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# OPERATING CONDITIONS OF WHEEL DRIVES OF ACIVE SEMI-TRAILERS

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**Summary**. The article considers the basic conditions of work maintenance in a traction mode of an active semi-trailer with an uncontrollable hydro-drive of the wheels, intended for work in a unit with a wheel tractor with mechanical transmission.

**Keywords**: tractor train, active semi-trailer, mixed drive, working process, conditions of work maintenance.

## INTRODUCTION

Creation of all-wheel drive in tractor units is a basic way of an increase of their traction indicators. The research and natural experimental tests of shaft gearbox variants of a drive of a semi-trailer's wheels from a synchronous shaft of a tractor selection capacity have shown that they have a number of drawbacks and are structurally more difficult than variants of an uncontrollable hydro-volume drive, moreover they do not fully possess a necessary power and operational flexibility [1, 2, 3].

From an analysis of advertising materials and the patents registered in various countries one can see some examples of technical solutions of an active trailer with an uncontrollable hydro-volume wheel drives. Such a drive is simple enough. It uses axial-piston or gerotor hydro-motors, which allow to simplify or exclude mechanical transfers from a hydro-motor shaft to wheels of the trailer or to a ridge roller from which the moment is transferred to semi-trailer wheels (see Fig. 1).

Fig. 1. An active running semi-trailer module

Application of “breaking” lever of chassis on such semi-trailers pursues the aims of perfection of shunting property and increase the moving ability of tractor units on turns in the constrained conditions. The range of use of active semi-trailers equipped with the corresponding cargo platform is wide, especially in case of adverse soil-climatic conditions of movement of a tractor train at performance of various agricultural works.

However, operational properties combining united transmission and running systems of such a tractor unit have not been sufficiently studied and there are no recommendations for parameter choice of a semi-trailer wheel drive, rational operating modes, ways of management of a wheel drive or a drive lever of chassis.

A definition of conditions of maintenance of demanded indicators of traction properties of a tractor at work in a unit with an active trailer with a wheel drive would be of a considerable scientific and practical interest.

## OPERATING MODES OF WHEELS OF A SEMI-TRAILER WITH HYDRO-DRIVE

Let us consider the work of a wheel drive in a semi-trailer of gerotor-hydromotors. Before inclusion in a leading mode of bridges of the semitrailer, current angular speed $\omega_{3_i}^{\hat{e}}$ whose wheels are in a conducted mode, is equal $\omega_{3_i}^{\hat{e}} = \frac{v_i}{r_3^o}$ – here the index 3 corresponds to semi-trailer bridges, $v_i$ – current speed of movement of the unit, $r_3^o$ – radius of rotation of semi-trailer wheels in a conducted mode. Conditionally, we name the angular speed of the size $\omega_{3_i}^{\hat{e}}$: «on a course».

Let us assume that after connection of a drive of bridges of the trailer the angular speed of a shaft of the engine is equal $\omega_{dv_i}$. To it there corresponds angular speed of a shaft of pump $\omega_{H_i}$ and its current giving $Q\left(\omega_{H_i}\right)$ which defines angular speed of a shaft of the hydraulic motor according to the expression [4]:

$$\omega_{M_i} = \omega_{H_i} \cdot \frac{v_{0_M}}{v_{0_H}} \cdot \eta_{0_H} \cdot \eta_{0_M},$$

where $\eta_{0_H}, \eta_{0_M}$ – volume efficiency of the pump and the hydro-motor, $v_{0_M}$, $v_{0_H}$ – working volumes of hydrocars. At this value $\omega_{M_i}$ angular speed of a transmission roller n $\omega_{M_i} = \omega_{P_i}$. As it is possible to accept the transfer relation of a roller-tyre transfer of wheel cart $u_{rsh}$ in size of a constant we will receive angular speed of a driving wheel of the semitrailer:

$$\omega_{3_i}^{d} = \omega_{P_i} / u_{rsh},$$

which conditionally we name its angular speed «on a drive».

Following operating modes of a drive of wheels of the semi-trailer there are possible:

1) If $\omega_{3_i}^{d} = \omega_{3_i}^{k}$ full kinematic conformity of angular speed «on a course» and angular speed «on a drive» then pressure in a pressure head highway of the hydro-motor is close to zero, and the ridge roller will not transfer twisting moment to wheels, the tandem of the wheel cart of the semi-trailer (Fig. 1) takes place;

2) If $\omega_{3_i}^{d} < \omega_{3_i}^{k}$ from road the wheel will aspire to rotate a shaft of the motor with the speed higher than the necessary speed «on a course», which will lead to depression in a feeding highway of the hydro-motor that is inadmissible;

3) If $\omega_{3_i}^{d} > \omega_{3_i}^{k}$ , it will lead to an occurrence of the twisting moments on wheels of each board of the semi-trailer according to loading on wheels and relative wheel slipping on the given surface of movement.

At change of pressure in the pressure head of a highway gerotor, the motor from 0 to a maximum limited to a safety valve, change of frequency of rotation occurs in conformity to the typical characteristic of the motor (see Fig. 2). On the characteristic flat curves correspond to pressure of a working liquid, and abruptly falling curves – to the twisting moments developed by the hydromotor at corresponding portions of a working liquid.

As pump portion depends on the frequency of rotation of an engine it gives possibility to ensure functioning of bridges of a semi-trailer and on partial modes, but only on one transfer gearbox to mechanical step transmission of a tractor at which there will be no kinematic outstrip «on a course» wheels of bridges of the semitrailer.

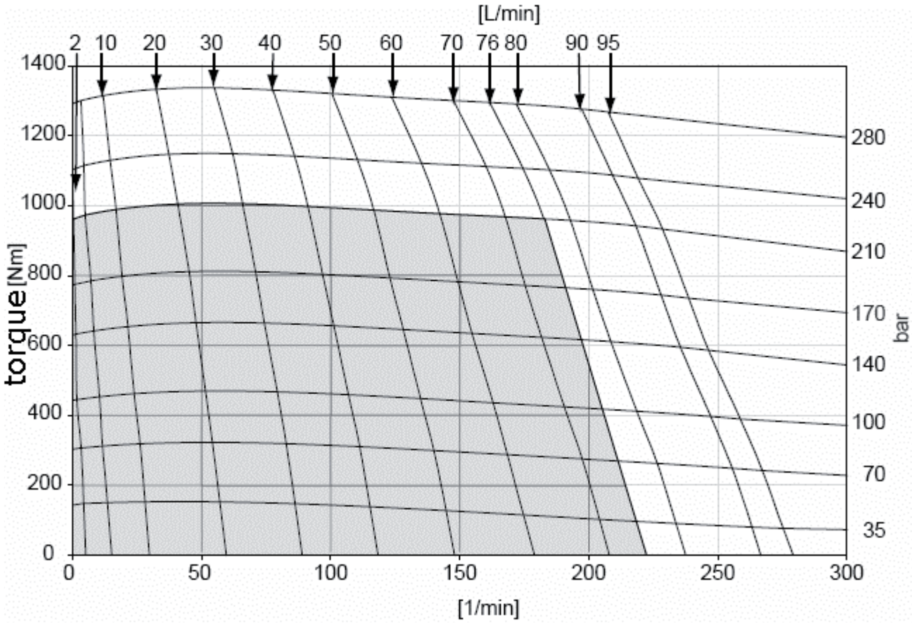


Fig. 2. The typical characteristic gerotor motor

From the technical characteristics resulted as an illustrative example of a gerotor motor it follows, that $n_{M_{\max}} = 277$ minute$^{-1}$ at the maximum expense $Q_{H_{\max}}$ litre/minute we will define now its volume productivity from the characteristic of the pump of hydro-system of a tractor $Q_{H_{\max}}$ at the corresponding frequency of rotation, taking into account the transfer relation of a drive of a shaft of the hydro-pump, nominal frequency of rotation of a cranked shaft of the engine. As it is real, that $Q_{H_{\max}} < Q_{M_{\max}}$ to value $Q_{H_{\max}}$ there will correspond lower value of frequency of rotation of a shaft of hydro-motor $n_{M_{\max}}$ ($Q_{H_{\max}}$).

«On a course» speeds $v^k_{MTA}$ of the tractor unit should not be higher than «on a drive» speeds $v^d_3$, that is $v^k_{MTA} \le v^d_3$ or:

$$v_{MTA} \le \eta_{M_{\max}} \cdot \frac{\pi}{30} \cdot \frac{1}{u_{rsh}} \cdot r^0_3, \text{ Km/h.}$$

With the account of the optimum moment of connection of a drive of wheels of the semi-trailer, at $\delta^*_2 = 6\%$[1] where $\delta^*_2$ – slipping of wheels of the basic leading bridge of a tractor, we define theoretical (in the absence of slipping of wheels) speed of tractor $v^{theor}_{MTA}$ km/h. Then under the kinematic characteristic of a tractor we define the number including transfer in a transmission of a tractor which will provide performance of the mentioned condition $v_{MTA}^{k} \le v_{3}^{d}$.

Such valid speeds $v_{MTA} = \frac{n_{d_{nom}} \cdot \pi}{30} \cdot \frac{1}{u_{tr_j}} \cdot r_2^0 \left(1-\delta_2^*\right)$ will be at transfer relation $u_{tr_j}$ transmission of a tractor which we will define from a parity

$$\frac{n_{d_{nom}} \cdot \pi}{30} \cdot \frac{r_2^0 \left(1-\delta_2^*\right)}{u_{tr_j}} < \frac{n_{M_{\max}} \cdot \pi}{30} \cdot \frac{1}{u_{rsh}} \cdot r_3^0,$$

Whence we will definitively receive, that $u_{tr_j} > \frac{n_{d_{nom}}}{n_{M_{\max}}} \cdot \frac{r_2^0 \left(1-\delta_2^*\right)}{r_3^0} \cdot u_{rsh}$.

Thus, the drive of wheels of a semi-trailer should be connected to numbers of transfers in a tractor transmission not above those on which the transfer relation of transmission of a tractor is lower than the value calculated in the last expression.

Let us estimate now an influence of characteristics of turn on traction qualities of tractor units. So at the blocked mechanical drive of wheels of a tractor and wheels of a semi-trailer factor $k_{23}$ of kinematic discrepancy of district speeds of wheels of the semi-trailer concerning back wheels of a tractor is defined by mismatches: a constructive mismatch of drive $k_{pr_{23}}$, a mismatch of instant angular speeds $k_{\omega_{23}}$, a mismatch of radiuses of trajectories $k_{R_{23}}$ and a mismatch of corners of withdrawal $\psi_i$ wheels $k_{\psi_{23}}$ [1]:

$$k_{23} = 1 - k_{pr_{23}} \cdot k_{\omega_{23}} \cdot k_{R_{23}} \cdot k_{\psi_{23}} =$$
$$= 1 - \frac{r_2^0}{r_3^0} \cdot \frac{u_3}{u_2} \cdot \frac{\cos\gamma_1 \cdot \cos\left(\theta_0 - \psi_1\right) \cdot \cos\left[\left(\theta_0 - \psi_1\right) + \psi_2\right]}{\left(1-\cos^2\varphi_0 \cdot \sin^2\gamma_1\right) \cdot \cos\psi_3 \cdot \cos\left[\left(\gamma_1 + \psi_3\right) - \psi_2\right]}.$$

In case of a hydro-volume drive of wheels of a sem-trailer, angular speed of its wheels «on a course» is defined with the account of radius of a trajectory (see the right scheme in Fig. 3).

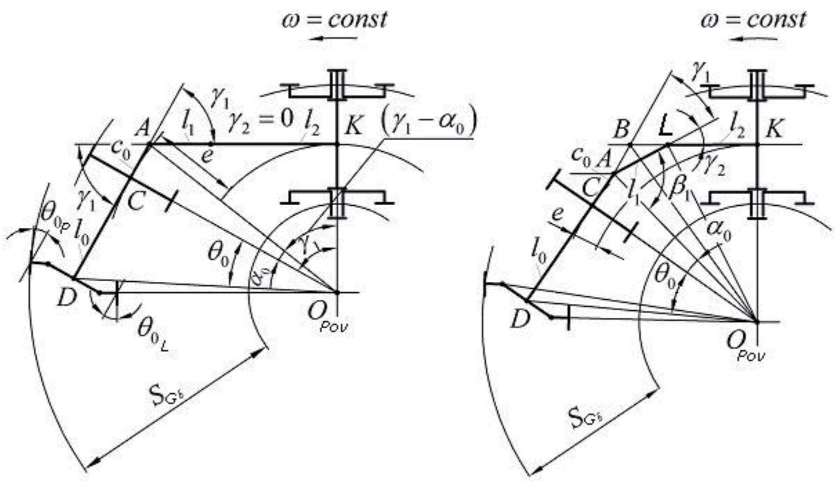


Fig. 3. Schemes of turn of a tractor with a semi-trailer:
with various corners of turn of a “breaking” part lever of chassis

Angular speed of turn of a tractor unit is defined from expression $\omega_{MTA} = \frac{v}{R_C}$.

For internal wheels of a semi-trailer:

$$v_{vn.k} = \omega_{MTA} \cdot \left(R_K - 0,5 \cdot b_{tl}\right) = v \cdot \frac{\left(R_K - 0,5 \cdot b_{tl}\right)}{R_C}.$$

For external wheels of a semi-trailer:

$$v_{nar.k} = \omega_{MTA} \cdot \left(R_K + 0,5 \cdot b_{tl}\right) = v \cdot \frac{\left(R_K + 0,5 \cdot b_{tl}\right)}{R_C}, \text{ as } v = \frac{\omega_i}{u_j} \cdot r_2^0,$$

then

$$v_{vn.k} = \frac{\omega_i}{u_j} \cdot r_2^0 \cdot \frac{\left(R_K - 0,5 \cdot b_{tl}\right)}{R_C},$$

and

$$\omega_{3vn_i}^k = \frac{v_{vn.k}}{r_3^0} = \frac{\omega_i}{u_j} \cdot \frac{r_2^0}{r_3^0} \cdot \frac{\left(R_K - 0,5 \cdot b_{tl}\right)}{\left(R_C - 0,5 \cdot b_{tr}\right)},$$

$$\omega_{3vn_i}^{\ddot{a}} = \frac{n_{M_i} \cdot \pi}{30} \cdot \frac{1}{u_{rsh}},$$

where: $n_{M_i} = f\left(\omega_i\right)$ – also undertakes from the hydro-motor characteristic, then

$k_{23}^{konstr} = \frac{\omega_{3vn_i}^d - \omega_{3vn_i}^k}{\omega_{3vn_i}^d} = 1 - \frac{\omega_{3vn_i}^k}{\omega_{3vn_i}^d}$, or, having expressed it in corresponding speeds, we will receive

$$k_{23}^{konstr} = 1 - \frac{\pi \cdot n_{dv_i}}{30 \cdot u_j} \cdot \frac{r_2^0}{r_3^0} \cdot \frac{\left(R_K - 0,5 \cdot b_{tl}\right)}{R_C} \frac{30 \cdot u_{rsh}}{n_{M_i} \cdot \pi} =$$

$$= 1 - \frac{n_{dv_i}}{n_{M_i}} \cdot \frac{r_2^0}{r_3^0} \cdot \frac{u_{rsh}}{u_j} \cdot \frac{\left(R_K - 0,5 \cdot b_{tl}\right)}{R_C},$$

that in structure corresponds to the expression for kinematic discrepancy in the blocked mechanical drive.

Calculations for a real design of a tractor train with an active trailer have shown that at the turn of operated wheels of a tractor by 30 degrees and change of a corner of turn of a forward part “breaking” lever of chassis concerning back from 0 to 30 degrees, the factor of kinematic discrepancy $k_{23}^{konstr}$ changes from 61,4 % to 44,65 %. These values say that semi-trailer wheels run strongly, thus an increase in the corner of break of a rotary part lever of chassis leads to a reduction of kinematic discrepancy $k_{23}^{konstr}$.

It is sensible to admit, that the curve of slipping of a semi-trailer does not change at change of normal loading. Then traction effort of a wheel at loading on wheels of one board of a semi-trailer $R_{3borta}$ it is equal: $T_{3_1} = \varphi_{3_{\max}} \left(1 - e^{-k_3 \cdot \delta_3}\right) \cdot \frac{R_{3_b}}{2}$, two wheels of one board .

Theoretically, at $\delta_3$ the resulted moment on the motor of one board of the semi-trailer should be equal $M_{M_b}^{priv} = T_{3_1} \cdot 2 \cdot u_{rsh} \cdot r_3^0$. However, if $M_{M_{borta}}^{priveden} > M_{M_{b\max}}$ it will result in that pressure in a feeding high-way of the motor will reach the limit bounded to the safety valve adjustment, part of the working liquid does not pass through the motor, its frequency of rotation will decrease to the corresponding value $M_{M_{\max}}$. And to this value $M_{M_{\max}}$ at known loading on a wheel, equal $\frac{R_{3borta}}{2}$, there will correspond true slipping $\delta_3^{theor}$ of a wheel, smaller, than $\delta_3^{istin}$.

Thus, the power coordination of drives of the back bridge of a tractor and wheels (on boards) tandem at the wheel cart of a semi-trailer will correspond to radiuses of trajectories described by wheels. The same picture is observed at rectilinear movement.

In case $k_{23} > 0$ and $k_{23} = \delta_3^{theor} < \delta_3^d$ and – on a curve of slipping of a wheel, that is if semi-trailer wheels "run" can be found at the working point of a drive.

Frequencies of rotation of shaft of the pump and the hydro-motor are defined from expression [4]:

$$n_H = \frac{n_d}{u_{dn}} \text{ and } n_M = n_H \cdot \frac{V_{0_H}}{V_{0_M}} \cdot \eta_{0_H} \cdot \eta_{0_M},$$

then

$$k_{23}^{konstr} = 1 - \frac{V_2^{dvig}}{V_3^M}, \text{ where } V_2^{dvig} = \frac{n_d \cdot 3{,}14 \cdot r_2^0}{30 \cdot u_{tr_j}};\ V_3^M = \frac{n_M \cdot 3{,}14 \cdot r_3^0}{30 \cdot u_{rsh}}.$$

As $$n_M = \frac{n_d}{u_{dn}} \cdot \frac{V_{0_H}}{V_{0_M}} \cdot \eta_{0_H} \cdot \eta_{0_M},\ V_3^M = \frac{n_d}{u_{dn}} \cdot \frac{V_{0_H}}{V_{0_M}} \cdot \eta_{0_H} \cdot \eta_{0_M} \cdot \frac{3{,}14 \cdot r_3^0}{30 \cdot u_{rsh}}.$$

Then $$k_{23}^{konstr} = 1 - \frac{r_2^0}{r_3^0} \cdot \frac{u_{dn} \cdot u_{rsh}}{u_{tr_j}} \cdot \frac{V_{0_H}}{V_{0_M}} \cdot \frac{1}{\eta_{0_H} \cdot \eta_{0_M}}.$$

As $v_2 = f(\delta_2)$ depends on traction loading $v_2^{deistv} = v_2^{po\_dvig}(1-\delta_2)$, then theoretical slipping – a kinematic mismatch of wheels of the semi-trailer:

$$k_{23} = \delta_3(\delta_2) = 1 - \frac{r_2^0(1-\delta_2)}{r_3^0} \cdot \frac{u_{dn} \cdot u_{rsh}}{u_{tr_j}} \cdot \frac{V_{0_H}}{V_{0_M}} \cdot \frac{1}{\eta_{0_H} \cdot \eta_{0_M}}.$$

However this slipping will be only in the case when the moment on a wheel under the traction characteristic is equal to the moment developed by the hydro-motor at given turns of the engine:

$$r_3^0 \cdot R_{3b} \cdot \varphi_{3\max} \cdot \left(1 - e^{-k_3 \delta_3^{at\ M_{M\max}}}\right) = M_{M_b} u_{rsh},$$

then on $\delta_3^{at\ M_{M\max}}$ – we will define from the last expression:

$$\delta_3^{at\ M_{M\,po\ krivoi\ buks}} = -\frac{1}{k_3} \cdot \ln\left(-\frac{M_{M_{bort\max}}}{r_3^0 \cdot R_{3_b} \cdot \varphi_{3\max}} + 1\right).$$

At $k_{23} \neq \delta_3^{at\ M_{M\max}}$ – any small deviation from this working point towards big $k_{23}$ will result in a hydro-motor exit for limits of a working zone and then to operation of safety valves in a hydro-motor drive. At reduction of resistance to movement of tractor units if $\delta_3^{at\ M_{M\min}} \le k_{23}^{konstr}$ semi-trailer wheels start lagging behind and the drive is disconnected.

So in one of variants of calculations on wood soil for the mentioned tractor train at $k_3$ = 5,48 and $\varphi_{3\max} = 0{,}55$ there was received $\delta_3^{at\ M_{M\max}} = 5{,}66\%$. At rectilinear movement and realisation of the full moment in case of $u_j$ = 138,4973 and $\delta_2$ = 0,05 on 4th transfer of 1st range of a transmission:

$$k_{23} = 1 - \frac{v_2^{dvig}}{v_3^{po\ motoru}} = 3{,}25\%.$$

That is, as semi-railer wheels run, therefore the hydro-motor will start to transfer loading and its frequency of rotation will fall according to its characteristic so that to bring kinematic discrepancy to naught. The new dynamic equilibrium mode [4] will thus be established:

$$\eta \cdot \frac{R_{SK}}{4} \cdot \varphi_{\max} \cdot r_3^0 \cdot \left[1 - e^{-k_3 \cdot \left(1 - \frac{\frac{n_{dv} \cdot (1-\delta_2)}{u_{tr_j}} \cdot r_2^0}{\frac{n_M}{u_{rsh}} \cdot r_3^0}\right)}\right] = M_M \cdot u_{rsh}.$$

As a result of approximation of a working branch of the characteristic of the hydro-motor by analytical expression:

$$M_M = f\left(n_M\right) = \frac{A}{n_M} - B,$$

after substitution in the previous expression we will receive:

$$\frac{R_{SK}}{2} \cdot \varphi_{\max} \cdot r_3^0 \cdot \left[ 1 - e^{-k_3 \left( 1 - \frac{n_{dv} \cdot (1-\delta_2) \cdot r_2^0 \cdot u_{rsh}}{n_M \cdot r_3^0 \cdot u_{tr_j}} \right)} \right] = \left( \frac{A}{n_M} - B \right) \cdot u_{rsh},$$

whence we find $n_i$ and $M_M$, and, further, value of the valid slipping of wheels of semi-trailer $\delta_\chi$ – on expression:

$$\delta_\chi = -\frac{1}{k_3} \cdot \ln\left( 1 - \frac{M_M \cdot u_{\delta ø} \cdot 2}{R_{SK} \cdot \varphi_{\max} \cdot r_3^0} \right).$$

In a considered variant of calculation it is received:

$n_i = 73,408$ Rpm; $M_M = 190,668$ Н·м; $\delta_3 = 0,012 = 1,2\%$, and traction effort of all wheels of the semi-trailer equally $T_\Sigma = 2 \cdot M_M \cdot u_{\delta ø} \cdot \frac{1}{r_3^0} = 2416,016$ Н.

As total force of resistance to semi-trailer movement thus appears to be equal to $F_\Sigma = 4 \cdot 21160 \cdot 0,1 = 8464$ H, and total draught of wheels of semitrailer N $\sum_{i=1}^{4} T_{3i} = 2416,016$ it will provide efforts of a stretching in the towing device, that favorably affects stability of movement MTA. If to include in KP the following – higher transfer with $u_{j+1} = 114,8176$ similar calculations will give the following values: $\delta_3 = k_{23} = -0,1669 = -16,7\%$. That is, in this case semi-trailer wheels become “lagging behind”, and the drive of wheels should not be included as semi-trailer wheels will rotate from pushing influence of a frame of the semi-trailer with higher in the angular speed, than can be providd by the hydro-motor.

The resulted numerical examples show, that for normal working capacity of a drive (on wood soil) it is necessary to work only on one transfer of a transmission.

Let us define, at what loading of the semitrailer by transported cargo on a concrete surface of movement it is expedient to include a drive of wheels of the semi-trailer.

As in a working zone of the characteristic of the hydro-motor the maximum twisting moment changes very slightly with the account of the characteristic of slipping of wheels of the semitrailer it is possible to define limiting slipping which will not lead to a hydro-motor overload on the moment on various kinds of basic surfaces from expression:

$$\frac{M_{M_{\max}}}{2} \cdot u_{rsh} = \frac{R_{\Sigma K}}{4} \cdot \varphi_{\max} \cdot \left(1 - e^{-k \cdot \delta_{dop}}\right) \cdot r_3^0,$$

whence: $\delta_{dop} = -\frac{1}{k} \cdot \ln\left( 1 - \frac{2 \cdot M_{M_{\max}} \cdot u_{rsh}}{R_{\Sigma K} \cdot \varphi_{\max} \cdot r_3^0} \right).$

Calculations have allowed to receive the following values by kinds of surfaces of movement: agricultural soil – $\delta_{dop}$ = 6,7%, soil road – $\delta_{dop}$ = 4,7%, asphalt – $\delta_{dop}$ = 1,3%, snow-covered soil road – $\delta_{dop}$ = 24,8%.

Total loading on semi-trailer $R_{\Sigma K}$ bridges should satisfy the condition:

$$R_{\Sigma K_{\min}} \geq \frac{2 \cdot M_M \cdot u_{\delta ø}}{\varphi_{\max} \cdot r_3^0} = \frac{C_G}{\varphi_{\max}},$$

where $C_G$ – a constant. Then at such total normal loading on wheels of the semitrailer the drive of wheels of the semitrailer can realise the maximum twisting moment of hydro-motors. Thus slippings of wheels will not exceed th,e values specified in Fig. 4. That is, at uncontrollable hydro-drive of wheels of a semi-trailer, possibilities of full realisation of coupling weight of wheels of the semitrailer are limited. Activization of wheels at inclusion of a hydro-volume drive of a ridge roller leads to a considerable redistribution of traction loadings between bridges of the tractor unit.

From the received results it follows in what way to provide in operation an adequately narrow range of slippings of wheels of a semi-trailer, which would be difficult without regulation of a drive of wheels. It should be noted that there is a possibility of work of hydro-motors of a drive of ridge rollers on a mode of inclusion of safety valves realisation of the maximum twisting moment of the hydro-motor. Force of draught which is thus realised by semi-trailer wheels is usually considerably lower than traction possibilities on coupling of wheels with a ground. At the same time the traction potential of an active semi-trailer in heavy road conditions can reduce a traction effort of a tractor by half.

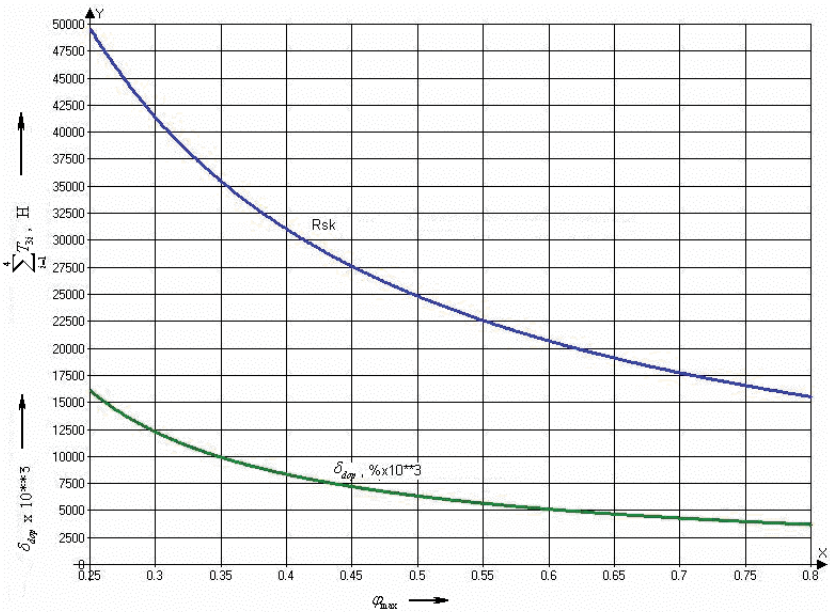


Fig. 4. Conditions of normal work of a drive of wheels of a semi-trailer in a traction mode

## THE CONCLUSION

Analytical expressions are received of the basic conditions of maintenance of work in a traction mode of an active semi-trailer with an uncontrollable hydro-drive of the wheels, intended for work in the unit with a wheel tractor with mechanical transmission.

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