Hardening of gear teeth depending on the concentration of abrasive particles in the transmission oil

Sherzodkhuja Mirzakhodjaev[1*], *Madraxim* Allanazarov[1], and *Khikmat* Ishmuratov[2]

[1]Tashkent State Agrarian University, str.Universitetskaya, 2 Tashkent region Kibray district 100140, Uzbekistan
[2]Tashkent State Technical University named after Islam Karimov, University street №2, Tashkent city; Uzbekistan

Abstract. The article deals with the issues of determining the life and limiting concentration of abrasive particles in the oil of transmission units, depending on the type of hardening of gear teeth. Resource was determined after volume hardening, hardening by current of high frequency and cementation by hardness of gears materials, on the friction machine on the samples which have been made of gears material, working in oil with abrasive particles, considering coefficient of acceleration at test. Maximum allowable concentration of abrasive particles in machine oil, were estimated on the basis of expression for calculation of wear rate, providing the set life, maximum allowable wear depending on modulus of gearing, hardness of gearing material, size of abrasive particles, geometrical and kinematic parameters of gearing.

1 Introduction

The required wear resistance of gear teeth of transmission units is achieved at ensuring the maximum permissible concentration of abrasive particles in the oil. In the process of operation of tractors in field conditions it is established that in oil of transmission units at their replacement are accumulated solid mechanical impurities consisting of abrasive particles of soil origin and wear products in approximately equal proportions up to 1.3% by mass [1]. In order to ensure the specified service life of gears in terms of wear of gear teeth in one period of oil replacement in the units should not exceed 0.25% (by mass) [2].

Thus, the purpose of this study is to obtain analytical dependence to calculate the maximum allowable concentration of mechanical impurities with abrasive properties, affecting the allowable wear rate of gear teeth, depending on the hardness of the gears material, the size of abrasive particles, geometric and kinematic parameters of the gearing, as well as changes in the maximum allowable concentration of abrasive particles in the oil of units from the module of meshing.

2 Material and method

To solve this problem the dependence allowing to calculate the maximum allowable wear rate of teeth of driven and driven gears, working in oil containing abrasive particles [3]:

$$[\gamma_a]_{sh.k} = \frac{22.33 \cdot d_{sr} \cdot [\varepsilon_k]^2 \cdot \sigma_a^2 \cdot G_{sh.k} \cdot n_{sh.k} \cdot m \cdot (i \mp 1) \cdot k_v \cdot \psi_{1.2}}{i \cdot b \cdot H_{sh.k}^2 \cdot z_{sh.k} \cdot n_{psh.k}} \quad (1)$$

where d_{sr} - average size of abrasive particles, abrasive particles in the oil of transmission units, involved in the wear process, mm; $[\varepsilon_k]$ - maximum allowable concentration of abrasive particles in the oil of the unit, involved in the wear process of gear teeth, %; σ_a- abrasive particle compressive strength, MPa; $G_{sh.k}$ - coefficient showing the correlation between the hardness of the material of the driven (slave) gear and the abrasive particle strength; $n_{sh.k}$ - rotation speed of the driven (slave) gear wheel, min^{-1} - m gear mesh modulus, mm; i - gear transmission ratio; k_v - abrasive particle shape factor; $\psi_{1.2}$ - slip factor between the teeth of drive and driven gears; b - teeth length of meshing gears, mm; - $H_{sh.k}$ material hardness of driving (driven) gears, MPa; $z_{sh.k}$ - number of teeth of driving (driven) gears; $n_{psh.k}$ - number of contact cycles of friction surfaces resulting in destruction of deformed tooth surfaces of driving (driven) gears in friction.

As an example, we determine the maximum allowable wear rate of the teeth of the $[\gamma_{ash.k}]$ drive (slave) gears with different meshing moduli, most commonly used in cotton wheeled tractors.

3 Results and discussion

The limit wear of gear teeth in the thickness of the gears in question must be within 10-20 % of the thickness of the teeth, along the arc of the initial circle. In irresponsible

* Corresponding author: sherzodxuja.mirzaxodjayev@mail.ru

gears tooth wear is allowed up to 30% of tooth thickness [4]. Taking the limit wear of gear teeth thickness 20 %, we define the maximum allowable wear rate of teeth of the driven gear with m=1 mm meshing module, subjected to the volume hardening, hardening by the current of high frequency and carburizing. Table 1 shows the change in hardness and service life of gears depending on the type of hardening of gear teeth. Service life of gears was determined on the machine of friction SMS-2 on samples, made of gears material, in oil with abrasive particles, herewith coefficient of acceleration of testing on the machine of friction was selection of size of samples from 30 mm to 50 mm – 1.67 times ; slippage of samples at equal diameters of samples according to design of the friction machine -1.2 times; frequency of rotation of samples on the friction machine 1000 rpm and the leading gear in operating conditions 120 rpm – 8.33 times; increase in concentration of abrasive particles in oil bath of the friction machine 4 times in comparison with operating conditions - 16 times) 267.16 times. The total duration of life test for one oil change in machine 1000 hours was 224 min (3.73 hours).

The maximum permissible wear rate of the teeth of the drive and idler gears, taking the wear limit and service life into account, is equal,

$$[\gamma_{ash.k}] = \frac{U_{sh.k}}{T_{sh.k}} = \frac{0.1 \cdot \pi \cdot m}{T_{sh.k}} \quad (2)$$

where $T_{sh.k}$ is the service life of the driving, driven gears.

Table 1. Change in gear life depending on the type of hardening the tooth surface and the hardness of the gear material.

Type of gear tooth surface hardening	**Toothed wheel**	**Gear tooth hardness, MPa**	**Duration of the resource test, hr.**	**Gear resource wheel, hour**
Cementation	Leading	600	30.69	8200
	Slave	550	28.06	7500
HF hardening	Leading	500	25.44	6800
	Slave	450	22.82	6100
Volumetric hardening	Leading	400	20.58	5500
	Slave	370	18.32	4900

Solving expression (1) for relatively maximum allowable concentration of abrasive particles in machine oil $[\varepsilon_k]$ for gears subjected to volumetric hardening of teeth at initial data: d_{cp} =0.02 mm; σ_a=109.3 MPa; n_{sh} =120 min^{-1}; n_k =60 min^{-1}; m =1 mm; i=2; k_v =1.07; ψ_1 =4.56; $\psi_2 = 4.18$; b =13 mm; z_{sh} =19; $z_k = 38$ G_{sh} =3.43; $G_k = 3.54$; n_{psh} =17.40; n_{pk} = 16,41 [5].

$$[\varepsilon_k]_{sh.k} = \frac{0.212 \cdot H_{sh.k}}{\sigma_a} \cdot \sqrt{\frac{[\gamma_a]_{sh.k} \cdot i \cdot b \cdot z_{sh.k} \cdot n_{psh.k}}{d_{cp} \cdot G_{sh.k} \cdot n_{sh.k} \cdot m \cdot (i \mp 1) \cdot k_v \cdot \psi_{1.2}}} \quad (3)$$

The calculated maximum permissible concentration of abrasive particles in the machine oil, calculated by expression (3), which ensures the determined service life, maximum permissible wear and wear rate of gears subjected to volumetric hardening depending on gear module, is shown in Table 2.

Based on the calculated results, expression (3) shows that gears subjected to volumetric hardening work in the unit until the oil replacement time of 1000 hours, and the concentration of accumulated abrasive particles is called a limit - allowable. At which the gears can reach the specified service life of the driven gear in conditions where the wear rate of the driven gear teeth is 8,6% higher than the wear rate of the driven gear teeth. In this case, the concentration of abrasive particles that provide the service life of the driven gear is 11.4% greater than that of the driven gear. Which can be attributed to the fact that during the operation of the unit, the driven wheel works in accordance with the gear ratio of the gear pair with a lower angular velocity compared to the driven gear, contributing to the work of the driven gear higher maximum permissible concentration of abrasive particles in the oil [7, 8].

Table 2. Variation of abrasive particle concentrations in oil and wear rates of volumetrically hardened gear teeth as a function of the meshing modulus.

Module of the gearing,	Gear teeth wear, mm	Tooth wear rate at the limit of abrasive particles in the oil, mm/h		Maximum concentration of abrasive particles in oil during volumetric quenching, %	
		Drive pinion	Slave ses-thorns	Drive pinion	Back of the gears
1	0.314	0.0000383	0.0000419	0.070	0.079
2	0.628	0.0000766	0.0000834	0.099	0.111
4	1.256	0.0001532	0.0001675	0.140	0.158
6	1.884	0.0002298	0.0002512	0.171	0.193
8	2.512	0.0004568	0.0003349	0.198	0.223
10	3.140	0.0003830	0.0004187	0.221	0.249
12	3.768	0.0004596	0.0005024	0.242	0.273

Let's consider determining the maximum allowable concentration of abrasive particles in the surface hardening of gear teeth by high frequency current hardening and carburizing. The use of these methods can be limited by exceeding the maximum allowable amount of wear, which may be greater than the thickness of the hardened layer. It is known that the thickness of the hardened layer in case of HF hardening is on average 2 mm and in case of carburizing - not more than 1 mm. The results of calculation show (see table 3) that in the bought-modular gears the limiting wear of teeth on thickness of teeth significantly exceeds values of the hardened layer, which leads to wear of teeth at higher rate, leading to reduction of service life of the considered gears. Therefore, the enclosed calculation methodology allows determining the oil replacement period in the unit, where surface-hardened gears are operated, at the stage of designing and manufacturing of gears, taking into account the ratio of hardened layer, calculated wear value and operating life of the gearing depending on the meshing modulus [3, 6].

The maximum permissible concentration of abrasive particles ensuring the service life of gears in terms of tooth wear after hardening by high frequency current is calculated by expressions (3), with the following initial data: d_{cp} =0.02 mm; $\sigma_{a=109}$.3 MPa; n_{sh} =120 min^{-1}; n_k =60 min^{-1}; m =1 mm; i =2; k_v =1.07; ψ_1 =4.56; $\psi_2 = 4.18$; b =13 mm; z_{sh} =19; $z_k = 38$ for hardening by high frequency current: G_{sh} =3.11; n_{psh} =25.29; 22.58; for cementation: G_{sh}=2.87; G_k =2.98; n_{psh} =28.06; npk=25.29 [5],

The results of calculating the maximum allowable concentration of abrasive particles in the oil of the driveline units as a function of the modulus of engagement are shown in table 3.

Table 3. Variation of abrasive particle concentrations in oil and wear rates of pinion teeth as a function of engagement modulus.

Mo-dual hooking, mm	HF hardening		Cementation		Rate of wear tines, mm/hour		The maximum concentration of abra- of gaseous particles in oil, %	
	Iznos, mm	Re-resource, hour	Wear, mm	Re-resource, hour	For quenching by high-frequency current	For cementation	For quenching by high-frequency current	For cementation
1	0.314	6800	0.314	8200	0.000046	0.000038	0.122	0.146
2	0.628	6800	0.628	8200	0.000092	0.000077	0.173	0.206
4	1.256	6800	1(1.256)	6529	0.000185	0.000153	0.244	0.292
6	1.884	6800	1(1.884)	4406	0.000277	0.000230	0.299	0.358
8	2(2.512)	5414	1(2.512)	3264	0.000369	0.000306	0.345	0.413
10	2(3.140)	4331	1(3.140)	2611	0.000462	0.000383	0.385	0.462
12	2(3.768)	3609	1(3.768)	2176	0.000554	0.000460	0.423	0.506

The thickness of the hardened layer by current hardening at high frequency and the value of limiting wear, the service life of the leading gearing equal to 6800 hours, was 2 mm. When the gearing with a modulus of engagement of 6 mm has a wear value of 1.884 mm, which is comparable to the hardened layer during current hardening at high frequency, the calculated concentration of abrasive particles in the oil was 0.3%. When the meshing module is 8 mm the service life of the gearing was reduced by 20.4 %, when the meshing module is 12 mm it was reduced to 46.9 %, the maximum allowable concentration of abrasive particles in the machine oil was increased and was 0.423 %. Thus, the calculation results show the expediency of using for gears subjected to current hardening of high frequency with the module of meshing not exceeding 6 mm [9,10].

The gears with cemented teeth have a resource according to table 3 is 8200 hours, which are observed only in gears with engagement module 1 and 2 mm, further increasing the engagement module leads to a reduced resource, at the engagement module 3 mm is reduced by 20.4%, at the engagement module 8 mm more than 60%, and at 12 mm reduced resource is 73.5%. Thus it is expedient to use cemented gearwheels in gears with a meshing module not more than 3 mm, at that the concentration of abrasive particles in the unit oil should not exceed 0.3 %. The reduction of service life of gears was calculated in relation to the difference of maximum allowable wear of teeth ([U]=0.2 m) and the thickness of hardened layer of teeth subjected to hardening by current of high frequency (2 mm) and cementation (1 mm) (see table 3) [5].

4 Conclusion

Gearwheels with a modulus of engagement not exceeding 1 and 2 mm, which are hardened by more than 20%, have a higher life than gears hardened by high frequency current when the concentration of abrasive particles in the machine oil does not exceed 0.2%.

The maximum permissible concentration of abrasive particles in the oil of the unit ensures the wear resistance of volume hardened pinion gears as the modulus of engagement increases, the maximum concentration of the driven gear is 1.13 times higher than that of the driven gear, regardless of the modulus of engagement.

The limiting concentration of abrasive particles in the aggregate oil of cemented gear teeth is 1.20 times higher than that of gears with current hardened high frequency teeth, in all the gearing modules considered.

References

1. U.A. Ikramov, Calculation of activity of abrasive particles. Collection of Scientific Works of Tashkent Polytechnic Institute. - Tashkent (1990)
2. H.K. Ishmuratov, Theoretical justification of gear life of cotton harvesting machines according to wear criterion. Ph.D. thesis in technical sciences (PhD). Tashkent, pp 156 (2019)
3. H.K. Ishmuratov, *Wear resistance of gear teeth, while rolling without participation of abrasive particles in wear process*, International Scientific and Practical Conference "Automobile and Tractor Engineering". –Mins., pp 16-20 (2019)
4. G. Ya Yampolsky, I.V. Kragelsky, Investigation of abrasive wear of elements of rolling friction pairs. - Moscow: Nauka. 63 (1973)
5. Q.Q. Mirzayev, A. Irgashev, Journal of Friction and Wear, **35**, 5, 439-442 (2014)
6. I.V. Kragelsky, et al. Moscow: Mechanical Engineering. 526. (1977)
7. T. Sasaki, Rolling friction at high speed (translated from English). // J. Mechanics. №5, 87 221-224 (1964)
8. V.F. Reschikov, Friction, wear and tear of heavily loaded gears. 231 (1975)
9. N.N. Mirzayev, M.A. Kudoyberdiyev, R.K. Khamroyev, Test Engineering and Management, **83**, 54-60 (2020)
10. A.A. Akhmetov, M.A. Allanazarov, L. Muratov, D. *Kambarova Installation of passive working tools with lancet foot in one row with overlapping*, International Conference CONMECHYDRO - TIIMSH, 533 (2021)