# Development of algorithm for excavation control

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# Development of algorithm for excavation control

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**Abstract.** In open-pit excavators there exists a discrepancy between their engineering designs and underuse of performance potential due to complexity of excavation and such intensity of carrying out working procedures which borders on physical limits of an operator. The excavating procedure is shown to involve joint functioning of main actuating mechanisms of an open-pit excavator for its thrusting and lifting operations and formation of a leverage transmission mechanism connecting those with a bucket. In that case, it was established, the excavation process is characterized by a 'conversion' of the main mechanisms since their operation parameters are formed according to kinematic properties of the leverage and energy-force parameters realized on the bucket. Dependencies were derived to calculate kinematic transfer functions of the leverage, which correlate the velocity of excavation and those of working motions (speeds of thrusting and lifting). The algorithm of calculating the velocities of working motions could be used to develop a digital system to control the motors of the main mechanisms.

## 1. Introduction

Transition to a new type of economics requires qualitative changes to be made in means of production. Improvement of manufacturing equipment, growth of science-intensive production are directly connected to intellectualization of both design and development of machinery and equipment and their operation.

Analysis of articles on typical excavation problems [1–8] shows that they are mainly dedicated to searching for newer technical solutions, modelling working processes, automation, robotization and optimization of equipment parameters. But the topics concerning formation of those operation parameters of the main excavator mechanisms which determine the quality of excavation control, the efficiency of the process and, in particular, its energy-force parameters – they are studied insufficiently.

Technical sources do not cite data on actual modes of joint operation performed by the main mechanisms while they are involved in excavation, giving only averaged diagrams of velocities and loads; developed systems for excavation control rely on abstract modelling – fuzzy logic [9], multiagent approach [10] and so on.

## 2. The main part

The research was aimed at increasing the efficiency of excavation control by coordinating operation parameters of the main mechanisms of an excavator during their joint working on excavation of rock masses. The object was the process of rock excavation, which involves the bucket (top of its cutting

edge) moving along equidistant trajectories parallel to a slope of the quarry face and extracting a layer ('chips') of rock to fill itself up. The study subject was the leverage mechanism with its kinematic properties, while the methods used were mathematical modelling and computational experiment.

Joint action of the lifting and thrusting mechanisms during the excavation leads to formation of a transmission mechanism (figure 1) connecting the main mechanisms and the bucket via links of the lifting mechanism (hoisting rope and head block of the boom) and thrusting mechanism (saddle bearing). At that, the bucket ('stick-bucket' link) becomes a driving (input) link, while the thrusting and lifting links – driven (output) ones. That is, the excavation process is characterized by a 'conversion' of the main mechanisms, in which case their operation parameters are determined in relation to kinematic properties of the whole mechanism.

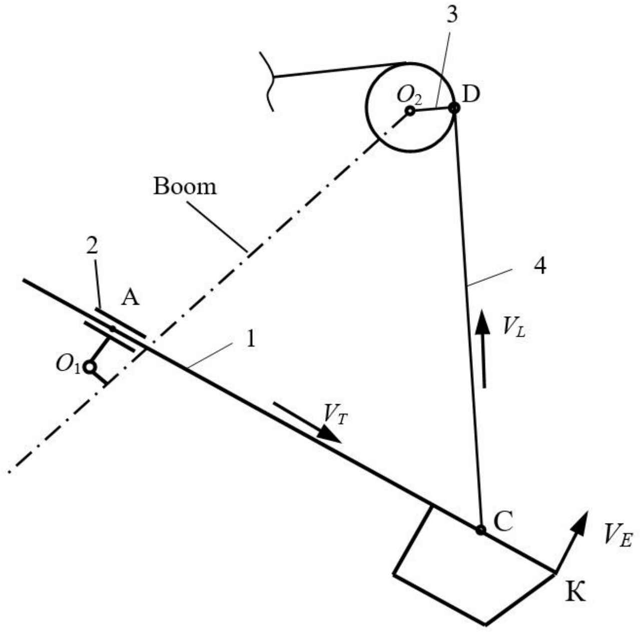


**Figure 1.** Diagram of transmission mechanism: 1 – 'stick-bucket' link; 2, 3 – crank; 4 – lifting rope; $V_E$, $V_L$, $V_T$ – velocities of excavation, lifting, thrusting.

Thus, while the open-pit excavator mechanisms act jointly on excavating rock masses, their operation parameters transform according to kinematic properties of the leverage, which complicates the excavation in general and conditions to run a kinematic analysis of the transmission mechanism (which was duly accomplished in the research).

To determine the speeds of lifting and thrusting motions, it is necessary to specify the laws of motion for an initial link – that is a trajectory of bucket movement (movement of the cutting edge top) and excavation velocity, along with dimensions of the transmission mechanism links.

Dependencies for determining kinematic transfer functions (correlations between those speeds and the excavation velocity) can be expressed in a general from as:

$$KTF_T = \frac{V_T}{V_E} = f_1\left(X_K, Y_K, l_C, l_V, \psi, \alpha, \phi_1, \phi_2, \gamma, \delta, \varepsilon\right);$$

$$KTF_L = \frac{V_L}{V_E} = f_2\left(X_K, Y_K, l_C, l_V, \psi, \alpha, \phi_1, \phi_2, \gamma, \delta, \varepsilon\right);$$

where $KTF_T$, $KTF_L$ are kinematic transfer functions of thrusting and lifting motions; $l_C$, $l_V$ – lengths of constant and variable links; ψ – inclination of a tangential trajectory for the bucket movement at the point $K$; α, φ1, φ2, γ, δ, ε – angles determining positions of the links.

To solve the problems set for the research, simulation modeling was conducted on the excavation process utilizing a mathematical model of the leverage [11].

Modelling the excavation on a set of values selected for the parameters which determine the position of the bucket within the working area of an excavator (coordinates of the cutting edge, excavation speed, inclination of a tangential trajectory for the bucket (cutting edge) movement, etc.) involves evaluating the operation parameters of its main mechanisms. In their general form, the results of simulation modelling are expressed as functionals, that is relations between energy-force parameters realized on the bucket and calculated at a specific point (or zone) of the working area and respective operation parameters of the main mechanisms and their motors.

Table 1 cites the results of a simulation run to get the operation parameters of an excavator (velocities of lifting $V_L$ and thrusting $V_T$, forces of lifting $F_L$ and thrusting $F_T$) when its bucket travels within the working area along initial, intermediate (that is in the middle of that area) and terminal trajectories with their inclinations corresponding to a slope of the quarry face.

**Table 1.** Lifting and thrusting operation parameters of an EKG-20A excavator.

| Position number | Initial data | | | | Calculated results | | |
|---|---|---|---|---|---|---|---|
| | $X_K$, m | $Y_K$, m | $G_{B+R}$, kN | $V_L$, m/s | $V_T$, m/s | $F_L$, kN | $F_T$, kN |
| Initial trajectory ($X_{K0}$ = 9 m) | | | | | | | |
| 1 | 9.00 | 0 | 400 | 0.95 | -0.87 | 290 | -630 |
| 2 | 10.15 | 2 | 435 | 0.92 | -0.81 | 350 | -620 |
| 3 | 11.30 | 4 | 470 | 0.84 | -0.70 | 420 | -605 |
| 4 | 12.45 | 6 | 500 | 0.70 | -0.51 | 520 | -580 |
| 5 | 13.60 | 8 | 540 | 0.52 | -0.19 | 700 | -555 |
| 6 | 14.75 | 10 | 575 | 0.50 | 0.19 | 975 | -590 |
| 7 | 15.90 | 12 | 610 | 0.66 | 0.50 | 1270 | -700 |
| 8 | 17.05 | 14 | 650 | 0.80 | 0.70 | 1560 | -850 |
| 9 | 18.20 | 16 | 680 | 0.89 | 0.81 | 1810 | -1005 |
| 10 | 18.80 | 17 | 700 | 0.91 | 0.84 | 1910 | -1060 |
| Intermediate trajectory ($X_{K0}$ = 13.5 m) | | | | | | | |
| 11 | 13.50 | 0 | 400 | 0.88 | -0.64 | 610 | -310 |
| 12 | 14.65 | 2 | 435 | 0.83 | -0.51 | 640 | -300 |
| 13 | 15.80 | 4 | 470 | 0.76 | -0.34 | 680 | -280 |
| 14 | 16.95 | 6 | 500 | 0.70 | -0.12 | 710 | -230 |
| 15 | 18.10 | 8 | 540 | 0.66 | 0.11 | 780 | -155 |
| 16 | 19.25 | 10 | 575 | 0.65 | 0.32 | 830 | -40 |
| 17 | 20.40 | 12 | 610 | 0.62 | 0.50 | 885 | 140 |
| 18 | 21.55 | 14 | 650 | 0.50 | 0.63 | 930 | 420 |
| 19 | 22.70 | 16 | 680 | 0.22 | 0.72 | 105 | 845 |
| 20 | 23.30 | 17 | 700 | 0.02 | 0.76 | 1125 | 1130 |
| Terminal trajectory ($X_{K0}$ = 18 m) | | | | | | | |
| 21 | 18.00 | 0 | 400 | 0.79 | -0.39 | 1020 | 110 |
| 22 | 19.15 | 2 | 450 | 0.73 | -0.25 | 1060 | 150 |
| 23 | 20.30 | 4 | 500 | 0.68 | -0.09 | 1100 | 210 |
| 24 | 21.45 | 6 | 550 | 0.61 | 0.07 | 1150 | 320 |
| 25 | 22.60 | 8 | 600 | 0.53 | 0.23 | 1210 | 480 |
| 26 | 23.75 | 10 | 650 | 0.42 | 0.38 | 1290 | 710 |
| 27 | 24.90 | 12 | 700 | 0.27 | 0.50 | 1420 | 1030 |

The data cited above indicates that the operation parameters of the main excavator mechanisms (velocities and forces of lifting and thrusting) change within a wide range across the whole work area and depend both on the height of excavation (coordinates $Y_K$ of the cutting edge) and its radius (coordinates $X_K$) or how far a current trajectory is away from the excavator.

The simulation model of excavation could be represented in a graphical form of hodographs for lifting and thrusting velocity vectors (figure 2). The model determines the algorithm of digital control to form control actions sent to the motors of the main mechanisms.

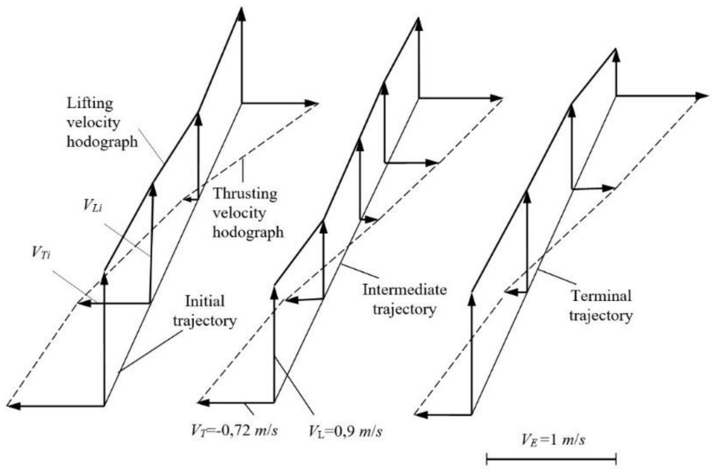


**Figure 2.** Hodographs for velocities of working motions while moving the bucket up to a specified excavation height: $V_L$, $V_T$ – velocities of lifting and thrusting.

## 3. Conclusion

Development of a program to determine the velocities of working excavator motions would help to form almost any trajectory of bucket movement by coordinating lifting and thrusting to achieve specified energy-force parameters on the bucket.

Properly assessing kinematic properties of the leverage mechanism could help to develop such a system of digital control for the drives of the main mechanisms during their joint action while excavating rock masses which would work in real time and provide rational values for the operation parameters of the main mechanisms in specific mining and technological conditions of functioning.

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