Comparative analysis of tracked vehicles steering mechanism functional properties

Y M Zemlyansky, A A Dyakonov, S V Kondakov* and I A Podzhivotova
South Ural State University, Chelyabinsk, Russia

* kondakovsv@susu.ru

Abstract. The article discusses the advantages for a tracked vehicle of a continuous steering control mechanism. Using the example of an idealized two-stream transmission of industrial tractor, an algorithm has been developed for separating two power flows from an internal combustion engine - to the main transmission and to the steering mechanism, with constant preservation of the maximum engine load.

Tracked vehicles (TV) due to a number of well-known to specialists indisputable advantages are widely used in various spheres of human activity. There is a large variety of TV types of civil (agricultural tractors; industrial tractors; timber industry tractors, etc.) and military (tanks, armored personnel carriers, speedy transport-and- traction vehicles, etc.) purpose. Many types of TV have originated at different times and have their own history of evolutionary development. However, despite significant differences in the TV design, there is a fundamental, common to all feature - side turn scheme, the essence of which is to give the tracks of the right and left sides different rotation speeds, which causes a change in the TV movement direction. The task of regulating the drive wheels (sprockets) rotation speeds of the right and left tracked units is performed by various steering mechanisms (SM), being, as a rule, an independent unit, placed behind the main gear and distributing the power flow between the tracks.

One of the important classification parameters of the SM, determining its structural type, is the method of power supply - single-flow, double-flow and with a separate power supply to each track, and the number of fixed turning radii of the TV - single, multi-stage (SM with discrete properties) and stepless (SM with continuous properties). In the future, the concept of "SM with discrete properties" will correspond to the generalized scheme of SM, presented in Figure 1, and the concept of "SM with continuous properties" - in Figure 2.

The purpose of the work is to evaluate the functional properties and applicability of various types of mechanisms for turning tracked vehicles.

In order to achieve this goal, it is necessary to compare the requirements, imposed on the parameters of the TV rotation due to conditions of its intension, operation and execution of technological operations, with the capabilities of the SM, determined by one or another construction type. In addition to the main requirement - regulating the speeds of the tracks, additional important requirements are placed on the SM, such as, for example, ensuring stable, straight motion of the TV and ensuring smooth entry of the TV into a turn and smooth exit from it, as well as a number of other requirements.
The most significant criteria, affecting the choice of a specific design of the SM, can be [1] energetic, structural, process, ergonomic (the complexity of rotating mechanisms control), and operational (smoothness and accuracy of the rotation operation). Moreover, the last two criteria can indirectly influence through operator fatigue and TV maneuverability on its technical performance.

Due to the increased power of the TV and increasing requirements for their speed and maneuverability, the requirements for maneuvers performing quality became stricter, which, first of all, concerns military tracked vehicles (MTV).

Maneuverability is one of the main tactical and technical characteristics of MTV. Maneuverability is often regarded as a complex vehicle parameter, including turn ability, controllability, terrain crossing capacity, and mobility. Turn ability and controllability are interpreted as ability to maintain or easily change under the action of the control system the direction of vehicle movement. Terrain crossing capacity and mobility, in
contrast to turn ability and controllability, usually poorly depend on the SM and will not be considered in such context.

Maneuverability is important for MTV when moving on the battlefield. Maneuverability is determined by the average movement speed, both along a straight and curved path, curvature of which in real motion conditions is constantly changing. Average movement speed to a large extent depends on the perfection of the transmission and the SM design, namely, on the ability of SM to implement any curvature on the ground at the request of the driver [2].

Experimental studies show [3] that for vehicles with discrete SM properties, the cyclicity of switching on the steering mechanism reaches 96 per kilometer of road, and the average speed limited by the psycho-physiological maximum capabilities of the driver to compensate for fast deviations does not exceed 36 km/h.

In the sphere of civil TVs important role is assigned to industrial tractors. The difference between track type tractors and tanks lies in the implementation of traction modes when operating at low speeds. Industrial use of tractors is characterized by a number of specific features of their operation, such as the cyclical nature of technological processes with poor maneuverability, high uneven loading of the earth-moving unit, etc. Wide using of earthmoving equipment on the basis of industrial tractors is reasoned by high performance at the lowest unit cost of earthmoving operations. A high proportion of tractor work is justified by the fact that, for example, for developing and transporting soil up to 100 m, bulldozing is most advantageous, and the cost of loosening with mounted tractor rippers when developing limestone is 2.3 ... 15 times cheaper than drilling and blasting, for sandstone - 5, 6 times, and for frozen soil - 2.8 times. When operating the bulldozer, soil development and relocating distance is up to 50 m at a speed of up to one meter per second (technological limit) is economically feasible. At longer distances, part of the contents of the blade is lost. From this point of view, the most effective development of the soil is by the trench method, in which walls of the trench prevent the soil losing, which improves productivity. Tractor technical performance is considered as criterion for evaluating its efficiency.

Further increasing in efficiency [4] of skidders operation is limited by imperfect construction of discrete SMs with friction control elements, operating dry and characterized by poor controllability.

Considering the working conditions of the skidder, one of the obvious ways to increase its operational efficiency and to optimize the operator working conditions is to use SMs with continuous properties. For example, a hydrostatic transmission made according to a side scheme, can be used as such SM, allowing step less changing the thrust force according to changes in resistance forces and smoothly turning the vehicle without dissipating energy in the steering mechanisms.

Thus, it is shown that power take-off on industrial tractors of various process duties can constitute a significant part of the engine power, available on board. Power can be taken-off may be either an attachment or a steering mechanism.

Installing of a differential steering mechanism, structurally including a hydrostatic drive (HSD), required separating the engine power into two flows. Moreover, main transmission, including hydro torque converter (HTC), and a hydrostatic SM drive have the features of joint operating with the engine. HTC has internal automaticity [5], and HDS - external automaticity [6]. Depending on the control action, the SM takes from the internal combustion engine as much power, as required for assuring the movement trajectory. Where,

$$\omega_M = \omega_{ICE} U_1,$$

where $\omega_M$ - HSD SM engine speed, $\omega_{ICE}$ - rotational speed of the engine crankshaft, $U_1$ - parameter of the HSD SM pump control (relative angle of rotation of the wobble plate of the HSD SM axial piston pump).

A transparent TC according to its loading properties (dimensionless characteristic of the torque coefficient) reduces the HTC pump and the associated engine of the engine crank shaft rotation speed, and, therefore, shifts the engine from the mode of a given potential power (Figure 3). As a result, pow-
er of the internal combustion engine decreases, and, accordingly, total net power of the bulldozer also decreases.

![Figure 3. Joint operation of the internal combustion engine and the HTC curve](image)

Absolutely similarly, two power flows interact in the usual sense of “work with power take-off”: the attachments take necessary amount of power, while the rest of the potential power of the engine cannot be fully used for moving due to the peculiarities of the joint operation of the TC blades and the engine.

Next, we consider a variant of an idealized main transmission - electric or hydrostatic [7,8]. Both of them make it possible to regulate the generator interaction (in the case of electric transmission) or the HSD pump (in the case of hydrostatic drive) with the internal combustion engine so that in any power take-off (including the SM) variant it would be possible to keep the power taking-off from the engine at the maximum level.

Advanced requirement can be formulated as follows: in case of arbitrary supply of the HSD pump of the steering mechanism, set by the operator, the tractor should move with the maximum possible (for a given position of the accelerator pedal) speed. For a numerical description of this requirement, the concept of linear tractor moving speed \( V \) and angular velocity of the tractor body rotation \( \omega \) around a vertical axis passing through its center of gravity is introduced.

It is necessary to establish a balance of power between rectilinear motion and rotation, that is, between \( V \) and \( \omega \) according to method [9]. Discussed problem is solved for high-speed track type vehicles. Low-speed, which include industrial track type, have a number of features taken into account in the calculation. In particular, the moment of resistance to turning

\[
M_C = \frac{\mu GL}{4},
\]

where \( \mu \) - coefficient of resistance to turning according to [10]; \( G \) - tractor weight, N; \( L \) - longitudinal base of the tractor, m.

Strength of resistance to movement, N:

\[
P_C = P_T = G\psi,
\]

where \( P_T \) - traction force, N; \( \psi \) - coefficient of resistance to the tractor's rectilinear motion. The power balance equation is:

\[
N_{ICE} = \frac{G\psi V}{\eta_{TR}} + \frac{\mu GL\omega}{4\eta_{SM}},
\]

where \( \eta_{TR} \), \( \eta_{SM} \) - Efficiency of the main transmission and steering mechanism, respectively. For the following initial conditions: \( \eta_{TR} = \eta_{SM} = 0.8 \), \( N_{ICE} = 100kW \), \( \psi = 0.2 \), \( \mu_{max} = 0.8 \) the solution of equation (1) is the functional dependence \( \omega (V) \), given in Figure 4.
Key to the generating the algorithm of the controller that controls the tractor’s transmission (supply of the main transmission HSD pump) is shown in the graph in Figure 4 by equation

\[ \omega = \omega_{ICE} U_1 i_1 \]

\[ V = \omega_{ICE} U_2 i_2 R_{DS} \]

where \( U_1, U_2 \) - relative parameters of the HSD SM pump and main transmission regulation, respectively; \( i_1, i_2 \) - gear ratios in the kinematic chain of the SM and the main transmission; \( R_{DS} \) - radius of the drive sprocket, m.

The dependence of \( \omega \) on \( V \) between angular and linear velocity of the tractor is approximated by a linear function:

\[ \omega = aV + b \],

where according to Figure 4

\[ a = -\frac{\omega_{ICE} i_1}{\omega_{ICE} i_2 R_{DS}}; \quad b = \omega_{ICE} i_1. \]

Solving jointly (2), (3) and (4) and taking into account (5), we get:

\[ \omega_{ICE} U_1 i_1 = a(\omega_{ICE} U_2 i_2 R_{DS}) + b \]

or

\[ U_1 = 1 - U_2 \]

Figure 4. The dependence of \( \omega \) on the power balance.

Equation (6) is a linearized representation of the relationship between the control action on the steering mechanism and the main transmission while maintaining the balance of power of the internal combustion engine.

Thus, the requirement for joint control of the steering mechanism and the main transmission has received a mathematical description.

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