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Constant angle line of distributing seeds and fertilisers by a horizontal centrifugal machine

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Abstract. The article presents the results of research on the distribution of mineral fertilisers and seeds by centrifugal spreaders on the field surface. A uniform distribution of seeds and mineral fertilisers by centrifugal spreaders depends on a variation of such parameters as mathematical expectation of a throwing angle and its standard deviation. The purpose of the research presented in the article is to check the reliability of the results of calculating the throwing angle of a centrifugal spreader by different methods in the Mathcad programme. The article considers the equation of particle motion on the blade of a centrifugal disc in order to determine the throwing angle of particles after coming off the blade. On the basis of this equation in the Mathcad programme, calculations of the throwing angle of the centrifugal distributor are made in three ways. The first two methods of calculation involve the use of the simplified formula of M.G. Doganovsky and V.V. Ryadnykh, obtained by solving the differential equation of particle motion along the blades of the centrifugal disc by discarding the exponent with a negative exponent. The third method of calculation is performed without simplifications and is taken by us as a reference. The results of comparative analysis of the used methods of calculation are given and the assumption about the violation of symmetry of the sieving sector with the increase in the seeding rate is put forward.

Keywords: centrifugal apparatus, calculation, characteristics, throwing angle, descent, scattering sector, particle movement, blade.

1 Introduction

Nowadays, trailed or mounted fertiliser spreaders with different designs of working bodies are used for spreading granular and powder fertilisers in crop production: centrifugal with blades on vertical or horizontal axes of rotation, a pendulum or boom type. The main objectives of research in the field of improvement of such devices are to reduce the unevenness of fertiliser distribution over the width, to increase the width of spreading, a throwing angle, as well as to reduce the time and labour costs of fertiliser application [1, 2].

The uniformity of fertiliser spreading by centrifugal devices depends on the correct adjustment of the numerical characteristics of the throwing angle: the mathematical expectation and its mean square deviation [3–7].

Moving the tuctor in the longitudinal or transverse direction leads to simultaneous changes in characteristics of the throwing angle, so the adjustment becomes more complicated, and it is not always possible to achieve the desired result [8].

Coordinate farming involves the use of a global positioning system to determine the coordinates of the field site and calculate the fertiliser application rate using an agrochemical map of the field and data on the planned yield [3]. The application rate is controlled by an on-board computer.

The design of the designed metering device must satisfy the condition that a change in the seeding rate of a mineral fertiliser would not lead to a change in the characteristics of the throwing angle. The main task facing the designers is to ensure a constant angle of descent during any fertiliser delivery to the centrifugal disc [9].

A special role in the design of centrifugal spreaders is played by the line of constant throwing angles that represent a geometric location of the fertiliser feed points on the disc, which ensure a constant set value of the angle of fertiliser run-off from the centrifugal disc of the spreader.

In previously published articles, such problem was solved in methodological terms. An approximate formula of M.G. Doganovsky and V.V. Ryadnykh was used to construct a line of constant throwing angles. The formula is obtained by solving the equation of particle motion along the centrifugal disc blade by discarding the exponent with a negative exponent.

Tests of the spreader with the metering device designed according to the simplified method were conducted in the educational and farming enterprise of

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the Azov-Black Sea Engineering Institute. The test results showed that the constancy of the mathematical expectation of the angle of fertiliser run-off from the centrifugal disc blade was not obtained. When increasing the feed, the sieve sector turns towards the centre of the sieve strip. Fertiliser spreading uniformity was adjusted using a two-section fertiliser catcher. The partition between its sections was located at an angle of 0.6 radian to the line of motion and it was tangential to the conditional disc of the radius $R_y = R\text{-}sin\theta$, where θ is the angle between the particle throwing velocity and the radius [10–13].

The purpose of the present work is to review the approaches to constructing a line of a constant throwing angle by three methods to find possible inaccuracies in the calculation and to obtain the constancy of the throwing angle.

2 Calculation methodology and discussion

Let us consider the movement of a fertiliser along the blades of a horizontal apparatus with blades deviated from the radius. In order to find numerical characteristics of particle motion (velocity and direction of motion) after its descend from the centrifugal distributor blade, it is necessary to consider the differential equation of particle motion on the blade of a horizontally rotating centrifugal disc (Fig. 1) [14, 15].

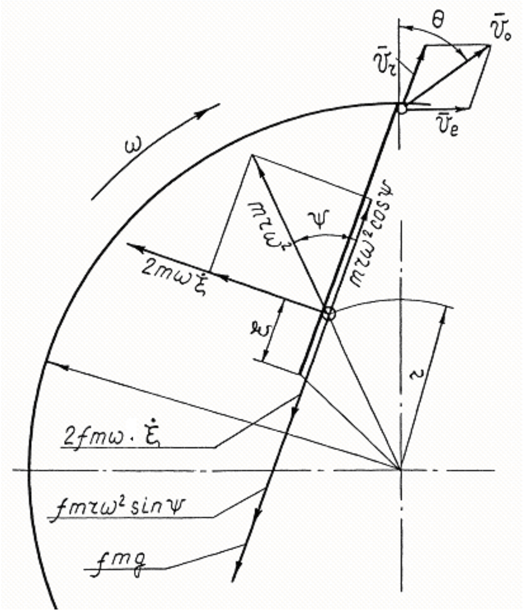


Fig. 1. Scheme for determining the displacement and velocity of the particle relative to the blade

The following forces act on a particle of mass m that falls on the blade of a centrifugal, horizontally rotating disc:

1) centrifugal force of inertia: $P_{ц} = mr\omega^2$;
2) Coriolis force of inertia: $Px = 2m\omega\xi'$;
3) normal support reaction: N;
4) frictional forces: fmg and fN.

Here, f *is* the coefficient of friction of a fertiliser against the blade and disc; ξ is the coordinate axis directed along the blade; r is the radius-vector of the particle.

The differential equation of motion of the particle has the form:

$$\xi'' = r\omega^2 \cdot cos\psi - fg - fr\omega^2 \cdot sin\psi - 2f\omega\xi'. \quad (1)$$

Since $r\ sin\psi = r_0\ sin\psi_0$ and $r\ cos\psi = \xi + r_0\ cos\psi_0$, then after transformations of the equation (1), we obtain:

$$\xi'' + 2f\omega\xi' - \omega^2\xi = r_0\omega^2 \cdot \frac{cos(\psi_0 + \varphi)}{cos\,\varphi} - fg, \quad (2)$$

where φ is the angle of friction of particles on the blade surface; r_0 is the radius of particle feeding on the blade; ψ is the blade inclination angle [16].

The left-hand side of the equation (2) with the characteristic equation: $\lambda^2 + 2f\text{-}\omega\text{-}\lambda - \omega^2 = 0$, has two real roots:

$$\lambda_1 = \frac{1 - sin\varphi}{cos\,\varphi}\omega; \text{ and } \lambda_2 = -\frac{1 + sin\varphi}{cos\,\varphi}\omega.$$

The partial solution of the equation (2) when $\xi' = 0$ and $\xi'' = 0$ is of the form: $\hat{\xi} = -r_0\dfrac{cos(\psi_0 + \varphi)}{cos\,\varphi} + \dfrac{fg}{\omega^2}$, in which we denote $A = \dfrac{fg}{\omega^2}$ and $B = r_0\dfrac{\cos(\psi_0 + \varphi)}{\cos\varphi}$, and then $\hat{\xi} = A - B$.

The overall decision is as follows:

$$\xi = C_1 e^{\lambda_1 \cdot t} + C_2 e^{\lambda_2 \cdot t} - B + A. \quad (3)$$

The integration constants are found when $t = 0;\quad \xi' = 0;\quad \xi'' = 0$:

$$C_1 = \frac{(B - A)\cdot\lambda_2}{\lambda_2 - \lambda_1} \text{ and } C_2 = -\frac{(B - A)\cdot\lambda_1}{\lambda_2 - \lambda_1}.$$

Substituting the integration constants into equation (3), we obtain:

$$\xi = (B - A)\left(\frac{\lambda_2}{\lambda_2 - \lambda_1}exp(\lambda_1 t) - \frac{\lambda_1}{\lambda_2 - \lambda_1}exp(\lambda_2 t) - 1\right). \quad (4)$$

According to the equation (4), we can plot the graph of the function $\xi(t)$. If on the same graph we draw a line corresponding to the full length of the blade, then by their intersection we will find the solution of the transcendental equation. The path of the ξ_R particle at the end of the blade is equal to:

$$\xi_R = R\,cos\psi_R - r_0\,cos\psi_0. \quad (5)$$

The point of intersection of the graphs of equations (4) and (5) gives the time of motion of the particle along the blade.

Using a multifunctional interactive calculator, a computer system Mathcad, the time t_1 of the particle's motion along the disc is more accurately found by solving the transcendental equation with the root function [17].

The relative velocity of particle movement along the blade is determined by differentiating the displacement by time:

$$\xi' = (B-A)\cdot\frac{\lambda_1\lambda_2}{\lambda_2-\lambda_1}\cdot(e^{\lambda_1 t}-e^{\lambda_2 t}). \quad (6)$$

The absolute velocity of the particle at the moment of its descend from the disc is found by summation of the vectors of the relative velocity $v_r = \xi'$ and the transport velocity $v_e = \omega R$ (Fig. 1).

The angle of the particle descend, i.e. angular displacement of the particle in absolute motion up to the moment of the descend from the blade, is found by the formula:

$$\omega t_1 = \omega t_1 + (\psi_0 - \psi_R). \quad (7)$$

Neglecting the terms fg/ω^2 and $e^{-\lambda 1t}$, M.G. Doganovsky and V.V. Ryadnykh obtained the formula:

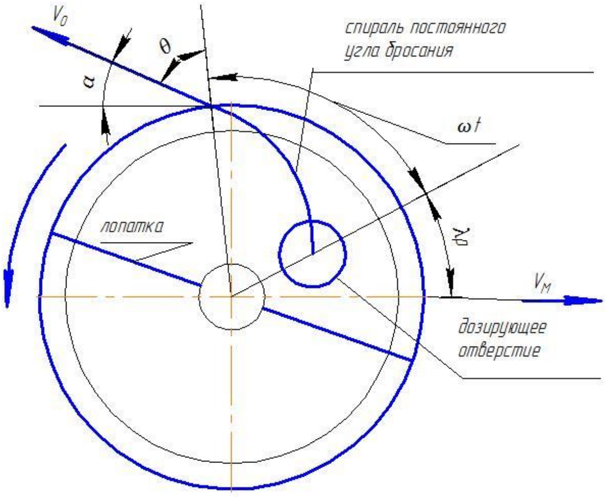
$$\omega t_1 = \frac{\cos\varphi}{1-\sin\varphi} ln\frac{2(r_0\cos(\varphi\mp\psi_0)+l\cos\varphi)}{r_0(1+\sin\varphi)\cos(\varphi\mp\psi_0)}, \quad (8)$$

where l *is* the length of the working part of the blade.

Let us call the angle α between the longitudinal coordinate axis and the initial velocity vector V_1 as the throwing angle. Obviously, for the left disc of the double-disc apparatus (Fig. 2):

$$\alpha = \lambda_p + \omega t + \theta - \pi, \quad (9)$$

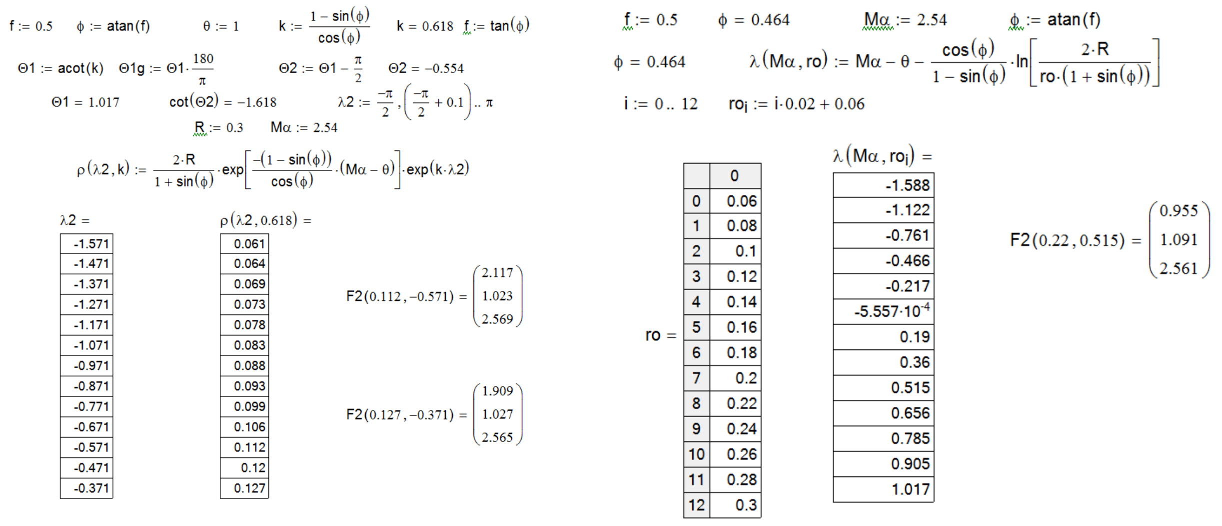
where λ_p is the polar angle of the particle feed point; ωt is the particle convergence angle.



Spiral of the constant throwing angle Blade Dispensing orifice
Fig. 2. Scheme for determining the throwing angle

If the throwing angle is counted from the velocity vector of the machine, then $\alpha = \lambda_p + \omega t + \theta$.

Let us compare the methods of constructing the line of a constant throwing angle for a disc with radial blades. The first method is described in a previously published scientific paper [2] and is shown in Figure 3a, and the second method is shown in Figure 3b [18].



$$f := 0.5 \quad \phi := \mathrm{atan}(f) \quad \theta := 1 \quad k := \frac{1-\sin(\phi)}{\cos(\phi)} \quad k = 0.618 \quad f := \tan(\phi)$$

$$\Theta1 := \mathrm{acot}(k) \quad \Theta1g := \Theta1\cdot\frac{180}{\pi} \quad \Theta2 := \Theta1 - \frac{\pi}{2} \quad \Theta2 = -0.554$$

$$\Theta1 = 1.017 \quad \cot(\Theta2) = -1.618 \quad \lambda2 := \frac{-\pi}{2}, \left(\frac{-\pi}{2}+0.1\right) .. \pi$$

$$R := 0.3 \quad M\alpha := 2.54$$

$$\rho(\lambda2, k) := \frac{2\cdot R}{1+\sin(\phi)}\cdot\exp\left[\frac{-(1-\sin(\phi))}{\cos(\phi)}\cdot(M\alpha-\theta)\right]\cdot\exp(k\cdot\lambda2)$$

λ2 =	ρ(λ2, 0.618) =
-1.571	0.061
-1.471	0.064
-1.371	0.069
-1.271	0.073
-1.171	0.078
-1.071	0.083
-0.971	0.088
-0.871	0.093
-0.771	0.099
-0.671	0.106
-0.571	0.112
-0.471	0.12
-0.371	0.127

$$F2(0.112, -0.571) = \begin{pmatrix} 2.117 \\ 1.023 \\ 2.569 \end{pmatrix}$$

$$F2(0.127, -0.371) = \begin{pmatrix} 1.909 \\ 1.027 \\ 2.565 \end{pmatrix}$$

(a)

$$f := 0.5 \quad \phi = 0.464 \quad M\alpha := 2.54 \quad \phi := \mathrm{atan}(f)$$

$$\phi = 0.464 \quad \lambda(M\alpha, ro) := M\alpha - \theta - \frac{\cos(\phi)}{1-\sin(\phi)}\cdot\ln\left[\frac{2\cdot R}{ro\cdot(1+\sin(\phi))}\right]$$

$$i := 0 .. 12 \quad ro_i := i\cdot 0.02 + 0.06$$

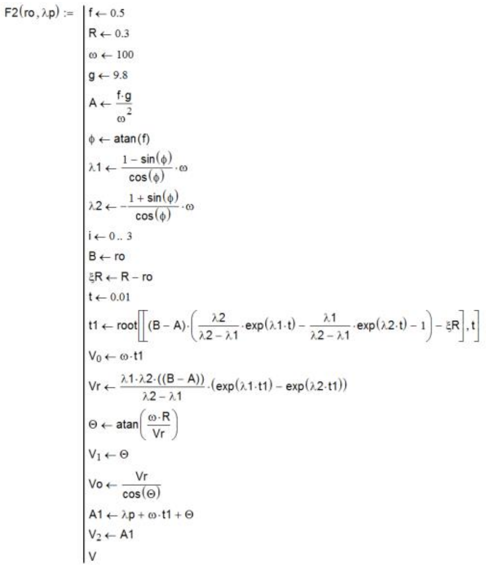
ro =	0	λ(Mα, ro$_i$) =
0	0.06	-1.588
1	0.08	-1.122
2	0.1	-0.761
3	0.12	-0.466
4	0.14	-0.217
5	0.16	$-5.557\cdot10^{-4}$
6	0.18	0.19
7	0.2	0.36
8	0.22	0.515
9	0.24	0.656
10	0.26	0.785
11	0.28	0.905
12	0.3	1.017

$$F2(0.22, 0.515) = \begin{pmatrix} 0.955 \\ 1.091 \\ 2.561 \end{pmatrix}$$

(b)

Fig. 3. Calculation of coordinates of the line of a constant throwing angle in Mathcad: a) by the first method; b) by the second method

The programme in the multifunctional interactive calculator Mathcad calculates the angle of throwing by the third method shown in Figure 4.



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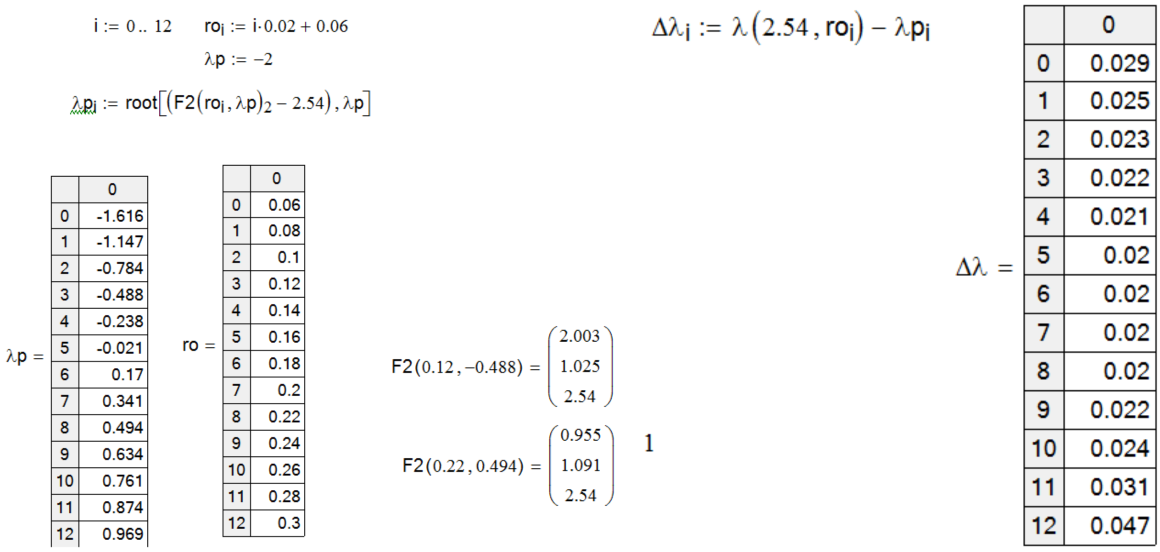
F2(ro, λp) := | f ← 0.5
              | R ← 0.3
              | ω ← 100
              | g ← 9.8
              | A ← $\frac{f \cdot g}{\omega^2}$
              | ϕ ← atan(f)
              | λ1 ← $\frac{1-\sin(\phi)}{\cos(\phi)} \cdot \omega$
              | λ2 ← $-\frac{1+\sin(\phi)}{\cos(\phi)} \cdot \omega$
              | i ← 0.. 3
              | B ← ro
              | ξR ← R − ro
              | t ← 0.01
              | t1 ← root$\left[\left[(B-A)\cdot\left(\frac{\lambda 2}{\lambda 2-\lambda 1}\cdot\exp(\lambda 1\cdot t)-\frac{\lambda 1}{\lambda 2-\lambda 1}\cdot\exp(\lambda 2\cdot t)-1\right)-\xi R\right],t\right]$
              | V_0 ← ω·t1
              | Vr ← $\frac{\lambda 1\cdot\lambda 2\cdot((B-A))}{\lambda 2-\lambda 1}\cdot(\exp(\lambda 1\cdot t1)-\exp(\lambda 2\cdot t1))$
              | Θ ← atan$\left(\frac{\omega\cdot R}{Vr}\right)$
              | V_1 ← Θ
              | Vo ← $\frac{Vr}{\cos(\Theta)}$
              | A1 ← λp + ω·t1 + Θ
              | V_2 ← A1
              | V
```

Fig. 4. Programme listing for the Mathcad computer system for calculating the throwing angle

Figure 5a shows the calculation of the coordinates of the line of a constant throwing angle by the third method. Figure 5b shows the error of the coordinates of the line of a constant throwing angle by the second and third methods of calculation [19, 20].



$i := 0..12 \qquad ro_i := i \cdot 0.02 + 0.06$

$\lambda p := -2$

$\lambda p_i := \mathrm{root}\left[\left(F2(ro_i, \lambda p)_2 - 2.54\right), \lambda p\right]$

λp =

	0
0	-1.616
1	-1.147
2	-0.784
3	-0.488
4	-0.238
5	-0.021
6	0.17
7	0.341
8	0.494
9	0.634
10	0.761
11	0.874
12	0.969

ro =

	0
0	0.06
1	0.08
2	0.1
3	0.12
4	0.14
5	0.16
6	0.18
7	0.2
8	0.22
9	0.24
10	0.26
11	0.28
12	0.3

$$F2(0.12, -0.488) = \begin{pmatrix} 2.003 \\ 1.025 \\ 2.54 \end{pmatrix}$$

$$F2(0.22, 0.494) = \begin{pmatrix} 0.955 \\ 1.091 \\ 2.54 \end{pmatrix} \quad 1$$

$\Delta\lambda_i := \lambda(2.54, ro_i) - \lambda p_i$

Δλ =

	0
0	0.029
1	0.025
2	0.023
3	0.022
4	0.021
5	0.02
6	0.02
7	0.02
8	0.02
9	0.022
10	0.024
11	0.031
12	0.047

(a) (b)

Fig. 5. Calculation of the coordinates of the line of a constant throwing angle by the third method (a) and the error of the coordinates of the line of a constant throwing angle when calculated by the second and third methods (b)

Analysing the data (see Fig. 5b), we note that the calculation error equal to 0.02...0.03 radians cannot be the reason for the violation of symmetry of the sieve sector with respect to the partition set at an angle of 0.6 radians to the line of motion [21].

The only reason for the symmetry of the sieving sector in relation to the partition to be broken is that the impact interaction between the fertiliser jet and the blade is more significant when the feed radius is increased. As a result of the impact, the fertiliser feed zone on the blade is pulled out in the direction of disc rotation. The angle of additional rotation of the sieving sector due to the impact of the fertiliser jet with the blade is found using the inverse normal distribution function, which was found using the computer algebra system Mathcad (Figure 6a) [22].

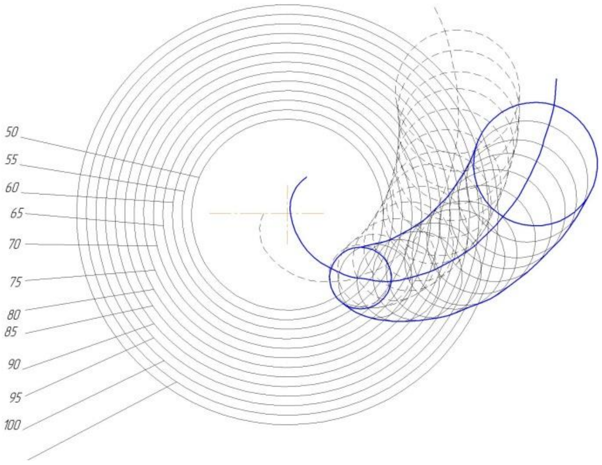
Therefore, the sieve sector is rotated in the direction of disc rotation by 29°. In order to obtain a symmetrical sieving sector with respect to the partition, it is necessary to rotate the slot of the dosing flap with respect to the centre of the small opening by 29° against the rotation of the disc (Figure 6b) [22].

$$\mathrm{qnorm}(0.8, 0.6, 0.6) = 1.105$$

$$1.105 - 0.6 = 0.505$$

$$0.505 \cdot \frac{180}{\pi} = 28.934$$

(a)



(b)

Fig. 6. Calculation of the angle of rotation of the sieve sector due to the impact action of the blade (a) and construction of the metering slot (b)

3 Conclusion

Based on the calculations performed and their discussion, the following conclusions can be drawn:

1. Construction of the line of a constant throwing angle by an approximate formula gives an error of 0.02...0.03 radians, which is acceptable when designing the metering unit.
2. The test of the spreader with metering flaps made according to logarithmic spirals showed that the spreading sector during maximum feeding rotates in the direction of disc rotation by an angle of up to 29 degrees.
3. In order to obtain a scattering sector symmetrical with respect to the baffle set at an angle of 0.6 radians with respect to the line of travel, it is necessary to rotate the metering slot by an angle of 29° with respect to the centre of the small metering hole [23–24].

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