The pulse stepless onion planter gear reducer

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Abstract. Increasing the yield of agricultural crops is the main goal of improvement of technological processes in the agricultural industry. One of the most important stages in the technological chain of agricultural crops cultivation is the process of sowing or planting. Sowing should provide the most favorable conditions for seed germination and further development of plants, which can increase the field germination and crop yield. These conditions are created if the sowing time, the seeding rate, the area of plant nutrition and the planting technology have been correctly chosen. The article describes the design of an impulse stepless gearbox with target design parameters to drive the shaft of the seeding machine of the onion-set planter. The loads acting on the shafts have been determined. A check calculation for the driven shaft was performed taking into account the safety factor. Modernization of the onion planter with an impulse stepless gearbox made it possible to set a seeding rate without significant labor and time costs, which will improve the productivity of operated planters.

1. Introduction

The main task of planting onion is to ensure the optimal plant density and their uniform distribution over the sown field, i.e. to create required conditions for plants: lighting, heat, water and chemical elements [1-5]. Optimal distribution contributes to a significant increase in productivity and an improvement in the quality of grown onions [2, 4].

One of the most important technological operations in the cultivation of bulbous crops is planting; it is necessary to ensure the uniform distribution of bulbs along the row length and their oriented feeding into the soil with the bottom down while maintaining this position when seeding [4-8]. If the above requirements are met, the most favorable conditions are created for the germination of onion and its further development, which increase the crop yield.

Violation of the orientation of onion in the sowing process decreases the yield 2-3 times [4].

Foreign variable gearboxes have been installed on Russian seeders, which makes it possible to adjust the seeding rate. However, the foreign variable gearboxes are expensive, which increases the cost of seeding units and technological dependence on potential competitors' manufacturers. All this affects the final consumer. Therefore, it is necessary to design Russian machines products.

2. Materials and methods

Seeders for planting onion have been designed [9-11]. Their disadvantages are portioned seed supply, low productivity, high energy consumption, damage to seeds, which leads to uneven seedlings and a decrease in productivity. Devices for stepless regulation of the seeding rate [12-13] are also used. Their disadvantages are metal consumption cyclic rotation of the sowing device shaft, due to three cams; to establish a larger range of speed control of the driven shaft, it is necessary to increase the size
of cams with a triangular profile, which increases the gearbox dimensions, and its metal consumption and cost.

Thus, an analysis of the available technical solutions made it possible to identify shortcomings that affect the quality of the seeding machine.

The design and research of structures of mechanisms and machines for agricultural production are based on the use of geometric constructions associated with the strength of parts of mechanisms and units, manufacturability of their manufacture.

3. Results and Discussion
Penza State Agrarian University has developed an impulse stepless gearbox shown in figure 1 [14].

![Figure 1](image-url)  
**Figure 1.** The stepless gearbox design  
1 - case; 2 - bearings; 3 - driven shaft; 4 - overrunning clutches; 5 - levers of pushers; 6 - rollers; 7 - springs; 8 - guide; 9 - adjusting lever; 10 - cams; 11 - drive shaft

The impulse stepless gearbox of the onion-set planter consists of body 1, overrunning clutches 2 mounted on driven shaft 3, pusher levers 4 pivotally connected to overrunning clutches 2, springs 5, guide 6 with adjusting lever 7 and four cams 8 fixed on drive shaft 9, while the working profiles of the cam at approach angle $\phi_c$ and distance angle $\phi_u$ are made along the brachistochrone, and radius $r$ of the cam profile rounding at the distance angle $\phi_u$ is $r = (0.60 \ldots 0.63) R$, where $R$ is the pusher roller radius.

When drive shaft 11 rotates, cams 10 act on rollers 6 of pushers 5, pivotally connected to overrunning clutches 4, while pushers 5 with overrunning clutches 4 perform reciprocating movements interacting by means of springs 7 of one of rollers 6 with cam 10, and other roller 6 - with a track of guide 8. Springs 7 return the levers of pushers 5 to their original position. The rotational speed of driven shaft 3 is adjusted by lever 9 by changing the angle of rotation of guide 8, which changes the stroke of pushers as a result of which the rotational speed of driven shaft 3 changes.

During the operation of the gearbox, its parts and assemblies experience loads; the gearbox can deteriorate its performance. Consider the loads acting on the drive and driven shaft during its operation.
During the normal operation, the shaft torque is 15-18 Nm; taking into account the safety factor for dynamic loads \( n_d = 2.0 \), it will be 30 ... 36 Nm.

Taking into account the dynamic coefficient, at the maximum torque, the circumferential force \( (F_t) \) is determined by formula

\[
F_t = \frac{T}{l},
\]

where \( T \) is the shaft torque, N mm, \( T = 36000 \) N mm;

\( l \) is the distance from the axis of rotation of the driven shaft to the attachment point of the lever with an overrunning clutch, mm, \( l = 42 \) mm.

\[
F_t = \frac{36 \cdot 10^3}{42} = 857 \text{ N}.
\]

**Figure 2.** The diagram of forces acting on the continuously variable gearbox

Determine the amount of torque on the drive shaft. Figure 2 shows that the condition of static equilibrium relative to point \( O_2 \) is determined by formula

\[
\sum m_{O_2} = 0; \quad F_{t2} l - F_1 a = 0.
\] (1)

From equation 1, calculate force \( F_1 \) on the lever acting on the overrunning clutch of the driven shaft.

\[
F_1 = \frac{F_{t2} l}{a} = \frac{857 \cdot 42}{27} = 1333 \text{ N}.
\]

When the cam is acting on the lever roller, the smallest torque is

\[
T_1 = F_{t1} \cdot l,
\]

Circumferential force \( F_{t1} \) is calculated by formula

\[
F_{t1} = \frac{F_1}{\cos \alpha} = \frac{1333}{\cos 24^\circ} = 1459 \text{ N}.
\]

Thus, the largest torque is

\[
T_1 = 1459 \cdot 30 = 43770 \text{ Nmm}.
\]

With further rotation of the drive shaft, the cam radius will increase and the torque will reach its maximum

\[
T_{max1} = 1459 \cdot 45 = 65655 \text{ Nmm}.
\]

Proceeding from the fact that the strength of the driven shaft of a continuously variable impulse gearbox is affected by external force factors, materials, operating modes (loading cycle), transverse
dimensions, surface treatment quality, shaft geometry (fillets, keyways), the shaft strength was assessed by the safety factor strength.

Determine the radial force from the coupling acting on the cantilever section of the driven shaft

\[ F_u = 50\sqrt{36} = 300 \text{ Nm}, \]

where \( T \) is the driven shaft torque, Nm.

The support reactions from strength \( F_u \) are

\[
\begin{align*}
\sum M_A &= 0 \\
F_u \cdot (l_1 + l_2) - R_c \cdot l_1 &= 0 \\
\sum M_c &= 0 \\
F_u \cdot l_2 + R_A \cdot l_1 &= 0.
\end{align*}
\]

Having built the equations of bending moments, the bending moments were determined and their diagrams were plotted to determine the dangerous section along the shaft length.

The strength was checked by the safety factor over the section on which the greatest bending moment acts, and the stress concentrator is pressing. When pressed, \( K_{s/s_0} = 2.8, K_{t/t_0} = 2.2 \) with a diameter \( d = 25 \text{ mm} \) and an ultimate strength of the shaft material \( \sigma_v = 700 \text{ MPa} \).

Shaft endurance limits in bending and torsion are

\[
\begin{align*}
\sigma_{-1} &= 0.43 \sigma_v = 0.43 \cdot 700 = 301 \text{ MPa}, \\
\tau_{-1} &= 0.58 \sigma_v = 0.58 \cdot 177.2 = 174.6 \text{ MPa}.
\end{align*}
\]

The axial moment of resistance is

\[
W_x = \frac{\pi \cdot d^3}{32} = \frac{3.14 \cdot 25^3}{32} = 1534 \text{ mm}^3.
\]

In this case, the polar moment of resistance is

\[
W_p = \frac{\pi \cdot d^3}{16} = \frac{3.14 \cdot 25^3}{16} = 3068 \text{ mm}^3.
\]

The amplitude of normal stresses is

\[
\sigma_a = \frac{M_u}{W_x} = \frac{10,2 \cdot 10^3}{1534} = 6.65 \text{ MPa}.
\]

The amplitude and average shear stresses are

\[
\tau_a = \tau_m = \frac{T}{2 \cdot W_p} = \frac{3.6 \cdot 10^3}{2 \cdot 3068} = 5.87 \text{ MPa}.
\]

Thus, the safety factor for shear stresses is

\[
s_{\sigma} = \frac{K_{s/s_0} \cdot \sigma_a + \psi_\sigma \sigma_m}{\beta \cdot \varepsilon_\sigma} = \frac{2.8}{1.0} \cdot 6.65 + 0.2 \cdot 0 = 16.17.
\]

The safety factor for shear stresses is

\[
s_{\tau} = \frac{K_{t/t_0} \cdot \tau_a + \psi_\tau \tau_m}{\beta \cdot \varepsilon_\tau} = \frac{2.2}{1.0} \cdot 5.87 + 0.1 \cdot 5.87 = 12.93.
\]

The safety factor of the shaft for the dangerous section is

\[
s = \frac{s_{\sigma} \cdot s_{\tau}}{\sqrt{s_{\sigma}^2 + s_{\tau}^2}} = \sqrt{16.17^2 + 12.93^2} = 10.1.
\]

The calculated safety factor exceeds the permissible value \([s] = 2.5\); the required strength value for the driven shaft of the pulsed continuously variable gearbox has been achieved.

4. Conclusion

The impulse stepless reducer of the onion set planter ensures the smooth regulation of the rate of single-piece planting, regardless of the planter speed, which increases the seeder performance. The
calculations made it possible to determine the torque of the steps of the stepless gearbox to drive the shaft of the planter and loads acting on the driven shaft. The refined calculation of the most dangerous section of the driven shaft showed that the required strength value for the driven shaft of the gearbox was achieved under dynamic loads.

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