Modeling of mechanized cutting of fruit trees

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Abstract. In the complex of agrotechnical measures for garden care, cutting is one of the most effective methods of stimulating plants. With the help of cutting, crowns of young plants are formed, during the period of increasing aging, the crown is rejuvenated to restore growth, increase productivity and quality of fruits. In the practice of gardening, thickened plantings are widely introduced, in which the number of plants per unit area is significantly increased. In growing fruit trees in a row close together. In such plantings, the crowns are formed with one, maximum two branching orders. This makes it possible to cut the crowns of trees from above or from the sides in the same plane, without violating the subordination of branches. Such cutting can be carried out using machines and thus significantly reduce the amount of manual cutting, which will be reduced to removing the conductor and thinning the thickening branches in the central part of the crown. Contour cutting helps increase the productivity of pest and disease tree control units, reducing the consumption of pesticides. Machines for contour cutting the crown must provide a high-quality cut of branches with a diameter of 5 ... 75 mm. Studies of national and foreign scientists have found that segmental cutting devices satisfactorily cut branches up to 20 mm in diameter, and disk-type cutting devices cut branches over 20 mm. However, in gardens, branches of different diameters occupy a very different spatial position. To significantly expand the capabilities of machines with different forms of cutting (light, heavy), fruit tree crown cutters are often equipped with interchangeable cutting devices (segment and disk). This complicates the machine, but makes it possible to use the cutting device of the most optimal type when cutting in specific conditions.

1. Introduction
Caring for the crown of fruit trees is a very time-consuming process, and, as a rule, it is performed manually, which is associated with significant labor costs [1-3]. The efficiency of cutting at intensive gardening can be significantly improved by using various means of mechanization, in particular, machines for contour cutting [4-6].

Disk-type machines for contour cutting the fruit tree crown perform a cut without a counter-cutting support. In this case, the branches are bent, which negatively affects the quality of the cut. This means that in these machines it is important not only to choose a rational type of working part, but also to set the optimal mode of its operation, to determine the optimal design and kinematic parameters.

Currently, there are machines for contour crown cutting with three types of disc cutting devices: arrow, pendulum and rotary.

The arrow-shaped cutting device is a frame with disk saws located on it. Overlapping of working parts is achieved by their step-by-step arrangement. The cutting and feeding speeds are constant both in
value and direction. A pendulum-type cutting device has a frame oscillating in a certain plane with working parts located at the end.

2. Research results
The linear speed of swing (oscillation) of the saw is determined by the formula:

\[ v_0 = \frac{\ell}{h} r \omega \sin \omega t, \]  
(1)

where \( \ell \) is the connecting rod length; \( h \) is the distance from the swing axis to the axis of the connecting rod finger on the frame; \( r \) is the radius of the crank; \( \omega \) is the angular speed of the crank.

Absolute saw blade speed (feed rate):

\[ v_a = \sqrt{v_n^2 + v_n^2 + 2v_n v_0 \cos \alpha_0}, \]  
(2)

where \( v_n \) is portable saw speed; \( \alpha_0 \) is the angle between speed directions.

Substituting the value in the expression (2), we get:

\[ v_a = \sqrt{\left( \frac{\ell}{h} r \omega \sin \omega t \right)^2 + v_n^2 + 2v_n \frac{\ell}{h} r \omega \cos \omega t \alpha_0}. \]  
(3)

The speed \( v_a \) is constant in value and direction. Speed \( v_0 \) is a variable value. To determine the speed \( v_a \) in the extreme and intermediate positions of the oscillating frame, we substitute in the expression (3), respectively \( \omega t=0, \omega t=180^\circ, \omega t=90^\circ \). As a result, we get that in extreme positions:

\[ v_a = v_n, \]

but in the intermediate position:

\[ v_a = \sqrt{\left( \frac{\ell}{h} r \omega \right)^2 + v_n^2 + 2v_n \frac{\ell}{h} r \omega}. \]  

The speed \( v_a \) is maximum in the intermediate position (the point \( b \) in figure 1, a) and is minimal at the extremes (points \( a \) and \( c \) in figure 1, a) positions, which is a serious disadvantage of the cutting device in question. At \( \ell =1.5 \) m, \( r =0.2 \) m, \( h = 0.2 \) m, and \( n=10 \) rpm speed \( v_a \) for a half turn of the crank varies within the limits 0.36 to...1,2 m/sec. At the point \( b \) the ratio of cutting speeds \( v_0 \) and feeds \( v_n \) at cutting speed 70 m/s, is equal to \( \lambda =52 \), which is significantly less than acceptable, providing the required quality of the cut (\( \lambda \geq 125 \)). In addition, the speed \( v_a \) changes in the direction, which is also undesirable when the direction of rotation of the saw is constant.

The rotary cutting device is a crosspiece with working parts located at the ends of the arms [7]. To determine the absolute speed of saws at four diametrically opposite points (points \( a,b,c \) and \( b \), figure 1, b), we substitute \( \alpha = 0; 90; 270 \) and \( 180^\circ \) in formula (2), respectively. As a result, we get:

\[ \text{at } \alpha = 0 \quad v_a = v_n + v_0, \]
\[ \text{at } \alpha = 90; 270^\circ \quad v_a = \sqrt{v_n^2 + v_0^2}, \]
\[ \text{at } \alpha = 180^\circ \quad v_a = v_n - v_0. \]
Figure 1. Cutting speeds and feed rates of disk cutting machines.

a) pendulum type; b) rotary type.

The speed $v_a$ has a maximum value at the point $a$ and a minimum value at the point $c$ (see figure 1, b).

The criterion for evaluating the performance of cutting devices was the quality of the slices, which was set visually using a reference cut made by hand with a garden hacksaw. Depending on the state of the surface, the sections were divided into smooth, ragged and split.

Let’s consider the working part for cutting branches with a diameter of 1 ... 20 mm in the form of a disk (figure 2), the cutting edge of which is made of two branches of the Archimedean spiral, offset relative to each other by 180°. This disk provides a cut of branches of the specified diameters without torn and split sections.

The circumferential speed of the disk at point $1$ will be:

$$v_1 = \omega \rho_1,$$  \hspace{1cm} (4)

where $\rho_1$ is a minimum distance of the cutting edge from the axis of rotation of the disk.

When the disk is rotated by an angle $\varphi$ and, consequently, the radius vector is lengthened by a value $s$, the circumferential speed increases. For example, for a point 2:

$$v_2 = \omega (\rho_1 + s).$$  \hspace{1cm} (5)

For the point $B$ which is maximum remoted from the axis of rotation of the disk, the disk speed will be:

$$v_B = \omega (\rho_1 + z),$$  \hspace{1cm} (6)

where $z$ is the difference between the maximum and minimum distance of the cutting edge from the axis of rotation of the disk, always equal to half the step of the spiral.

Therefore, an increase in the circumferential speed of the disk due to an increase in the variable radius vector from $\rho_1$ to $\rho_1 + z$ at a constant angular velocity and the absence of translational velocity of the axis of rotation causes an increase in cutting speed, which at a point $B$ is equal to:
where \( n \) is a disk rotation speed, rpm.

\[
v_{\text{рез}} = \frac{(\rho_3 + z) - \rho_1}{30}n, \quad (7)
\]

The sliding speed of the knife blade along the cut material at any point on the cutting edge at a translational speed of the axis of the disk equal to zero will be:

\[
v_{\text{рез}} = \omega r = \frac{v_{\text{рез}}(\varphi_n^2 + 1)^{3/2}}{\varphi_n^2 + 2}, \quad (8)
\]

where \( R \) is the radius of curvature of the cutting edge at the slip point; \( \varphi_n \) is an angle of the disk rotation.

As can be seen from this equation, the speed of the blade sliding along the cut material increases with the increase in the angle of rotation of the disk, therefore, under these conditions, the branch section improves.

Segment cutting device for cutting branches of fruit trees consists of supporting lower fixed and upper mobile segments [8-11]. The cutting branches entering the cutting-edge solution consists of three stages: deflecting the branch with the cutting edge of the upper segment until it touches the counter-cutting edge of the lower segment, compressing the branch between the segment edges, and cutting.

At compressing a branch, it may slip, if the angle of the edge solution \( \psi \) is greater than the double angle of friction \( \varphi \) of the branch along these edges. The critical angle of pinching branches, in which there is no slip from the cutting edges of the segments, for blunted blades (with an edge thickness of 80...100 microns) is 22...25°, for sharp ones (with an edge thickness of 25 ... 30 microns – 45...50°).

Segment cutting machine we calculate based on the conditions that the slope of the branch to the horizon is 70° and cut the branch with a maximum diameter of \( d = 20 \) mm. Assuming that the segments are blunted, we take \( \psi =22° \). From here, the cutting angle will be \( \alpha = 0.5\psi = 11° \) (figure 3).

The minimum height of the cutting edges of segments is determined from the condition that a branch of the specified maximum diameter enters the solution of the cutting edges:

\[
h_{\text{max}} = 0.5d\left(1 + \frac{1}{\sin \alpha}\right), \quad (9)
\]

The width of the front of the segment is taken 6 ... 1.5 cm, given the supply of material for sharpening during operation. Then the width of the back of the segment is:

\[
a = b + 2htg \alpha. \quad (10)
\]

The distance (step) \( t \) between the segments of the knife is determined by the expression:
\[ t = b + c + 2k = b + (d + 3) + (2h - d)g \alpha. \]  

**Figure 3.** Scheme for segment calculation.

The optimal rotational speed of the eccentric shaft of the knife drive is found from the condition of cutting tree branches with the smallest longitudinal deviation, when the feed \( \ell \) in one stroke of the knife is equal to the height of the cutting edge of the segment, minus the average diameter of the cut branch \( (d_{cp} = 10 \text{ mm}) \):

\[ \ell = h - d_{cp}. \]  

The shaft speed will be:

\[ n = \frac{30v_u}{\ell}, \]  

where \( v_u \) is a tractor forward speed.

Average knife speed is:

\[ v_u = \frac{Sn}{30}, \]  

where \( S \) is knife stroke.

Optimum speed ratio is:

\[ \beta = \frac{v_u}{v_u}. \]

### 3. Conclusion

Of all the cutting devices studied, the arrow-type cutting device was the simplest and most reliable in operation, providing a sufficiently high quality of cutting branches (excluding branches with a diameter of up to 10 mm). Found that a good cutting of the branches of the disk cutting machine is provided with the following parameters: disk diameter – 630 mm, thickness of the disc – 2.8 mm, number of teeth 120, the ratio of the speeds of disk and machines \( \lambda = 115 \), the circumferential speed of the discs at the ends of the teeth 65...80 m/s at frequency of rotation of the disks up to 2400 rpm.

Parameters of segment cutting devices that can be used in machines for cutting branches up to 18 mm in diameter: \( h = 6 \text{ cm}; b = 1.5 \text{ cm}; a = 4 \text{ cm}; t = 7 \text{ cm}; \ell = 5 \text{ cm}; n = 402 \text{ rpm}; v_u = 0.95 \text{ m} / \text{s}, \beta = 1.45...1.47; \) the sharpening angle of the upper segments is 30\(^\circ\); the lower ones are 75\(^\circ\); the thickness of the upper segment plate is 3.6 mm; the lower one is 4.6 mm. To avoid swinging, it is recommended to attach the segments to the bars at three points. You can also mount it at two points if you install a...
metal stop plate between the segments with a thickness equal to the thickness of the segment plate, or make their lower part with protruding protrusions so that the segments fit on the bar end-to-end.

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