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Comprehensive Modernization of the Chassis of a Two-Link Tracked Transporter

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Abstract. The article considers the issue of modernization of the chassis of a two-link tracked transporter by applying the electromechanical drive sections. As a prototype was selected the chassis of the tracked transporters of the DT series with a mechanical transmission, which are produced serial in the Russian Federation. The proposed hybrid power installation concept can be classified as a "parallel-successive" hybrid. The relevance of the concept is determined by the expectation of operational advantages (increase of reliability, maneuverability, controllability, cross-country ability and traction-dynamic properties of the chassis and economy), which will allow to integrate such chassis into transport systems of regions with poorly developed road network infrastructure and will allow to distribution it on difficult terrain. The proposed set of modernization measures allows us to maintain the possibility of using two-link tracked transporter on soils with low bearing capacity, on off-highway, in the climatic conditions of the Far East, Far North, Arctic and Antarctic. Modernization can be carried out in the factory using components produced in the Russian Federation and technologies developed by Russian industry. The proposed design changes expand the operational capabilities of the machine without a significant increase in mass. Technical solutions are applicable when creating multi-link machines.

1. Introduction

The regions of the Far East and the Far North are traditionally characterized by poor infrastructure development and systemic problems in the efficiency of land transport management. The poorly developed road network and typical terrain characteristics (waterlogged areas, swamps of the second and third types, soils with a weak surface layer) make it necessary to use special vehicles of ultra-high cross-country ability to deliver important goods in the spring-summer period. Wherein floating two-link tracked conveyors, in Russia represented by the tracked transporters of the DT series, show the highest efficiency in off-highway conditions [1]. The tracked transporters are used to transport passengers and goods, including on a systemic basis (for example, pipe delivery during the construction of gas and oil pipelines).

These vehicles, in addition to high cross-country ability, have some significant disadvantages that impede integration into transport systems: high operating costs (primarily associated with high fuel consumption) and damaging effects on ecological systems (high level of emission of harmful substances, mechanical destruction of the surface of movement, etc. [2]). Therefore, the urgent issue is the comprehensive modernization of serial two-link tracked transporters, which would allow them to be effectively used to organize a systematically functioning transport network.

When working on the problem, the following main sources of literature were used: classic and modern monographs on the theory of movement of tracked vehicles [3,4,5,6] (special attention is paid to the mathematical description of the turn and analysis of the work of the tracked running gear); works in the field of designing tracked vehicles [7,8,9,10 et al.] (approaches to the design of dual-flow transmissions and the tracked undercarriage were analyzed); scientific works on the theory and design of hybrid power installation of transport vehicles [11,12,13,14 et al.] (analyzed to select a strategy for building the most reliable and simple scheme of a hybrid power installation and transmission).

In addition, modern publications related to the reduction of toxicity of emissions of heat engines were used [15], researches in the design of electromechanical transmissions of transport and transport-hauling machines [16,17,18,19,20,21,22,23,24,28], the theories of the tracked undercarriage [2.25.26 et al.], questions of designing the chassis of two-link machines [27] and others.

Based on an analysis of the construction of the machine, the specific conditions of its movement, modern and traditional literary sources in the field of theory and design engineering of tracked vehicles, the following tasks are formulated:

1. To propose a structural diagram of a hybrid power installation and transmission, which reduce fuel consumption, improve maneuverability and traction-dynamic properties of the chassis.

2. To propose a set of solutions aimed at reducing the damage caused by the vehicle to the environment.

2. Method and results of theoretical researches

At the present stage of development of domestic industry, it seems possible to consider the use of a hybrid drive for a two-section tracked vehicle. A prerequisite for this is works on “hybrid” power installations and transmissions [11,13,14,22]. Based on the performed analysis, it is proposed to use an electromechanical transmission to drive the rear link, and an additional electromechanical (hybrid) transmission to use the front link (by analogy with the proposals discussed in [14,17,18,19,20,21]). Wherein in both cases the heat engine (HE) provides the generation of energy that ensures the movement of the machine. Thus, the solution can be attributed to the group of “parallel-successive type hybrids” [14,16,21]. In both cases, the drive of the leading sprockets of the rear section is provided by a traction electric motor (TEM) through the range box, turning mechanism and final drives. The rear section can operate in slave mode, but the lead mode is preferred [25]. The location of the leading sprockets of the rear section is selected based on the function of the machine, as the efficiency work of the tracked undercarriage depends on the nature of the distribution of the normal load on the supporting surface [26,29] and the values of traction forces [6].

The presence of two gears in the range box will reduce the size and weight of the TEM. The TEM drive is expediently carried out from a high voltage network. The capacity of the energy accumulator is determined by the requirements for the duration of the autonomous operation of the chassis with an inoperative HE (standby mode). At the moment supercapacitor-based drives have the best size-mass characteristics [24], this is due to the properties of fast charging and discharging, long service life, high specific energy and specific power, wide range of operating temperatures, that is especially actual for the regions of the Far East and the Far North.

The main source of energy for the chassis is HE (traditionally this is diesel). According to the methodology traditional for the theory of movement of tracked vehicles [3], its maximum power is determined by the formula (1):

$$N_{HE} = N_1 + N_{\text{TEM}} = k_N \frac{Mgf_{\min}V_{\max}}{\eta_{rg}\eta_{tr}\eta_{eng}} \quad (1)$$

Where "N_{HE}" is HE power (kW); "N_1" is HE power spent on front section drive (kW); "N_{TEM}" is total power of TEM sections (kW); "k_N" is factor of power reserve (in the range of 1.10–1.15); "M" is gross vehicle weight (t); "g" is acceleration of gravity (m/s^2); "$f_{\min}$" is minimum rolling resistance coefficient for a range of operating conditions (driving on a dry dirt road); "$V_{\max}$" is maximum speed (m/s); "η_{rg}", "η_{tr}", "η_{eng}" are efficiency of the running gear, transmission of a two-link tracked transporter, engine corresponding to the maximum speed of movement.

The power of TD transporters of the DT-10 and DT-30 series is 521.9 kW and 574.0 kW respectively. The maximum speed on the ground reaches 37 km/h.

The TEM power of the rear section, as in the design of the drive of an active wheeled trailer, described in [16], is selected from the condition of ensuring its self-movement:

$$N_{\text{TEM2}} = \frac{mgf_{\min}V_{\max}}{\eta_{rg}\eta_{em}} \quad (2)$$

Where "m" is rear section weight (t); "η_{em}" is efficiency of electromechanical transmission of the rear section. Correction factor (by analogy with the previous dependence) is not introduced, so far as modern electric motors allow overload.

The calculated total TEM power of the rear section does not exceed 200 kW.

Figure 1 shows a schema of a dual-flow transmission of the front link. A parallel flow of power is fed from the TEM, which receives energy from the energy accumulator 8.

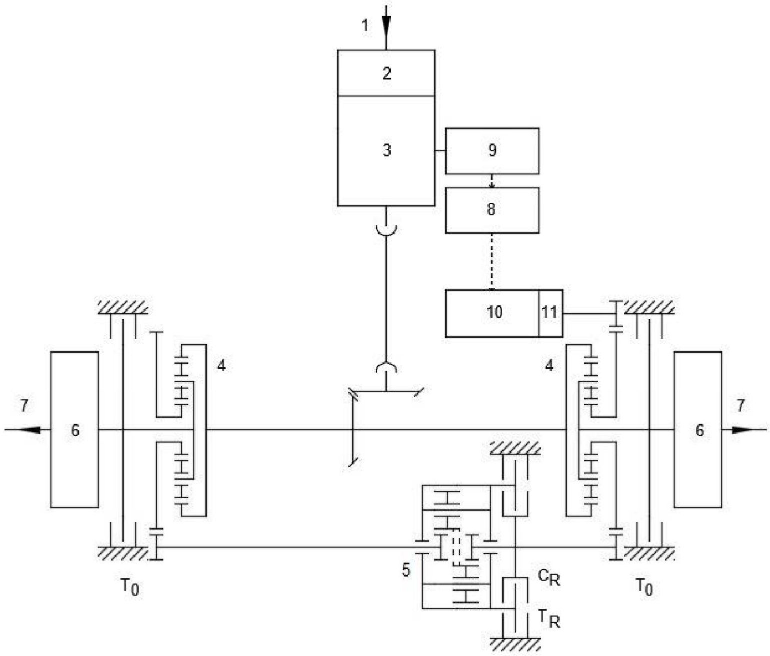

Figure 1. Simplified kinematic schema of transmission of the front link: 1 – from heat engine; 2 – the clutch; 3 – the central gearbox; 4 – the summing planetary mechanism; 5 – the differential with elements of control C_R and T_R; 6 – the final gear; 7 – power removal for drive sprockets; 8 – the energy accumulator; 9 – the traction generator; 10 – TEM or the double action electric machine (engine-generator); 11 – the box of ranges; T_0 – the brake.

The energy accumulator (supercapacitor), in turn, is charged from a generator 9, which is driven by a heat engine or gearbox 3. Dual-flow transmissions of tracked vehicles have been known for a long time [3,4,5,7 et al.]. However, the problem of their use for hybrid power installations (HPI) until recently, apparently, was not considered.

This mechanism functions similarly to the hybrid power distribution mechanism [22]. At rectilinear movement the friction clutch C_R of the rotation (turning) mechanism (Figure 1) is engaged. To redistribute power on the sides the brake T_R is activated in the turning mode. But there is no need to use this control when slipping [23], transporter turning in the entire ranges of radii occurs due from the TEM power. The box of ranges 11 is used to reduce the size of the TEM. This principle of transmission construction is applicable for tracked vehicles weighing 8-30 tons.

Operating modes: rectilinear movement is carried out using only HE; transporter turning - using HE and TEM; turning in place - using only TEM; forced mode of rectilinear movement - using HE and TEM; rectilinear movement - using only TEM and turning - using only HE (reserve modes).

The schema shown in Figure 1 (from the point of view of kinematics) allows for the turning of the front section (disconnected from the machine) around the center of gravity. The required the TEM power in this mode can be defined as:

$$N_{\mathrm{TEM1}}\big|_{\rho=0} = M_s\omega / \eta_g \quad (3)$$

Where "ρ" is relative turning radius; "M_S" is– moment resistance to turning (kNm); "ω" is angular velocity of turning (rad/s); η_g is efficiency gearings.

The relative turning radius "ρ" depends on the turning radius "R" (m) and the track width "B" (m) and is determined by the formula:

$$\rho = R / B \quad (4)$$

In accordance with the theory of movement of tracked vehicles [3,4,5], the moment resistance to turning M_S can be defined as

$$M_S = \mu G L / 4 \quad (5)$$

Where "G" is machine weight (kN); "L" is length of supporting surface (m).

The value of the angular velocity of turning ω is influenced by the linear speeds of the going faster side V_2 (m/s) and lagging side V_1 (m), as well as the track width B (m). The value of angular velocity of turning ω is determined by the expression

$$\omega = (V_2 - V_1) / B \quad (6)$$

For a separate section weighing about 15 tons, uniformly turning around the center of gravity on dry soddy loam (horizontal surface) with ω = 0.5 rad/s, the value $N\big|_{\rho=0}$ is about 50 kW. An assessment of the required power of the TEM along the boundary of a partial drift (movement on the ground with $\mu_{max} = 0.8$) showed that such power is sufficient for turning when ρ > 2. The angular velocity of the machine is limited by the resistance to turning when turning radius ρ is smaller than critical value. According to statistics, a high-speed tracked vehicle is in the turning mode from 50% [8] to 85% [10] of the movement time.

The total TEM power of the sections in this example does not exceed 250 kW.

So the power of the traction electric generator (TEG) can be defined as:

$$N_{TEG} = \left(N_{TEM1} + N_{TEM2}\right) / \eta_{en} \quad (7)$$

Where "η_{en}" is efficiency of direct and reverse conversion of mechanical energy and line losses.

The calculated value of the TEG power reaches 280 kW.

The selection of gear ratios of the box of ranges should be carried out taking into account the specifics of the transporter driving cycles.

In first gear, the machine must provide a minimum speed $V_{\min}$ at minimum engine revolutions $\omega_{TEM\min}$ and the condition for the transmission of the traction force of the consider section of transporter of the circumstance of the adhesion of tracks to the ground. In second gear, the transporter must provide movement with the maximum speed $V_{\max}$ on a dirt road (when TEM is working at maximum speed $\omega_{TEM\max}$):

$$u_I = \max\left\{V_{\min} \big/ \left(r_{ds}\omega_{TEM\min}u_0u_{fg}\right), mg\varphi r_{ds} \big/ \left(M_{TEM\max}u_0u_{fg}\right)\right\} \tag{8}$$

$$u_{II} = \min\left\{V_{\max} \big/ \left(r_{ds}\omega_{TEM\max}u_0u_{fg}\right), mg f_{\min} r_{ds} \big/ \left(M_{TEM\max}u_0u_{fg}\right)\right\} \tag{9}$$

Where "r_{ds}" is drive sprocket radius; "u_0" is the gear ratio of lower gear of the box of ranges; "u_{fg}" is the gear ratio of the final gear of the rear section; "φ" – calculated value of the coefficient of adhesion to the ground.

3. Discussion

The results of calculations of the stability of motion of the transporter of the DT series presented in working [27] show that when developing a version of a machine with an electromechanical transmission, it is advisable to preserve the geometric parameters and the distribution of weight of the serial chassis. When assessing the parameters of turning of the chassis, one can use the dependencies proposed in working [27].

The coupling device of the transporter should be simplified due to the absence of the need to transfer power along the mechanical branch to the transmission of the rear section.

Research to determine the parameters of the power distribution mechanism for a wheeled tractor with an articulated frame [17] show that the load on the turning mechanism can be reduced by controlling the distribution of power on the drive wheels.

The practical application of the proposed technical solutions will improve the key operational properties of the two-link tracked transporter, as expected, without a significant change in curb weight and without restriction on the geography of the regions of operation. Transmission upgrade costs can be partially offset by simplifying the design of the serial chassis. Of further interest is the use of the proposed principles in the design of the chassis of new tracked and wheeled vehicles and the modernization of existing ground vehicles for various purposes.

4. Conclusions

Thus, there is reason to expect that the proposed set of modernization measures will lead to an improvement in the following operational properties of the chassis:

1. The increase in efficiency is predicted by reducing fuel consumption and ensuring the operation of the heat engine mainly at the minimum fuel consumption mode.
2. Reducing emissions of harmful substances is expected due to a reduction in total emissions and the use of modern exhaust gas treatment technologies.
3. The use of double-flow electromechanical transmission will provide improved controllability of the machine and its traction-dynamic properties.
4. The destructive effect on soils with a weak surface layer will be reduced by aligning the normal reactions on the supporting surface of the mover.

The listed improvements in operational properties will make it possible to operate the transporter more efficiently and fit it into the logistic schemes of the transport network of regions with weak road infrastructure.

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