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Method of calculating the length of the cutting path tillage milling

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ABSTRACT: Investigated the length of the cutting path L-shaped knife. The effects of the radius of the milling drum, the kinematic mode and the number of knives on one side of the flange are determined. Conclusions and recommendations for reducing the energy intensity of tillage.

I. INTRODUCTION

The undeniable high agrotechnical efficiency of milling machines, despite the high energy intensity, makes them more and more indispensable in improving meadows and pastures, pre-sowing treatment, inter-row processing, as well as for working in gardens and vegetable gardens.

Intensive wear of working bodies and high energy intensity of soil mills still hinders their widespread use in agriculture. Theoretical and experimental studies conducted by many researchers show that under all equal conditions it is possible to reduce energy intensity by reducing the diameter of the milling drum and the choice of operating modes.

Some authors believe that the smaller the diameter of the drum cutter, the lower the metal intensity of the machine and the lower the torque on the shaft of the drum [1]. Others believe that the diameter of the drum does not significantly affect the energy intensity of the cutter [2], 1950), and I.S. Poltavtsev even believes that to reduce energy costs, it is advisable to increase the diameter of the cutter [3].

Many of them believe that reducing the diameter of the cutter leads to a decrease in the energy intensity of milling. All studies related to the study of the dependence of energy intensity on the diameter of the milling drum can be divided into two groups. Some researchers explain the reduction in power consumption for milling with a decrease in the diameter of the milling drum by reducing the thickness of the chips and the path traveled by the knife in the soil in one revolution of the cutter (Danielyan A.M., 1936, Poltavtsev I.S., 1954, Popov G.F., 1963, Surilov V.S., 1965)[3,4,5,6].

Others believe that with a decrease in the diameter of the milling drum at a constant high-speed mode, the chip thickness increases, and the specific energy consumption decreases (Söhne W and Thiel R, 1957, Kanev N.F., 1957, Bernatsky G., 1981)[7,8,9].

G.F. Popov recommends the diameter of the cutter to choose from the condition in which the gear housing, bolts and other protruding parts do not crash into untreated soil. He proposed the following dependency

$$R = \sqrt{r_n^2 - S + 2S\sqrt{h(\frac{\lambda}{\pi}Sz - h)}},$$

where m - is the radius of the circle described by the protruding parts of the disk;
z - is the number of one-sided knives on the disk [5].

V.Zone and R.Thiel recommends choosing a drum radius depending on the depth of processing from the ratio $h_{max}/R = 1$ [7].

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When choosing a diameter, A.D.Lukyanov suggests checking the drum for the condition of free unloading of cut soil from the space between the knives and the drum shaft:

$$R = 2azk_{раз}/(\lambda k_{зап}$$

where*a* - is the depth of processing;
z- is the number of knives;
k_{raz} - coefficient of soil loosening;
k_{zap} - the filling factor of the soil volume between the drum casing and the bottom surface [10].

All these conclusions and dependencies are based on predefined parameters of the tillage depth; drum radius, number of knives, knife feed, kinematic mode, and loosening and filling coefficients.

To check the effect of the drum diameter on the power consumption, a milling drum with L-shaped knives of three diameters (0.16; 0.24; and 0.32) was tested, the dependencies of the above parameters were plotted. The most favorable milling conditions from the point of view of energy expenditure at the depth of the drum (0.71 ... 0.83) D when milling "top-down", when milling "bottom-up" (0.8 ... 0.91) D. At the same time, the feed rate per knife (S) remained the same, and the peripheral speed, cutting speed and number of knives changed. It was determined that the reason for reducing energy costs is to reduce the length of the path traveled by the knife in the soil and the degree of crushing of the soil does not depend on the diameter of the cutter [11].

On the basis of these data, it can be concluded that with an increase in the drum radius and the depth of tillage, an increase in energy intensity obviously needs to be taken as an axiom. The influence of the number of knives and the kinematic mode must be clarified, since the precise determination of the effect of the parameters of the drum on the cutting path length is crucial in determining the depth of processing and determining the parameters of the milling drum. The purpose of this study was to calculate and determine the influence of the diameter of the milling drum, the kinematic mode and the number of knives on one side of the flange on the length of the cutting path of the soil by the end of the L-shaped knife.

II. THEORY AND METHODS

For the analytical study of the length of the cutting path using the formula [11]:

$$\ell = 2R\frac{1+\lambda}{\lambda}\left[2\int_0^{90^\circ}\sqrt{1-k^2 sin^2\varphi}d\varphi - \int_0^{90^\circ-\frac{\alpha 1}{2}}\sqrt{1-k^2 sin^2\varphi}d\varphi - \int_0^{90^\circ-\frac{\alpha 2}{2}}\sqrt{1-k^2 sin^2\varphi}d\varphi\right] \quad (1)$$

$$\ell = 2R\frac{1+\lambda}{\lambda}\left[\int_0^{90^\circ-\frac{\alpha 1}{2}}\sqrt{1-k^2 sin^2\varphi}d\varphi - \int_0^{90^\circ-\frac{\alpha 2}{2}}\sqrt{1-k^2 sin^2\varphi}d\varphi\right] \quad (2)$$

where ℓ - cutting line length, m;

$$k = \frac{2\sqrt{\lambda}}{1+\lambda}; \ \varphi = 90^\circ - \frac{\alpha_{1;2}}{2} \text{ or } \varphi = \frac{\alpha_{1;2}}{2};$$

α_1 – the angle between the vertical and the radius to the point of intersection of the trajectory of the point of the blade with the soil surface;
α_2– the angle between the vertical and the radius passing through the top of the ridge.

Formulas (1) and (2) refer to the type of elliptic integrals of the second kind. They can be calculated approximately using tables of elliptic integrals. The calculation in this way is very laborious and their results differ from the actual length of the cutting path.

Based on the above equations, it is difficult to assess the nature of the change in the length of the cutting line depending on the parameters R, λ, z, h.

The solution of the problem can be approached in another way, which is covered in the future.

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A. Direct rotation of the milling drum.

The extreme point of the blade of the knife when tilling the soil passes the way along the trochoid from point *D* to point *M* (Fig. 1, *a*). In this case, the cutter drum is rotated by an angle $\Delta\alpha$, which is determined by the difference in the angles α_1 and α_2 of the marking positions of the blade point of the knife at the beginning and end of cutting.

Along the relative trajectory it can be seen (Fig. 1, *b*) that the horizontal movement of the knife is equal to the length of the arc of the OS against the direction of the translational velocity υ in the radius r_0. The end of the knife blade extends the path along the arc *AB* in radius *R*, the direction of which is opposite to the translational velocity.

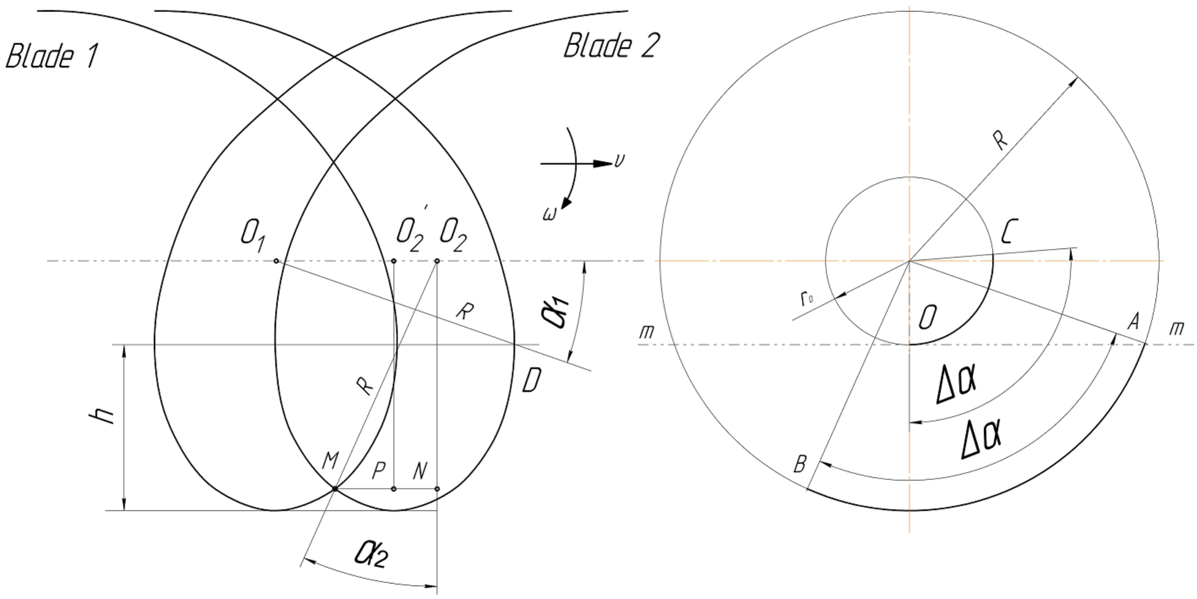

Fig.1. Schemes to determine the length of the cutting path for direct milling

By subtracting from the length of the arc *AB* the length of the arc *OC* and multiplying by the coefficient of complexity of the movement, you can determine the length of the arc, which is equal to the length of the cutting path,

$$\ell = k_\ell(\ell_{AB} - \ell_{OC}), \qquad (3)$$

where k_ℓ - the complexity of movement;

ℓ_{AB} - arc length along the radius *R*, m;

ℓ_{OC} - arc length along the radius r_0, m.

The lengths of the arcs *AB* and *OC* are determined by the formulas

$$\ell_{AB} = R\Delta\alpha \text{ и } \ell_{OC} = r_0\Delta\alpha \qquad (4)$$

Substituting (3) ℓ_{AB} and ℓ_{OC} , after transformations, we get

$$\ell_{AB} = (R - r_0)\Delta\alpha \qquad (5),$$

where $\Delta\alpha = \alpha_2 - \alpha_1$ is the difference between the angles of the beginning and end of cutting.

The angle at which the cutting starts is determined depending on the depth of processing.

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$$Sin\alpha_1 = \frac{R-h}{R} = 1 - \frac{h}{R},$$

where

$$\alpha_1 = arcsin\left(1 - \frac{h}{R}\right). \quad (6)$$

The angle at which the cutting ends is determined by approximate calculations described in [4].

Denote the angle between the radius of the drum, drawn from the center of the drum O_2 to the point M and the vertical line through α_2 (Figure 1, a). From the triangle O_2NM we find

$$Sin\alpha_2 = \frac{MP+PN}{R}.$$

The segment MP equals half the feed to the knife S, from the condition of symmetry of the crest relative to two adjacent cycloids, and the segment $PN = (R/\lambda)\alpha_2$ is equal to the distance that the center of rotation of the drum moves from the vertical position to coincide with point M. Substituting segments get

$$Sin\alpha_2 = \frac{\frac{S}{2}+\frac{R}{\lambda}\alpha_2}{R}.$$

Taking $Sin\alpha_2 \approx \alpha_2$ and making substitutions, we find

$$\alpha_2 = \frac{\pi}{z(\lambda-1)}. \quad (7)$$

Determine the angle difference

$$\Delta\alpha = \frac{\pi}{2} + \frac{\pi}{z(\lambda-1)} - \frac{\pi}{180^\circ} arcsin\left(1 - \frac{h}{R}\right). \quad (8)$$

Substituting (8) into (5) and taking into account that r0 = R ⁄ λ we have

$$\ell = k_\ell R \frac{\lambda-1}{\lambda}\left[\frac{\pi \cdot z(\lambda-1)+2}{2z(\lambda-1)} - arcsin\left(1 - \frac{h}{R}\right)\right]. \quad (9)$$

B. Reverse rotation of the milling drum.

In this case, the cutting begins at point M and ends at point D. The horizontal movement of the knife (Fig. 2, *b*) is equal to the length of the arc of the *OC* in the direction of the translational velocity υ within a radius of r_0. The end of the knife blade extends the path along the arc *AB* in radius *R*, the direction of which coincides with the direction of the translational speed.

We make solutions to this problem as in the previous paragraph, the difference lies in summing the lengths of arcs *AB* and *OC* and multiplying by the values of the coefficient of movement complexity, which differs in value,

$$\ell = k_\ell(\ell_{AB} + \ell_{OC}), \quad (10)$$

where k_ℓ - the complexity of movement;

ℓ_{AB} - arc length along the radius R, m;

ℓ_{OC} - arc length along the radius r_0, m.

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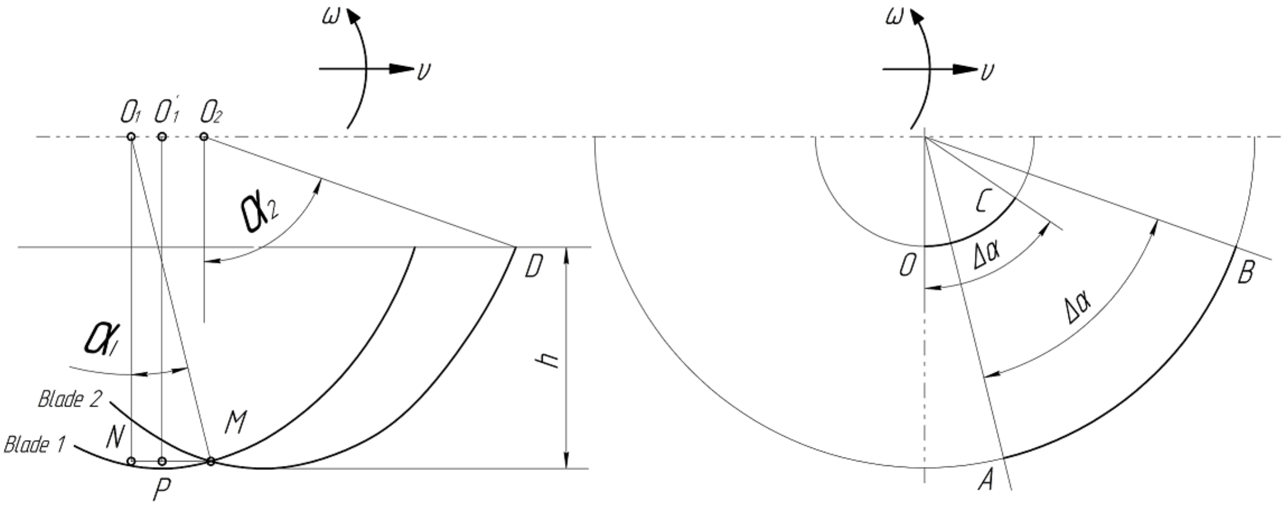

Fig.2. Schemes to determine the length of the cutting path during reverse milling

The lengths of the arcs *AB* and *OC* are determined by the formulas

$$\ell_{AB} = R\Delta\alpha \text{ и } \ell_{OC} = r_0\Delta\alpha \qquad (11)$$

Substituting in (11) ℓ_{AB} and ℓ_{OC}, after transformations, we get

$$\ell = (R + r_0)\Delta\alpha \qquad (12)$$

where $\Delta\alpha = \alpha_2 - \alpha_1$ is the difference between the angles of the beginning and end of cutting.

Without giving out the details of determining the angles α_1 and α_2, we write the deduced formula for determining the difference of angles

$$\Delta\alpha = \frac{\pi}{z(\lambda-1)} + arcsin\left(1 - \frac{h}{R}\right). \qquad (13)$$

Substituting (13) into (12) we obtain the formula for determining the length of the cutting path during the reverse milling of the soil with a milling drum,

$$\ell = k_\ell R\frac{\lambda+1}{\lambda}\left[\frac{\pi}{z(\lambda-1)} + arcsin\left(1 - \frac{h}{R}\right)\right]. \qquad (14)$$

The derived relationships encompass all the basic parameters of the milling drum and fully reflect the influence of parameters on the tillage process.

II. DISCUSSION

To check the correctness of the work done, the trajectory of the end of the knife with varying all parameters of the milling drum was constructed and the length of the cutting path was measured. The obtained results confirm the accuracy and correctness of the derived formulas, which are given in the following dependencies of the connecting parameters of the milling drum.

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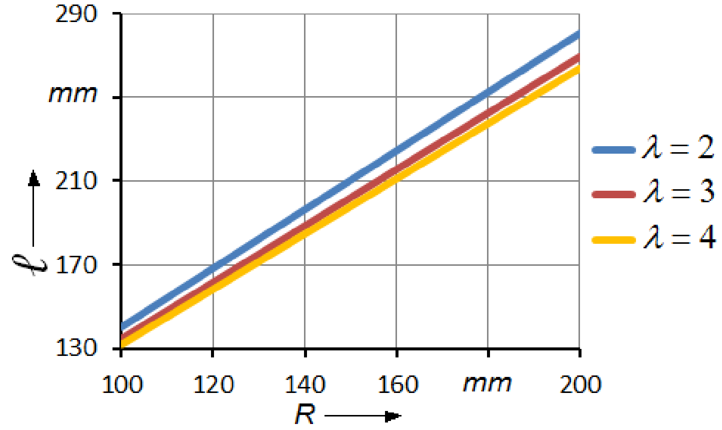
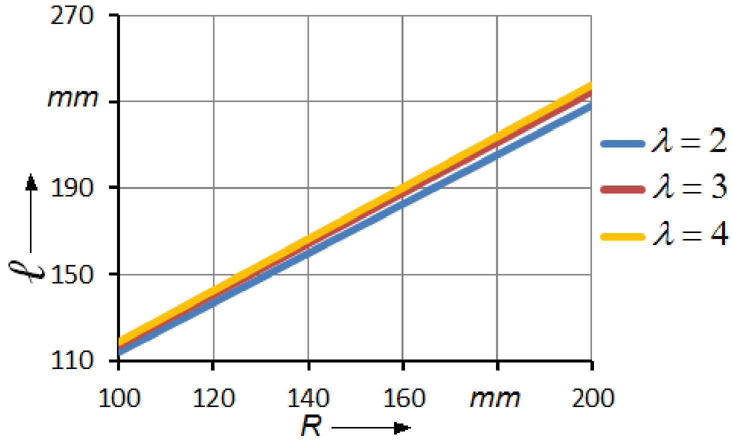
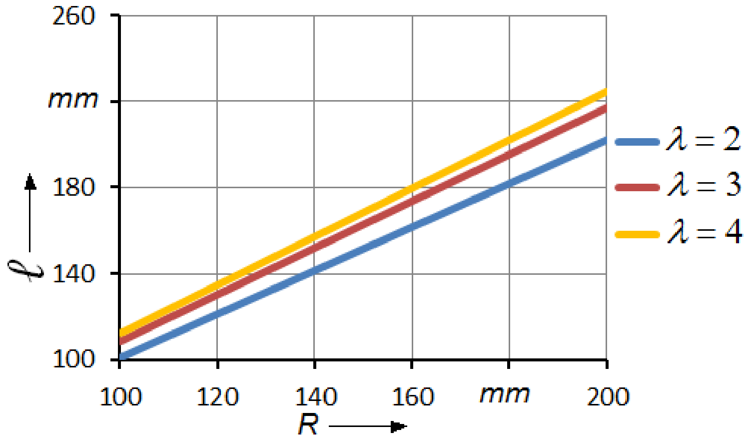
Analysis of the results of expression (9) shows that there is a linear relationship between the cutting length and the diameter of the cutter at a constant kinematic mode.
According to the dependencies (Fig. 3), it can be seen that with the same number of knives on one side of the flange, an increase in the kinematic mode always leads to an increase in the length of the cutting path.



a)



b)



c)

Fig.3. The relationship between the milling radius and the length of the cutting path when a) $z = 2$, b) $z = 3$, c) $z = 4$ on one side of the flange

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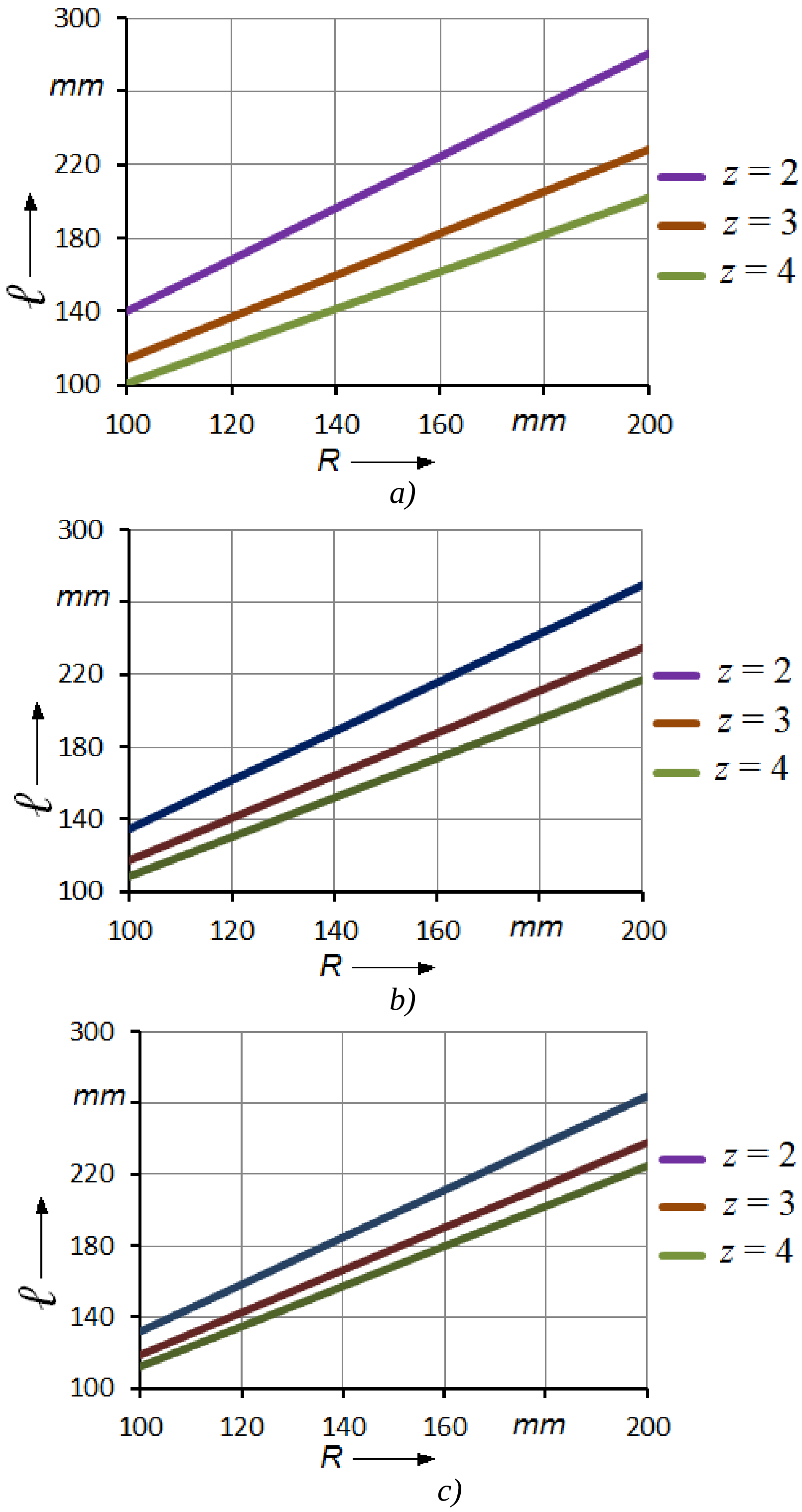

Fig.4. The relationship between the milling radius and the length of the cutting path when a) $\lambda = 2$, b) $\lambda = 3$, c) $\lambda = 4$.

With constant kinematic mode (Fig. 4), varying the number of knives does not change the pattern of growth of the cutting path length.

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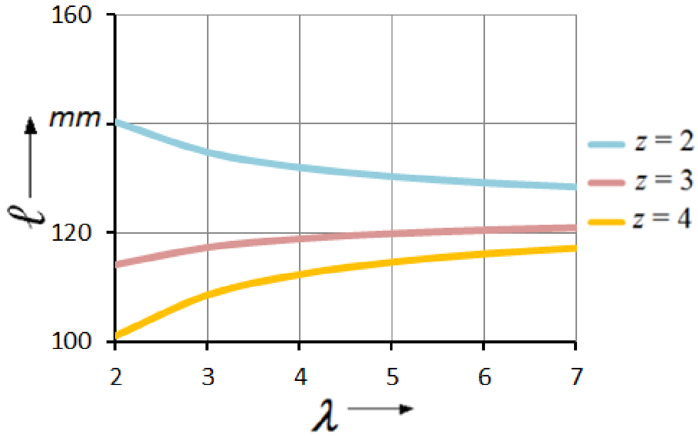

Fig.5. The relationship between the kinematic mode (λ) and the length of the cutting path (ℓ).

The dependence of the length of the cutting path on the kinematic mode for different values of z (z = 2, z = 3, z = 4) shows (Fig. 5); when the number of blades is z = 2, the length of the cutting path decreases with increasing kinematic mode; for z = 3 , z = 4 increases. This is explained by the fact that when z = 2 the lower branch of the trochoid lengthens, consequently the feed to the knife is shortened, and naturally the length of the cutting path decreases.

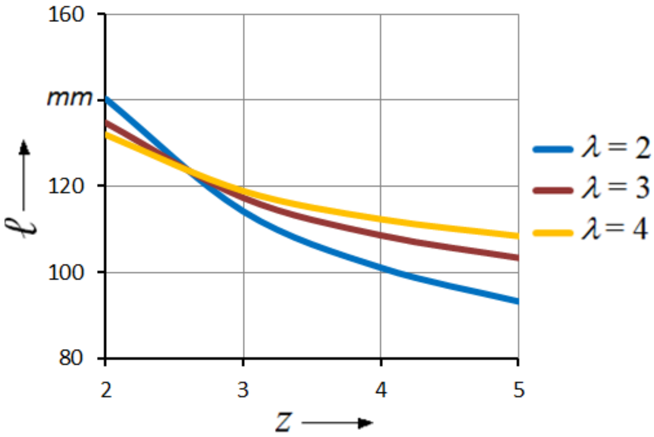

Fig.6. The relationship between the number of knives on one side of the flange and the length of the cutting path (ℓ).

With constant modes, the change in the number of knives (Fig. 6) due to a decrease in the feed to the knife changes in the direction of reduction.

IV. CONCLUSION

Analysis of formula (9,14) gives similar results, as in direct milling.

Based on the above, conclusions can be drawn.

An increase in the diameter of the milling drum and the depth of tillage will entail a directly proportional increase in the length of the cutting path, which explains the increase in the intensity of cutting.

An increase in the value of the kinematic mode leads to an increase in the length of the cutting path.

Increasing the number of knives on one side of the flange reduces the length of the cutting path when z = 2, but does

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not reduce the energy intensity of the tillage process.

For each value of the milling drum radius, there is the shortest cutting path, which helps reduce energy costs with a large number of knives on one side of the flange and possibly the smallest kinematic mode, since the shortest cutting path and tillage speed is obtained.

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