Research of seeding fulfilled with the help of stud-roller feed

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Abstract. This article is dedicated to increasing the quality of grain seeds distribution in a row using various parameters of the stud roller with new studs bent off to the side rotation, and also contains the results of theoretical and experimental investigations. In the frames of this investigation the optimal parameters of experimental seed wheel were defined, the factors influencing seed feed were identified, the formula of full working volume of seeds, thrown out by feeding mechanism per one rotation of roller, was generated, the following dependencies were detected: dependence of seed feed on quantity of roller studs, seed feed – on frequency of roller shaft rotation and seed feed – on degree of valve opening. The usage of the suggested seed-feeding device will help to reduce traumatization of seeds and pulsation of its flow, to increase equal distribution of seeds in the row.

1. Introduction

In modern crop research the important role is given to usage of energy-saving technologies. Development of this direction requires appliance of agricultural machines of the new generation, ensuring high quality of field works during every technological operation, and in the process of seeding as well. Structures of new machines have to be developed taking into account the requirements of multifunctional performance, energy consumption and resource saving, and its layout patterns have to comply with block-modular functionality. In process of development of seeding technologies, high attention is given to improvement of sowing machines structure [1-5], and also to betterment of seed-feeding devices [1-5]. Both, Russian and overseas scientist dedicated their works to these questions [6-14].

One of promising directions is represented by development of technological process of agricultural crops seeding with the usage of seed-feeding devices, whose working processes are based on formation of seeds flow by means of combining its free and forced outflow with the help of seed feed by stud-roller seed-feeding devices of different structural designs. These devices are universal in comparison to the existing ones, and they allow shaping more even flow of seeds which differ in terms of physical and mechanical properties. Goal of research is to develop and justify the structural-technological scheme, parameters and operation mode of the stud seed-feeding device, which will make provision for increase in evenness of seed distribution in soil in case of row agricultural crop seeding [15, 16].
2. Material and method
Mentioned investigations gave the opportunity to offer stud-roller feed with immovable roller, which ensures to improve the distribution of seeds in the row (figure 1). Seed-feeding devices can be installed on seed sowing machines of the SZ (grain seeder) family. It consists of forged body 1, roller 3, valve 5. Body is attached underneath to the seed bunker of the seed sowing machine, in the bottom of which there’s the window cut for the purpose of the seeds passage. Roller is composed of cylinder 3 with the incurred studs 4 attached along the way of rotation. The bottom of the feeder is represented by spring valve 5, fixed on the shaft of group discharge 6. Clearance between valve and roller studs is adjusted with the help of screw 7 [15, 16]. From the discharge outlet of the sowing machine’s seed hopper, grain is fed to the space of the seed hopper of the stud-roller feed on conditions of linked mode of grain flow, which is preserved while operation of the apparatus only in its starting part (first quadrant) [15].

![Image](image_url)

**Figure 1.** Scheme of improved stud-roller seed-feeding device. 1 – body frame; 2, 6 – shaft; 3 – roller; 4 – studs; 5 – valve; 7 – screw; 8 – restrictive rollway; I – first quadrant (self-motion of grain); II – second quadrant (uncontrolled and forced movement of grain); III – third quadrant (active movement of grain); IV – fourth quadrant.

Above the first quadrant of the functioning roller, where the direction of vectors of its rotational velocity changes from reversed towards perpendicular direction of grain flow axis, free movement of grain mass finishes by filling the inter-stud space of the roller with grain [15, 16]. In the second quadrant, the vectors of the roller's speed change from perpendicular to parallel direction towards grain flow. Free motion of grain flow in this quadrant happens simultaneously with forced moving of grain, that is filling its inter-stud space, by roller. In the third quadrant the free motion of grains finishes [15, 16]. Already in the second quadrant it’s possible to observe the impact of the impulse of a rotating functioning roller on free movement of grains. The roller, by forcefully moving the grains, which filled inter-studs space, by means of friction passes its impulse to underlying layers of grains that don’t touch directly to its studs, and actuates the movement of grains towards discharge outlet.

As a result of stud-roller feed operation, the linked mode of grain flow is completely violated by the functioning dosing unit — studs of the roller, i.e. total seeding with stud-roller is performed due to spontaneous, forced and active motion of grains [15, 16].

In order to define circumferential speed of operating roller of seed-feeding device, at which the discharge of inter-studs space from grains happens, and to establish interconnection between angle of roller’s deflection during grain fallout and its circumferential speed, the forced movement of grain flow in seed hopper was analyzed. For this, the position, when the grains are on the edge of the roller's stud (figure 2), was examined. If to suppose that in this point the speed of grain relative movement is equal to zero then according to D'Alembert principle, the forces applied to the grain (material point) will be in equilibrium [15-17]
Figure 2. Scheme of defining circumferential speed of operating roller of seeding apparatus.

Equilibrium equation:
Projection onto x axis:

\[ m g \sin \alpha + I_{tr} - F = 0 \]  \hspace{1cm} (1)

Projection onto y axis:

\[ N_1 - I_{cor} - mg \cos \alpha = 0 \]  \hspace{1cm} (2)

where:
\( I_{tr} \) – transportation inertial force, (H);
\( I_{cor} \) – Coriolis force (H);
\( F \) – friction force, (H);
\( N \) – reaction of support, (H);
\( mg \) – force of gravity, (H);
\( \alpha \) – tilt angle of stud, (degree) (angle between generator line of stud at point of grain fall and horizontal).

\[ I_{cor} = 2m\omega_{tr}v_{rel} \sin(\alpha_{tr}v_{rel}), [H] \]  \hspace{1cm} (3)

As \( v_{rel} = 0 \), and \( I_{cor} = 0 \), then the equation (2) will take the following shape:

\[ mg \sin \alpha + I_{tr} - fmg \cos \alpha = 0 \]  \hspace{1cm} (4)

Let’s replace \( I_{tr} \) with its value and reduce by mass:

\[ I_{tr} = m\frac{v_{roller}^2}{r_{roller}}, [H] \]  \hspace{1cm} (5)

where \( r_{roller} \) – roller’s radius, (m).

\[ g \sin \alpha + \frac{v_{roller}^2}{r_{roller}} - fg \cos \alpha = 0 \]  \hspace{1cm} (6)

Assuming that the grains move at a tangent, then friction coefficient – is \( tg \) of tangent tilt:

\[ f = tg \phi = \frac{\sin \phi}{\cos \phi} \]  \hspace{1cm} (7)

where \( \phi \) – friction angle of grain on material, (degree).

Then we have:

\[ v_{roller} = \sqrt{rg(f \cos \alpha - \sin \alpha)}, [m/s] \]  \hspace{1cm} (8)

where \( r \) – radius of the roller, (m).
Circumferential speed is defined from the provision that $\beta_{\text{roller}} < 90^\circ - \phi$. Knowing the value of coefficient of grain external friction on material $f$, it’s possible to find angle $\alpha$ from formula $\alpha = 90^\circ - \beta_{\text{roller}}$. By placing $\alpha$ into equation (8) we’ll receive:

$$v_{\text{roller}} = \sqrt{rg(f \cos(90^\circ - \beta_{\text{roller}}) - \sin(90^\circ - \beta_{\text{roller}}))}, [m/s]$$ (9)

Working volume is composed of volume $V_s$ of grains sunk into studs, and volume $V_{ac}$ of grains, thrown out of the active layer per one rotation of the roller.

Volume $V_s$ of inter-stud spaces we determine as the difference between cylinder’s volume with the radius $r_1$ and sum of cylinder’s volume with radius $r_2$ and volume of studs $k$ (figure. 3) [15-17].

![Figure 3. Shape of stud roller and calculation of inter-studs space volume.](image)

Volume $V_s$ of inter-stud space we define through the following formula:

$$V_s = V_1 - (V_2 + k \cdot V_{st}), [m^3]$$ (10)

where $k$ – is the quantity of studs, (pieces).

$$V_1 = \pi \cdot r_1^2 \cdot h, [m^3]$$ (11)

where:

$r_1$ – radius of the roller with studs, (mm) (figure. 3);
$h$ – length of the roller, (m).

$$V_2 = \pi \cdot r_2^2 \cdot h, [m^3]$$ (12)

where $r_2$ – radius of roller without studs, (m) (figure. 3).

Volume $V_{st}$ we find as the difference between volumes of half of cylinders (figure. 4).

$$V_{st} = V_3 - V_4, [m^3]$$ (13)

where:

$V_3$ – volume of cylinder with radius $r_3$, (m$^3$);
$V_4$ – volume of cylinder with radius $r_4$, (m$^3$).
By placing equations (11), (12), (13), (14), (15) into (10) taking into account the coefficient of bulk density $\beta$ we’ll receive:

$$V_s = \beta \left( \pi \left( h (r_1^2 - r_2^2) - \frac{1}{2} k h_1 (r_3^2 - r_4^2) \right) \right), [m^3]$$

(16)

Total working volume of grains discharged from seeding apparatus per one rotation of roller, taking into account the active layer, will be:

$$V_0 = V_s + V_{ac} = \beta \left( \pi \left( h (r_1^2 - r_2^2) - \frac{1}{2} k h_1 (r_3^2 - r_4^2) \right) \right) + \pi (d + c_{np}) c_{np} L_k, [m^3]$$

(17)

Taking into account the working mode of seed-feeding device, density of seed material and density coefficient of packing, let’s define mass theoretic discharge of seeds:

$$P_1 = \beta V_s P_s n_{roller}, [kg/min]$$

(18)

where:

- $V_s$ – volume of inter-stud space, ($m^3$);
- $P_s$ – density of seed material, ($kg/m^3$);
- $n_{roller}$ – frequency of roller rotation, ($min^{-1}$);
- $\beta$ – density coefficient of seed material packing.

Discharge capacity will be defined by availability of conditions for formation of grain volume between neighbouring studs, which in its turn will depend on structural parameters and working mode of seeding apparatus [15-17]. Apart from mentioned conditions, its productiveness will be also defined by transporting capabilities of roller’s studs with due regard to motion of grains in active layer:

$$P_2 = \beta V_0 n_{roller} P_s, [kg/min]$$

(19)

where $V_0$ – working volume of seeding machine, ($m^3$).
According to the results of theoretical research, the diagram of dependence of discharge $P$ (further named as $P$) from quantity of studs $k$ (further named as $q$) was constructed (figure 5).

![Figure 5](image-url)  
**Figure 5.** Dependence of seeds discharge $P$ on the number of studs on roller $Q$ in case when $n = 45\text{ min}^{-1}$.

Results of experimental investigations of the seeds discharge, showed that its maximum index and process of stable seed dosing are ensured in case of installing twenty four studs on the roller [15, 16]. Deviation of calculated values for seed discharge by stud-roller feed from the ones received through the experimental way lies in the interval $5\ldots10\%$, and this allows us to make a conclusion about correctness of theoretical suppositions (figure 5).

In the course of experimental research, the dependence of seed feed $P$ on frequency of roller rotation $n$ (figure 6) and width of seeding slot $h$ was established (figure. 7).

![Figure 6](image-url)  
**Figure 6.** Dependence of seed discharge $P$ on frequency of rotation of roller’s shaft $n$.

Proportional growth of seed feed $P$ with an increase of roller rotation frequency continues only till a certain value, after this the discharge of seeding material stabilizes and further reduces. The maximum index of discharge is compliant with values of roller rotation frequency close to $45\text{ min}^{-1}$.

The further levelling and reduction of discharge while increasing frequency of roller rotation in the seeding machine is explained by reduction in volume of seeding material, which is conveyed by studs [15, 16].

Linear character of change in seed discharge made by stud-roller feed defines the simplicity of setting the apparatus under research to the required seeding rate [15-17].
Analysis of dependence diagrams (figure 7) of the seed feed on valve opening value $h$, in different frequency of rotation $n$, shows that the process of seeding till value $h=6 \text{ mm}$ is characterized by the stable character of seed dosing. The further rate of $h$ value leads to steep increase of seed feed and violation of linear dependency. With that, the setting of the seeding machine for such a seeding rate turns out to be impossible.

![Dependence of seed discharge $P$ on valve opening rate $h$.](image)

By dependence diagrams (figure 5) of seed discharge while having different quantities of studs it’s apparent that with an increase of stud’s quantity on the roller, seed feed increases and reaches the highest rate in case of 24 studs. The further increase of studs quantity we consider impossible because the volume of inter-studs space significantly decreases [15-17]. Character of dependency received on the basis of experimental research is compliant with the theoretical one, with sufficiently high accuracy.

3. Conclusions
Experimental studies of seeding apparatus allowed to establish the following:

- usage of seeding machine roller with studs incurred along the way of its rotation ensures more precise distribution of seeds along the length of the row;
- basic factors influencing the seed discharge and evenness of seeding are represented by: studs quantity, frequency of roller rotation, valve opening rate in seed-feeding device;
- suggested seed-feeding apparatus assures the stable process of seeds dosing while installing on the roller twenty four studs incurred along the way of its rotation and rotation frequency 25…45 min$^{-1}$;
- optimal rate of valve opening depending on seed size should fall inside the limits of 2…6 mm, roller’s radius should be 25mm, so that to ensure even original stream of seed material.

4. Approbation and credibility
Credibility of theoretic dependencies is proved by experimental studies in laboratory and field conditions at the premises of Scientific Educational Manufacturing Centre “Integration” of Federal State Budgetary Educational Institution of Higher Education “Orel State Agrarian University”. For sowing wheat seeds using experimental stud-roller feed, its following structural parameters are recommended: spanning angle $\beta r$ of the roller by valve 50°, quantity of incurred studs on it - twenty four [15, 16].

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