Calculation of the resource of spiroid transmissions from wear in the step of loading mode

Alexander Zaitsev

1Siberian Transport University, 191, st. D. Kovalchuk, 630049, Novosibirsk, Russia
E-mail: zaitsev.zaw@yandex.ru

Abstract. The analysis of the failure causes of the mechanisms and drives of lifting, construction, road machines on the basis of gearing gears, as well as gears of the worm class, which are contact destruction of the active surfaces of gear teeth, leading to malfunctions, breakdowns, failures in the form of wear and scuffing. A cyclogram describing the mode of operation of the gear pair, taking into account the effect of maximum load on the contact endurance and on the endurance of the teeth during bending, and which is used in strength calculations of spur and helical gears, is given. The necessity of creating a method for calculating the wear of spiroid gears based on the variable loading mode and load time taking into account the loading schedule analysis of mechanisms and drives of hoisting-and-transport machines and equipment where this type of gear is used, in particular, in the drive of stop valve mechanisms, in the drive of screw horizontal conveyor, the cable-assembly mechanism of the electric loader, in the drive of the traction winch of the packing crane UK-25/9-18 for tugging packages of rail track panel, is substantiated. The developed method makes it possible, taking into account the actual operation modes of hoisting-and-transport machines, equipment and mechanisms, by experimentally obtained dependence of the wear rate of the spiroid wheel teeth on the torque values on the output shaft of the spiroid gearbox, to determine the values of wear intensity and calculate the duration of the resource of the spiroid gearbox in accordance with the established schedule of variable mechanism loading for lifting, construction and road cars.

1. Introduction

As an action result of constant or variable during the time of useful resistances, in the process of operation, arising on the working equipment, in gearing of mechanical gears, contact fractures of the active surfaces of the links, wear, tears on the side surfaces of the teeth and fractures are formed, which causes the failure of the drive mechanisms of lifting, construction and road machines. This type of destruction is characteristic for hardened surfaces of the gears teeth and is detected by progressive chipping of the material, which can reach considerable sizes, as well as on the hardened surfaces of the teeth by peeling large areas of the metal layer [1, 2].

For gears of both open and closed gears and gears of the worm class operating in an environment clogged with abrasive particles, wear and jamming of the teeth is a typical cause of failure (Figure 1) [3].

A distinctive feature of the gears of the worm class is the relative slip at any contact point of the active surfaces of the pair links, the speed magnitude of which increases with increasing gear ratio.
Figure 1. Spiroid wheels [3], where: a-wear tooth; b-teasers on tooth surfaces.

When calculating the strength of spur and helical gears with steel wheels, according to Russian State Standard GOST 21354-87, use the cyclogram (Figure 2) taking into account the effect of the maximum load \( F_{r(1)} \) on the contact endurance and endurance of the teeth during bending [4].

For drive mechanisms of lifting, construction and road machines, there are characterized rotary-short loading modes with varying torques on the output shaft of the gearbox during the operating time of the operation cycle. These modes are characterized by low circumferential speed and concomitant increased loads, as well as frequent starts and high contact stresses, leading to destruction of the teeth surface of the contacting links and, as a consequence of wear.

Figure 2. The cyclogram characterizing the operation mode of the gear pair [4-5].

In parallel with the worm gears, the last half century in various areas of technology, spiroid gears are used, which are of the worm type (Figure 3). They are widely used in mechanism drives of hoisting-and-transport machines and equipment, operating both in constant and alternating loading conditions.
Figure 3. The spiroid gear.

Table 1 presents the loading schedules of the mechanisms of hoisting-and-transport machines and equipment where a spiroid gearbox is used.

**Table 1.** The loading mechanisms schedules of hoisting-and-transport machines and equipment, where a spiroid gearbox is used.

| №  | Name of the mechanism | Schedule |
|----|----------------------|----------|
| 1  | Mechanism drive for closing and opening valves. A quarter-turn spiroid gearbox is used [12]. | $T$, N·m |

$$T = f(t)$$
2 Mechanism drive for closing and opening valves. A multi-turn spiroid gearbox is used [12].

3 Drive of screw horizontal conveyor. A gearbox RS is used [16].

4 Cable assembly mechanism of electric lift. A gearbox RS is used [17-19].
Traction winch for pulling the packs of the links of the rail and sleeper grid of the packing crane UK-25/9-18.

Traction winch for tugging packages of rail track panel of the packing crane UK-25/9-18. A gearbox RS is used.

2. Materials and Methods

Due to the fact that a significant number of drives of lifting, construction and road machines are operated under conditions of variable load on working equipment during a cycle, creating a method for calculating the resource of a spiroid gear by wear, taking into account the load variability, becomes an actual task.

The difficulty of creating a universal method of calculating gears by wear is to determine the values of torque on the output shaft of the gearbox during loading cycles and the duration of their action, taking into account the operating conditions of lifting, construction and road machines.

Also, the greater labor intensity of the complexity presents the experimental determination of the intensity of wear of gear materials, which requires the creation of laboratory universal equipment for testing field and model samples, which would provide a wide range of test condition changes that simulate the actual operation modes of machines and mechanisms.

Figure 4 shows the experimental dependences of the intensity $J_h$ of wear and the resource $L$ of the spiroid wheel teeth on the values of the torque on the output shaft of the gearbox $T_i$. This dependence $J_h=F(T_i)$ makes it possible to find the wear rate of the spiroid wheel tooth for the corresponding values of the torque $T_i$ of the established variable loading schedule.
3. Results
The procedure for calculating the resource of spiroid cylindrical gear under variable loading conditions
1. The schedule of mechanism loading is established in accordance with the number of ranked relative values of torques on the output shaft of the spiroid gearbox in decreasing order and the relative duration of their action (Figure 5).
2. Calculate the basic parameters of the spiroid gearbox, necessary for the calculation of the resource (Table 2).
Table 2. The main parameters of the spiroid gearbox required to calculate the resource in accordance with GOST 22850-77.

| №  | Name of the main geometric parameters of the gearbox       | Designation (calculation formula) | Dimension |
|----|----------------------------------------------------------|-----------------------------------|-----------|
| 1  | Center distance                                          | $a_w$                             | mm        |
| 2  | Nominal (maximum) torque at the output shaft             | $T_2=T_{max}$                     | N·mm      |
| 3  | Nominal rotational speed of input shaft                  | $n_1$                             | min$^{-1}$|
| 4  | Nominal output speed                                     | $n_2=n_1/u$                       | min$^{-1}$|
| 5  | Direction rotational speed of output shaft               |                                   |           |
| 6  | Efficiency coefficient in continuous operation (calculated) | $\eta$                           |           |
| 7  | Gear ratio (from worm to worm wheel)                     | $u_{12}$                          |           |
| 8  | Worm material                                            | Steel 40Ch                        |           |
| 8.1| Modulus of elasticity                                    | $E_1$                             | MPa       |
| 8.2| Poisson's ratio                                          | $\mu_1$                           |           |
| 9  | Material of a spiroid wheel                              | Bronse                            |           |
| 9.1| Modulus of elasticity                                    | $E_2$                             | MPa       |
| 9.2| Poisson's ratio                                          | $\mu_2$                           |           |
| 10 | Roughness of worm turn surfaces                          | $R_a$                             | $\mu$m    |
| 11 | Parameters of the worm                                   |                                   |           |
| 11.1| Diameter factor of the worm                              | $q$                               |           |
| 11.2| Screw parameter                                         | $P_y=mz_1/2$                      | mm        |
| 11.2| Angle of inclination of the straight line                | $\alpha=\gamma$                  | degree    |
| 11.3| Design module of the spiroid worm coil along the generatrix | $m$                               | mm        |
| 11.4| Calculated axial module of the spiroid worm              | $m_c = m$                         | mm        |
| 11.5| Number of sets                                          | $z_1$                             |           |
| 11.6| Dividing elevation angle of the worm turn line           | $\gamma$                          | degree    |
| 11.7| Kind of worm                                            |                                   |           |
| 11.8| Direction of the turn line                               |                                   |           |

Figure 5. Established schedule of variable loading mechanism
11.9 dividing diameter of the worm

\[ d_1 = q_m \, \text{mm} \]

11.10 the diameter of the turn tops

\[ d_{st} \, \text{mm} \]

11.11 length of the cut part

\[ b_1 \, \text{mm} \]

11.12 diameter of troughs

\[ d_f \, \text{mm} \]

11.13 dividing axial turn profile angle

\[ \alpha_{xR} \, \text{degree} \]

\[ \alpha_{xL} \, \text{degree} \]

12 Worm wheel parameters

12.1 internal diameter

\[ d_2 \, \text{mm} \]

12.2 outer diameter

\[ d_c \, \text{mm} \]

12.3 number of teeth wheel

\[ z_2 \]

13 The given radius of curvature at the calculated point of contact of the wheel teeth

13.1 For the right dividing axial angle of the turn profile

\[ (\rho_{red12})_R \, \text{mm} \]

13.2 For the left dividing axial angle of the turn profile

\[ (\rho_{red12})_L \, \text{mm} \]

14 Elastic constant of contiguous links

\[ \eta \, \text{mm}^2/\text{N} \]

15 Peripheral speed at calculated points of the wheel teeth profile

\[ V_{FY2} \, \text{mm/s} \]

16 Sliding speed at calculated points of the wheel teeth profile

\[ V_{SY2} \, \text{mm/s} \]

17 Lubricating material: CAT TDTO SAE 30 API GL-3 transmission oil - an analog of TM-3-9 according to Russian State Standard GOST 17479.2 - 85

3. Calculate the maximum allowable wear of the spiroid wheel teeth \([h_2]\):

\[ [h_2] = [1.57 - (\tan \alpha_{xR} + \tan \alpha_{xL})]m_x . \]  (1)

4. The specific calculated force in the engagement corresponding to the torque on the output shaft of the gearbox \(T_i\) [6-9]:

\[ w_{HEi} = \frac{T_i}{T_{max}}w_{HEmax} , \]  (2)

where \(T_i/T_{max}\) - the relative torque values determined from the established variable loading schedule;

\(w_{HEmax}\) - specific calculated force in the gearing corresponding to the torque on the output shaft of the gearbox \(T_{max}\).

5. Determine the wear value of the spiroid gear wheel tooth for the cycle of mechanism operation, corresponding to the value of the working torque on the output shaft of the gearbox \(T_i\) and its duration \(t_i\), mm:

\[ h_i = 2.25J_{hi}&2\sqrt{\frac{w_{HEi}}{\eta(\rho_{red1,2})_R}} \frac{V_{SY2}}{V_{FY2}} n_2 i \left( \frac{t_i}{60} \right) , \]  (3)

where \(J_{hi}\) - the experimentally determined value of the wear rate of the spiroid wheel material corresponding to the working torque \(T_i\) (determined from the graph in Figure 4); \(t_i\) - the action time of the working torque \(T_i\) on the output shaft of the spiroid gearbox of the mechanism for its operation cycle in accordance with the established schedule of the variable loading (Figure 5), \(i=1\) is the number of gearing pairs with the gear wheel in question.

6. Set the cycle value of the mechanism operation to the maximum allowable wear of the spiroid wheel teeth \([h_2]\):

\[ N_\Sigma = \frac{[h_2]}{n} , \]  (4)

where \(n\) - the number of the load step in accordance with the established schedule of variable loading.
7. Calculate the resource of the spiroid gear mechanism with an established schedule of variable loading:

\[ L = \frac{N \times t}{3600} \]  \hspace{1cm} (5)

4. Discussion

An experimental dependence of the wear rate \( J_h \) of the spiroid wheel teeth (brass material BrA9Zh4) on the torque values on the output shaft of the spiroid gearbox \( T_i \), which allows to determine the values of wear intensity and calculate the resource of the spiroid gearbox with an established schedule of variable loading, is obtained.

5. Conclusions

- An algorithm for calculating the resource of the spiroid gearbox by the wear of the spiroid wheel based on the experimental dependence of the wear rate on the load moment \( J_h = F(T_i) \) is given.
- A significant number of mechanisms and drives of lifting, construction and road machines are operated under variable loading conditions.

References

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