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Transmissions with Controlled Slipping of the Friction Mechanism in Parallel Power Flow for Tractors

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Abstract. Two-flow transmissions are widely used in industrial and agricultural tractors. The article offers options for constructing two-stream transmission schemes, where the power distribution mechanism is replaced by a friction mechanism using controlled slippage of the control disc. This replacement will allow in the future to abandon the import of the power distribution mechanism and reduce the cost of the tractor. A controlled slip friction mechanism controls the distribution of power to the drive wheels and provides a quasi-infinite transmission effect. The authors proposed a method for determining the gear ratio of the power distribution mechanism from the condition of overcoming the torque gap between the second and third gears in the automatic transmission. The possibility of manufacturing and testing a controlled power distribution mechanism based on technologies of Russian industry was assessed.

INTRODUCTION

One of the ways to improve a number of technical characteristics of modern agricultural and industrial tractors is to use a hydrostatic gear in the transmission [1]. The main advantage associated with the use of the hydrostatic gear is a smooth, continuous change in the torque transmitted through the transmission, in the entire range of operating modes, which is preferable in the production of many agricultural works [2-4].

A significant disadvantage of the hydrostatic gear is the relatively low efficiency in most of the modes and it is a complex, expensive unit. Currently, there is no domestic competitive hydrostatic transmission for use in the transmission of a tractor of the fourth traction class.

The use of a two-flow transmission allows you to use the main advantage of the hydrostatic gear while achieving a satisfactory economy of the transmission as a whole [5-6]. In such a transmission, there is a branching of the power flow. The main flow goes through a branch containing a mechanical torque transformer (for a modern tractor, this is an automated or automatic transmission). The hydrostatic gear is installed in the parallel branch. The algorithm for the shared use of branches is based on the condition for obtaining the transmission efficiency exceeding the efficiency of the hydrostatic transmission itself [7-8]. The Favorit 926 Vario tractor is an example of the implementation of a two-line transmission with hydrostatic transmission [9]. Tractors with the hydrostatic gear as part of a two-flow transmission occupy their own (in terms of price and performance combination) segment of the agricultural machinery market.

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Transmissions that include a stepped automatic or automatic transmission can compete with the hydrostatic transmission on promising tractors with a capacity of 140–440 kW [10-11], can compete with such machines. To do this, it is proposed to replace the hydrostatic gear with an alternative - an electric motor [12] or an friction mechanism, in which the principle of controlled slipping is implemented, as part of a two-flow transmission (in the simplest case - a disc friction clutch). The friction mechanism may include a reducer.

MATERIALS AND METHODS

Using an electric motor will require the installation of a powerful generator and energy storage. This matches the design of a parallel-series hybrid powertrain in practice.

Research on the creation of such mechanisms in relation to transport-tracked vehicles has long been conducted at the St. Petersburg Polytechnic University [13-16]. The operating conditions and the very functions of such a mechanism as part of the transmissions of the transport-tracked vehicles [17-18] and agricultural tractors [19-21] differ significantly. The friction mechanism of transport-tracked vehicles controls the direction of travel [17-18]. On a wheeled tractor, it is necessary to ensure a smooth change in the transmitted torque.

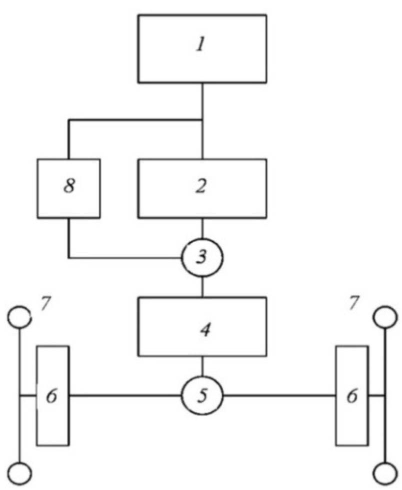
As a prototype of the mechanism for performing this function, a two-flow power distribution mechanism can be proposed [7]. The purpose of this work is to propose options for the design of the tractor transmission without the hydrostatic gear, providing equivalent or better consumer characteristics at a lower cost. To achieve this goal, the following research tasks were set:

- To develop a two-flow transmission scheme with a friction mechanism and a power distribution mechanism, which allows to control the power distribution over the driving wheels and provide the effect of a quasi-continuously variable transmission.
- Propose an approach to determining the gear ratio of the power distribution mechanism.
- Consider the issue of the possibility of producing and testing controlled power distribution mechanisms based on technologies mastered in Russian industry.

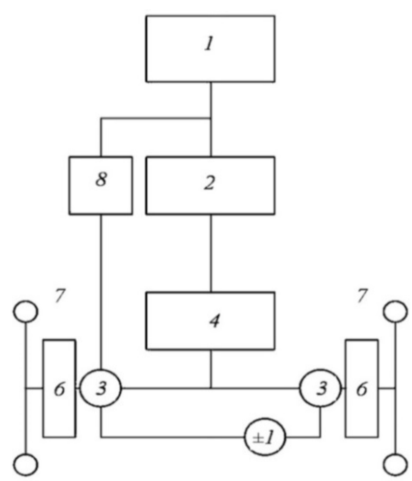
RESULTS

Two-Flow Transmission Options

Generalized diagrams of transmissions containing power distribution mechanisms of this type are shown in Fig. 1.



(a)



(b)

FIGURE 1. Generalized diagram of the transmission of a wheeled tractor (a) with branching of the power flow or (b) two-flow with power distribution control over the driving wheels: 1 is internal combustion engine; 2 is automatic or automated gearbox; 3 is summarizing planetary gear set; 4 is additional gearbox; 5 is symmetric differential; 6 is wheel reduction gear; 7 is driving wheels; 8 is friction mechanism.

In both cases, the power distribution mechanism operates under the control of an electronic control system that has an output to the bus, which makes it possible to use it on the chassis of an unmanned tractor integrated into a precision farming system [22-23].

The branching of the power flow was carried out using a gear transmission as part of the P_0 gearbox (Figure 2). The unification of streams was carried out using the summing planetary gear set. When carrying out the kinematic and force analysis of the variants of the schemes, one should also consider the case when the branching was carried out using the planetary gear set, and the summation is carried out using the transmission with fixed axes of rotation of the links.

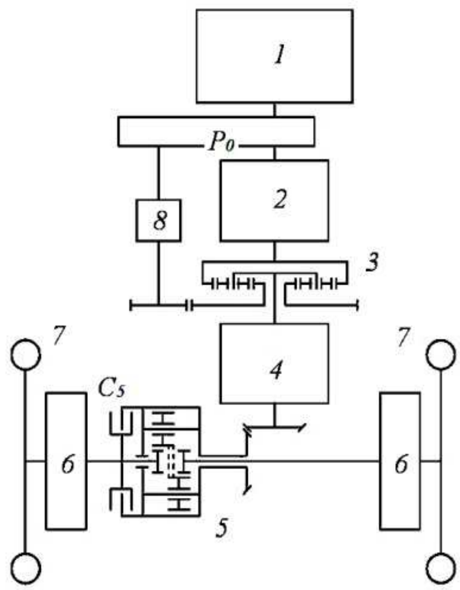


FIGURE 2. Transmission with power flow branching for a wheeled tractor: 1 is internal combustion engine; 2 is automatic or automated gearbox; 3 is summarizing planetary gear set; 4 is additional gearbox; 5 is symmetric differential; 6 is wheel reduction gear; 7 is driving wheels; 8 is friction mechanism.

The power distribution mechanism consists of a friction mechanism and a summing planetary gear set, which performs the function of the reduction gear part of the power distribution mechanism [24]. It is possible to supply power bypassing the automatic transmission to an additional gearbox. An additional gearbox may be missing, then its functions are transferred to the automatic transmission.

Another variant of the scheme is to connect the summarizing planetary gear set sun gear with the main transmission branch, and the epicycle with a parallel branch. The necessary unit for this approach to the construction of the kinematic transmission scheme is the inter wheel differential. In Fig. 2 shows a simple symmetrical cylindrical differential 5, equipped with a controlled disc blocking clutch C5. The differential box is connected to the output shaft of the 4 by means of a pair of bevel gears that perform the function of the first stage of the main gear. Wheel reducer 6 can be considered as the second stage. It should be noted that when using a planetary automatic transmission, there is usually no clutch. The clutch, cardan gears, power take-off shaft and wheel brakes are not conventionally shown in Figures.

The considered transmission scheme is designed for use on a two-flow chassis with a drive to the rear axle. On the basis of such a scheme, it is possible to build the transmission of an all-wheel drive vehicle, which is important for tractors of 5-8 traction classes. The switchable front axle drive will be carried out through the center differential, which can be located in a single unit with the automatic transmission. To cover the market of road-building equipment, on the basis of the proposed circuit solution, it is possible to develop a variant of the transmission of a multi-axle chassis.

A more complex scheme with a two-line transmission, which allows to control the tractive effort on the driving wheels 7, is shown in Fig. 3. The flow branching is carried out using the P0 reducer.

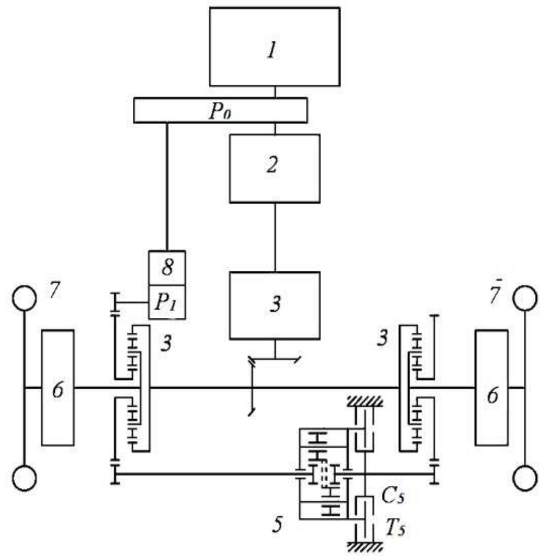


FIGURE 3. Two-flow transmission with power distribution control over the drive wheels: 1 is internal combustion engine; 2 is automatic or automated gearbox; 3 is summarizing planetary gear set; 4 is additional gearbox; 5 is symmetric differential; 6 is wheel reduction gear; 7 is driving wheels; 8 is friction mechanism.

The power distribution mechanism includes a gear part P_1, which provides a reverse of the output shaft. The summation of the streams is carried out before the wheel reduction gear *6* using two summarizing planetary gear set *3*. The sun gears of the summarizing planetary gear set are interconnected through the shafts brought out to the gears of the differential 5. The differential has two control elements: blocking clutch *C5* and carrier brake *T5*. When the *C5* is turned on, the differential is locked, its gear ratio is equal to one. The installation of a cross-axle differential is not required. Its function is performed by the summarizing planetary gear set.

To control the tractive effort on the driving wheel *7* in the parallel branch, the T_5 brake is activated. The differential box stops, the gear ratio of the unit becomes equal to one. The sun gears of the summarizing planetary gear set rotate in opposite directions, which makes it possible, using controlled slip in the friction mechanism, to increase the traction force on one side and decrease on the other, due to which a turning moment arises on the chassis. This principle is used in two-flow differential transmission and turning mechanisms of the transport tracked vehicles [25-26]. If it is necessary to change the direction of the reversing moment in the P_1 gearbox, the output shaft is reversed.

The control of slipping of disks in the friction mechanism can be carried out using pulse-width modulation of the control pressure in the hydraulic drive. The possibility of pulse-width modulation of the control pressure in the hydraulic drive of a disk control element has been studied in relation to tracked and wheeled vehicles [25-26].

Gear Ratio Calculation

When determining the gear ratio of the power distribution mechanism of the car, the coordination of the radii of the kinematic and power turn is considered [11]. In our case, the main function of the power distribution mechanism is to supply additional power bypassing the gearbox to reduce the number of changes and improve the smooth operation of the transmission within the engaged gear. This means that it must transmit an additional torque equal to the difference in torque on adjacent gears. In accordance with the scheme (Fig. 1, *a*):

$$M_{MPM} = M_j - M_{j+1} = M_0\left(u_j - u_{j+1}\right) = M_0 u_{j+1}\left(u_j / u_{j+1} - 1\right) \tag{1}$$

where M_j, M_{j+1}, M_0 are moments on adjacent gears and on the motor shaft ($M_j > M_{j+1}$); u_j, u_{j+1} are gear ratios on adjacent gears in the gearbox; $j = \overline{1, n}$ is transmission number, n is number of gears. When splitting gears in a geometric progression, the denominator of the progression can be taken equal to $q = u_j / u_{j+1}$.

Since it is impractical to have n stages in the gear part of the power distribution mechanism, the moment is selected from the condition $\max\{M_{\mathrm{MPM}}\}$, $j=\overline{1,n}$.

Formally it corresponds to this *j* = 1, but the first transmission is rarely used, so it is accepted *j* = 1. Then the gear ratio of the power distribution mechanism is determined by the dependence:

$$u_{MPM} = u_3\left(u_2/u_3 - 1\right) > 1 \tag{2}$$

When designing power distribution mechanism, it is advisable to use the methods of synthesis of kinematic diagrams, methods of calculating parts for strength and durability, tested in the military-industrial complex in the production of military tracked vehicles. In this same industry, special materials have been developed and used to ensure sufficient durability of the friction discs of the friction control elements. A tracking control system has been developed and tested [27], on the basis of which an power distribution mechanism control system can be manufactured. Bench equipment has been tested for testing and fine-tuning the layout of the control system and transmission.

DISCUSSION

The proposed approach to the construction of the transmission can provide a smooth quasi-stepless torque change without the use of the hydrostatic transmission.

It seems promising to develop algorithms for the joint operation of friction mechanisms and automatic transmission, in which they will relieve the automatic transmission control elements from slipping.

As part of the transmission under consideration, controlled power distribution mechanisms of various types can be used, which determines the interest in research related to the adaptation of known power distribution mechanisms to work as part of the tractor transmission and the search for new kinematic schemes. In the future, the proposed mechanism can be used as part of the transmission of an unmanned tractor in order to simplify the algorithms for controlling the machine when operating in an autonomous mode. Further interest is the use of the proposed mechanism in the design of the chassis of new tracked and wheeled vehicles and the modernization of existing models of ground vehicles for various purposes.

CONCLUSION

The power distribution mechanism in the parallel branch of the tractor transmission can be changed to friction mechanism or gear power distribution mechanism using controlled slip of the disc control. The main purpose of the replacement is the ability to abandon the import of the power distribution mechanism (It can reduce the cost of the tractor). This approach is applicable for the basic version of the tractor.

A transmission scheme has been proposed, which makes it possible to realize an operational property that is atypical for agricultural wheeled tractors - the ability to control the traction force on the driving wheels. It should be noted that such a technical solution leads to the complication of the transmission and should be considered as an option installed at the factory upon the customer's request.

The gear ratio and the loads on the parts of the proposed mechanism can be determined from the condition of the need to bridge the gap by the value of the moment between the second and third gears in the automatic transmission.

In the serial production of transmission units, it is possible to use materials and technologies developed to date for the needs of the military-industrial complex of Russia.

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