Design layout of the cutting unit and operating parameters of the bucket wheel type agitator

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Abstract. The problem of speeding up and reducing cost of road construction without sacrificing their quality can be solved by creating a complex of units of continuous operation. The aggregates, in sequence, carry out the whole complex of works aimed at road construction. The use of satellite navigation opens up broad prospects for full automation of the aggregates, so the overall goal is to create a complex of aggregates that carry out the continuous construction of roads, mainly in automatic mode. One of the devices which are part of the units of continuous operation is a bucket wheel type agitator. The use of direct-flow rotary rippers for soil development is restrained by insufficient theoretical justification of their parameters. Before analyzing the interaction of the elements of bucket wheel type agitator with the ground, it is necessary to clarify the design layout of the bucket wheel type rotor. Some design parameters of the bucket-wheel type agitator are derived from logical reasoning. Other parameters of a bucket wheel type agitator are obtained by plotting the impact of the blade on the ground in the plane and spatial simulation. The conclusion about the necessity to install a small rotor in addition to the large rotor coaxially with it has been drawn from here. The feed to the end-knife, i.e., the thickness of the layer cut by the end-knife, has been determined. Based on the adopted methodology, the geometric and operating parameters of a large bucket wheel type agitator rotor have been determined. Maximum small radius of circumferential and end knives of the big rotor is established. To excavate near the rotational axis of the bucket-wheel type agitator, a small rotor with a higher angular velocity must be installed in coaxial alignment.

1 Introduction

The problem of speeding up and cheapening the construction of roads without reducing their quality can be solved by creating a complex of units of continuous operation [1]. Aggregates, following each other, carry out the whole complex of works aimed at road construction. The use of satellite navigation opens up broad prospects for full automation of aggregates, so the

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overall goal is to create a complex of aggregates that carry out continuous road construction, mainly in automatic mode.

One of the devices that make up the units of continuous operation is the straight-line rotary ripper. Straight-line rotary rippers are designed for loosening the soil with its subsequent removal by other technical means. Fig. 1 shows a variant of using a bucket wheel type ripper as part of a unit for ditch and canal construction. The unit includes a power device of ripper 3 with a cutter blade 1 mounted on the front linkage 2. Straight-line rotary ripper 11 is placed on the ripper frame 8 attached to the rear linkage 5. The bucket wheel type agitator drive can be either hydraulic or mechanical, which includes power takeoff box 4, cardan shaft of the ripper drive 6, transmission 7, safety device 9 and bearing unit 10.

Preliminary scheme of bucket wheel type agitator with four rows of knives, i.e., the rows of knives are deployed in a circle at an angle of 90° with respect to each other, is shown in Fig. 2. The all-welded rotor has a shaft 5 with a supporting disk 4 welded to it, with holders 7 and blades 6. Circular knives 1 and end knives 3, mounted by the ledge, are attached to the blades. The spiral blade 2 is attached to the shaft.

Although the theoretical bases of soil excavation are very thoroughly considered [2, 3, 4, 5], interaction of bucket wheel type agitator elements with soil is almost not studied. The use of direct-flow rotary rippers for soil development is constrained by insufficient theoretical justification of their parameters. For example, some researchers tried to use a straight-line rotary ripper with blades similar in shape to the blades of an airplane or ship propeller. Without sufficient theoretical justification, these attempts were unsuccessful. Before analyzing the interaction of the elements of bucket wheel type agitator with the ground, it is necessary to clarify the design layout of the bucket wheel type agitator rotor.

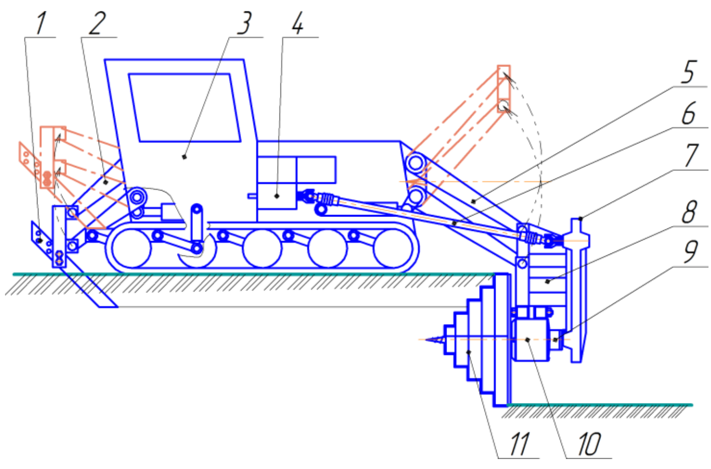

Fig. 1. Diagram of bucket wheel type agitator in the unit with power device: 1 - skim jointer; 2 - front hitch; 3 - power device of ripper; 4 - power takeoff box; 5 - rear hitch; 6 - cardan shaft of ripper drive; 7 - transmission; 8 - ripper frame; 9 - safety device; 10 - bearing unit; 11 – bucket wheel type agitator

2 Materials and Methods

Some design parameters of bucket wheel type agitator are derived from logical reasoning. In particular, it is not reasonable to use long, expensive blades in a rotary ripper. Stones or other objects are possible in soil, which can bend or break expensive blades. Therefore, it is advisable to use a variety of small, diamond-shaped, unitized knives in a straight-line rotary ripper (Fig. 3), which could be easily replaced if damaged.

Circular and end knives have a recess with a reverse chamfer to secure them. The diamond-shaped cross section of the knife creates the possibility of doubling its service life by turning it 180° after the cutting edge has been blunted.

The grinding angle of the knife must be smaller than the angle of friction of the steel on the ground. It varies widely, but on average $\varphi \approx 26°$. If the cutting angle of the knife is greater than the angle of friction of the steel against the ground, cutting with the blade will be transformed into punch cutting. On the other hand, too small sharpening angle will lead to blade pitting during cutting. On this basis, let's take the blade sharpening angle i=20°. Then, the dimensions of the blade elements in its cross section are obtained from the structural layout.

Other parameters of bucket wheel type agitator are obtained by constructing schemes of blade impact on the ground in the plane and spatial modeling. Initially, the bucket wheel type agitator rotor with a diameter of one meter was taken for the calculation.

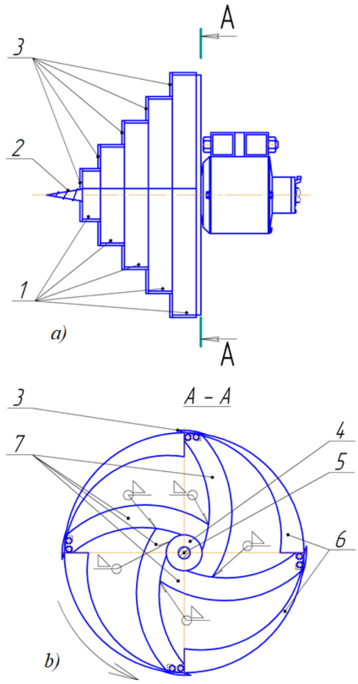

Fig. 2. Bucket wheel type agitator: a - side view; b - section A - A; 1 - circular knife; 2 - spiral knife; 3 - end knife; 4 - supporting disk; 5 - shaft; 6 - blade; 7 – holder.

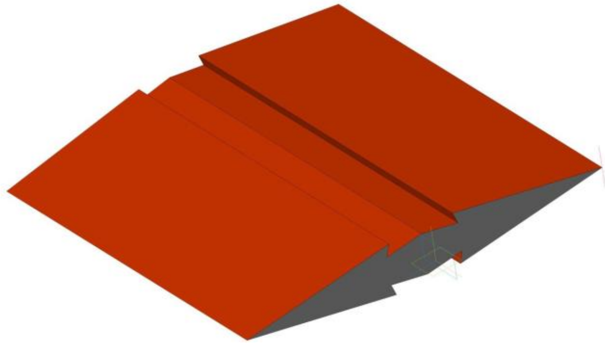

Fig. 3. Diamond-shaped knife.

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3 Results

We assign numbers to the circumferential and end knives: No. 1, No. 2, No. 3... as we approach from the periphery of the rotor to its rotation axis. Let's assume that the circumferential blade is parallel to the axis of the rotor shaft. Let's represent the cross-section of the circular knife number 1 by the transversal-vertical plane (Fig. 4), i.e., the plane perpendicular to the rotor rotation axis, when its blade is in the lower position.

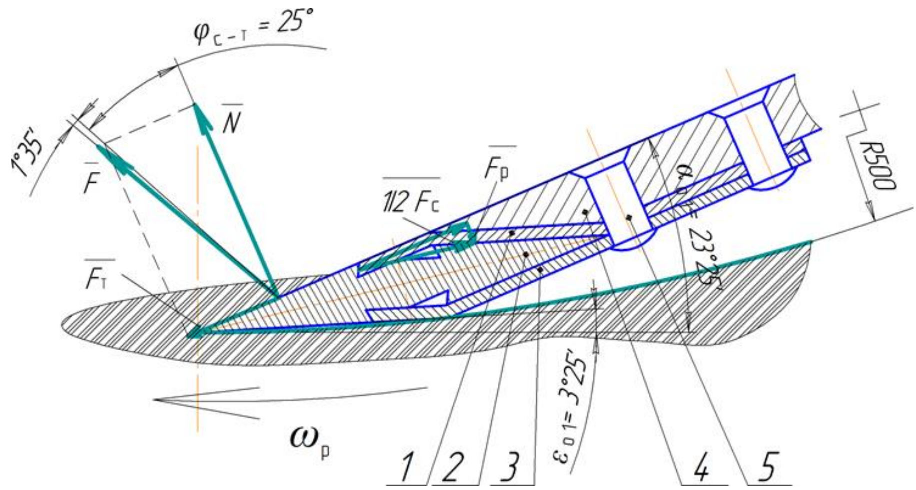

Fig. 4. Knife connection design and force diagrams of interaction of circular knife No. 1, the most distant from the shaft, and the ground: 1 - inner bucca; 2 - knife; 3 - outer bucca; 4 - blade; 5 – rivet.

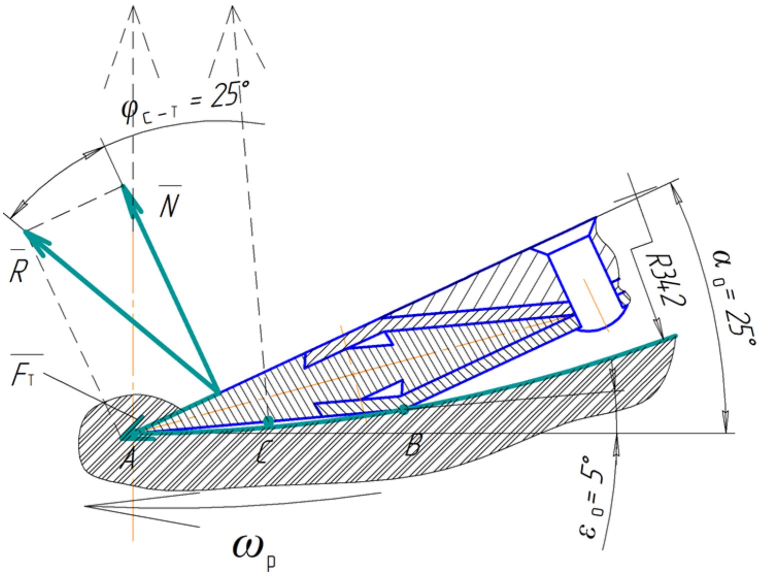

Fig. 5. Determining the minimum radius of the rotor when the blade is parallel its longitudinal-radial plane.

The inner bucca 1 and outer bucca 3 are riveted to the blade 4 with rivets 5, which are made of spring steel. The knife 2 is inserted between the inner bucca and the outer bucca. From the diagram of forces of influence of the knife back chamfer on the inner cheek it is clear that during cutting the force F will appear, pressing the inner cheek to the knife. An equal force on the other side will press the outer bucca against the knife. The greater the resistance of the ground to cutting, the greater the force F. This will ensure that the blade is securely attached.

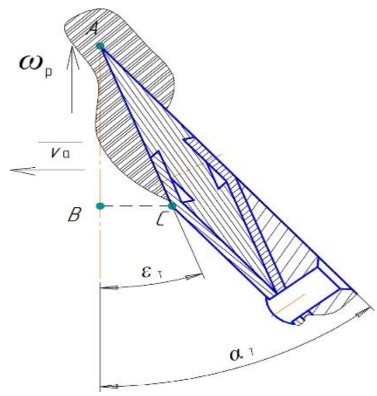

Fig. 6. Interaction with the ground of the end blade No. 1, farthest from the rotor axis.

From the construction it is seen that the back angle of the circular knife No. 1, the farthest from the shaft, ε_{o1} ≈3.4°. If the knife blade is parallel to the shaft axis, the front angle of circular knife No. 1 $\alpha_{o1} = \varepsilon_{o1} + i$=3.4+20≈23.4°. The diagram of forces acting on the front surface of the blade on the ground shows that the force acting on the ground is deflected from the normal by an angle larger than the angle of friction of the steel against the ground. Therefore, the ground will not rest against the front surface of the circular knife No. 1, but will slide on it. The blade will cut.

Let's denote the blade in the circumferential knife section by point A (Fig. 5). Assume that the outer cheek touches the ground at point B.

Dividing the segment AB in half, draw a ray from the point C to the intersection with the vertical ray from the point A of the circular knife blade. From the obtained center draw an arc passing through points A and B, measure its radius. If the circular blade is parallel to the axis of the rotor shaft, the smallest possible radius at which the circular blade, which is the farthest from the rotor shaft, can cut with its blade is 342 mm.

Let's consider interaction with the ground of the end blade No. 1, the farthest from the rotor rotation axis (Fig. 6). It rotates with angular velocity ω and moves with the machine at the speed v. In order to perform blade cutting, the front angle of an end knife, as well as a circular knife, must be $\alpha \leq 26°$. Assume that $\alpha = 25°$, then $\varepsilon = 5°$. In order for the rear surface of the blade not to rest on the ground while point B moves to a distance BC, point A must move along an arc to a distance AB. As the end blade moves farthest from the rotor's axis of rotation, the arc AB differs insignificantly from the segment AB, so

$$\tan(\varepsilon_{T\,1\,min}) = \frac{BC}{AB} = \frac{v_a}{v_{T\,1\,max}},$$

here $v_{T\,1\,max}$ – circumferential speed of the point on the end knife furthest from the rotor rotation axis, equal to the minimum circumferential speed of the blade of circular knife No.1: $v_{T\,1\,max} = v_{cir\,1} = v_{cir\,min}$. Hence,

$$v_{cir\,1} = \frac{v_a}{\tan(\varepsilon_{T\,1\,min})}. \quad (1)$$

Since the operating speed of the unit is v_a = 0.085 m/s [6], $v_{per\,1}$ = 0.97 m/s. In order to avoid friction of the rear surface of the cutter blade No. 1 against the ground during its cutting, we will take the minimum peripheral speed of the cutter blade No. 1 to be equal to the maximum peripheral speed of the outer point of the blade of the cutter blade: $v_{cir\,min} = v_{T\,1\,max} = 1\,m/s$.

It is not practical to position the circular knife blades parallel to the rotor shaft axis. To reduce energy costs, it is desirable that sliding cutting is performed. When the blade of the knife performs cutting with the knife sliding sharpening in the direction of its reduction. To unify the knives, it is desirable that the blade deflection angle in the cutting plane of the end knives and circumferential knives is the same. Meanwhile, in order to carry out cutting with the blade, the front angle should be $\alpha_{T,0} \leq 25°$. By spatial modeling, we determine the angle of knife blade sharpening depending on the angle of blade deflection in the cutting plane β. Dependence of the blade sharpening angle on the blade deflection angle from the direction perpendicular to the cutting, if the blade sharpening angle is 20°, is shown in Fig. 7.

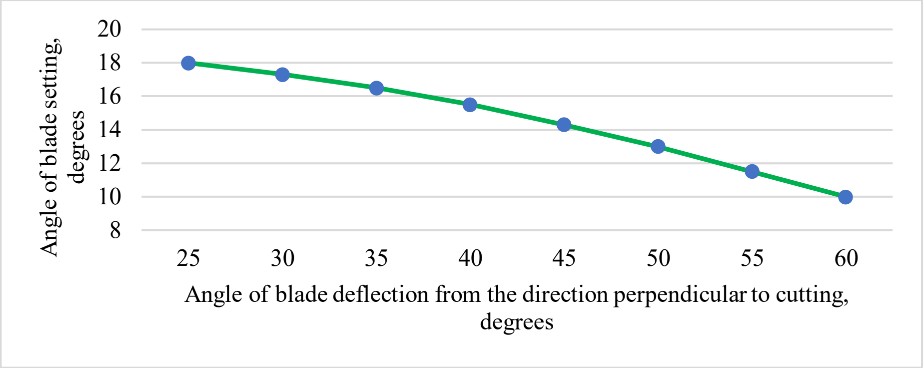

Fig. 7. Dependence of the blade sharpening angle on the blade deflection angle from the direction, perpendicular to cutting; blade sharpening angle 20°.

The greater the angle β of the blade deflection in the cutting plane with respect to the cutting direction, the greater the transformation of the blade angle of sharpening, the smaller the knife blade angle of sharpening. As the angle β increases, the smallest radius at which a circular knife blade can be positioned decreases, provided $\alpha_{T,0} \leq 25°$. At the same time as the angle β increases, the length of the blade increases.

In order for the soil to pass in the space between the end knives, the distance between their blades must be greater than the thickness of the cut layer of soil. Proceeding from the dimensions of diamond-shaped knives (see Fig. 3), we accept the lengths of the projections of the end knives blades on the longitudinal-radial plane as 100 mm. To unify the projections of circular knives blades on the longitudinal-radial plane we also take 100 mm.

To avoid ground impact on the surface, the end knife should be positioned so that its blade is not in the longitudinal-radial plane, but at an angle to both longitudinal-radial plane and to the direction of machine movement. Similar to formula (1) for the point of the blade of the end blade No.1, approximated to the rotor rotation axis,

$$\tan(\varepsilon_{T\,1\,min}) \geq \frac{v_a}{v_{T\,1\,min}} = \frac{0.085}{0.8} = 0.106,$$

then

$$\varepsilon_{T\,1\,max} \geq arctg(0.106) = 6.06°. \qquad (2)$$

Having made the constructions similar to those shown in Fig. 5, we will reveal the extremely small radii, on which the circular knife blade can be located in the rotor, when it is not parallel to the longitudinal-radial plane of the rotor (Fig.s 8, 9). Dependence of blade length on blade deflection angle with respect to direction perpendicular to cutting is shown in Fig. 10.

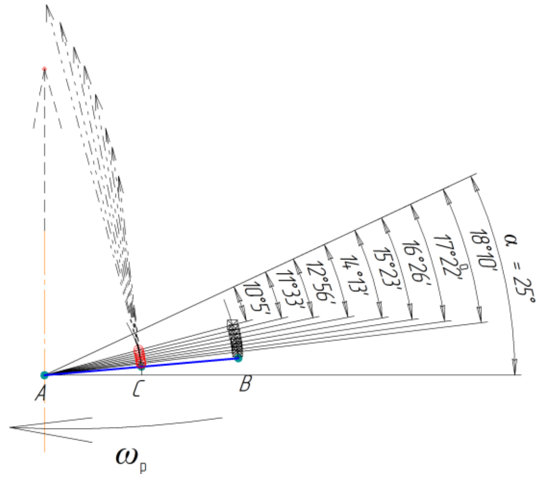

Fig. 8. To determine the smallest radius at which a circular knife blade can be located from the angle of deflection of the blade with respect to the direction perpendicular to the cutting.

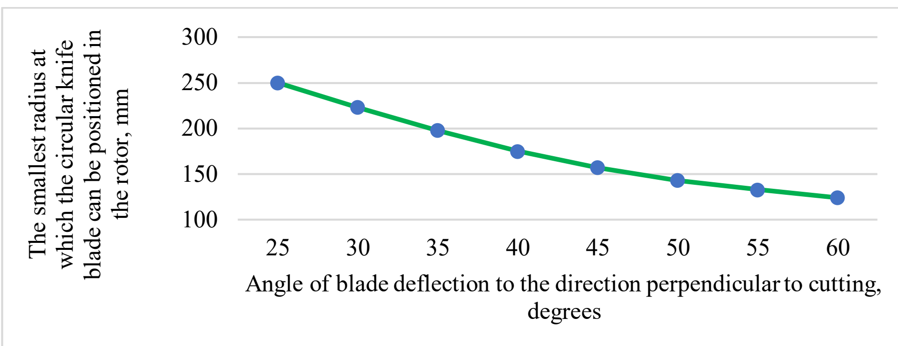

Fig. 9. Dependence of the smallest radius at which a circular knife blade can be located on the angle of deflection of the blade in relation to the direction perpendicular to the cutting.

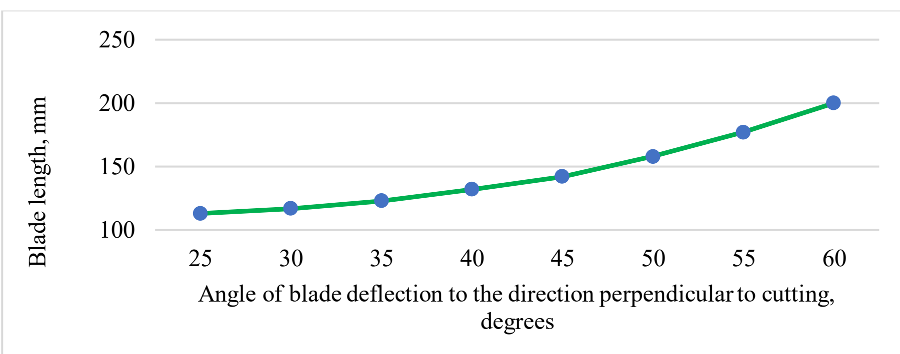

Fig. 10. Dependence of the blade length on the blade deflection angle in relation to the direction perpendicular to the cutting.

The greater the angle in the cutting plane with respect to the cutting direction, the smaller the blade sharpening angle (Fig. 7). Therefore, it is desirable to increase this angle. However, if the circular blades are set so that the blades are at a greater angle in the cutting plane with respect to the direction of cutting, they will need to be bent. The radius of curvature of the circular knives depends on their location in the rotor, that is, their distance from the rotor's axis of rotation. The blades of the end knives must also be concave depending on their location in the rotor. It is not technologically feasible to bend circular knives and end knives. There would be no unification of the knives. Therefore, we will accept a compromise design solution: angle of blade deflection in the cutting plane in relation to cutting direction is 30° (Fig. 11), minimally exceeding the angle of ground friction on steel. The smallest radius at which a circular knife blade can be located in the rotor, in which the blade deflection angle in the cutting plane β=30°, is 224 mm (Fig. 9). Consequently, circumferential knives closer to the rotor's axis of rotation will not perform blade cutting. As you get closer to the rotor's axis of rotation, the cutting will be increasingly transformed into punch cutting as the forward angle α_0 >26°

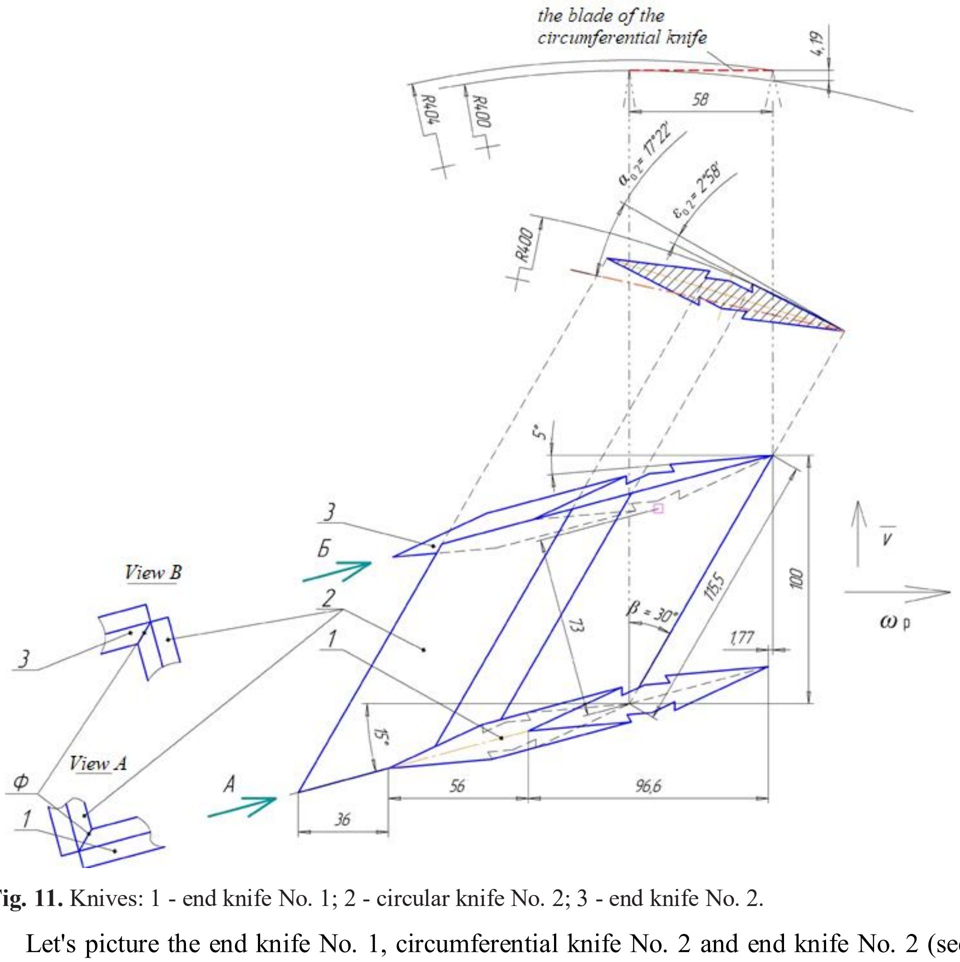

Fig. 11. Knives: 1 - end knife No. 1; 2 - circular knife No. 2; 3 - end knife No. 2.

Let's picture the end knife No. 1, circumferential knife No. 2 and end knife No. 2 (see Fig. 11, below) as if looking at circumferential knife No. 2 from above.

Point circular knife No. 2 so that its blade is docked with the blade of end knife No. 1 and directed at a 30° angle to the longitudinal-radial plane. Having continued the line of the blade of the circular knife No.2 (in the picture to the right upwards), let's represent its cross-section, inscribed in the friend with radius 400 mm. This is the radius of the point of the end-knife blade No. 1 closest to the rotor rotation axis. Let us mark the front angle α_{02} taking into account transformation of the blade sharpening angle. Let us depict the end knife No. 1 and the end knife No. 2 adjoining the circular knife No. 2 (view A and view B) with chamfers. The endknife No. 1 is adjacent to circumferential knife No. 2 on one side (in the Fig. above), and endknife No. 2 on the other side (in the Fig. below). From the construction, the distance between end blade No. 1 and end blade No. 2 is 73 mm.

The 30° angle of the circular knife blades to the longitudinal-radial plane does not account for the transformation of the angle of sharpening of the circular knife blades associated with the progressive movement of the unit. Since the machine is moving, the cutting direction of the circular knives will not be located in a transversal-radial plane. Therefore, there is an additional transformation in the sharpening of the circular knife blades. To ensure that the set angles of the circular knives are not less than $\varepsilon_T = 5°$ (Fig. 6) to the blade angle of the circular knives *b*=30° many add 5° to account for the transformation of the angles of sharpening of the circular knife blades, associated with the progressive movement of the unit. Then the smallest radius will decrease from 224 mm to 199 mm (see Fig. 9): $r_{\min y\,k} = 199\,mm \approx$ 0.2 m. The arrangement of circular knife No. 4 meets this requirement. Consequently, there will be 4 circumferential knives and three end knives in one row of the large rotor.

If the distance from the rotor rotation axis to the knife point is less than 199 mm, the minimum ratio between the circumferential speed of the knife point and the forward speed of the machine will not be met. Therefore, a small rotor with a higher angular velocity must be coaxial to excavate near the rotor rotation axis of the bucket wheel type agitator.

Angular velocity of the large rotor

$$\omega_p = \frac{v_{cir\,min}}{r_i}. \tag{3}$$

Since $v_{cir\,min} = v_{T\,1\,max} = 1\,m/s$, $r_{\min y\,k} \approx 0.2$, the required angular velocity of the large rotor $\omega_p = 5\,rad/s$.

Preliminarily accepted the arrangement of knives in the rotor in four rows. But at such angular speed of the rotor the thickness of soil layer, cut by blades, will decrease. Excessive loosening of the soil is undesirable due to the increase in energy for this process. Installation of knives in two rows is not rational because it will lead to increase of stresses in the drive of the rotor shaft at change of local resistances of soil. Therefore, we will accept arrangement of knives in three rows, that is, rows of knives along the circumference are deployed at an angle of 120° with respect to each other. The number of circular knives is 12, and the number of end knives is 9. There are 21 unified knives in the big rotor [7, 8, 9, 10].

Time of one rotor revolution is:

$$\tau_1 = \frac{2\pi}{\omega_p}; \quad \tau_1 = 1.256\,s.$$

Time 1/3 of rotor revolution $\tau_{1/3} = \frac{1.256}{3} \approx 0.419\,s$. Flipping on the end knife

$$s_{k\,l} = v_a \tau_{1/3}, \tag{4}$$

here $\tau_{1/3}$ is the time 1/3 of rotor revolution. Since the speed of the unit is $v_a = 0.85\,m/s$ [11,12,13,14,15], deliver on the end knife, i.e., the thickness of the layer cut by the end knife is $s_{k\,l} \approx 0.035\,m$. Even taking into account loosening, the ground will pass freely in the space between the unified blades (Fig. 11).

4 Conclusion

By means of logical reasoning, calculations and constructions in plane and space the geometrical and regime parameters of the big bucket wheel type agitator rotor with diameter of 1 m are determined. An extremely small radius of circumferential and end knives of a big rotor is established. In order to excavate near the rotary axis of the bucket wheel type agitator a small rotor with a higher angular speed must be installed coaxially. The direction of rotation of the small rotor must be opposite to that of the large rotor to partially compensate for the reaction torque created by the large rotor.

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