DOI: 10.22620/agrisci.2016.20.014

CUTTING ANGLE OF THE VERTICAL ROTARY SOIL TILLAGE UNIT WITH AN ACTIVE DRIVE

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Abstract

The theoretical study is designed to determine the cutting angle of the soil processing plant with an active movement, and a vertical axis of rotation. The angle of cutting is formed by the front working surface of the blade and the tangent to the trajectory that passes through the knife blade and coincides with the direction of the cutting speed. The cutting angle during the process of cutting the soil chips is constantly changing depending on the angle of rotation of the knife.

As a result of the study the influence of the working mode was established and a theoretical dependence of the cutting angle was derived – $\alpha P=\alpha min+\Delta\alpha max-\Delta\alpha$. Its value was determined depending on the mode of operation and design parameters of the working units of the machine.

Key words: tillage, cutting angle.

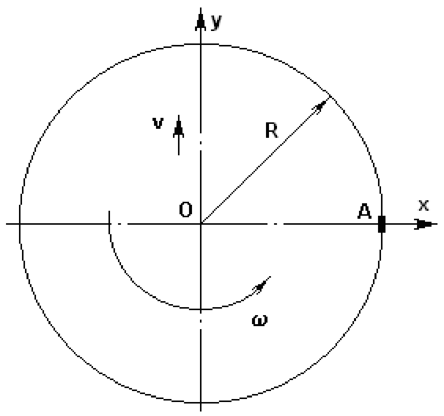
INTRODUCTION

The Quality of energy expense of the technological process for Tilling machines with active drive and a vertical axis of rotation is influenced by many factors, the main ones are: physical and mechanical properties of soil; cutting speed; particle thickness of the soil; cutting angle; the length of the cutting path; shape of the soil particle (Marchenko, Bychkov, 1980).

The cutting angle in this type of tilling machines is formed from the front working surface of the knife and the tangent to the trajectory of movement that passes through the cutting edge of the blade and coincides with the direction of the cutting speed. The cutting angle depends on the structural and kinematic parameters of the working bodies of the machine. (Marchenko, Bychkov, 1979; Marchenko, Bychkov, 1981). Kinematics characteristic of this type of tilling machines is that a variation of the angle of rotation of the blades contribute to change the angle of cut. (Jatsuk et al., 1971).

Purpose of theoretical research is to derive analytical dependence for determining the cutting angle of the cultivating working body with actively drive and a vertical axis of rotation depending on the mode of operation, structural and kinematics parameters.

Object of the theoretical study is a vertical rotor with two blades (z=2). Vertical knife ”A” is with initial position t=0 on the x-axis Ox. Forward movement has a speed ”v”(carrying speed) in the direction of the ordinate Oy. The rotational movement (relative) is with angular velocity ω, having an axis with rotation perpendicular to the plane Oxy (fig. 1).



Structural and cinematic parameters:
R=160 mm - radius of the circle described by blade A;
n=300 min^{-1} – rotational speed of the knife;.
u=5,03 m/s – peripheral (relative) speed of the knife;
The equation describing the path of the blade A (Guglev, 2011):

$$y=\frac{R}{\lambda}.\left[\arccos\left(\frac{x}{R}\right)\right]+\sqrt{R^2-x^2}\ ,\ 0\le\varphi\le\pi\ ;$$

$$y=\frac{R}{\lambda}.\left[2\pi-\arccos\left(\frac{x}{R}\right)\right]-\sqrt{R^2-x^2}\ ,\ \pi<\varphi\le 2\pi\ ;$$

φ=ω.t - rotation angle of the knife;
t – time;
$\lambda=\frac{u}{v}$ - cinematic parameter.

***Fig. 1.** Initial position of the knife A at t=0*

Fig. 2. *Scheme of the vertical rotary soil tillage unit with active drive*

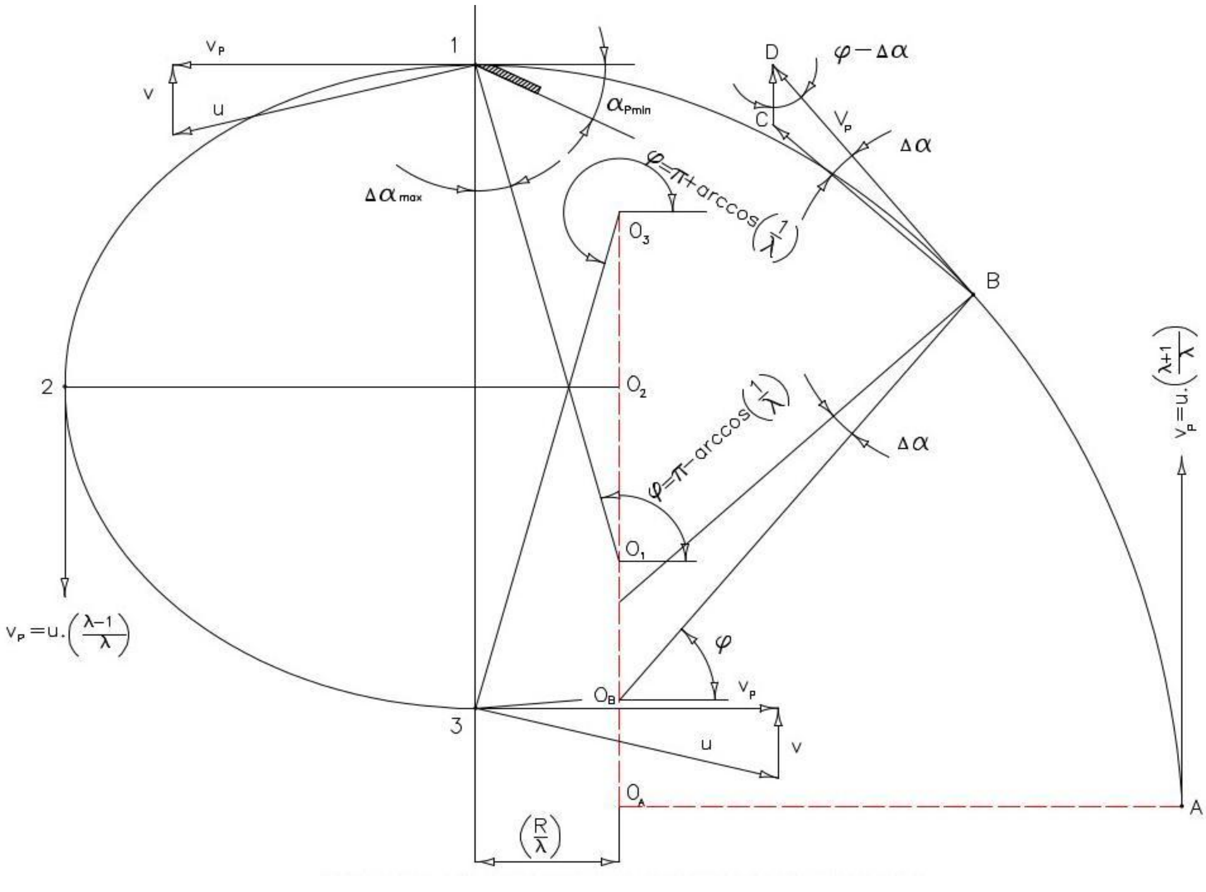


Fig. 3. *The path of the knife A*

MATERIALS AND METHODS

To clarify the influence, the mode of operation is making to the cutting angle, a theoretical study was conducted with the following values of kinematics parameters: λ_1=3,27 (v_1=1,54 m/s; S_1=15,4 cm and λ_2=5,05 (v_2=1,27 m/s; S_2=10,0 cm) (Guglev, 2014). Table 1 gives the magnitude and direction of the cutting speed for the key points of the path of the knife A (fig. 3).

Cutting speed - v_P

In the initial position of the blade (fig. 3, point A, ϕ=0), the cutting speed is the algebraic sum of the carrying and the relative speed, as they are collinear and unidirectional vectors.

$$v_P = u.\left(\frac{\lambda+1}{\lambda}\right) \quad (1)$$

When increasing angle of rotation of the blade, the direction of the relative velocity deviates from the direction of the carrying speed, resulting in the reduction of the cutting speed. From ΔBCD in fig. 3, in point B, the cutting speed is:

$$v_P = u.\left[\cos\Delta\alpha + \frac{1}{\lambda}.\cos(\varphi - \Delta\alpha)\right] \qquad (2)$$

where Δα is the angle between the directions of the cutting speed and the relative speed of the knife (angle between the tangents to the relative and absolute path of the blade).

Determining the angle between the cutting speed and the relative speed of the knife - Δα

From ΔBCD on fig. 3, using the sinus theorem $\frac{u}{\sin(\varphi-\Delta\alpha)} = \frac{v}{\sin\Delta\alpha}$, but $v = \frac{u}{\lambda}$. Therefore $\frac{u}{\sin(\varphi-\Delta\alpha)} = \frac{u}{\lambda.\sin\Delta\alpha}$, and after appropriate transformations, angle Δα equals:

$$\Delta\alpha = \arcsin\left(\frac{\sin\varphi}{\sqrt{\lambda^2 + 2.\lambda.\cos\varphi + 1}}\right) \qquad (3)$$

The analysis of equation (3) shows that the angle between the cutting speed and the relative speed of the blade depends on the angle of rotation of the knife and of the kinematics parameter. Table 2 indicates the values of the angle Δα for key points on the trajectory of the knife.

From formula (3) and fig. 4 a, b it is indicated that angle Δα decreases with the increasing value of the kinematic parameter and amended by sinusoidal law.

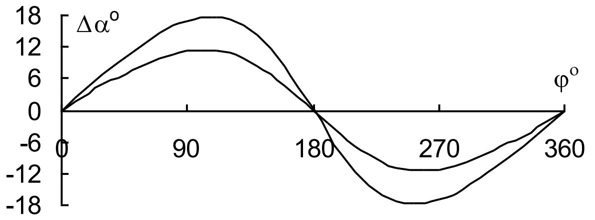
The initial $\phi_H=\omega.t_H$ and final $\phi_K=\omega.t_K$ angles of cutting of the soil chip are calculated after determining the periods t_H and t_K through iteration (Guglev, 2009).

Table 1. Size and direction of cutting speed v_P

Point	Angle of rotation of the knife φ, rad	Cutting speed - v_P	
		Magnitude	Direction
A	0	$u.\left(\frac{\lambda+1}{\lambda}\right)$	Collinear and with the same direction as the carrying speed
B	$0 < \varphi < \pi - \arccos\left(\frac{1}{\lambda}\right)$	$u.\left[\cos\Delta\alpha + \frac{1}{\lambda}.\cos(\varphi-\Delta\alpha)\right]$	Deviated with angle Δα from the relative speed
2	$\pi - \arccos\left(\frac{1}{\lambda}\right)$	$u.\cos\Delta\alpha$	Perpendicular to the carrying speed
3	π	$u.\left(\frac{\lambda-1}{\lambda}\right)$	Collinear and with the opposite direction of the carrying speed
4	$\pi + \arccos\left(\frac{1}{\lambda}\right)$	$u.\cos\Delta\alpha$	Perpendicular to the carrying speed

Table 2. Values of the angle Δα for specific points of the knifes path

φ, rad	0	$\frac{\pi}{2}$	$\pi - \arccos\left(\frac{1}{\lambda}\right)$	π	$\pi + \arccos\left(\frac{1}{\lambda}\right)$	$\frac{3\pi}{2}$	2π
Δα, rad	0	$\arcsin\left(\frac{1}{\sqrt{\lambda^2+1}}\right)$	$\arcsin\left(\frac{1}{\lambda}\right)$	0	$-\arcsin\left(\frac{1}{\lambda}\right)$	$-\arcsin\left(\frac{1}{\sqrt{\lambda^2+1}}\right)$	0



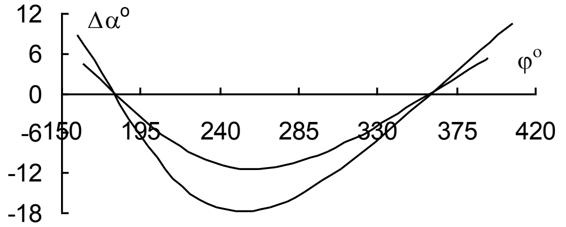
Maximum and minimum values of angle Δα

λ	$\Delta\alpha_{max}$ °	φ_1 °	$\Delta\alpha_{min}$ °	φ_2 °
3,27	17,8	107,8	-17,8	252,2
5,05	11,4	101,4	-11,4	258,6

$$\varphi_1 + \varphi_2 = 2\pi$$

$$|\Delta\alpha_{min}| = |\Delta\alpha_{max}|$$

Fig. 4 a. *Amendment of the angle* $\Delta\alpha = f(\lambda,\varphi)$ *for the rotation angle of the knife* $0 \le \varphi \le 2\pi$



λ	φ_H °	$\Delta\alpha_H$ °	φ_K °	$\Delta\alpha_K$ °
3,27	158,5	8,9	407,0	10,5
5,05	161,6	4,4	392,8	5,2

Fig. 4 b. *Amendment of the angle* $\Delta\alpha = f(\lambda,\varphi)$ *for the period of cutting soil chip* $\varphi_H \le \varphi \le \varphi_K$

Maximum and minimum values of the angle Δα

To determine the maximum and minimum values of the composite function Δα it is necessary Δα=0.

After the appropriate transformations of equation (3) the maximum and minimum values of the angle between the direction of the cutting speed and the relative speed of the blade, it is obtained:

- $\Delta\alpha_{max}$=arcsin (1/λ), which is achieved when the rotation angle of the knife is φ_1=π-arccos (1/λ);

- $\Delta\alpha_{min}$=-arcsin(1/λ), which is achieved whe the rotation angle of the knife is φ_2=π+arccos(1/λ).

With an increase in the kinematics parameter λ, the value of angle ϕ_1 decreases and angle ϕ_2 increases.Therefore $\Delta\alpha_{max}$ and $\Delta\alpha_{min}$ depend solely on the kinematics indicator. For values of, absolute values $|\Delta\alpha_{min}|$ and $|\Delta\alpha_{max}|$ grow intensive (fig. 5.), which influences the cutting angle. By increasing the value of λ, absolute values $|\Delta\alpha_{min}|$ and $|\Delta\alpha_{max}|$ decrease. The analysis of $\Delta\alpha_{max} = f(\lambda)$ and $\Delta\alpha_{min} = f(\lambda)$ shows that we can recommend values for kinematics parameter in the range $3{,}5 \le \lambda \le 6{,}0$. When λ>6, for the selected structural and kinematics parameters, the carrying speed reduces to (v<0,84 m/s), which is associated with a reduction step and increase crushing of the soil and increase of the energy intensity of the process.

The maximum and minimum values of the angle Δα are achieved at the intersection of the trajectory of the blade (trohoid) with the fixed centroid (Pisarev A. M. et al, 1974.). The fixed centroid is the geometric position of the instantaneous centers of rotation of the blade, and is extending from the axis of rotation with distance R/λ. In the case of p.1 and p.3 in fig. 2. With the increase of the kinematics parameter λ, the value of R/λ is reduced. This means that the fixed centroid approaches the geometric axis of the rotor.

RESULTS AND DISCUSSION

Cutting angle - α_P

The minimum value of the cutting angle is determined by the constructive parameters of the blade (Jatsuk E.P. et al. 1971):

$$\alpha_{min}=\beta+\Delta\varepsilon,$$

where β=20°÷25° is the sharpening angle of the knife; Δε=3°÷5° - the angle between the rear surface of the blade and tangent to the trohoid, providing minimum distance between the rear edge of the knife and untreated soil.

This value of the cutting angle is achieved when the rotation angle of the knife is φ_1=π-arccos (1/λ), wherein the angle between the direction of the cutting speed and the relative speed of the knife Δα is a maximal (fig. 3, point 1).

For the study the minimum value of the cutting angle is α_{min}=25,4°.

In the initial position of the blade (fig. 3, p. A, φ=0), angle Δα=0, cutting angle coincides with the direction of the cutting speed and the value is determined by the equation:

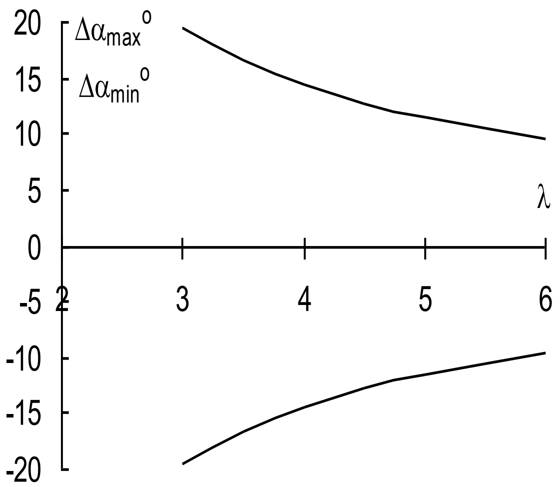
$$\alpha_P=\alpha_{min}+\Delta\alpha_{max} \quad (4)$$

With increasing angle of rotation of the blade, angle Δα is also growing and the final formula for the cutting angle acquires the kind:

$$\alpha_P=\alpha_{min}+\Delta\alpha_{max}-\Delta\alpha \quad (5)$$

where Δα is the current value of the angle between the directions of the cutting speed and the relative speed.

With increasing kinematics parameter λ range for the cutting angle constricts (fig. 6). The minimum value of the cutting angle is $\alpha_{P_{min}}=\alpha_{min}$ and is achieved at an angle of rotation of the knife φ_1=π-arccos (1/λ) where Δα angle has a maximum value. The maximum value of the cutting angle is $\alpha_{P_{max}}=\alpha_{min}+2\Delta\alpha_{max}$ at φ_2=π+arccos (1/λ) where Δα angle has a minimum value. Therefore cutting angle varies between $\alpha_{min}\le\alpha_P\le\alpha_{min}+2\Delta\alpha_{max}$.

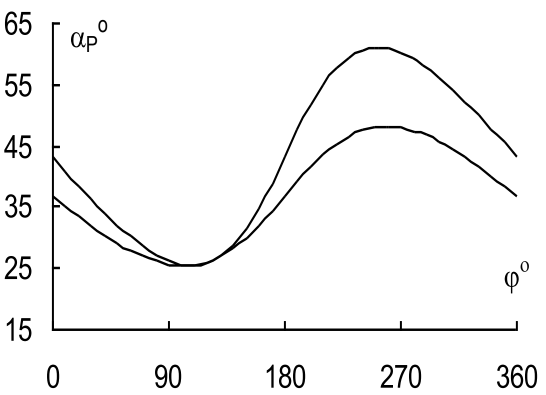


λ	3	4	5	6
$\Delta\alpha_{max}$°	19,5	14,5	11,5	9,6
$\Delta\alpha_{min}$°	-19,5	-14,5	-11,5	-9,6
R/λ, mm	53,3	40,0	32,0	26,7

z	λ	v, m/s	S, cm	R/λ, mm
2	3	1,68	16,8	53,3
	4	1,27	12,6	40,0
	5	1,00	10,0	32,0
	6	0,84	8,4	26,7

$v=10^{-3}.\pi.n.R/30.\lambda$, m/s; $S=0,1.\pi.D/\lambda.z$, cm

Fig. 5. *Modification of the angles* $\Delta\alpha_{max}$ *and* $\Delta\alpha_{min}$ *depending on the kinematics parameter* λ



φ, rad	0	$\frac{\pi}{2}$	π-arccos(1/λ)	π	π+arccos(1/λ)	2π
λ_1=3,27						
α_P°	43,2	26,2	25,4	43,2	61,0	43,2
λ_2=5,05						
α_P°	36,8	25,6	25,4	36,8	48,2	36,8

Fig. 6. *Modification of the cutting angle* α_P *depending on the angle of rotation of the knife* $0\le\varphi\le2\pi$

Ratio of variation of the cutting angle for rotation of the knife $0 \le \varphi \le 2\pi$

$$k_\alpha = \frac{\alpha_{P_{max}}}{\alpha_{P_{min}}} = \frac{\alpha_{min} + 2\Delta\alpha_{max}}{\alpha_{P_{min}}} = 1 + \frac{2\Delta\alpha_{max}}{\alpha_{P_{min}}}$$

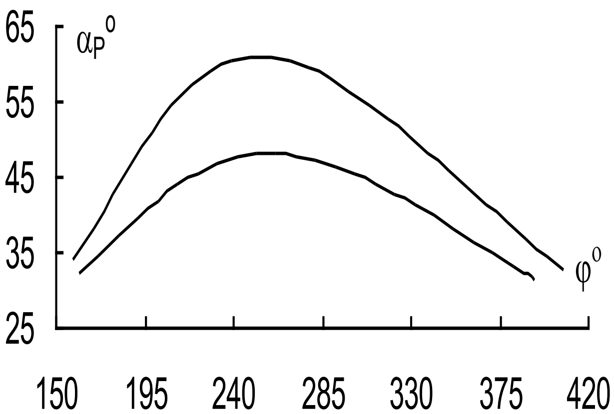
In fig. 7 shows variation of the cutting angle for the period of cutting a soil chip.

At λ_1=3,27. At the beginning of the soil chip cutting, the cutting angle is $\alpha_{P_H} = 34{,}3^\circ$ With increasing angle of rotation of the blade, the cutting angle increases and at $\varphi = 252{,}2^\circ$ reaches its maximum value - $\alpha_{P_{max}} = 61{,}0^\circ$ **.** With further increase in angle ϕ, the cutting angle decreases. At the end of the soil chip cutting - $\alpha_{P_K} = 32{,}7^\circ$. The difference between α_{P_H} and α_{P_K} is minor - 1,6˚. The difference between the maximum and minimum values of the cutting angle for the period of the soil chip cutting $\alpha_{P_{max}} - \alpha_{P_K} = 28{,}3$ °. The ratio of increase of the cutting angle for the period of the soil chip cutting is k_α=1,78.

At λ2=5,05. At the beginning of the soil chip cutting - $\alpha_{P_H} = 32{,}4^\circ$. With increasing angle of rotation of the blade, the cutting angle α_P increases and at $\varphi = 258{,}6^\circ$ reaches it's maximal value. With further increase in the angle of rotation of the knife, the cutting angle decreases. At the end of the soil chip cutting - $\alpha_{P_K} = 31{,}6^\circ$. The difference between α_{P_H} and α_{P_K} is minor - 0,8˚. The difference between the maximum and minimum values of the cutting angle for the period of the soil chip cutting is $\alpha_{P_{max}} - \alpha_{P_K} = 16{,}6^\circ$. The ratio of increase of the cutting angle for the period of the soil chip cutting is k_α=1,49.

Therefore, when increasing the value of the kinematics parameter λ, the value of the cutting angle decreases. The difference between the maximum values of the cutting angle for the studied modes is 12,8˚.

For the angle of rotation of the blade $\varphi = 2\pi - \arccos\left(\frac{1}{\lambda}\right)$ where, the soil chip has a maximum thickness - δ_{max} (Guglev, Vassileva, 2010), the cutting angle is α_P=58,1° (λ=3,27), α_P=47,4° (λ=5,05), $\varphi_{\delta_{max}} - \varphi_{\alpha_{P\,max}} = \pi - 2\arccos\left(\frac{1}{\lambda}\right)$ as. These values of the cutting angle are very close to maximum value of the cutting angle - $\alpha_{P_{max}}$ for the respective mode of operation, as $\varphi_{\delta_{max}}$ is achieved after $\varphi_{\alpha_{P\,max}}$.



β=20˚; $\Delta\varepsilon = 5{,}4^\circ$

α_{min}=25,4°

λ	$\alpha_{P_H}{}^\circ$	$\alpha_{P_{max}}{}^\circ$	$\alpha_{P_K}{}^\circ$	$\alpha_{P_{CP}}{}^\circ$
3,27	34,3	61,0	32,7	49,2
5,05	32,4	48,2	31,6	41,1

Fig. 7. *Modification of the cutting angle α_P for the period of cutting of the soil chip* $\varphi_H \le \varphi \le \varphi_K$.

λ	$\varphi_{\delta_{max}}{}^\circ$	$\alpha_P{}^\circ$	$\varphi_{\delta_{max}} - \varphi_{\alpha_{P\,max}}{}^\circ$
3,27	287,8	58,1	35,6
5,05	281,4	47,4	22,8

CONCLUSIONS

1. As a result of theoretical study it has been established analytical dependency of the cutting angle for soil processing machines with active drive and a vertical axis of rotation - $\alpha_P = \alpha_{min} + \Delta\alpha_{max} - \Delta\alpha$.

2. Cutting angle α_P is amended by sinusoidal law and by the increasing kinematics parameter λ, the value and limits of its amendment are reduced.

3. The range for cutting angle is $\alpha_{min} \le \alpha_P \le \alpha_{min} + 2\Delta\alpha_{max}$.

4. The difference between the values of angle of rotation with the maximum thickness of the soil chip and the maximum angle of cut is

$$\varphi_{\delta_{max}} - \varphi_{\alpha_{P\,max}} = \pi - 2\arccos\left(\frac{1}{\lambda}\right).$$

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