Coulter Traction Resistance Analysis

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Abstract. The results of theoretical research to determine the dependence of traction resistance on the coulter design and setting parameters are given in this article. In the course of theoretical research the mathematical model allowing to determine the coulter traction resistance is obtained.

1. Introduction
Russia's national agricultural project provides for intensive development of flax farming [1]. One of the main operations allowing to intensify flax production is seeding. There are two ways to increase the productivity of the sowing unit. The first way is extensive, connected with increase of overall dimensions of machines, increase of working speed and other similar aspects. The second way - intensive, provides for research with the purpose of expansion of constructive possibilities at the expense of mobilization of the decisive factors influencing quantitative and qualitative indicators of machine or unit operation [2]. Realization of the second way is constrained in view of insufficient studying of process of seeding.

On the basis of the analysis of ways of realization of technological processes of sowing and constructions for their realization which are applied at cultivation of finely seeded cultures, it is offered to consider technological process of sowing of seeds of flax-long-dead. This process consists in the formation of the furrow by the working bodies with compacted seed bed, the distribution of seeds on the bottom of the furrow and their subsequent seeding with a loose soil layer [3, 4, 5]. According to this, the technological operation of sowing is carried out in three stages: moving the surface layer of soil and the formation of a compacted seed bed; placement of seeds on the bottom of the formed furrow; filling the furrow with seeds of the loose layer of soil. At the same time, the most important requirement for this sowing operation is to reduce energy consumption [6, 7].

The analysis of technical solutions for sowing flax seeds indicates that none of the existing working bodies can not qualitatively implement the proposed method of technological operation of sowing [8, 9, 10].

The resistance of the machine unit has a significant impact on the performance of the energy facility, which determines the value of downtime during sowing [11].

The purpose of the research: to obtain dependence of influence of constructive and technological parameters of the two-line keel-shaped coulter with supporting "skis" on its traction resistance.

Objectives of the study:
- To reveal the forces acting on the two-line keel-shaped coulter with supporting "skis";
- On the basis of the obtained forces to derive an expression for determining the traction resistance of a two-line keel-shaped coulter;
- Get dependence of influence of constructive and technological parameters of the two-line keel-shaped coulter with supporting "skis" on its traction resistance;
- To determine the range of traction resistance value of the coulter according to its rational design and technological parameters.

2. Object and research methods

The constructive and technological scheme of sowing long-stalked flax is offered in figure 1. The sowing process is as follows. When moving along the field, the anchor coulters paired on one wing, under the force of spring and the weight of the seed drill, extend the upper layer of soil and compacted the lower, wetter layer, forming the necessary space for targeted distribution of seeds on the feeding area. At the same time, a pair of depth guidance skis provide the coulter's stability. The seeds from the sowing unit and spreader (not shown in the diagram) then flow into the coulter and are distributed over the seeded area. After passing the coulter, the loose soil layer distributed on the sides covers the seeds sown at a given depth [12, 13, 14].

To reveal factors influencing coulter traction resistance and to reveal ways of its reduction it is necessary to determine and analyze forces acting on coulter from the soil side under different modes and working conditions [15,16, 17].

By analyzing the forces acting on the working device (Fig. 2), we will determine the main components of traction resistance. The resultant resistance force $F_{rr}$, acting on the coulter, consists of a vector sum of the cutting resistance forces $R_c$, dynamic $R_d$, friction force $F_f$, and soil resistance forces $N$. We obtain the following equation of the resultant coulter drag resistance force:

$$F_{rr} = R_c + 2R_d + F_f + N$$  \hspace{1cm} (1)
Figure 2. Scheme of forces acting on the coulter from the soil side.

When moving the working body in the soil, on each elementary site of the deepened working part of the coulter operates elementary force $P_i$, which is the specific resistance of the soil to buckling, varying in accordance with the relationship:

$$P_i = q \cdot h_i$$  \hspace{1cm} (2)

The resultant force P acting on the coulter will be equal to the sum of elementary forces $P_i$, therefore:

$$P = \int_0^h dP_i$$  \hspace{1cm} (3)

The elemental force of $dR_p$ can be expressed as:

$$dR_p = P_i \cdot dS_i ,$$  \hspace{1cm} (4)

where $dS$ – elementary coulter platform.

The area of the coulter side surface is determined by the formula:

$$dS = dS_1 + dS_2 + dS_3$$  \hspace{1cm} (5)

The area of the rhombus, which is the geometric figure of ABFG (Fig. 3) is defined as the width of the base by height, height is the processing depth $h$, therefore:

$$dS_1 = dS_{ABFG} = a \cdot h$$  \hspace{1cm} (6)

The height of the CDEF rhombus is $h'$, therefore (Fig.3):

$$dS_2 = dS_{CDEF} = c \cdot h' = c \cdot (h - r)$$  \hspace{1cm} (7)

The area of the ACD sector is defined as:

$$dS_3 = \frac{\pi \cdot \beta \cdot r^2}{360^\circ} ,$$  \hspace{1cm} (8)

where $\beta=180^\circ - \alpha$, then:

$$dS_3 = \frac{\pi \cdot (180^\circ - \alpha) \cdot r^2}{360^\circ}$$  \hspace{1cm} (9)
By substituting expressions (6), (7) and (9) in (5), we get:

\[ dS = a \cdot h + c \cdot (h - r) + \frac{\pi \cdot (180^\circ - \alpha) \cdot r^2}{360^\circ} \]  

(10)

By substituting expressions (10) in (2), we get:

\[ R_p = \int_0^h q \cdot (a \cdot h + c \cdot (h - r) + \frac{\pi \cdot (180^\circ - \alpha) \cdot r^2}{360^\circ}) \]  

(11)

At movement of a working device on the deepened part of the coulter from the soil side the dynamic force \( R_d \) acts, arising at movement of particles [18].

\[ R_d \cdot t = m_s V_{avg}, \]  

(12)

where \( V_{avg} \) - progressive travel speed, km/h;
\( t \) - travel time, s;
\( m_s \) - soil mass, kg.

The mass of the soil layer is defined as:

\[ m_{s,n} = V_s \cdot \rho_s \]  

(13)

\( V_s \) - soil volume, m³;
\( \rho_s \) - soil density, kg/m³.

The volume of the soil layer to be determined from the expression 10 and the width of the coulter \( H \):

\[ V_s = H \cdot \left( a \cdot h + c \cdot (h - r) + \frac{\pi \cdot (180^\circ - \alpha) \cdot r^2}{360^\circ} \right) \]  

(14)

\[ R_d = \frac{\rho_s \cdot H \cdot \left( a \cdot h + c \cdot (h - r) + \frac{\pi \cdot (180^\circ - \alpha) \cdot r^2}{360^\circ} \right) V_{avg}}{t} \]  

(15)

At movement of the coulter in soil under the influence of normal resultant force \( R_n \) arises friction force \( F_f \), acting on the deepened part of the coulter, and is applied in the rack plane, as well as the force of the friction on the sole of the coulter [19].

\[ F_f = f \cdot R_n, \]  

(16)

where \( f \) - tiller friction factor.

Friction force \( F_f \) is expressed as a vector sum of dynamic force \( R_d \) and cutting resistance force \( R_{cr} \). The vector sum of dynamic force \( R_d \) and cutting resistance force \( R_c \) will be expressed as:

\[ R_c = \sqrt{R_{cr}^2 + R_d^2} \]  

(17)

Therefore:

\[ F_f = f \cdot \sqrt{R_{cr}^2 + R_d^2} = t g \varphi \sqrt{R_{cr}^2 + R_d^2}, \]  

(18)

where \( \varphi \) - soil angle against material, degree.

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**Figure 3.** Lateral surface of the coulter stand.
The support reaction $N$ is defined as the sum of forces acting on the soil from the support, E.P. Ogryzkov takes proportional soil hardness [20]:

$$N = k \cdot \tau \cdot S_b,$$

(19)

where $k$ – the proportionality factor;

$\tau$ – soil hardness;

$S_b$ – bearing surface area.

Let's make a graphic representation of the forces acting on the coulter (Fig.4). Next, let us add the forces acting on the ski supports in accordance with Fig. 4.

The coulter pulling resistance will be determined as:

$$F_w = \sin \alpha \left\{ \frac{a}{b} \cdot q \cdot (a \cdot h + c \cdot (h - r) + \frac{\pi \cdot (180^\circ - a) \cdot r^2}{360^\circ}) + \frac{\rho_s \cdot H \left( a \cdot h + c \cdot (h - r) + \frac{\pi \cdot (180^\circ - a) \cdot r^2}{360^\circ} \right)}{t} \right\}$$

$$+ \sin \phi \left\{ \frac{a}{b} \cdot q \cdot (a \cdot h + c \cdot (h - r) + \frac{\pi \cdot (180^\circ - a) \cdot r^2}{360^\circ}) \right\} ^2$$

$$+ \rho_s \cdot H \left( a \cdot h + c \cdot (h - r) + \frac{\pi \cdot (180^\circ - a) \cdot r^2}{360^\circ} \right) \left( \frac{1}{t} \right)$$

$$+ mg \sin \phi + F_n \frac{L'}{L} \sin \phi.$$

(20)

Fig. 4. Powers acting on coulter.

Let's simplify the expression (20) and get the calculated formula of the coulter traction resistance:

$$F_w = (a \cdot h + c \cdot (h - r) + \frac{\pi \cdot (180^\circ - a) \cdot r^2}{360^\circ}) \left( \sin \alpha \left\{ \frac{b}{a} \cdot q \cdot \rho_s \cdot \frac{H \cdot V_{ag}}{t} + \frac{1}{t} \cdot \left( \sin \alpha \right) \right\}^2 \right.$$  

$$+ \frac{\rho_s \cdot H \cdot V_{ag}}{t} \left( \sin \alpha \right) + \frac{m \cdot g \cdot \sin \phi + F_n \frac{L'}{L} \sin \phi}{t}.$$  

(21)

where $r$ – coulter sock radius, m;

$h$ – sowing depth, m;

$t$ – travel time, s;

$L$ – the length of the wing to the coulter attachment point, m;

$L'$ – distance from the axis of rotation of the wing to the point of attachment of the spring, m;

$F_n$ – spring force, H.

In doing so, we will accept the following parameters as constant:

- volume buckling ratio $q$, $q = 5 \cdot 10^6 \, H / m^3$;

- coulter blade thickness $H$, $H = 0.02$ m;

- material angle $\phi$, $\phi = 35$ град;

- soil density $\rho_n$, $\rho_n = 1100$ кг/м$^3$;

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– coulter weight \( m \), \( m = 5 \text{ kg} \);
– occipital coulter \( a \), \( a = 0.02 \text{ m} \);
– conical coulter section \( c \), \( c = 0.06 \text{ m} \);
– coulter angle of attack \( \alpha \), \( \alpha = 75^\circ \);
– unit speed \( V_{agg} \), \( V_{agg} = 2.0 \text{ m/c} \).

3. The results of the research

On the basis of the received equation (21) we shall construct plots of dependences of traction resistance of the coulter on constructive and technological parameters, specifying moreover areas of their rational values (fig. 5-8).

![Figure 5](image)

**Figure 5.** Traction Resistance Dependence \( F_{tr} \), H from sowing depth \( h \), m.

The analysis of the graph presented in Figure 5 allows to draw a conclusion that the set sowing depth considerably influences the traction resistance of the coulter and the unit as a whole and has a directly proportional square relation. At the set agronomical requirements sowing depth of 3 sm coulter traction resistance is 65 H.

![Figure 6](image)

**Figure 6.** Traction Resistance Dependence \( F_{tr} \), H from the speed of the machine \( V_{agg} \), m/sec.

The analysis of the graph shown in Figure 6 also allows us to conclude that the speed of the machine directly affects the traction resistance of the machine and the coulter. At the sowing speed of 2 m/s, set by agrotechnical requirements, the coulter traction resistance is 50 H.
The analysis of the graph shown in Figure 7 also allows to conclude that the coulter angle of attack influences the coulter traction resistance in inverse proportion to the quadratic dependency. With a rational coulter angle of attack of 90-120°, the pulling resistance varies between 38-46 H.

The analysis of the graph presented in Figure 8 allows to draw a conclusion that the radius of the coulter toe directly proportional to the quadratic dependence influences the traction resistance of the coulter. At rational values of a toe radius 0.02-0.05 m, the traction resistance fluctuates in a range of 45-48 H.

4. Conclusion

The conducted analysis of forces acting on the coulter has allowed to receive the dependences defining influence of constructive and technological parameters of two-line keel-shaped coulter with supporting "skis" on its traction resistance. So at speed $V_{agg} = 2.0$ m/s and depth of sowing $h = 0.03$ m, and also at rational values of radius of a toe of the coulter $r = 0.02...0.05$ m and an angle of attack of the coulter $\alpha = 90...120^\circ$, values of traction resistance of one coulter make $F_{tr}, = 38-65$ H that is optimum value.

5. References

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