system OXY (Fig. 3). The circles in Fig. 4 were drawn by using the well–known parametric equations

$$x_r(t,\gamma) = R\cos(\gamma) + v_M t, \quad y_r(\gamma) = R\sin(\gamma),$$

and taking in computations γ = 0. 0.01,…, 2π.
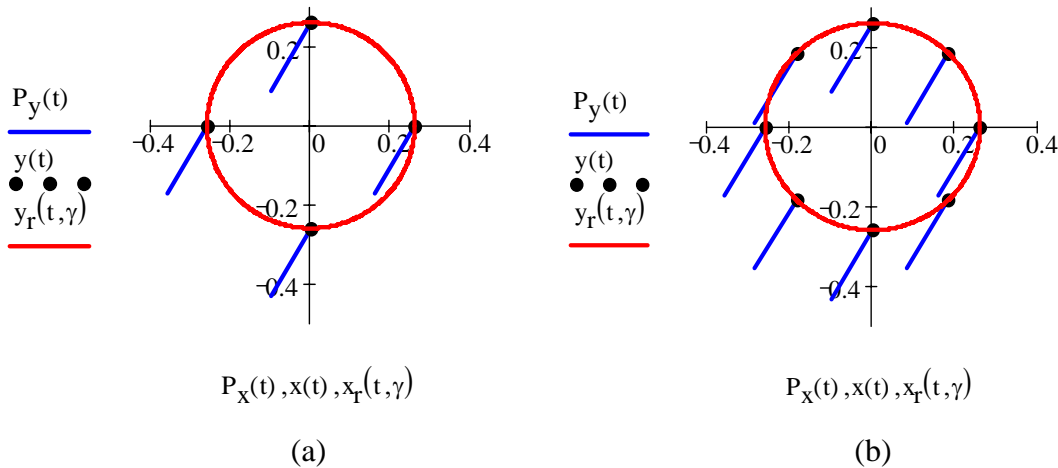

(a)   (b)

Figure 4. Virtual models of the harvester's reel with 4 (a) and 8 (b) rakes (line segments)

Figure 5 presents a virtual model of the reel with 8 rakes together with the circular part of the guidance for berries, which was drawn by using the following parametric equations:

$$x'(t,\gamma') = R\cos(\gamma') + v_M t - L_p\cos(\beta), \quad y'(\gamma') = R\sin(\gamma') + L_p\sin(\beta)$$

In computations we took $\gamma' = \dfrac{r\pi}{16}, \dfrac{r\pi}{16} + 0.01, ..., r_1$, where $r_1 = \dfrac{3\pi}{2}$. To end the circular part of the guidance for berries at the upper bound A of the layer of berries we chose $r = 17.8$.

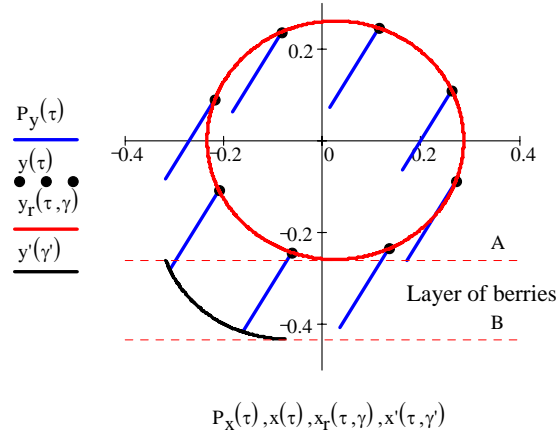$$P_x(\tau), x(\tau), x_r(\tau,\gamma), x'(\tau,\gamma)$$

Figure 5. The virtual model of the reel together with the circular part of the guidance for berries

A virtual model of the reel with 8 rakes together with the cross-section of elongated guidance for berries between lines C and D is shown in Fig. 6. This elongation was made by using of the vectors

$$p'_x(\tau) = \begin{pmatrix} x'\left(\tau, \dfrac{3}{2}\cdot\pi\right) \\ x'\left(\tau, \dfrac{3}{2}\cdot\pi\right) + 0.245\cdot m \end{pmatrix}, \quad p'_y = \begin{pmatrix} y'\left(\dfrac{3}{2}\cdot\pi\right) \\ y'\left(\dfrac{3}{2}\cdot\pi\right) \end{pmatrix}.$$

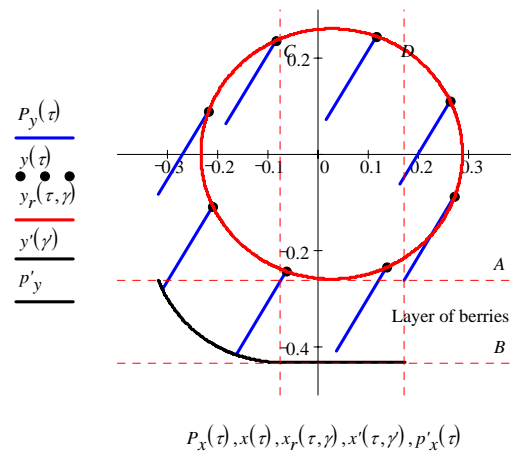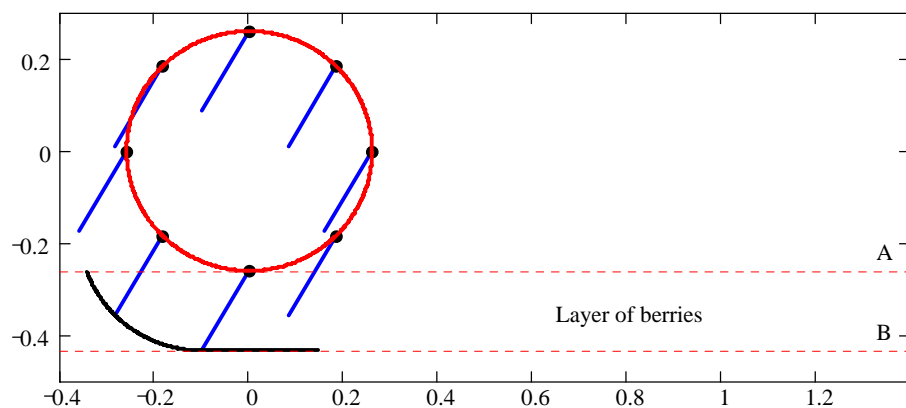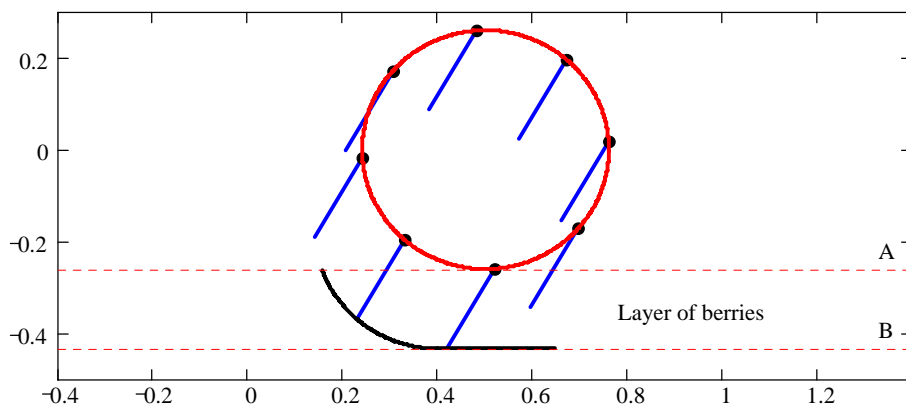$$P_x(\tau), x(\tau), x_r(\tau,\gamma), x'(\tau,\gamma), p'_x(\tau)$$

Figure 6. The virtual model of the reel together with the guidance for berries

Figure 7 depicts three frames ((a): $t = 0$ s, (b): $t = 0.5$ s and (c): $t = 1.0$ s) of the composed video clip, showing the simulation of the working process of the virtual model of the reel with 8 rakes, when $R = 0.26$ m and $L_p = 0.20$ m.

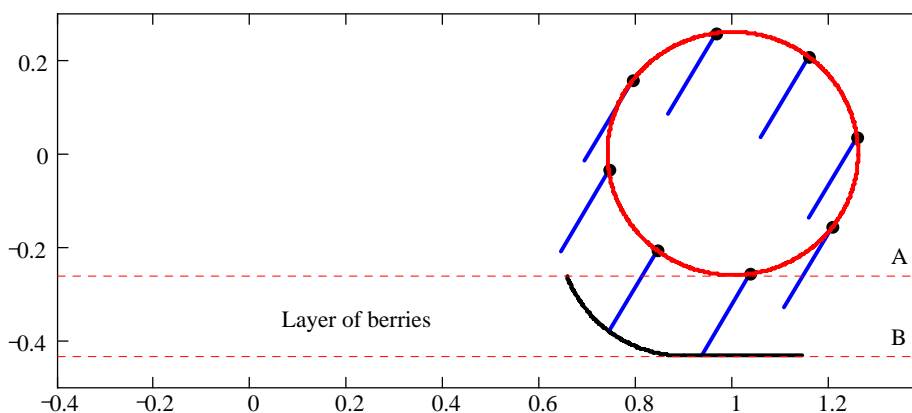M. Heinloo "A Virtual Reality Technology Based Method for Study the Working Process of a Blueberry Harvester's Picking Reel". Agricultural Engineering International: the CIGR Ejournal. Manuscript IT 07 001. Vol. IX. June, 2007.

(a)

(b)

Figure 7. Three frames from the video clip simulating the working process
of the virtual picking reel with 8 rakes

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Blueberry Harvester's Picking Reel". Agricultural Engineering International: the CIGR Ejournal.
Manuscript IT 07 001. Vol. IX. June, 2007.

3. ANALYSIS OF THE TRAJECTORIES OF THE BERRIES, FLYING OUT OF THE REEL

For graphic presentation of geometric vectors let us define the function Bertjajev (2005):

$$V'(t,\alpha) = \begin{vmatrix} v_O \leftarrow E'(t,\alpha) \\ \\ I \leftarrow \begin{pmatrix} 0 & 0.95 & 0.85 & 1 & 0.85 & 0.95 \\ 0 & 0 & 0.04 & 0 & -0.04 & 0 \end{pmatrix}^T \\ \\ \Omega \leftarrow \begin{pmatrix} f_x(t,\alpha) & f_y(t,\alpha) \\ -f_y(t,\alpha) & f_x(t,\alpha) \end{pmatrix} \\ \\ v_O + 0.05 \cdot v'(t,\alpha) \cdot I \cdot \Omega \cdot s \end{vmatrix} \qquad (6)$$

where,

$$v'_x(t,\alpha) = \frac{dX'(t,\alpha)}{dt}, \qquad v'_y(t,\alpha) = \frac{dY'(t,\alpha)}{dt}, \qquad v'(t,\alpha) = \sqrt{v'_x(t,\alpha)^2 + v'_y(t,\alpha)^2},$$

$$f'_x(t,\alpha) = \frac{v'_x(t,\alpha)}{v'(t,\alpha)}, \quad f'_y(t,\alpha) = \frac{v'_y(t,\alpha)}{v'(t,\alpha)}, \quad E'(t,\alpha) = \begin{pmatrix} X'(t,\alpha) & Y'(t,\alpha) \\ X'(t,\alpha) & Y'(t,\alpha) \\ X'(t,\alpha) & Y'(t,\alpha) \\ X'(t,\alpha) & Y'(t,\alpha) \\ X'(t,\alpha) & Y'(t,\alpha) \\ X'(t,\alpha) & Y'(t,\alpha) \end{pmatrix}$$ and T denotes the
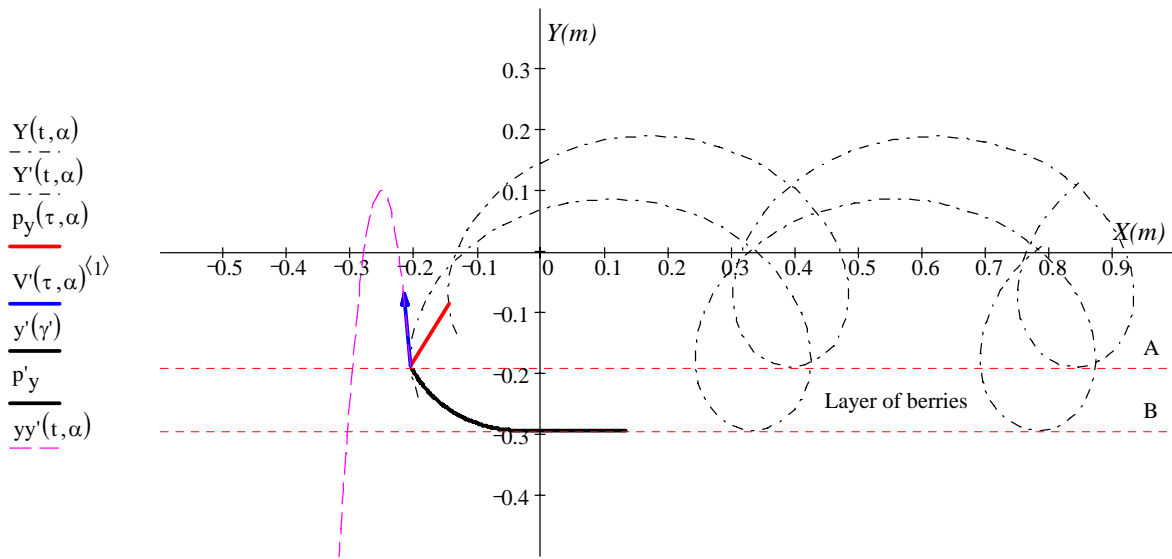
transposition of the matrix.

The trajectory of a berry, leaving the reel is determined by the following formulae

$$xx'(t) = v'_x(\tau,\alpha)t + X'(\tau,\alpha), \qquad yy'(t) = -\frac{gt^2}{2} + v'_y(\tau,\alpha)t + Y'(\tau,\alpha) \qquad (7)$$

Figures 8a - 8d show a rake and the trajectories (cycloids) of its endpoints and the trajectory of a blueberry flying out of the a rake's point shown by the vector of its initial velocity. It follows from these figures that the dimensions of cycloids and the trajectory of s berry essentially depend on the number of rakes Z, on the radius R of the reel and on the length L_p of the teeth of the rake. Note that in a real situation the other berries are hindering a certain berry from flying out and its real trajectory will be lower and narrower. A designer of berry harvesters should study also the influence of other parameters of the reel on the trajectory of a berry.

$$Y(t,\alpha)$$
$$Y'(t,\alpha)$$
$$p_y(\tau,\alpha)$$
$$V'(\tau,\alpha)^{\langle 1\rangle}$$
$$y'(\gamma)$$
$$p'_y$$
$$yy'(t,\alpha)$$
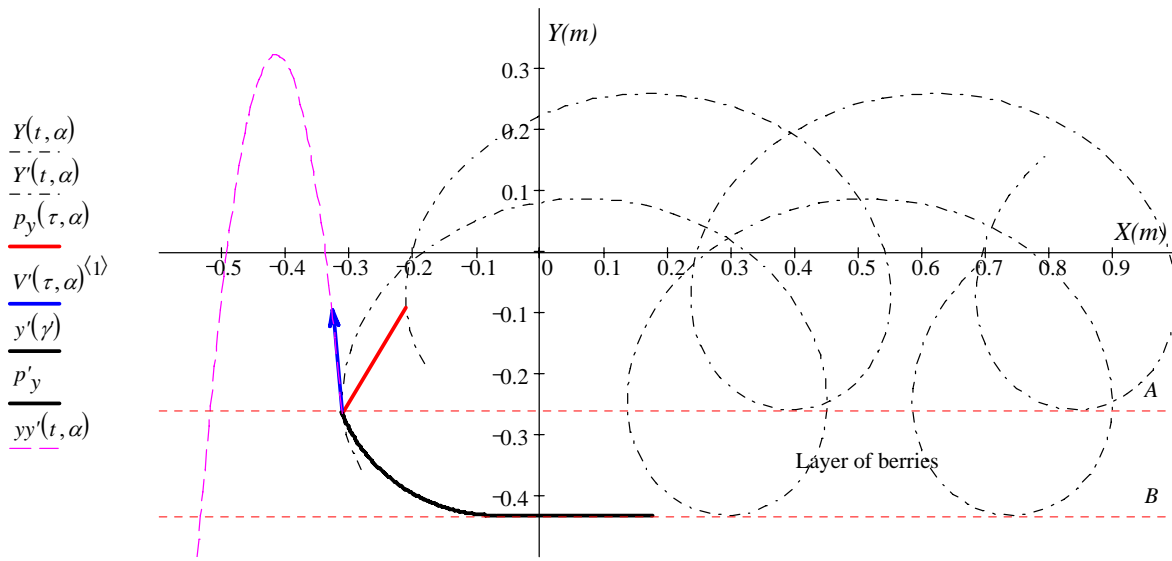
$$X(t,\alpha),X'(t,\alpha),p_x(\tau,\alpha),V'(\tau,\alpha)^{\langle 0\rangle},x'(\tau,\gamma),p'_x(\tau),xx'(t,\alpha)$$

(a) $Z = 8$, $R = 0.26$ m and $L_p = 0.20$ m

$$Y(t,\alpha)$$
$$Y'(t,\alpha)$$
$$p_y(\tau,\alpha)$$
$$V'(\tau,\alpha)^{\langle 1\rangle}$$
$$y'(\gamma')$$
$$p'y$$
$$yy'(t,\alpha)$$

$$X(t,\alpha),X'(t,\alpha),p_x(\tau,\alpha),V'(\tau,\alpha)^{\langle 0\rangle},x'(\tau,\gamma'),p'_x(\tau),xx'(t,\alpha)$$

(b) $Z = 8$, $R = 0.19$ m and $L_p = 0.12$ m

$Y(t,\alpha)$
$Y'(t,\alpha)$
$p_y(\tau,\alpha)$
$V'(\tau,\alpha)^{\langle 1 \rangle}$
$y'(\gamma')$
p'_y
$yy'(t,\alpha)$

$X(t,\alpha),X'(t,\alpha),p_x(\tau,\alpha),V'(\tau,\alpha)^{\langle 0 \rangle},x'(\tau,\gamma'),p'_x(\tau),xx'(t,\alpha)$

(c) $Z = 4$, $R = 0.26$ m, $L_p = 0.20$ m

$Y(t,\alpha)$
$Y'(t,\alpha)$
$p_y(\tau,\alpha)$
$V'(\tau,\alpha)^{\langle 1 \rangle}$
$y'(\gamma')$
p'_y
$yy'(t,\alpha)$

$X(t,\alpha),X'(t,\alpha),p_x(\tau,\alpha),V'(\tau,\alpha)^{\langle 0 \rangle},x'(\tau,\gamma'),p'_x(\tau),xx'(t,\alpha)$

(d) $Z = 4$, $R = 0.19$ m and $L_p = 0.12$ m
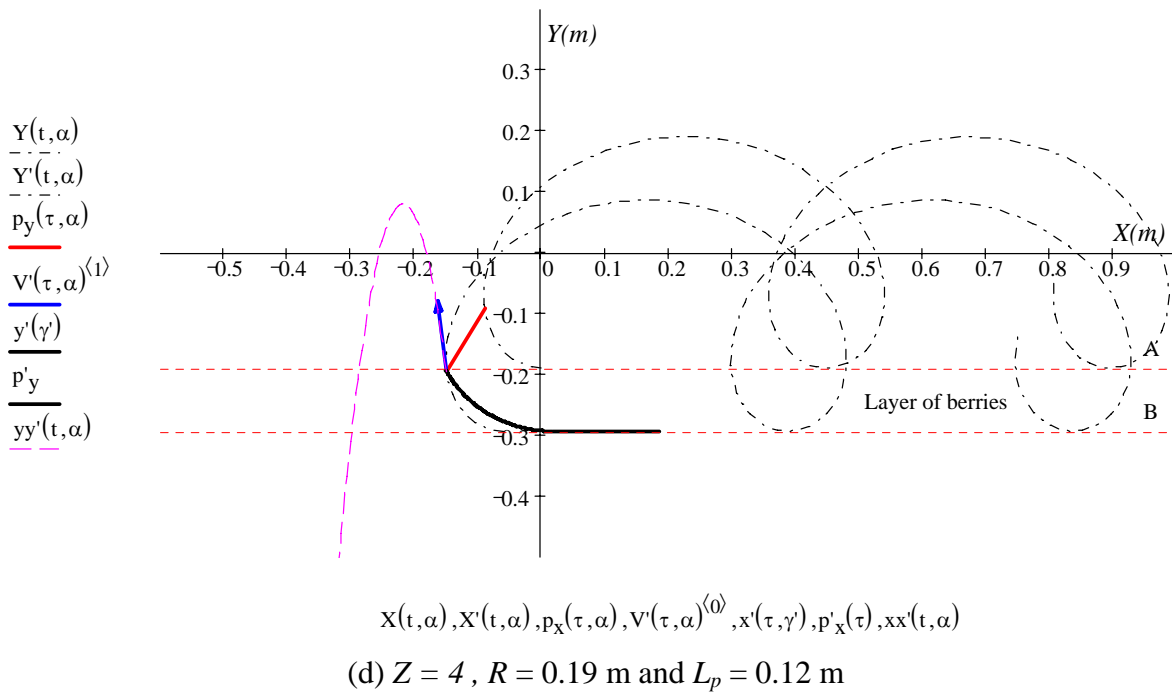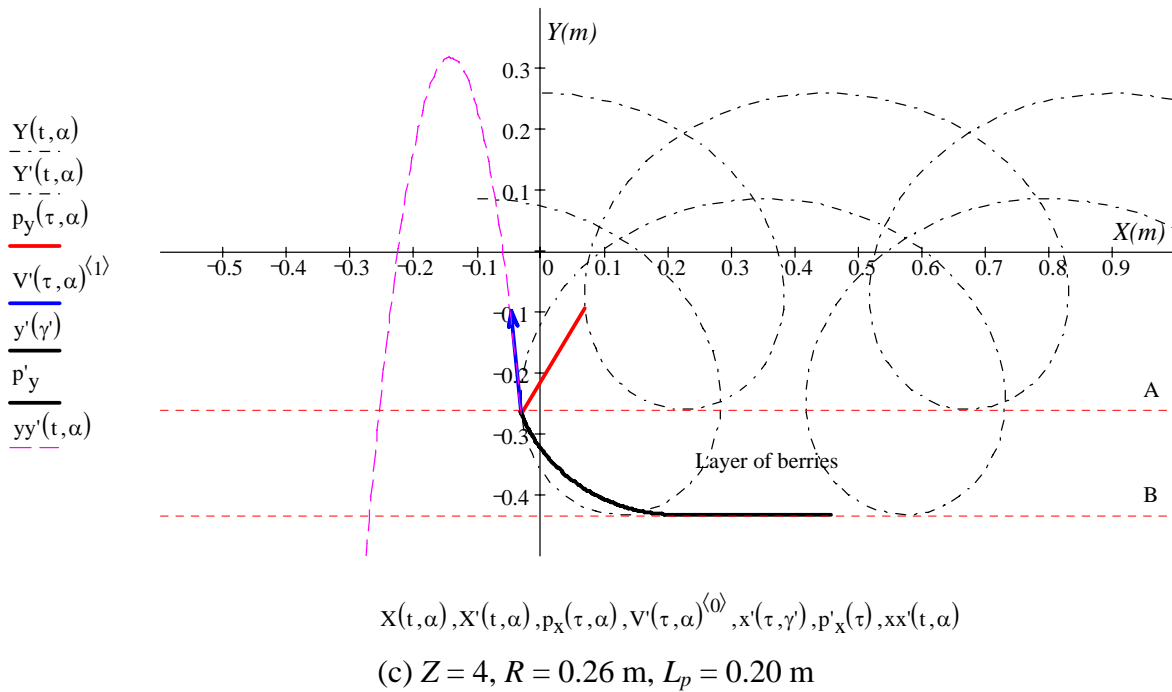
Figure. 8. Trajectories of the endpoints of a rake and the trajectory of a blueberry, flying out of the reel

4. ANALYSIS OF THE QUALITY OF PICKING BERRIES BY THE REEL

To depict the region where berries will be picked off, we define the functions

$$YY(t,\alpha) = if\,(Y(t,\alpha) > A, A, Y(t,\alpha)), \quad YY'(t,\alpha) = if\,(Y'(t,\alpha) > A, A, Y'(t,\alpha))$$

$$pp_y(t,\alpha) = \begin{pmatrix} YY(t,\alpha) \\ YY'(t,\alpha) \end{pmatrix},$$

$$L_y(t) = \begin{vmatrix} A \leftarrow augment\big(pp_y(t,\alpha_0), pp_y(t,\alpha_1)\big) \\ for\ \ i \in 2..Z-1 \\ \quad A \leftarrow augment\big(A, pp_y(t,\alpha_i)\big) \end{vmatrix}, \qquad L_x(t) = \begin{vmatrix} A \leftarrow augment\big(p_x(t,\alpha_0), p_x(t,\alpha_1)\big) \\ for\ \ i \in 2..Z-1 \\ \quad A \leftarrow augment\big(A, p_x(t,\alpha_i)\big) \end{vmatrix},$$

$$Ly = \begin{vmatrix} A \leftarrow augment\big(L_y(0\cdot s), L_y(h)\big) \\ for\ \ t \in 2\cdot h, 3\cdot h .. 1\cdot s \\ \quad A \leftarrow augment\big(A, L_y(t)\big) \end{vmatrix}, \qquad Lx = \begin{vmatrix} A \leftarrow augment\big(L_x(0\cdot s), L_x(h)\big) \\ for\ \ t \in 2\cdot h, 3\cdot h .. 1\cdot s \\ \quad A \leftarrow augment\big(A, L_x(t)\big) \end{vmatrix}.$$

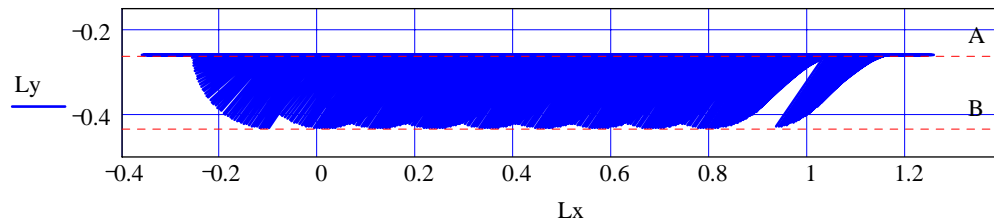Vectors Lx and Ly depict the spoors of rakes. These spoors denote the region, where berries can be picked up.

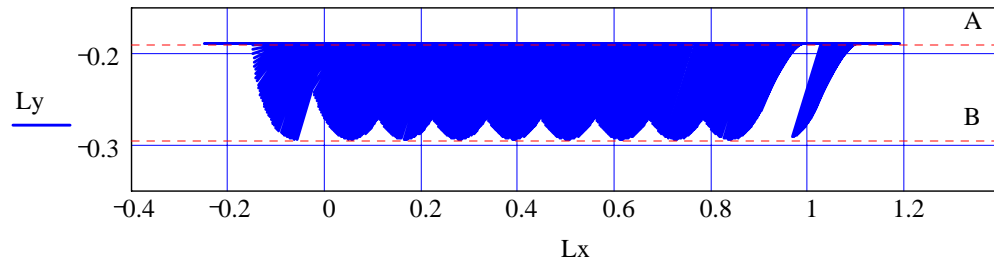The regions where berries can be picked up at the time interval of $0\ s < t < 1\ s$ are presented in Figs 9a – 9d.
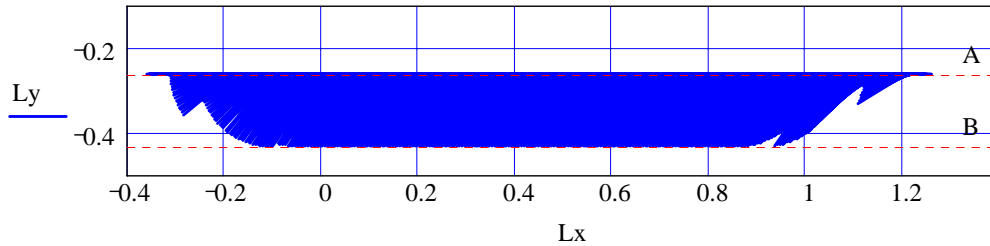
(a) $Z = 8$, $R = 0.26$ m, $L_p = 0.20$ m
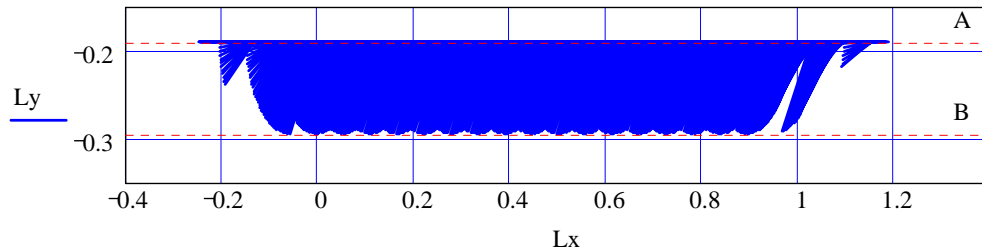
(b) $Z = 8$, $R = 0.19$ m, $L_p = 0.12$ m

(c) $Z = 4$, $R = 0.26$ m, $L_p = 0.20$ m

(d) $Z = 4$, $R = 0.19$ m, $L_p = 0.12$ m

Figure 9. Regions where the blueberries can be picked up during the time interval $0\,s < t < 1\,s$

From Figs 9a - 9d we can conclude that increasing the reel's radius R, the length of teeth L_p and the number of rakes contributes to the quality of picking up berries. Sufficient quality can be obtained by the reel of the radius $R = 0.26$ m with $Z = 8$ rakes and the length $L_p = 0.20$ m of teeth. The influence the other parameters of a reel on the quality of berry picking should be taken into account in the design of berry harvesters.

5. CONCLUSIONS

Useful information for designers of berry harvesters has been obtained by employing the virtual reality technology. This fact confirms the applicability of virtual reality technology in the study of machine elements. In this paper the computations were made with the computer program Mathcad, but others programs for the virtual design of machine elements can be used as well.

6. ACKNOWLEDGEMENT

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