On technical means of obtaining wood chips, as a way to increase soil fertility

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Abstract. The proposed work outlines the ways to search for new technical solutions that increase the efficiency of the process of ejection of chips from disk chippers, by theoretically substantiating the design and technological parameters of the elements involved in the working process of evacuation of chopped wood. The resulting chips can be used as a mulching agent, which is one of the means of increasing soil fertility. Disc chippers are the most widely used for wood chipping. The chips they produce are best suited for mulching. But disk chippers have such disadvantages as the high energy intensity of the work performed for the processing of wood raw materials into chips. Therefore, it is necessary to justify the design and technological parameters of the chipper elements. To achieve the stated goal of the study, we used a modification of the part dynamics method. Within the framework of this method, the stream of chips was broken up into separate spherical elements. The developed computer program made it possible to carry out a two-factor optimization of the parameters that most significantly affect the efficiency of the equipment. It has been established that two-factor three-criteria optimization of equipment parameters makes it possible to find an optimal combination of structural elements of the chip ejection mechanism. Calculations have shown that the optimal size of the gap between the chipping disc blades and the lateral surface of the cylindrical part of the casing is 9 ... 11 mm, and the best chip pipe diameter will be 230 ... 300 mm. In this case, the speed of chip ejection will be at least 2.0 m/s, and the share of chips ejected from the first revolution of the chipping disk will be at least 80%. Power consumption for the release of chopped wood will not exceed 700 W.

1. Introduction
To increase soil fertility, experts use such an agricultural technique as mulching. It is the covering of the soil with a thin layer of crushed material, which reduces moisture evaporation and reduces the effect of sunlight on soil temperature. Also, this agronomic technique prevents the growth of weeds and, after rotting, fills the soil with nutrients. The most effective material for mulching is wood waste (sawdust, wood chips). Any wood chips are suitable for covering the soil, but the effectiveness of its effect on soil fertility depends on the breed and size.

Waste wood during rotting draws out a lot of nitrogen from the soil, this occurs as a result of the vital activity of bacteria, which ensure the decomposition of complex organic matter into simple...
components and produce humus. Therefore, the larger the wood waste, the less their effect on the soil, since they have a smaller area of contact with the ground and bacteria have to take most of the nitrogen necessary for nutrition from the air.

For this reason, large chips are most suitable for mulching any plants and large seedlings. Medium and fine chips are suitable for dumping any adult plants, while mulch soil must be watered with nitrogen-containing fertilizers. In this case, the influence of fresh and not rotted wood will be minimal [1]. To obtain this type of covering material, it is necessary to grind wood raw materials, which can be obtained as waste wood processing production or produced for use in agriculture using wood waste chippers [2].

In disc chippers, wood is cut at an angle to the grain of the wood and is carried out between the knives mounted on the knife disc (rotor) and the counter knife on the receiving chuck (branch pipe). Loading of material into disc chippers is carried out horizontally from the feeding conveyor [3]. Sometimes large chippers are equipped with their own feed drive. For the loaded material of short length, the design of disc chippers with inclined material feed is provided. In this case, the in feed conveyor is positioned above the chipper and the material is fed to the knives by its own weight.

The chips can be ejected downward (onto the discharge conveyor or into the inlet) or upward (into a cyclone or heap). Thanks to the high speed of rotation, the blade disc acts as a fan here, allowing the chips to be thrown over a considerable distance. In drum chippers, the cutting tool is a rotor (drum) with cutting knives or cutters attached to it. The drum is solid (chips enter the foot depressions) and hollow (chips enter the drum). The drum machines are loaded horizontally from the feed conveyor and are equipped with a roller feed drive with a mechanical or hydraulic clamp. But there are machines with free filling of raw materials, but this type of loading is used for short-sized materials (up to 1.5 m in length). The chips are unloaded downwards onto the conveyor or into the inlet of the pneumatic conveying system.

Currently, chippers are produced for shredding wood waste (pallets, wooden containers, cable drums, sleepers, old furniture). This type of shredder is called a shredder. The resulting crushed fraction is suitable for further use as a mulching material. Depending on the installation of the machine, the type of material to be fed and the local conditions, the wood raw material is fed into the receiving hopper of the shredder by means of a wheel loader, belt conveyor or other conveying system. For more efficient shredding and increased productivity, shredders are equipped with a hydraulic pusher that pushes the material against the shredder rotor.

The gripping of the material to be crushed is carried out by the driven rollers, which evenly feed the wood to the chopper rotor. The design of the feed mechanism in this case is similar to the feed mechanisms of drum chippers. Depending on the purpose of the machine and its capacity, shredders are equipped with rotors of various designs, with a diameter of 250 to 1100 mm and a width of up to 5 m. Wood shredding takes place between the rotor blades rotating against the material and the blades fixed to the bed. The rotors can be flat or profiled and equipped with welded teeth or replaceable teeth fixed to the shaft using screw fasteners [4]. Practice has shown that disc chippers are most widely used in the production of wood chips. A wide range of applications of this type of machines testifies to the versatility of the design schemes used, which are characterized by: maneuverability, high productivity and compactness [5].

However, disc chippers also have disadvantages, the main of which is the high energy intensity of the work performed for the processing of wood raw materials into chips. Therefore, the introduction of new disc chippers for crushing logging waste will have an impact on the indicators of agricultural production, as one of the means of increasing soil fertility [6]. The existing theoretical developments on the substantiation of the parameters of chipping disk machines cannot be fully used due to the specifics of the working conditions, which leads to the need to develop methods for calculating their design parameters. The aim of the study was to search for new technical solutions that increase the efficiency of the process of ejecting chips from disk chippers, by theoretically substantiating the design and technological parameters of the elements involved in the work process of evacuating the chipped wood (figure 1).
2. Materials and methods

A new design of a disk chipper was chosen as the object of research (figure 1) [7-8].

Figure 1. Diagram of a new design of a disk chipper: 1-loading chuck body with 2-dimensional plates; 3-chip pipe; 4-chopper; 5-belt transmission; 6-drive shaft; 7-feed mechanism; 8-feed rollers; 9-loading device; 10-lower platform with arrow-shaped grips; 11-upper platform with inclined walls; 12,13,14-hinges; 15-thrust; 16-hydraulic cylinder; 17-pipeline; 18,19,20-pulleys; 21,22-shafts; 23-V-belt transmission; 24-reducer.

A modification of the particle dynamics method was used to theoretically substantiate the design and technological parameters of the chipper elements involved in the work process of the evacuation of crushed wood. Within the framework of this method, the stream of chips was broken up into separate spherical elements. Chip elements have the physical properties of wood and their properties are described by density, elasticity and viscous friction [7-10]. In contrast to approximations in a continuous medium, in the method of particle dynamics, elements can move in space, like separate physical bodies, obeying the laws of classical dynamics. In this case, the elements can interact with each other and with the working surfaces of the chip ejection mechanism (figure 2).

This division of the medium into separate elements allows reproducing complex phenomena in a moving stream: redistribution of kinetic energy, vortex and turbulent motion, mixing of streams with different kinetic parameters [11-12]. Each i-th chip element in the model was set by six variables: location in space is set by the Cartesian coordinates \( x_i, y_i, z_i \); the speed of movement is set by the components \( v_{xi}, v_{yi}, v_{zi} \).

The mechanical movement of elements, as separate bodies, was described using Newton's second law. The system of second-order differential equations was solved by the functions \( x_i(t), y_i(t), z_i(t) \), which determined the trajectories of the chips elements in the ejection device and made it possible to evaluate the efficiency of the entire device [13-14]. The elementary surfaces of the chip ejection mechanism were set by analytical equations, which can be used to determine the distance \( r_{ij} \) between the center of element \( i \) and elementary surface \( j \). Equations 1 are second-order differential equations and are solved in the course of modeling by a numerical method - the second-order Runge-Kutta method [15]:

\[
\begin{align*}
  x_{i}^{\tau+1} &= x_{i}^{\tau} + v_{xi}^{\tau} \cdot \Delta t + a_{xi}^{\tau} \cdot \frac{(\Delta t)^2}{2}; \\
  v_{xi}^{\tau+1} &= v_{xi}^{\tau} + a_{xi}^{\tau} \cdot \Delta t; \\
  y_{i}^{\tau+1} &= y_{i}^{\tau} + v_{yi}^{\tau} \cdot \Delta t + a_{yi}^{\tau} \cdot \frac{(\Delta t)^2}{2}; \\
  v_{yi}^{\tau+1} &= v_{yi}^{\tau} + a_{yi}^{\tau} \cdot \Delta t; \\
  z_{i}^{\tau+1} &= z_{i}^{\tau} + v_{zi}^{\tau} \cdot \Delta t + a_{zi}^{\tau} \cdot \frac{(\Delta t)^2}{2}; \\
  v_{zi}^{\tau+1} &= v_{zi}^{\tau} + a_{zi}^{\tau} \cdot \Delta t,
\end{align*}
\]

Where \( i \) -the number of the chip element, \( \tau \) and \( \tau + 1 \) - the indices of the current and next time step; \( \Delta t \) - the time integration step; \( (x_{i}, y_{i}, z_{i}), (v_{xi}, v_{yi}, v_{zi}) \) and \( (a_{xi}, a_{yi}, a_{zi}) \) - position, speed, acceleration of the element.
To theoretically substantiate the design and technological parameters of the elements involved in the work process of the evacuation of crushed wood, the computer program "Program for modeling the mechanism of ejection of chips from a disk chipper" in Object Pascal in the Delphi 7 development environment was used (figure 2) [16-17].

![Figure 2](image)

**Figure 2.** Forces arising from the contact of two elements of wood chips (a) and between the element and the working surface of the mechanism (b): $F_y$ - elastic forces; $F_C$ and $F_B$ - forces of dry and viscous friction.

The program is designed to carry out computer experiments on the movement of wood chips in the casing and chippings and to study the effect of the design parameters of the mechanism on its efficiency. In the program code, the basic geometrical parameters of the flow of chips, chipping disc, casing, chip pipe are set or changed [18]. In the process of simulation, the program displays three projections of the chip ejection mechanism, the current values of the process parameters. The program is applicable in a wide range of geometrical parameters of chips pipe and chip flow parameters [19-20].

When carrying out a computer experiment at the initial moment of time, there are no chip elements in the model. In the course of a computer experiment, a portion of chips regularly appears in the area of space corresponding to the location of the place of interaction of the blades of the chopping disc with the cutting debris, and at those moments in time when one of the four blades of the disk passes the given place of grinding the cuttings. The chip elements added to the model are given a speed in the tangential (tangential) direction to the chopping disk, proportional to the distance from the disk axis. When chip elements come into contact with the boundaries of the model space in the form of a parallelepiped, the elements experience elastic repulsion and return to the model volume.

### 3. Results

In order to establish the simultaneous influence of several parameters on the efficiency indicators of the chip ejection mechanism from the disk chipper, a two-factor optimization of the device design was performed. From the total number of design parameters of the chip ejection mechanism, two parameters have been selected that most significantly affect the efficiency of the equipment:

- Clearance $L_3$ - the distance between the lateral surface of the cylindrical part of the casing and the protruding blades of the chipping disk;
- Diameter $d_2$ of the round zone of the chip line, which determines the effective conductivity of the chip line. When the diameter $d_2$ was changed, the geometrical parameters of the inlet and outlet parts of the chip line, affecting the conductivity of the chips, were changed in agreement.
The following were chosen as optimization criteria:

- \( V_B \) - chip ejection speed at the chip pipe outlet;
- \( R_p \) is the probability of splitting chips from the first revolution of the chipping disc (a certain fraction of chips, adversely hitting the walls, is not thrown out from the first revolution of the chipping disc, settles under the action of gravity, and is later carried away by the blades from the bottom of the casing);
- \( N_B \) - losses of mechanical power for the chip ejection after chopping the cut residues with knives.

To solve the two-factor optimization problem, nine computer experiments were carried out, in which \( L_3 \) was changed at levels of 5, 10, 15 mm with a simultaneous change in \( d_2 \) at levels 100, 250, 400 mm. Based on the research, analytical formulas were obtained for the functions \( v_B(L_3, d_2) \), \( p_1(L_3, d_2) \) and \( N_B(L_3, d_2) \), which were approximated by second-order polynomials in the form (2):

\[
K(L_3, d_2) = k_1 L_3^2 + k_2 d_2^2 + k_3 L_3 d_2 + k_4 L_3 + k_5 d_2 + k_6,
\]

(4)

Where \( K \) is an optimization criterion (\( v_B, p_1 \) or \( N_B \)); \( k_1 \) ... \( k_6 \) - parameters of the polynomial.

The parameters of the polynomials were determined by the least squares method (OLS), within which the sum of the squares of the deviations of the analytical dependence on the results of a computer experiment was minimized. For approximation by the LSM method, a calculation was made in the MathCAD 14 program. As a result of the calculations, the following analytical formulas were obtained for the efficiency indicators of the chip ejection mechanism:

\[
v_B(L_3, d_2) = -4.001 \times 10^{-3} L_3^2 - 2.889 \times 10^{-5} d_2^2 - 6.667 \times 10^{-5} L_3 d_2 + 0.057 L_3 + 0.015 d_2 + 0.467,
\]

(5)

\[
p_1(L_3, d_2) = -7.333 \times 10^{-4} L_3^2 - 8.593 \times 10^{-6} d_2^2 - 2.001 \times 10^{-5} L_3 d_2 + 0.006 L_3 + 4.785 \times 10^{-3} d_2 + 0.226,
\]

(6)

\[
N_B(L_3, d_2) = 11.47 L_3^2 + 4.741 \times 10^{-3} d_2^2 + 0.023 L_3 d_2 - 307.8 L_3 - 2.759 d_2 + 2889
\]

(7)

Where \( L_3 \) and \( d_2 \) are measured in mm, \( v_B \) - in m/s, \( p_1 \) - dimensionless quantity, \( N_B \) - in W.

The formulas obtained can be used to quickly evaluate (without performing real or computer experiments) the efficiency indicators of the chip ejection mechanism. For further analysis, the functions \( v_B(L_3, d_2) \), \( p_1(L_3, d_2) \) and \( N_B(L_3, d_2) \) are presented in the form of cartograms (figure 3). The graphs allow you to visually understand the nature of the influence of the gap and the diameter of the chip line on the speed of chip ejection, the probability of chip ejection from the first turn and the power consumption of the ejection mechanism. Due to the need for visual analysis by projections, graphics allow us to understand patterns only at a qualitative level; for quantitative analysis, the graphs were rebuilt into cartograms: views of the graphs from above, with the image of the response surface by level lines (figure 3).
An example of using cartograms is shown in figure 3, a. If the gap between the chipping disc and the casing is 12 mm (point A) and the diameter of the chip line is 200 mm (point B), then the corresponding point of the factor space C falls between the level lines of 2.1 and 2.2 m/s, but closer to the line level 2.2 m/s. That is, the ejection velocity $v_B$ will be about 2.16 m/s. In a similar graphic-analytical way, you can determine other performance indicators for the corresponding cartograms. On the cartograms, areas of favorable values of indicators are darkened: high values of the ejection rate and the probability of ejection during the first revolution of the chopping disk, as well as low values of power consumption for ejection. The threshold values for dividing into favorable and unfavorable areas were chosen $v_B = 2.0$ m/s (figure 3, a) and $p_1 = 0.80$ (figure 3, b) and $N_B = 700$ W (figure 3, c).

The threshold values are selected based on the conditions that the favorable area will occupy a significant fraction of the factor space, include the highest or the lowest criterion values, and the area boundary will be a level line on the cartogram. The intersection of favorable areas (figure 3, d) is an optimal area in which the requirements for each three of the performance indicators are simultaneously taken into account. According to the location of the optimal one in the factor space (figure 3, d), the following conclusion can be drawn. The optimal size of the gap between the chipping disc blades and the lateral surface of the cylindrical part of the casing is 9 ... 11 mm, the optimal chip pipe diameter is 230 ... 300 mm. In this case, the chip ejection speed will be at least 2.0 m/s, the share of chips ejected from the first revolution of the chopping disk will be at least 80%, the power consumption for the ejection will not exceed 700 W.

4. Conclusion
The conducted studies of the search for new technical solutions that increase the efficiency of the process of ejecting chips from disk chippers, carried out by theoretical substantiation of the design and technological parameters of the elements involved in the work process of evacuation of chopped wood showed that two-factor three-criterion optimization of equipment parameters makes it possible to find an optimal combination of structural elements of the chip ejection mechanism.
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