Calculation algorithm of allowable travel speed of a dynamic tillage tool

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Abstract The algorithm is the basis for creating a computer program to calculate and forecast the allowable travel speed (maximum and minimum) of innovative dynamic tillage tools attached to relevant implements. The source data for calculation were soil hardness, the coefficient of terra-dynamic resistance and the specific tractive resistance per unit of the active frontal area of an innovative dynamic tillage tool. The limitations, which were set by the agrotechnical requirements to the surface tillage, were the uneven tillage depth, the roughness of the field surface, the ridges on the field surface after the tillage, and the soil loosening degree. The study aimed to design an algorithm and its generalized block diagram for determining and forecasting the allowable travel speed of an innovative dynamic tillage tool in various operational conditions. The study object was an arrow-shaped innovative dynamic tillage tool with the working width of 330 mm designed for the surface soil tillage to the depth of up to 14 cm. The study subject was a calculation algorithm for parameters and indicators that affect the allowable travel speed of a dynamic tillage tool. The study applied the methods of mathematical modelling and experimental investigations for the energy assessment of soil tillage tools. The scientific novelty of research is an algorithm and its generalized block diagram for calculating and forecasting the allowable travel speed of a dynamic tillage tool. The paper presents the procedure for calculating the parameters that have a significant effect on the allowable travel speed of a tillage tool.

1. Introduction
The current stage of agricultural engineering development requires new approaches and methods, which would expedite the designing of farm machinery to satisfy consumer demand. They should provide a high technical level and quality of machines and equipment and to improve their competitiveness in the domestic and foreign markets. One relevant tool in this respect is to create and introduce into practice special software, which generally speeds up the development of new machines, tools and assemblies using computer-aided design systems.

The task of such systems, in the long run, is to ensure the rational structural and technological parameters of the designed machines [1].

The practical experience shows that the principles of state-of-the-art designing of new machinery for manufacture of highly standardized machines reduce the development time and costs, while ensuring a decrease in the total energy inputs by 35 - 40% and labor inputs by 25 - 30%.

At present, the scientists and specialists are developing and applying various computer programs for calculating and forecasting the performance of machines, equipment and technologies. The
examples are the forecasting results of the use of tillage machines with active working bodies; assessing the effectiveness of digital technologies in soil tillage [2, 3]; the concept of a smart experimental field implying the creation of shared information space in the form of an information system – a set of sensors, communication equipment and a computer program with a database [4, 5].

The introduction of robotic technologies and designing of smart robotic machines for the agro-industrial complex is considered for technical and technological support of agricultural production in connection with the drop in the rural population and the increasing importance to provide the food security in the country [6 - 8].

The authors of [9, 10] developed a method for selecting the composition of the machine and tractor fleet in market conditions, based on determining the volume of agricultural production by optimizing the use of production resources of a farm by an algorithm allowing to change the structure, tasks and the number of competing tractors and agricultural machines.

We have also analyzed various algorithms and computer programs created by other authors for calculating and forecasting the parameters and indicators of tillage machines efficiency. For example, [11 - 13] present the algorithms for automated optimal designing and identification of structural and technological parameters of tillage and sowing units.

Taking into account the above, the development of an algorithm for calculating the allowable travel speed of innovative dynamic tillage tools is an urgent task.

2. Materials and methods
The study object was an innovative dynamic tillage arrow-shaped tool on a rigid tine with an operating width of 330 mm for the surface tillage to a depth up to 14 cm (Fig. 1).

![Figure 1. Dynamic tillage tool](image)

Generally, dynamic tillage tools act as a vibration damper providing a rapid decrease in the amplitude of load fluctuations to acceptable limits and a mechanical damper of the external load fluctuations of a tillage unit.

Application of dynamic tillage tools within the tillage machines provides the following possibilities:
- to reduce instantly and automatically the frontal area and the cutting angle within the specified limits and to increase the specific pressure on the (hard) dense soil layer. This allows to respond instantly to the dynamic soil pressure, to stabilize partially the vibrations and to reduce the tractive resistance and its dispersion measure;
- to improve the soil loosening owing to high-frequency vibrations of individual elements of the tillage tools when they work at higher speeds;
- to apply the higher operational speeds resulting in the improved productivity and energy efficiency of tillage implements;
- to design the tillage machines with higher energy efficiency of soil tillage against the domestic and foreign analogues;
- to improve the general energy efficiency of soil tillage practices.

The dynamic tillage tool was tested in the experiments on the experimental field of IEEP - branch of FSAC VIM with the measuring and information system designed and manufactured in the institute mounted on MTZ-920 tractor (Fig. 2).

Figure 2. Experimental testing of the dynamic tillage tool with the measuring and information system designed and manufactured in the institute mounted on MTZ-920 tractor

The soil conditions of the experimental testing were as follows: the soil type – sod-mesopodzolic; middle (light) loamy soils above morain clay; the ground contour – 1-2 degrees; the height of ridges on the field surface after tillage – 3-4 cm; the soil hardness before tillage in the soil layer of 5 to 20 cm – 0.85-1.0 MP; the soil moisture content in the layer of 0 to 10 cm – 13.5%, in the layer of 10 to 20 cm – 16.8%.

The study subject was an algorithm for calculating the parameters and indicators that affect the allowable travel speed of the dynamic tillage tool.

The study applied the methods of mathematical modelling and experimental investigations associated with the energy assessment of soil tillage tools.

3. Results and discussion

The source data for calculation were the soil hardness, the coefficient of terra-dynamic resistance and the specific tractive resistance per unit of the active frontal area of the innovative dynamic tillage tool. The limitations set by the agro-technical requirements to the surface tillage were the uneven tillage depth $\Delta_h = \pm 1$ cm, the roughness of the field surface $\Delta_R <= 15$ sm, the ridgeness of the field surface after the tillage $\Delta_g <= 7$ sm, and the soil loosening degree $K_o <= 85 - 95\%$. 
A mathematical model was created for calculating the allowable travel speed of an innovative dynamic tillage tool:

\[
V_{w}^{dop} = \left( 2 C_{PR} R_{tt} / K_{tdr} T_{sh} \right)^{1/2},
\]  
  \( (1) \)

Where

- \( C_{PR} \) – coefficient of proportionality depending on dimension units of parameters \( R_{tt}, T_{s}, V_{w} \) and \( F^{*n} \);
- \( R_{tt} \) – specific tractive resistance per unit of the active frontal area of a dynamic tillage tool;
- \( K_{tdr} \) – the coefficient of terra-dynamic resistance of a dynamic tillage tool;
- \( T_{sh} \) – soil hardness, kg/cm\(^2\).

The algorithm created on the basis of expression (1) allows calculating and forecasting the allowable travel speed (maximum and minimum) of innovative dynamic tillage tools within tillage implements for different conditions of their operation.

The algorithm has the following steps.

1). Identifying the need for the tool under development.

Demand, as a criterion, should be maximum in order to ensure the economic efficiency of the production of the working body of enterprises producing agricultural machinery. The need as a criterion, should be maximum in order to ensure the economic performance of agricultural engineering enterprises, which manufacture the developed tool.

The need for an innovative dynamic tillage tool is assessed by the following indicators:

- Coefficient of the need for the research product:

\[
K_{NEED} = \frac{R}{D} \Rightarrow \text{optimum},
\]  
  \( (2) \)

where \( R \) – relevance of the research product; \( D \) – demand for the research product

- Coefficient of the research product efficiency:

\[
K_{EF} = \frac{D}{P} \Rightarrow 1,
\]  
  \( (3) \)

where \( D \) – demand for the research product; \( P \) – proposals of the research product.

2). Measuring the soil hardness.

The soil hardness is measured with a tester – penetrometer or penetrollogger, in 30 or more points located along the diagonal of the test plot. Hardness testers should provide a measuring accuracy below 5%. For hardness testers that directly record the force, the soil hardness is determined by the values of the force corresponding to the compression of a spring.

3). Calculating the coefficient of terra-dynamic resistance of a dynamic tillage tool.

The coefficient of terra-dynamic resistance \( K_{tdr} \) of a dynamic tillage working tool is calculated by the experimental testing results by the formula from:

\[
K_{\delta} = C_{PR} \frac{2 R_{y}}{T_{sh} V_{w}^{2} F^{*p}},
\]  
  \( (4) \)

where \( C_{PR} \) – coefficient of proportionality depending on dimension units of parameters \( R_{y}, T_{s}, V_{w} \) and \( F^{*n} \);
- \( R_{y} \) – tractive resistance of a dynamic tillage tool, kN;
- \( T_{sh} \) – soil hardness, kg/cm\(^2\);
- \( V_{w} \) – travel speed of a dynamic tillage tool, m/s;
- \( F^{*p} \) – active frontal area of one dynamic tillage tool, m\(^2\).
4). Determining the active frontal area of a dynamic tillage tool.

The active frontal area of a dynamic tillage working tool is determined by measuring the parameters of its frontal projection. The value of the active frontal area varies within certain limits depending on the tillage depth.

5). Determining the tractive resistance of a dynamic tillage tool.

The tractive resistance of a dynamic tillage working tool is determined according to the results of an energy assessment using strain gauges and equipment.

To measure the tractive resistance, the laboratory-scale information and measuring complex designed at the institute was used. It consisted of a 1.4 draw-bar capacity tractor and a mounted unit with strain gauge trolleys and a licensed measuring and information system IP 264 of the Russian Research Institute for Testing of Agricultural Technologies and Machinery – RosNIITiM (Russia).

6). Calculating the specific tractive resistance per unit of the active frontal area of a dynamic tillage tool.

The specific tractive resistance per unit of the active frontal area of a dynamic tillage tool $R_{tt}$ is calculated by the formula from [14]:

$$ R_{tt}^u = \frac{R_{tt}}{F^{tt}}, \quad \text{kN/m}^2 $$

(5)

Where

$R_{tt}$ — tractive resistance of a dynamic tillage tool, kN;

$F^{tt}$ — active frontal area of a dynamic tillage tool, m$^2$.

The values of $R_{tt}$ and $F^{tt}$ are determined experimentally according to the above Items 4 and 5.

Figure 3 shows the graphical and empirical dependences, which were obtained in the experimental studies, of specific tractive resistance per unit of the active frontal area of a dynamic tillage tool and a typical tillage tool under their different travel speeds.

![Figure 3](image)

Figure 3. Dependencies of the specific tractive resistance $R_{tt}^u$ per unit of the active frontal area of a dynamic (1) and typical (2) tillage tool with the rigid tine on their travel speed $V_w$ under the tilling depth of 12 cm

Our previous experiments established that the operation of a dynamic tillage tool demonstrated no displacement and dumping of the soil to the side owing to the variation in the spanning angle of its wings and the working width. According to the research results, the specific resistance $R_{tt}^u$ per unit of the active frontal area of a dynamic tool on a rigid tine is 48.2 - 67.3% smaller than that of a typical tool [15].

7). Determining the allowable travel speed of innovative dynamic tillage tools.

5
The allowable travel speed of innovative dynamic tillage tools is calculated by the formula (1). It should provide the high performance and energy efficiency of tillage implements as well as the improved quality of soil tillage.

Figure 4 shows a generalized block diagram of the algorithm for calculating and forecasting the maximum allowable travel speed of dynamic tillage working tools.

The developed algorithm of the computer program allows calculating the values of the allowable travel speed of the tools within the tillage implements in order to increase their energy efficiency when performing the technological processes of soil tillage.

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**Figure 4.** Generalized block diagram of the algorithm for calculating and forecasting the allowable travel speed of dynamic tillage tools

4. Conclusions
The developed algorithm allows to create in the future a computer program for automated calculation of the allowable travel speed of dynamic tillage tools.

The proposed algorithm can be used to calculate and forecast the allowable travel speed of typical tillage tools that do not have the property of dynamism.

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