Evaluation of the degree of abrasive particles activity in oil of machine units involved in the wear process of toothed wheels

A Irgashev¹, B A Irgashev¹; A B Aliyorov²

¹Tashkent State Technical University named after Islam Karimov, Tashkent 900095, 2, Universitetskaya str.
²National University of Uzbekistan named after Mirzo Ulugbek, Tashkent 900095, 1, Universitetskaya str.

E-mail: irgashevamirkul@mail.ru

Abstract. This article discusses the regularities of changes in the activity of abrasive particles in the oil of machine units participating in the process of gear-wheel wear at constant and increasing concentrations. They vary depending on the number of loading cycles of gear teeth, considering the share of crushed abrasive particles in one loading cycle of the gear teeth. This makes it possible to obtain regularities in the change of concentrations of active abrasive particles in the oil depending on the gear modules and the number of loading cycles, taking into the account the fraction of crushed abrasive particles per cycle of loading the gear. This technique can be used to determine the duration of the test of the gear wheel material on samples at a constant total concentration of abrasive particles in the oil change for the units of machines with gear drives operating in the presence of abrasive particles in the working environment. The case under consideration corresponds to the operating conditions of the gear transmission in the unit, which allows calculating the oil change period in the units of machines operating in an abrasive environment.

1. Introduction
One of the factors that most significantly affect the results of calculation and experimental determination of the wear resistance of gear materials is the degree of activity of abrasive particles in the oil of machinery transmission units.

In the process of friction of gear teeth in each cycle of loading, the concentration of active abrasive particles in the oil of the machine constantly changes. It occurs because of crushing abrasive particles, being in oil of the aggregate, and the obtainment of a fresh portion from environment [1, 2]. Therefore, when assessing the wear resistance of gear teeth and the oil change period in the units, it is necessary to consider the regularities of activity change of abrasive particles in the process of oil circulation. Analysis of the state of the matter in question showed that in the literature this issue is not sufficiently covered, mainly limited to the study of the process of crushing abrasive particles located in the contact zone of gear teeth [3, 4, 8, 9].
The purpose of this work is to obtain computational dependences for estimating the activity of abrasive particles at their constant and increasing concentrations.

2. Materials and research methods
In heavily loaded gears, the load falling to the abrasive particles in the wedge-shaped gap of gear teeth in most cases exceeds their compressive strength, as a result of which these particles are subjected to crushing [5, 6, 10]. Due to the fact that, according to [3, 11], the coefficient of re-crushing of abrasive particles is equal to 7 after the crushing process, the size of crushed abrasive particles should not exceed:

\[ da < R_z + h_0, \ m, \]  

where \( R_z \) is the roughness height of the friction surfaces of the gear teeth, m; \( h_0 \) is the thickness of the oil film between the friction surfaces of the gear teeth, m.

In the process of gear teeth wear, abrasive particles of the size corresponding to expression (1) do not come into force interaction with friction surfaces, and wear from their influence does not occur.

The total concentration of abrasive particles in the oil of the unit can be constant and increasing in time because of their penetration from the environment. Let us see how the abrasive particles activity changes for these cases.

3. Research results and discussion
The total concentration of abrasive particles in the oil is constant; its value in time remains constant, i.e., no new portions of abrasive particles enter the oil from the outside. This variant is characteristic of testing the roller samples of cogwheels for wear resistance on the friction machine MI-1M. The size of abrasive particles used for wear testing should be greater than the sum of the roughness height and oil film thickness (exceeding 4 microns). In this case, the initial concentration of abrasive particles in the unit oil was taken equal to their total concentration \( (e_{\text{max}}) \).

1. During the crushing of active abrasive particles, depending on the number of loading cycles, their concentration decreases (Figure 1, graphs 1, 2). Let us consider changes of abrasive particles activity in the process of the wear resistance test, after each loading cycle. The loading cycle is one complete revolution of a spherical toothed wheel specimen, which is dipped into oil containing abrasive particles of the spherical shape.

After the first load cycle, the concentration of crushed abrasive particles:

\[ e_{1d} = e_{\text{max}} A_1, \]  

where \( A_1 \) is a coefficient taking into account the share of crushed abrasive particles per cycle of loading at the constant total concentration of abrasive particles in oil. To calculate the \( A_1 \) value, the dependence is offered [7, 12]:

\[ A_1 = \frac{2\pi R d_{av} \gamma_m}{G_{m,t}}, \]  

where \( R \) - radius of the curvature of the sample, surrounded in oil, m; \( d_{av} \) - average size of abrasive particles, participating in the wear process, m; \( l \) - contact length of samples, m; \( \gamma_m \) - oil density, kg/m\(^3\); \( G_{m,t} \) - amount of oil, poured into the friction machine tank when testing the wear resistance of samples, made of the cogwheel material, kg.

The concentration of active abrasive particles in the friction machine oil after the first loading cycle:
After the second loading cycle, the concentration of crushed abrasive particles:

\[ \varepsilon_{1d} = \varepsilon_{1} = \varepsilon_{\text{max}} (1 - A_{1}) \]

the concentration of active abrasive particles:

\[ \varepsilon_{2} = \varepsilon_{1} - \varepsilon_{1d} = \varepsilon_{\text{max}} A_{1} (1 - A) = \varepsilon_{\text{max}} (1 - A_{1})^{2} \]

Similarly, after \( k \) loading cycles, the concentration of crushed abrasive particles:

\[ \varepsilon_{kd} = \varepsilon_{k} A_{k} = \varepsilon_{\text{max}} A_{1} (1 - A_{1})^{k-1} \]

the concentration of active abrasive particles:

\[ \varepsilon_{k} = \varepsilon_{\text{max}} (1 - A_{1})^{k} \]

The obtained analytical dependencies show that at the constant total concentration of abrasive particles, which are in oil, the increase in the abrasive particles size, radius of curvature and the width of contact of samples, made of toothed wheels material, dipped in oils in the friction machine tub, lead to the growth of their crushing intensity. This is explained by the fact that increasing the radius of curvature leads to a narrowing of the wedge-shaped gap between the samples of the friction process. This leads to an increase in the contact area between the surfaces of samples and abrasive particles, due to which, the number of adhered and crushed abrasive particles on the contact surfaces of friction increases.

The received analytical dependencies show that at the constant total concentration of the abrasive particles being in oil, the increase in size of abrasive particles, radius of curvature and width of contact of the samples made of the gear wheel material dipped in oils in the bath of friction machine leads to increase in intensity of their crushing. This is explained by the fact that increasing the radius of curvature leads to a narrowing of the wedge-shaped gap between the samples occurring in the friction process, leading to an increase in the contact area between the surfaces of samples and abrasive particles. Thereby this increases the number of adhered and crushed abrasive particles on the contact surfaces of friction.

2. The initial concentration of abrasive particles in the oil of the unit is zero; it increases with increasing the number of loading cycles of the driven gear (Figure 1, graphs 3, 4). This case corresponds to the real operating conditions of the gear transmission in the unit.

Let us assume that tightness of crankcase and dustiness of environment during exploitation of machines remain constant. As a result, penetrated abrasive particles from the environment are subjected to crushing and the concentration of active abrasive particles in the machine oil changes constantly during each load cycle.

After the first loading cycle of the gear wheel, the concentration of crushed abrasive particles:

\[ \varepsilon_{1d} = 0 \]

the concentration of active abrasive particles:

\[ \varepsilon_{1} = \delta_{1} \]

where \( \delta_{1} \) is the number of active abrasive particles entering the unit oil during one cycle of the driven gear loading, %/rev.

After the second cycle of gear wheel loading, the concentration of crushed abrasive particles:

\[ \varepsilon_{2d} = \delta_{1} B \]

where \( B \) - coefficient taking into account the share of crushed abrasive particles at their arrival from the environment, corresponding to the operating conditions of machine units:
\[ B = \frac{2n_1md_{av}L\gamma_m k_p}{G_m} \]  

where \( n_1 \) - number of gear pairs in the unit, dipping in oil; \( m \) - meshing module, m; \( L \) - gear tooth length, m; \( G_m \) - quantity of oil in the unit, kg; \( k_p \) - coefficient taking into account the heterogeneity of abrasive particles size that penetrate into the unit, depending on the dusty environment and abrasive particle size value in the oil \( k_p = 0.40 - 0.65 \):

\[ \varepsilon_z = 2\delta_z - \delta_z B = \delta_z (2 - B) \].

Similarly, after \( k_1 \) cycles of the gear wheel loading, the concentration of crushed abrasive particles:

\[ \varepsilon_{k,d} = \delta_z B (k_1 - 1) ; \]  

the concentration of active abrasive particles:

\[ \varepsilon_k = k_1 \delta_z - \varepsilon_{k,d} = \delta_z (k_1 - B (k_1 - 1)) ; \]  

**Figure 1.** Change in the concentration of active abrasive particles in aggregate oil from the meshing module and the number of loading cycles: 1, 2 - total concentration of abrasive particles in oil is constant; 3, 4 - initial concentration of abrasive particles in aggregate equals zero and changes for each loading cycle; 1, 3 - \( m = 0.010 \) m; 2, 4 - \( m = 0.015 \) m

Graphical dependencies presented in Figure 1, obtained from expression (6 and 8) of graphs 3, 4, constructed at: \( n_1 = 2; d_{av} = 0.000012 \) m; \( L = 0.058 \) m; \( \gamma_m = 910 \) kg/m\(^3\); \( k_p = 0.5 \); \( G_m = 20 \) kg; \( \delta_z = 0.65 \times 10^{-6} \) %/rev show the following. If the initial concentration of abrasive particles in oil is zero, with the increase of the loading cycles, the concentration of crushed abrasive particles gradually increases. After its value reaches some critical value, it slightly decreases. This can
be explained by the excessive amount of crushed abrasive particles in the oil of the unit compared to the abrasive particles coming into the unit from the environment.

4. Conclusion
Thus, the obtained expressions for determining the activity of abrasive particles (9) make it possible to calculate:
1) durations of wear testing of the gear wheel material on samples at a constant total concentration of abrasive particles in the oil;
2) period of oil replacement of units of machines with toothed gears, working in the presence of abrasive particles in the working environment.

References
[1] Irgashev B A, Irgashev A I 2015 Forecasting the consumption of spare parts in machines based on the content of wear particles in oil Journal of Friction and Wear 36(5) 441-448
[2] Mirzayev Q Q, Irgashev A I 2014 Wear resistance of rolling-ball bearings operating in an abrasive medium Journal of Friction and Wear, 35(5) 439-442
[3] Yampolsky G Y, Kragelsky I V 1973 Investigation of abrasive wear of rolling friction pair elements (Moscow: Nauka)
[4] Zhigaev V D 1971 Journal of Durability of quartz sand grains 1 101-105
[5] Mirzayev N N, Kudoberdyev M A, Khamroyev R K 2020 Theoretical Research Of The Technical Operation Indicators Of Grain Transportation Of New Generation High-Capacity Trucks Test Engineering and Management 83(4) 54-60
[6] Ikramov U A 1990 Calculation of activity of abrasive particles. Collection of Scientific Works of Tashkent Polytechnic Institute. (Tashkent)
[7] Ishmuratov H K, Irgashev B A 2020 Assessment of the Wear Resistance for Gearwheel Teeth in an Open Toothed Gear under the Conditions of a High Level of Dust. Journal of Friction and Wear. 41(1) 85-90
[8] Irgashev A 2005 Methodological bases of increasing the wear resistance of gears of heavy-loaded gears of machine aggregates Dissertation of the Doctor of Technical Sciences. (Tashkent)
[9] Ikramov U A, Irgashev A, Makhkamov K H 2003 A calculation model for evaluating the wear resistance of gears based on the concentrations of wear products in oil Journal of Friction and wear 24(6) 620-625
[10] Zamyatin A Yu, Zamyatin V Yu 1999 Friction-fatigue properties of gears Journal of Friction and wear 21(3) 394-397
[11] Melnikov V Z 1999 Increasing the bearing capacity and wear resistance of gears Journal of Tractors and agricultural machines 2 45-47
[12] Journeymen K V 2000 Experimental assessment of the influence of local defects of rolling body surfaces on the probability of their micro-contact Journal of Friction and wear 2(3) 18-21