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Determination of functions of controlling drives of main executive mechanisms of mining excavators

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Abstract. It is shown that a special shovel is a feature of the structure of the drives of the main mechanisms (mechanisms of lifting and pressure) of career excavators with working equipment, the presence in the transfer device of a two-crank-lever mechanism of working equipment that connects the main mechanisms with the working body (bucket). In this case, the transformation of the mechanical energy parameters of the motors into energy-force parameters realized at the cutting edge of the bucket (teeth) takes place depending on the type of the kinematic scheme of the two-link-lever mechanism. The concept of "control function" defining the relationship between the parameters characterizing the position of the bucket in the face (the coordinates of the tip of the cutting edge of the bucket, the digging speed) and the required control level are introduced. These are the values of the lifting and head speeds ensuring the bucket movement along a given trajectory.

1. Introduction

One of the main reserves of productivity growth for career excavators is the formation and maintenance of rational modes of joint operation of the main executive mechanisms (lifting and pressure) in the digging process for specific operating conditions that ensure the full implementation of the technical capabilities of equipment and the degree of use of the installed capacity of power equipment.

The operating modes of the engines of the executive mechanisms (lifting and pressure mechanisms) of career excavators are characterized by a large number of inclusions, a significant variation in the loads and speeds of work movements. The management of the workflow under these conditions (a large amount of information about the work process, a time deficit) is difficult.

The analysis of the control systems of the digging process [1, 2, 3] shows that the main factor affecting the efficiency of the process is the difficulty in identifying the state of the control object.

Improving the quality and efficiency of management requires combining the systems of a mining excavator - mechanical, electrical, information, etc., into a mechatronic facility with computer control.

The reduction of the various types of connections (kinematic, energy, etc.) into a single theoretical model will make it possible to create an adaptive self-adjusting workflow control system for specific mining conditions.

2. Purpose and objectives of the study

The goal is to improve the efficiency of workflow management on the basis of identification of the modes of operation of executive mechanisms.

Problems solved in this work:

- analysis of the degree of transformation by the lever mechanism of the working equipment of the regime parameters of the main executive mechanisms (speeds and forces of lifting and pressure) into the energy-force parameters realized on the ladle during excavation;

- establishment of interrelations between the regime parameters of the main mechanisms and parameters of the excavation process (trajectory of the bucket displacement, digging speed, cutting angle, etc.);

- determination of the control functions of the main mechanisms in the implementation of the specified bucket trajectory.

3. Solving research problems

The basis for the development of a drive control system for the main mechanisms of a mining excavator is the simulation model of the excavation process as a control object [4, 5].

As a method of research, a computational experiment was adopted. For algorithmic models, experimentation using a model is identical to finding the values of output characteristics for given values of input variables and constant arguments under different operating conditions. A search of variants of solutions is carried out with a given step of variation. During the calculation and calibration of the mathematical model, information about the functionality of the control object is accumulated. The results of simulation are a set of computational data characterizing the process under study.

Modes of operation of the main working mechanisms (lifting and pressure mechanisms) of mining excavators depend significantly on the mining conditions of development and, mainly, the physical and mechanical properties of rocks [6-14].

The control of the working process of excavation consists in the realization of the speeds of the working movements (lifting and head speeds) providing the specified trajectories of the bucket motion (the tops of the cutting edge) -equidistant (curves removed at the same distance equal to the thickness of the layer of the cut rock layer) for connected and blown semi- rocky rocks, and broken (with bends) curves for poor preparation of rock mass (the presence of oversized and large pieces with dimensions of 0.5-1.0 m).

Alayered excavation of rocks when the bucket (the tip of the cutting edge) is moved along equidistant trajectories parallel to the slope of the ledge is accepted as the main working operation of a mining excavator.

In the work based on the mathematical model of the working process of a mining excavator, a computational experiment was performed to calculate the speeds of the working motions of the main mechanisms when the bucket is moved within the excavator working area.

The excavator ECG-20 (ECG-20A) manufactured by PJSC Uralmashzavod was used as an object of computational experiment.

The values of the initial data for calculating the regime parameters of the main mechanisms are as follows:

- angles of inclination of the trajectories of the bucket displacement (tip of the cutting edge - points K) are taken to be ψ = 50, 60 and 70 degrees, which corresponds to the actual values of the slope angles of the slope;

- digging speed V_κ = 1 m / s;

- maximum digging radius $R_{k\ max}$ = 24 m; the maximum digging height is $H_{k\ max}$ = 18 m.

Figure 1 shows the calculated trajectories of the bucket displacement within the working area of the excavator - the initial, medium and final ones.

Tables 1-3 give the calculated values of the speeds of working movements when the bucket is moved along equidistant trajectories (initial, middle and final) with different angles of inclination.
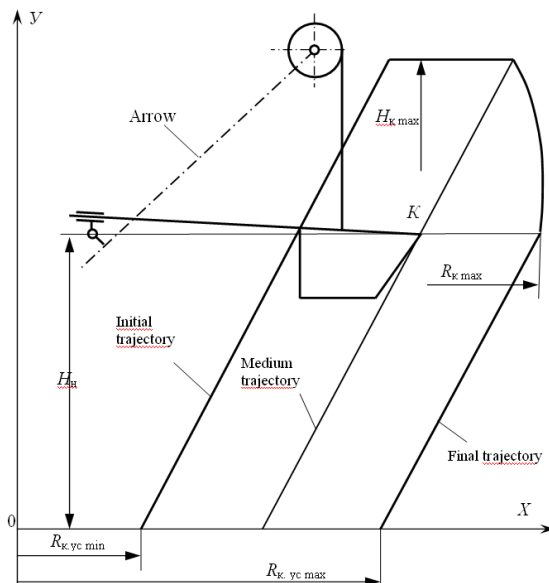
Figure 1. Working area of a mining excavator (mehlopaty):
X0Y - coordinate system: 0X - stand level of the excavator; 0Y - the axis of rotation of the platform; $H_\text{н}$ - height of the axis of the pressure shaft; $H_\text{к.max}$ - maximum digging height; $R_\text{к max}$ - the maximum digging radius; $R_\text{c.m·min}$, $R_\text{k. us max}$ - minimum and maximum digging radii at the level of standing of the excavator.
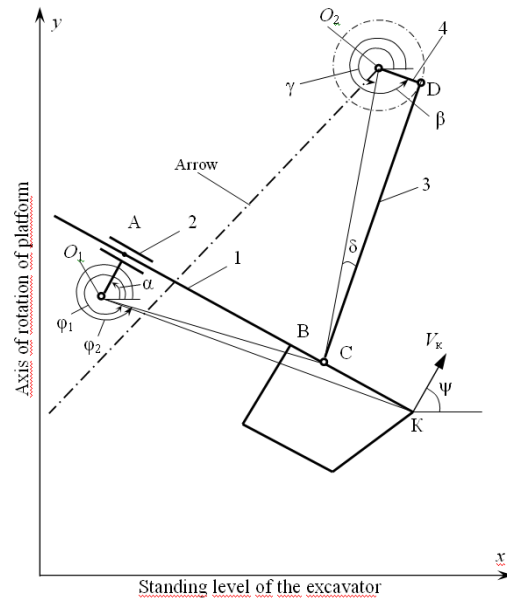
Figure 2. Kinematic scheme of the working equipment mechanism:
1 - link "handle-bucket"; 2 - saddle bearing; 3 - fragment of the hoisting rope; 4 - head unit; α, β, γ, φ_1, φ_2, ψ - angles defining the positions of the links

As follows from the data given, the rates of lifting and pressure vary depending on the digging height, and the digging radius, i.e. the trajectory of the bucket displacement - initial, middle and final.

Table 1. Speeds of working movements when bucket is moved along equidistant trajectories ($\psi = 50\,°$)

$Y_\text{к}$	Initial trajectory			Middle trajectory			Final trajectory		
	$X_\text{к}$	$V_\text{п}$	$V_\text{н}$	$X_\text{к}$	$V_\text{п}$	$V_\text{н}$	$X_\text{к}$	$V_\text{п}$	$V_\text{н}$
0	9	0.92	-0.77	13	0.82	-0.53	14	0.80	-0.46
2	10.7	0.86	-0.65	14.7	0.76	-0.35	15.7	0.73	-0.28
4	12.4	0.76	-0.46	16.4	0.68	-0.13	17.4	0.66	-0.06
6	14.1	0.65	-0.17	18.1	0.61	0.11	19.1	0.59	0.16
8	15.8	0.60	0.17	19.8	0.55	0.34	20.8	0.51	0.36
10	17.5	0.63	0.45	21.5	0.45	0.51	22.5	0.38	0.52
12	19.2	0.64	0.64	23.2	0.26	0.64	24.2*	0.17	0.64
14	20,9	0.49	0.76	24.9*	-0.01	0.73			
16	22.6	0.09	0.83						
18	24.3*	-0.36	0.88						

* Not implemented (point K is outside the work area).

Table 2. Speeds of working movements when bucket is moved along equidistant trajectories ($\psi = 60\ °$)

$Y_к$	Initial trajectory			Middle trajectory			Final trajectory		
	$X_к$	$V_п$	$V_н$	$X_к$	$V_п$	$V_н$	$X_к$	$V_п$	$V_н$
0	9	0.95	-0.87	13	0.89	-0.67	17	0.81	-0.44
2	10.15	0.91	-0.81	14.15	0.84	-0.54	18.15	0.76	-0.30
4	11.3	0.84	-0.70	15.3	0.77	-0.37	19.3	0.70	-0.14
6	12.45	0.70	-0.51	16.45	0.70	-0.16	20.45	0.64	0.04
8	13.6	0.52	-0.19	17.6	0.66	0.09	21.6	0.58	0.21
10	14.75	0.50	0.19	18.75	0.66	0.32	22.75	0.49	0.37
12	15.9	0.66	0.50	19.9	0.65	0.50	23.9	0.34	0.50
14	17.05	0.80	0.70	21.05	0.57	0.64	25.05*	0.13	0.60
16	18.2	0.89	0.81	22.2	0.30	0.73			
18	19.35	0.93	0,87	23.35*	-0.13	0.80			

* Not implemented (point K is outside the work area).

Table 3. Speeds of working movements when bucket is moved along equidistant trajectories ($\psi = 70\ °$)

$Y_к$	Initial trajectory			Middle trajectory			Final trajectory		
	$X_к$	$V_п$	$V_н$	$X_к$	$V_п$	$V_н$	$X_к$	$V_п$	$V_н$
0	12	0.93	-0.83	13	0.92	-0.79	17	0.87	-0.59
2	12,75	0.89	-0.76	13.75	0.88	-0.70	17.75	0.84	-0.48
4	13.5	0.82	-0.65	14.5	0.81	-0.58	18.5	0.79	-0.35
6	14.25	0.71	-0.48	15.25	0.72	-0.41	19.25	0.74	-0.18
8	15	0.59	-0.24	16	0.64	-0.17	20	0.71	0.0
10	15.75	0.55	0.06	16.75	0.62	0.10	20.75	0.67	0.18
12	16.5	0.63	0.34	17.5	0.68	0.34	21.5	0.63	0.34
14	17.25	0.74	0.56	18.25	0.76	0.53	22.25	0.53	0.48
16	18	0.82	0.70	19	0.83	0.67	23	0.32	0.59
18	18.75	0.65	0.79	19.75	0.86	0.76	23.75*	-0.01	0.67

* Not implemented (point K is outside the work area).

In general, the variation in the values of the regime parameters of the main mechanisms in the process of excavation is determined by changing the distances (linear and angular) between the links of the working equipment mechanism and the directions of the vectors of the rates of ascent, pressure, and digging.

On the basis of the kinematic analysis of the two-crank mechanism of the working equipment of a mining excavator (Figure 2), analytical expressions were obtained to determine the relationships between the parameters characterizing the position of the bucket in the face and the required level of control (lifting and head pressure, which ensure the bucket travels along a given trajectory) - functions for controlling the drives of the lifting mechanisms of the FCF and the head of the FCS.

Expressions for the definition of control functions have the form:

$$FCS = \frac{V_к \cos(\psi - \varphi_1)}{\sin(\alpha - \varphi_1)};$$

$$V_{C1} = \frac{V_к O_1 C \cos(\psi - \alpha)}{O_1 K \sin(\alpha - \varphi_1)};$$

FCF = FCF_1 when moving the bucket at the bottom of the face ($\varphi 1 + 0.5\pi < \psi$).
FCF = FCF_2 when moving the bucket at the top of the face ($\varphi 1 + 0.5\pi \geq \psi$)

$$\text{FCF}_1 = V_C \sin(\varphi_2 + \delta + \varepsilon - \gamma) \, ;$$

$$V_C = (V_\text{н}^2 + V_{C1}^2 + 2|V_\text{н}||V_{C1}| \cos(\alpha - \varphi_2))^{0,5} \, ;$$

$$\varepsilon = \arcsin\left(\frac{|V_\text{н}| \sin(\alpha - \varphi_2)}{V_C} \right) ;$$

$$\text{FCF}_2 = V_C \sin(\varphi_2 + \delta - \varepsilon - \gamma) \, ;$$

$$V_C = (V_\text{н}^2 + V_{C1}^2 - 2 V_\text{н} V_{C1} \cos(\alpha - \varphi_2))^{0,5} \, ;$$

$$\varepsilon = \arcsin\left(\frac{V_\text{н} \sin(\alpha - \varphi_2)}{V_C} \right) ,$$

$$\varphi_1 = \operatorname{arctg} \frac{Y_\text{к} - Y_{01}}{X_C - X_{01}} \, ;$$

$$\alpha = \varphi_1 + \alpha_0 \, ;$$

$$\alpha_0 = \operatorname{arctg} \frac{AK}{O_1 A} \, ;$$

$$AK = (O_1 K^2 - O_1 A^2)^{0,5} \, ;$$

$$AC = AK - CK \, ;$$

$$O_1 K = ((X_\text{к} - X_{01})^2 + (Y_\text{к} - Y_{01})^2)^{0,5} \, ;$$

$$X_C = X_{01} + O_1 A \cos \alpha + AC \sin \alpha \, ;$$

$$Y_C = Y_{01} + O_1 A \sin \alpha - AC \cos \alpha \, ;$$

$$\varphi_2 = \operatorname{arctg} \frac{Y_C - Y_{01}}{X_C - X_{01}} \, ;$$

$$\gamma = \operatorname{arctg} \frac{Y_C - Y_{02}}{X_C - X_{02}} \, ;$$

$$l_\text{п} = ((X_C - X_{02})^2 + (Y_C - Y_{02})^2 - R^2)^{0,5} \, ;$$

$$\delta = \operatorname{arctg} \frac{R}{l_\text{п}} ,$$

X_{01}, Y_{01}, X_{02}, Y_{02} − coordinates of the axis of pressure shaft O_1 and the axis of head unit O_2 (Figure 1); O_1A, CK, $R(O_2D)$ - dimensions of the elements of the working equipment.

The obtained analytical dependencies make it possible to determine the required values of the control functions (lifting speeds and head) according to a special computer program for the implementation of the specified bucket trajectory.

4. Conclusion

Use of the proposed control functions in the engine control system of executive mechanisms will improve the efficiency of a mining excavator in specific mining conditions of development.

The proposed method for calculating the regime parameters (lifting and pressure rates) of the main mechanisms of mining excavators by means of a numerical experiment makes it possible to determine the actual values of the speeds of working motions in specific mining conditions (slope dimensions, type of bucket trajectory, etc.).

The establishment of interdependencies between the regime parameters of the main mechanisms in the process of excavating the soil can serve as the basis for the development of an adaptive workflow

management system, which, by matching the speeds of working movements in specific operating conditions, improves the performance of the excavator.

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