Research of process overcoming obstacles by tillage tools

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Abstract: The patterns of interaction between tillage tools and obstacles in forest soils (stumps, roots, stones) are important for the development of specialized forestry tools. They largely determine the type of a tool, tool geometry and modes of operation. In this study, the process of overcoming obstacles with a tillage tool using the method of multibody dynamics (MBD) was studied. For this purpose, CAD SolidWorks and a software program for engineering calculations SolidWorks Motion in which a virtual test bench was created was used. The forces applied on the standard, experimental and disk cultivator tillage tools were studied in various interactions with an obstacle. Studies have shown that in frontal interaction with an obstacle an experimental tillage tool has power characteristics similar to a disk cultivator, and in lateral interaction they are similar to the standard one. It provides reliable in overcoming obstacles with a small mass. Laboratory studies were conducted in the soil channel to test the simulation results. On the basis of the results of the experimental test the differences of the theoretical and practical values of traction resistance of a cultivator section were established during the overcome of an obstacle. For the experimental tillage tool, the differences in the maximum values at the entrance to the stump are 3.9%, for the disk, 1.7%.

1. Introduction

Weed control in forestry is one of the most important reforestation operations determining the further development of the forest cultures. It is carried out with cultivators several times per season for the initial few years. At least 40% of the total cost of growing forest cultures is spent on weed control. Thus the operation of cultivators is complicated by a considerable number of stumps, stones, roots of trees and bushes in forest soils [1].

For these reasons disk cultivators are generally used for weed control. Disks overcome obstacles well, do not get clogged with soil and vegetation, but they are less effective when it comes to removing weeds and their depth of tillage is not constant.

Sweep tools are widely used in agricultural cultivators. Their depth of tillage is constant, they effectively remove weeds and have low tractive resistance. They are have the following limitations: they get clogging with fragments of plants, they are not sufficiently reliable when it comes to overcoming obstacles and it is necessary to use protective devices [1]. The use of cultivator sweep tools in the conditions of forest cutting requires changes in their design, strength and geometrical parameters.

To create workable tools for forest cultivators, first of all it is necessary to research their ability to overcome various obstacles. These studies should be carried using computer simulation to the maximum.
At the moment, the simulation of the interaction of tillage tools with obstacles is studied only in a two-dimensional coordinate system [2-3]. This leads to significant simplification of the geometry of the operational parts and to a decrease in the reliability of the studies. The existing studies of volumetric interaction of tillage tools relates to the research of their interaction with homogeneous soil. In this case, either the finite element method (FEM) [4-5] or the discrete element method (DEM) [6-8] is used. However, these methods are not applicable to simulating the dynamics of multi-link mechanisms. In this case the best choice is to use the method of multibody dynamics (MBD) that is widely used to simulate the movement of a vehicle suspension [9-11]. Thus, the purpose of the study is to research the dynamics of overcoming obstacles by tillage tools using multibody dynamics methods and to seek experimental confirmation of the data obtained. The scientific novelty lies in the development of a virtual stand to simulate the overcoming of various obstacles by tillage tools and virtual test techniques.

2. Material and methods

To study the kinematics and dynamics of obstacles overcome models of standard, experimental and disk tillage tools were created in the program SolidWorks 2011 (figure 1).

![Figure 1. Real life cultivator tools and their 3D-models: (a) – standard, (b) – experimental, (c) – disk.](image)

The next step was to create a model of the virtual stand (figure 2) to be analyzed in the program SolidWorks Motion.

The stand consists of basis 1, two cylindrical slide ways 2, carriages 3 and conditionally designated soil 4. Section 5 of the cultivator with standard, disc and experimental 6 cultivator tools was fixed on the carriage that can move in a straight line without friction. A stump 7 with different lateral displacement is installed at the base.

The cultivator sections drive is a linear engine operating at steady speed. The parameters of real life springs set the parameters of the virtual springs of the safety mechanism. Also the density of materials of all the components allowing to calculate their mass characteristics was set. Mutual 3D-contact with
the following parameters was set for components of the cultivator sections: steel-steel dry friction; rigidity 99998.4 N/m, maximum vibration damping 49.03 mm/s (from the program database); mutual penetration is absent. For the tested cultivator tools and obstacles, mutual 3D-contact was established with the following parameters: a steel-steel dry friction; elastic interaction is absent. The reason for that is that in standard databases there is no suitable material to imitate the properties of wood. The simulation of interaction of cultivator tools with the soil was not carried out.

During the virtual simulation experiment the following factors were changed: type of cultivator tool (standard, experimental and disk ones); stump height (0, 5 and 10 cm); the characteristics of the interaction (frontal, lateral displacement of 15 and 30 cm stumps). The speed in all experiments was at steady 3 km/h, the diameter of the stump was 50 cm and also remained unchanged. The conditional processing depth in all experiments was 12 cm.

![Virtual stand](image)

**Figure 2.** Virtual stand: 1 – basis; 2 – cylindrical slide ways; 3 – carriages; 4 – conditionally designated soil; 5 – section of a cultivator; 6 – cultivator tools; 7 – stump.

### 3. Results and discussion

The carried out kinematic and dynamic analysis has allowed to measure the following parameters: angular displacement, speeds, accelerations, the inertia moments, impulses, kinetic energy of cultivator tools and links of the safety mechanism, the forces in springs in case of different types of interaction with a stump.

Let us consider the dynamics of the force created by the springs as it characterizes the loading of the cultivator tool and the mechanism as a whole.

![Changing forces](image)

**Figure 3.** Changing forces in a spring of standard, experimental and disk cultivator tool with frontal interaction with a stump.
The diagrams in figure 3 show changing forces in springs when the type of a cultivator tool and the height of a stump are changed. A standard cultivator tool with a stump height of 10 cm has the greatest force on the spring of the safety mechanism equal to 5770 N, the experimental cultivator is slightly less than 5679 N, and the minimum force 5346 N is observed for the disk tool.

Lateral displacement of the stump relative to the cultivator tool does not cause significant changes in the nature of the increase and decrease of forces in the spring, with nothing but the overall duration of the process of overcoming the stump decreasing (figure 4). Only when the displacement is 30 cm, the experimental and standard cultivator tools show a decrease in the maximum force. The reason for that is that only the side edge of a sweep tool interacts with the stump, and the cultivator tool deviates on a smaller angle.

![Figure 4. The change of the force created by a spring with different lateral displacement of 10 cm stump.](image)

Figure 5 shows diagrams of angular speeds of the cultivating tools are presented in a frontal interaction with a 10 cm stump. Angular speed is at its maximum when a cultivator tool descends from the stump. It is 2327 deg/s for the standard cultivator tool, 1630 deg/s for the experimental one and –966 deg/s for the disk one.

In case of lateral interaction with a stump, angular speeds of the cultivator tool decrease with the increase in lateral displacement. It can be attributed to the reduction of the lifting height and an increase in the duration of the contact of the cultivator tool with an obstacle.

Figure 6 shows diagrams displaying the force on the linear engine that drives the virtual test bench carriage. The increase in force at the entrance on the obstacle of different cultivating tools does not have significant quantitative and qualitative differences. However, when a cultivator tool falls, when it bumps into stopping devices, considerable quantitative differences are observed. The least fluctuation of force is observed when a standard cultivator tool falls (12320 N), while an experimental one has 15009 N, and the disk cultivator tool has a maximum fluctuation in the force of 83814 N. It can be explained by a considerable difference between the masses of the sweep and disk cultivator tools and by the different location of their center of gravity.
Thus, the design of the experimental cultivator tool and the safety mechanism allows to overcome stumps of different height and lateral displacement. In a frontal interaction with an obstacle the experimental cultivator tool has the power characteristics similar to the disk cultivator tool, and in a lateral interaction they are identical to the ones of a standard cultivator tools.

An experimental verification was carried out in order to corroborate the obtained data. The strain-gauging method was used to record the data on a computer that allows to carry out reliable research [12-13]. For that purpose the strain-gauge equipment 1 was fixed on traction trolley 2 (figure 7). The traction resistance was recorded using strain gauge 3 and the rotation angles of the safety mechanism using rotation angle sensor 4. The received electric signals were transferred to modules ADAM and processed by computer 5 [14].

For comparison the turning angle of the cultivator tool’s support was chosen. This parameter is recorded directly by the angle sensor. These diagrams shows the turning angle of the experimental tool’s support (figure 8) and the disk one (figure 9) in overcoming a 10 cm stump with the processing depth of 12 cm.
Figure 8. The angle of rotation of the experimental cultivator tool at overcoming of 10 cm stump received experimentally and theoretically.

Figure 9. The angle of rotation of the disk cultivator tool at overcoming of 10 cm stump received experimentally and theoretically.

The analysis of the diagrams shows that the theoretical data is sufficiently reliable. Unique difference of experimental data is step character of change of an angle, which is explained by the frequency of obtaining data from sensors.

The reliability of the force parameters was verified by comparing the traction resistance and the forces in the virtual engine (figure 10, 11). The difference between the maximum values at the entrance to the stump for the experimental cultivator tool amounts to 3.9 %, and for the disk one it is 1.7 %. When the tool moves on the horizontal surface of the stump, the difference increases, although a decrease in traction resistance is observed.

Figure 10. Traction resistance of an experimental cultivator tool obtained experimentally and theoretically.

Figure 11. Traction resistance of a disk cultivator tool obtained experimentally and theoretically.

Divergences of data, possibly, have arisen that in model the solid stump excluding incision and jamming of cutting edges of cultivator tool has been used. Thus, received theoretical by shock loadings at the moment of falling of cultivator tool can be accepted with sufficient degree of accuracy.
It is especially important, because owing to a design measuring equipment and characteristics of a used data-acquisition equipment fixation of the given parameter is impossible.

4. Conclusions

The results of the simulation using the method of multibody dynamics (MBD) have confirmed that an experimental tillage cultivator tool can overcome stumps with different heights and lateral displacement. In case of a frontal interaction with an obstacle, the experimental cultivator tool has force characteristics similar to a disk tool, and in case of a lateral interaction it is identical to a standard one. It allows to overcome obstacles without accidents (in comparison with a serial tool) and significant shock loads (in comparison with a disk less than 5.6 times).

The estimates of the traction resistance on a virtual stand corresponds closely to the data obtained in the laboratory studies. The difference between the strain gauge measurements and the simulation results for the experimental cultivator is 3.9%, and for the disk one it is 1.7%.

In the future the measured forces of the obstacles overcoming process can be the basis for carrying out strength calculations using the finite element method (FEM). An installation for three-dimensional dynamometry of the obstacles overcoming process can be designed on the basis of the existing virtual installation. Such an installation will allow to record not only the traction resistance, but also the lateral and vertical forces.

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