Pulse gear reducer model to improve the efficiency and quality of onion sets

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Abstract. Currently, one of the main directions for the development of the agro-industrial complex is the development of vegetable production, in particular onions, which occupies a significant place in the total production of vegetables, but the production structure currently in Russia is not able to fully provide the population with the domestic product year-round, which leads to dependence on imports. Thus, the industrial production of commercial onions, and therefore the study aimed at improving the quality of onion planting with the development and use of onion seed planters that increase their productivity seem quite relevant. The paper presents the designed three-dimensional model of the pulse reducer, describes its operation, and provides a justification of the design parameters of the parts of the proposed pulse gear reducer of the onion planter, which makes it possible to ensure the downward planting of the onion bulb stem in the speed range from 3.6 m/s to 5.4 m/s.

1. Introduction

The volume of sown areas of onions in the industrial sector of the Russian Federation amounts to about 25-28 thousand hectares, which indicates the popularity of this vegetable crop. The commercial production of onions is mainly concentrated in the Lower Volga region and the Stavropol Territory. These regions have the appropriate soil and climatic conditions necessary for the production of this agricultural crop. The successful development of commercial production in a market economy is associated with modern technical equipment that allows complying with advanced technologies, which in turn makes it possible to obtain high-quality products in planned quantity, thus entering the market at the right time. Planting is the most important agrotechnological operation for cultivating onions and thus affecting its yield and quality [1–4]. Most of currently used onion planters are equipped with roller, fork, scoop-wheel and belt seeding mechanism [3–7].

The capacity of the seeder is determined by its speed of movement, working width, planting method, as well as the time of auxiliary technological operations [7–12]. The existing belt seeding mechanism used for onion sets provides for the placement of bulbs in a row at a distance of 8...10 cm for small varieties, and for varieties that give three or more bulbs in a nest – at a distance of 10...15 cm. In case of belt seeding mechanism, the seeding rate is controlled using replaceable gear star wheels [1, 9]. This method of controlling the seeding rate requires additional time for auxiliary technological operations related to the replacement of star wheels during the transition of onion planting from one fraction to another. Consequently, it is possible to increase the efficiency of the onion set planter due to certain technical solutions aimed at reducing the time for auxiliary operations related to the replacement of star wheels when the seeding rate changes [13–18].

2. Materials and methods

The use of a pulse reducer-variator with a wide span of speed ratios to adjust the seeding rate in onion planters makes it possible to increase the performance of the seeding unit during its operation. Figure 1 shows a three-dimensional model of a variable pulse gear reducer for a shaft drive of the onion planter (Patent 2744377 of the Russian Federation. Publ. 09.03.21, Bul. No. 7) developed at State Agrarian University. The variable pulse gear reducer of the onion planter includes a housing (1), rolling bearings (2), a driven shaft (3), free-wheel clutches (4) fitted on the driven shaft (3), push rods (5) with rollers (6), which are pivotally connected to free-wheel clutches (4), tension springs (7), a guide (8), an adjustment lever (9), as well as four cams (10) fixed on the drive shaft (11) [19–20].

The proposed variable pulse reducer of the onion planter operates as follows. When the driven shaft rotates the cams act on rollers of push rods pivotally connected with free-wheel clutches drive shaft. The push rods pivotally connected with free-wheel clutches reciprocate, and one of the rollers interacts with the cam by means of tension springs, and the other one – with a guide track. Tension springs return push rods to initial position. The speed of the driven shaft is adjusted using the adjustment lever by changing the rotation angle of the guide, which changes the stroke of push rods per unit time, thus changing the speed of the driven shaft [21].

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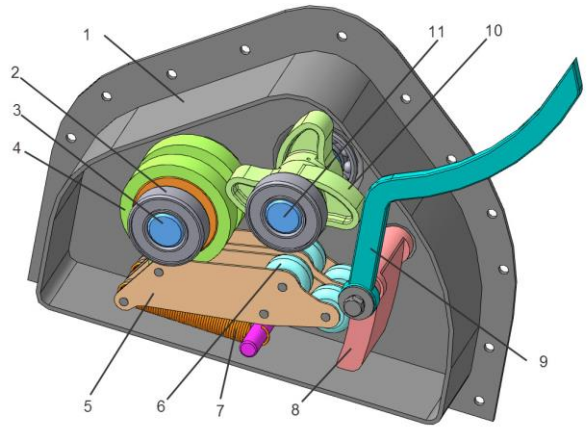

Fig. 1. Variable pulse reducer

3. Results and Discussion

The cam mechanism is usually a three-link mechanism with a higher pair of kinematic elements including an input link, which is a cam, and the output link – a push rod (or a rocker) moving according to a certain principle. Often, in order to replace both the cam and the push rod in the higher pair of sliding friction by rolling friction and reduce wear, an additional link is included in the mechanism – a roller that does not change the transfer functions of the mechanism.

Reciprocating movement of push rod levers, which are pivotally connected to free-wheel clutches, can be ensured by a cam mechanism. The rotational movement of the cam is a change in some argument, and the stroke of the push rod is a necessary pattern as some function of the argument, which can generally be written as follows:

$$\lambda = f_\lambda(z). \quad (1)$$

This pattern indicates the numerical relationship between the radius ρ of the cam profile and the angle of rotation φ, at which a given stroke of the push rod is provided based on the operating conditions of the variable pulse reducer.

The straight travel of the push rod using $m\lambda$ and mx scales for λ and z will be written as follows:

$$x = f_x(\varphi). \quad (2)$$

where x – straight-line movement of the push rod when the cam is turned by the angle φ; f_x – specified continuous pattern.

The m_x scale for reproducing λ through x and m_φ for transforming z into φ is determined by the following dependencies:

$$\varphi - \varphi_н = m_\varphi(z - z_0), \quad (3)$$

$$x - x_н = m_x(\lambda - \lambda_н), \quad (4)$$

where z_0 – initial value of the argument, to which $\varphi_н$ usually corresponds;

$$\lambda_н = f_\lambda(z_0). \quad (5)$$

The scale factor m_x is defined as follows:

$$m_x \geq \frac{[\partial\rho]}{[\delta\lambda]} \cdot \frac{1}{1-\zeta}, \quad (6)$$

where $[\delta\rho]$ – specified cam profile subject to manufacturing inaccuracy; $[\delta\lambda]$ – specified dependent variable λ subject to inaccuracy; ζ – discontinuous function at the point ζ =0.25…0.75, since errors in the radius ρ and the angle of rotation φ are equally probable, then it should be ζ=0.5.

The maximum increment (Figure 2) is determined by the formula:

$$\Delta x_{max} = x_{max} - x_{min}. \quad (7)$$

After the m_x is calculated and the ζ is chosen, the m_φ is determined by the formula:

$$m_\varphi = \frac{[\partial\varphi]}{[\delta\lambda]} \cdot \frac{\left(\frac{\delta\lambda}{\delta z}\right)_{max}}{\zeta}, \quad (8)$$

where $[\delta\varphi]$ – specified allowable inaccuracy in setting the angle of cam rotation; $\left(\frac{\delta\lambda}{\delta z}\right)_{max}$ – largest derivative of the implemented function.

Next, the interval is determined

$$\varphi_{max} - \varphi_н = m_\varphi \cdot (z_{max} - z_0). \quad (9)$$

The formula below determines the number of active turns of the cam

$$n = \frac{\varphi_{max} - \varphi_н}{2\pi}. \quad (10)$$

Figure 3 shows that the stroke intensity of the push rod is determined not by the elevation angle of the profile α_x at point A, but by the angle α perpendicular to Ox axis and the tangent curve equidistant to the cam profile curve passing through the center of the roller A_1. Thus, the ρ=x distance should be used in the calculation.

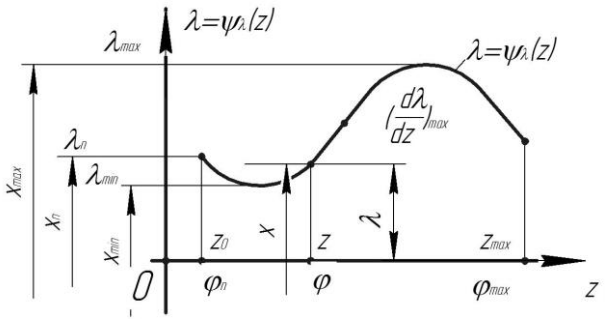

Fig. 2. Variable pulse reducer

Since ρ_0=x_0, then the cam radius vector may be expressed as follows:

$$\rho = \rho_0 + m_x f_\lambda(z). \quad (11)$$

Since the dimensions of the tip (roller radius R) are smaller than the dimensions of the cam, therefor ρ and ρ_x of the same order and hence the manufacturing inaccuracies by ρ_x and φ_x without the noticeable error

can be attributed to radii ρ and angles φ. This makes it possible to carry out the above calculations by the equidistant A_1B_1 the desired profile AB with coordinates ρ_x and φ_x. The cam profile itself can be obtained by constructing the envelope AB to circles with radius R, the centers of which are located on the equidistant A_1B_1. We can avaoid finding an envelope AB of the true profile, but limit ourselves to the coordinates ρ and φ of the equidistant A_1B_1 if the tool for manufacturing and monitoring the cam surface is made the same radius R as the push rod tip (Figure 3) [22].

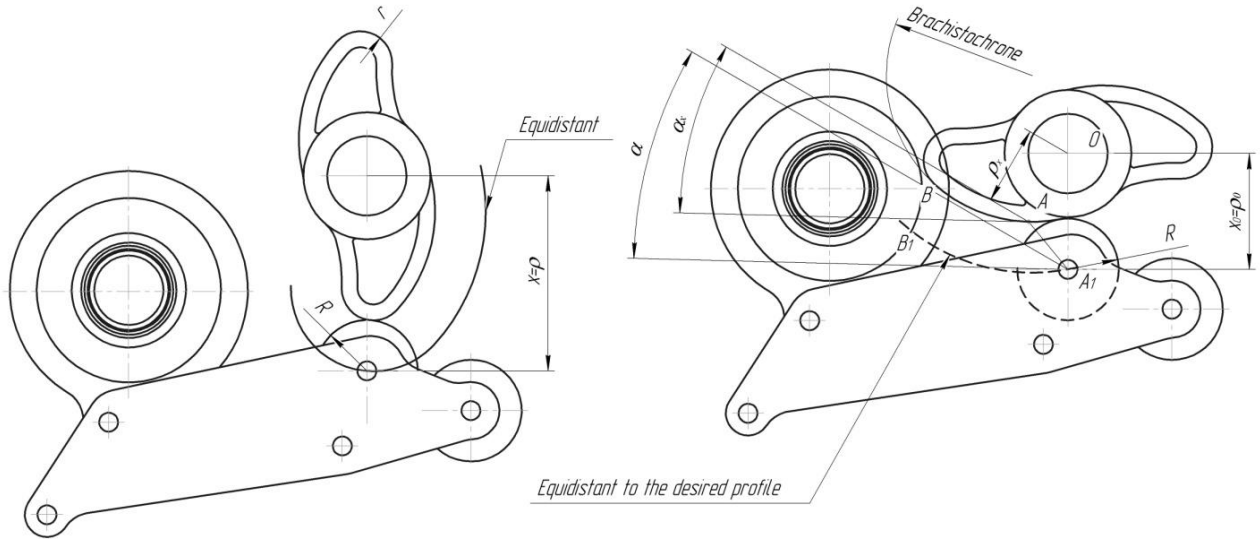

Fig. 3. Parameters of cam mechanism

Formulas (3) and (11) are used to calculate ρ and φ of the equidistant A_1B_1. The corresponding products $\left(\frac{1}{\rho}\cdot\frac{\delta\rho}{\delta\varphi}\right)$ are then calculated from the resulting table and α is determined based on formula (12).

$$tg\alpha = \frac{1}{\rho}\cdot\frac{\delta\rho}{\delta\varphi}. \quad (12)$$

Let us consider Figure 3 to find the coordinates ρ_x and φ_x of the desired AB profile.

For OA_1A triangle we can write

$$r\cdot cos\alpha + \rho_x cos\delta\varphi = x$$

$$\rho_x cos\delta\varphi = r\cdot sin\alpha$$

Then

$$tg\delta\alpha = \frac{r\cdot sin\alpha}{x - r\cdot cos\alpha} \quad (13)$$

$$\rho_x = \frac{x - r\cdot cos\alpha}{cos\delta\varphi} \quad (14)$$

$$\varphi_x = \varphi + \delta\varphi \quad (15)$$

Formulas (14) and (15) give a tabular dependence of the cam profile

$$\rho_x = f(\varphi_x).$$

The working cam profile of the designed variable pulse reducer at contingence at angle φs (Figure 4) is made along the brachistochron, and the radius r of the brachistochron rounding with the profile of the far cam standing at angle φd is r=(0,60…0,63)R, where R – radius of the push rod roller. The roller radius is selected for design reasons and it should not be larger than the minimum radius of curvature of the theoretical profile.

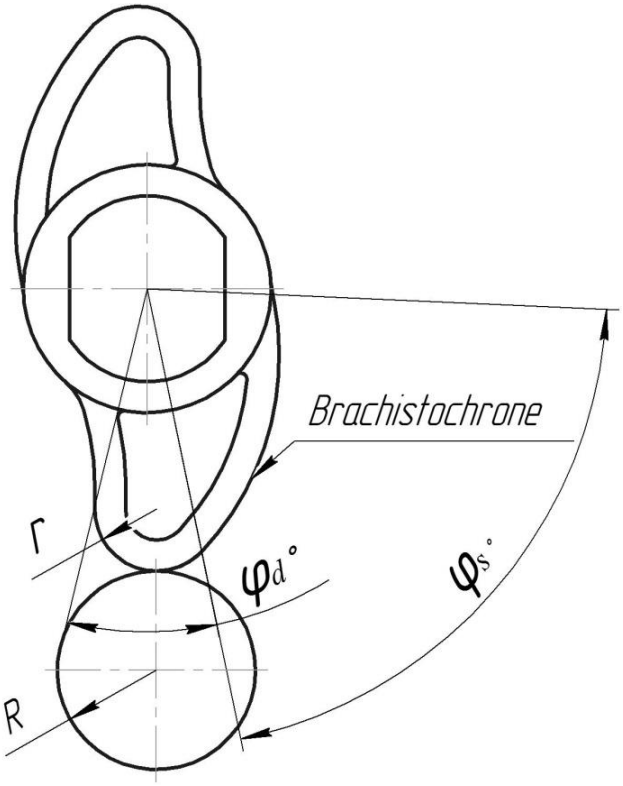

Fig. 4. Pulse reducer cam profile

The gear ratio of the variable pulse reducer is determined by the formula:

$$i = \frac{n_1}{n_2},$$

where n_1 – input speed, min^{-1}; n_2 – output speed, min^{-1}.

Since the cams provide constant cyclic action on the push rods, then the rotation angle of the driven shaft 3 (Figure 1), and hence the gear ratio of the variable pulse reducer is changed due to a change in the guide position.

When the reducer-variator is used to drive sowing machines, the seeding rate, which is set before starting, will depend on the gear ratio.

The position of the guide is changed by means of a pivoted lever, which is rigidly connected with one end to the guide with possibility of changing the angle of rotation relative to the axis. The free end of the pivoted lever indicates a divided scale [23].

When the pivoted lever shows zero, the guide takes its initial position, at which the push rod levers placed relative to the articulated connection with the free-wheel clutch make a simple rocking motion rolled by rollers along the tracks of the guide. In this case the holder of the free-wheel clutch remains stationary without driving the driven shaft of the variable pulse reducer. When the lever is moved to intermediate position, the guide is turned relative to the axis through some angle and one of the push rod rollers is rolled along the cam surface coupled with it, and the second roller is rolled along the guide tracks. As a result, the push rod performs a complex reciprocating movement, while rotating the holder of the free-wheel clutch, and with it the driven shaft at some angle γ. The increase in seeding rate increases the guide angle of rotation from vertical position, as well as the stroke of push rods, which increases the angle of rotation γ of the free-wheel clutch holder and the speed of rotation of the driven shaft of the variable pulse reducer.

The results of the study are shown in the table 1.

Table 1. Variable pulse reducer gear ratio ratio depending on scale division

Reducer scale division	Reducer gear ratio	Reducer scale division	Reducer gear ratio
5	21.95	55	4.60
10	17.15	60	4.35
15	13.75	65	3.90
20	10.90	70	3.65
25	8.95	75	3.40
30	7.68	80	3.10
35	6.60	85	2.75
40	6.15	90	2.60
45	5.55	95	2.50
50	5.10	100	2.48

4. Conclusion

The design of the variable pulse reducer is presented. Theoretical substantiation of design parameters of the driven shaft cam mechanism with required gear ratios of the variable pulse reducer is performed. This makes it possible to regulate the specified seeding rate for different onion fractions. As a result, labor costs for changes in the seeding rate are reduced and the productivity of the onion planter is increased.

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