Assessment of ambient dust limit of open gear of cotton harvester

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Abstract. The article considers the methodology of determining the limiting dustiness of the environment at the place of operation of the open gear of the cotton picker, taking into account the limiting wear and wear rate of the teeth of the driven gear, providing a specified resource, depending on the engagement module of the gear, the length of the tooth, gear ratio, the number of meshing gears teeth, the degree of slippage between the gears teeth, the rotation frequency of the gears, the hardness of the gears material, the abrasive particles strength, the ratio of the gears material hardness, the abrasive particles strength, the number of loading cycles, which lead to the destruction of the deformed friction surfaces.

1. Introduction
Cotton pickers are the main agricultural machines in Uzbekistan. Considering this, a lot of research work is being carried out to develop and improve the design of cotton pickers [1-6].

The analysis of cotton harvesters operation for the reasons of faults occurrence in the extractor of the harvester, due to the failure to provide the wear resistance of teeth of the driven gear of the extractor with the number of teeth $z=12$ and $m=3$ mm meshing module, increases by 1.7 times, in connection with this the downtime for this gear replacement in field conditions increases in comparison with cotton harvesters working with normal parameters, corresponding to the requirements of their operating conditions by 1.5 - times [6].

Dustiness of ambient air of the cotton harvester determines reliability of operation of its constituent parts, in particular gears of the puller drive. Depending on the geometric and kinematic parameters of the gears and the mechanical properties of the gear material, the maximum permissible dustiness of the environment, providing the service life of the gears can vary over a wide range.

The purpose of this work is to determine the maximum permissible dust content of the environment, taking into account the maximum allowable wear on the thickness of the teeth of driven gears.
2. Materials and methods of research

The maximum permissible air dust content at the place of operation of the driven gear puller of the harvester is determined on the basis of the expression for calculating the wear rate of the teeth with abrasive particles, given in [7, 8],

$$
\gamma_{a(h,k)} = \frac{20,4 \cdot k_a^{1/2} \cdot \varepsilon_v^{1/2} \cdot m^{3/2} \cdot \sigma_a^2 \cdot G_k \cdot d_w^{1/2} \cdot n_k \cdot (z_k - 1) \cdot \psi_2^2}{H_k^2 \cdot n_{pk} \cdot \gamma_a^{1/2} \cdot z_k \cdot z_{sh} \cdot L \cdot i}
$$

(1)

here $k_a$ - coefficient, taking into account the share of abrasive particles, participating in the wear process; $\varepsilon_v$ - air dust content, g/m$^3$; $m$ - meshing module, mm; $\sigma_a$ - abrasive particle compressive strength, MPa; $G_k$ - ratio of hardness of the driven gear material to the abrasive particle strength; $d_w$ - average size of abrasive particles involved in the process of tooth wear, mm; $n_k$ - speed of the driven gear, 1/min; $z_{sh}$ - number of teeth of the gear; $z_k$ - number of gear teeth; $\gamma_a$ - abrasive particle material density kg/m$^3$; $\psi_2$ - degree of slippage between the driven gear tooth head and the drive gear tooth foot; $H_k$ - hardness of the driven gear material; $n_{p(k)}$ - number of deformation cycles, which lead to destruction of deformed layer of driven gear tooth surface; $L$ - tooth length of meshing gears, mm; $i$ - gear ratio of accelerating gearing (has values less than unity).

Solving expression (1) in the allowable limits of the wear rate of the teeth, a dependence is obtained, which allows us to calculate the maximum permissible dust content of the environment at the place of operation of the considered gearwheel, then this dependence has the form,

$$
\gamma_{a(h,k)} = \frac{20,4 \cdot k_a^{1/2} \cdot \varepsilon_v^{1/2} \cdot m^{3/2} \cdot \sigma_a^2 \cdot G_k \cdot d_w^{1/2} \cdot n_k \cdot (z_k - 1) \cdot \psi_2^2}{H_k^2 \cdot n_{p(k)} \cdot \gamma_a^{1/2} \cdot z_k \cdot z_{sh} \cdot L \cdot i}
$$

(2)

In expression (2), the ratio of the hardness of the driven gear material to the abrasion strength $G_k$ is determined according to [1, 6]:

$$
G_k = \frac{3(H_k \sigma_a - \sigma_a^3)^{1/2}}{H_k} + 4 \left( \frac{\sigma_a}{H_k} \right)^{1/2}
$$

The coefficient of relative slippage of gear teeth, when the meshing occurs between the protrusion of the tooth head of the driven gear wheel and the trough of the leading gear tooth foot is equal to [7],

$$
\psi_2 = \sqrt{z_{sh}^2 \sin^2 \alpha + 4(z_{sh} - 1) - z_{sh} \sin \alpha}.
$$

(3)

To calculate the number of deformation cycles, which lead to destruction of deformed layer of driven gear tooth surface the following interrelation is offered [8],

$$
n_{pk} = \psi_k
$$

where $\psi_k$ is the coefficient of relative lengthening of the gear-wheel material, %; $t$ is the coefficient of frictional fatigue of the gear-wheel material, for steel, $t=1.3$ [9].
3. Results of researches and their discussion
The limit value of wear rate of teeth is determined by the limit value of thickness wear of teeth, the value of which according to the recommendations [8] is supposed to be taken in the range of 20-25% of the pitch of the teeth meshing. In this case, taking into account high responsibility on quality of cotton harvesting, to solve this problem, the limit wear of teeth on thickness of driven wheel was taken as 20% of gear pitch. Then the value of limiting wear of teeth of driven gear of puller by thickness is equal to,

\[
[ U_p ] = 0.2 \frac{\pi \cdot m}{2}, \text{ mm}
\]

(4)

The limiting speed of wear of teeth of the slave girth gear with the module of \( m=3 \) mm, defined on the accepted limiting wear of teeth of the slave girth gear on thickness makes,

\[
[ \gamma_{ak} ] = 0.1 \cdot \frac{\pi \cdot m}{T_v} = \frac{3.14 \cdot 0.1 \cdot 0.003}{500} = 0.001884 \text{ mm/h}
\]

where is \( T_v \) - the output of the driven gear up to the limit tooth wear, hour.

Thus, according to the obtained expression for determining the maximum ambient dust content at the place of operation of the driven wheel of the open gear drive puller shows that increasing the hardness, tooth length, number of teeth of the driven gear and the gear ratio of the open gear leads to an increase in the maximum permissible ambient dust content at the place of operation of the puller.

Figure 1. Variation of Maximum Permissible Ambient Dustiness of the driven gear depending on the size of abrasive particles: 1 - steel 40X; 2 - steel 65 G.

With increasing the gearing modulus, the average size of abrasive particles in suspension in the air, the speed of the driven gear wheel drive puller, the dustiness of the environment at the place of the harvester decreases: the average size of abrasive particles on the law of inverse proportionality, the speed of the driven gear wheel changes by the law of the second degree [10].
Numerical calculation of the maximum permissible dust content of the environment, on the place of operation of the driven gear, were carried out with the following initial data: \(d_{cr} = 0.02\) mm; \(\sigma_a = 50\) MPa \([11]\); \(i = 0.133\); \(L = 35\) mm; \(k_a = 0.45\); \(\psi_2 = 5.322\); \(\gamma_{ak} = 0.001884\) mm/hour; \(n_{k} = 1500\) rp/m; \(m = 3\) mm; \(z_{sh} = 90\); \(z_k = 12\); \(\gamma_a = 2.2\) g/cm\(^3\); for steel 40X: \(G_k = 1.984\); \(H_k = 600\) MPa; \(n_{pk(k)} = 14.929\); for steel 65G: \(G_k = 1.968\); \(H_k = 610\) MPa; \(n_{pk(k)} = 19.953\).

Figure 1 shows the change in the maximum permissible ambient dust content, providing the specified wear resistance of the driven gear teeth depending on the size of abrasive particles, at the place of operation of the driven gear wheel of the sweeper, depending on the average size of abrasive particles involved in the process of wear.

According to Figure 1, an increase in the size of abrasive particles leads to an increase in the maximum permissible dust content of abrasive particles, providing the wear resistance of the teeth. This is due to the fact that small abrasive particles can stay in the air in a suspended position for a longer time than larger abrasive particles. Larger abrasive particles, due to their higher mass, settle to the surface faster. The maximum permissible ambient dust content affecting the wear resistance of the teeth depends on the mechanical properties of the gear material. Thus, a driven gear wheel made of 65G steel of 610 MPa hardness and 10% coefficient of relative elongation, in comparison with a driven gear wheel made of 40X steel of 600 MPa hardness and 8% coefficient of relative elongation has 1.94 times higher limiting permissible dust content \([12]\).

The maximum permissible dust content of the environment in the area of the driven gear depending on the engagement module and the tooth length, shown in Table 1, shows that increasing the engagement module from 2 to 6 mm leads to a reduction of the maximum permissible dust content by 27 times. This is explained by the fact that at small dimensions of the meshing modulus, due to the small height of the teeth, the probability of abrasive particles getting into the contact zone of the teeth is significantly reduced, which leads to a decrease in their wear rate.

Using in the manufacture of the experimental version of the gears of steel 65G with improved mechanical properties compared with the base version (steel 40X) has more than 1.9 times the maximum permissible dust content, which provides wear resistance teeth driven gear.

The pattern of change of the ambient dust content with the increase of the gear module from 2 mm to 6 mm leads to a decrease of the maximum permissible dust content in 27.0 times, while it increases with the increase of the tooth length from 23.4 mm to 70.1 mm in 8.95 times (table 1).

**Table 1.** Variation of Maximum Permissible Dust Exposure of Enclosed Sprocket Work Zone Depending on Gearing Modulus and Gear Length

| Gearing module, mm | Maximum permissible environmental dust content, g/m\(^3\) | Length mesh tooth length, m | Maximum permissible ambient dust content, g/m\(^3\) |
|-------------------|---------------------------------|-----------------------------|-----------------------------------------------|
| 2                 | 40X steel 3.321 | 65G steel 6.446 | 23.4 | 40X steel 0.440 | 65G steel 0.854 |
| 3                 | 40X steel 0.984 | 65G steel 1.910 | 30.0 | 40X steel 0.984 | 65G steel 1.910 |
| 4                 | 40X steel 0.415 | 65G steel 0.806 | 46.7 | 40X steel 1.752 | 65G steel 3.400 |
| 5                 | 40X steel 0.213 | 65G steel 0.413 | 58.4 | 40X steel 2.740 | 65G steel 5.318 |
| 6                 | 40X steel 0.123 | 65G steel 0.239 | 70.1 | 40X steel 3.936 | 65G steel 7.640 |
Changing the maximum permissible ambient dust content in the zone of operation of the driven gear drive sweeper, depending on the gear ratio and speed of the driven gear is shown in table 2. The lowest dustiness of the environment corresponds to lower values of the gear ratio, which is associated with a decrease in the number of revolutions of the driven wheel, leading to the preservation in the air of larger abrasive particles, where this wheel works. Increase of gear ratio from 0.10 to 0.35 results in increase of maximum permissible dustiness in more than 12.2 times.

**Table 2. Change of Maximum Permissible Ambient Dust Level in Sprocket Work Area Depending on Gear Ratio and Rotation Frequency**

| Gear ratio | Maximum permissible ambient dust content, g/m³ | Rotational speed, rpm | Maximum permissible ambient dust content, g/m³ |
|------------|-----------------------------------------------|-----------------------|-----------------------------------------------|
|            | Steel 40X 65G steel                            |                       | Steel 40X 65G steel                            |
| 0.10       | 0.553 1.436                                   | 600                   | 6.150 11.938                                  |
| 0.15       | 1.244 3.231                                   | 900                   | 2.733 5.305                                   |
| 0.20       | 2.132 5.744                                   | 1200                  | 1.538 2.984                                   |
| 0.25       | 3.456 8.975                                   | 1500                  | 0.984 1.910                                   |
| 0.30       | 4.977 12.924                                  | 1800                  | 0.683 1.326                                   |
| 0.35       | 6.774 17.591                                  | 2100                  | 0.502 0.974                                   |

The results of the tests showed that the use of an experimental driven toothed wheel made of 65G steel has an increased maximum permissible dust content of the environment, exceeding more than 1.9 times the basic version of the manufacture of a driven toothed wheel, made of 40X steel.

Comparative tests of the gear transmission of the cotton harvester on gear ratios have shown that the value of the maximum permissible environmental dust content of driven gear made of steel 40X and driven gear made of steel 65G, the experimental variant in 2.6 times higher than that of the driven gear material of the base variant of manufacture from steel 40X.

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4. Conclusion

The maximum permissible dust content of the environment providing the required wear resistance of the teeth of the driven gear of the harvesting machine:

1) is at manufacture of a geared wheel from steel 65 G with hardness 610 MPa – 1.86 g/m³ in comparison with the base variant 40Kh with hardness 600 MPa – 0.96 g/m³, i.e. increases on 1.94 times;

2) it increases by 12.25 times with increase of transmission ratio from 0.10 to 0.35, it decreases by 12.25 times with increase of speed of the driven wheel from 600 to 2100 rpm

3) on the transmission ratio in 2.6 times more in the driven gearwheel of the experimental version made of steel 65 as compared with the driven gearwheel of the base version of steel 40X.
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