Research on parameters of the bladed pneumatic screw mechanism of the digging and transport machine

A A Kovalev¹*, V V Kutuzov¹ and I I Elkina¹

¹V.I. Vernadsky Crimean Federal University, ProspektVernadskogo 4, Simferopol, 295007, Republic of Crimea, Russian Federation

E-mail: kovaland59@mail.ru

Abstract. The main intensifiers that increase the efficiency of the bulldozer are considered. The concept of the digging and transport machine for bulk material is proposed, the design of which combines the positive qualities of pneumatic and bulldozer equipment. The machine is mainly intended for use in reclamation construction for filling holes, ravines, deep wells, filling the water-resistant layer of the bottom of a pond or reservoir, and also for supplying finely divided stone mining waste (sawdust, coal powder, limestone flour, carbonate sand, etc.) in the back of a dump truck or to the blade. The machine can also be used as auxiliary equipment and to fight a fire in the field by supplying a bulk fire-extinguishing agent directly to the edge of the flame front.

1. Introduction

The bulldozer is one of the main machines used in industrial, civil, road, reclamation construction, as its design is simple, versatile and has a low cost of work.

Improving the design of the working body of the bulldozer, according to the works [1,2, 3, 7, 10], it is one of the main ways to improve its performance. It is known that the main advantage of pneumatic mechanical equipment is the ability to simultaneously perform operations of grinding and moving bulk material (for example, sand) in the screw-pressure mechanism, as well as mixing it with compressed air in the mixing air chamber and further supplying the aeromaterial mixture to the warehouse.

In the patent RU 2 414273 “Fire extinguishing composition, method of its preparation and method of fire extinguishing” [11] it is noted that crushed limestone (calcium carbonate) in the form of limestone flour is a well-known safety tool in coal mining. Explosive fire can be suppressed by scattering limestone flour in the air. Under strong heating, limestone decomposes chemically: \( \text{CaCO}_3 \rightarrow \text{CaO} + \text{CO}_2 \). This decomposition reaction requires energy and therefore produces a cooling effect. Therefore, such a digging and transport machine (DTM) can be used as an auxiliary equipment and to extinguish a fire in the field by supplying bulk fire extinguishing agent directly to the edge of the flame front.

The working name of the machine is pneumatic-screw bulldozer. A special feature of the design is the presence of a loading rectangular hole in the plane of the bulldozer blade and the location of a pneumatic-mechanical installation behind it.

The purpose of the study was to assess the possibility of implementing bladed – pneumatic and screw device in the construction of digging and transport machine (DTM) and to determine the theoretical relationship of main parameters of pneumatic and screw and bulldozer equipment of DTM.
2. Materials and methods

In work [2] it is noted that “one of the topical issues is the creation of universal construction equipment that works on new physical and technical principles of interaction with the environment and has high environmental qualities”.

Performance of the bulldozer blade (see [8]) when digging is

\[ P = B \cdot h \cdot \vartheta_\sigma \cdot C_l \]  

(1)

where \( B \) - width of the bulldozer blade, m; \( h \) - depth of ground digging, m; \( \vartheta_\sigma \) - speed of the base machine, m/s; \( C_l \) - the coefficient of the soil loosening.

The capacity of screw auger intensifier (see [8]) is:

\[ P_{SC} = 3600 \cdot \frac{\pi (D_{st} - d_s^2)}{4} \cdot S \cdot n_{SC} \cdot \psi \]  

(2)

where \( D_{st} \) - outer diameter of screw turns, m; \( d_s \) - the shaft diameter of the screw, m; \( S \) - the step of the screw winding, m; \( n_{SC} \) - the frequency of the screw rotation, \( s^{-1} \); \( \psi \) - the coefficient of filling space between turns in the screw.

Formula for determining the relation between the rotation speed of the screw auger intensifier from its geometric parameters and the speed of the base machine:

\[ n_{SC} = \frac{B_B \cdot h \cdot \vartheta_\sigma \cdot C_l}{900 \pi (D_{st}^2 - d_s^2) \cdot S \cdot \psi} \]  

(3)

The performance of the pneumatic installation in the pneumatic lift mode is noted in [6], determined by the last pressure turns of the screw according to the formula:

\[ \Pi_{SC} = 0.785 \cdot (D_{SC}^2 - d_s^2) \cdot S_1' \cdot C_{FR} \cdot \rho_0 \cdot n / 60 \]  

(4)

where \( D_{SC} \) - screw diameter, m; \( d_s \) - the shaft diameter of the screw, m; \( S_1' \) - step of the last pressure turn without the turn thickness; \( C_{FR} \) - the friction coefficient of the screw; \( \rho_0 \) - volume mass of the material, t/m\(^3\); \( n \) - the frequency of the screw rotation, \( \text{min}^{-1} \).

Figure 1. Dependence of the components of the sliding coefficient: a) \( B \) on lift angle \( \alpha_{mn} \) of the screw line of the last pressure turn of the screw; b) \( S \) on the compression ratio of the screw \( K_y \); c) \( \xi \) on the screw diameter \( D_{SC} \).

Power consumption (kW) per screw drive

\[ N_{SC} = 430 \cdot p_C \cdot D_{SC}^2 \cdot n \]  

(5)

where 430 cm\(^2\)m\(^{-1}\)s\(^{-1}\) - coefficient; \( p_C \) - overpressure in the mixing chamber of the feeder, MPa.

3. Results

The previously considered intensifiers of the working process of the bulldozer, in general, accelerated the process of forming the drawing prism when used on various soils.
A distinctive feature of the proposed DTM intensifier (see Fig. 2) consists, firstly, in the fact that the loading window 2 in the design of the blade 1 plays the role of a flow forming element, and secondly, it is used for finely ground and loosened stone crushing waste (hereinafter referred to as bulk material). Pneumatic mechanical installation (PMI) 3 is located behind the bulldozer blade 1. The plane of the opening of the receiving chamber 4 of PMI 3 is located horizontally (in its normal working position). The loading window 2 and the receiving chamber 4 are connected by hopper 8.

![Figure 2. a) scheme of the bladed pneumatic screw mechanism of the digging and transport machine: 1 - bulldozer blade; 2 - loading window of the bulldozer blade; 3 - pneumatic screw equipment (pneumatic screw installation); 4 - receiving chamber; 5 - cylindrical body (cylinder); 6 - universal mixing air chamber; 7 - screw; 8 - hopper; 9 - drive; b) general scheme of the mechanism of a bladed pneumatic screw digging and transport machine: 1 - basic machine; 2 - blade; 3 - loading window; 4 - pneumatic and mechanical installation with a unified mixing chamber; 5 - discharge line; 6 - flexible pipeline section; 7 - hopper-extinguisher; 8 - main hopper; 9 - switcher of the direction of the material flow; 10 - nozzle for material flow outlet; 11 - flexible pipeline; 12 - device for lifting flexible pipeline; 13 - side pneumatic unloader; 14 - nozzle for air outlet to the filter.]

The PMI contains in its design a cylindrical body 5 (hereinafter referred to as the cylinder) with a screw 7 and a universal mixing air chamber 6.

The layout scheme of the bladed pneumatic screw mechanism of the DTM is shown in Fig. 2.

To describe the working process of the machine, we use Fig. 2 b).

At the first stage of the working process, a layer of pre-loosened bulk material moves along the surface of the blade 2. Then the bulk material moves to the loading window 3 and enters the hopper through it. In the lower part of the hopper is the PMI receiving chamber.

At the second stage, the loosened material is sent from the receiving chamber by the screw along the cylindrical body to the universal mixing air chamber, where it is mixed with air. In the process of moving along the cylindrical body, the screw grinds and crushes the lumps of material being moved. Then the crushed material is sent to the mixing air chamber.

At the third stage in the mixing air chamber, the flow of particles of crushed material is mixed with compressed air and enters the discharge line 5.

Then the aeromaterial mixture under the influence of overpressure of compressed air moves through the hopper-extinguisher 7 to the main hopper 8. The flow switcher 9 directs the flow to the nozzle 10 and further to the flexible pipeline 11 in the case of outlet of the material into the car.

A side pneumatic unloader 13 is also used to unload the hopper 8. Lifting and lowering of the flexible pipeline 11 is performed using a system of blocks and polispasts 12. Air is diverted through the nozzle 14 for cleaning.

1. Assumptions underlying the calculation model:
1.1. The design of the bulldozer blade contains a hole through which the material cut off by the blade during the course of the bulldozer enters in a steady mode;
1.2. Further transportation of the material is carried out by a single- or double-support screw (having two opposite (or counter) directed screw surfaces);
1.3. The material is collected in a hopper located behind the bulldozer.

2. The main balance ratio.
From the assumption (1.1) about the steady mode of movement of material to the screw mechanism, it follows that \( Q_0 = Q_{SC} \), where \( Q_0 \) is the volume of cut material, \( Q_{SC} \) is the volume of material transported by the screw mechanism, per unit of time (in calculations – for 1 second).

3. Geometric parameters of elements of the bladed mechanism.

- \( h \) – depth of the cut layer \((m)\);
- \( v \) – speed of the bulldozer \((m \cdot s^{-1})\);
- \( L \) – the width of the blade \((m)\)

Hence: \( Q_b = Lvh \) \( (6) \)

Geometric and kinematic parameters of the screw mechanism: \( D \) – screw diameter \((m)\); \( d_{SC} \) – the shaft diameter of the screw \((m)\); \( s \) – screw step \((m)\); \( n \) – the rotation speed of the shaft of the screw, rpm; \( \omega \) – speed rotation of the screw shaft, rps

Volume capacity of one screw (with one cylindrical body)

\[ Q_{SC}^1 = 0.785 \cdot (D^2 - d_{SC}^2) \cdot n \cdot S_p' \cdot C_{FR} / 60 \] \( (7) \)

with the two screws (with the two cylindrical bodies)

\[ Q_{SC}^2 = 1.57 \cdot (D^2 - d_{SC}^2) \cdot n \cdot S_p' \cdot C_{FR} / 60 \] \( (8) \)

Preliminary discussion of possible technical solutions.

Parameters \( h, L, v, m \) (number of cylindrical bodies (cylinders) - 1 or 2), \( D, d, s, n, S_p', C_{FR} \) cannot be set arbitrarily. The ratio (1) that coordinates their interaction sharply narrows the range of possible technical solutions. Moreover, depending on the application conditions of the device, various combinations of these parameters are possible.

In this regard, we note the fact that the listed parameters differ significantly in their role in the balance dependence: \( h, v \) have a continuous nature of change and well-defined ranges of change: \( h = 0.15 \ldots 0.2 \) (m), \( v = 0.25 \ldots 0.75 \) (m/s).

At the same time, the parameters \( L, m, D, d, s, n \) take discrete series of values, this is due to the presence of specific devices with known geometric and kinematic values.

To ensure compatibility, we equate expressions (6) and (7).

The depth of the cut-off soil layer \( h \) of a bulldozer with a bladed pneumatic screw pressure mechanism is determined depending on \( D, d_{sc}, S_p', n, L, v \), according to the formula:

\[ h = \left[ 0.785(D^2 - d_{SC}^2) \cdot n / 60 \cdot S_p' \cdot C_{FR} \right] / (L \times v) \] \( (9) \)

Let us substitute dependency (5) in expression (14) and get

\[ h = \left[ 0.785(D^2 - d_{SC}^2) \cdot 16.67 \cdot S_p' \cdot B \cdot S \cdot (10 \cdot P_C)^{0.5} \right] / (L \times v) \] \( (10) \)

where \( P_C \) - excess pressure in the mixing chamber of PMI, MPa.

We fix the parameter values \( D = 0.2 \) m, \( d_{SC} = 0.1 \) m, \( S_p = 0.12 \) m, \( \omega = 16.67 \) rps, \( v = 0.25 \) m/s, \( L = 4.25 \) m.

Then we can write: \( h = 0.044 \cdot B \cdot S \cdot (10 \cdot P_C)^{0.5} \) \( (11) \)

Next, we take the value of the screw compaction coefficient \( K_s = 1.1 \) and according to graph a) in Fig.1, we get \( S = 0.52 \).
Then, we take the lifting angle of the helical line of the turn by the average radius $\alpha_{cp}=18^0$ and according to the graph b) in Fig. 1, we get the value $B=0.6$.

Then for screw $D=0.2$ m we get $h = 0.014 \cdot (10 \cdot P_c) ^\xi$, where $\xi = 1$ (see the graph c) Fig. 1).

This means that $h = 0.014 \cdot (10 \cdot P_c)$.

Variation range $h = 0.02$ m; 0.25 m; 0.3 m; 0.35; 0.4 m. $P_c=0.11 \text{ MPa}; 0.12 \text{ MPa}; 0.13 \text{ MPa}; 0.14 \text{ MPa}; 0.15 \text{ MPa}$.

Let us fix the value of the parameters $D=0.18$ m, $d_{Sc}=0.1$ m, $S'_p = 0.096$m, $\omega = 16.67 \text{ rps}$, $v = 0.25$ m/s, $L = 4.25$m.

Next, we take the value of the screw compaction coefficient $K_y = 1.136$ according to graph a) in Fig.1, we get $S=0.47$.

Then, we take the lifting angle of the helix of the turn along the average radiuses $\alpha_{cp} = 18^0$ and according to the graph b) in Fig. 1 get the value $B=0.6$.

Then for screw $D=0.18$ m we get $h = 0.007 \cdot (10 \cdot P_c) ^\xi$, where $\xi = 1.28$ (see the graph c) Fig. 1).

Therefore $h = 0.007 \cdot (10 \cdot P_c) ^{1.28}$.

Let us fix the value of the parameters $D = 0.25$ m, $d_{Sc}=0.1$ m, $S'_p = 0.12$ m, $\omega = 16.67$ rps, $v = 0.25$ m/s, $L = 4.25$ m.

Next, we take the value of the screw compaction coefficient $K_y = 1.136$ according to graph a) in Fig.1, we get $S = 0.47$.

Then, we take the lifting angle of the helix of the turn along the average radius $\alpha_{cp}=18^0$ and according to graph b) in Fig. 1, we get the value $B = 0.6$.

![Figure 3](image-url)

**Figure 3.** The dependence of the cut depth $h$ on the excess pressure $P_c$ in the mixing chamber of the PMI of DTM.

![Figure 4](image-url)

**Figure 4.** The dependence of the cut depth $h$ on the excess pressure $P_c$ in the mixing chamber
Then for screw $D = 0.25 \text{ m}$ we get $h = 0.06 \cdot (10 \cdot P_C)^\xi$, where $\xi = 0.67$ (see the graph c) Fig. 1). Hence $h = 0.06 \cdot (10 \cdot P_C)^{0.67}$.

![Graph](image)

**Figure 5.** The dependence of the cut depth $h$ on the excess pressure $P_c$ in the mixing chamber of the PMI of DTM.

4. **Summary**

1. Based on the review of scientific literature [1, 2, 3, 5, 7, 9] and patent research [4] it was found that one of the directions of development of digging and transport machines is the use of various modulators of the workflow, the designs of which are based not only on physical-mechanical soil properties, but also the nature of the physical effects underlying the technical solutions, for example, from the use of compressed air;

2. Features of the concept of the bladed pneumatic screw mechanism of the proposed DTM is that a loading window is made in the center of the bulldozer blade, and the receiving chamber of the pneumatic and mechanical installation is located under the transition hopper.

3. In this study, the power dependence of the depth of the section of loosened material on the pressure of compressed air in the mixing air chamber of the bladed pneumatic screw digging and transport machine is established.

Let us note that a special role in the degree of non-linearity of the dependence of the depth of the cut of bulk material on the pressure of compressed air in the mixing air chamber has a parameter such as the diameter of the screw of the bladed pneumatic DTM. The dividing line is the size of the screw diameter $D = 0.2 \text{ m}$.

4. Introduction of bladed pneumatic screw devices in the structures of bulldozer blades allows not only to increase the productivity of digging and transport machines, but also to create environmentally safe equipment.

5. **References**

[1] Balovnev V I 2001 Road-building machines and systems: textbook / under the general editorship of V I. Balovnev 2nd ed., add. and rev. SibADI Publishing House 525

[2] Balovnev V I, Khmara L A 1993 Intensification of soil development in road construction M.: Transport 383

[3] Bochkareva T M 2015 Technology of planning and digging works: educ.-method. manual Perm: Publishing house of Perm National Research Polytechnic 132

[4] Goncharova O V, Vakhrushev S I Patent research on improving the design of bulldozer blades Online journal of Perm National Research Polytechnic University “Construction and architecture. Experience and modern technologies: based on the materials of the VIII All-Russian youth conference of postgraduates, young scientists and students” Access mode: http://sborniksff.pstu.ru/council/?n=6&s=302

[5] Evtyukov S A Shatunov M M 2005 Handbook of pneumatic complexes and pneumatic transport
equipment Under of general editorship M.M. Shapunov. SPb.: “Publishing house of DNA” 456

[6] Kalinushkin M P, Koppel M A, Seryakov V S, Shapunov M M 1986 Pneumotransport equipment: DirectoryInternational Journal of Engineering; under the general ed. of M.P. Kalinushkin L.: mechanical engineering, Leningrad 286

[7] Pavlov V P, Minin V V, Baykalov V A, Artemyev M I 2011 Machines for construction and maintenance of roads and airfields: Research, calculation, construction: textbook. manual Krasnoyarsk: Siberian Federal University 196

[8] Khmara L A, Krol R N 2005 Theoretical study of the operating modes of the screw intensifier Interstroymekh - 2005: proceedings of the international scientific and technical conference Part 1. Tyumen 262 – 266

[9] Shestopalov K K 2017 Lifting and transport, construction and road machinery and M.: Academia 414

[10] Yanson R A, Agapov A B, Demin A A, Koshkarev E V, Petenko V F 2012 Machines for earthwork and construction and installation works. Educational edition Moscow: ASV Publishing House 358

[11] Fire extinguishing agent, its preparation method and fire extinguishing method: pat.RU 2 414273 Rus.Federation BorkYan. 2008110691/05; declared 22.09.06; published 10.11 2009 Byul 31 (2)