Electromechanical transmission of an all-wheel drive vehicle with a central traction electric motor

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Abstract. Modern approaches to the construction of a kinematic scheme of an electromechanical transmission are considered. It is shown that for all-wheel drive transport and transport-technological mobile platforms, it is advisable to use a central traction electric motor operating with a two-mode reduction gear connected in series and a transmission based on controlled inter-axle and inter-wheel power distribution mechanisms. It is shown that such a scheme makes it possible to improve the operating conditions of the traction motor, reduce its installed power, dimensions and weight. At the same time, it remains possible to fully control the traction force on the drive wheels, use power recovery, and work in the mode of dynamic stabilization of the motion trajectory. The structure of the electromechanical transmission based on the described principles is proposed. The principles of operation of controlled interaxle and interwheel power distribution mechanisms based on gear differentials are considered. Examples of simplified kinematic schemes of promising mechanisms are given and principles of their control are proposed. The principles of determination of external parameters and synthesis of kinematic schemes of interaxle and interwheel differentials with friction control are considered.

1 Introduction

Despite the high technical characteristics of traction electric motors achieved at the present stage, the direct (gearless) drive of the drive wheel from the traction electric motor (TEM) has positively proven itself mainly in individual electric vehicles. Often, in the design of such vehicles there is a single-stage (reducing) gearbox. An increase in the mass of the vehicle requires the use of at least a two-stage gearbox operating with a TEM. This allows you to significantly reduce the dimensions and weight of the TEM.

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The individual drive of the driving wheels according to the “motor-wheel” scheme, due to the significant unsprung masses, becomes unacceptable for a machine developing sufficiently high speeds, and is replaced by the “motor-axle axle” scheme.

The “motor-half-axle” scheme turns out to be less effective compared to the central TEM, which is paired with an inter-axle controlled power distribution mechanism (PDM), if the vehicle uses a dynamic stabilization system or the onboard steering principle is applied. The central TEM is more compact and lighter than two “onboard” ones, it works in more favorable conditions, in particular, because the PDM can allow power recovery in a turn and thereby reduce the load on the TEM.

For an all-wheel drive vehicle, a similar choice can be justified in favor of an electromechanical transmission with a central TEM and controlled inter-axle and inter-wheel PDMs.

In recent decades, in the literature on the stability and controllability of vehicles, much attention has been paid to the issue of correcting the trajectory of the car by creating a turning moment acting in the plane of movement of the car. Examples of such literary sources are works [1-8]. The turning moment is most simply created by redistributing the traction force between the drive wheels of the axle. This principle is implemented, for example, with the help of controlled cross-axle differentials (see works [9-10]). Such devices are often referred to as controlled power distribution mechanisms (PDMs). Abroad, controlled cross-wheel PDMs are mass-produced (PDMs are known ZF Vector Drive, AYC, etc., see reference literature [11]). In the Russian Federation, a number of technical solutions have been proposed to create alternative kinematic schemes and ensure the control of such PDMs, and approaches to the design and production of such mechanisms have been described (works [12-14]).

Cross-axle PDM is usually a planetary gearbox having two degrees of freedom in rectilinear motion. This allows you to maintain a differential connection between the wheels of the axle. In most cases, the PDM is based on a conical or cylindrical simple differential, or on a planetary gear set with kinematic parameter k_0 = (+2). Additional planetary gears, controlled by friction controls (PMT - brakes or locking clutches), provide power redistribution between the drive wheels. PMTs can have an electrohydraulic [15,16] or electromechanical drive, which in turn is controlled by a closed digital electronic control system. PDM is part of the vehicle's dynamic stabilization system.

Cross-wheel PDMs are used mainly in transmissions of passenger cars, not necessarily all-wheel drive. There are works in which it is proposed to adapt the PDM to work as part of the transmission of a tractor and other transport and traction machines, including skidders and forwarders, typical for the timber industry (see [12-14]).

In the domestic literature, despite the fundamental theoretical work in the field of the theory and design of differentials (see, for example, work [17]), the topic of controlled interwheel PDMs is represented by a few publications [12–14]. It is reasonable to agree with the main conclusions of the authors and the technical proposals formulated in these publications, although the controlled cross-wheel PDM of domestic design, apparently, was never manufactured and tested.

A controlled cross-axle PDM can be useful in a tractor transmission, but trucks, forestry and mining machines have a need to redistribute power between the drive axles: when driving without a load, it is more profitable to use a symmetrical distribution, and when the machine is fully loaded, it is advisable to apply 2/3 of the power to the rear bridge (rear axles). The controlled inter-axle PDM will be related to the inter-wheel one.

2 Results and Discussion

On Figure 1 shows a simplified structure of the transmission of a two-axle vehicle, containing controlled interwheel and interaxle PDM.

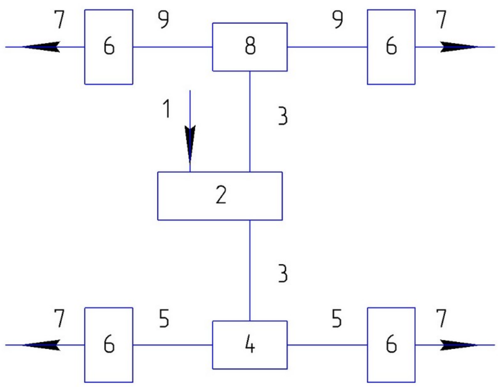

Fig. 1. The structure of the distributing part of the transmission of an all-wheel drive two-axle machine: 1 – power supply; 2 – interaxial MRM; 3 – cardan gears; 4 – main gear and MRM of the rear axle; 5 – axle shafts; 6 – onboard or wheel gear; 7 – power outlet to the drive wheels; 8 – main gear and MRM of the front axle; 9 – half shafts with CV joints.

Shown in Figure 1 scheme allows you to provide full control over the distribution of power on the driving wheels of the mobile platform. The scheme can be implemented using an internal combustion engine, a hybrid power plant or an electromechanical drive as an energy source.

Due to the specifics described above, a controlled interaxle PDM must combine the capabilities of symmetrical and asymmetric differentials typical for transport engineering. It is also desirable to provide for the possibility of disabling one of the drive axles.

On Fig. 2 shows an example of a kinematic scheme of a controlled interaxle PDM built according to these principles.

Shown in Fig. 2 scheme is based on a traditional asymmetric differential, providing the issuance of 1/3 of the torque to the front axle and 2/3 of the torque to the rear axle. The inclusion of the blocking clutch C_2 will allow you to use this mode of operation.

However, when the brake T_1 is turned on, a mechanism built on the scheme of a symmetrical cylindrical differential additionally operates in the kinematic chain of the rear axle drive. The kinematic and force analysis of the operation of the mechanism, performed according to traditional methods [18-20], will show that the distribution of angular velocities and torques between the driving axles in this case will be symmetrical.

Turning on the T_A brake will transfer all the power to the front drive axle.

Thus, the PDM of such a family, with the controls disabled, has three degrees of freedom, and when the vehicle is moving, it has two.

The question of the expediency of controlling the distribution of power between axles (the implementation of controlled slipping in such a PDM) requires additional research.

Obviously, in order to simplify the design of the PDM, it is possible to replace the disc brakes and the clutch with gear clutches, which will be controlled while the vehicle is stopped, and the drive can be made completely mechanical.

Efficient operation of the cross-wheel PDM requires the use of a closed-loop digital feedback control system, for example, in terms of the angular speed of the machine's turn. When the PMT is off, the cross-wheel PDM must maintain a differential connection between the wheels of the axle, and when the PMT is fully turned on, it must match the kinematic (minimum specified for the steered wheels by the steering gear) and the calculated (fixed) power (obtained due to the difference in traction forces on the sides in the absence of slipping in PMT PDM) turning radii.

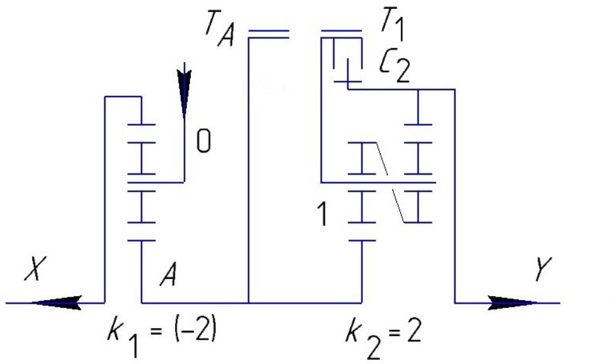

Fig. 2. Simplified kinematic diagram of an interaxle PDM with friction control: 0, X and Y – driving and driven links; A and 1 – connecting and brake links; $T_{1, A}$ and C_2 – controls; $k_{1,2}$ – kinematic parameters of planetary mechanisms.

This principle is true for both a monohull car and a road train. On Figure 3, a design scheme for turning a road train with an active trailer-dissolution is proposed.

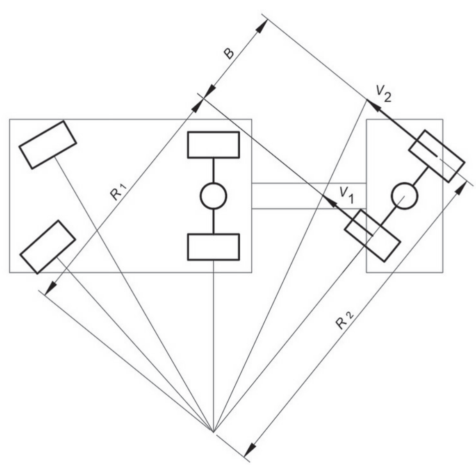

Fig. 3. Calculation scheme for determining the external parameters of an interwheel PDM with friction control (the case of an active trailer-dissolution) of a road train with a single-axle active trailer-dissolution: B – trailer track width; $R_{1,2}$ and $V_{1,2}$ – turning radii and linear speeds of the inner and outer sides.

The external parameters that characterize the PDM, regardless of its kinematic scheme, are a set of gear ratios for typical operating modes.

With rectilinear motion $u_0 = 1$ (as a result, the kinematic scheme of such an PDM is often based on a simple differential or a series that functionally replaces it with a kinematic parameter equal to (+2)).

It is possible to connect the inter-board gear ratio with the relative radius of the power turn using the dependencies obtained in [21]:

$$u = (\rho + 0,5)/(\rho - 0,5) \text{ and } \rho = 0,5(u+1)/(u-1). \qquad (1)$$

Using fig. 3, you can see:

$$\rho = R/B \text{ and } R = (R_2 + R_1)/2 \quad (2)$$

Where B the track width in is this case of the active trailer.

Intermediate stable turning radii can be obtained using the principle of slip control in a PMT disk package [15-16].

For most transport and technological machines, the value $\rho \in [3,4]$ is in demand.

On Figure 4 shows an example of a simplified kinematic diagram of an inter-wheel PDM, which makes it possible to obtain the value of the minimum relative turning radius ρ = 2.78, which will correspond to the inter-board gear ratio u(ρ) = 1.44.

Planetary gears with an internal gear ratio of k_3 = 2.05 and k_4 = 2.37 are used to control the power distribution between the wheels of the drive axle [22].

As a PMT, it is supposed to use disc brakes and a hydromechanical or electromechanical drive. Service brakes and wheel reduction gears in Figure 4 are conventionally not shown.

The synthesis of the kinematic scheme of the planetary PDM with two degrees of freedom was carried out on the basis of recommendations from the sources [18-20].

Since the interaxle and interwheel PDMs are based on a gear part based on planetary mechanisms, it is advisable to use the experience gained in the domestic tank building and automotive industry in their design, manufacture and operation [15, 18-19].

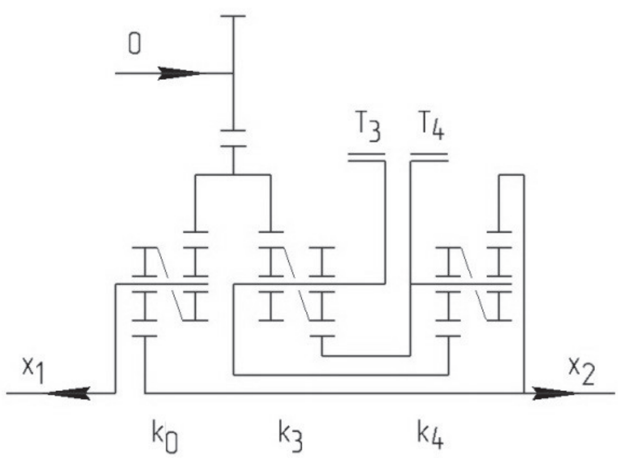

Fig. 4. Simplified kinematic diagram of an interaxle PDM with friction control: 0, x_1 and x_2 – driving and driven links; $T_{3,4}$ – brakes; $k_{0,3,4}$ – kinematic parameters of planetary mechanisms [5].

3 Conclusion

In conclusion, the following main conclusions can be drawn.

- The joint use of controlled inter-wheel and inter-axle PDM will improve the performance of wheeled and tracked vehicles and multi-link machines based on them.
- The most compact and energy efficient are currently PDMs based on gear planetary gears using electronic-hydraulic or electromechanical control; control system - closed, digital.

- When designing, manufacturing, and operating controlled PDMs, it is advisable to use experience in the manufacture and use of planetary gearboxes for military tracked vehicles.

Acknowledgments

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