TEKA Kom. Mot. i Energ. Roln. – OL PAN, 2010, 10A, 50-56

MULTIPARAMETER MULTIPLE-FACTOR ANALYSIS OF THE CLIMBING CRANES' DYNAMICS

Leonid Budikov

Department of Lifting and Transport Technique, Faculty of Logistics
Volodymyr Dal East-Ukrainian National University, Lugansk, Ukraine

Summary. Multiparameter multiple-factor investigations of the motor plugging dynamics of the bridge cranes with 10 tons hoisting capacity had been made. The statistical model of the optimization generalized criterion dependence from dominate factors had been built. The efficiency of this research method from the point of climbing cranes dynamics reduction had been shown.

Key words: climbing cranes, multiparametric optimization, braking processes, the generalized criterion.

INTRODUCTION

Climbing cranes operate in the recursive short-time mode of mechanisms activation. This mode is characterized by frequent mechanisms' start-stops, and is followed by heavy dynamic load of crane's driving mechanism and metalware. Especially hard dynamic loads follow after fast-speed bridge cranes' plugging by electric motors, which is widespread during the cranes' exploitation [Budikov L.Y. Kanaev S.F.]. It is possible to reduce dynamic loads in the cranes' elements with the help of optimal (rational) formation of the driving elements' mechanical characteristics in the modes of plugging by electrical motors.

OBJECTS AND PROBLEMS

The bridge cranes with 10 tons hoisting capacity, made by VNIIPTMACH (Vkr = 2 m/s, L = 22,5-34,5 m, separate drive, inside work) had been examined. Driving system of cranes, which are assigned for inside work, consists of engine MTF 211-6 (N = 7,5 kW, PV = 40%, n_H = 930 rpm, M_{max} = 191 N·m), reduction unit TC2-300 (u_p = 9.8), brakes TGK - 160 ($M_{t\ (max)}$ = 100 N·m), running wheel with the radius r_k = 0,2 m and connected to each other muffs. Fig. 1 shows the mechanical characteristics of the driving system during its work in the traction mode (curves 1-5) and the mode of plugging by the electric motor (curves 1'-5 ').

Mechanical characteristics of the cranes' driving system in the traction mode P_d and the mode of plugging by the electric motor P_{pl} are quite accurately described by next formulas [Budikov L.Y. 2003]:

$$P_d = \frac{K_q \cdot (v_o - \dot{x}_\kappa)}{B_q + (v_o - \dot{x}_\kappa)^2}; \qquad P_{pl} = -\frac{K_q \cdot (v_o + \dot{x}_\kappa)}{B_q + (v_o + \dot{x}_\kappa)^2}, \tag{1}$$

where $K_q = \dfrac{2M_k \cdot s_{kq} \cdot v_o \cdot u_m \cdot \eta}{r_k}$; $B_q = s_{kq}^2 \cdot v_o^2$; $M_k = \lambda \cdot M_H$ - critical (overturning) engine moment; s_{kq} - critical slip on the mechanical characteristic q; $v_0 = v_k \cdot n_0 / n_d$ - crane's movement speed which corresponds to the synchronous speed of the engine rotor rotation; u_m - ratio of the driving system; r_k – radius of the running wheel; $\dot{x}_k$ - current value of the crane's movement speed.

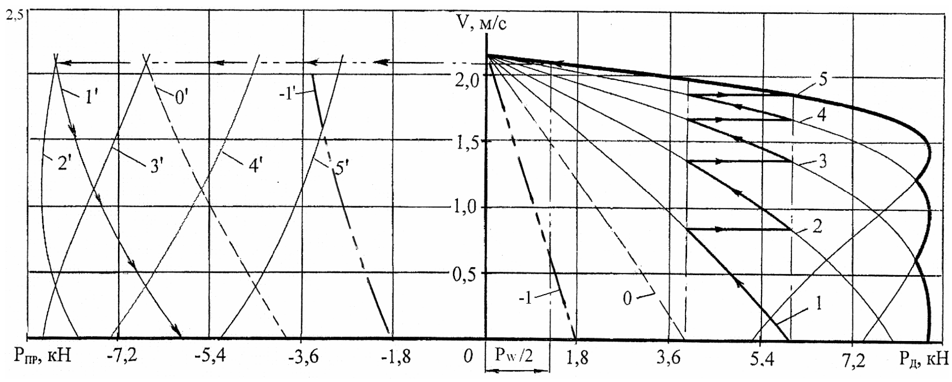

Fig. 1. Mechanical characteristics of the driving system of the crane with 10 tons hoisting capacity

RESULTS OF RESEARCH

The calculation of transient processes' dynamic parameters usually comes to a system of nonlinear differential quadratic equations [Budikov L.Y. 2003]. The solution of such system comes out of the motion equations' numeral integration for a fixed set of factors, the solution is given in the form of curves, which show the changes of the hoisting machine's studied parameters in time. For the plugging of bridge cranes by electric motors, which had been investigated in this article, such parameters are: driving system's reduced force $P_r = f_1(t)$; horizontal metalware's inertial loading $P_m = f_2(t)$; horizontal component of the load rape's tension $P_k = f_3(t)$; speed of end girders' movement $v_k = f_4(t)$, etc. (see fig. 3).

For the studied group of cranes, the variable factors, which have a dominant influence on the transition process's parameters value, are critical slip (s_{kq}) on the mechanical characteristic q, reduced to the end girders (m_k) and to the midspan (m_M) of the crane's weight, metalware's rigidity in the horizontal plane (the research had been made for the length of the suspension load ℓ = 5 m).

"Quality" of the bridge crane's braking can be described only with the set of parameters, among them determinative ones are: crane's braking time t_T, maximum dynamic load on the metalware $P_M^{\max}$, maximum horizontal component of the load rapes' tension $P_k^{\max}$ (maximum amplitude of the load's deviation from the vertical line $A^{\max} = \frac{P_k^{\max}}{c_k}$). The above-mentioned parameters fully and sufficiently describe the transition process and determine crane's technical and operational characteristics.

Thus, one of the adopted methods's of cranes' dynamics features analysis is multivariate braking processes "quality's" estimation.

There are different approaches to the several parameters optimization's problem solving. In this case, it is possible to give a preliminary assessment of each individual parameter of the transition process, that's why it is convenient to use Harrington's generalized desirability function D as a generalized criterion [Achnazarova S.L., Kafarov V.V. 1978]. For the construction of this criterion it is necessary to transform the values of parameters $t_{\text{т}i}$, $P_{\text{м}i}^{\max}$, $A_i^{\max}$, … to the values of non-dimensional particular desirability d_{1i}, d_{2i}, d_{3i}, ... and find D_i as an average geometric value of this desirability (i – experiment's sequence number).

Bridge cranes' braking time t_T is limited from two sides: on the one hand this time must be longer than the minimum braking time $t_{\min}$, when the grip of the running wheels and rail is violated, and on the other – it should be less than maximum braking time $t_{\max}$, which is determined by features of the crane's technological process. For the investigated cranes, values $t_{\min}$ = 2s, and $t_{\max}$ = 12 s correspond to the function's branch value d_1 = 0,37 (2), and the value d_1^* = 0,80 corresponds to t_T = 4 s.

For the bilateral constrain, which looks like $t_{\min} \le t_{\text{т}} \le t_{\max}$, it is possible to transform t_T values in the d_1 scale, using the function

$$d_1 = \exp[-(|\,y'|)^w]. \tag{2}$$

For this example

$$w = \frac{\ln(\ln(1/d_1^*))}{\ln\left|(2\cdot t_{\text{т}}^* - (t_{\max}+t_{\min}))/(t_{\max}-t_{\min})\right|} = 2{,}936\ ,$$

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

Restrictions for the parameter $P_{\text{м}}^{\max}$ are unilateral. The exponential dependence

$$d_2 = \exp[-\exp(-y'_2)], \tag{3}$$

where: $y'_2 = a_0 + a_1 \cdot P_{\text{м}}^{\max}$, is used to transform $P_{\text{м}}^{\max}$ to d_{2i}.

The coefficients a_0 and a_1 are defined using the correspondence between particular desirability function's values d_2 = 0,37 and d_2 = 0,95, starting (which occur during crane's braking after switching motors to mechanical characteristic 1') and desired (expected after electric motors' switching to the optimal mechanical properties) values $P_м^{max}$.

For this example:

$$d_{2i} = \exp[-\exp(-4{,}242 + 0{,}212 \cdot |P_{мi}^{max}|)]. \quad (4)$$

The aggregation of particular desirabilities to the generalized desirability D was made according to the formula

$$D_i = \sqrt{d_{1i} \cdot d_{2i}}\ , \quad (5)$$

where: i - experiment's sequence number.

Variation ranges of factors c_m, m_k, m_M had been determined, using real parameters of the bridge cranes with 10 tons hoisting capacity, spans L = 22,5 ... 34,5m, made by VNIIPTMASH. On the basis of a priori information, $S_{K\,(min)} = 4{,}2$ (fig. 1, curve 0'), and $S_{K(max)} = 9{,}6$ (fig. 1, curve -1') had been set.

Basic (zero) levels ($s_{кO}, c_{MO}, m_{кO}, m_{мO}$), variability intervals ($\Delta s_к, \Delta c_м, \Delta m_к, \Delta m_м$), factors' upper and lower levels are in the table. 1

Table 1. **Factor's levels and variability intervals**

Factors	$s_к$	$c_м$, N/м	$m_к$, kg	$m_м$, kg
Code (Z_j)	Z_1	Z_2	Z_3	Z_4
Basic levels ($Z_j = 0$)	6,9	$1{,}2 \cdot 10^6$	$1{,}5 \cdot 10^4$	$0{,}85 \cdot 10^4$
Variability intervals (ΔZ_j)	2,7	$0{,}4 \cdot 10^6$	$0{,}5 \cdot 10^4$	$0{,}35 \cdot 10^4$
Upper levels ($Z_j = +1$)	9,6	$1{,}6 \cdot 10^6$	$2{,}0 \cdot 10^4$	$1{,}2 \cdot 10^4$
Lower levels ($Z_j = -1$)	4,2	$0{,}8 \cdot 10^6$	$1{,}0 \cdot 10^4$	$0{,}5 \cdot 10^4$

The normalizing (coding) of factors has been done to transform them from dimensional to nondimensional ones:

$$Z_1 = \frac{s_{кi} - s_{кo}}{\Delta s_к}; \quad Z_2 = \frac{c_{мi} - c_{мo}}{\Delta c_м}; \quad Z_3 = \frac{m_{кi} - m_{кo}}{\Delta m_к},\ Z_4 = \frac{m_{мi} - m_{мo}}{\Delta m_м},$$

where Z_1, Z_2, Z_3, Z_4 - coded values of factors $s_к$, $c_м$, $m_к$, $m_м$; $s_{кi}$, $c_{мi}$, $m_{кi}$, $m_{мi}$ –values of factors in the i-th experiment.

The plan B_k, where the number of experiments is defined by formula:

$$N = 2^k + 2 \cdot k + n_0, \quad (6)$$

where: 2_k – number of core's plan experiments, which form the complete factorial; $2 \cdot k$ – number of star point experiments, for which the star lever $\alpha = 1$; n_0 – number of experience in the center of the plan,

had been chosen for the regression analysis, i.e. for the second order polynomial modeling (7).

The full scale plan of experiment B_4 was placed in the accepted plan's graphs 2-5 (see table 2). The results of computer simulation are shown in graphs 6-7, values of particular desirability functions d_1 and d_2, which correspond to the results of i-th computing experiment, are in graphs 8-9, value of the generalized criterion D_i^e is shown in the graph 10.

Table 2. **Computer simulation's plan and results**

№ of experiment	$s_к$	$c_м \cdot 10^4$, N/м	$m_к \cdot 10^4$, kg	$m_м \cdot 10^4$, kg	t_{Ti}, c	$P_{мi}$, кN	d_{1i}	d_{2i}	D_i^e
1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
1	9,6	160	2,0	1,2	11,56	-8,978	0,466	0,908	0,651
2	9,6	160	2,0	0,5	10,62	-6,893	0,679	0,940	0,799
3	9,6	160	1,0	1,2	10,00	-10,559	0,800	0,874	0,836
4	9,6	160	1,0	0,5	7,71	-8,672	0,997	0,914	0,954
5	9,6	80	2,0	1,2	11,53	-8,890	0,473	0,910	0,656
6	9,6	80	2,0	0,5	10,61	-6,888	0,681	0,940	0,800
7	9,6	80	1,0	1,2	9,95	-10,563	0,809	0,874	0,841
8	9,6	80	1,0	0,5	7,68	-8,647	0,997	0,914	0,955
9	4,2	160	2,0	1,2	6,87	-15,124	1,000	0,702	0,838
10	4,2	160	2,0	0,5	5,91	-11,912	0,989	0,836	0,909
11	4,2	160	1,0	1,2	5,12	-18,181	0,945	0,508	0,693
12	4,2	160	1,0	0,5	3,96	-15,372	0,793	0,689	0,739
13	4,2	80	2,0	1,2	6,79	-14,936	1,000	0,712	0,844
14	4,2	80	2,0	0,5	5,79	-11,855	0,985	0,838	0,908
15	4,2	80	1,0	1,2	5,15	-18,129	0,947	0,512	0,697
16	4,2	80	1,0	0,5	3,97	-15,249	0,795	0,695	0,743
17	6,9	120	1,5	0,85	7,66	-10,985	0,997	0,863	0,928
18	9,6	120	1,5	0,85	10,43	-8,742	0,718	0,912	0,810
19	4,2	120	1,5	0,85	5,48	-15,071	0,970	0,705	0,827
20	6,9	160	1,5	0,85	7,69	-10,949	0,997	0,864	0,928
21	6,9	80	1,5	0,85	7,71	-11,013	0,997	0,862	0,927
22	6,9	120	2,0	0,85	8,38	-9,968	0,977	0,888	0,932
23	6,9	120	1,0	0,85	7,02	-12,260	1,000	0,824	0,908
24	6,9	120	1,5	1,2	8,11	-12,063	0,988	0,831	0,906
25	6,9	120	1,5	0,5	7,28	-9,640	1,000	0,895	0,946

The coefficients of the regression equation, which describes values of the generalized criterion D_i^p in the specified area of factors' $s_к$, $c_м$, $m_к$, and $m_м$ estimation, had been counted using least-squares procedure. As a result, next regression equation had been received:

$$D^p = 0{,}929 + 5{,}778 \cdot 10^{-3} \cdot Z_1 - 1{,}333 \cdot 10^{-3} \cdot Z_2 - 1{,}611 \cdot 10^{-3} \cdot Z_3 - 0{,}044 \cdot Z_4 - 0{,}111 \cdot Z_1^2 -$$
$$-1{,}785 \cdot 10^{-3} \cdot Z_2^2 - 9{,}285 \cdot 10^{-3} \cdot Z_3^2 - 3{,}285 \cdot 10^{-3} \cdot Z_4^2 + 6{,}25 \cdot 10^{-5} \cdot Z_1 \cdot Z_2 - 0{,}082 \cdot Z_1 \cdot Z_3 -$$

$$– 0{,}019·Z_1·Z_4 + 1{,}875·10^{-4}·Z_2·Z_3 – 9{,}375·10^{-4}·Z_2·Z_4 – 6{,}438·10^{-3}·Z_3·Z_4. \quad (7)$$

The adequacy of the regression equation (7) was estimated by the variation coefficient:

$$\rho = \frac{1}{D_{cp}} \cdot \sqrt{\frac{\sum (D_i^э - D_i^p)^2}{N - k_1}} \le \alpha, \quad (8)$$

where $D_{sr} = b_0$ - the average value of the transient process's "quality" criterion; D_i^e - the value of the "quality" criterion in the i-th point of the plan, which had been received during the computational experiment (i.e. numerical integration of the "drive-metalware-load" system's motion equation; D_i^p - the value of the "quality" criterion in the i-th point of the plan, counted with the help of polynomial (7); N – the total amount of experiences; k_1 – total number of regression coefficients).

Model verification (7) gave the result ρ = 0,115. Statistical model (7), which describes the dependence $D^p = f(s_к, c_м, m_к, m_м)$, allows to estimate influence and mutual influence of factors $s_к$, $c_м$, $m_к$, $m_м$ on the "quality" of the examined cranes' braking process in the mode of electric motors opposite circuit.

Within the bounds of the article, the author had limited himself to graphing of dependence $D^p = f(s_к)$ for cranes with spans 22,5 m, 28,5 m and 34,5 m (see fig.2). Thereto the values of the coded factors Z_2, Z_3, Z_4, which correspond to the above-mentioned crane spans' values $c_м$, $m_к$, $m_м$, had been inserted to the equation (7)

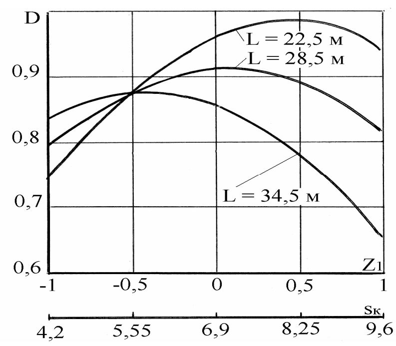

Fig. 2. Graphs of the dependence D = f (s_k) for cranes with different spans

The graphs of the braking processes parameters while crane's with the span 28,5m braking, using the switching to reasonable mechanical characteristics s_k=6,9, are shown at fig. 3. In this case $P_м^{max}$ = 11,78 kN, t_T = 7,65 s.

The similar calculation had been made during the braking process of the same crane, but using the switching to the mechanical characteristic 1' (see fig. 1), what occur during the real cranes exploitation [Budikov L.Y. Kanaev S.F. 2009]. The aim of these calculations was to evaluate the received effect. In this case $P'^{max}_м$ = 20,37 кN, $t'_т$ = 3,92 c.

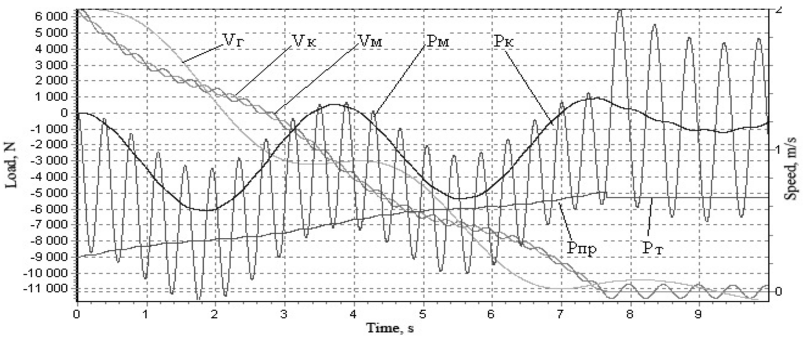

Fig. 3. Graphs of the parameters during crane's braking L = 28,5 m, using the switching to reasonable mechanical characteristic

CONCLUSION

1. The method of multiparameter multiple-factor analysis of the climbing cranes' movement dynamics, which is grounded on the combined use of the classical approach to the machines' dynamics questions and mathematical theory of multiple-factor experiments, allows to fulfill multiparameter analysis of different factors' influence on cranes' dynamics, to count reasonable, according to the generalized criterion, mechanical characteristics of the movement drive.

2. In the article it was shown that choosing the reasonable braking mechanical characteristics, it is possible to reduce considerably (1,5 - 2 times) dynamic loads with acceptable duration of the braking processes. Statistical model (7), which describes the dependence $D^p = f(s_к, c_м, m_к, m_м)$, allows to evaluate the influence and mutual influence of factors $s_к$, $c_м$, $m_к$, $m_м$ on the "quality" of the investigated cranes' braking in the mode of plugging by electric motors.

REFERENCES

1. Achnazarova S.L., Kafarov V.V., 1978. Experiment's optimization in chemistry and chemical engineering. High school. Moscow: 319.
2. Budikov L.Y. Kanaev S.F., 2009. Advantages and disadvantages of cranes' plugging by electric motors. Lifting constructions. Special mechanisms, №4(92). Astroprint. Odessa: 21-24.
3. Budikov L.Y., 2003. Multiparameter analysis of bridge hoisting cranes' dynamics. EUNU publishing house. Lugansk: 210.

МНОГОПАРАМЕТРИЧЕСКИЙ МНОГОФАКТОРНЫЙ АНАЛИЗ ДИНАМИКИ ГРУЗОПОДЪЕМНЫХ КРАНОВ

Будиков Л.Я.

Аннотация. Выполнены многопараметрические многофакторные исследования динамики торможения мостовых кранов грузоподъемностью 10 т противовключением электродвигателей. Построена статистическая модель зависимости обобщенного критерия оптимизации от доминирующих факторов. Показана эффективность метода исследований с точки зрения снижения динамики грузоподъемных кранов.

Ключевые слова: грузоподъемные краны, многопараметрическая оптимизация, тормозные процессы, обобщенный критерий.