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Reduction of Torsional Vibrations in the Transmission of Transport Vehicles

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Abstract. This article discusses the influence of transmission reliability on the efficiency of transport vehicles. The durability of the main transmission parts is determined by the loading mode and external operating conditions. This work presents methods for reduction of the level of torsional vibrations, one of which is the installation of a coupling with elastic dynamic links in the Cardan drive. The proposed technique is elaborated and the results of calculating a coupler with elastic dynamic links are presented. In the process of using a coupler 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 practical implementation of this design solution will improve the reliability of transport vehicles transmissions. The article also reviews damping devices and torsional vibrations absorbers as well as the key properties of materials used for parts and mechanisms of vehicles. Recommendations for choosing proper materials are also given.

Keywords: Reliability · Transmission · Oscillatory processes · Dampers · Suppressors · Oscillations

1 Introduction

The efficient operation of transport equipment 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 [1, 2].

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 [3].

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2 Ways to Reduce Torsional Vibrations

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 [4–6].

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.

In tractor construction, mainly spring-friction dampers of torsional vibrations are used, installed in the driven discs of the clutches (Fig. 1).

On the slave disk there are friction pads on both sides, thanks to which, due to the friction force, the slave disk takes over the rotation from the drive disk. There are also special cuts on the slave disk to avoid warping the disk in case of strong heating, and there is also a device called a torsional vibration damper. The driven clutch disc is a composite part. It has its own hub, which does not have a rigid connection with the disk. The hub has internal slots for connection to the slots of the drive shaft of the gearbox, and it is installed inside the driven disc itself. A torsional vibration damper is installed on one side of the driven disk. Friction plates are fixed with rivets on the damper and on the driven disk itself. Damper discs and oil reflectors are installed on both sides of the hub flange and the driven disc. Oil reflectors, damper discs and hub flange are connected to each other by rivets.

Thus, the driven disk turns out to be free and can rotate at a certain angle relative to the hub. In the damper discs, the damper ring and the driven disk, windows are arranged into which springs with support plates are inserted. The springs are in a pre-compressed, but not completely, state. The rotation of the flywheel is transmitted to the clutch housing, and from it to the pressure plate. From the pressure disc, rotation due to friction is transmitted to the friction pads and to the steel disc of the driven disc, then through the springs of the torsional vibration damper to the damper discs, then to the hub flange, to the hub and through the slots to the drive shaft of the gearbox. With a sharp change in the speed of rotation, the damper springs are compressed and, due to this, torsional vibrations are somewhat reduced, which helps to avoid damage to gearbox parts.

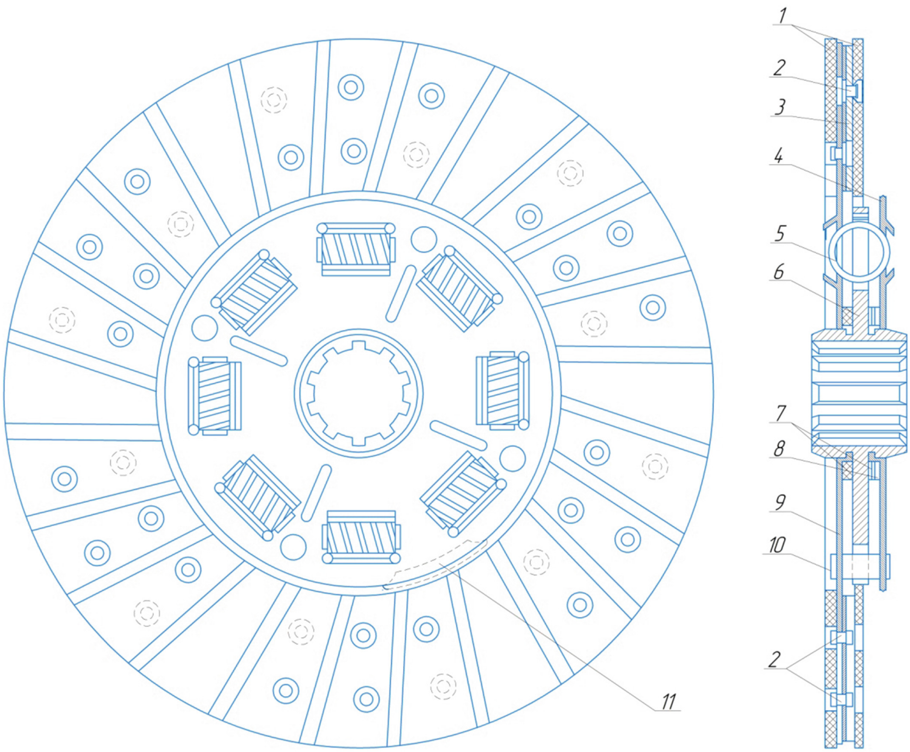

Fig. 1. Driven clutch disc: 1-friction pads, 2-rivets, 3-spring of the driven disc, 4-damper plate, 5-damper spring, 6-hub, 7-friction rings, 8-adjusting rings, 9-driven disc, 10-thrust pin, 11-balancing weight.

The positive quality of such driven discs is their constructive simplicity and low cost, and the main disadvantage is that they do not provide smooth clutch activation. Driven disks with axial and tangential compliance are more promising.

The use of driven discs with axial malleability ensures smooth engagement of the clutch, which simplifies the process of controlling the machine when starting off and increases the durability of the friction linings by ensuring a more stable contact of the lining with the friction surface of the drive disc when it warps.

The axial malleability of the driven disk is ensured by the use of shaped slots of its base, followed by the execution of petals in the form of plate springs. The petals are alternately bent in different directions and friction pads are glued to them. As a result, a gap of 1…1.5 mm is formed in the free state between the pads. When the clutch is turned on, the driven disk is compressed due to the pliability of the petals, the rubbing surfaces smoothly touch and the friction force between them increases gradually. The disadvantage of this design is that it is almost impossible to obtain the same stiffness of all the petals of the base.

A more promising and devoid of this drawback is a driven disk, the axial malleability of which is ensured by the use of separate plate springs installed between the friction pads and fixed to a small radius of the steel base. The plate springs of such a disk are made of sheet steel of a smaller thickness than its base, and have increased malleability.

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 [3]. When manufacturing the base of the driven disk, it is recommended to use the metal-cutting tools described in [7–9].

Processing methods and metal-cutting tools [7–9] obtain a qualitatively new state of the surface layer of the part, reducing their wear with an increase in resource and thereby reducing the cost of manufacturing the product.

Studies [10–12] 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 (Fig. 2). 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.

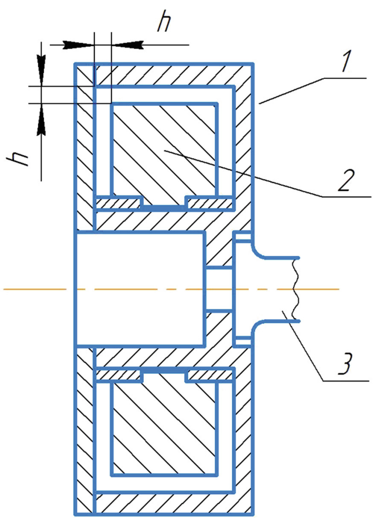

Fig. 2. Silicone damper: 1-housing, 2-flywheel, 3-crankshaft

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 [13] 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 main purpose of elastic couplings is reliable torque transmission, compensation of shaft axis displacements (axial, radial and angular), reduction of stresses caused by torsional fluctuations and temperature deformations. An image of the displacement of the axis shafts is shown in Fig. 3.

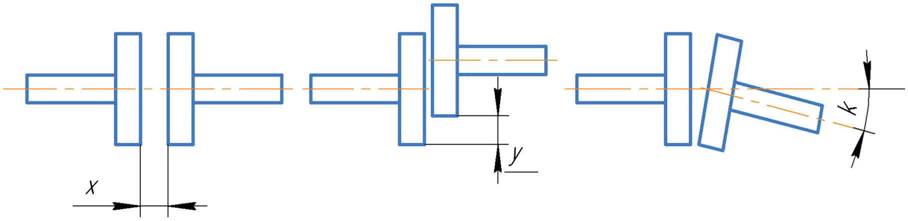

Fig. 3. Displacement of shaft axes.

In the case of diesel engines, the installation of an elastic coupling along with dampers is a necessity designed to reduce the torsional vibrations that occur and prevent the fatigue destruction of individual elements of the cardan transmission caused by them. Elastic couplings can carry a safety function, collapsing during overload, preserving the integrity of the shaft axes, which allows, after replacing the coupling, to continue operating the machine or mechanism.

Figure 4 shows a coupling with elastic dynamic connections. 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.

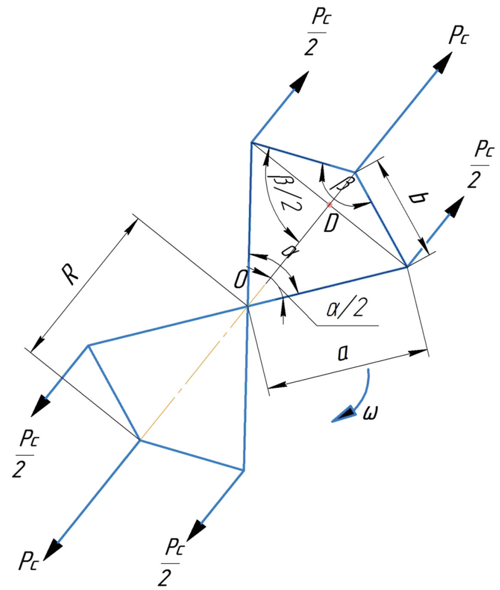

Fig. 4. Driving cardan transmission with a coupling with elastic dynamic links (EDL).

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

$$M_{t'} = \frac{P_c}{2} \times BD = \frac{P_c}{2} \times a \times \sin\frac{\alpha}{2} \tag{1}$$

where P_c– centrifugal force, N; $M_{t'}$ – torque generated by the reduced mass of the joint A.

The total torque is

$$M_t = 2 \times M_{t'} = P_c \times a \times \sin\frac{\alpha}{2} \tag{2}$$

$$P_c = m \times R \times \omega^2 \tag{3}$$

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}.

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

$$M_t = m \times \omega^2 \times \left(a \times \cos\frac{\alpha}{2} + b \times \cos\frac{\beta}{2}\right) \tag{5}$$

The angle β is determined by the equation

$$\sin\frac{\beta}{2} = \frac{BD}{b} = \frac{a \times \sin\frac{\alpha}{2}}{b} \tag{6}$$

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 Fig. 5.

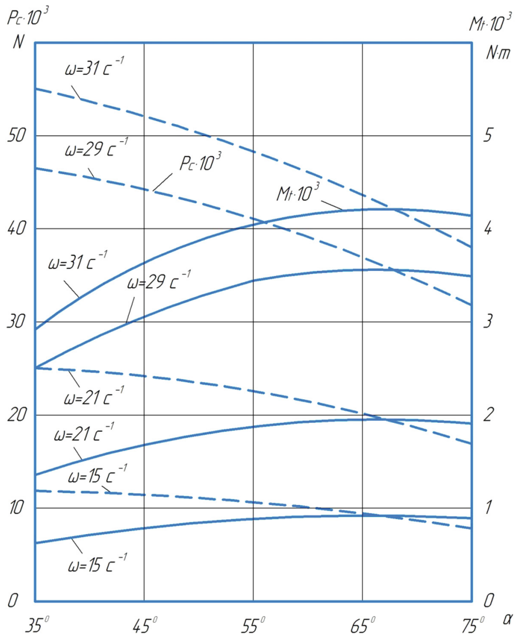

Fig. 5. Graph of changes in centrifugal force and torque depending on the angle of rotation of the half-couplings.

It follows from the graph that with increasing angle α, 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 [12–14].

Another direction of increasing the reliability of transmissions of transport equipment is to increase the wear resistance of the friction elements of clutch clutches and brakes.

In most friction units, dry surface friction is used. At the same time, designs are used in which the rubbing surfaces work in an oily environment.

Due to the growing energy saturation of transport vehicles and the development of electric vehicles [15, 16], increased requirements are imposed on the friction materials of these assemblies and mechanisms:

- high wear resistance;
- high value of the coefficient of friction;
- high heat resistance;

- fast workability with the surface of the metal disk friction pairs and others.

Friction materials used in assemblies and mechanisms of transport vehicles are divided into asbestos-friction and metal-ceramic 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, the asbestos-friction materials used on transport vehicles are divided into woven and molded. Woven friction materials, representing a multilayer fabric 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. The materials of the first type are mainly used for the manufacture of belt brake linings with different diameters of friction surfaces. At the same time, elastic woven-bakelite friction materials have significant disadvantages: unstable coefficient of friction and relatively low wear resistance when heated. Therefore, these materials are very sensitive to temperature changes [2, 3].

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 heats. It is used for the manufacture of friction linings of clutch couplings and pad brakes.

Molded friction materials are made from different mixtures, which include: asbestos, friction fillers and binders. Molded friction materials are divided into three groups:

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

The materials of the asbestos rubber composition have a 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.

For materials of an asbestos-resin composition (plastics) characterized by higher wear resistance and stability of the coefficient of friction at elevated temperatures.

Combined binders are mixtures of various types of rubbers and resins. By changing the ratio of rubbers and resins, the properties of 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 reduces 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. Metal-ceramic friction materials are made of fine powders of pure metals with the addition of inorganic fillers and friction modifiers.

The main advantages of metal-ceramic friction materials in comparison with asbestos-friction materials are: high thermal conductivity and wear resistance, stable friction properties at elevated temperatures, insensitivity to moisture and oil.

For friction units operating in particularly harsh conditions, more promising materials are metal-ceramic materials based on iron, which can operate at temperatures up to 1000 °C.

These recommendations allow you to choose a friction material designed to work in conditions similar to those of the units and mechanisms of transport vehicles being developed and upgraded. But in order for the design of friction units using selected friction materials to be optimal for their operating modes, a large volume of bench and operational materials is required.

3 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 practical implementation of the specified design solution, given in this paper, can significantly increase the resource and reliability of transport equipment and reduce operating costs for maintaining its operability.

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