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# THE TECHNOLOGICAL RESOURCE OF DIGGING AND TRANSPORT HEAVY EQUIPMENTS USED IN ROAD CONSTRUCTIONS

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## ABSTRACT

*For it can be applied the efficiency analysis of a mecanical system , on the basis of probabilistic transform and correlation methods , in the case of industrial tractors which are working in aggregate with different equipments , it must be determined the machine power on a technological working cycle .*

## 1. INTRODUCTION

The models for the calculation of dynamic stresses in the working outfit and the structure of the machine from the work [1], is taking into account $F_R = f(\hat{x})$ and of the interaction between the motor – transmission and rolling system.

## 2. THEORETIC ELEMENTS OF EFFICIENCY OF MECHANICAL SYSTEMS ON THE BASIS OF TRANSFORMING AND CORRELATION METHODS

The idea of the machines' synthesis which use the efficiency's methods, consists in the determination of the realisable possibilities of the basis data concerning the limiting level, which indicates the exhausting functional capacity and the working time until the beginning of that moment, that is the establishment of the most possible working term [ 3].

In the case of industrial tractors aggregated with outfits of digging and transporting the ground, the basic time is represented by the specific working cycle for the technology executed by the tractor with the bulldozer, bulldozer – scarificator or the scraper [1,2].

The method is standing at the formal basis of the probabilities' transforming of these parameters and of the determination of their statistic characteristics.

If there are analysed two accidental sizes, which are linked functionally, which is the case of construction machines' structure with one dependence [for example loading which are acting long-term (on the basis of the energetic criterium of the efficiency of the industrial tractor with the help of the traction diagram [2], taking into account the general energetic potential for tractors aggregated with bulldozer, bulldozer – scarificator or scraper, therefore:

$$\overline{P}_e = \overline{P}_s \cdot F_s + \overline{P}_b \cdot F_b + \overline{P}_{bs} \cdot F_{bs} , \qquad (1.1)$$

where: $\overline{P}_s, \overline{P}_b, \overline{P}_{bs}$ - total energetical indicators in the case of the tractor's aggregation with the scraper, the buldozer and the buldozer – scarificator;

$F_s$, $F_b$, $F_{bs}$ - the probability of the aggregation.

The total energetic indicator of the power for the aggregation with all the types of outfits is [2] :

$$\overline{P} = \frac{\overline{P}_{cr}}{1 + 0.277 \cdot K_c \cdot \overline{V}_r} , \qquad (1.2)$$

where: $\overline{P}_{cr}$ - the average power at the hook in kW:

$K_c$ - the cyclic coefficient depending on the idling speed and on the distribution of the ground work,

$K_c$ = 0,3 – 0,7 s/m;

$\overline{V}_r$ - average real speed in m/s), according to which appear plastic deformations on usage's] then the static characteristic of a single aleatory size y, as an accidental function of the argument x [y=f(x)] is determined if it is known the distribution law of x.

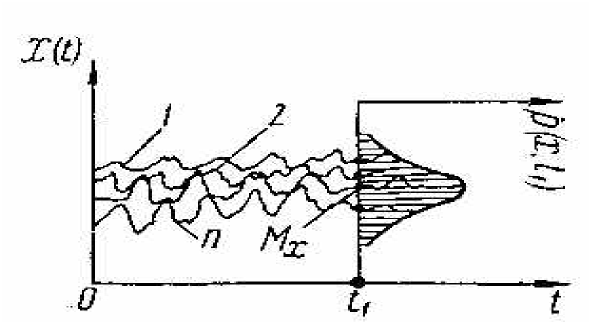


Figure 1,a The distribution of loads 1 ..n in the mechanical systems

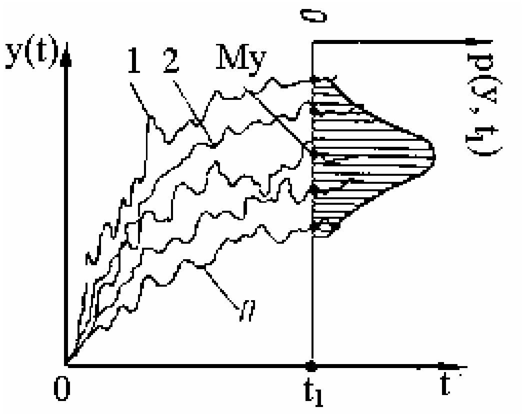


Figure 1,bThe distribution of issue parameters with 1 ..n realizations

If at the entrance of the system is applied a perturbation x(t) ( for example given by the loads’ shape in mechanical systems, or of the signals from automatic command systems, with a totality of realisations 1,2 ..n (figure 1,a), any moment $t_1$ (on the elements of the working cycle) id characterised by the totality of the distribution $p(x,t_1)$. Following the action of these loading, the issue parameter has the value y(t) (for example the tension of the material for the limiting state, the rigid or elastic deformation, or the usage which appears in the compounds of the projected system) (figure 1,b).

The dynamic behavior of the tractor working aggregated with digging and transporting equipment’s (figure 2) is represented by the following characteristics of factors are representing the loading schedule, as:

1p – the working process of the ground at advance walking of the machine;
1x – the idling displacement of the tractor;
2 – the mass of the aggregate;
3 – the loading of the machine;
4 – the duration for experimental recording (for de cases a - screper , b - bulldozer, and c- bulldozer-scarificator );
5 – the recording diagrams of the critical force at the hook with different equipments;
6 – the mass of the transporting equipment of the ground;
7 – the vertical loadings at the ground working;
8 – the distribution of traction forces of the machine;
9 – the acting system of the machine, the power and the speed of the Diesel engine

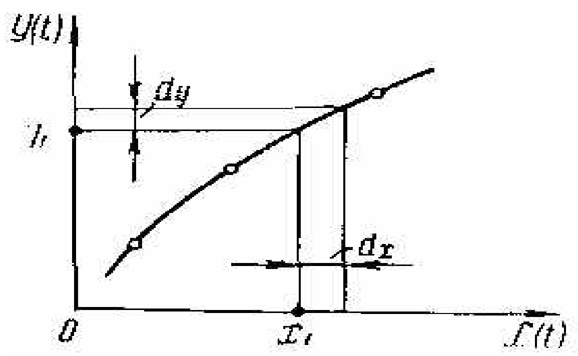


Figure 1,c. The probability of the entrance and issue parameter at the moment $t_1$

Then the distribution totality of this internal parameter is possible to be determined, if it is judged in this way. If it is taken the condition of the equality for probabilities belonging to the entrance parameter at the moment $t_1$ for the segment $X_1 \le X \le X_1 + dx$ (figure 1,e) and to the issue parameter in the same moment for the segment $y_1 \le y \le y_1 + dy$,

then it can be written:

$$p(x,t_1)dx = p(y,t_1)dy \,; \qquad (1.3)$$

from where

$$p(y,t_1)dx = p(x,t_1)\frac{dx}{dy} \,; \qquad (1.4)$$

where x is expressed by y, varying monotonly the function f(x).

The relationship (1.4) is the basic equation for transforming the probabilities of the – issue parameter, which determination presents interest in the projection of new machines.

The process itself of seeking for the shape of the formula, which determines the probabilistic density curve, in any case conjugated with a special complexity, is doing that using the probability method, the calculation is tending to a determination of numeric characteristics for moments of the distribution of the aleatory sizes.

The first order moment of the mathematical attending supposes the average from the aleatory values of the function x(t) which can be expressed in the independent experiences and which are done in the same conditions.

$$M[x(t)] = \int_{-\infty}^{\infty} xp(x,t)dx \qquad (1.5)$$

For the complete characterization of the aleatory function it is necessary to determine the value which indicates the order of dispersion for possible values, for aleatory sizes, about the average value.
The initial moment used for this second order is written as:

$$\bar{y}^2 = M\{Y^2[x(t)]\} = \int_{-\infty}^{\infty} y^2(x)\ p(x,t)dx \qquad (1.6)$$

The dispersion of the second order central moment is:

$$D_y = M\left[(Y - my)^2\right] = \int \{y(x) - M[Y(x)]\}\ p(x,t)dx \qquad (1.7)$$

The ultimate relationship allows to determine the dispersion of the issue parameter of the system, having known the band function y(t) and the density of the probability for the issue parameter.
Taking into account the previous considerations, the calculation of the probability and durability of the system by helping of the probabilities transformation can be done in the following ordfer [3] :
1) There are determined the factors which are influencing on the system behavior, which may be described as a final number of aleatory parameters using the law of distribution and of probabilities:

$$d_1, d_2, \ .., \ d_m; \ P_{g1}, \ P_{g2}, \ .., P_{gr}, \qquad (1.8)$$

where: $d_1$, .., $d_m$ - the parameters which characterize the internal factors (for example when there are known the technological characteristics of the possible functional and technological parameters realized for equipment; or the parameters which characterize the interior "composition' of the system, the digression from the geometrical shape, the mechanical properties, the surface stage, etc.)
$P_{g1}$, ..,$P_{gr}$ - the parameters which characterize the loading and another external conditions of the exploitation.
2) The grouping indicated of factors suppose by self the named sizes of entrance parameters of (machine) or system: $y_1$, $y_2$, ..,$y_m$.
3) It is determined the shape of the relationship between entrance and issue parameters on the basis of experimental or theoretical data:

$$y_I = Y_1\ (d_1, \ ..,d_m; \ P_{g1}, \ ..,P_{gr}), \ I = 1,2, \ ..,n \qquad (1.9)$$

4) It is determined the density shape that is issue parameters of the system.
The working performances of industrial tractors are put in evidence by the energetical balance and traction characteristic aggregated with digging and transporting equipments. The schedule of the tractor aggregated with working equipment is presented in the figure 2.

In the work [2] are indicated the following working hypotheses:

*The first hypothesis* – shows that the energetical balance of the functioning aggregate is a stationary process parallel with the displacement of the mechanical transmission tractor, for which is considered the power balance:

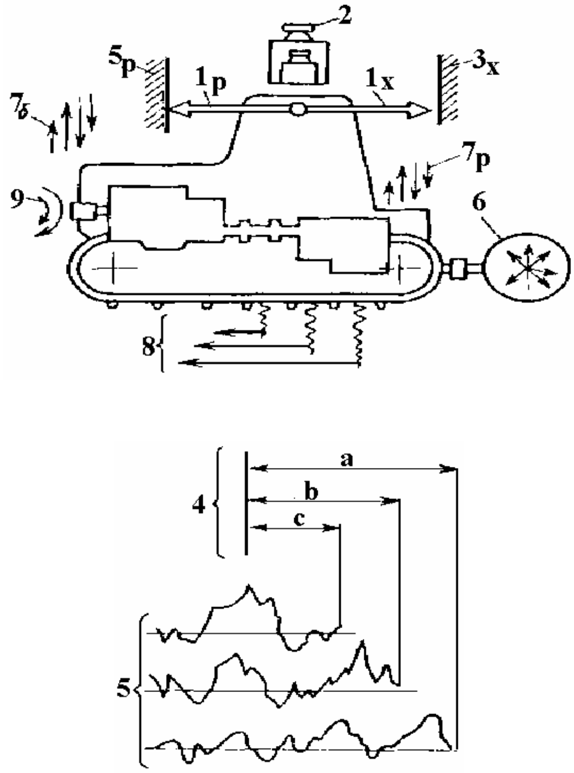


Figure 2 The working schedule of the tractor in aggregate with road construction equipments[2].

$$P_{cr} = P_R - P_f - P_s\ , \qquad (2.1)$$

where:

$P_R$ – the power developed at the driving wheel $P_R = P_m - P_{tr} = P_m\ \eta_{tr}$;

$P_{tr}$ – the consumed power for the defeating of frictions during the transmission;

$\eta_{tr}$ - the mechanical efficiency of the transmission;

$P_f$ şi $P_\delta$ - the power for the defeating of the global rolling strength and for the slipping of wheels;

$$P_{cr} = \frac{P_R \cdot F_{cr} \cdot (1-\delta)}{F_{cr} + f \cdot G_a} \quad (2.2)$$

The specific critical power:

$$P_{cr,sp} = P_{R,sp} - P_{f,sp} - P_{\delta,sp} = \frac{P_{Rsp} \cdot \varphi_{cr} \cdot (1-\delta)}{(\varphi_{cr} + f_s)}, \quad (2.3)$$

where

$$P_{R,sp} = \left(\frac{P_e}{G_a}\right) \cdot \eta_{tr}$$

The link between the power to the wheel $P_R$ and torsion moment $M_t$ at the shaft of the engine:

$$P_R = M_R \cdot \omega_R ;$$

$$M_R = F_R \cdot r_R = (F_{cr} + f_s \cdot G_a) \cdot r_R ,$$

$$\omega_R = \frac{\omega_T}{u} ; \quad (2.4)$$

where: $\omega_R$, $\omega_T$ - the angular speed to the wheel; respectively to the shaft of the engine;

u - the nominal transmission ratio.

The transmission factor is $i_M = \frac{u}{r_R}$.

The formula (2.9) becomes:

$$P_R = (F_{cr} + f_s \cdot G_a) \cdot \omega_T \cdot \frac{1}{i_M} = \frac{F_R \cdot \omega_T}{i_M}$$

or

$$P_{R,sp} = \frac{\varphi_R \cdot \omega_T}{i_M}$$

The traction forces to the wheel

$$F_R = M_T \cdot \frac{i_M \cdot \eta_{tr}}{r_R}$$

or

$$M_T = \frac{F_R \cdot r_R}{i_M \cdot \eta_{tr}}$$

where: $M_t$ – is the torsion critical moment at the shaft of the engine.

From the adherence condition of the machine results:

$$M_T = \frac{\varphi_R \cdot G_a}{i_M \cdot \eta_{tr}} .$$

The specific power to the driving wheel is a function of :

$$P_{R,so}\left[(M_T/G_a)(\omega_T), i_M, \eta_{tr}, \varphi_R\right] \quad (2.5)$$

The critical power has the shape:

$$P_{cr} = P_e - P_{tr} - P_f - P_\delta ,$$

or:

$$P_{cr} = P_e - P_{Nm} - P_{tr} - P_f - P_\delta , \quad (2.6)$$

where: $P_{Mm}$ – the nominal power corresponding to the critical moment mechanically transmitted.

*The second hypothesis.* The energetical balance characterizes the functioning of the tractor, taking into account the statistical values of powers transmitted at the driving wheel by help of the hydrotransformer.

The working moment of the mechanical transmission is represented by:

$$M^x_{T_1}(\omega_T)\left[M_T, \nu_\varphi\right] \quad (2.7)$$

where: $M_T$ – the moment of the transmission;

$\nu_\varphi$ - the frequency of the loading. The characteristic given by the dynamical loading moment at the first shaft of the hydraulic transformer is:

$$M^{xx}_{T_1}(\omega_T)\left[M_T, \nu_\varphi, M_{MT}\right] \quad (2.8)$$

The slipping of driving wheels $\delta(\varphi_{cr})$ is given by a statistical function.

The specific slipping power of the tractor is a function of:

$$P^x_{\delta,sp}\left[\delta^x(\varphi_{cr}), G_a, \varphi_{R\max}, \nu_\varphi\right] \quad (2.9)$$

where: $\delta^x(\varphi_{cr})$ and $P^x_{\delta,sp}$ - are respectively the slipping coefficient according to the critical adherence coefficient $\varphi_{cr}$ and specific slipping power given by the dynamical loading of the machine;

$G_a$ – the weight of the working aggregate.

The global static coefficient for rolling friction

$$f_s = \frac{F_f}{G_a} .$$

The consumed power for defeating the rolling strength

$$P_f\left[f^x_s(\varphi_{cr}, v_m), G_a, \varphi_{Rmx}\right] \quad .10)$$

The energetic balance of powers is:

$$P_{cr} = P_e - P_{Nm} - P_{HT} - P_{tr} - P^x_m - P^x_f - P^x_\delta , \quad (2.11)$$

where: $P^x_m$ - the static and dynamic consumed power as the characteristic of the engine;

$P_{HT}$ - the power consumed by the hydrotransformer.

## 3. THE ENERGETIC POTENTIAL ON THE CYCLE OF THE EXPLOITATION TECHNOLOGY OF THE INDUSTRIAL TRACTOR AGGREGATED WITH DIFFERENT EQUIPMENTS

It is starting from the productivity of the equipment [2] :

$$P = \frac{W_p \cdot K_c}{T_e}, \qquad (3.1)$$

where: $W_p$ – is the volume of the ground prism $W_p = K_1 \cdot G_T \cdot K_0 \cdot K_S$ in which: $K_1$ – the volume coefficient of the material prism in function of the tractor mass; $G_T$ – the tractor weight; $K_0$ – a coefficient taking into account the shape of the blade; $K_s$ – coefficient of the digging distance of the ground;

$K_c = K_p \cdot K_\varphi \cdot K_{mot} \cdot K_{tp}$ - the correction coefficient on a cycle composed by the product of some coefficients which are taking into account: the power of the engine ($K_p$); the traction force according to the adherence of the machine ($K_\varphi$); the functioning characteristic of the engine ($K_{mat}$); the transformation of the working potential productivity into the real one ($K_{tp}$);

$T_c$ – the duration of the working cycle, specific to the aggregate industrial tractor – working equipment.

The necessary technological power depending on the traction critical force (at the hook in the case of experiments) developed as well as the working speed during the digging process on a cycle is

$$A = F_{cr} \cdot V_p \cdot \tau, \qquad (3.2)$$

where τ is the time factor

$$\tau = \frac{T_{px}}{T_c} \qquad (3.3).$$

For the working technology of the buldozer, the working cycle has the form:

$$T_c = T_{px} + T_{xx} + T_{\text{int}} = \frac{S_p}{V_p} + \frac{S_{xx}}{V_{xx}} + T_{\text{int}} \qquad (3.4)$$

where: $T_{px}$, $T_{xx}$, $T_{int}$ – are necessary working times for digging without loading or the time of returning;

$S_p$, $S_{xx}$ – working distances for digging, transporting and respectively idling.

Introducing (3.4) into (3.3) the factor of time is:

$$\tau = \frac{1}{1 + \left( \frac{1}{V_{xx}} + \frac{T_{\text{int}}}{S_p} \right) \cdot S_p} \qquad (3.5)$$

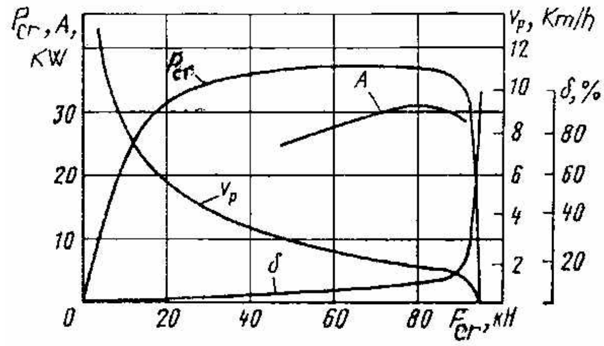


Figure 3 - The characteristic of the tractor with an engine of 58,5 kW; δ – the slipping factor according to the work [ 2 ]

If it is introduced (3.5) into (3.2) the necessary power on a working technological cycle results according to the digging critical power:

$$A = \frac{P_{cr}}{1 + \left( \frac{1}{V_{xx}} + \frac{T_{\text{int}}}{S_p} \right) \cdot V_p} \qquad (3.6)$$

It is considered the power $P_{cr}$ according to [2] of a tractor of 58 kW, which is working aggregated with a bulldozer - scarificator of 10 t.

The working characteristic of the tractor is presented in figure 3. The notations done have the following semnification: $A(F_{cr})$ - the necessary working power on a technologic cycle; $P_{cr}(F_{cr})$ - the power characteristic according to the traction critical force at the realzation of digging workings; δ - the slipping characteristic of wheels.

The function $A(F_{cr})$ is corresponding for the working conditions of slipping 30% which assures the critical power of the tractor at digging.

It is determined from the relation (3.6) , $A(F_{cr})$ on the basis of the tractor characteristics from figure 3.

The traction characteristics $F_{cr}(t)$ and $F_R(t)$ are given on the basis of the power $P_{cr}$. The relationship (3.6) is calculated knowing $P_{cr}$ and V according to $F_{cr}(t)$, when $t \in T$.

The energetic potential at the shaft of the driving wheel as a function of $F_{cr}$ and V is:

$$P = \frac{\int_0^\infty P_{cr}\left(F_{cr}\right) f\left(F_{cr}\right) dF_{cr}}{1 + \left(\frac{1}{V_{xx}} + \frac{T_{\text{int}}}{S_p}\right) \int_0^\infty V_p\left(F_{cr}\right) f\left(F_{cr}\right) dF_{cr}} \quad (3.7)$$

where:

$$\int_0^\infty P_{cr}\left(F_{cr}\right) f\left(F_{cr}\right) dF_{cr}$$

and

$$\int_0^\infty V_p\left(F_{cr}\right) f\left(F_{cr}\right) dF_{cr},$$

are the distribution of the power and the speed, according to the traction critical force in the digging process.

The values $\overline{\mathrm{F}}_{\mathrm{cr}}$ and $\overline{\mathrm{V}}_{\mathrm{r}}$ from the previous relationships (including the relationships (1.2)) is determined for each type of aggregate using the adherent weight of the tractor with the bulldozer, bulldozer – scarificator and the scraper with the grapho – analytical method and the traction diagram [ 2].

## 4. CONCLUSIONS

The power of the machine on a technologic cycle depending on the critical force of the tractor aggregated with different equipments permits the raising of real loadins for the analysis of the durability, usage and the structure.

## REFERENCES

[1].**PANĂ GH., SÂRBU L., MLADIN GH**. *Maşini de tracţiune şi de ridicat pentru construcţia căilor de comuninţie***,** Partea a-3-a, I.C.B., Bucureşti, 1985, pag. 86 – 156;

[2].**ГИНЗБУРГ Ю.В., ШБЕА А.И., ПОРФЕNОВ А.П**. – *Промышленные теaktогы*, Москва, Мащиностгоение, 1986, pag 58 – 59;

[3].**ГИРЬКОВ М.М.**, D*инамика н прогнознгуюшнй гасует механиуескихсистем*, Минск, Вышвишая Школа, 1980, pag 38 – 44;