LOPPER FOR TRIMMING TREES DRIVEN BY LINEAR ELECTRIC MOTOR

Sergey Antonov, Gennady Nikitenko
Stavropol State Agrarian University, Russia
antonov_serg@mail.ru, nikitenko_gv@mail.ru

Abstract. The main goal of the intensive development of gardening is to provide the population with high-quality fruit and vegetable products. The level of mechanization of gardening reaches 60 %. This is usually agrotechnical measures for plowing, fertilizing, spraying and contour trimming. A very important factor affecting the yield and quality of fruit products is the detailed pruning of branches. The choice of design parameters for garden care devices depends on the physicomechanical properties and dimensional parameters of the branches. Analyzing existing studies on the dimensional characteristics of the cut branches, we can conclude: from 60 to 80 % of the cut branches have a diameter of up to 15 mm; from 20 to 40 % of cut branches have a diameter of more than 15 mm. Secateurs are used for pruning branches with a diameter of up to 15 mm. To trim branches with a diameter of 15 m and above, it is necessary to use more powerful devices – delimbers. Currently, there are many mechanized devices for pruning trees (HISEED, GREENWORKS, SWANSOFT, etc.). They allow trimming branches with a diameter of up to 50 mm. The main disadvantage of these devices is the use of a DC motor to drive the blades. This leads to increased energy consumption, as well as to the use of rechargeable batteries with large mass and overall dimensions. Using a linear electric motor improves the energy efficiency of the delimbers. This is due to the simplification of the kinematic scheme of the device, as well as through the use of kinetic energy of the armature and the movable blade.

Keywords: fruit growing; pruning; pruning shears; linear electric motor; delimbers; energy efficiency.

Introduction

Improving the production efficiency of fruits and berries requires the development of a modern garden care tool. Up to 25 % of the cost is the detailed pruning of trees [1; 2]. The most effective is the use of an electrified hand tool for pruning branches [3; 4; 5; 6]. An existing tool is usually designed to trim branches with a diameter of up to 15 mm. Pruning of branches over 15 mm should be carried out with a special tool – delimbers.

The delimber (Fig. 1) consists of a fixed blade 1, in which a movable blade (2) is placed, connected with a screw (3) to the armature (4) of the linear electric motor (5). Armature (4) consists of an upper magnetic sleeve (6), a non-magnetic sleeve (7) and a lower magnetic sleeve (8). Armature (4) is installed using a non-magnetic sliding bearing (9) in the magnetic circuit (10) and a non-magnetic sliding bearing (11) mounted on the lower magnetic sleeve (8). In the housing (12) there are a power button (13), a control unit (14), a magnetic housing (15), the first magnetizing coil (16), the second magnetizing coil (17), the battery (18) and the spring (19). At the same time, the fixed blade (1) is secured to the housing (12) by means of a bolt (20). Tree branch (21) is located next to the delimber.

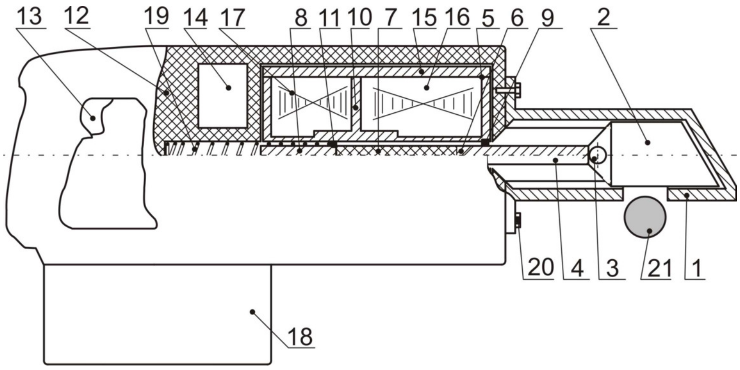

Fig. 1. **Delimber**

The proposed delimber works as follows: in the absence of power to the first magnetizing coil (16) of the linear electric motor (5), the movable blade (2) occupies the upper position (Fig. 2. a). When the power button (13) is pressed on the first magnetizing coil (16) of the linear electric motor (5), 24 V voltage is supplied from the battery (18) through the control unit (14), while current begins to flow through the first magnetizing coil (16), creating a magnetic flux Φ_1 that closes along the magnetic housing (15) and the magnetic circuit (10) (Fig. 2. b).

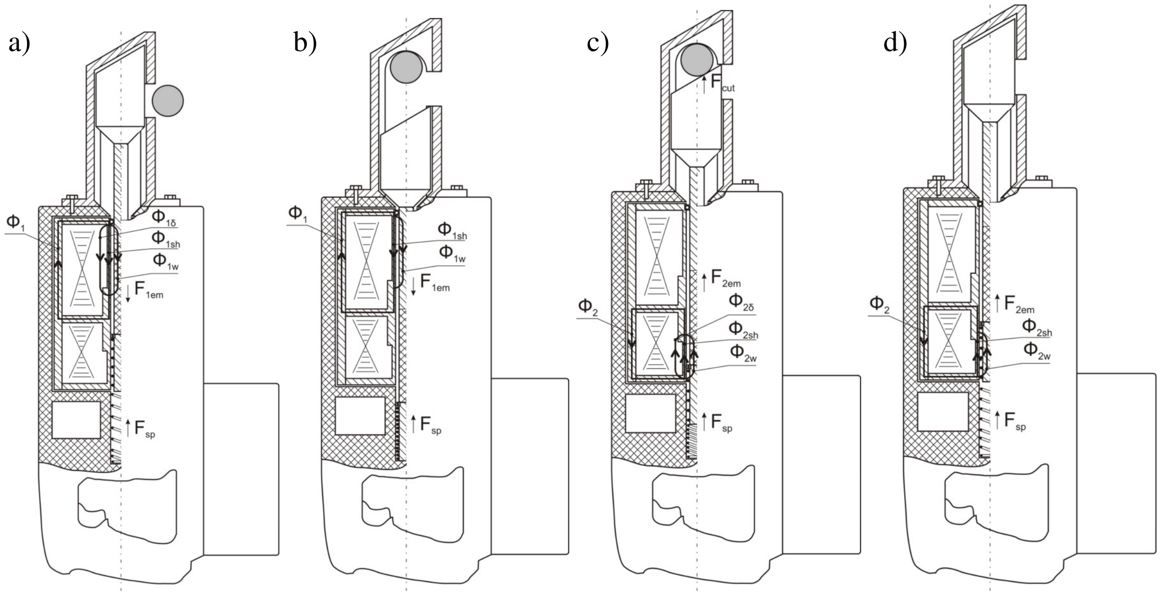

Fig. 2. **Delimber operating principle**

The magnetic flux Φ_1 at the first narrowing of the magnetic circuit (10) is divided into a working magnetic flux Φ_{1w} passing through the upper magnetic sleeve (6) and a non-magnetic sleeve (7), a shunting magnetic flux $\Phi_{1\mathrm{sh}}$ passing through the first narrowing of the magnetic circuit (10), as well as diffused magnetic flux $\Phi_{1\delta}$ passing through the first magnetizing coil (16), then they are summed up in the magnetic circuit (10). Separation of the magnetic flux Φ_1 at the first narrowing of the magnetic circuit (10) into a working magnetic flux Φ_{1w}, shunting magnetic flux $\Phi_{1\mathrm{sh}}$ and diffused magnetic flux $\Phi_{1\delta}$ is due to the first narrowing of the magnetic circuit (10), which leads to magnetic saturation of this section and the expulsion of the magnetic fluxes Φ_{1w} and $\Phi_{1\delta}$, while the magnetic resistances to the passage of the magnetic fluxes Φ_{1w}, $\Phi_{1\mathrm{sh}}$ and $\Phi_{1\delta}$ are comparable to each other due to the presence of a non-magnetic sleeve (7). As a result of the passage of the working magnetic flux Φ_{1w} (Fig. 2. b), the electromagnetic force (F_{1em}) of the first magnetizing coil (16) arises, directed counter to the spring force F_{sp}, which leads to the movement of the armature (4) in the lower position, at which the electromagnetic force (F_{1em}) of the first magnetizing coil (16) is greater than the spring expanding force (F_{sp}) ($F_{1em} > F_{sp}$), while the magnetic flux Φ_1 at the first narrowing of the magnetic circuit (10) is divided into a working magnetic flux Φ_{1w} passing through the upper magnetic sleeve (6), shunting magnetic flux $\Phi_{1\mathrm{sh}}$ passing along the first narrowing of the magnetic circuit (10), and due to the decrease in magnetic resistance in the path of the working magnetic flux Φ_{1w}, the diffused magnetic flux $\Phi_{1\delta}$ disappears.

At the moment when the armature (4) has moved to the lower position together with the movable blade (2), while the fixed blade (1) is secured by means of a bolt (20) on the housing (12), the tree branch (21) is bringing in. By releasing the power button (13), the power of the first magnetizing coil (16) is turned off and the armature (4), connected by a screw (3) with a movable blade (2), under the action of the spring (19) begins to move to the upper position. When the movable blade (2) reaches the tree branch (21) (Fig. 2. c) located in the fixed blade (1), the control unit (14) supplies 24 V from the battery (18) to the second magnetizing coil (17) of the linear electric motor (5), through which the current generating the magnetic flux Φ_2 begins to flow, locking on the magnetic housing (15) and the magnetic circuit (10). The magnetic flux Φ_2 in the second narrowing of the magnetic circuit (10) is divided into a working magnetic flux Φ_{2w} passing through the lower magnetic sleeve (8) and a non-magnetic sleeve (7), a shunting magnetic flux $\Phi_{2\mathrm{sh}}$ passing through the second narrowing of the magnetic circuit (10), as well as diffused magnetic flux $\Phi_{2\delta}$ passing through the second magnetizing coil (17), then they are summed up in the magnetic circuit (10). The separation of the magnetic flux Φ_2 in the place of the second narrowing of the magnetic circuit (10) into the working magnetic flux Φ_{2w}, the shunting magnetic flux $\Phi_{2\mathrm{sh}}$ and the diffused magnetic flux $\Phi_{2\delta}$ occur due to the presence of the second narrowing of the magnetic circuit (10), which leads to magnetic saturation of this section and the expulsion of the magnetic fluxes Φ_{2w} and $\Phi_{2\delta}$, the magnetic resistances to the passage of magnetic fluxes Φ_{2w}, $\Phi_{2\mathrm{sh}}$ and $\Phi_{2\delta}$ are comparable to each other due to the presence of the non-magnetic sleeve

(7). As a result of the passage of the working magnetic flux Φ_{2w}, the electromagnetic force (F_{2em}) of the second magnetizing coil (17) is summing up with the expanding force (F_{sp}) of the spring (19) while exerting a destructive action of the movable blade (2) on the tree branch (21). The cutting force (F_{cut}) of the movable blade (2) will be equal to the sum of the electromagnetic force (F_{2em}) of the second magnetizing coils (17), and the expanding forces (F_{sp}) of the spring (19) ($F_{cut} = F_{2em} + F_{sp}$).

When the armature (4) is reached together with the movable blade (2) of the upper position, the tree branch (21) is cut (Fig. 2. d), the working magnetic flux Φ_{2w} passing through the lower magnetic sleeve (8), the shunting magnetic flux Φ_{2sh} passing along the second narrowing of the magnetic circuit (10), and due to the decrease in magnetic resistance in the path of the working magnetic flux Φ_{2w}, the diffused magnetic flux $\Phi_{2\delta}$ disappears.

By using the delimber movable blade (2) connected by means of a screw (3) with the armature (4), the kinematic scheme of power transmission is simplified, and as a result, the reliability and service life are increased. The use of the linear electric motor (5) and the battery (18) for its power supply allows increasing the work efficiency and reducing operating costs.

Materials and methods

The cutting pair (movable and fixed blades) acts on the wood by pressure, carries out the cutting process. The fixed blade acts as an abutment for the wood, while the movable blade is embedded in the wood. The process of cutting wood with a blade can be divided into several stages (Fig. 3, Fig. 4).

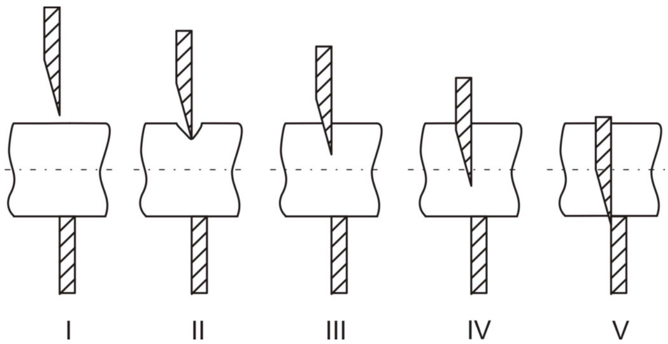

Fig. 3. **Stages of the branch cutting process**

Idle mode is the first stage of operation of the delimber (Fig. 3., Fig. 4. – I) until it comes into contact with the cut wood. The next cutting step (Fig. 3, Fig. 4 – II) is the so-called elastic deformation of the wood to a force value, causing its mechanical destruction, with a sharp decrease in the cutting force. This decrease is associated with a sharp decrease in the deformation processes in wood and transition to the cutting process. The next step is an increase in the cutting force (Fig. 3, Fig. 4 – III) in proportion to the depth of penetration of the movable blade into the wood. When the edge of the movable blade reaches the middle of the cut branch, the cutting force begins to decrease (Fig. 3, Fig. 4 – IV) until it is completely cut. After that, the movable blade goes to the end position with an effort equal to idle mode (Fig. 3, Fig. 4 – V).

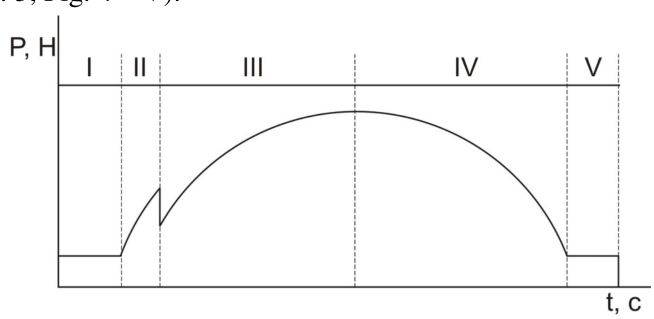

Fig. 4. **Mechanical characteristics of the branch cutting process**

The rationale for the cutting process involves determining the cutting force through the hardness of the material according to the formula

$$P_{cut} = H \cdot S \,, \tag{1}$$

where H – hardness of the material, MPa;
S – cutting area, m^2.

The nature of the cutting force curve depends on the cross-sectional shape of the cut branch. Ideally, the cross section can be represented as a circle. The thickness of the movable delimbing blade is taken no more than 2 mm. Based on this, the equivalent thickness of the cutting part of the blade is recommended not more than 1 mm. The maximum value of the cut branch diameter of fruit trees by delimbers, taken from an analysis of scientific literature, is in the range from 15 to 30 mm. Based on this, it is possible to draw up a visual cut model of a fruit tree branch with a diameter of 30 mm (Fig. 5).

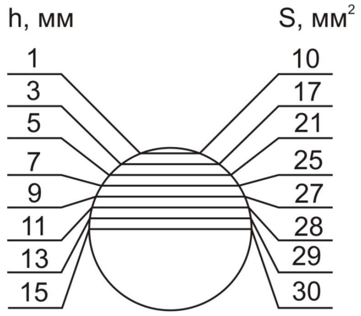

Fig. 5. **Cross-sectional cut model of a fruit tree branch**

Modeling of the cutting process is necessary to build the mechanical characteristics of the delimbers. When the blade penetrates to a depth h (mm) of the fruit tree branch, the area affecting the branch cut will be S (mm^2).

Results and discussion

Using the presented model and the research results [7; 8], it is possible to determine the minimum required force created by a linear electric motor for cutting branches, for example pears.

According to garden care technology, pruning of branches must be carried out before the beginning of active sap flow. Based on this, it is necessary to determine the required force created by the linear electric motor for the implementation of the cutting process. Taking into account the density of wood at different temperatures (-10 ºC, 0 ºC and + 10 ºC) of the environment [7; 8] we obtain the results of the required cutting force. The results of the cutting force of pear are presented in Tables 1-3.

Table 1

Cutting force of pear tree branches (variety Lesnaya krasavica) at the temperature -10 ºC (N)

Moisture, %	Blade penetration depth, mm							
	1	**3**	**5**	**7**	**9**	**11**	**13**	**15**
10	387.0	657.9	812.7	967.5	1044.9	1083.6	1122.3	1161.0
20	355.0	603.5	745.5	887.5	958.5	994.0	1029.5	1065.0
30	351.0	596.7	737.1	877.5	947.7	982.8	1017.9	1053.0
40	352.0	598.4	739.2	880.0	950.4	985.6	1020.8	1056.0
50	353.0	600.1	741.3	882.5	953.1	988.4	1023.7	1059.0

Table 2

Cutting force of apple tree branches (variety Lesnaya krasavica) at the temperature 0 ºC (N)

Moisture, %	Blade penetration depth, mm							
	1	**3**	**5**	**7**	**9**	**11**	**13**	**15**
10	304.0	516.8	638.4	760.0	820.8	851.2	881.6	912.0
20	283.0	481.1	594.3	707.5	764.1	792.4	820.7	849.0
30	282.0	479.4	592.2	705.0	761.4	789.6	817.8	846.0
40	283.0	481.1	594.3	707.5	764.1	792.4	820.7	849.0
50	284.0	482.8	596.4	710.0	766.8	795.2	823.6	852.0

Table 3

Cutting force of apple tree branches (variety Lesnaya krasavica) at the temperature + 10 ºC (N)

Moisture, %	Blade penetration depth, mm							
	1	3	5	7	9	11	13	15
10	269.0	457.3	564.9	672.5	726.3	753.2	780.1	807.0
20	247.0	419.9	518.7	617.5	666.9	691.6	716.3	741.0
30	250.0	425.0	525.0	625.0	675.0	700.0	725.0	750.0
40	243.0	413.0	510.3	607.5	656.1	680.4	704.7	729.0
50	251.0	426.7	527.1	627.5	677.7	702.8	727.9	753.0

Analyzing the obtained results, it can be noted that an increase in wood moisture leads to a decrease in the cutting force. A decrease in ambient temperature during pruning leads to an increase in the cutting force of the branches.

The design of the delimbers based on a linear electric motor should be carried out according to the maximum values of the cutting force, taking into account the safety factor $K_з$ = 1.3.

Conclusions

Analyzing existing studies on the dimensional characteristics of the cut branches, we can conclude: from 60 to 80 % of the cut branches have a diameter of up to 15 mm; from 20 to 40 % of cut branches have a diameter of more than 15 mm. Secateurs are used for pruning branches with a diameter of up to 15 mm. To trim branches with a diameter of 15 m and above, it is necessary to use more powerful devices – delimbers.

Based on the above calculations, we can conclude that the maximum cutting force of pear tree branches (P = 1161N) is observed at a wood moisture content of 10 % and an ambient temperature of -10 ºC. Given this fact, the force developed by a linear electric motor, taking into account the safety factor, should be at least 1509.3 N.

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