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# EFFECT OF CHOSEN WORKING PARAMETERS OF FINGER HUMP WITH SHAKER MECHANISM ON SEPARATION QUALITY

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**Summary.** The paper presents one of the possibilities of increasing the separation efficiency of the working groups of potato combines. The result was attained by modification of the finger hump (use of cam mechanism to shake its working surface). An influence of kinematics parameters of the cam mechanism on the efficiency of finger hump separation was considered. The laboratory and field study confirmed the legitimacy of the working hypothesis. It was found out that the working speed of the finger hump surface, its depression angle and amplitude of shake, have a significant influence on the quality of separation of soil limps from the crop.

**Key words:** finger hump, cam shake mechanism, working parameters, kinematics, quality of separation.

## INTRODUCTION

One of the possibilities of enhancing the operation combine harvesters is to increase the separation capacity of their working assemblies. In most combines for potato harvesting the technological mix is separated on rod conveyors, and at the final stage on the finger hump of haulm separating assemblies [Marks et al. 1997; Lisowski 1999; Tanaś 2001].

The finger hump has the possibility of adjustment of the angle of inclination $\beta$ within the range of 35 ...55$^{o}$. For the purpose of limitation of potato losses during harvest, the angle of inclination is set to its maximum value. This, however, leads to increased levels of contamination of the crop, especially with soil lumps or clods. As a result of that process, the crop is of limited cleanliness and thus does not meet the agrotechnical requirements [Tanaś and Zawierucha 2006; Tanaś and Kuzmitski 2008].

## MATERIAL AND METHODS

Taking into account that the finger hump is one of the more expensive working assemblies of KSK-4-1 combine, its role cannot be reduced to that of a factor improving crop cleanliness. Therefore, there is a need for an improvement of the design of the finger hump with a view to enhance the efficiency of the separation process on its surface. To that aim an upgrade was performed for a series-production finger hump (Fig. 1). The conveyor, transporting the technological mass at the rate of 1.4 m · $s^{-1}$, was set at an angle of $8^o$.

On the inner side of the finger hump three rows of cams were attached. Cam spacing in a row was $t$ = 0.16 m, and cam length was $c$ = 0.065 m. To ensure free passage of the cams, the shafts of the finger hump are of annular design. In the upper section of the finger hump a roller shaft was installed, with radius r = 0.03 m, provided with a mechanism permitting change of amplitude $A$ of hump surface shaking through a change in the positioning of the shaft with the rollers.

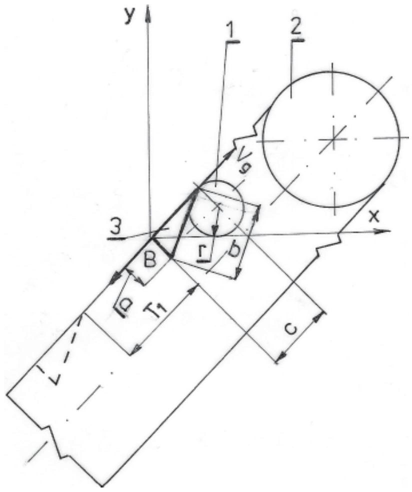


Fig. 1. Schematic of finger hump surface shake mechanism: 1 – roller, 2 – hump, 3 – cam

As a result of the above modification, soil lumps should be broken, and potatoes, tossed up by the cam mechanism, should be deposited onto the offload conveyor of the combine (Fig. 2).

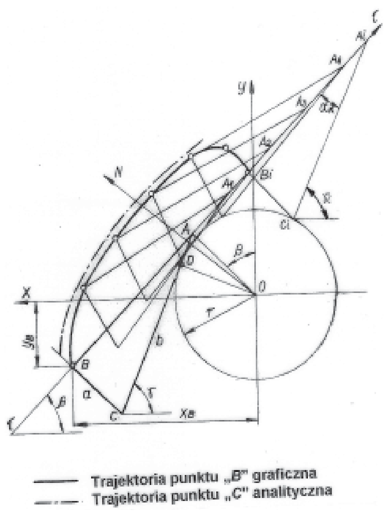


Fig. 2. Kinematics of the cam mechanism

With the movement of the finger hump surface, the cams run onto the rollers, the position of which can be set with relation to the hump frame, and perform a complex motion with direction *ON* and rotation around point *D*. The cam apex *A* will move in the direction *TT*, and point *B* will move along a non-linear compound trajectory described by the following relations (1):

$$X_b = \frac{r\sin\beta}{\cos\alpha_k} - V_g t\cos\beta + (a+b)\cos\left[\operatorname{arctg}\sqrt{\frac{1}{\cos^2\alpha_k} + \frac{V_g^2 t^2}{r^2} - 1} + \operatorname{arctg}\frac{r\operatorname{tg}\beta - V_g t\cos\alpha_k}{r + V_g t\cos\alpha_k}\right];$$
$$Y_b = \frac{r\cos\beta}{\cos\alpha_k} + V_g t\sin\beta + (a-b)\sin\left[\operatorname{arctg}\sqrt{\frac{1}{\cos^2\alpha_k} + \frac{V_g^2 t^2}{r^2} - 1} + \operatorname{arctg}\frac{r\operatorname{tg}\beta - V_g t\cos\alpha_k}{r + V_g t\cos\alpha_k}\right]; \quad (1)$$

where:
r – roller radius,
$\alpha_k$ – cam angle,
a,b – cam dimensions,
l = 0.6-0.7 m, distance of roller axis to the lower axis of the drive shaft of the finger hump.

Under the action of the hump surface, at point „*B*” potatoes and soil lumps will be subject to free motion thanks to the initial speed at the moment of loss of contact with it. To determine the manner of the motion of potatoes and soil lumps relative to the hump surface, the origin of the system of coordinates will be set at point „*B*”, and the axes of coordinates as shown in Fig. 3.

In the new system, $\varepsilon 0_1 \eta$, translation of point „*B*” can be defined by means of the relations (2).

$$\eta = \left[\frac{r\sin\beta}{\cos\alpha_k} - V_g t\cos\beta + (a+b)\cos\gamma - l\right]\cos\beta + \left[\frac{r\cos\beta}{\cos\alpha_k} + V_g t\sin\beta + (a-b)\sin\gamma - c\right]\sin\beta \quad (2)$$

$$\varepsilon = \left[\frac{r\sin\beta}{\cos\alpha_k} - V_g t\cos\beta + (a-b)\cos\gamma - l\right]\sin\beta + \left[\frac{r\cos\beta}{\cos\alpha_k} + V_g t\sin\beta + (a-b)\sin\gamma - c\right]\cos\beta.$$

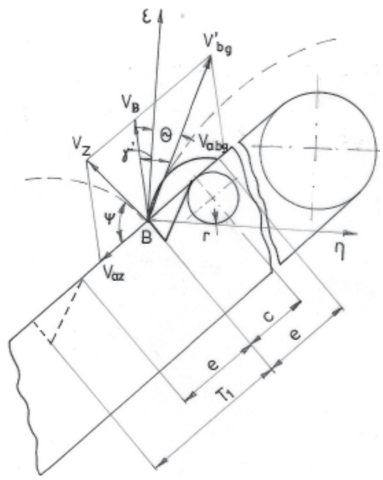


Fig. 3. Trajectories of movement of point “B” (potatoes and soil lumps) at toss

By differentiating relations (2) we obtain the velocities of the finger hump surface at point „*B*" as projected onto aces η and ε.

$$V_\eta = -V_g\cos^2\beta - (a+b)\cos\beta\sin\gamma\frac{d\gamma}{dt} + V_g\sin^2\beta + (a-b)\sin\beta\cos\gamma\frac{d\gamma}{dt}\,, \tag{3}$$

$$V\varepsilon = V_g\cos\beta\sin\beta + (a+b)\sin\beta\sin\gamma\frac{d\gamma}{dt} + V_g\sin\beta\cos\beta + (a-b)\cos\beta\cos\gamma\frac{d\gamma}{dt}\,,$$

where:

$$\frac{d\gamma}{dt} = (\sec^2\alpha_k + 0{,}5V_g^2t^2)^{-1}V_g^2t\left[1+\left(\frac{rtg\beta - V_g\cos\alpha_k}{r+V_gt\cos\alpha_k}\right)^2\right]^{-1} x\,\frac{-rV_g\cos\alpha_k(1-tg\beta)}{(r+V_gt\cos\alpha_k)^2}\,. \tag{4}$$

Acceleration of the hump surface at point „*B*" is defined through integration of the relations (3).

$$j_\eta = -(a+b)\cos\beta\cos\gamma\left(\frac{d\gamma}{dt}\right)^2 - (a+b)\cos\beta\sin\gamma\frac{d^2\gamma}{dt^2} - (a-b)\sin\beta\sin\gamma\left(\frac{d\gamma}{dt}\right)^2 + (a-b)\sin\beta\cos\gamma\, dt^2\frac{d^2\gamma}{dt^2}\,, \tag{5}$$

$$j\varepsilon = (a+b)\sin\beta\cos\gamma\left(\frac{d\gamma}{dt}\right)^2 + (a+b)\sin\beta\sin\gamma\frac{d^2\gamma}{dt^2} + (a-b)\cos\beta\cos\gamma\frac{d^2\gamma}{dt^2} - (a-b)\cos\beta\sin\gamma\left(\frac{d\gamma}{dt}\right)^2,$$

where:

$$\frac{d^2\gamma}{dt^2} = \{-\left(\sec^2\alpha_k + 0{,}5V_g^2t^2\right)^{-2} + \left(\sec^2\alpha_k + 0{,}5V_g^2t^2\right)^{-1}V_g^2\}\times\left[1+\left(\frac{rtg\beta - V_gt\cos\alpha_k}{r+V_gt\cos\alpha_k}\right)^2\right]^{-1}\times$$
$$\times\frac{-rV_g\cos\alpha_k(1-tg\beta)}{(r+V_gt\cos\alpha_k)^2} + \left(\sec^2\alpha_k + 0{,}5V_g^2t^2\right)^{-1}V_g^2t\left[1+\left(\frac{rtg\beta - V_gt\cos\alpha_k}{r+V_gt\cos\alpha_k}\right)^2\right]^{-2}\times \tag{6}$$
$$\times\frac{2r(1+tg\beta)V_g\cos\alpha_k\left(rtg\beta - V_gt\cos\alpha_k\right)}{(r+V_gt\cos\alpha_k)^3}\times\frac{-rV_g\cos\alpha_k(1-tg\beta)}{(r+V_gt\cos\alpha_k)^2} + \left(\sec^2\alpha_k + 0{,}5V_g^2t^2\right)^{-1}V_g^2t\times$$
$$\times\left[1+\left(\frac{rtg\beta - V_gt\cos\alpha_k}{r+V_gt\cos\alpha_k}\right)^2\right]^{-1}\times\frac{2rV_g^2\cos^2\alpha_k(1-tg\beta)(r+V_gt\cos\alpha_k)}{(r+V_gt\cos\alpha_k)^4}\,.$$

On the basis of equations (3) we obtain graphs of the relations and of absolute velocity of the hump surface at point „*B*", at various parameters of the cam mechanism:

$$V_B = \sqrt{V_\eta^2 + V_\varepsilon^2}\,. \tag{7}$$

Fig. 4 presents graphs of the relation $V_B$ *(Vg, β)*.

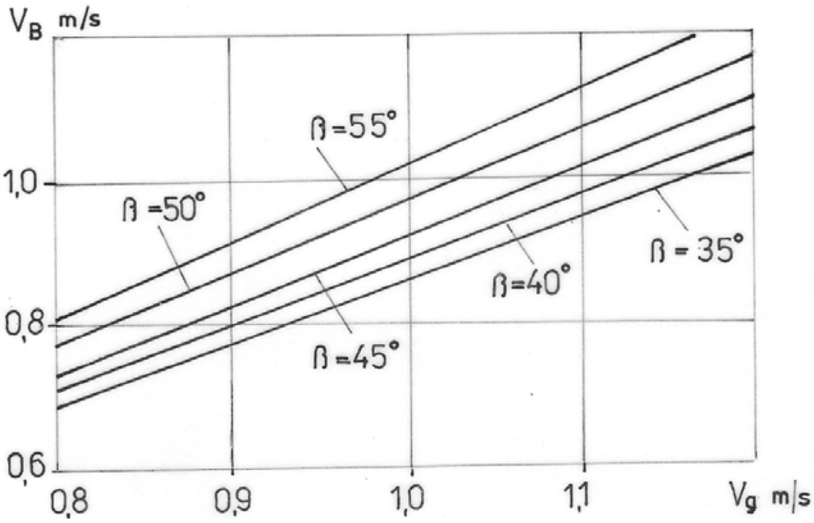


Fig. 4. Diagram of the relation $V_B = \oint(V_g)$

The relation $V_B = \oint(V_g)$ has a linear character. With an increase in the hump velocity $V_g$ and in the angle of its inclination $\beta$, the velocity of point „*B”* increases.

The relation $V_B = \oint(\beta)$ is parabolic, with the convex profile downwards (Fig. 5).

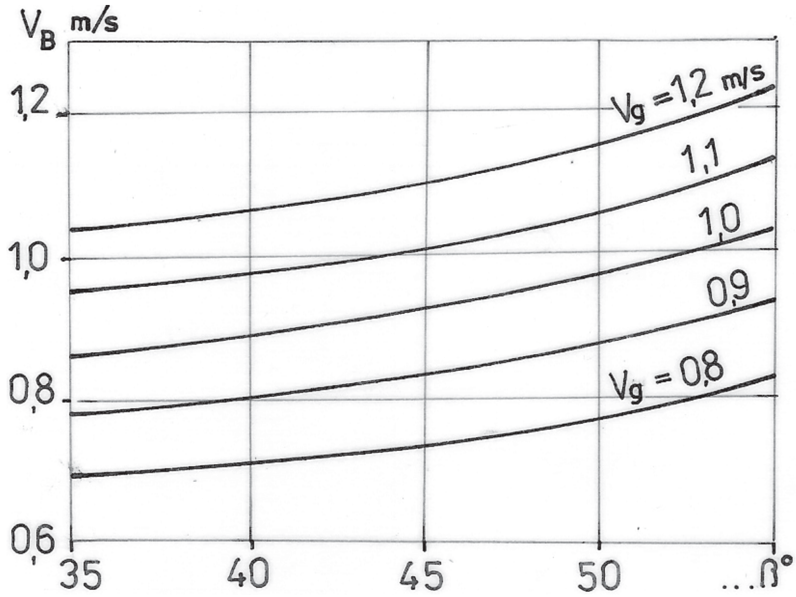


Fig. 5. Diagram of the relation $V_B = \oint(\beta)$

The relation of velocity $V_B$ to the working angle of the cam, $\alpha_k$, is given in Fig. 6 and 7.

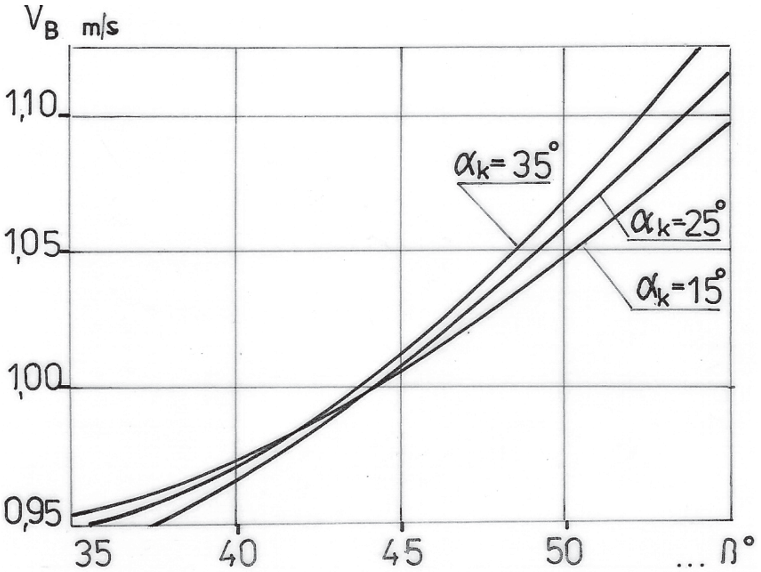


Fig. 6. Diagram of the relation $V_B = \oint(\beta,\alpha_k)$

The performed analysis shows that velocity $V_B$ is significantly affected by the hump speed $V_g$ and its depression angle $\beta$. With a decreased angle $\beta$ the hump speed $V_g$ should be increased.

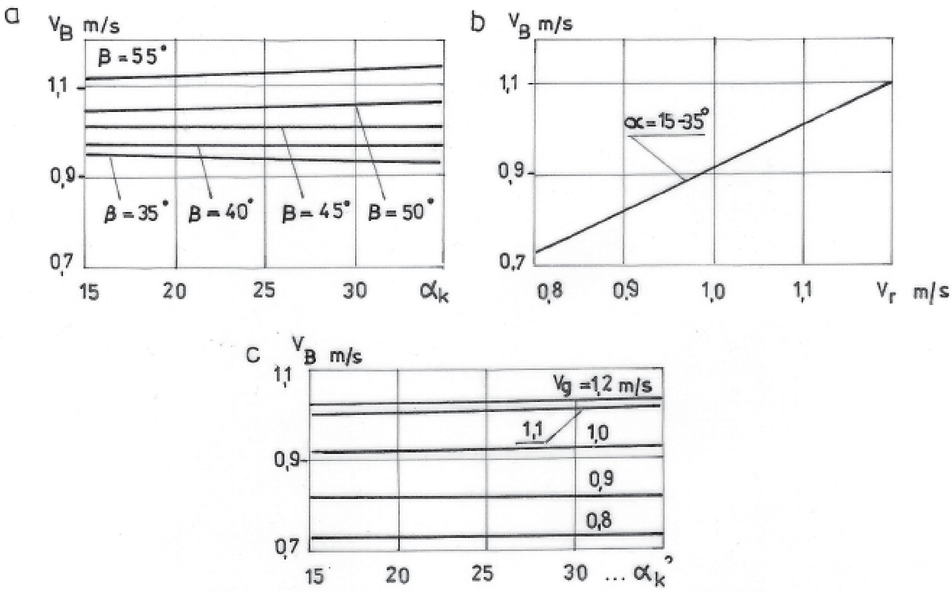


Fig. 7. Diagram of the relations: a – $V_B = \oint(\alpha_k,\beta)$; b – $V_B = \oint(\alpha_k,V_g)$; c – $V_B = \oint(V_g,\alpha_k)$

Assuming that potatoes roll down the hump surface with speed $V_{az}$ and the speed of soil lumps $V_{abg}$ is equal to the hump speed $V_g$, the value of potato speed $V'_z$ at the moment of toss can be determined from relation 8.

$$V'_z = \sqrt{\left[V_B - V_{a_z}\sin(\beta+\Theta)\right]^2 + V_{a_z}^2\cos^2(\beta+\Theta)}\,. \tag{8}$$

The initial velocity of soil lumps at the moment of toss will be:

$$V'_{bg} \approx V_B. \tag{9}$$

Speeds $V'_z$ and $V'_{bg}$ will be oriented at angles $\psi$ and $\Theta$ , respectively.

$$\Psi = \left(\frac{\Pi}{2} + \Theta\right) - \gamma, \tag{10}$$

where:

$\Theta$ – is determined graphically, and:

$$\gamma' = \mathrm{arctg}\frac{V_{az}\cos(\beta+\Theta)}{V_B - V_{az}\sin(\beta+\Theta)}. \tag{11}$$

With known initial speeds $V'_z$, $V'_{bg}$ and toss angles $\psi$ and $\Theta$, the movement of potatoes and soil lumps relative to the axes of coordinates $\eta O\varepsilon$ can be described by means of the following relations:

$$\eta_z = V'_z t\cos\psi; \qquad \varepsilon_z = V'_z t\sin\psi - \frac{gt^2}{2};$$
$$\eta_{bg} = V_B t\sin\Theta; \qquad \varepsilon_{bg} = V_B t\cos\Theta - \frac{gt^2}{2}. \tag{12}$$

On the basis of relation (11), trajectories of potatoes and soil lumps at toss were obtained (Fig. 8).

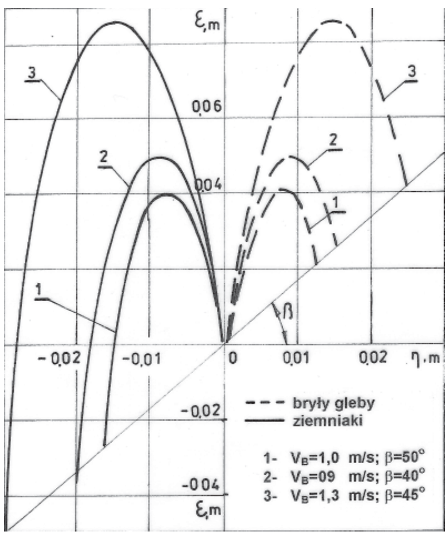


Fig. 8. Separation of potatoes at the shaking of hump area

As follows from Fig. 8, during the shaking of the finger hump working surface by means of the cam mechanism there takes place an efficient separation of the components of the technological mass; potatoes roll down the hump surface, and soil lumps and plant residue are carried by the upper hump surface section to the field behind the combine.

One of the factors affecting the character of the operation of the shake mechanism is the toss height, especially when it is limited from above, e.g. by the haulm separator conveyor. Such a situation may lead to disturbance in the process of separation of the components.

The highest position is attained by potatoes at point $\eta_1$, and by soil lumps at point $\eta_2$, when the vertical projection of speed equals zero, i.e. the components start to fall.

As a result of integration of relations (12) we obtain:

$$V_{\varepsilon Z} = V_Z \sin\psi - gt_1' = 0;$$
$$V_{\varepsilon bg} = V_S \cos\Theta - gt_1'' = 0, \tag{13}$$

where:
$V_s$ – fall speed.

Relations (13) permitted obtaining expressions defining the time of the start of falling:

$$t_1' = \frac{V_Z \sin\psi}{g},$$
$$t_1'' = \frac{V_S \cos\Theta}{g}. \tag{14}$$

Substituting the values $t_1'$ and $t_1''$ in relations (13) we obtained the coordinates of potatoes and soil lumps at the moment of their drop onto the hump surface after the toss (15):

$$\eta_Z = \frac{V_Z^2 \sin\psi \cos\psi}{g} = -\frac{V_Z^2 \sin 2\psi}{2g}; \quad \varepsilon_{1Z} = \frac{V_Z^2 \sin^2\psi}{2g}, \tag{15}$$
$$\eta_{1bg} = \frac{V_S^2 \sin 2\Theta}{g}; \quad \varepsilon_{1bg} = \frac{V_S^2 \cos^2\Theta}{2g}.$$

On the basis of relations (15), the optimum height of potato drop onto the hump – $h_z$ – was determined:

$$h_Z = \varepsilon_{1Z} + \eta_{1Z} \mathrm{tg}\beta. \tag{16}$$

To minimise potato damage during their drop onto the hump it is necessary that the condition (17) be fulfilled:

$$\sqrt{2gh_Z} \le |V_Z|, \tag{17}$$

where:
$|V_Z| = 2{,}2\ \mathrm{m \cdot s^{-1}}$ – permissible speed of potato impact [Pietrow 1982].

The optimum cam spacing $T_1$ (Fig. 3) results from the condition:

$$T_1 = e + c \text{ or } T_1 = 2c + r, \tag{18}$$

where:
$c$ – cam length,
$e \approx c + r$ – length of arc created by point „$B$”,
$r$ – radium of shaking roller.

If $T_1 > 2c+r$, then a part of the potatoes will pass above the shake mechanism, but without the toss, and if $T_1 < 2c + r$, then the surface of the hump will not drop onto the roller and the process of tossing will not be possible.

To determine the efficiency of the modification of the finger hump, a laboratory-field test was performed using a KSK-4-1 combine equipped with the modified finger hump. On the basis of the obtained results, an analysis was made of the relation:

$$Z,P = f(\beta, A, V_g), \tag{19}$$

where:
$\beta$ – depression angle of the hump ($X_1$),
$A$ – shake amplitude ($X_2$),
$V_g$ – working speed of the hump surface ($X_3$),
$Z$ – $Y_{1'}$ – crop purity,
$P$ –$Y_{2'}$ – level of losses.

Realization of the field tests permitted the obtainment of regression equations describing the process of separation on the finger hump:

$$Y_1 = 84{,}81 + 7{,}8X_1 - 2{,}9X_2 - 3{,}0X_3 - 4{,}3X_1^2 - 10{,}9X_2^2 - 7{,}0X_3^2. \tag{20}$$

$$Y_2 = 7{,}1 - 5{,}2X_1 - 3{,}5X_2 - 1{,}1X_3 + 3{,}5X_2^2 + 1{,}9X_1X_2. \tag{21}$$

As a result of differentiation of relations (18) and (19), the optimum values were obtained for the operation parameters of the modified hump, at which the crop purity $Z$ is the maximum and the losses of tubers $P$ are minimal:

for $Z_{max} = 88.9\%$
$\beta_{opt} = 40.4^o$
$A_{opt} = 11.8$ mm
$Vg_{opt} = 1.02$ m· s$^{-1}$

for: $P_{\min} = 3.0\%$
$\beta_{opt} = 50^o$
$A_{opt} = 15$ mm
$Vg_{opt} = 0.89$ m· s$^{-1}$.

The data were analysed according to literature given by Mielnikov [1980] and Pabis [1985].

## CONCLUSION

An analysis of the above parameters shows that the separation capacity of the finger hump can be increased through the changing of the values of amplitude $A$ and velocity $Vg$. It is more difficult to obtain that aim through changing the depression angle $\beta$ of the hump, as there is a feedback relation between the crop purity and crop losses.

To reduce tuber losses to a minimum, angle $\beta$ should be increased to 45$^o$, and the shake amplitudes to $A$ = 13 mm. With such operation parameters of the modified hump the crop purity level was $Z$ = 85.1% , tuber losses were $P$ = 7.4%, while for the production finger hump those values were $Zs$ = 80% and $Ps$ =16%, respectively.

Application of the modified finger hump in the KSK-4-1 combine permitted labour reduction by 220 man-hours, and a reduction of total costs of harvesting and post-harvest processing by PLN 10,528 for a model plantation of 100 ha.

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## WPŁYW WYBRANYCH PARAMETRÓW ROBOCZYCH GÓRKI PALCOWEJ Z MECHANIZMEM WSTRZĄSAJĄCYM NA JAKOŚĆ SEPARACJI

**Streszczenie.** W publikacji przedstawiono jedną z możliwości zwiększenia skuteczności separacji mieszaniny technologicznej na górce palcowej w maszynach do zbioru ziemniaków. Efekt ten uzyskano poprzez zastosowanie mechanizmu wstrząsającego. Rozpatrzono wpływ parametrów roboczych zmodernizowanego zespołu na jakość separacji mieszaniny technologicznej. W wyniku przeprowadzonej analizy procesu separacji określono optymalne wartości parametrów roboczych.

**Słowa kluczowe:** górka palcowa, mechanizm wstrząsający, parametry robocze, kinematyka, jakość separacji.