Failures and methods of ensuring the service life of friction discs of gearboxes

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Abstract. The resource of a complex machine is determined by the resource of its units and components. As a result of the normal operation of energy-intensive mobile vehicles of the K-7 series, it was established that the service life of the hydromechanical gearbox does not exceed 3000 engine hours, and the experimental probability of its failure is more than 0.55 of all machine units. The cause of failure of the hydromechanical gearbox is failure of the clutches and drive shaft. Failures of friction clutches are associated with significant overheating of the friction discs, their wear, welding and changes in spatial geometry. In the practice of normal operation of mobile machines, the drive shaft is repaired or replaced with a new one. Failure of friction discs occurs due to changes in spatial geometry (experimental probability of failure - 0.76), wear (experimental probability of failure - 0.63), destruction (experimental probability of failure - 0.38) and welding (experimental probability of failure - 0.34) friction discs. The work examines the use of the method of restoring friction discs by flat dimensional grinding, and conducts comparative life tests of restored friction discs.

1 Introduction

The practice of production and trial operation of mobile energy vehicles has established that for repaired and new tractors of the K-7 series, the service life of the machine transmission is determined by failures of the hydromechanical gearbox. The experimental probability of gearbox failure is more than 0.55 of all machine components. The main component leading to the failure of the GPC is the friction clutches and the drive shaft, which are subjected to significant off-design and uneven cyclic, dynamic and thermal loads. Analysis of statistical data shows that in more than 80% of hydraulic transmission units the main failure is the failure of the drive shaft [1].

2 Materials and methods

In the process of monitoring the trial operation of machines, it was experimentally established that the characteristic causes of drive shaft failures are as follows: wear, destruction of sealing elements and non-compliance with the specified parameters of the oil pressure in the
hydraulic system of the hydromechanical transmission, as well as a significant excess of the traction force on the hook when performing technological and transport operations.

As a result of the extreme impact of loads on the drive shaft, the engagement time of the clutches increases significantly, while the friction discs are in slipping mode, resulting in their failure. Failure of friction discs is expressed in the presence of friction, scuffing, metal envelopment, ring wear, warping (change in spatial geometry) and other defects on the surface [2,3]. If the drive shaft fails, it is replaced with a new or repaired one. In the approved regulatory documents for the repair of K-7 series tractors, the operation of replacing the drive shaft is classified as the most labour-intensive - the third group of complexity.

The serviceability coefficient of recovered disks using existing technologies is 0.71. The discs located at the support neck of the drive drum are subject to significant wear. The wear rate of friction discs is not the same and depends on the position of the disc in the clutch pack and the gear number. A change in the spatial geometry of friction discs is a consequence of a change in their stress-strain state as a result of thermal cyclic loading. The profile map of changes in the spatial geometry of the disks represents a truncated cone, or bending and twisting of the disk [3-5].

The limiting state of friction discs in terms of wear and changes in their spatial shape is determined based on the movement of the actuators and the size of the gaps in them, as well as the number of pairs of friction discs, and the amount of disc wear in a package of 24 friction discs should not exceed 0.4 - 0.6 mm, change in spatial geometry no more than 2.5 - 3.3 mm [6-7]. By changing the spatial geometry, we mean the difference in the diameters of the friction disc and the drum. As a result of wear of the friction discs, the slipping time of the clutch increases, this leads to the formation of a temperature gradient at the periphery of the friction disc, resulting in an irreversible process of its deformation. In addition, the friction disks have a temperature regime that does not meet the operating requirements, which is a prerequisite for a change in their spatial geometry. A package of friction discs with a modified spatial geometry leads to an uncontrolled break in the power flow in the gearbox [8-10].

3 Results and discussion

Modern designs of the hydromechanical gearbox of the St. Petersburg Kirov Plant use steel sulfocyanated friction discs, which can significantly increase the service life of the drive shaft.

Research to assess the service life of friction discs was carried out in operating conditions and modes characteristic of the K-7 tractor. During the period of normal operation of K-7 series tractors for 2000 - 3000 motor hours, it was established that failure of friction discs occurs due to changes in spatial geometry (experimental probability of failure - 0.76), wear (experimental probability of failure 0.63), destruction (experimental probability of failure – 0.38) and welding (experimental probability of failure – 0.34) of friction discs.

Figures 1 and 2 show graphs of the changes in the spatial geometry of the driven and driven ones, and the amount of wear of the friction discs.
Fig. 1. Graph of the dependence of changes in the spatial geometry of driven and driven friction discs.

With increasing operating time, the magnitude of the change in spatial geometry for the drive disks is about 4 mm. In the process of contact between the surfaces of the disks, as a result of the generation of heat from friction, zones of contact interaction between the surfaces are formed, having stresses of different magnitudes and signs. With significant heat input into the friction disc as a result of technological load, conditions arise under which the temperature gradient forms an alternating stress in the friction disc, which causes a change in the shape of the disc and its diameter. As a result of a change in the shape of the disk, reducing the area of actual contact of the disks in the package, and this is a consequence of the emergency condition and the accumulation of residual and plastic deformations and wear marks in the disks (Figure 2).

![Graph of the dependence of changes in the spatial geometry of driven and driven friction discs.](image1)

**y = 2E-05x + 0.0444**

**y = 4E-05x + 0.0473**

Fig. 2. Graph of the dependence of the wear of friction discs.

Failure of the package with a deviation in the size of the disks in thickness by a value of +0.06 to +0.09 mm is due to the heating of the disks above the temperature resistance of the materials, which resulted in a change in their shape and led to welding of the package. Failure of a package with disc heights from -0.03 to +0.05 relative to the technical requirements for repairs is also due to uneven heating and cooling of the friction discs, while the service life of the friction disc package decreased by 25 - 45 percent, relative to a package equipped with discs of the recommended thickness (new).

When repairing the clutch, it is equipped with new friction discs that have been in use, but have an acceptable amount of wear and traces of damage, or have been restored. The
service life of repaired clutches of a hydromechanical transmission depends on the technical condition of the disk groups and the method of their assembly.

The study established the dependence of the hardness of the friction discs, indicating that in order to ensure the required overhaul life it is necessary to ensure the hardness of the driving discs is NV 357 - 375, the driven discs are 217 - 256 according to NV. When the friction hardness decreases to HB 150–170, the wear rate increases by 28–50% (Figure 3).

![Fig. 3. Graph of the dependence of the wear rate of the package of driven and driven clutch disks.](image)

Based on the research results, a correlation dependence of wear intensity on the height of the driving and driven friction discs was established (Figure 4). From the dependence graph it follows that when the height of the friction discs is from 2.3 to 2.7 mm, no significant change in the values of spatial deformation and wear is observed. When the height of the driving and driven friction discs is less than 2.3 mm, a twofold increase in wear intensity is observed, which is due to the uneven distribution of contact stresses along the contact surface of the discs. Thus, the permissible height of the driven disk should not be less than 2.6–0.03, and the driving disk - 3.5–0.05 mm.

![Fig. 4. Graph of the dependence of the intensity of wear values \( J_y \) (1, 2, 3) and the spatial geometry \( J_u \) (4, 5, 6) of the driven (2, 5) and driving disks on their height.](image)

To ensure the overhaul life of the friction disks of the drive shaft, it is necessary to use a restoration method that uses compensation for frictional heating of the surface layers of the disk materials. It is known that the thermal dynamics of frictional contact is based on fundamental dependencies that determine convective exchange during friction processes. The equations of thermal dynamics of friction during frictional contact of disks can be presented in the form of functional dependencies:
\[ v = v(\tau, f, N) \]  
\[ HB = HB(T, n) \]

\( \tau \) – disk operating time;  
\( f \) – friction coefficient;  
\( HB \) – hardness of friction disc surfaces;  
\( n \) – number of friction disc loading cycles;  
\( T \) – volumetric temperature in the friction zone.

Taking into account dependencies (1), (2), the equation describing the wear rate of the contacting materials of the disks can be presented in the form

\[ J = \int_0^T J(v) f \cdot p \cdot A_t \, dt \]  

\( J(v) \) – energetic wear rate at maximum friction temperature;  
\( f \) – friction coefficient;  
\( p \) – pressure in the contact zone;  
\( A_t \) – contact surface area.

Equation (3) indicates that the criterion for the restoration method is the constancy of the tribological characteristics of the contacting materials.

In the practice of repair production, a rational method is to grind the friction discs until signs of wear are removed. With this method of restoring friction discs, the requirements for identical wear resistance, taken into account by dependence (2), are preserved. As a result of using this restoration method, the technical properties of the disc materials are preserved, corresponding to the properties of new discs.

Restoring disks using the method of flat dimensional grinding makes it possible to ensure the required service life between repairs with disk wear less than 0.2 mm and the absence of other defects on the working surfaces. The friction discs were packaged in a package with a height of 32–35 mm.

Figure 5 shows comparative data on the magnitude of spatial deformation and the amount of wear of restored friction discs using the grinding method.

Fig. 5. Comparative test schedule for remanufactured friction discs.

The use of discs after grinding does not reduce the service life of the repaired clutches, which makes it possible to significantly increase the volume of the repair fund. During operation of the restored friction discs, an uneven distribution of wear was detected in the area of the support flange of the inner drum. The diagram of the map of the worn surface is explained by the lack of lubricant supply when feeding it into the package. In addition,
operational tests have shown that in order to eliminate spatial deformation of more than 0.25...0.3 mm, it is necessary to heat fix the restored disks.

4 Conclusion
As a result of the study, it was established as follows:
1. The experimental probability of failure of the gearbox of a mobile energy vehicle of the K-7 series is more than 0.55 of all units of the machine.
2. Failure of friction discs occurs due to changes in spatial geometry (experimental probability of failure - 0.76), wear (experimental probability of failure - 0.63), destruction (experimental probability of failure - 0.38) and welding (experimental probability of failure – 0.34)
3. Failure of a pack of friction discs is caused by heating of the discs above the temperature resistance of the materials, which leads to changes in their shape, spatial geometry and welding of the pack.
4. To ensure the required overhaul life, it is necessary to ensure the hardness of the drive disks is NV 357 - 375, the driven disks are 217 - 256 according to NV. When the friction hardness is reduced to HB 150–170, the wear rate increases by 28–50%
5. The use of restored friction discs ensures the service life of the repaired clutches at the level of new ones.

References
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