Prediction of the Expected Wear Resistance of Soil-Cutting Elements by the Simulation Loading Method

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Abstract. The practice of the agricultural implements’ work is always accompanied by natural wear and tear of the soil-cutting elements of the movable operating tool parts. In order to reduce the wear intensity of soil-cutting elements of new structures, the soil pressures should be estimated occurring at different parts of these elements, and then necessary hardening for the application of wear-resistant materials can be set. In this paper, we propose a shortcut method of laboratory tests to predict the expected wear rates of various parts of soil-cutting elements.

1 Introduction

Any technology of plant cultivation as a rule includes mechanical soil treatment, intended for loosening the soil and cutting weed plants. So in turn the work of agricultural machines is accompanied by the impact of soil-cutting parts on the soil and natural wear changing initial parameters of the part itself in such cases [1]. The cause of deterioration of soil-cutting elements is peculiarities of natural soil composition. The structural unit of the soil is a micro aggregate, in the center of which there is a particle of native rock, more often it is quartz or feldspar inside the horny organic shell [2]. Silicon dioxide is the basis of the native rocks and is the main wear for the soil cutting tools elements.

Wear of the soil-cutting parts, as a rule, leads to additional energy costs during the cultivation of the soil and reduces the quality of the work performed by agricultural implements. At the brake wear of the soil-cutting parts an average weight lost consists only 10-30% of the initial one, so the parts reach the end of their service life, thus the urgency of the study how to prolong their durability is proved [3]. Rational pre-hardening technologies for soil-cutting elements require exact information about places or local areas of greater or lesser expected abrasion [4]. Forecasting the results of abrasive wear at the stage of creating soil-cutting details of new structures is difficult mainly due to the complexity of taking into account the various specific pressures that arise during the working process on the surface of the parts [5]. To determine or measure theoretically or experimentally reliable data of the values of different specific pressures on the entire surface of the part is a very complicated technical task [6]. The results of abrasive wear are usually established by mechanical measurements of wear after the use of soil-cutting elements for several agronomic seasons [7].

2 Materials and methods

Thus, an important technical task has arisen and it requires its own solution while creating new designs for the working organs of agricultural implements. The task is to find a method for predicting the expected wear on different parts of the working elements of the agricultural implement. At the same time, it is necessary to exclude the long time spent on prolonged multi-season tests under conditions of actual operation.
The following hypothesis for the solution of the technical problem was supposed to be applied: a thin layer of low wear resistance material should be spread on the surface of the new working organ and after imitating wear it will determine different wear rates of local areas on the surface of the working organ. For reasoning of this hypothesis the following circumstances were accepted. Abrasion (wear) of the spread layer of material from the surface of the working organ is carried out due to the frictional force of Amonton-Coulomb [8].

\[ F = N \mu, \]  

where \( N \) - normal pressure, \( \mu \) - coefficient of friction.

Considering that the coefficient of friction will be equal on the entire surface of the working element (the same material) and only the change in the values of normal pressures is the determines the wear rate [9]. Then the technical problem is initially reduced to the definition of normal pressure diagrams over friction surfaces of the working tools. The relative changes in the values of normal pressures presume a greater or lesser intensity of wear at each local section of the friction surface. To reduce the time for testing, a bench was used for intensifying the imitation tests, where real sandy soils were used as an abrasive, and the speed of movement of the working organ and other test conditions corresponded to the conditions of operation of agricultural implements in real practice.

The scheme of accelerated imitation tests is shown in Fig. 1a, where cylinder 1 contains sandy soil 2, and the shaft 3 by means of struts 4 fixes the test organ 5 (in this case a flat soil-cutting part - straight wedge). The working element 5 was covered with a thin layer of light abrading coating 6 (see Fig. 1c), the thickness of which was determined with the magneto-induction method by touching the coating with the friction surface by the core 7.

**Figure 1.** The scheme of simulation tests
a) scheme of the test bench, where 1 - cylinder, 2 - soil, 3 - shaft, 4 - struts, 5 - working element; b) the scheme of magnetic induction measurement, where 5 - working element, 6 - easily abraded layer, 7 - core, 8 - coils; c) general view of the loading scheme.
During the work of the test bench, the thickness of an easily abraded layer was measured at specific points and diagrams were plotted. In this case, the coordinates of the measurement points were retained the same by a tool-guide. Fig. 1b schematically shows the working parts of a magneto-induction device with a core 7 and magnetic induction coils 8. Based on the measurement results, diagrams were constructed to demonstrate the change in the thickness of a layer of easily wearing material or, what is the same, the values of normal pressures in relative values. The results are shown in Fig. 1c.

The linear speed of movement of the soil-cutting part (a straight wedge) was selected in the interval 2.2-2.8 m/s. The initial aggregate state of the soil is shown in Fig. 2.

3 Results

Experimental studies of the surface wear of a straight wedge were performed at different angles \( \alpha \) of its inclination to the direction of motion (conditional horizontal line). The following angles \( \alpha \) were chosen: 20/180, 30/180, 45/180, 67/180. Figure 3c depicts the diagrams of the variation of the normal pressure over the friction surface of a straight wedge, where the abscissa \( X \) represents the linear dimensions from the edge of the blade to the top face of the straight wedge; the coordinate axis \( \Delta h \) shows the wear of easily wearable material from the wedge surface or the normal pressure \( N \) in relative values. Curves of the changes in the values of normal soil pressures on a straight wedge along its entire length from the edge of the blade to the top face are marked by functionals, for example, \( y (30/180) = f (x) \) to each corresponding angle \( \alpha \).

As a result of processing the measurement results, the following equations for the relative values of the normal pressures were obtained:

\[
y (\frac{20}{180}) = f (x); \quad y = -0.0031x^3 + 0.0819x^2 - 0.5808x + 5.8394. \quad R^2 = 0.85.
\]
For clarity, the graphs of the functions of normal pressures 1.2.3.4 operating along the length of the straight wedge as a function of the angle of inclination to the direction of motion are plotted in Fig. 3, where the values of normal pressures $N$ are plotted along the ordinate $Y$, and the length of the friction path from the blade to the back. It follows from the graphs that when the $\alpha$ varies from $20/180$ to $30/180$, the values of the normal pressures $N$ vary slightly, but further at $\alpha = 45/180$ and $67/180$ there is a significant increase in $N$. The reason for this is that in the first two cases a uniform motion of soil particles along the length of the blade was observed, and in the third and fourth cases, the soil was thickened, which increased the normal pressure. The latter circumstance occurs when the angle $\alpha$ was set equal to or greater than the friction angle of the soil about the surface of the straight wedge, and then there was no uniform motion of the soil, and soil thickening appeared.

4 Discussions

Having diagrams of normal pressure changes, it is possible to determine the value of the total pressure $N_c$ on a straight wedge by determining the area of the diagram.

$$N_c = \sum_{i=1}^{n} N_i = \int_{0}^{12 \times 10^{-2}} f(x) \, dx$$

(6)

Further, the integration of the equations 1, 2, 3, 4 within the length of the straight wedge blade makes it possible to compare the values of the total pressures on the straight wedge as a function of the angle $\alpha$. At the same time possessing the value:

$$N_{c1} = \sum_{i=1}^{n} N_{ci} = \int_{0}^{12 \times 10^{-2}} y \left( \frac{20}{180} \pi \right) f(x) \, dx = 1$$

(7)

Thus, creating new working organs of agricultural implements for calculating parts and fastenings, it is necessary to know the coordinate of the soil pressure center on the soil-cutting part [10]. In this case, when examining a straight wedge, the coordinate of the pressure center is a certain point located on the friction surface at some distance $L$ from the blade of the wedge. Applying the principle of determining the center of gravity of irregular geometric shapes, we posses:

$$L = \frac{\int_{0}^{12 \times 10^{-2}} (f(x))^2 \, dx}{\int_{0}^{12 \times 10^{-2}} f(x) \, dx}$$

(8)

Then for the diagrams bounded by the equations 1,2,3,4, we have the following coordinates of pressure centers:

$$L_1 = 2.5 \times 10^{-2}; L_2 = 3.3 \times 10^{-2}; L_3 = 8.3 \times 10^{-2}; L_4 = 10.5 \times 10^{-2}.$$  

(9)

Conclusions

1. Predicting the expected wear for new forms of created soil-cutting parts, it is necessary to identify the diagrams of normal pressures that are expected in the practice of their further operation. Proceeding
from the schemes of the expected normal pressures and friction on the surfaces of the soil-cutting parts, it is not difficult to assign the amount and dimensions of the application of a wear-resistant material that provides the required durability in subsequent operation.

2. It is noteworthy that an agricultural implement destroys the physical form of the soil in the layer of its contact with the soil-cutting part. It is clearly seen in the schemes of normal pressures. Stratum size of the soil layer with the destroyed physical form grows as the angle of inclination to the horizontal increases in the case of a straight wedge application.

3. Scheme of normal pressures and soil pressure centers on soil-cutting details obtained by means of their arrangement are the initial data in the calculation of new designs of the working organs of agricultural implements and their soil-cutting elements.

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