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ADAPTATION OF ALL-WHEEL DRIVE WHEELED TRANSPORT AND TRACTION VEHICLES TO NATURAL AND CLIMATIC CONDITIONS

The article develops a methodology for adapting all-wheel drive vehicles to natural and climatic conditions. To achieve this goal, the following tasks have been solved: the conditions that the longitudinal base and horizontal coordinate of the centre of mass of a multi-axle wheeled tractor with a given operating weight should meet are determined; the balance of the train's capacities in low and high mountainous areas is determined; the methodology for increasing the manoeuvrability of an all-wheel drive vehicle depending on the traction properties of the propulsion systems is substantiated. All-wheel drive vehicles are operated on roads of different quality, and in some cases off-road. It is difficult to classify and quantify all the variety of road conditions, especially when you take into account that, depending on the season and specific regional conditions, the complex interaction of similar roads when a vehicle is driving can vary. The wheel overload of an 8-axle wheel tractor with an operating weight of 120 kN does not exceed 20% when the centre of mass is shifted forward by 0.38 m. When operating this tractor with a loaded trailer weighing 10 tonnes in high mountainous terrain, its tractive power is reduced by 6.0% compared to operation in lowland terrain. When an all-wheel drive tractor with a loaded trailer is operating in high mountainous terrain, its tractive power is reduced by 6.0% compared to lowland terrain. One of the ways to increase the manoeuvrability of wheeled all-wheel drive vehicles may be to reduce their longitudinal base. At the same time, it should be noted that with an increase in the turning speed and a decrease in wheel grip of shortened vehicles, the increase in their manoeuvrability is not significant.

Key words: *traction vehicle, all-wheel drive vehicle, centre of mass, longitudinal base, manoeuvrability, power balance, traction properties, natural and climatic conditions.*

Formulation of the problem. All-wheel drive wheeled transport and traction vehicles (AWTTV) are designed to perform transport work in particularly difficult climatic conditions [1]. Usually, these machines are operated under different climatic and road conditions with instability of loading modes of operation. It is known [2] that atmospheric instability is significantly influenced by four climate-related factors: humidity, heat supply, thermal conditions of the cold period, and continental climate [3]. The operation of AWTTVs is possible on roads in low and high mountainous areas under different atmospheric pressures, which leads to instability in the values of its traction and power indicators [4].

Analysis of recent research and publications. All-wheel drive vehicles are operated on roads of varying quality, and in some cases off-road. It is difficult to classify and quantify all the variety of road conditions, especially if we take into account that, depending on the season and specific regional conditions, the complex interaction of similar roads when a vehicle is driving may vary. Therefore, to assess the road and climatic conditions of AWTTVs, the following approach has become widespread: the overall assessment of the complexity of the operating conditions is qualitative; quantitative assessment is given only by individual indicators that characterise a particular property of the road, a factor of road and climatic conditions [5, 6]. The adaptation of AWTTVs to natural and climatic conditions is assessed on the roads:

– dirt and forest roads during the off-road period;
– broken dirt roads, in dry and sandy terrain;
– natural dirt roads, virgin steppe, marshy soils.

The level of cross-country ability of AWTTVs is characterised by a set of the following, largely interrelated, features [6, 7]:

– the number of driving axles or wheel formula – two-axle (4x4), three-axle (6x6), four-axle (8x8) and multi-axle (10x10, 12x12, etc.) vehicles and road trains with active semi-trailers

– conditional average ground pressure (kPa) created by the vehicle's engines with a full load, which is equal to the ratio of the full load from the wheels of the vehicle to the projection area of the overall dimensions of all tyres on the bearing surface;

– even distribution of the AWTTV gross weight along the axles, which is close to optimal for off-road vehicles, as it ensures less rutting and reduced driving resistance;

– to reduce driving resistance on bad roads and off-road, AWTTVs in a road train must have the same track and tyre pitch on the tractor and trailer when the tractor weight exceeds the trailer weight.

In Ukraine, the most popular all-wheel drive vehicles are classical and special-purpose (Fig. 1).

a *b*

Fig. 1. Four-wheel drive vehicles: ***a*** **– KrAZ-6446 Burlak truck tractor;** ***b*** **– KrAZ-6511C6 dump truck**

Task statement. The purpose of the article is to develop a methodology for adapting all-wheel drive vehicles to natural and climatic conditions. To achieve this goal, it is necessary to solve the following tasks:

– to determine the conditions that the longitudinal base and horizontal coordinate of the centre of mass of a multi-axle wheeled tractor with a given operating weight must meet;

– to determine the balance of road train capacities in lowland and highland areas;

– to substantiate the methodology for increasing the manoeuvrability of an all-wheel drive vehicle depending on the traction properties of the propulsion systems.

Outline of the main material of the study. Determination of the conditions that must be met for the longitudinal base and horizontal coordinate of the centre of mass of a multi-axle wheeled tractor with a given operating weight. Determine the conditions that the longitudinal base and horizontal coordinate of the centre of mass of a multi-axle wheeled tractor with an operating weight of 120 kN must meet so that the overload of the wheels during continuous operation does not exceed 20%, and during the nominal mode with a hook pulling force $P_{h.l}$ = 50 kN, the load of the wheels is distributed equally.

Tractor design features: individual suspension, reduced to the axles of the support wheels, stiffness is constant and the same for all wheels. All wheels are drive wheels, the set height is constant. The height of the coupling point is h_h = 0.8 m. The design scheme of the tractor (Fig. 2), given the known kinematic parameters l_n, x_g, x_i, h, h_h, a, L, allows us to assess its loading modes.

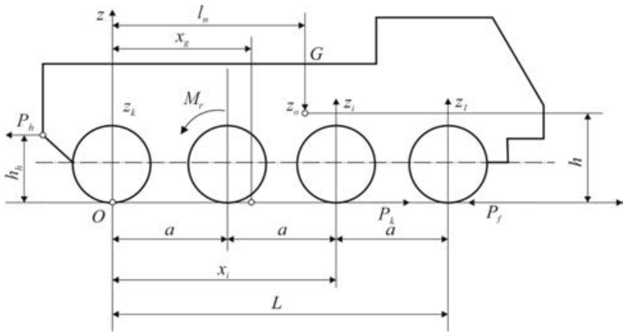

Fig. 2. Design scheme of a multi-axle wheel tractor

According to this scheme, when the number of support wheels is k, the distribution of reactions z_i of the contact of the tractor's support wheel with the road is estimated:

$$\left.\begin{aligned} & z_a = \sum_{i=1}^{k} z_i / k; \\ & \beta = \frac{z_k - z_a}{z_a}; \;\; z_i = z_1 + \Delta z(i-1); \\ & \Delta z = (z_k - z_1)/(k-1); \;\; x_i = a(k-i) \end{aligned}\right\}. \quad (1)$$

From the conditions for determining the centre of pressure of the wheels x_g on the ground, taking into account the dependencies (1), with $a=L/(k–1)$, we have

$$x_g = L\left[\frac{k}{k-1} - z_1\frac{(k+1)}{2(k-1)z_a} - \frac{(z_k - z_1)(k+1)}{3z_k(k-1)}\right]. \quad (2)$$

Since

$$z_a = \sum_{i=1}^{k} z_i / k = (z_1 + z_k)/2; \; z_k / z_a = 1+\beta; \; z_1 / z_a = 1-\beta$$

dependence (2) is written in the form

$$x_g = \frac{L}{2}\left(1 - \frac{\beta}{3}\cdot\frac{k+1}{k-1}\right). \quad (3)$$

Thus, in order to avoid overloading the outer wheels, the overload coefficient should not exceed –0,2 $\le \beta \le$ +0,2.

When operating with the maximum hook pull, the overload of the rear wheel must satisfy the condition ($\beta \le 0{,}2$)

$$x_g \ge \frac{L}{2}\left[1 - \frac{1}{15}\left(\frac{k+1}{k-1}\right)\right]. \quad (4)$$

When working without hook traction, the front wheel will be overloaded ($\beta \geq -0{,}2$)

$$x_g \leq \frac{L}{2}\left[1+\frac{1}{15}\left(\frac{k+1}{k-1}\right)\right]. \quad (5)$$

Given the operating weight of the tractor G, the rolling resistance coefficient f at the dynamic wheel radius r_d, the rolling resistance moment is written as

$$M_r = fGr_d.$$

Neglecting the air resistance, from the equation of moments of acting forces we obtain

$$x_g = \left(Gl_n - M_r - P_h h_h\right)/G \quad (6)$$

keeping in mind that $x_o=G$.

At the largest value of the traction force on the hook, from the equation of force projections on the x-axis, given that the largest tangential force P_h of traction on the clutch $P_h=\varphi G$, we obtain

$$P_{h\ \max} = P_h - P_f = (\varphi - f)G. \quad (7)$$

Substituting (7) into (4), the overload of the rear wheel during the operation of the tractor with the maximum traction force on the hook is estimated by inequality

$$\frac{Gl_n - M_o - G(\varphi - f)h_h}{G} \geq \frac{L}{2}\left[1-\frac{1}{15}\left(\frac{k+1}{k-1}\right)\right], \quad (8)$$

If P_h=0, condition (5) will take the form

$$\frac{Gl_n - M_r}{G} \leq \frac{L}{2}\left[1-\frac{1}{15}\left(\frac{k+1}{k-1}\right)\right]. \quad (9)$$

Comparing (9) and (8), we obtain the inequality

$$(\varphi - f)h_h \leq \frac{L}{15}\cdot\frac{k+1}{k-1}, \quad (10)$$

from where

$$L \geq \frac{15(\varphi - f)h_h(k-1)}{(k+1)}. \quad (11)$$

At h_h=0,8 m; φ=0,7; f=0,1 we obtain

$$L \geq 7{,}2\frac{k-1}{k+2}. \quad (12)$$

With the number of wheels K=8, we have L>0,77 m; K=6–L>5,15 m.

At the value of the tractor base that satisfies condition (12), we have the coordinates of the centre of mass at the dynamic radius and wheel r_d=0,5 м

$$L\left(0{,}5-0{,}0333\frac{k+1}{k-1}\right)+0{,}53 \leq l_n \leq L\left(0{,}5+0{,}0333\frac{k+1}{k-1}\right)+0{,}05\cdot$$

Consequently, at ,

$$K = 8 - 0{,}521L + 0{,}53 \leq l_n \leq 0{,}621L + 0{,}05,$$

$$K = 6 - 0{,}453L + 0{,}53 \leq l_n \leq 0{,}547L + 0{,}05.$$

The uniform distribution of loads over the wheels corresponds to β=0 or $x_g=L/2$ according to (1). Therefore, from equation (5), when $P_h=P_{h.n}$, we obtain

$$l_n = \frac{L}{2} + \frac{P_{h.n}h_h + M_r}{G}. \quad (13)$$

Equation (13) shows that for a uniform distribution of loads over the wheels during the nominal operating mode, regardless of the support base and the number of wheels, the centre of mass of the tractor must be shifted forward from the average surface by

$$x = l_n - \frac{L}{2} = \left(P_{h.n}h_h + M_r\right)/G = \frac{50\cdot 0{,}8}{120} + 0{,}05 = 0{,}38\,\text{m}.$$

Thus, the wheel overload of an 8-axle tractor with an operating weight of 120 kN will not exceed 20% when the centre of mass is shifted forward by 0.38 m.

Determination of the balance of road train capacities in lowland and highland areas. Determine the power balance of a road train in low and high mountainous terrain under the following conditions: a 15 t all-wheel drive tractor with a 10 t trailer is moving on roads of the first category (off-road) at a speed of 10 km/h. Calculate the power balance of the road train for two cases of movement on the terrain:

– owland at an atmospheric pressure of 101.325 kPa and an air temperature of +6°C;

– highlands at an atmospheric pressure of 75.99 kPa and an air temperature of –15°C.

Wheel adhesion coefficient φ= 0.7; tractor transmission efficiency η_T = 0.92, tractor cross-sectional area 7 m^2, streamlining factor C_x= 0.7. The wheel shape of the tractor is 6x4 with 10 tyres of size 9.00 R20.

The power balance of the road train coming from the engine to the transmission is written in the form:

$$N_p = P_f v + (G+Q)v\sin\alpha + P_w + P_k\delta v/(1-\delta), \quad (14)$$

where P_f is the force of resistance to rolling of the wheels of a road train on the road; v is the speed of the road train; G, Q is the gross weight of the tractor and trailer; α is the angle of the road slope; P_k, δ is the total tangential traction force of the drive wheels and their slip coefficient; P_w is the air resistance force.

The first two components of equation (14) are the power consumed to overcome the total road resistance:

$$P_f = f_v(G+Q),$$

where the coefficient f_v takes into account the rolling speed of the wheels $f_v=f(1+2{,}5\cdot10^{-4}v^2)$=0,0285.

The slopes on the roads of the first category do not exceed 30% [7], so the total coefficient of road resistance, assuming $tg\alpha=\sin\alpha=\alpha$; $\cos\alpha$=1, is determined by $\psi=f_v\ cos\alpha+sin\alpha$=0,0586. The power consumed to overcome the path resistance is шляху $v(P_f+G\ sin\alpha)=\psi v(G+Q)$=400 kW.

The tangential traction force from the traction balance equation is estimated by Eq:

$$P_k = \psi(G+Q)+P_w, \tag{15}$$

where is the air resistance pressure force

$$P_w = C'_x \rho F v^2 / 2, \tag{16}$$

C'_x is the coefficient of resistance to flow of the road train, which is 10% higher than the same value for the tractor, i.e. G'_k=0,77; ρ is the air density when the road train is operating in lowland areas 1.37 kg/m^3, in highland areas 0.89 kg/m^3.

The force P_w and power $N_w=P_w v$ consumed to overcome this resistance when operating a road train in lowland terrain is P_w=2849 N, N_w=79.1 kW; in highland terrain – P_w=1851 N, N_w=51.4 kW. The tangential traction force of all drive wheels according to Equation (15) in the first case is P_{k1}=17.2-103 N, in the second case P_{k2}=16.2-103 N. When the tractor wheels slip δ =5.0 %, the power consumption for sliding in the first case is N_δ=2.48 kW, in the second case – 2.24 kW.

The power supplied from the engine to the transmission goes to the transmission of the tractor vehicle, calculated by dependence (14), in the first case N_{p1}=523.3 kW, in the second – 493.1 kW.

Thus, the operation of an all-wheel drive tractor with a loaded trailer in high mountainous terrain reduces its traction power by 6.0% compared to operation in lowland terrain.

Substantiation of a methodology for increasing the manoeuvrability of an all-wheel drive vehicle depending on the traction properties of the propulsion systems. We substantiate a methodology for increasing the manoeuvrability of an all-wheel drive vehicle with a wheel formula 8x8 and a longitudinal base L = 4.4 m at a turning speed of 2.5 m/s to 3.1 m/s, depending on the traction properties of the propulsion systems.

Manoeuvrability in conjunction with controllability is one of the most important operational properties of wheeled vehicles that determine the efficiency of use and traffic safety [8, 9]. The proposed turning scheme of a vehicle with a wheel formula 8x8 is aimed at reducing the longitudinal axis to make a turn with a minimum radius (Fig. 3).

The turning radius R of the vehicle is determined by the formula

$$R = L \cdot ctg\varphi, \tag{17}$$

where L is the longitudinal base of the vehicle, φ is the average steering angle of the steered wheels.

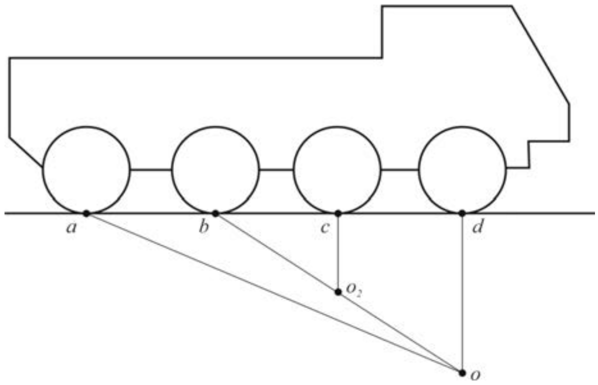

Fig. 3. Turning pattern with a minimum turning radius for an all-wheel drive vehicle with a reduced longitudinal base

When manoeuvring while driving or in a stationary state with $R>R_{min}$, the steered wheels of the first and second drive axles turn at certain angles, providing the required vehicle trajectory. Moreover, the steering trapezoids of the axles ensure that the steered wheels do not slip within the same side (point *o* is the common centre of rotation). The longitudinal base of the vehicle is *ad*, and the turning radius is *od* (Fig. 3).

It is proposed [8] to simultaneously lift the first (point *d*) and fourth (point *a*) drive axles. In this case, the longitudinal base is determined by the segment *bc*, the centre of rotation of the vehicle moves to the point o_2 with a turning radius $R=o_2c$. The main trajectory of the vehicle when performing one of the most commonly used manoeuvring schemes (90° or 180° turn, overtaking or overtaking) consists of three sections: the input, circular and output.

The circular section of the main trajectory is an arc of a circle with a radius R_o min, which reduces the central angle φ_k: $R_{omin}=L/tg\varphi_{max}$. Transition sections of the main trajectory (input and output) are curves described by the parametric equations:

$$\left.\begin{aligned} x_o &= \frac{1}{k_n}\int_o^{\varphi_{\max}} \cos\left(-\frac{l_n\cos\varphi_o}{\kappa_n L}\right)d\varphi_o; \\ y_o &= \frac{1}{k_n}\int_o^{\varphi_{\max}} \sin\left(-\frac{l_n\cos\varphi_o}{k_n L}\right)d\varphi_o \end{aligned}\right\}, \tag{18}$$

where φ_o is the angle of inclination of the longitudinal axis of the vehicle to the abscissa axis; $k_n=\dot{\varphi}/v_o$ is the turning mode parameter; $\dot{\varphi}$ is steering wheel turning speed; v_o is the vehicle turning speed.

The minimum value of the mode parameter depends on the longitudinal base L, the turning speed v_o and the coefficient of adhesion of the wheels to the ground φ_c (Fig. 4, Fig. 5):

$$k_n \le arctg\frac{q\varphi_c}{v_o^2}\cdot\frac{L}{v_o \cdot t}. \tag{19}$$

The analysis of these dependencies allows us to conclude that one of the ways to increase the manoeuvrability of all-wheel drive wheeled vehicles can be to reduce their longitudinal base. At the same time, it should be noted that with an increase in turning speed and a decrease in wheel adhesion to the ground, the efficiency of shortened vehicles does not significantly increase their manoeuvrability.

When designing all-wheel drive transport and traction vehicles, in particular a heavy military truck with a 6x6 wheel formula [9], the effectiveness of modelling its dynamics in relation to kinematic parameters has been proven.

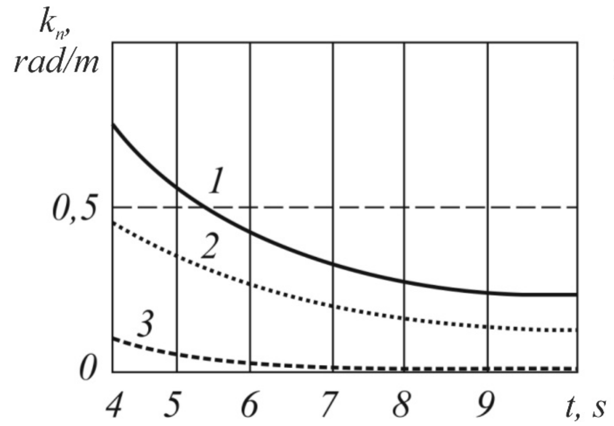

Fig. 4. Dependence of the mode parameter k_n on the time of turning the angle of different turning speeds: 1 – v_o=1,8 m/s; 2 – v_o=2,2 m/s; 3 – v_o=4,2 m/s

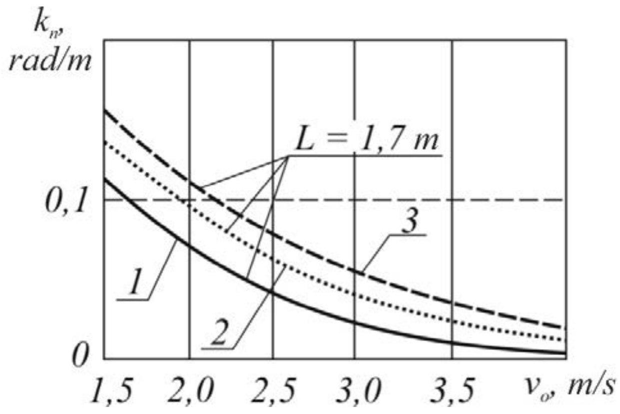

Fig. 5. Dependence of the mode parameter k_n on the turning speed v_o within 10 sec for: 1 – φ_c=0,4; 2 – φ_c=0,6; 3 – φ_c=0,8

Conclusions. All-wheel-drive wheeled transport and traction machines are designed to perform transport work in particularly difficult natural and climatic conditions. The wheel overload of an 8-axle wheel tractor with an operating weight of 120 kN does not exceed 20% when the centre of mass is shifted forward by 0.38 m. When operating this tractor with a loaded trailer weighing 10 tonnes in high mountainous terrain, its tractive power is reduced by 6.0% compared to operation in lowland terrain.

One of the ways to increase the manoeuvrability of wheeled all-wheel drive vehicles is to reduce their longitudinal base. At the same time, it should be noted that with an increase in turning speed and a decrease in wheel grip, shortened vehicles do not significantly increase their manoeuvrability.

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Коробко А.І., Семенов І.В. АДАПТАЦІЯ ПОВНОПРИВІДНИХ КОЛІСНИХ ТРАНСПОРТНО-ТЯГОВИХ МАШИН ДО ПРИРОДНО-КЛІМАТИЧНИХ УМОВ

У статті розроблено методику адаптації повнопривідних автомобілів до природно-кліматичних умов. Для досягнення поставленої мети вирішено наступні задачі: визначено умови, яким повинна відповідати поздовжня база і горизонтальна координата центру мас багатоопорного колісного тягача з заданою експлуатаційною масою; визначено баланс потужностей автопоїзду в низинній та високогірній місцевості; обґрунтовано методику підвищення маневреності повнопривідного транспортного засобу у залежності від зчіпних властивостей рушіїв. Повнопривідні автомобілі експлуатуються на дорогах різної якості, а у ряді випадків по бездоріжжю. Класифікувати й кількісно оцінити усе різноманіття дорожніх умов складно, особливо якщо прийняти до уваги, що у залежності від сезону та специфічних умов регіону комплексна взаємодія однотипних доріг при русі автомобіля може бути різною. Перевантаження коліс 8-ми опорного колісного тягача з експлуатаційною вагою 120 кН не перевищує 20% при зміщенні центру мас вперед на 0,38 м. При роботі даного тягача із завантаженим причепом масою 10 т на високогірній місцевості його тягова потужність знижується на 6,0% у порівнянні з роботою в низинній місцевості. При роботі повнопривідного колісного тягача з завантаженим причепом на високогірній місцевості знижується його тягова потужність на 6,0% у порівнянні із роботою на низинній місцевості. Одним зі шляхів підвищення маневреності колісних повнопривідних транспортних машин може бути зменшення їх поздовжньої бази. Одночасно необхідно відмітити, що з підвищенням швидкості повороту і зниження зчеплення коліс з ґрунтом укорочених транспортних машин підвищення їх маневреності не суттєве.

Ключові слова: *тягова машина, повнопривідна машина, центр мас, поздовжня база, маневреність, баланс потужності, зчіпні властивості, природно-кліматичні умови.*

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