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FORECASTING OF TOWING INDICATORS OF TRACTORS WITH 4k4 WHEEL ARRANGEMENTS

Dmitry S. Gapich[1], Roman A. Kosulnikov[2] and Natalya S. Vorobyeva[2]
[1]Department of Machines Maintenance and Technology of Construction Materials, Volgograd State Agrarian University, Volgograd, Russia
[2]Volgograd State Agrarian University, Volgograd, Russia
E-Mail: sciencescience57@yahoo.com

ABSTRACT

The article deals with mathematical model of forecasting of towing indicators of tractors with 4K4 wheel formula which take into account geometric parameters of tractor's driving wheel tire, physical and mechanical attributes of soil, and constructive peculiarities of AWD tractor. The offered mathematical model allows automatizing calculation of forecasting evaluations for towing and energy indicators of tractor in machine-tractor aggregates.

Keywords: driving wheel, wheel slipping, tractor, tire, grouser.

INTRODUCTION

Assembly of machine-tractor aggregates(MTA) on the basis of tractorswith 4K4 wheel formula consists in substantiation of their mass and energy parameters which ensure high quality of technological process, maximal efficiency with minimal specific fuel and economic and financial costs, and ecological aspects of MTA work which are determined by soil and climatic conditions of exploitation of the machinery [1].Selection of such rational regimes of aggregation is, as a rule, based on the use of theoretical towing characteristics of tractor. Its most important component is dependence of coefficient of movers' sliding δ on towing force on tractor hook $P_{\kappa p}$. Receipt of exact dependence $\delta(P_{\kappa p})$ is possible only in experimental way [2].

From this point of view, mathematical apparatus for forecasting of towing and adhesion indicators of wheel tractors, providing good compliance of results of calculation with results of natural towing tests, becomes actual.

The main theoretical provisions of the offered mathematical model consist in the following [3].

For wheel mover, it is possible to nalytically calculate three peculiar spots which determine main regimes of its work: $1-(1;P_{T\max})$ maximal towing force of wheel; $2-(\delta_{cp};P_{Tcp})$–sliding coefficient at which shift of all "soil bricks" in the spot of tire's contact with soil and corresponding towing force of mover appear; $3-(\delta_{\partial э};P_{T\partial э})$- admissible coefficient of sliding according to ecological attribute and corresponding towing force.

The whole sliding curve is approximated by fractional rational function

$$\delta = \frac{k_\delta p}{1-(1-k_\delta)p^3}, \qquad (1)$$

where $p = P_T / P_{T\max}$ - relative towing force which is a ratio of towing force of movers to maximal possible force for wheel's adhesion with soil; k_δ –proportionality factor.

Parameters of characteristic spots and fractional rational function p and k_δ are calculated according to the following algorithm:

1. Determination of $P_{T\max}$ from the system of equations:

ARPN Journal of Engineering and Applied Sciences

$$\begin{cases} P_{T\max} = Q\left\{\dfrac{(S-b)}{S}\left[\dfrac{2c_0 r_0 (B+2t_н)}{C_r e} + tg\psi - \dfrac{2c_0(B+2t_н)}{C_r}\right] + \mu b\right\} \\ Q = Qc + \dfrac{P_{T\max} h_{кр}}{L} \\ e = e_c + \dfrac{P_{T\max} h_{кр}}{L\left[1.44\sqrt[3]{\dfrac{C_r^2 Q\left(1+\sqrt{k+1}\right)^2}{r_0}}\right]} \end{cases} \quad (2)$$

where Q – vertical load on tractor's driving wheel, H; S - circular pitch of grousers, m; b – width of grouser, m; c_0 - coefficient of soil adhesion, N/m^2; r_0 – wheel's free radius, m; B – tire width, m; t_H - external height of grouser, m; C_r - radial stiffness of singular tires sector, N/(m·rad); e - maximal vertical deformation of tire, m; ψ – angle of internal friction of soil; μ – coefficient of rubber's friction with soil; Q_c - static load on tractor's driving wheel, H; $h_{кр}$ – height of hook loading point, m; L – long base of tractor, m; k – coefficient of relative stiffness of tire, e_c – deformation of driving wheel's tire under the influence of static vertical load, m.

2. Calculation of parameters of shift of all "soil bricks": sliding coefficient δ_{cp} and corresponding towing force P_{Tcp}:

$$\begin{cases} \left(r_0 - \dfrac{t}{2}\right)\dfrac{t_p}{t}\delta_{cp} = \left(1-\delta_{cp}\right)^2 \dfrac{S-b}{S} r_0\left[\dfrac{2c_0(B+2t_н)r_0}{C_r e} + tg\psi - \dfrac{2c_0(B+2t_н)}{C_r}\right] \\ Q = Q_c + \dfrac{P_{Tcp} h_{кр}}{L} \\ e = 1{,}04\cdot\sqrt[3]{\dfrac{Q^2 r_0}{C_r{}^2\left(1+\sqrt{k+1}\right)^2}} \\ P_{Tcp} = Q\ \dfrac{S-b}{S}\cdot\dfrac{r_0}{r_0 - e}\cdot\left[\dfrac{2c_0(B+2t_н)r_0}{C_r e} + tg\psi - \dfrac{2c_0(B+2t_н)}{C_r}\right] + \mu Q\dfrac{b}{S}\delta_{cp} \end{cases} \quad (3)$$

where $t_p = 0,5(t+t_н)$ – planned height of grouser, m; t - height of grouser, m.

3. Calculation of admissible coefficient of sliding $\delta_{дэ}$ and corresponding towing force $P_{Tдэ}$.

$$\begin{cases} \delta_{дэ} = \dfrac{\delta_{cp}}{i_{py}} \\ P_{T_{дэ}} = \mu\left(Q - Q_m\dfrac{S-b}{S}\right)\delta_{дэ} + Q\dfrac{i_{py}\delta_{дэ}}{1-i_{py}\delta_{дэ}}\cdot\dfrac{r_0 - \frac{t}{2}}{r_0 - e}\cdot\dfrac{t_p}{t} + \dfrac{\delta_{дэ} Q_{m_{cp}}}{r_0 - e}\cdot\dfrac{S-b}{S}\cdot r_0 \times \\ \quad \times\left[\dfrac{2c_0(B+2t_н)r_0}{C_r e_{m_{cp}}} + tg\psi - \dfrac{2c_0(B+2t_н)}{C_r}\right] \end{cases} \quad (4)$$

ARPN Journal of Engineering and Applied Sciences

where i_{py} - planned number of contractions of "soil brick".

Parameter of fractional rational function that passes through point $2-\left(\delta_{cp};P_{Tcp}\right)$, which characterizes the shift of all "soil bricks" or point $3-\left(\delta_{\partial э};P_{T\partial э}\right)$, which characterizes admissible shift of "soil brick", are calculated by the following formula

$$k_\delta = \frac{\delta_{23}\left(1-p^3\right)}{p-\delta_{23}p^3} \quad (5)$$

Parameter k_δ of fractional rational function is – by physical sense – slope ratio of tangent line to curve $\delta = f(P_T)$ at the beginning of coordinates. Therefore, the closer characteristic point is to work (initial) area of sliding curve, the more precisely fractional rational function describes the process of wheel tractor's sliding.

The results of calculation of support points and curves of sliding in coordinates $(P_T;\delta)$ for front (lagging) and rear (running ahead) axles of tractor HTZ-150K, under the condition that at the initial stage the work of driving axles is viewed independently of each other, are shown in Figure-1.

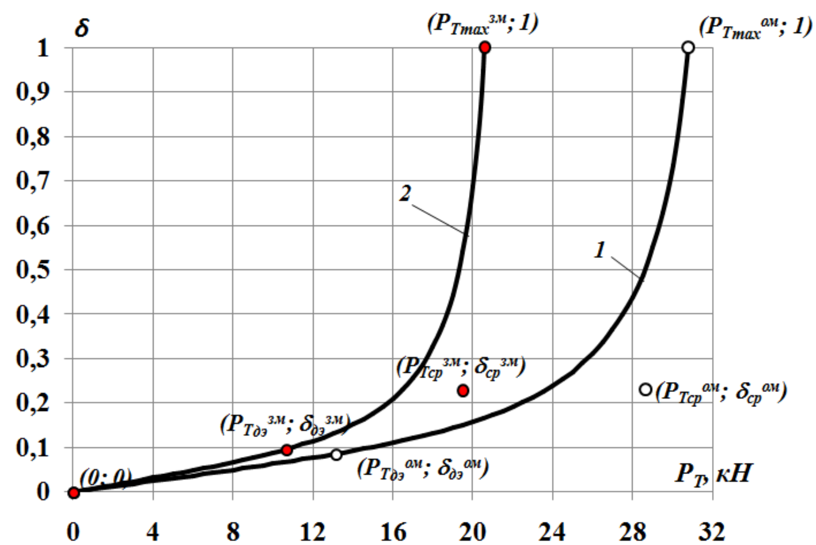

Figure-1. Correspondence of sliding coefficients on the realized towing force by movers of driving axles of tractor HTZ-150K. *1* - front axlemovers; *2* - rear axle movers.

Such presentation of sliding curves of wheel tractor is not informative for specialists on tractors exploitation. They need a general sliding curve which takes into account towing efficiency of the whole tractor [4]. Viewing sliding coefficient of AWD tractor as an energy parameter, we have the following correspondence:

$$\delta = \frac{\delta_1 P_{k_1}(1-\delta_1)+\delta_2 P_{k_2}(1-\delta_2)}{P_{k_1}(1-\delta_1)+P_{k_2}(1-\delta_2)}, \quad (6)$$

where δ - certain conventional sliding coefficient of AWD tractor; P_{k_1}, P_{k_2} – tangential forces, produces by movers of front and rear axles of tractor, N; δ_1, δ_2 - sliding of movers offront and rear axles of tractor.

Therefore, addition of curves of sliding of front and rear tractor axles is possible, but only in coordinates $\delta = f(P_к)$. Transition from correspondence $\delta = f(P_T)$ to correspondence $\delta = f(P_к)$ for tractor T-150Kis presented by the following equation systems:
for front (lagging) axle:

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$$\begin{cases} 1) \quad P^3_{k\max}(\delta_{\partial э}P_{k_{cp}} - \delta_{cp}P_{k_{\partial э}}) - P_{k\max}\delta_{\partial э}\delta_{cp}(P^3_{k_{cp}} - P^3_{k_{\partial э}}) + \\ + P_{k_{\partial э}}P_{k_{cp}}(P^2_{k_{cp}}\delta_{cp} - P^2_{k_{\partial э}}\delta_{\partial э}) = 0, \\ 2) \quad P_{k_{\partial э}} = \frac{1}{1-\mu_k Q_{\partial э} r_b}\left\{\left[\frac{cBk^2_{\Pi}}{(1-\delta_{\partial э})^2} + \frac{\alpha C_r}{r_0 - e_{\partial э}}\right]\frac{e^2_{\partial э}}{2} + \mu_k P_{кр_{\partial э}} Q_{\partial э} r_b\right\} + \\ + Q_{\partial э}\cdot\frac{r_0 - \frac{t}{2}}{r_0 - e_{\partial э}}\cdot\frac{i_{py}\delta_{\partial э}}{1 - i_{py}\delta_{\partial э}}\cdot\frac{t_p}{t} + \mu\left(Q_{\partial э} - Q_{m_{\partial э}}\cdot\frac{S-b}{S}\right)\delta_{\partial э} + \frac{\delta_{\partial э}M_{(cp)}}{r_0 - e_{\partial э}}, \\ 3) \quad P_{k_{cp}} = \frac{1}{1-\mu_k Q_{cp} r_b}\left\{\left[\frac{cBk^2_{\Pi}}{(1-\delta_{cp})^2} + \frac{\alpha C_r}{r_0 - e_{cp}}\right]\frac{e^2_{cp}}{2} + \mu_k P_{кр_{cp}} Q_{cp} r_b\right\} + \\ + \frac{S-b}{S}\cdot\frac{r_0 Q_{m_{cp}}}{r_0 - e_{cp}}\left(\frac{2c_0 r_0(B+2t_н)}{C_r e_{m_{cp}}} + tg\psi - \frac{2c_0(B+2t_н)}{C_r}\right) + \mu\left(Q_{cp} - Q_{m_{cp}}\cdot\frac{S-b}{S}\right)\delta_{cp}; \end{cases}$$

for rear (running ahead) axle:

$$\begin{cases} 1) \quad P^3_{k\max}(\delta_{\partial э}P_{k_{cp}} - \delta_{cp}P_{k_{\partial э}}) - P_{k\max}\delta_{\partial э}\delta_{cp}(P^3_{k_{cp}} - P^3_{k_{\partial э}}) + \\ + P_{k_{\partial э}}P_{k_{cp}}(P^2_{k_{cp}}\delta_{cp} - P^2_{k_{\partial э}}\delta_{\partial э}) = 0, \\ 2) \quad P_{k_{\partial э}} = \frac{\mu_k P_{кр_{\partial э}} Q_{\partial э} r_b}{1-\mu_k Q_{\partial э} r_b} + Q_{\partial э}\frac{r_0 - \frac{t}{2}}{r_0 - e_{\partial э}}\cdot\frac{i_{py}\delta_{\partial э}}{1 - i_{py}\delta_{\partial э}}\cdot\frac{t_p}{t} + \mu\left(Q_{\partial э} - Q_{m_{\partial э}}\frac{S-b}{S}\right)\delta_{\partial э} + \\ + \frac{\delta_{\partial э}M_{(cp)}}{r_0 - e_{\partial э}}, \\ 3) \quad P_{k_{cp}} = \frac{\mu_k P_{кр_{cp}} Q_{cp} r_b}{1-\mu_k Q_{cp} r_b} + \frac{S-b}{S}\cdot\frac{r_0 Q_{m_{cp}}}{r_0 - e_{cp}}\left(\frac{2c_0 r_0(B+2t_н)}{C_r e_{m_{cp}}} + tg\psi - \frac{2c_0(B+2t_н)}{C_r}\right) + \\ + \mu\left(Q_{cp} - Q_{m_{cp}}\cdot\frac{S-b}{S}\right)\delta_{cp}, \end{cases} \tag{7}$$

where representation of parameters is the same as in formulas (1,2), but for movers of front and rear tractor axles, accordingly.

Coordination of work of tractor's driving axles is determined by equality of advance speeds [5], so the values of support point of sliding curve of movers of the least loaded axle (running ahead) is corrected according to values of support points of sliding curve of movers of most loaded axle (lagging) by the following correspondences:

$$\delta^{зм}_{\partial э_{расч}} = \frac{\delta^{ом}_{\partial э} - k_н}{1 - k_н},$$

$$P^{зм}_{k_{опт}} = p^{зм}_{опт}\cdot P^{зм}_{k\max} \tag{8}$$

ARPN Journal of Engineering and Applied Sciences

where $k_H = 1 - \frac{r^{зм}_{\partial}}{r^{ом}_{\partial}} \frac{i^{ом}}{i^{зм}}$ - coefficient of kinematic irrelevance of driving axles' movers; $r^{зм}_{\partial}$, $r^{ом}_{\partial}$ – dynamic radii of rolling motion of running ahead and lagging wheels; $i^{зм}$, $i^{ом}$ – transmission numbers of drive of running ahead and lagging wheels; $p^{зм}_{опт}$ - relative towing force of rear (running ahead) axle, calculated by the equation's result.

$$\left(p^{зм}_{опт}\right)^3 + \frac{k^{зм}_{\delta}}{\delta^{зм}_{\partial э_{расч}}(1-k^{зм}_{\delta})} p^{зм}_{опт} - \frac{1}{1-k^{зм}_{\delta}} = 0; \quad (9)$$

$k^{зм}_{\delta}$ – coefficient of proportion of fractional rational approximation of rear axle $\delta^{зм} = f(P_k)$; $P^{зм}_{k_{\max}}$ – maximal tangential force at rear axle.

Calculation of characteristic points and sliding curves in coordinates $(P_k; \delta)$ for movers of front and rear axles of tractor HTZ-150K are represented by graphical dependencies of Figure-2 (curves 1 and 2).

Total optimal tangential force, developed by movers of front and rear axle, is calculated the following way:

$$P_к = P^{зм}_{к_{опт}} + P^{ом}_{к_{опт}}. \quad (10)$$

Corresponding sliding coefficient for this planned optimal total tangential force is calculated according to the formula (6).

Calculations for this algorithm allow determining characteristic work regime of AWD tractor which corresponds to nominal (admissible) tangential force. This point could be used for analytical determination of proportion coefficient k_{δ} of fractional rational function, describing "conventional" sliding curve of the whole tractor. Results of calculation are presented by curve 3 in Figure-2, with results of natural towing tests of tractor HTZ-150K (curve 4).

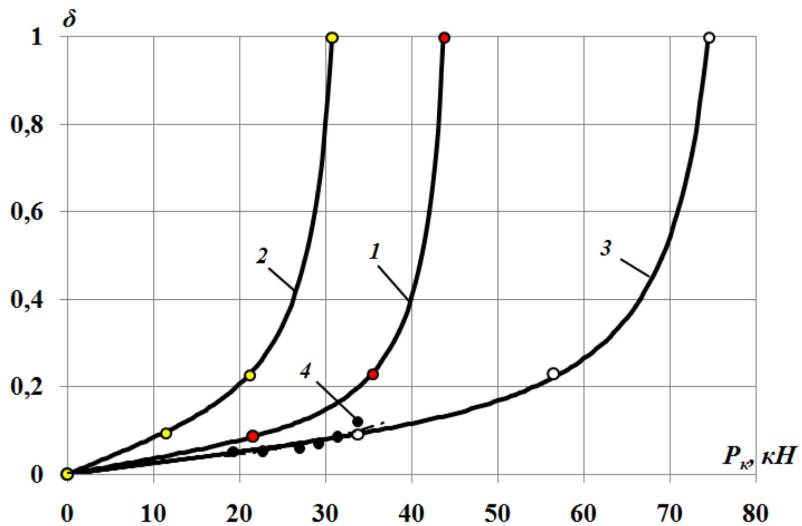

Figure-2. Correspondences of sliding coefficient to realized tangential force by movers of driving wheels of tractor HTZ-150K. *1* - movers of front axle; *2* - movers of rear axle; *3* - total tangential force of movers of front and rear axles; 4 - experimental data.

Programming of the offered mathematical models in *Mathcad* allowed developing a package of applied software "*Tractive Power"*, which allows forecasting analytically the towing capacities of wheeltractorsof various constructive schemes and evaluating their exploitation indicators in view of regional work peculiarities [6].

On the whole, the Tractive Power package could be used for:

a) comparative evaluation of towing attributes of wheeltractorsrelating to one towing class;

b) evaluation of suitability of wheel tractors to local conditions of exploitation and regimes of their violation in MTA;

c) evaluation of correspondence of designed wheel tractorsto technical task;

d) determination of admissible regimes of tractor loading in MTA;

e) making decisions on expedience of purchase of a wheel tractor for current park of tillage machinery.

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