

Research Article

Theoretical Description of the Movement of Soil Clods Due to Interaction with the Loosening Drum of the Separator Machine

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Abstract

This article explores the theoretical foundations of soil clod movement during their interaction with the loosening drum of a separator machine. The study primarily focuses on the mechanisms of clod disintegration under free impact conditions and their subsequent separation through the elevator gaps. Special attention is given to the physical principles governing the fragmentation of soil clods, taking into account both kinematic and dynamic aspects of their interaction with the drum pegs. To comprehensively analyze the process, mathematical models have been developed to describe the motion parameters, impact dynamics, and resulting fragmentation behavior of the clods. The research also evaluates the energy consumption associated with overcoming soil resistance and achieving effective fragmentation. Furthermore, differential equations have been formulated to depict the soil clod motion along the separating elevator, providing a clear understanding of their behavior under working conditions. The solutions to these equations are illustrated graphically, offering visual insights into the separation process. The theoretical approach adopted in this study draws on established analogies from the theory of threshing drums, enabling the application of existing scientific findings to enhance the efficiency and performance of separator machines. Such an approach contributes to the rational selection of design parameters and operating modes aimed at improving soil processing efficiency.

Keywords

Destruction of Soil Clods, Free Impact, Separating Elevator, Kinetic Energy, Differential Equations, Separator Machine

1. Introduction

The classical theory of the collision of solid bodies, developed by a number of researchers beginning with Galileo, considered the colliding bodies as absolutely rigid and the collision process as instantaneous. This theory, strictly speaking, only allowed for the determination of the results of the impact — the

change in velocities of the colliding bodies. A significant contribution to the study of the contact interaction of elastic bodies was made in the research of H. Hertz [1]. Hertz succeeded in analytically determining the relationship between the magnitude of the contact force and the duration of the impact in terms of

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the bodies' masses and pre-impact velocities.

As can be seen from the above, the difficulties associated with the theoretical study of the impact process necessitate the introduction of a number of simplified hypotheses, most of which are not sufficiently supported by experimental evidence. Moreover, all methods for calculating the impact process are approximate.

Therefore, it should be recognized that, at present, experimental studies play a leading role in the investigation of phenomena related to the impact of solid bodies. It is necessary to improve theoretical research methods and strive to bring them in line with the demands of modern mechanical engineering.

The analysis of literary sources on the theory of threshing drums highlights the significant work of academician V. P. Goryachkin [2]. His classical equations of the drum form the foundation of all subsequent theories in this field [3-7].

2. Materials and Research Results

Taking the above into account, in our case, the main principle of soil clod crushing—on which the operation of the clod-destroying loosening drum is based—is the fragmentation of soil clods into small particles by means of a free impact and their separation through the gaps between the elevator rods [8, 9].

The principle of destruction by free impact functions as follows: blades 2 (Figure 1), mounted on the surface of the drum 1, move with a speed of v_1 and, encountering soil clods 3 in their path, break them into several pieces by impact, which are subsequently separated through the gaps between the elevator rods.

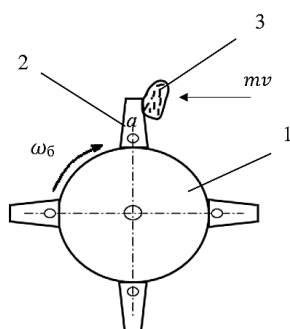


Figure 1. Method of soil clod destruction by impact.

In this case, the action of the spike on the soil clod occurs unilaterally from the side of the spike, and the counteraction is the force impulse.

$$P_{\Delta}t = mv, \quad (1)$$

where m is the mass of the soil clods (kg), and v is the impact velocity (m/s).

Before the impact, the particle has a velocity of $\pm v_2$.

Therefore, at the moment of impact, the impact velocity is equal to the vector sum of the velocities of the spike and the soil clods (Figure 2).

$$v = v_1 \pm v_2 \cdot \cos \alpha \quad (2)$$

Having a certain strength at a given velocity, the soil clod will be destroyed into smaller fragments. Then, after a certain period of time, the impact force will decrease in proportion to the particle size.

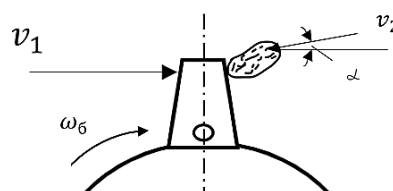


Figure 2. The sum of the velocity vectors of the beater and the soil clod.

The theory of this process is analogous to that of a threshing drum; therefore, the existing results from the theory of the threshing drum can be applied in this case [10].

The energy of the drum, which it receives from the tractor's power take-off shaft through the gearbox and chain transmission, is used to perform work to overcome various resistances and to carry out the process of breaking soil clods.

$$A = A_1 + A_2, \quad (3)$$

A - work expended by the tractor; A_1 - work used to overcome resistances (bearing friction, belt slippage); A_2 - work used for the destruction of soil clods.

The value of A_1 depends on the speed of the moving particles and, in general terms, can be expressed as a function of speed. This functional dependence reflects the relationship between kinetic parameters and the corresponding energy components, and may be written in the following general form [11]:

$$A_1 = q_0 \cdot \omega + B_0 \cdot \omega^3. \quad (4)$$

Here, the first term represents the loss due to mechanical resistance, and the second term — due to air resistance. In our case, air resistance can be neglected, then:

$$A_1 = q_0 \cdot \omega$$

The kinetic energy used in the process of soil clod destruction is determined by the following formula:

$$A_2 = \frac{J_M \omega}{2}, \quad (5)$$

where J_M is the moment of inertia of the beater relative to the axis of drum rotation; ω is the angular velocity of the beater after the impact.

Soil Clod Destruction Energy Balance Explanation:

When a soil clod is struck by a peg (or another working organ), the law of conservation of energy applies. According to this principle, the total energy imparted to the clod during impact is redistributed among different energy-consuming processes [12, 13].

This can be expressed by the following energy balance equation:

$$A_0 = A_M + A_3 + A_{\text{деф}}, \quad (6)$$

where A_0 is the kinetic energy of the beater before impact, equal to:

$$A_0 = J_M \frac{\omega_0^2}{2},$$

where J_M is the moment of inertia of the beater relative to the axis of rotation of the drum; A_M is the kinetic energy of the beater after impact, equal to:

$$A_M = J_M \frac{\omega^2}{2}.$$

The kinetic energy of the impact can be neglected, as the initial velocity is significantly lower.

The change in the kinematic moment of the beater during impact is equal to:

$$J_M \omega_0 - J_M \omega = mvr \text{ или } J_M (\omega_0 - \omega) = mvr,$$

where $A_{\text{деф}}$ is the kinetic energy expended for the work of deformation;

$$A_{\text{деф}} = A_0 - A_M$$

or

$$A_{\text{деф}} = J_i \frac{(\omega_0^2 - \omega^2)}{2} - J_M \frac{\omega^2}{2} = J_i \frac{(\omega_0 - \omega) \cdot \omega}{2} - J_M \frac{\omega^2}{2}$$

The differential equation of the motion of soil clods on the separating elevator after being impacted by the beaters is described as follows [14, 15]:

$$m \frac{dv}{dt} = -F_{mp}, \quad (7)$$

where v_k is the velocity of the clod moving on the separating elevator:

$$v_k = \dot{\varphi} \cdot r,$$

where φ is the angular velocity of the drum;

$$\frac{dv}{dt} = \ddot{\varphi}^2.$$

The friction force is determined by

$$F_{mp} = \frac{mv_k^2}{2} f = \frac{m}{2} (\dot{\varphi} r)^2 f,$$

where f is the coefficient of sliding friction of the soil clod on the separating elevator (0.6); m is the mass of the soil clods, then

$$2\ddot{\varphi}m = \frac{m}{r} (\dot{\varphi} r) f;$$

$$\ddot{\varphi} = -\dot{\varphi} f;$$

$$m\ddot{\varphi}r = -\frac{mf}{r} (\dot{\varphi} r)^2;$$

Therefore

$$\varepsilon = \ddot{\varphi} = -\dot{\varphi}^2 f. \quad (8)$$

Equation (8) is a second-order differential equation that describes the movement of soil clods along the surface of the separating elevator.

Equation (8) was integrated and solved using the MATHCAD software. The calculated results are presented in graphical form in Figure 3.

3. Conclusions

Thus, Figure 3 illustrates the trajectories of both the peg and the soil clods within the separating elevator system. The plotted curves clearly demonstrate that the first contact between the peg and the soil clod occurs at point B — a moment referred to as the ‘impact for crushing.’ At this point, the soil clod undergoes primary fragmentation, breaking into several smaller parts. However, complete destruction of the soil clods does not occur immediately at the point of impact. Instead, it continues within the BC zone, where repeated interactions between the rotating drum pegs and the clod fragments take place. In this zone, the crushing is completed through the application of the least energy-intensive method — the so-called ‘impact-cut’ mechanism. This mechanism involves a combination of impact and shear (cutting) forces generated between the drum pegs and the separating conveyor, which facilitates efficient fragmentation of the soil clods into finer particles.

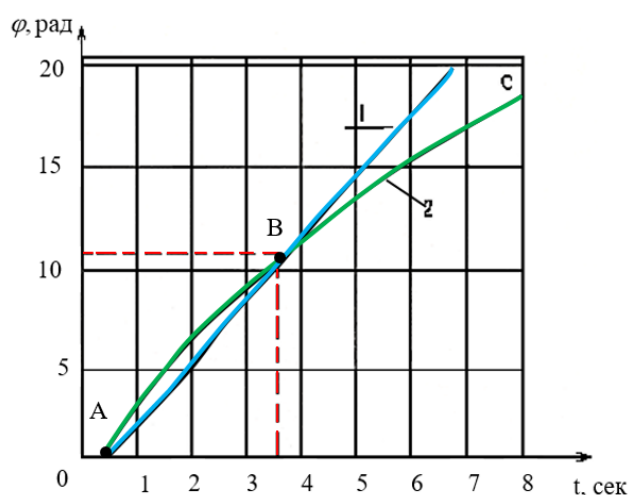


Figure 3. Trajectories of the movement of the peg (1) and soil clods (2).

Abbreviations

- v_k The Velocity of the Clod Moving on the Separating Elevator
 A Work Expended by the Tractor
 A_1 Work Used to Overcome Resistances (Bearing Friction, belt Slippage)
 A_2 Work Used for the Destruction of Soil Clods

Author Contributions

Nabijon Bayboboev: Conceptualization, Formal Analysis, Funding acquisition, Methodology, Project administration, Supervision, Validation, Visualization

Gayrat Baxadirov: Conceptualization, Data curation, Formal Analysis, Methodology, Software, Supervision, Validation, Visualization, Writing – review & editing

Nuriddin Abdaliyev: Formal Analysis, Funding acquisition, Methodology, Resources, Software, Supervision, Visualization, Writing – review & editing

Jurabek Umirzoqov: Conceptualization, Formal Analysis, Investigation, Project administration, Resources, Validation, Visualization, Writing – original draft, Writing – review & editing

Conflicts of Interest

The authors declare no conflicts of interest.

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Biography



Nabijon Bayboboev is a highly respected Doctor of Technical Sciences and a professor, renowned for his extensive contributions to the field. He has conducted extensive research in the field of agricultural machinery, particularly in fertilizer application and potato cultivation technologies. Currently, he works as a professor at the Department of Agricultural Mechanization at the Namangan State Technical University. He is also the chairman of the specialized academic council for doctoral dissertations in technical sciences. Bayboboev is the author of more than 100 scientific publications, including monographs, articles, and teaching manuals. He holds several patents for inventions that have been practically implemented in Uzbekistan's agricultural sector.



Gayrat Baxadirov is a Doctor of Technical Sciences and a professor, highly respected in his field. He has conducted extensive scientific research in the areas of mechanical engineering and the mechanics of technological equipment. Currently, he serves as a senior and leading researcher at the M.T. Urozbayev Institute of Mechanics and Seismic Stability of Structures. In addition, he holds the position of Chief Scientific Secretary of the Academy of Sciences. Bakhadirov is the author of more than 600 scientific works, including 8 monographs and 100 inventions.



Nuriddin Abdualiyev is a PhD in Technical Sciences and an associate professor at Bukhara State Technical University. He specializes in agricultural mechanization, particularly in soil tillage and compaction machinery and technologies. His effective work in both theoretical and applied research supports innovative development in Uzbekistan's mechanized agriculture sector.



Jurabek Umirzoqov is currently a PhD student at Namangan State Technical University. He is conducting scientific research in the field of agricultural engineering. To date, he has published more than 10 scientific articles related to this field.

Research Field

Nabijon Bayboboev: Agricultural mechanization, design of fertilizer application systems, potato-harvesting technologies, development of resource-efficient machinery for soil cultivation.

Gayrat Baxadirov: Mechanical Engineering - Theory of Machines and Mechanisms, Machine Elements Design, Applied Mechanics

Nuriddin Abdualiyev: Agricultural Engineering - Design and Parametric Justification of Soil Compaction Devices for Inter-Row Field Bed Formation in Cotton Cultivation

Jurabek Umirzoqov: Agricultural Engineering - Development and Optimization of Soil Preparation Machinery for Potato Cultivation