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PHYSICO-MATHEMATICAL MODEL OF MOTOR VEHICLE OF DIVIDED WEIGHT WITH UNIFYING ENERGETIC ELEMENT

Л.М. Петров, *Т.М. Борисенко*, *О.В. Лисий.* **Фізико-математична модель автомобільного транспортного засобу розділеної ваги з поєднуючим енергетичним елементом.** Тягово-зчіпні властивості мають велике значення для забезпечення робочого процесу автомобільного транспортного засобу. При забезпеченні тягово-зчіпних властивостей збільшується середня швидкість переміщення мобільного енергетичного засобу, підвищується значення енерговитрат на виконання робочого процесу, а витрати на експлуатацію зменшуються. Забезпечення реалізації тягово-зчіпних властивостей здійснює трансмісія мобільного енергетичного засобу. ***Мета:*** Метою роботи є удосконалення технології передачі крутного моменту від двигуна до колісних рушіїв шляхом створення нової конструкції трансмісії автомобільного транспортного засобу розділеної ваги. ***Матеріали і методи:*** У якості механічної системи розглядався автомобільний транспортний засіб розділеної ваги, у якому поєднуючий енергетичний елемент здійснює обертальний рух відносно рами. ***Результати:*** Показано, що момент, який створює обертальний рух, залежить від модуля та напрямку абсолютних швидкостей повороту поєднуючого енергетичного елементу. Вперше запропонована технологія та конструкція трансмісії автомобіля, який відрізняється від попередніх конструкцій значним спрощенням передачі крутного моменту від двигуна до ведучих коліс при підвищеному значенні коефіцієнту корисної дії.
Ключові слова: трансмісія, крутний момент, колове зусилля, осьове зусилля, передаточне відношення.

L.M. Petrov, *T.M. Borisenko*, *O.V. Lysyi.* **Physico-mathematical model of motor vehicle of divided weight with unifying energetic element.** The traction characteristics are important for ensuring of motor vehicle work process. In providing the traction characteristics the average velocity of mobile energetic transport grows, energy costs for work process execution are uprating and operation costs are reducing. The implementation of traction characteristics is performed by transmission of mobile energetic transport. ***Aim:*** The aim of the work is improvement of torque transfer technology from the engine to the wheel driving forces through the establishment of new construction of divided weight vehicle transmission. ***Materials and Methods:*** Consider a motor vehicle of divided weight with unifying energetic element which performs rotary motions relative to the vehicle frame. ***Results:*** It was shown that, the momentum which creates the rotational motion depends on the module and the direction of rotation speed of the unifying energetic element. For the first time, the technology and design of vehicle transmission which differs from previous designs by significant simplifying of the torque transmission from the engine to driving wheels at increased value of efficiency coefficient were proposed.
Keywords: transmission, torque, circular force, thrust force, angular speed ratio.

Introduction. The traction characteristics are important for ensuring of motor vehicle work process. In providing the traction characteristics the average velocity of mobile energetic transport grows, energy costs for work process execution are uprating and operation costs are reducing. The implementation of traction characteristics is performed by transmission of mobile energetic transport. The design of the vehicle transmission is largely determined by the number of its driving axles. The vehicles with mechanical transmissions, which have two or three of the bridge, are the most common.

Transmission consists of clutch, gearbox, drive shaft, the main gear and rear-wheel drive. The torque transmit from the engine to driving wheels requires the most coherent work of all components of the transmission. To do this, all components are connected with each other by the hinges, shafts, and pinions. For example, the Mercedes-Benz engine [1] generates the sufficient power in a narrow range of rotational speeds of the crankshaft. In order to engine was able to generate the necessary tractive force, the vehicle is equipped with magnetic gearbox with different gear ratios.

New John Deere tractors — for example, 9410R, and 9460R — are equipped with 24-speed mechanical transmission PowerSync, or 18-speed transmission PowerShift with Efficiency Manager

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System, which is standard for all caterpillar models and more powerful wheeled models [2]. Efficiency Manager System [3] enables the operator to accurately control the movement speed (on all models for movement speeds up to 40 km/h), and simply adjust the speed for field and transport works. The most widely used operating range of speeds from 4,8 to 12,9 km/h contains 10 gears, and the step of speed change is 0,8 km/h. Uniform distribution of gear ratios allows the engine to operate at optimum RPM range, and this, in turn, ensures optimum fuel consumption. PowerSync and PowerShift transmissions can improve fuel efficiency and optimize the performance of the engine. Transmission changes the load on the engine; automatically selects the tractor's start speed and provides its move to appropriate speed while performing field or transport operations. The maximum speed for wheeled models is 40 km/h; and for caterpillar models — 35 km/h.

John Deere 9510R, and 9560R tractors are equipped with a bilateral reducer in planetary train, that allows to increase the movement speed [4]. This reduces the load on the entire transmission in general, especially on internal components and gear ring and pinions, and increases the reliability and durability of the transmission.

Deutz-Fahr tractors are equipped with new Sense-Shift transmission [5], which installed on the Deutz-Fahr 6-Series. Transmission has 6 bands, each of which has 4 gears that can be switched under the load. Thus, there are 24 speeds in each direction with the ability to setup the reducing gear for 4 lowest bands, the total of 80 (40 + 40) speeds. The broad range of gears overlap allows to store a single gear band in different work conditions, while changing the gear inside of the one band is automatically regulated by the standard function, which is in each model of the transmission. In addition, a new feature Sense Clutch [6] implemented in some transmissions; this feature allows the driver to smooth the power flow. To ensure the stability of the tractor during plowing or transport works, transmission management has been optimized: the electronic unit manages the connection of all-wheel drive and differential lock depending on the speed and the angle of rotation of the wheels.

P-Series tractors are equipped with an automatic transmission — electronic control system selects the appropriate gears in each range, optimizing engine performance and reducing fuel consumption.

Lamborghini R8, R7, R6 and R5-Series tractors are equipped with PowerShift transmission [7] with automatic change-over. The electronic unit controls the transmission and selects the optimum gear according to the current load and rotational speed of the crankshaft at a particular time. Shifting gears in R8-Series is carried out automatically under load without power flow discontinuity.
The evolution of tractor industry aims at improving efficiency of machine-tractor units.

Progressive direction in the development of designs of tractor transmissions is the development of hydro-mechanical and hydraulic displacement transmissions that allow to improve tractor's control and reduce dynamic loads.

Currently, the mechanical transmissions are most common, and their design is constantly perfected. This is explained by the fact that the use of hydro-mechanical transmissions is efficiently only for large load fluctuation, which is typical for industrial tractors.

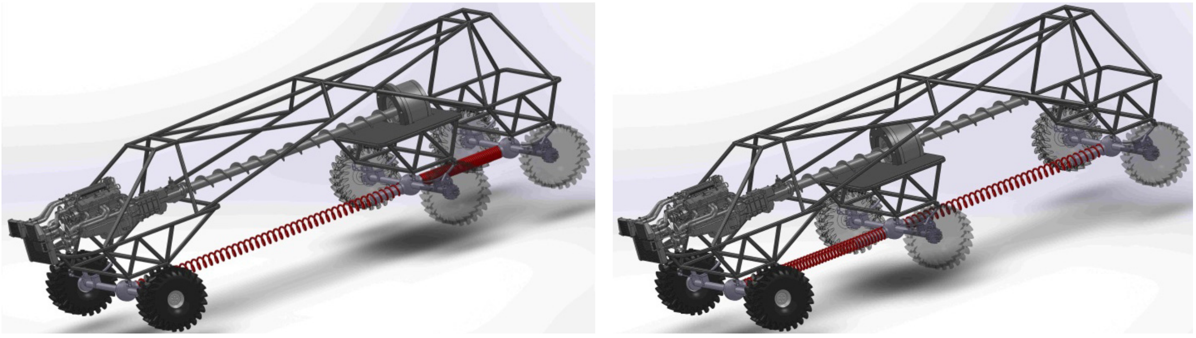
The aim of the work is improvement of torque transfer technology from the engine to the wheel driving forces through the establishment of new construction of divided weight vehicle transmission.

Materials and Methods. Consider a motor vehicle of divided weight with unifying energetic element which performs rotary motions relative to the vehicle frame (Fig. 1).

Define the change of angular momentum of the mechanical system relative to the longitudinal axis of the vehicle by the formula

$$\frac{dL}{dt} = M^E .$$

The external force acting on the mechanical system is weight G that has not momentum to the longitudinal axis and normal force of the vehicle frame. So, the main external forces momentum M^E is the main normal force momentum exerted by vehicle frame.



a *b*

Fig. 1. The motor vehicle of divided weight: a — "position 1"; b — "position 2"

So, consider a vehicle frame whose state at time *t* is "position 1", and at time *t+dt* — "position 2" (Fig. 1). The vehicle mass in each state is equal

$$m_1 = m_2 = m = \frac{G}{g} dt \,. \tag{1}$$

The change of angular momentum of the motor vehicle relative to the longitudinal axis during a time *dt* can be represented as the difference of the angular momentums of mass during a time *dt:*

$$dL = mv_2 R_2 - mv_1 R_1 \,, \tag{2}$$

$$R_1 = r\cos\alpha_1 \,, \tag{3}$$

$$R_2 = r\cos\alpha_2 \,, \tag{4}$$

where R_1 — arm of force $m\upsilon_1$ relative to the longitudinal axis;
R_2 — arm of force $m\upsilon_2$ relative to the longitudinal axis;
r — radius of the unifying energetic element;
α_1 — turning angle of the unifying energetic element in the position 1;
α_2 — turning angle of the unifying energetic element in the position 2.

We substitute (1), (3) and (4) to (2) and finally the change of the angular momentum can be represented as

$$dL = \frac{G}{g} dt\, v_2 r\cos\alpha_2 - \frac{G}{g} dt\, v_1 r\cos\alpha_1 \,.$$

Finally, the change of the angular momentum of the concerned mechanical system during *dt* can be represented as the sum of *dL*

$$dL = \sum_{i=1}^{n} dL_{1,2} = \frac{G}{g} dt (v_2 r\cos\alpha_2 - v_1 r\cos\alpha_1) \,.$$

Integrating the obtained equation and using the principle of conservation of angular momentum, we can find the main external forces momentum that impede the movement of the motor vehicle

$$\int dL = \int \sum_{i=1}^{n} dL_{1,2} = \int \frac{G}{g} dt (v_2 r\cos\alpha_2 - v_1 r\cos\alpha_1) \,.$$

The total change in the angular momentum M^E can be represented as

$$M^E = \frac{G}{g} (v_2 r\cos\alpha_2 - v_1 r\cos\alpha_1) \,.$$

Hence, angular momentum M_{sc} must be applied by ball screw, and equal in absolute value and opposite in direction to M^E

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$$M_{sc} = -M^E = \frac{G}{g}(v_1 r \cos\alpha_1 - v_2 r \cos\alpha_2)\,. \tag{5}$$

The equation (5) shows that the momentum which creates the rotational motion depends on the module and the direction of rotation speed of the unifying energetic element.

On the basis of the preceding material was issued a patent for utility model [8].

Results. According to design of motor vehicle of divided weight the angular speed ratio is created by the torque transmission from the engine to the unifying energetic element and can be represented as

$$u = \frac{S}{S_1}\,, \tag{6}$$

where S — circular movement of the engine flywheel,
S_1 — movement of the unifying energetic element.

The circular movement of the engine flywheel and the movement of the unifying energetic element from formula (6) can be represented using geometrical parameters as

$$u = \frac{\pi d_m}{P_t}\,, \tag{7}$$

where d_m — diameter of the engine flywheel, mm;
P_t — path of the unifying energetic element, mm.

For developed motor vehicle of divided weight we propose to consider following forces that determine the vehicle movement.

So, the dependence between circular force F_t applied to the engine flywheel and thrust moving force F_a can be represented as

$$F_t = F_a u \eta\,, \tag{8}$$

where η is efficiency coefficient of the unifying energetic element.

The variables for numerical computations are given in Table 1.

The calculated results using formula (7) are given in Table 2.

To calculate the dependence of thrust moving force F_a on circular force F_t, use the formula (8) and data from Tables 1 and 2.

Table 1.

The variables

η	0,873	0,884	0,895	0,907	0,914	0,926	0,937	0,945	0,956	0,962
d_m, mm	300	355	410	465	505	550	615	660	709	766
P_t, mm	4	4,5	5,2	5,8	6,1	6,6	7,2	7,7	8,4	8,8
F_a, kN	33	36	43	48	55	61	67	74	79	85

Table 2.

The results of numerical computations

u	235,5	247,71	247,58	251,74	259,95	261,67	268,21	269,14	265,03	273,32
F_t, N	6784,5	7883,2	9528	10960	13068	14781	16838	18821	20016	22350

According to the data from Tables 1 and 2, we plot the graphs of following dependences.

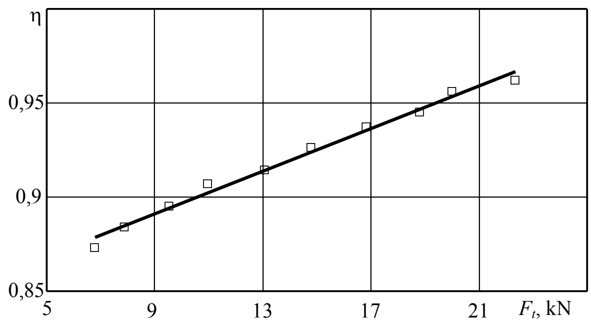

Fig. 2. Dependence of efficiency coefficient of the unifying energetic element on circular force

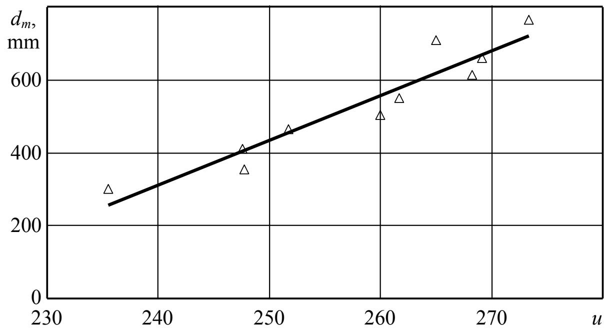

Fig. 3. Dependence of diameter of the engine flywheel on angular speed ratio

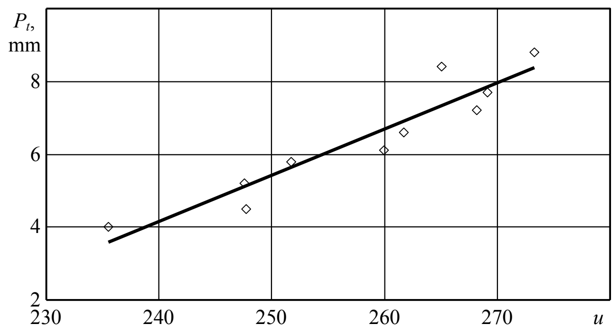

Fig. 4. Dependence of path of the unifying energetic element on angular speed ratio

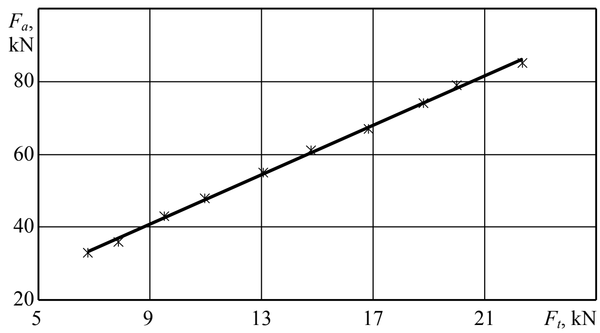

Fig. 5. Dependence of thrust moving force on circular force

Conclusions. The following conclusions have been drawn from this study:

— The big value of angular speed ratio u can be obtained with low value of circular force F_t and relatively large diameter of the engine flywheel d_m.

— In spite of simple and compact design of proposed motor vehicle, the driver can receive a great advantage in draw-bar force, and make slow and precise movements.

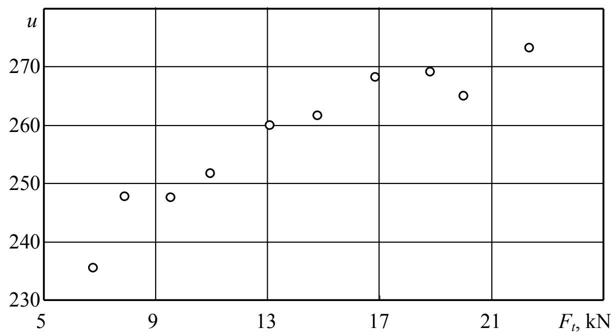

Fig. 6. Dependence of angular speed ratio on circular force

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