Wear Resistance of Gear Teeth of Gearbox Gears of Tractors Operating in Dusty Conditions

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Abstract: The article deals with the issues of wear resistance of gear teeth of wheel tractor gearboxes operating in dusty conditions. Methods are developed: modelling of gears being in coupling with samples having a cylindrical shape; experimental studies of wear occurring on the contact areas of the tooth profile surface, taking into account the degree of oil contamination by abrasive particles and wear products, load and the process of slippage between the teeth of gears.

1 INTRODUCTION

Carrying out of researches directed on determination of term of replacement of oil in a gearbox, in real friction pairs, demands much time and big expenses of material means as during carrying out of tests in field conditions oil samples are taken from a gearbox with intervals of 125 hours of work and volume of 200-250 ml, with the subsequent filling of fresh oil in a crankcase of the unit. The final oil sampling is carried out after 1000 hours of operation, as the specified time corresponds to the frequency of oil change in the unit, according to the technical instructions for the tractor operation for the gearbox (Ishmuratov et al., 2023).

2 MATERIALS AND METHODS

During tractor operation, considerable amounts of mechanical impurities accumulate in the gearbox. The main component is abrasive particles of soil origin, mainly consisting of oxides of silicon, aluminium and wear products in the form of iron. The composition of mechanical impurities in the oil was determined by spectral analysis on the photometric unit MFS-3, and the concentration of mechanical impurities according to the results of analysis of oil samples relating to each pair of gears of the gearbox gears that are in the meshing.

The results of the analysis of the composition of mechanical impurities show the presence in the oil of the unit wear products in the form of iron, as well as abrasive particles in the form of silicon oxides and aluminium. The tests were carried out in the gearbox oil during one replacement period corresponding to 1000 hours of tractor operation (Irgashev, 2005).

In order to reduce the duration, increase the degree of accuracy of experimental studies carried out to determine the wear resistance of gear teeth, it is advisable to conduct tests on the friction machine, using roller samples, whose dimensions correspond to the geometric and kinematic parameters of the gear gearing, which determine the radius of curvature of the contact surfaces and the degree of slippage occurring between the teeth of gears.

Determination of the acceleration coefficient of wear test of gear teeth with abrasive particles is based on a linear relationship between the concentration of abrasive particles in the tub of the friction machine and the amount of wear occurring in the samples of gears with abrasive particles.

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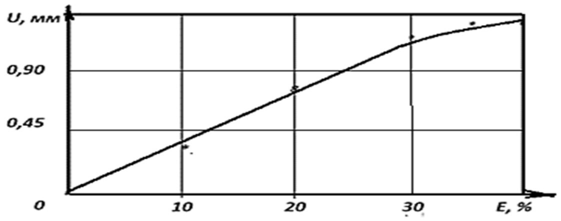

Figure 1: Variation of the wear value of the roller specimen depending on the concentration of abrasive particles in the oil Variation of the wear value of the roller specimen depending on the concentration of abrasive particles in the oil.

Carrying out of wear test on the friction machine allows to reduce duration of works as: firstly, angular speeds of samples established on a shaft of the friction machine are higher, than speeds of gears in a gearbox; secondly, concentration of abrasive particles in oil change in operational conditions, at dustiness of environment 0,82 g/m3, habituates 0,35 %. According to the figure 1, the dependence of change of wear value on the concentration of abrasive particles is linear, so the increase in the concentration of abrasive particles is maintained up to 31,5 %.

Increase of acceleration coefficient of wear test (see table 1) in 158,4 times gave the possibility to reduce the duration of wear test of gear wheel from 300 hours to 113,6 min, the test was carried out on roller samples modelled by expressions (Ishmuratov & Irgashev, 2020; Ishmuradov & Hamroev, 2024).

Each meshing point of the gear has its own radius of curvature and degree of relative slip between them according to the profile of the involute to be meshed. In order to obtain a wear curve, the involute tooth surface was divided into 8 parts, for each of which the characteristic values of the degree of slippage were determined.

Test specimens are made of gear material, the surfaces of which are hardened in accordance with the modes provided by the technological process of hardening gear teeth (Myshkin & Petrokovets, 2007).

If in the gear meshing occurs between the head of the tooth of the leading (driven) and the foot of the tooth of the (leading) gear, then the radius of the sample modelling the head (foot) of the tooth of the leading (driven) gear is equal to:

$$\rho_{шг} = 0,5 \cdot m \cdot \psi_{1,2}$$

where $\psi_{1,2}$ - the degree of relative slippage occurring between the head (foot) of the tooth of the leading (driven) and the foot (head) of the tooth of the tooth of the slave tooth of the (driving) gear.

The calculated values of the degree of relative slip occurring between the teeth of the meshing gears were determined by the following expressions:

- provided that the meshing occurs between the tooth head of the driving gear and the tooth stem of the driven gear:

$$\psi_1 = \sqrt{z_ш^2 \cdot \sin^2\alpha + 4 \cdot \kappa \cdot z_ш \cdot \sin\alpha \pm 4 \cdot \kappa^2} \qquad (1)$$

- provided that the engagement is between the tooth head of the idler gear and the tooth foot of the drive gear:

$$\psi_2 = \sqrt{z_к^2 \cdot \sin^2\alpha + 4 \cdot \kappa \cdot z_к \cdot \sin\alpha \mp 4 \cdot \kappa^2} \qquad (2)$$

Then, the radius of curvature of the samples modelling the operation of gears meshing occurs between the head (foot) of the tooth of the driving (driven) gear and the foot (head) of the tooth of the driven (master) gear:

- the head (foot) of the tooth of the drive (driven) pinion:

$$\rho_ш = 0,5 \cdot m \cdot \sqrt{z_ш^2 \cdot \sin^2\alpha + 4 \cdot \kappa \cdot z_ш \cdot \sin\alpha \pm 4 \cdot \kappa^2} \qquad (3)$$

- of the tooth of the idler gear tooth (head):

$$\rho_к = 0,5 \cdot m \cdot \sqrt{z_к^2 \cdot \sin^2\alpha + 4 \cdot \kappa \cdot z_к \cdot \sin\alpha \mp 4 \cdot \kappa^2} \qquad (4)$$

The sizes of abrasive particles participating in the process of wear are chosen according to GOST 9206-80 26/22, 10/8,5 microns and the sizes of the same abrasive particles according to GOST 3647-80 are designated by M28, M10. Average sizes of abrasive particles added to oils in a tub of the friction machine at wear test made 14,9 microns.

Duration of testing samples of gears for wear resistance on the friction machine depend on the material of gear teeth, modes of heat treatment, geometric and kinematic parameters, coefficient of acceleration of wear test. Calculated indicators affecting the coefficient of acceleration of wear test, wear resistance and duration of wear test of samples made of gear materials on the rolling friction machine are given in Table 1.

Table 1: Gear indicators affecting the test acceleration factor and the duration of the wear test of the specimens.

Indicatorsnwear test	**II**	**III**	**IY**	**Total**
Percentage of oil change time, %	15	30	25	70
Proportion of oil change time, hours	150	300	250	700
Average speed of driven shaft, min^{-1}	476	567	667	-
Number of revolutions of the output shaft during the oil change period (ten thousand revolutions)	428,4	1020,6	1000,5	2449,5
Rotational speed of the lower sample, min^{-1}	1000	1000	1000	-
Number of revolutions of the lower friction sample (ten thousand revolutions)	900	1800	1500	4200
Acceleration coefficient of test specimens and gearbox drive shaft test	2,10	1,76	1,50	1,71
Concentration of abrasive accumulations during the oil change period, %	0,35			
Concentration of abrasive particles in friction machine oil, %	31,5			
Test acceleration factor at 31.5% abrasive particle concentration in oil	90			
Total test acceleration factor	189,0	158,4	135,0	153,9
Duration of the wear test on the friction machine	47,6	113,6	111,1	272,3

The speed of rotation of the drive shaft of the gearbox during one minute is determined by the speed of rotation of the engine crankshaft, according to the ratio below:

$$n_i = \frac{n_{д}}{i_{ду} \cdot i_i}$$

where $n_{д}$ - the frequency of rotation of the crankshaft of the engine during one minute, $n_{д}$ = 2200 min^{-1}; $i_{ду}$ - the gear ratio of the gear transmission, transferring torque to the intermediate shaft of the transmission box, with the value $i_{ду}$=1,29, which will provide the average speed of rotation of the intermediate shaft 1700 min^{-1}. The number of revolutions of the driving shaft of the gearbox perfect for one term of oil change is calculated by the following expression:

$$N_{ма} = n_i \cdot t_{мх}$$

where $t_{мх}$ - gearbox oil change period, min

The wear test was carried out on the friction machine on samples made on the radius of curvature of gear teeth, heat treatment of friction surfaces of which was carried out taking into account the load to the real conditions of operation of gear wheels, taking into account their location in the intermediate and driven shafts of the transmission box. Thus tested lower samples had contact with oil in a bath of the friction machine having a composition of abrasive particles. The wear test of the specimens was carried out at the rotational speed of the bottom specimen of the friction machine 1000 min^{-1}.

The general coefficient of acceleration of wear test includes two components, one of them takes into account the rotational speed of the bottom specimen mounted on the friction machine and is determined by the expression:

$$\kappa_{ac} = \frac{N_{им}}{N_{ук}}$$

where $N_{им}$ - number of revolutions of the lower sample tested for wear resistance on the friction machine; $N_{ук}$ - number of revolutions of the driven shaft for the period of oil change in the gearbox.

The second component was determined by the ratio of the maximum concentration of abrasive particles in the oil of the friction machine tub, which has a linear dependence on the maximum wear of the samples (1.25 mm), presented in Figure 1.

At carrying out of experimental researches the used abrasive particles on maximum and minimum sizes and on strength have special values which should correspond to requirements of GOST 9206 and GOST 3647-80.

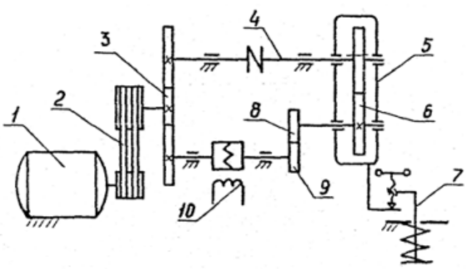

Figure 2: Kinematic scheme of the rolling friction machine 1 - electric motor; 2 - V-belt transmission; 3 - gear transfer box; 4 - shaft; 5 - carriage; 6 - gear drive upper sample; 7 - spring loading mechanism; 8 - upper sample; 9 - lower sample; 10 - inductive sensor for measuring the friction torque.

The acceleration factor of a wear test involving abrasive particles in oil is equal to:

$$\kappa_a = \frac{\varepsilon_{им}}{\varepsilon_{ук}}$$

where $\varepsilon_{им}$ - concentration of abrasive particles in the tub of the friction machine before the test, %; $\varepsilon_{ук}$ - concentration of abrasive particles in the gearbox oil corresponding to the period of their replacement, %. The calculated values of the acceleration coefficient of the wear test were $\kappa_a = 90$.

The total coefficient of acceleration of wear test is determined as a product of coefficients of acceleration of wear test of samples, being in oil bath of the friction machine (Fig. 2) and with participation of abrasive particles in oil, that is:

$$\kappa = \kappa_{ac} \cdot \kappa_a$$

where κ_{ac} - acceleration coefficient of wear test of specimens being in the oil bath of the friction machine.

Time wear test on the friction machine friction samples made of gearbox gear materials, determined for the period of oil change for each gear, taking into account their share in each gear and the coefficient of acceleration of wear resistance test, is determined by the following ratio:

$$t_{им} = \frac{t_x}{\kappa}$$

where t_x - the fraction of oil change time in the gearbox under consideration, min.

3 RESULTS AND DISCUSSION

Determination of the average wear rate of gear teeth arising during the oil change period of the tractor gearbox operating in an abrasive environment, makes it possible to determine the service life of gears in operating conditions. Modelling the work of gear teeth involved in meshing samples - roller analogues on the basis of geometric and kinematic parameters allows you to reduce the duration of wear test and has an impact on improving the accuracy of measurement of wear of the friction surfaces under study.

For definition of average wear rate of samples the following expression is offered:

$$\gamma_м = \frac{M_м}{0,033 \cdot \pi \cdot \gamma_e \cdot \rho \cdot в \cdot t_м}$$

where - value of wear of the sample by mass, g; - density of wear products, g/mm3; - radius of the tested sample for wear by mass, mm; - contact width of the tested sample for wear, mm; - duration of wear test of the sample, min.

The value of wear of the samples tested for wear resistance was determined by weighing on analytical scales by the difference in mass of samples before and after wear test, the measurement was carried out with an accuracy of 0.1 mg. The results of the study are given in Table 2.

Table 2: Results of wear test of specimens made of gear materials on the radius of curvature curvature of gear teeth, carried out on a rolling friction machine.

№	Indicators	Gear tooth height factor, k		
		On the head of the tooth	At the engagement pole	On the stem of the tooth
		1,0	0	1,0
1	Radius of curvature of tested samples of gear teeth, mm			
	On a permanent hitch: on the drive shaft; intermediate shaft	28,94 35,78	23,94 30,78	28,06 35,07
	In first gear: intermediate shaft; idler shaft	49,46 15,26	44,46 10,26	48,95 13,53
	In second gear: intermediate shaft; idler shaft	47,75 16,97	42,75 11,98	47,22 15,43
	In third gear: the intermediate shaft; idler shaft	46,03 18,68	41,04 13,68	45,49 17,29
	In fourth gear: intermediate shaft; idler shaft	44,33 20,39	39,33 15,39	43,76 19,12

	In fifth gear: intermediate shaft; idler shaft	38,34 26,38	33,34 21,38	37,69 25,41
	In sixth gear: intermediate shaft; idler shaft	32,36 32,36	27,36 27,36	31,58 31,58
2	Wear value of the gear test specimen by mass, gr			
	On a permanent hitch: on the drive shaft; intermediate shaft	0,071 0,088	0,007 0,009	0,069 0,086
	In first gear: intermediate shaft; idler shaft	0,121 0,037	0,012 0,004	0,120 0,033
	In second gear: intermediate shaft; idler shaft	0,117 0,042	0,012 0,004	0,116 0,038
	In third gear: intermediate shaft; idler shaft	0,113 0,046	0,011 0,005	0,111 0,042
	In fourth gear: intermediate shaft; idler shaft	0,109 0,056	0,011 0,006	0,107 0,047
	In fifth gear: intermediate shaft; idler shaft	0,094 0,065	0,009 0,007	0,092 0,062
	In sixth gear: intermediate shaft; idler shaft	0,079 0,080	0,008 0,008	0,077 0,077
3	Value of linear wear of the gear test specimen, mm			
	On a permanent hitch: on the drive shaft; intermediate shaft	0,644 0,499	0,061 0,047	0,614 0,476
	In first gear: Intermediate shaft idler shaft	0,065 0,015	0,006 0,002	0,062 0,014
	In second gear: intermediate shaft; idler shaft	0,134 0,038	0,013 0,004	0,128 0,036
	In third gear: intermediate shaft; idler shaft	0,257 0,086	0,024 0,008	0,245 0,082
	In fourth gear: intermediate shaft; idler shaft	0,205 0.080	0,020 0,008	0,196 0,076
	In fifth gear: gear on the intermediate shaft; pinion on the idler shaft	0,104 0,067	0,010 0,006	0,099 0,065
	In sixth gear: intermediate shaft; idler shaft	0,046 0,046	0,005 0,005	0,044 0,044
4	Wear rate of the gear sample, mm/hour			
	On a permanent hitch: on the drive shaft;	0,00064	0,00006	0,00061

	intermediate shaft	0,00050	0,00005	0,00048
	In first gear: intermediate shaft; idler shaft	 0,00093 0,00021	 0,00009 0,00002	 0,00089 0,00020
	In second gear: intermediate shaft; idler shaft	 0,00089 0,00025	 0,00008 0,00002	 0,00085 0,00024
	In third gear: intermediate shaft; idler shaft	 0,00086 0,00029	 0,00008 0,00003	 0,00082 0,00028
	In fourth gear: intermediate shaft; idler shaft	 0,00082 0,00032	 0,00008 0,00003	 0,00078 0,00031
	In fifth gear: intermediate shaft; idler shaft	 0,00069 0,00045	 0,00007 0,00004	 0,00066 0,00043
	In sixth gear: intermediate shaft; idler shaft	 0,00058 0,00058	 0,00005 0,00005	 0,00055 0,00055

4 CONCLUSIONS

1. Analytical dependencies are offered, allowing to calculate the degrees of relative slippage occurring between the teeth of the meshed gears and radius of curvature of the contact line radius of the teeth of the driving and driven gears taking into account, geometric and kinematic parameters of the gear meshing.
2. Developed a method of accelerated wear test of the gear gearing modelling the work of gear teeth roller samples made by their radius of curvature, while providing high accuracy of the results obtained on the wear profile of gear teeth determined by wear test roller analogues.
3. Analytical dependence is obtained, allowing to determine the wear rates of the teeth of the driving and driven gears, taking into account the values of wear on the mass of samples, radius of curvature, contact width and duration of wear test.

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