Auger orienting device for planting sugar beet root crops

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Abstract. The mechanization of the technological process in planting sugar beet root crops determines the efficiency of sugar beet seeds production. At the same time, the limiting factor is the use of manual labor in the process of planting sugar beet mother liquors. The article presents a three-dimensional model of an auger orienting device with given design parameters for sowing sugar beet mother liquors. The power for the drive of the auger rollers orienting device is determined, which provides the necessary piece-by-piece supply of sugar beet mother liquors at a speed of the sowing unit of 3.6 km/h. The authors carried out the consistency substantiation of the kinematic parameters in auger orienting device operation with the landing apparatus of the sowing machine, taking into account the design parameters of the presented device. The energy calculation of the auger drive orienting device was carried out and the loads acting on the drive shaft of the roller were determined. The gear wheels of the roller drive have been designed, and the stress-strain analysis of the drive shaft of the auger roller has been carried out. The main parameters of the simulated spur gear were determined using the KOMPAS 3D computer-aided design system, which ensure the reliable operation of the auger orienting device of the machine for planting sugar beet root crops with the required productivity.

1. Introduction
The Russian Federation is one of the world leading sugar producers and a leader in cultivation of sugar beet crops in the global production capacity. However, the provision of domestic seed material is very low, so in 2019, domestic seeds accounted for only 0.6% of the total volume of sown seeds.

At the moment, a limited number of economic entities are engaged in the production of selected seeds in our country, and an important limiting factor here is the use of manual labor when planting sugar beet crops [1-3]. Obtaining high yields of sugar beet seeds is largely determined by compliance with agrotechnological requirements for sowing operations, which determine the implementation of the technological process of sowing sugar beet mother liquors [4-5].

The technical and economic indicators of the use of planting machines are largely determined by the productivity of its work, which is influenced by the speed of movement of the unit, as well as the method of feeding seeds [6].

An important role in planting sugar beet mother liquors is carried out with the help of an orienting device, the operation of which largely determines the technological process of single-piece feeding of beet crops into the sowing cones of the planting apparatus, followed by embedding them with a cone downward in the soil and maintaining their original position [6].

2. Materials and methods
Analysis of modern technologies used in the production of sugar beet seeds allows us to conclude that there is not a sufficient level of automation and mechanization when planting root crops mother plants. Thus, it is possible to automate some technological operations, such as the feeding and orientation of
sugar beet mother liquors into the planting apparatus of the sowing machine, thereby reducing the cost of manual labor during sowing.

After reviewing and analyzing the existing structures and means of mechanization of orientation of conical bodies, we could conclude that a reliable orientation device is needed that completely eliminates the cost of manual labor. A patent search of already existing devices made it possible to reveal that they do not allow for fully mechanical orientation. According to patents RU No. 2705317 and RU 192886, obtained by Penza State Agrarian University, a three-dimensional model of an auger orienting device was developed.

The results of the conducted studies of the auger orienting device in the helical elastic winding having a variable pitch made it possible to determine the factors that have a decisive influence on the qualitative performance of the investigated device for orienting the sowing of sugar beet crops.

3. Designing a 3-D model of the auger orienting device

Nowadays, several devices have already been designed for orienting some objects of conical shape, using the difference in the diameters of the head and tail of root crops (А.C. No. 146241 USSR B.I., 1962, No. 7; А.C. 244162. USSR, B.I., 1969, No. 7; A.C. 361934 USSR. Б.I. 1973, No. 2; A.C. USSR No. 422372MKII A 01C 11/00 Bulletin No. 13 1974; patent RF No. 2299548, МПК А01С 11/02, Bulletin No. 15 dated 27.05.2007; patent RF No. 2633543, МПК А01С 11/00, Bulletin No. 29 dated 13.10.2017). The disadvantages of these devices are: the orientation of root crops is possible to provide only when the sowing material is divided into small and large fractions; due to the synchronization lack of the root crops supply, the established sowing interval is not provided and damage to the heads of root crops occurs; root crops are unevenly dispersed along the length of the rollers, as a result of which the orientation process becomes random.

The developed auger orienting device provides an improvement in the uniform supply of sugar beet root crops to the sowing apparatus without sorting and separation into fractions; at different speeds of the sowing machine, which increases productivity and reduces the cost of manual labor in the production of seeds.

On the cylindrical part of the rollers there is a helical winding with a variable pitch \( p_i \), which is determined by the dependence of the arithmetic progression

\[
p_i = p_1 + (i - 1) \cdot d,
\]

where \( i \) is the ordinal member of the arithmetic progression;

\( p_1 \) is the first member of the arithmetic progression (pitch of the auger winding) being 10 ... 20% more than the average length (l) of the root crop;

\( d \) is the step of the difference in progression, equal to 1/5 of the diameter of the cylindrical part of the roller, and the helical winding on the cylindrical part of the rollers is made of an elastic material with bending rigidity that ensures the movement of the sugar beet sowings along the rollers of the auger orienting device.

The presented 3-D model of the auger orienting device consists of a frame 1, which is a welded structure made of a shaped tube, to which the bearing housings are screwed 2. The bearings are equipped with rollers 3, which consist of: a cylindrical part with a helical winding 4 made of elastic material with bending stiffness ensuring the movement of root crops along the rollers and conical with a taper of 1:15. Gear wheels 5 are fixed on the shafts 6 of the orienting rollers 5. The rotation of the orienting rollers 3 is carried out through a coupling 7 mounted on the drive shaft 6 of one of the rollers.
The auger orienting device of the sowing seeder for oriented sowing of beets operates as follows. When the planting machine moves, the root crops are fed from the hopper to the cylindrical part of the rollers 3, where they, due to the variable pitch of winding from elastic material 4, moving along the rollers 3, are dispersed at some distance from each other. Having moved to the smooth conical part of the rollers 3 with a taper of 1:15, they with a sharp end fall into the gap between the rollers 3 rotating towards each other, where they are grasped by the trays of the sowing apparatus and embedded in the soil.

4. Results and discussion

The movement speed of sugar beet mother liquors along the rollers would depend on the physical and mechanical properties of the transported material. Due to the fact that the rollers rotate towards each other with the same angular velocity, then, accordingly, their peripheral speeds would be equal, and their total vector would be equal to zero.

Thus, the speed (m/s) of displacement of the sugar beet sowing with rollers having a helical winding with a variable pitch along the axis can be determined by the following formula:

\[
V_i = K_\beta \frac{p_i \cdot n_b}{60} = K_\beta \frac{p_1 + (i - 1) \cdot d \cdot n_b}{60},
\]

where \(V_i\) is the speed of the beet mother liquor at the \(i\) step, m/s;

\(p_i\) – variable pitch of screw winding of the roller, m;

\(n_b\) – drum rotation frequency, min\(^{-1}\);

\(K_\beta\) – coefficient of axial speed reduction due to the friction of the root crop against the drum, taking into account the angle of inclination of the rollers, with the horizontal arrangement of the rollers \(K_\beta = 1.0\) [6].

The total time of moving one sugar beet mother liquor by the rollers of the auger device should be equal to the time of embedding one root crop in the soil with the sowing apparatus.

According to agrotechnical requirements, the speed of the sowing seeder when sowing sugar beet crops with a sowing step of 0.60 varies within 1.8…3.6 km/h (0.5…1.0 m/s).

At maximum drive speed of the sowing seeder.

The rotation frequency of the sowing apparatus, providing a landing step of 0.6 m, at a sowing speed of 1.0 m/s would be:

\[
n_{an} = \frac{60 \cdot V_m}{s \cdot z} = \frac{60 \cdot 1.0}{0.6 \cdot 4} = 25 \text{ min}^{-1},
\]

where \(V_m\) is the speed of the sowing machine, m/s;
The angular speed of rotation of the planting apparatus is:

\[ \omega = \frac{\pi \cdot n_{an}}{30} = \frac{3.14 \cdot 25}{30} = 2.62 \text{ s}^{-1}, \]

where \( n_{an} \) is the rotational speed of the seeding unit, min\(^{-1}\).

The time of one revolution of the planting apparatus is:

\[ t = \frac{2 \cdot \pi}{\omega} = \frac{2 \cdot 3.14}{2.62} = 2.4 \text{ s}, \]

where \( \omega \) – the angular velocity of the landing apparatus, s\(^{-1}\).

Taking into account the existing physical dependencies and design features of the sowing apparatus, namely, the number of capture trays \( z \), the sowing time for one root crop would be:

\[ t = \frac{60}{z \cdot n_{an}} = \frac{60}{4 \cdot 25} = 0.6 \text{ s}. \]

With the design parameters of the auger orienting device, namely the length of the roller \( L_B \), knowing the path traveled by the sowing of sugar beet crops before it is captured by the catching trays of the sowing apparatus, it is possible to determine the linear speed of movement of the root crop, which would be equal to:

\[ V_k = \frac{S_c}{t} = \frac{1.2}{0.6} = 2.0 \text{ m/s}. \]

Having taken the movement speed of the root crop equal to the critical speed, we determine the critical frequency of the rollers rotation in the auger orienting device:

\[ n_{a} = \frac{60 \cdot V_k}{\pi \cdot D} = \frac{60 \cdot 2.0}{3.14 \cdot 0.16} = 239 \text{ min}^{-1} \]

where \( D \) is the diameter of the roller of the auger orienting device, m.

To ensure the operation of the sowing machine with a given capacity, the power for the drive of the roller orienting device was calculated, which has a helical winding of elastic material with a variable pitch.

The productivity of the auger orienting device \( (\text{kg/s}) \) is determined by:

\[ Q = \frac{m \cdot n_{an} \cdot z}{60} = \frac{1.33 \cdot 25 \cdot 4}{60} = 2.22 \text{ kg/s}, \]

where \( m \) is the mass of one root crop, kg (the weight of the root crop is up to 1.33 kg) \[9\];
\( n_{an} \) is the rotational speed of the seeding unit, min\(^{-1}\).

For a given capacity, the power per drive of one roller of the auger orienting device would be:

\[ P_{a} = \frac{K \cdot K_z C_p \cdot Q \cdot g \cdot L (\omega_0 + sin\beta)}{1000} = \frac{1.4 \cdot 1.2 \cdot 1 \cdot 2.22 \cdot 9.81 \cdot 1.2 (2.5 + sin0)}{1000} = 0.11 \text{ kW}, \]

where \( Q \) is the productivity of the roller conveyor, kg/s;
\( K \) – coefficient taking into account the power loss for mixing and crushing of the load during the rotation of the propeller, \( K = 1.04 \ldots 1.4 \) (large values for blade and tape propellers);
\( K_z \) – coefficient of increasing power to overcome resistance from mass inertia when starting the conveyor, \( K_z = 1.15 \ldots 1.2 \);
\( L \) is the length of the working part of the conveyor, m;
\( \beta \) – angle of inclination of the conveyor, degree;
\( \omega_0 \) – generalized coefficient of resistance of the load, depending on the class (root crops) and the density of the load, with \( p = 0.65 \ldots 1.0 \), \( \omega_0 = 2.5 \);
\( C_p \) – coefficient taking into account power losses at the horizontal position of the conveyor, at
\[
\beta = 0^\circ \quad C_r = 1.
\]
In this case, the value of the maximum torque \( T_b \) for the drive of two rollers is determined by the formula:

\[
T_b = 9.55 \cdot \frac{2 \cdot P_{\text{al}}}{n_r} = 9.55 \cdot \frac{2 \cdot 110}{239} = 8.8 \text{ Nm},
\]

where \( n_r \) is the rotational speed of the rollers, \text{min}^{-1}.

The main parameters of the simulated spur gear using the KOMPAS 3D computer-aided design system are presented in Table 1.

Reliable operation of the gear transmission is largely ensured by the strength and rigidity of the shafts, while the deflections of the shafts on which the gear wheels are fixed should be less than the permissible values.

| Table 1. Main parameters of spur gears |
|--------------------------------------|
| **Parameter name and designation**    | **Drive wheel** | **Driven wheel** |
|--------------------------------------|-----------------|-----------------|
| **Initial data**                     |                 |                 |
| Number of teeth \( Z_1, Z_2 \)       | 43              | 43              |
| Module, mm \( m_n \)                 | 5               |                 |
| The angle of inclination of the claws on the indexing cylinder \( \beta \) | 12°14'58''     |                 |
| Initial contour profile angle \( \alpha \) | 20°00'00''    |                 |
| Ring gear width, mm \( b \)          | 20              | 20              |
| **Defined parameters**               |                 |                 |
| Material                             | drive           | driven          |
| Design load (torque on the driving wheel), Nm \( T_{\text{max}} \) | 8.8             | 8.8             |
| Drive wheel rotation frequency, min\(-1 \) \( n_1 \) | 239             | 239             |
| Peripheral speed in engagement, m/s \( v \) | 2.75            | 2.75            |
| Circumferential force on the indexing cylinder, N \( F_t \) | 79.997          |                 |
| Rated contact voltage, MPa \( \sigma_{H_{\text{max}}} \) | 246.04          |                 |
| Permissible contact voltage, MPa \( \sigma_{H_{\text{max}}} \) | 1050            | 1050            |
| Safety factor for contact voltages \( n_H \) | 4.27            | 4.27            |
| Design bending stress, MPa \( \sigma_{F_{\text{max}}} \) | 39.82           | 39.82           |
| Allowable bending stress, MPa \( \sigma_{F_{\text{max}}} \) | 1058            | 1058            |
| Safety factor for bending stresses \( n_F \) | 24.99           | 24.99           |

Let us determine the loads acting on the shaft of the drum of the auger orienting device: the circumferential force acting on the shaft \( (F_t) \) is equal to:

\[
F_t = \frac{2 \cdot T}{d} = \frac{2 \cdot 8800}{26} = 677 \text{ N},
\]

where \( T \) is the torque on the roller shaft of the auger orienting device, N-mm, \( d \) – the diameter of the gear seat, mm, \( d = 26 \text{ mm} \);

\( (F_r) \) - radial force in spur gear:

\[
F_r = F_t \cdot \frac{\tan \alpha}{\cos \beta} = 80 \cdot \frac{\tan 20^\circ}{\cos 12^\circ 14' 58''} = 30 \text{ N},
\]

where \( F_t \) is the circumferential force on the indexing cylinder of the gear wheel, N, \( F_t = 91 \text{ N} \);

\( \beta \) – angle of inclination of the claws of the helical gear transmission, \( \beta = 12^\circ 14' 58'' \);

\( (F_a) \) - axial force in spur gear train:
The APM FEM module for KOMPAS-3D was used to determine the stress-strain state of the drive shaft of the auger orienting device.

The results of statistical calculation of the stress-strain state of the roll shaft of the auger orienting device are shown in Figures 2 and 3.

\[ F_a = F_t \cdot \tan \beta = 30 \cdot \tan 12^\circ 14' 58'' = 6,5 \, N. \]

**Figure 2. Drum Shaft Equivalent Stresses**

**Figure 3. Total displacement of the roller shaft**
5. Conclusion
The calculations made it possible to substantiate the kinematic parameters of the developed auger device in determining the rotational speed of the rollers having a helical winding with a variable pitch of 239 min⁻¹, which ensures the planting of sugar beet mother liquors with a step of 0.60 m. Power and energy calculation of the drive allows making the conclusion that at a given speed of the sowing machine the developed auger orienting device provides the required productivity of the sowing machine.

The analysis of the obtained results of the stress-strain state of the roller drive shaft shows that the maximum value of the equivalent stress according to von Mises is 92.45 MPa, which is significantly lower than the yield point for steel grade "Steel 10", and the minimum value of the yield factor is 2.9. In addition, from the results obtained, it could be concluded that the maximum deformation of the shaft is about 0.003 mm, therefore, the strength and rigidity of the shaft of the roller of the auger orienting device are fully ensured.

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