Forming of the optimum braking performance of gears movements of mobile cranes

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Summary: the concept of a method of calculation of the optimum (rational) braking performance of gears of movement of the mobile cranes, based on the multiparameter multifactorial analysis of transient effects are stat, the example of calculation are consider. Fig. 4, tab. 3, lit. 20.
Key words: bridge cranes, optimization of braking processes.

1. GENERAL PROVISIONS

1.1. Statement of a problem in a general view. It agreed [2, 7, 9, 10, 16-18, etc.] value of brake torque of the gear of movement of the mobile crane are determine from a repayment provision of a kinetic energy rotate and are translational moving weights of a drive and the crane for set time or on the set braking distance. Value of brake torque at whom the set reserve of hooking of tradable wheels with rails are ensure, determined at motion of the crane without freight. At determination of brake torque the crane are consider as a solid state; braking characteristics of the gear, real mass distribution, elastic properties of elements of the gear and a metal structures, the flexible podves of freight was not consider real, etc.

1.2. Analysis of the main researches and publications. In case of the equipment of cranes operate braking devices arisen the task of forming of braking characteristics of gears of movement ensure optimum (rational) braking action. In the sources enumerate above these tasks was not consider. For the first time the task of calculation (forming) of the optimum braking performance of gears of movement of mobile cranes are put in [4-5, 13, 14].

1.3. The statement are more whole than the article. The purpose of the article was presentation on a particular example of a method of calculation of the optimum (rational) braking performance of gears of movement of the mobile cranes which are based on the multiparameter multifactorial analysis of transient effects.

Of ways of raise of technical-operational parameters of mobile cranes optimization of transient effects are one. Such approach became actual in connection with creation of the operate starting and braking devices ensure adjustment of force of a drive largely. It are especially important, with a position of raise of efficiency, reliability and an operational safety of mobile cranes, optimization of processes of the braking action, assume determination and realization of such law of change of a braking force of the gear at whom main specifications of transient effect (*a braking time* of t_T, *maximum dynamic loads of a metal structure* P_m^{max} *and a drive* P_{pr}^{max}, *the maximum amplitude of deflection of freight from a vertical* A^{max} (a horizontal component of tension of freight chain cables P_k^{max} *etc.*) received most acceptable values.

2. CALCULATION OF THE OPTIMUM BRAKING PERFORMANCE OF GEARS OF MOVEMENT MOBILE CRANES ON THE BASIS OF THE MULTIPARAMETER MULTIFACTORIAL ANALYSIS OF TRANSIENT EFFECTS

The example of calculation of the rational braking characteristic of the bridge hook crane of a construction ASRILTM (*load* 10 t, by V_k =2 m/s, L =34,5 m, a drive separate) which gear of movement are equipped with the device for electrodynamic braking action are more low consider. Each drive of movement of the crane intend for activity indoors, consisted of the MTF 211-6 engine (N = 7,5 kW, n_n = 15,5 sec^{-1}, M_{max} = 191 N·m), the reduction gearbox (u = 9,8), brakes TT-160 ($M_{t\ (max)}$ = 100 N·m), a tradable wheel in radius of r_k = 0,2 m bridge among themselves by joints. Weight of the crane span of 34,5 m of m_{kr} = 31300 kg, weight of a dolly of $m_т$ = 2600 kg.

Owing to random character of the braking process determine by variable entry conditions of braking action (in the speed of the crane in the beginning of braking action, a weight cargo and altitude are more its than the suspension, to a vibration phase of freight, etc.) and a kind of the braking characteristic of the gear, the solution of such optimizing task possibly if to limit area of researches and to consider process of braking action as determine, that is the fix values of parameters of the crane and entry conditions of braking action. In this case the solution of a task of optimization of processes of braking action of mobile cranes actuated below-mentioned stages [8].

2.1 ***Construction of dynamic and mathematical models of the crane.*** At the first phase of researches experiment are reasonable for put on a mathematical model (computing experiment) and it consisted in determination of main specifications of transient effect (t_{ri}, $P_{mi}^{мах}$, $P_{ki}^{мах}$, $P_{pri}^{мах}$) numerical integration of the equations of motion of the crane with freight at braking action on i-oh braking characteristic.

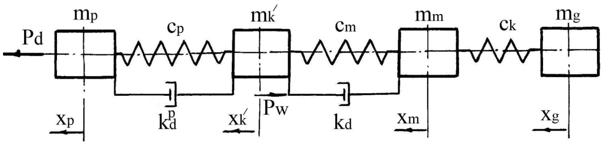

Fig. 1. Four-mass dynamic mock-up of a bridge crane

Research and optimization of transient effects of movement of bridge cranes, with sufficient accuracy for practical calculations, it are possible to execute on discrete a four-mass three-coherent dynamic mock-up [4, 11-14, etc.].

Motion of dynamic mock-up locate on fig.1 are describe by the equations:

$$m_p \cdot \ddot{x}_p + k_d^p \cdot (\dot{x}_p - \dot{x}'_k) + c_p \cdot (x_p - x'_k) - P_d = 0;$$

$$m'_к \cdot \ddot{x}'_k - k_d^p \cdot (\dot{x}_p - \dot{x}'_k) - c_p \cdot (x_p - x'_k) +$$
$$+ k_d \cdot (\dot{x}'_k - \dot{x}_m) + c_m \cdot (x'_k - x_m) + P_w = 0; \quad (1)$$

$$m_m \cdot \ddot{x}_m - k_d \cdot (\dot{x}'_k - \dot{x}_m) - c_m \cdot (x'_k - x_m) +$$
$$+ c_k \cdot (x_m - x_g) = 0;$$
$$m_g \cdot \ddot{x}_g - c_k \cdot (x_m - x_g) = 0.$$

On fig. 1 and in the equations (1) designations was receive:

m_p – the reduced weight of rotate parts of drives of the mechanism of movement to tradable wheels; m'_k - the weight of the bridge to moving of end girders; m_m – the reduced weight of mean parts of the bridge to midbay and an empty dilly; m_g - a weight cargo kg,

P_d - reduced to a rim the driving of tradable wheels force of the engine of the mechanism of movement of the crane (in braking modes of P_d = R_t); P_w - force of static resistance to movement of the crane N,

c_p - the coefficient of rigidity mechanism of movement le to tradable wheels; $c_м$ - coefficient of rigidity of a metal structures of the crane in a horizontal plane; $c_k = G/\ell$ - a horizontal component of tension of freight chain cables at (x_m – x_g) = 1 (thus the horizontal component is considered to proportional amplitude of deflection of freight), N/m (here ℓ - a length of the levitation of freight m),

k_d^p - an attenuation factor of oscillations (damp) of the mechanism movement of the crane; k_d - an attenuation factor of oscillations of a metal structures in a horizontal plane N·s/m,

x_p, x'_k, x_m, x_g - the ways pass by correspond weights from the origin m.

(1) values enter in the differential equations for the consider crane was equal:

- reduced masses: m_p = 860 kg; $m'_к$ = 18890 kg, $m_м$ = 12645 kg, m_g = 10000 kg,
- coefficients of rigidity: c_p =12520000 N/m, c_m = 868286 N/m, c_k = 19620 N/m (at ℓ = 5 m),
- resistance to the movement crane with freight under a grade in premise (the friction of detachable flanges are not consider) P_w = 2330 N,
- damping ratios: a drive of k_d^p = 2500 N s/m and metal structures in a horizontal plane of k_d = 130,7 N s/m.

2.2 About the independent variable (factors) which are unequivocally determine (set) the braking characteristic of the mechanism (drive). The case when the mechanism movement of the crane is equipped with the device for electro dynamic braking action with a separate excitation and the asymmetrical scheme of jointing of a direct-current source with a stator winding are consider. Any mechanic characteristic of an asynchronous motor in a mode of a dynamic braking can be set unequivocally by means of two factors (a current of excitation of I_B and the fetch resistance of R_P of a chain of a blade ring), M_{kq} determine the maximum moment and critical slip of the s_{kq} [6, 20] electric motor. In a mode of a dynamic braking reduced to translational movement of the crane a braking force of the mechanism (fig. 2) are describe by the first equation of system (2):

$$P_т = \begin{cases} -\dfrac{2 \cdot M_{kq} \cdot s_{kq} \cdot v_0 \cdot u \cdot \dot{x}'_k \cdot \eta}{r_k \cdot (s_{kq}^2 \cdot v_0^2 + \dot{x}'^2_k)} & \text{при} \quad \dot{x}'_k > v_{вq}; \\ -M_т \cdot u \cdot \eta / r_к & \text{при} \quad \dot{x}'_k \le v_{вq}, \end{cases} \tag{2}$$

where:

in addition to the values mention earlier: M_{kq} – the critical (overturn) moment and s_{kq} – critical slip of the electric motor in a mode dynamic braking action on q-oh characteristic (fig. 2 see); $v_0 = v_k\ (v_0/v_n)$ – speed of movement of the crane, correspond to synchronous rotational speed of a blade ring of the electric motor.

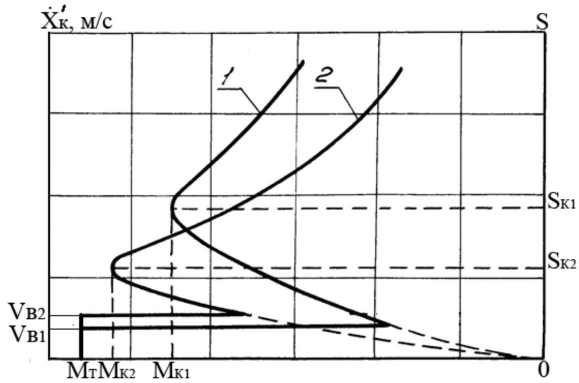

Fig. 2. Mechanic characteristics of the gear of movement the crane at a combination electrodynamic and mechanic braking action: 1–the initial; 2–the rational

As seen (fig. 2), value of brake torque in process of a speed reduction of crane movement are sharply moderate, and braking action became ineffective. It is reasonable to use and capabilities of normally closed expanding shoe type brakes. In this case braking action of the crane will be perform in two stages. In the beginning electric motors of the mechanism of movement worked in a mode of a dynamic braking that created the best conditions of dynamic loading of a metal structures and elements of the mechanism, promoted damping of oscillations of freight, and then, at achievement of the determined drop speed of V_{Bq}, engines was disconnect and the further braking action of the crane to it is stop is perform with constant brake torque of $M_т$ normally closed expanding shoe type brakes (a combination of electrodynamic and mechanic braking action).

In this case the braking characteristic is function of three factors: $P_т(M_{kq}, s_{kq}, v_{Bq})$.

2.3 ***Selection of the generalize criterion of braking process "quality.*** For optimization of braking processes it is necessary to be able to value them "quality". Transient effects of movement of the hoisting crane comprehensively could describe only by set of parameters. In particular "quality" of braking processes of bridge cranes is full enough characterized by means of four parameters: t_{Ti}, P_{mi}^{max}, $P_{ki}^{ma}x$, P_{pri}^{max}.

To the solution of multi parameter optimizing tasks there were different lines of thought. In the case under consideration the aprioristic information allowed to state a tentative estimation to each separate parameter of transient effect, therefore as the generalize criterion it are convenient to use a generalized function of desirability of Harrington [1, 3, 15, 19]. For it constructions it are necessary to receive the relations, allow to transform value of parameters of t_{Ti}, P_{mi}^{max}, P_{ki}^{max}, P_{pri}^{max} in values of dimensionless functions of desirability's of $d_{1i} = f_1\,(t_{Ti})$, $d_{2i} = f_2(P_{mi}^{max})$, $d_{3i} = f_3\,(P_{ki}^{max})$ and $d_{4i} = f_4\,(P_{pri}^{max})$, and the last - in value of the generalize desirability of D_i (here i – serial number of experience).

On fig. 3 schedules of functions of desirabilities of d1, $d_{2,3,4}$, a dimensionless scale of y ′, and also scales of transfer of parameters of $t_т$, P_m^{max}, P_k^{max}, P_{pr}^{max} was present to private desirabilities. For obtaining of relations of $d_{1i} = f_1(t_{Ti})$, $d_{2i} = f_2(P_{mi}^{max})$, $d_{3i} = f_3(P_{ki}^{max})$ and $d_{4i} = f_4(P_{pri}^{max})$ to boundary values of parameters should be g to by in correspondence of a mark on a scale of desirability.

The braking time of bridge cranes of $t_т$ are limit with two parties: on the one hand it should be more minimum braking time of t_{min} at whom hooking the driven tradable wheels with rails are upset, and with another – less maximum braking time of t_{max} is determined from features of a manufacturing process for whom the crane is intend.

To limit the type of two-way $t_{min} \le t_т \le t_{max}$ conversion of values of $t_т$ to a scale of d_l are effect by function:

$$d_1 = \exp[-(|y'|)^w]. \tag{3}$$

On fig. 3 at construction of the schedule of function (3) for a bridge crane load 10 т to value of d_l = 0,37 scales of the desirabilities, on border of areas "satisfactorily" and "badly", was put in correspondence of t_{min} = 6s (it are determine from condition of braking action of the crane by brakes TT-160, adjust on the maximum brake torques) and t_{max} = 12 s (are determine from features of a manufacturing process), and to value of d^*_1 = 0,80, l on border of areas "very well" and "well", - t^*_T = 8 s. The steepness of branches of curve d_1 depended on what value of t^*_T will be put in correspondence to value of d^*_1 = 0,80.

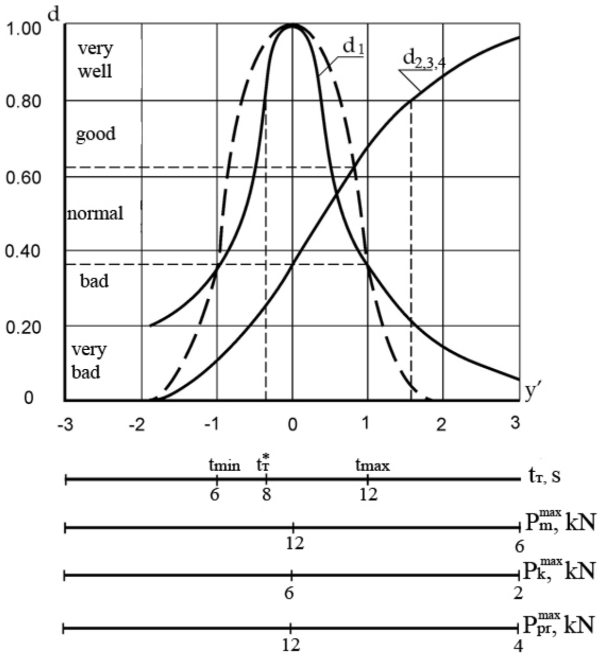

Fig. 3. Schedules of functions of desirabilities

For a case of combined braking action:

$$w = \frac{\ln(\ln(1/d_1^*))}{\ln\left|(2\cdot t_T^* - (t_{max}+t_{min}))/(t_{max}-t_{min})\right|} =$$

$$= \frac{\ln(\ln(1/0,8))}{\ln\left|(2\cdot 8-(12+6))/(12-6)\right|} = 1,365;$$

$$y' = \frac{2\cdot t_{Ti} - (t_{max}+t_{min})}{t_{max}-t_{min}} = \frac{2\cdot t_{Ti}-(12+6)}{12-6}.$$

Thus, expression for private function of desirability of d1i = looked like f1 (t_{Ti}):

$$d_{1i} = \exp[-(\left|(2\cdot t_{Ti} - (12+6))/(12-6)\right|)^{1,365}]\cdot \quad (4)$$

Limitations for parameters P_m^{max}, P_k^{max}, P_{pr}^{max} had one-way character. The form conversion to d_2 is more their, d_3, served d_4 an exponential relation:

$$d_{2,3,4} = \exp[-\exp(-y'_{2,3,4})], \quad (5)$$

where:

$$y'_2 = b_{02} + b_{12}\cdot P_m^{max} \quad y'_3 = b_{03} + b_{13}\cdot P_k^{max}$$

$$y'_4 = b_{04} + b_{14}\cdot P_{pr}^{max}.$$

Coefficients of b_{02}, b_{03}, b_{04}, and b_{12}, b_{13}, b_{14} determined ha set value of 0,37 private functions of desirabilities of d_2, d_3, d_4 as much as possible acceptable values correspond to them P_m^{max}, P_k^{max}, P_{pr}^{max} (fig. 3, a curve of $d_{2,3,4}$ see), and to value 0,95 - desirable values of these parameters.

Let's consider determination of coefficients of b_{02}, b_{12} in the equation:

$$d_{2i} = \exp[-\exp(-b_{02} - b_{12}\cdot P_{mi}^{max})]. \quad (6)$$

Let's appropriate to values of d_{2i} = 0,37 and d_{2i} = 0,95 acceptable and wish values of P_m^{max} (fig. 3):

$$0,37 = \exp[-\exp(-b_{02} - b_{12}\cdot 12)],$$

$$0,95 = \exp[-\exp(-b_{02} - b_{12}\cdot 6]\cdot$$

Decide the system of the equations, we will find b_{02} = +5,946 and b_{12} =-0,495.

Ultimately for conversion of the values of Pmi^{max} receive at computing experiment to values of d_{2i} the relation are receive:

$$d_{2i} = \exp[-\exp(-5,946 + 0,495\cdot P_{mi}^{max})]\cdot \quad (7)$$

For conversion of values of P_{ki}^{max} and P_{pri}^{max} in values of d_{3i} and d_{4i} relations was receiv:

$$d_{3i} = \exp[-\exp(-4,461 + 0,743\cdot P_{ki}^{max})], \quad (8)$$

$$d_{4i} = \exp[-\exp(-4,452 + 0,371\cdot P_{pri}^{max})], \quad (9)$$

Value of the generalize desirability of D_i in an i-ohm computing experiment:

$$D_i^э = \sqrt[4]{d_{1i}\cdot d_{2i}\cdot d_{3i}\cdot d_{4i}}\cdot \quad (10)$$

where: i – serial number of experience.

2.4 Calculation of the rational braking characteristic of the mechanism of movement of the crane by a method of abrupt climbing.

2.4.1 *Determination of the main level* $\tilde{z}_{jo}$ *and intervals of a variation* $\Delta\tilde{z}_j$ *of each factor.* Values of the main level of each factors (that is mechanic characteristic of a drive with whom researches begun) got out proceeding from the aprioristic information.

At selection of intervals of a variation of factors $\Delta\tilde{z}_j$ it is necessary to consider that too big values could lead that the equation of a regression (11) will appear inadequate to probe process, and too small - to not conspicuity of results of experiment.

2.4.2 *Selection of a kind of the regression equation.* In conduct research the task of determination of a gradient of response function $D_p = f(Z_j)$, therefore as a mathematical model the polynomial of the first order who contained the information on a direction of a gradient are receive

$$D_i^P = a_0 + \sum_{j=1}^{k} a_j \cdot Z_{ji}, \tag{11}$$

where: a_0, a_j - coefficients of a regression, Z_{ji} - the cod value of j-go of the factor in an i-ohm experience.

Communication between cod Z_j and natural $\tilde{z}_j$ values of factors are express by the formula

$$Z_j = (\tilde{z}_j - \tilde{z}_{j0}) / \Delta\tilde{z}_j. \tag{12}$$

2.4.3 *Selection of the plan of experiment.* Coefficients of a_0, a_1, a_2..., a_j of the equation of a regression (11) was calculate by handling of the values of the generalize criterion of optimization of $D_i^э$ receive as a result of computing experiment. As the plan of experiment it is possible to recommend at figure of factors of k≤4 the full factorial plan of type 2^k, at k> 4 - fractional factorial plans of type 2^{k-c} (c - figure of the linear effects equal to coupling effects).

2.4.4 Calculation of the rational braking characteristic of the movement mechanism of the crane is execute by a method of abrupt climbing. Values of the main levels of factors $\tilde{z}_{jo}$, intervals them a variation $\Delta\tilde{z}_j$ was locate in tab. 1.

Table 1. Entry conditions of experiences

Factors	M_{kq}, N m	S_{kq}	v_{Bq}, m/s
Main levels ($\tilde{z}_{jo}$)	80	0,20	0,20
Intervals of a variation ($\Delta\tilde{z}_j$)	5	0,05	0,05
Upper layers ($Z_j = +1$)	85	0,25	0,25
Lower layers ($Z_j = -1$)	75	0,15	0,15

For calculation of coefficients of the linear regression equation (11) complete factorial experiment of type 23 are put, the plan (columns 2-4) and which results (columns 5-8) was locate in tab. 2. In columns 9-12 was locate calculate on formulas (4, 7-9) values of private functions of desirabilities, and in column 13 – a generalized function of desirability.

2.4.5 *Realization of computing experiment.* As it are mark above, at the first phase of researches experiment is reasonable for put on a mathematical model of the crane (computing experiment). To each experience there corresponded the solution of system of the differential equations of crane motion (1) for a case of braking action on one of the mechanic characteristics, determine by values of factors $\tilde{z}_{ji}$ (column of 2-4 tab.2) in an i-ohm experience of the full (fractional) factorial plan. As results of experiment was receive in an i-ohm experience of value of t_{ri}, P_{mi}^{max}, P_{ki}^{max}, P_{pri}^{max} (columns of 5-8 tab. 2) and private desirabilities of $d_{\ell i}$ correspond to them, (columns of 9-12 tab. 2) by convertible in the generalize criterion of optimization of $D_i^э$ (column of 13 tab. 2).

2.4.6 Determination of coefficients of a regression and check of adequacy of model (11).

By results of the conduct series of computing experiments (tab. 2, column 13) was calculate by a method of least squares coefficients of the linear equation of a regression

$$D^p = 0{,}678 + 0{,}03398 \cdot Z_1 + 0{,}05703 \cdot Z_2 + 0{,}01333 \cdot Z_3 \tag{13}$$

As an estimation of approximation accuracy the variation are e

$$\rho = \frac{1}{a_0}\sqrt{\frac{\sum(D_i^P - D_i^Э)^2}{N - n^*}} < \alpha, \tag{14}$$

where:

$D_i^э$ and D_i^P – accordingly receive in computing experiments and the regressions (13) values of a generalized function of desirability forecast by the equation (tab. 2 see, columns 13 and 14), N and n* - accordingly figure of experiences of a die of planning and figure of coefficients of the regression equation (13).

(13) it is possible to consider the linear equation of a regression adequate, as for a consider case $\rho = 0{,}03 < \alpha = 0{,}05$.

2.4.7 *Abrupt climbing on a surface of the response.* After construction of linear model (13) for each factor the step of abrupt climbing are calculate. By a step on most strongly act factor was set, and on remaining factors the step are calculate from the relation

$$\frac{h^*}{h_j} = \frac{a^* \cdot \Delta\tilde{z}^*}{a_j \cdot \Delta\tilde{z}_j}, \tag{15}$$

Table 2. The plan and results of the first series of experiences at combined braking action

№	M_{kq}, N m	S_{kq}	$v_{вq}$, m/s	t_{Ti}, s	P_{mi}^{max} kN	P_{ki}^{max} kN	P_{pri}^{max} kN	d_{1i}	d_{2i}	d_{3i}	d_{4i}	$D_i^э$	D_i^p
1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**
1	85	0,25	0,25	10,44	8,385	3,700	8,108	0,693	0,847	0,835	0,791	0,782	0,789
2	85	0,25	0,15	10,61	8,385	3,700	9,681	0,652	0,847	0,835	0,657	0,756	0,742
3	85	0,15	0,25	12,41	7,814	3,357	7,756	0,304	0,882	0,870	0,814	0,668	0,660
4	85	0,15	0,15	12,42	7,814	3,357	7,924	0,302	0,882	0,870	0,803	0,642	0,657
5	75	0,25	0,25	11,22	8,383	3,576	8,624	0,515	0,847	0,848	0,753	0,714	0,727
6	75	0,25	0,15	11,38	7,744	3,576	10,220	0,483	0,886	0,848	0,598	0,688	0,683
7	75	0,15	0,25	13,39	7,780	3,275	7,355	0,186	0,884	0,877	0,838	0,600	0,590
8	75	0,15	0,15	13,44	6,927	3,116	8,710	0,181	0,922	0,890	0,746	0,574	0,577

Table 3. The plan and results of experiences of abrupt climbing at combined braking action

№	M_{kq}, N·m	S_{kq}	$v_{вq}$, m/s	t_{Ti}, c	P_{mi}^{max} kN	P_{ki}^{max} kN	$P_{пpi}^{max}$ kN	d_{1i}	d_{2i}	d_{3i}	d_{4i}	$D_i^э$
1	81,2	0,22	0,205	11,21	8,233	3,817	8,634	0,517	0,857	0,822	0,752	0,7235
2	82,4	0,24	0,210	10,79	7,935	3,617	8,655	0,610	0,876	0,844	0,750	0,7626
3	83,6	0,26	0,215	10,49	8,792	3,733	8,704	0,681	0,816	0,831	0,746	0,7662
4	84,8	0,28	0,220	10,02	9,017	3,947	8,795	0,795	0,797	0,805	0,739	0,7836
5	**86,0**	**0,30**	**0,225**	**9,62**	**9,305**	**4,144**	**8,927**	**0,890**	**0,770**	**0,778**	**0,728**	**0,7893**
6	87,2	0,32	0,230	9,38	9,604	4,312	9,066	0,942	0,738	0,753	0,716	0,7823
7	88,4	0,34	0,235	9,05	9,816	4,454	9,651	0,996	0,714	0,729	0,660	0,7649

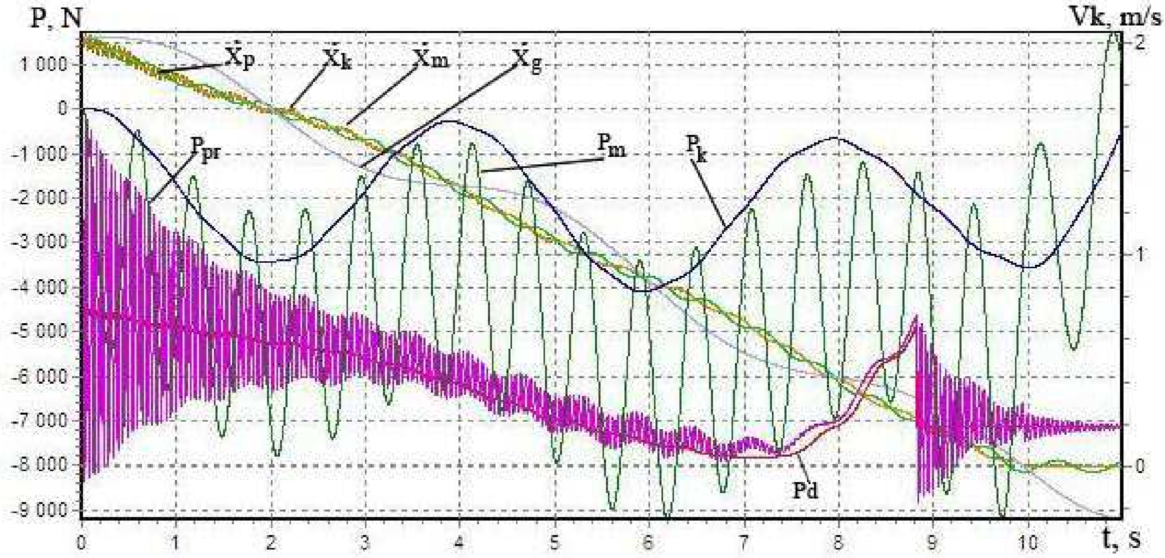

Fig. 4. Schedules of parameters at braking action of the crane load 10 т span of 34,5 m on the rational combined characteristic

where:

h^* and h_j - a step of abrupt climbing on most strongly act and to a j-ohm to factors; a^*, a_j - coefficients of the regression equation (13) at correspond factors; $\Delta\tilde{z}^*, \Delta\tilde{z}_j$ - natural values of intervals of a variation of correspond factors.

Abrupt climbing began from the main level. Conditions of realization of experiences of abrupt climbing on a surface of the response received consecutive addition (subtraction) to values of factors at the main level of value of a step on correspond factors.

In a consider example the step on the second factor are receive equal $\Delta_2 = 0,02$, then:

$$\Delta_1 = \Delta_2 \cdot \frac{b_1 \cdot \Delta M_к}{b_2 \cdot \Delta s_к} = 0,02 \cdot \frac{(0,03398) \cdot 5}{(0,05703) \cdot 0,05} = 1,19 \ N \cdot m ;$$

$$\Delta_3 = \Delta_2 \cdot \frac{b_3 \cdot \Delta v_в}{b_2 \cdot \Delta s_к} = 0,02 \cdot \frac{(0,01333) \cdot 0,2}{(0,05703) \cdot 0,05} = 0,0047 \ m/s .$$

After rounding the step for the first factor is receive equal $\Delta_1 = 1,2$ N·m, for third $\Delta_3 = 0,005$m/s.

In tab. 3 the plan of experiences of abrupt climbing and the values of parameters of τri receive as a result of computing experiment, P_{mi}^{max}, P_{ki}^{max}, P_{pri}^{max}, and also values of d_{ni} correspond to them and D_i was locate.

The generalize criterion of optimization of $D_i^э$ = 0,7893 reaching a peak value in fifth experience. Schedules of parameters of a bridge crane braking process load 10 т on the rational characteristic of the mechanism (tab. 3, experience 5) was locate by span of 34,5 m on fig. 4.

Motion on a gradient proceeded until improvement of the generalize criterion of optimization of $D_i^э$ took place. As soon as it value will start to be moderate, or the task of optimization is decide (if the contributor is satisfy by the receive results), or a new series of experiences with center of $\tilde{z}_{ji}^*$, to correspond conditions of the best reach result are conduct. In a consider example it was decided to stop at the achieved results.

CONCLUSIONS

The offer method allowed to calculate the optimum (rational) braking performance of gears of movement of the mobile cranes arrange with various types of braking devices. It considered objective braking parameters, real mass distribution, rigidity of elastic elements of the crane, etc. that done not allow to make methods exist now. Researches on development of a similar method of calculation for turn mechanism of hoisting cranes was perspective.

REFERENSES

1. **Adler Yu.P., Markova of E.V., Granovsky Yu.V., 1976.:** Planning of experiment by search of optimum conditions. - M.: Science. – 279.
2. **Alexandrov M. P., 1976.:** Brakes of lift-and-carry machines. - M.: Mechanical engineering. – 383.
3. **Akhnazarova of S.L., Kafarov of Century of Century, 1978.:** Optimization of experiment in chemistry and chemical technologists. – M.: The higher school. – 319.
4. **Budikov L. Ya., 2003.:** Multiparameter analysis of dynamics of mobile cranes of bridge type. – Lugansk: publishing house of VNU. – 210.
5. **Budikov L.Y., Shishkin R.V., 2012.:** About forming of the optimum braking performance of gears of movement of mobile cranes on the basis of the multiparameter analysis of transient effects. – Odessa, "Jacking facilities. Special engineering". № 7-8 (126), 19-22.
6. **Budikov L.Ya., Stoyanov of L.A., 1991.:** The multicriteria approach to a question of optimization of transient operational modes of mobile cranes. M.Vestnik of mechanical engineering. № 2. – 26-29.
7. **Gaydamaka V. F., 1989.:** Hoisting machines - To.: Выща шк. – 328.
8. **Gaydamaka V.F., 1988.:** Activity of hoisting machines at stepless braking action. – Kharkov, Vyshcha шк. - 141.
9. **Alexandrov M. P., 1985.:** Lift-and-carry machines. - M. The higher school. - 520.
10. **Dmittriy Syomin, Yaroslav Maltsev, Marina Maltseva., 2012.:** Reseach of influence of brake devise on dynamic properties of elektro-pneumatic valve. – Lublin, "Teka", Vol 12 № 3. 151-154.
11. **Cosack S.A., 1968.:** Dynamics of bridge cranes. - M.Mashinostroyeniye. - 332.
12. **Mosquito M.S., 1969.:** Dynamics of gears and machines. – M.Mashinostroyeniye. – 296.
13. **Leonid Budikov, 2010.:** Multiparameter multiple factor analysis of the climbing cranes' dynamics. – Lublin, "Teka". Vol XA, 50-56.
14. **Lobov N.A., 1987.:** Dynamics of mobile cranes. - M.Mashinostroyeniye. – 160.
15. **Novick F.S., Arsov Ya.B., 1980.:** Optimisation of processes of technology of metals by methods of planning of experiments. – M.Mashinostroyeniye; Sofia. Engineering. – 304.
16. **Baryshev of A.I., Budishevsky V.A., Sklyarov of N.A., Zhitkov of Yu.V., 2009.:** Justification and calculations of parametres of hoisting machines. – Donetsk "DONNTU". – 307.
17. **Parnitsky A.P., Shabashov of A.P., Lysyakov of A.G., 1971.:** Bridge cranes of general purpose.- M.: Mechanical engineering. – 352.
18. RTM 24.090.28-77. Cranes load-lifting. Gear of movement. Method of calculation.
19. **Hartman K., Letsky Э., Schaefer V., etc., 1977.:** Planning of experiment in research of manufacturing processes. – M.Mir. – 552.
20. **Vladimir Morkun, Sergey Goncharov, Andrey Pikilnyak, Andrey Krivenko, 2012.:** Irone ore benefication processes optimisation. – Lublin, "Teka", Vol 12. – № 4. 162-166.

ФОРМИРОВАНИЕ ОПТИМАЛЬНЫХ ТОРМОЗНЫХ ХАРАКТЕРИСТИК МЕХАНИЗМОВ ПЕРЕДВИЖЕНИЯ ГРУЗОПОДЪЕМНЫХ КРАНОВ

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Аннотация. Изложена концепция метода расчета оптимальных (рациональных) тормозных характеристик механизмов передвижения грузоподъемных кранов, базирующаяся на многопараметрическом многофакторном анализе переходных процессов, рассмотрен пример расчета. Рис. 4, табл. 3, ист. 20.

Ключевые слова: мостовые краны, оптимизация тормозных процессов.