ИНФОРМАЦИЯ О ПУБЛИКАЦИИ

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ОСНОВНЫЕ НАПРАВЛЕНИЯ ПОВЫШЕНИЯ НАДЕЖНОСТИ ТРАНСМИССИЙ ТРАНСПОРТНОЙ ТЕХНИКИ

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КЛЮЧЕВЫЕ СЛОВА:

НАДЕЖНОСТЬ, ТРАНСМИССИЯ, КОЛЕБАТЕЛЬНЫЕ ПРОЦЕССЫ, ДЕМПФЕРЫ, ГАСИТЕЛИ, КОЛЕБАНИЯ, УПРУГИЕ ДИНАМИЧЕСКИЕ СВЯЗИ

АННОТАЦИЯ:

В данной работе приведены основные направления повышения надежности трансмиссий транспортной техники. Это снижение динамических нагрузок, уменьшение темпа изнашивания сопряженных поверхностей деталей и повышение износостойкости фрикционных элементов муфт сцепления и тормозов. В работе приводятся методы снижения уровня крутильных колебаний, одним из которых является установка в карданной передаче соединительной муфты с упругими динамическими связями. Предложена методика и приведены результаты расчета соединительной муфты с упругими динамическими связями. В процессе использования соединительной муфты с упругими динамическими связями максимальное значение центробежной силы будет при номинальных значениях крутящего момента двигателя. При увеличении крутящего момента центробежная сила уменьшается. В работе также проведен обзор демфирующих устройств и гасителей крутильных колебаний. Предложено конструктивное решение, комплексно решающее вопросы увеличения долговечности шестерен, подшипников качения, подшипников скольжения, повышения стабильности физико-химических свойств масла и увеличения срока их службы на основе принудительной системы смазки трансмиссии с фильтрацией и регулированием температуры масла...

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The main directions of increasing the reliability of transmissions of transport equipment

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Abstracts. In this work, the main directions of increasing the reliability of transmissions of transport equipment are given. These are: a decrease in dynamic loads, a decrease in the rate of wear of the mating surfaces of parts and an increase in the wear resistance of the friction elements of the clutches and brakes. The work presents methods for reducing the level of torsional vibrations, one of which is the installation of a coupling with elastic dynamic links in the cardan transmission. A technique is proposed and the results of calculating a coupling with elastic dynamic links are presented. In the process of using a coupling with elastic dynamic couplings, the maximum value of the centrifugal force will be at the nominal values of the motor torque. As the torque increases, the centrifugal force decreases. The work also provides a review of damping devices and torsional vibration dampers. A constructive solution is proposed that comprehensively decides the issues of increasing the durability of gears, rolling bearings, sliding bearings, increasing the stability of the physicochemical properties of the oil and increasing their service life on the basis of a forced lubrication system of the transmission with filtration and regulation of the oil temperature. The characteristics of friction materials used in units and mechanisms of transport equipment are considered. Recommendations for the choice of friction material are given. Practical implementation of the recommendations specified in the work will improve the reliability of transmissions of transport equipment.

Keywords: reliability, transmission, oscillatory processes, dampers, suppressors, oscillations, elastic dynamic links

1. Introduction

The efficient operation of transport equipment (cars, tractors, road-building machines, etc) largely depends on the reliability of their transmissions. The durability of the main transmission parts is determined by the loading mode and external operating conditions. Numerous studies have established the following directions for improving the reliability of transmissions of transport equipment [1-5]:

- reduction of dynamic loads due to the installation of damping devices and torsional vibration dampers;
- reducing the rate of wear of the mating surfaces of gears, rolling and plain bearings;
- increasing the wear resistance of the friction elements of the clutches and brakes.

The transmission of a transport vehicle is an oscillating system with discrete masses connected by shafts of different stiffness. During the operation of the machine, torsional vibrations are excited in the transmission, the sources of which are the harmonic components of the engine torque, oscillatory processes in the transmission and load impulses in unsteady modes and with a sharp change in the resistance to motion.

Sometimes the frequency of forced vibrations can approach one of the natural vibration frequencies of transmission parts, which leads to the appearance of a torsional vibration resonance, leading to a significant increase in stresses. Vibrations appear in the transmission, noise increases, and the durability of parts decreases. At the same time, cyclic loads can reach the design moment and even exceed them. The frequency of change of cyclic loads is 300 Hz and more [6].

It is possible to reduce the level of torsional vibrations by limiting the exciting action of individual sources of vibrations, choosing a rational constructive scheme of the power transmission, as well as influencing the frequency response of the transmission with special mechanisms: torsional vibration dampers installed in the driven clutch discs; damping devices built into the power train parts; installation of a cardan transmission with a coupling with elastic dynamic links (EDL).

Torsional vibration dampers installed in the clutch driven discs mainly reduce the torsional vibration generated by the harmonic components of the engine torque. The designs of torsional vibration dampers are diverse, but a characteristic feature of all is the presence of an elastic element that provides relative movement of the driving and driven parts, and a friction element that dissipates the energy of torsional vibrations due to friction forces. Depending on the elastic element, there are spring-friction dampers, dampers with hydraulic and rubber elements, and torsion-friction dampers. Spring-friction and torsion-friction dampers dissipate the energy of torsional vibrations due to dry friction between the friction elements. In absorbers with a hydraulic element, the energy of torsional vibrations is dissipated due to the frictional forces of the fluid when it flows through calibrated holes, and in absorbers with a rubber element - due to intramolecular friction of rubber [7-9].

The listed dampers are widely used in the global automotive industry. Studies have shown that they significantly reduce the amplitudes of torsional vibrations in resonant modes.

2. Dampers and torsional vibration dampers

In tractor construction, mainly spring-friction dampers of torsional vibrations are used, installed in the driven discs of the clutches. Studies [10, 11] have established that torsional vibration dampers on driven clutch discs are an effective means of reducing cyclic loads arising from uneven engine torque, which is ensured both by dissipation of vibration energy by the friction element of the damper and by displacement of resonant vibration zones beyond the operating range of the engine crankshaft speed. At the same time, such dampers do not provide a noticeable reduction in peak dynamic loads in the tractor transmission at unsteady modes. As a result, the installation of a torsional vibration damper significantly increased the durability of the splined connection of the coupling shaft and gear teeth of the gearbox.

Silicone dampers are an effective means of reducing torsional vibrations in internal combustion engines (Figure 1). This is a type of liquid damper, the working space of which is filled with polymethylsiloxane liquid. The main parameter that determines the operation of the damper is the damping coefficient, which is defined as the ratio of the frictional moment in the damper to the relative speed of movement of the driving and driven elements.

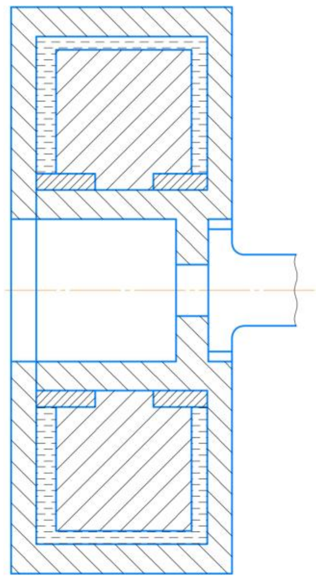

Figure 1. Silicone damper

The motion that occurs in a viscous fluid during vibrations of solid bodies immersed in it is of an oscillatory nature and, with distance from the solid body, the vibrations damp out.

Conducted theoretical studies [12] showed a nonlinear dependence of the damping coefficient on the gap between the flywheel and the damper housing, the dynamic viscosity of the fluid and the vibration frequency. A general formula for determining the damping coefficient of a liquid damper of any value installed on any engine is obtained.

In transmissions of tractors with a planetary swing mechanism, it is of practical interest to install an elastic element between the hub and the rim of the sun gear brake drum. The sun gear brake drum is acted upon by approximately one third of the torque transmitted through the planetary swing mechanism. This makes it possible, with relatively small dimensions of the damping mechanism, to provide a greater angle of relative rotation of the driving and driven links in comparison with the torsional vibration damper installed in the driven disc of the clutch.

A significantly greater effect of reducing cyclic loads can be obtained if a coupling with elastic dynamic links (EDL) is installed in the cardan transmission, the diagram of which is shown in Figure 2.

Two half-couplings are interconnected by an axis (point O) and pivotally by links a and b. They can rotate relative to each other at an angle, the value of which is determined constructively. During operation, the angle α changes under the action of centrifugal force. The maximum value of centrifugal force will be at the nominal values of the engine torque and the angular speed of the propeller shaft. With an increase in torque or a decrease in revolutions, the centrifugal force decreases, but the distance from the centrifugal force to the axis connecting the half-couplings increases. The amount of torque changes.

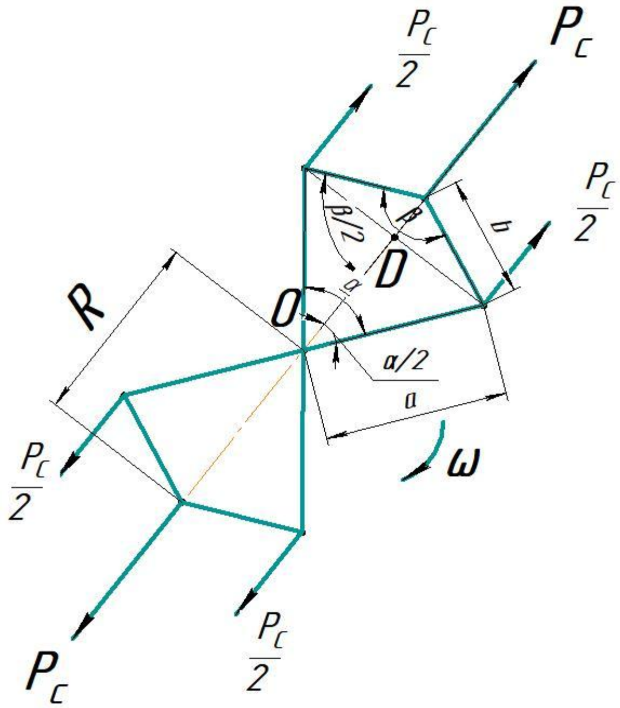

Figure 2. Driving cardan transmission with a coupling with elastic dynamic links (EDL)

We donate $AB = AC = b$ and $OB = OC = a$, then

$$M'_{kr} = \frac{P_c}{2} \times BD = \frac{P_c}{2} \times a \times sin\frac{\alpha}{2} \quad (1)$$

where P_c – centrifugal force, N; M'_{kr} – torque generated by the reduced mass of the joint A.
The total torque is

$$M_{kr} = 2 \times M'_{kr} = P_c \times a \times sin\frac{\alpha}{2} \quad (2)$$

$$P_c = m \times R \times \omega^2 \quad (3)$$

where m – mass equal to the sum of the masses of links a and b reduced to the joint A, and the mass of the joint A, kg, R – distance from the axis of the coupling to the joint A, м, ω – universal joint angular speed, s^{-1}.

$$R = OD + AD = a \times cos\frac{\alpha}{2} + b \times cos\frac{\beta}{2} \quad (4)$$

$$M_{kr} = m \times \omega^2 \times (a \times cos\frac{\alpha}{2} + b \times cos\frac{\beta}{2}) \quad (5)$$

The angle β is determined by the equation

$$sin\frac{\beta}{2} = \frac{BD}{b} = \frac{a \times sin\frac{\alpha}{2}}{b} \quad (6)$$

To determine the nature of the change in the torque that can be transmitted by the coupling with the UDS, a calculation was made for the mass kg. The graph of changes in centrifugal force and torque depending on the angle of rotation of the half-couplings is shown in Figure 3.

It follows from the graph that with increasing angle a, the centrifugal force decreases and the torque increases. The optimum range of variation of the angle a is 20° (from 35° to 55°). In this range, dynamic loads are partially damped due to friction in the joints of the coupling, and are partially filtered with relative rotation of the coupling halves in the specified range. It is possible to increase the efficiency of reducing dynamic loads due to the use of rubber elements in the hinge mechanism of the coupling with EDL [13, 14].

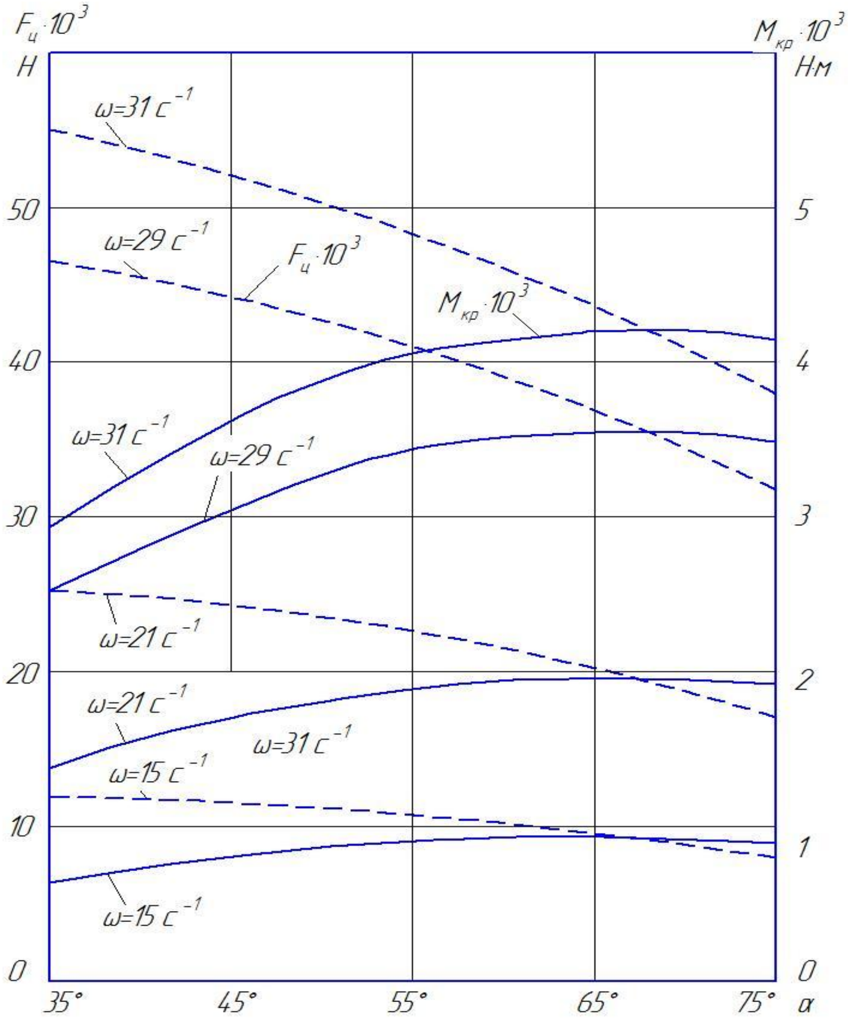

Figure 3. Graph of changes in centrifugal force and torque depending on the angle of rotation of the half-couplings

3. Lubricating efficiency of oil

The performance of gearbox parts of transport equipment, along with structural, technological and other factors, largely depends on the correct choice of the lubrication method.

The most common wear of heavily loaded gears is chipping of the tooth surfaces, which is dependent on the lubrication conditions. The degree of influence of the lubricant on the chipping of the surfaces of the teeth is determined by the viscosity and quality of the oil supplied to the rubbing surfaces.

Studies conducted by a number of scientists have established that with poor lubrication of gears by dipping, the limit of contact endurance of the surfaces of the teeth increases in comparison with abundant lubrication. For this reason, jet lubrication is recommended. At the same time, in high-speed gears, oil should be supplied to the zone where the teeth come out of engagement to prevent contact destruction of the material on the teeth of the gears. With jet lubrication, the efficiency of the gear transmission is higher than with dip lubrication, due to the reduction of power losses due to overshooting and oil splashing, which increase with a decrease in the operating temperature of the transmission.

The reliability and durability of gears operation also depends on the temperature of the working surfaces. There are known cases of failure of transmission gears due to thermal stress.

An increase in the temperature of the rubbing surfaces is associated with the appearance in the process of friction of the so-called "temperature" flashes, i.e. short-term and at the same time sufficiently high temperature jumps. The duration of temperature flashes is usually 0.001 s or less. Their value under friction reaches 500 °C.

Bearing performance also depends on bearing temperature. Heating the bearings above 120 ... 130 °C leads to a change in the geometric shape and dimensions of the parts, the interaction of the mating parts is disrupted due to changes in the fit interference and clearances in the bearing, and the lubrication conditions deteriorate.

The practice of machines, mechanisms and equipment with plain bearing shells made of various antifriction materials has shown that grease, which is closely related to the quality of the bearing material, is of decisive importance for their reliable operation and service life.

In plain bearings, the lubricant should reduce friction losses, reduce wear on the working surfaces and facilitate the removal of heat generated in the friction zone [15, 16]. The temperature of the sliding bearing sliding surfaces has a significant effect on their wear. Minimal wear occurs at the optimum temperature. When studying the wear of engine parts, it was found that when the temperature deviates from the optimal one, the wear of the plain bearings sharply increases.

The formation and retention of a layer of oil between the shaft journal and the bearing is possible when the internal pressure in this layer is sufficient to balance the external load.

The simplest and most economical way to create pressure in the lubricating layer is the hydrodynamic friction regime, for the implementation of which the following basic conditions are required:

- the presence of a gap between the shaft journal and the bearing surface;
- the presence of a lubricant of a certain viscosity;
- rotation at an angular velocity sufficient to create a bearing lubricant layer.

The most advanced type of lubrication is a pressure circulating lubrication system. However, if the bearing does not withstand too heavy loads, then there is no need for a pressure supply. In many cases, the oil is fed into the bearing by centrifugal force due to the movement of the parts. The grooves cut in the direction of this force allow the oil to be directed to the bearing feed hole. The oil consumption in this case depends on the magnitude of the centrifugal forces and the geometry of the inlet groove, as well as on the geometry of the bearing feed hole.

Transmission parts are more likely to fail due to abrasive wear. Abrasive wear of parts is caused by solid particles in soil dust. Metal particles - wear products insignificantly affect mechanical and fatigue spalling of gear teeth surfaces.

The presence of 0.25 % (by weight) of soil dust in the transmission oil leads to significant wear of the gear teeth and smallpox-like chipping of the working surfaces of the teeth. Abrasive wear reduces the durability of rolling bearings even more dramatically than of gears. The specified concentration of dust in the oil reduces the service life of rolling bearings by up to 10 times compared to the calculated one. Abrasive wear occurs in 62 % of ball bearings and 47 % of roller bearings.

In practice, bearing wear can be significantly reduced by keeping the lubricating oil as clean as possible. The abrasive content in the oil should not exceed 0.1 %. This can be achieved either by improving the operation of the seals, or by introducing forced oil cleaning in the transmission [17].

The most important causes of wear in plain bearings based on statistical studies are:

- contaminated grease – 42.98 %;
- assembly errors – 13,43 %;
- lack of lubrication – 12,66 %;
- overload – 9,47 %;
- corrosion – 6,33 %;
- unknown reasons – 5,03 %.

It follows from this that the main condition for the normal operation of sleeve bearings is the absence of abrasives in the lubricated oil, i.e. it is necessary to ensure continuous filtration of the oil.

Thus, the effect of oils on the durability and reliability of the operation of transmission parts of transport machines is also determined by the ability to protect rubbing surfaces from wear. The lubricating performance of an oil depends on a combination of numerous, closely intertwined factors. The main characteristic of transmission oil, which determines the friction behavior, is viscosity. In addition, a number of requirements are imposed on oils in relation to their performance properties: stability, corrosion resistance, mobility at low temperatures.

The oil ages during operation, i.e. its original properties change as a result of physical and chemical processes. During operation, the oil becomes clogged with products of oxidation, polymerization, condensation and decomposition of the oil itself, contaminated with wear products of lubricated surfaces and abrasives. The change in oil properties under operating conditions is primarily due to the oxidation reaction. Oil oxidation occurs as a result of contact with atmospheric oxygen, which leads to irreversible changes in its chemical composition, asphaltenes and coke are released from the oil. Oxidation is stimulated by the action of the metals in contact with the oil and progresses rapidly with increasing temperature. When the oil temperature rises by 10°C, the rate of chemical reactions increases by an average of 2...3 times.

The stability of the oil against aging also depends on the volatility of the light ends. As the temperature rises, the properties of the oil change. It has been established that oils can prevent scuffing of rubbing surfaces only up to a certain temperature for each oil, which is called the critical temperature. Upon reaching this temperature, disorientation of the surface layers of the lubricant occurs, caused by the desorption of previously adsorbed molecules.
To prevent scuffing at elevated temperatures and to reduce progressive wear, extreme pressure and antiwear additives are added to lubricating oils. At high friction temperatures, they react with metal surfaces and form compounds that prevent galling (sulfur, chlorine) and progressive wear (phosphorus). However, when overheating caused by the generation of heat in the rubbing joints, the additives are ineffective and seizure can occur. To prevent this from happening, it is necessary to maintain the oil temperature within certain limits.
Operation of the oil at low temperatures is accompanied by an increased tendency of the oil to emulsify with water, which leads to a decrease in the efficiency of transmissions due to an increase in losses due to oil stirring by rotating parts. The increased viscosity of the oil at low temperatures sharply deteriorates the lubrication of rubbing surfaces. To improve the performance of the transmission oil at low temperatures, it is necessary to accelerate its warming up.
The increase in the service life of the transmission oil is of great economic importance. However, the transition to long-term use of transmission oil is possible only with the introduction of design changes that make it possible to reduce the intensity of the increase in the concentration of pollution products and ensure a normal temperature regime.
Such a constructive solution, comprehensively deciding the issues of increasing the durability of gears, rolling bearings, sliding bearings, increasing the stability of the physicochemical properties of the oil and increasing their service life, is the forced lubrication system of the transmission with filtration and regulation of the oil temperature.
To determine the effectiveness of the forced lubrication system, bench and field tests of transmissions of caterpillar tractors with power from 66 to 110 kW were carried out.
The forced lubrication system with filtration and oil temperature control according to the results of operational tests provides a 1.87 times reduction in gear wear, 2...2.7 times of bearings, and allows to increase the oil service life by 2 times. A radiator in the lubrication system is necessary to ensure the normal temperature regime of the transmission oil at an ambient temperature below +10 °C.

4. Friction mechanisms of transport machines

Modern transport vehicles have clutches, brakes, slewing clutches, and others that work on the principle of using various friction materials. The performance and reliability of these units and mechanisms depends on the quality of the friction materials.
Most friction assemblies use dry friction. At the same time, constructions are used in which the rubbing surfaces work in an oil environment, for example, gearshift clutches in tractor gearboxes [18-20].
In connection with the growth of the energy saturation of transport vehicles, increased requirements are imposed on the friction materials of these units and mechanisms:
- high wear resistance;
- high coefficient of friction;
- high heat resistance;
- fast running-in with the surface of a metal disc, friction pairs and others.

Friction materials used in units and mechanisms of transport machines are divided into two groups:
- asbestos-friction materials;
- cermet materials.

The basis of asbestos-friction materials is asbestos, the fibers of which have good mechanical strength and high heat resistance.
According to the manufacturing method, asbestos-friction materials used on transport machines are divided into woven and molded.
Woven friction materials, which are multilayer fabrics woven from asbestos and cotton threads, into which brass wire is woven, are made of two types: elastic material and woven-bakelite material that does not have elasticity. Materials of the first type are mainly used for the manufacture of band brake linings with different diameters of friction surfaces. At the same time, elastic woven friction materials have significant disadvantages: an unstable coefficient of friction and a relatively low wear resistance when heated. Therefore, these materials are very sensitive to temperature changes [21].

Inelastic woven-bakelite friction material, in comparison with elastic materials, has a more stable coefficient of friction and is characterized by higher wear resistance at elevated temperatures. Used for the manufacture of friction linings for clutches and shoe brakes.

The performance of the clutch is highly dependent on the design of the driven disc and the material of the friction linings. For better adherence of the friction linings to the friction surfaces of the driving discs and to prevent warping of the steel base when heated, it is made with radial slots ending with a slightly larger diameter hole [6]. When manufacturing the base of the driven disk, it is recommended to use the metal-cutting tools described in [22-24].

Molded friction materials are made from different mixtures, which include: asbestos, friction fillers (red lead iron, zinc oxide, red lead, slaked lime and others) and binders (gasoline solution of SKB rubber, phenol-cresol-formaldehyde resin or mixtures thereof). Molded friction materials are classified into three groups:

- asbestos-rubber composition materials made on a rubber binder;
- materials of asbestos-resin composition (plastics) made on resin binder;
- materials on a combined binder.

Asbestos-rubber composition materials have low hardness, but have a relatively high coefficient of friction at temperatures up to 220...250 °C. Therefore, they are used for light working conditions.

The materials of the asbestos-resin composition (plastics) are characterized by higher wear resistance and stability of the coefficient of friction at elevated temperatures. For example, it is advisable to use the ‘Retinax’ material at specific pressures up to 6 MPa, sliding speeds up to 100 m/s and a bulk temperature of the order of 450...500 °C. In this case, the surface temperature should not exceed 1200 °C.

Combined binders are mixtures of different types of rubbers and resins. By changing the ratio of rubbers to resins, the properties of the friction materials can be changed. An increase in the amount of resin in the combined binder increases the hardness, thermal and wear resistance of the friction material, and an increase in the amount of rubber decreases the hardness and increases the coefficient of friction and its stability.

Molded materials of various configurations are used in clutches, various types of brakes and other friction units.

Sintered friction materials are made from finely dispersed powders of pure metals with the addition of inorganic fillers and friction modifiers. According to the main component, they are divided into two types:

- copper-based materials;
- iron-based materials.

The main advantages of cermet friction materials over asbestos-friction materials are: high thermal conductivity and wear resistance, stable frictional properties at elevated temperatures, insensitivity to moisture and oil.

Ceramic-metal materials on a copper basis are used in friction units with an operating temperature of up to 500 °C. The most widespread use of these friction materials is found in friction units operating in oil.

For friction units operating in especially severe conditions, more promising materials are metal-ceramic materials on an iron basis, which can operate at temperatures up to 1000 °C.

The above recommendations allow you to choose a friction material designed to work in conditions similar to the operating conditions of the developed and modernized units and mechanisms of transport machines. But in order for the design of friction units using the selected friction materials to be optimal for their modes of operation, a large volume of bench and operating materials is required..

5. Conclusions

The reliability of the transmissions of transport equipment depends on the design parameters, modes and operating conditions of the machine, on the organization and implementation of preventive work and the methods and means used in this case.

The main directions for improving the design of individual units and transmission mechanisms are given in this work. The practical implementation of these design solutions can significantly increase the resource and reliability of the transport equipment and reduce the operating costs of maintaining its operability.

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