Circulating power in transmissions of transport and technological machines for agricultural purposes

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Abstract. The article discusses the process of the occurrence of energy circulation arising in planetary gearboxes of wheeled and tracked transport vehicles for agricultural purposes. The high efficiency of the planetary gear in the absence of circulating energy in it is predetermined by the correct choice of its kinematic scheme and the use of friction elements for gear shifting, which will allow changing gears while the machine is moving without interrupting the power flow supplied to the driving wheels. The analysis of the work carried out in the study of transmissions of modern transport wheeled and tracked vehicles shows that in the absolute majority of them the already mentioned circulating energy arises during operation. This indicates the importance of the problem and the need, firstly, to analyse it, and secondly, to identify ways to improve and find optimal technical solutions in the field of planetary gearboxes, which will improve the technical and economic performance of the transmission and the machine as a whole. Therefore, at present, the question of the advisability of a more thorough study of the study of such programs has become very relevant.

1 Introduction

At the present stage of development of the industry, innovative technologies are important, using new technical solutions corresponding to the XXI century. At the same time, a special place is occupied by machinery and technologies of the agro-industrial complex (AIC), since this is the basis of the state's food security.

If we focus on the analysis of the current level of development of the agro-industrial complex, then we can state a clear tendency towards a systematic approach to the development of technologies and the solution of the following systemic problems:
- rational organization of technological processes;
- development and implementation of accurate and adaptive agricultural methods;
- development of innovative highly efficient circuit, technical and design solutions for agricultural machinery

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An important place in the fulfillment of these tasks is occupied by the improvement of transport and technological machines for agricultural purposes.

Transmissions of wheeled and tracked agricultural transport vehicles are designed to transfer power from the engine to the driving wheels and stars. The engines of transport vehicles in most cases are internal combustion engines (ICEs), which, as a rule, have insufficiently wide ranges of the required rotational speed and torque values to obtain the required traction and speed qualities of the machine. In addition, ICEs have very limited self-regulation properties - automatic changes in torque and speed depending on external resistances.

Therefore, transmissions must be equipped with a practically obligatory device - a gearbox (gearbox), which brings the existing engine operating parameters into line with the required ones. Currently, there are many types and different schemes of gearboxes of transport vehicles, each of which has its own advantages and disadvantages. Actually, it is by the type of gearbox that the functionality of the transmission, its advantages and disadvantages, differ.

The most promising mechanical gearboxes are planetary gearboxes (SCP). They have smaller dimensions and weight, while significantly increasing the range of gear ratios, they have a high transmission efficiency, but this will be true in the absence of the so-called "circulating power" in the control panel. The service life and quiet operation of the planetary gear under the same conditions is higher than that of a gearbox with fixed shafts, due to the less strenuous operation of the gear wheels. Studies show that the transition from conventional gears to planetary gears, under equal conditions, leads to a weight loss of 1.5 to 5 times. The disadvantages of planetary gears include the complexity of their manufacture and assembly, as well as friction losses in the switched off clutches and brakes, which significantly reduce the transmission efficiency [1].

If we take into consideration hydromechanical gearboxes, then their advantages over conventional and planetary gearboxes are a stepless change in the gear ratio without interrupting the power flow, a sufficiently high energy consumption, simplicity of the mechanical part of the structure, and reliability in operation. The durability of the engine and power train is therefore significantly increased. Management is greatly simplified and facilitated. In hydromechanical transmission, the possibility of spontaneous engine shutdown is excluded. Due to the smooth acceleration without rupture in traction and the damping effect of the main element of the unit - the torque converter - the comfort of the machine increases. Their main disadvantage is low efficiency. To some extent, this drawback is corrected by the possibility of operating the engine in economical modes. But such disadvantages as large dimensions, weight and cost, calculated to transmit the full power of the engine, remain incorrigible [2].

Electromechanical transmissions are also used in transmissions of transport vehicles. Electromechanical gearboxes have the following advantages: high adaptability; by simple means, soft start, reversal, use of the electric motor as a brake (in generator mode) is carried out. Along with these positive features, electromechanical transmissions have significant disadvantages: large dimensions and weight, the need for the manufacture of expensive non-ferrous metals (copper), low efficiency, which even at optimal modes does not exceed 75%. The field of application of electromechanical transmissions is transport vehicles with four-wheel drive and multi-link road trains with active trailers. In these cases, power transmissions are comparable to hydrodynamic and volumetric hydraulic transmissions [3].

It should also be noted that the high efficiency of the planetary gear, in the absence of circulating power in it, will be predetermined by the correct choice of its kinematic scheme and the use of friction elements for gear shifting, which makes it possible to change gears while the machine is moving without interrupting the power flow supplied to the drive wheels.

The analysis of transmissions of modern transport wheeled and tracked vehicles shows that in the absolute majority of them, the already mentioned circulating power arises during operation. This indicates the importance of the problem and the need, firstly, to analyze it, and secondly, to identify ways to improve and find optimal technical solutions in the field of control panels, which will improve the technical and economic performance of the transmission and the machine as a whole. Therefore, at present, the question of the advisability of a more thorough study of the study of such programs has become very relevant.

2 Materials and methods

Power circulation is a phenomenon that can occur in the presence of a closed power loop in any transmissions, and is characterized by the fact that in one parallel branch from the leading link to the slave, not only the transmitted, but also additional (circulating) power is transmitted. The circulating power is not useful, it additionally loads the transmission and creates additional mechanical losses in it.

The priority in the study of circulating power, in explaining its appearance, in a detailed identification of the conditions under which it arises, belongs to Academician E.A. Chudakov. The academician with his students and followers created the school of the theory of the automobile, laid the foundations of the theory of cross-country ability, and allowed to solve a number of practical issues of creating wheeled vehicles of high cross-country ability with all-wheel drive [4 - 7].

In addition to transport scientists, a great contribution to the study of the regularities of the circulating power was made by D.P. Volkov, A.F. Krainev, V.N. Kudryavtsev, K.D. Shabanov, P.N. Ivanchenko, Yu.A. Sushkov, A.D. Vashets [8 - 14].

When two main links are connected by a closing mechanism with a variable gear ratio, a closed differential gear is formed with a wide range of stepless control of transmitted speeds and torques, which ensures the coordinated operation of the mechanisms while maintaining small weight and dimensions. At the same time, a decrease in the power flow transmitted through the weakest infinitely variable link leads to a decrease in the overall control range of a closed multi-stream transmission, and an increase in the control range is possible only when the power flow is circulating, i.e. when the transmission is overloaded [7, 11].

As you know, practically in all branches of mechanical engineering there is a general tendency - automation of control processes of machines, units and their individual elements. An effective solution in this area is the use of various types of differential mechanisms. In this regard, it should be noted a new approach to solving this problem, which appeared on the scene in the 60s of the last century. This approach expands the scope of application of gear, electromechanical, hydromechanical and hydrostatic transmissions, which makes it possible to create new types of adaptive drives [15, 16].

Let us consider the phenomenon of the occurrence of circulating power in more detail. To begin with, we should discuss the terminology used by various authors.

Most authors have called the power created by additional internal forces in the transmissions of wheeled and tracked vehicles "circulating power" [9, 10]. However, in [8, 9] A.F. Krainev indicated and reasonably suggested his own term, namely, "circulating energy." The same A.F. Krainev in works [11, 12] arguably proved the inadmissibility of using the term "circulating power", replacing it with the term "circulating energy". Unfortunately, few of the subsequent authors supported A.F. Kraineva. The majority still continued to use the term "circulating power" [11].

In addition, some authors used not quite ordinary and, frankly, exotic terms: “parasitic power” [12], “return power” [13], “closed power” [14], and even “wandering power” [15] ...

In most cases, however, the authors dispensed with any name when explaining the principle of operation of the corresponding equipment [13-14].

How does the circulating energy really manifest itself in wheeled and tracked vehicles?

A distinctive feature of the operating conditions of the transmissions of trucks with all-wheel drive is that the number of possible combinations of operating modes of the driving wheels at any given time is significantly greater compared to rear-wheel drive vehicles and passenger cars with all-wheel drive. This is especially noticeable with an increase in the number of bridges (axles) and with curvilinear movement, movement on deformable soils and on uneven supporting surfaces. Moreover, the likelihood of power and speed asymmetry between individual bridges (axles) and the wheels of the propeller increases not only with an increase in the number of wheels, but also with an increase in the mass-dimensional parameters of the vehicle. Therefore, the most important factor when choosing power distribution schemes and type of transmission, especially for multi-axle machines.

The theoretical studies carried out in recent years and the results of experimental work confirm the prospects for further studies of the possibility of increasing traction, fuel efficiency and cross-country ability of vehicles with four-wheel drive by improving their designs. At present, there is no doubt that a significant decrease in the rolling resistance of a car when driving on a hard surface and ground (in particular, a decrease in the depth of the track) can be achieved if the adopted design solutions will provide the necessary (optimal) combination of torque applied to the wheels. moments with the values of vertical reactions to them. This issue is related to the layout of the car, the choice of the transmission concept and the characteristics of its units that distribute the engine torque to the drive wheels, as well as the characteristics of the propulsion unit and its elements [14].

The closed circuits in which the power circulates are not only the combination of the front and rear drive axles. Figure 1 shows the schemes of local energy circulation in individual nodes of the transmission and chassis due to the fact that under the wheels there is different relief (Figure 1, a), $\boldsymbol{r'_d} \neq \boldsymbol{r''_d}$ (Figure 1, b), $\boldsymbol{G'_H} \neq \boldsymbol{G''_H}$ (Figure 1, c).

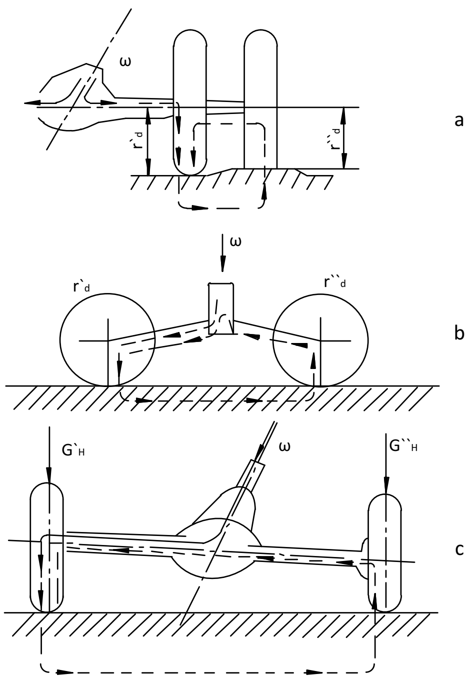

Fig. 1. Schemes of local energy circulation in individual nodes of the transmission and the chassis of vehicles

Energy circulation is a process that occurs when the kinematic correspondence in the rigid drive of the driving wheels is violated. When the lagging wheels begin to move with sliding (skidding), in the spot of their contact with the road, a reaction Rn occurs (Figure 2), directed in the opposite direction compared to the Xn reaction.

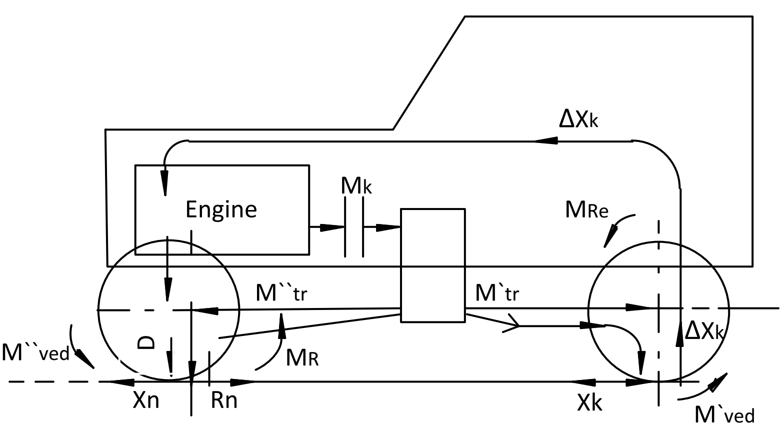

Fig. 2. Diagram of forces and moments causing energy circulation

As a result of this, the driving moment M''_{ved} on the lagging wheels supplied from the engine through the transmission begins to perform the function of a brake in relation to the moment created by the reaction of the soil:

$$M_R = R_n \cdot r_d, \quad (1)$$

which tends to rotate the lagging wheels at a higher speed than the speed supplied to them from the transmission. As follows from the physics of the process, some part of the pushing reaction ΔX_K of the running wheels is spent on the formation of the reaction of the soil R_n and the moment from it M_R. The M_R moment through the front axle and the propeller shaft to it, through the transfer case, the propeller shaft and the rear axle is transmitted to the rear (running) wheels and complements the driving moment M'_{ved}, transmitted to these wheels from the engine. The M_{Re} moment transmitted to the rear axle from the front axle is less than the M_R moment, which was formed as a result of the action of the soil reaction R_n, by the value of the transmission efficiency through which it passed. The greater the kinematic discrepancy, the greater the M_R moment is transferred from the lagging wheels to the leading ones.

Thus, there is a circulation of torque and power in a closed loop “contact patch of running wheels with the soil - tractor body - contact patch of lagging wheels with soil - transmission - running wheels”.

A similar process occurs in the drive of caterpillar tractors when power is distributed along the sides when cornering. In these machines it is called energy recovery.

Energy circulation is accompanied by additional energy losses in the transmission and the contact patch of lagging wheels with the supporting surface. In addition, the traction force, additionally expended on the creation of sliding of the lagging wheels, increases the slip of the running wheels.

With a locked drive and the presence of a kinematic mismatch, losses are especially pronounced with good adhesion of the wheels to the road. Then slipping of running wheels or slipping of lagging wheels requires a lot of energy. The loss is the energy spent mainly on the friction of the tire tread on the road surface. This affects performance through reduced tire durability and increased fuel consumption.

Agricultural tractors 4 × 4 perform energy-intensive operations on basic soil backgrounds with increased slippage (10-20%), which more than compensates for wheel slip due to kinematic mismatch in the drive. Therefore, the operation of the tractor as part of soil cultivation and seeding units with a locked drive increases its traction and coupling properties and traction efficiency.

3 Results and discussions

In principle, transmissions of vehicles with all-wheel drive can be divided into two groups: with a locked and differential drive.

In transmissions with a differential drive, center differentials are installed in the transfer cases, with the help of which the torque is distributed between the drive axles in a given ratio. When the drive is locked, the drive shafts of the axle main gears are connected by a rigid kinematic connection, and always rotate at the same speed.

Due to the fact that when the car moves with low resistance in the locked drive, power circulation occurs, such a drive is made disengaged. When driving in light conditions, only one or two closely spaced bridges are left leading.

The drive to the remaining axles is disconnected from the engine using couplings. The differential drive is made, as a rule, constantly switched on, and to increase the cross-country ability of vehicles when driving in difficult road conditions, automatic or forced locking of differentials is provided [15].

The scheme of the power drive (transmission) of three-axle vehicles with a 6x6 wheel formula is very diverse, since for the correct distribution of the torque transmitted from the engine between the six wheels, at best, there should be three differentials between the axle wheels, one symmetrical and one asymmetric differentials [15]. However, in practice, simplified schemes of a blocked power drive without wheel gears and only with differentials between the wheels of each axle are often used, which are widely used on cars of different carrying capacities and have long become familiar. In this case, the drive is carried out using cardan shafts and a through gear of the middle axle, or three cardan shafts when using unified middle and rear axles. Both approaches have their drawbacks and are mainly used for design and layout reasons.

Many vehicles with a 6 × 6 wheel arrangement use transmissions with a locked drive and parallel transmission of torque from the engine to the drive axles, which have only differentials between the axle wheels. Such transmissions are used on domestic vehicles ZIL-157, ZIL-157K and ZIL-131. On ZIL-157 vehicles, the engine torque is transmitted to the drive axles through a two-stage transfer case with a locked drive using three cardan gears. The cardan transmission of the rear axle has an intermediate support fixed to the crankcase of the middle drive axle.

The URAL-375 car has a mixed drive transmission scheme with a through shaft for two rear axles. The transfer case is two-stage. The output shafts of the front and rear axle drives are located on the same axle. The torque transmitted from the engine is distributed in the transfer case between the front axle and the rear bogie axles in a ratio of 1: 2 by an asymmetric cylindrical center differential.

One of the main problems in the design of trucks with a 6x6 wheel arrangement is the choice of a drive scheme for driving wheels and axles. In the practice of the automotive industry, this issue is often resolved either on the basis of one-sided views, or on the basis of the constructive and technological continuity of the units of the designed vehicle with the units of the existing production.

The types of drives used in the construction of cars and road trains are divided into four main groups: individual, differential, locked and combined.

Individual drive assumes the presence of individual engines according to the number of wheels of the car in the presence of common or separate power plants.

A differential drive is usually characterized by the use of 3-link differentials (gear, worm, cam, etc.) in all branches of the power flow in the transmission: in transfer cases, inter-bead gearboxes, final drives, etc [15].

The locked drive is distinguished by the presence of a rigid mechanical connection of all the wheels of the propulsion device.

A combined drive is characterized by the simultaneous use of two or more drive elements of three types (individual, differential and locked).

In works [10-15], recommendations for choosing the optimal drive scheme for a cross-country vehicle with a 6 × 6 wheel arrangement are as follows:

- it is desirable to install a center differential between the rear bogie axles;
- it is advisable to provide for the possibility of disconnecting part of the driving axles to ensure movement on solid roads with one driving axle;
- on vehicles with a disengageable front axle drive, there is no need to install a center differential in the drive to the front axle.

However, in [8] it is stated that in cars with single-tire tires and with a balancing rear bogie, it is not advisable to install an interaxle differential in the bogie; the drive to the front axle when driving on hard roads must be disabled to prevent the appearance of circulating power and to reduce the rigidity of the drive; in order to facilitate the driver's work and eliminate the appearance of circulating power in the front axle drive, it is advisable to install a freewheel clutch to automatically engage the front axle drive; the optimal kinematic mismatch of the transmission is 3-5%.

Approximately the same conclusion is given in [9]: the installation of an interaxle differential in the rear bogie of cross-country vehicles with a wheel arrangement of 6 × 6, equipped with a centralized tire inflation system, is inappropriate. It is much easier to use a permanently blocked drive of the middle and rear axles. At the same time, fuel efficiency practically does not depend on the type of drive of the middle and rear axles. Deterioration in efficiency occurs when there is a significant difference in air pressure in the tires in the absence of a differential in the drive.

The data presented in [8], according to which it is the differential drive that gives the best indicators for the fuel consumption of cars and the increase in the durability of parts and tires, is in little agreement with the above.

4 Conclusion

Analysis of literature sources shows that, despite the large amount of research carried out and well-established design solutions, there are no universal drive schemes for drive axles and wheels at the present stage.

The results and conclusions of the researchers are contradictory, and the theoretical and practical task of comparing the locked and differential drive in terms of the final recommendations has not found an unambiguous solution.

The concepts of power circulation given in the work are considered unacceptable by the country's leading scientists [8, 9, 15], and the most accurate term energy circulation is not used by a number of scientists.

The need to minimize the described effect of energy circulation arising in planetary gearboxes, which in some cases may turn out to be excessive, since it is necessary to increase the stability of motion in transient processes of wheeled and tracked agricultural vehicles.

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