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To cite this article: O A Lukashuk *et al* 2020 *IOP Conf. Ser.: Mater. Sci. Eng.* **709** 022117

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# Developing a digital control system for the main drives of an open-pit excavator as a major field of increasing the efficiency of excavator operation

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**Abstract.** The specifics of rock excavation using a front-shovel operational equipment are addressed in the paper. Excavation, carried out by actuating (thrusting and lifting) mechanisms of an excavator, is shown to form a leverage mechanism which consists of operational equipment elements and connects the main actuating mechanisms with the bucket, thus forming a common transmission mechanism for their drives. Mechanical energy of the main drives is converted to energy-force parameters realized at the cutting edge of the bucket (its teeth) in agreement with kinematic properties of the mechanism. Expressions for transfer functions of the leverage, which define relations between the energy-force parameters at the cutting edge and operating parameters (velocities of operating motions), were obtained. A flow chart for calculating the operating parameters was developed. A digital control system on its basis would allow to increase the excavating efficiency.

## 1. Introduction

Limited physical and psychological abilities of a person who utilizes a modern technological equipment is the main limitation factor of productive forces. Production automation and robotization could help to solve that problem.

As for now, digital control systems designed for the main drives of actuating mechanisms used in an excavator are underdeveloped due to the complexity of matching and coordinating operating parameters of its thrusting and lifting mechanisms during excavation.

Survey of scientific publications dedicated to open-pit excavators [1–18] showed that they mostly suggest searching for new engineering solutions, simulating the operating processes, upgrading control systems and automatizing and robotizing the excavation equipment.

At the same time, issues concerning the formation of such performance characteristics of the main excavating mechanisms which determine energy-force parameters of the excavation process and, in general, the quality of control and efficiency of operation are insufficiently explored.

## 2. Aim of the research

This research is mainly focused on increasing the functional efficiency of an open-pit excavator.

The problems covered in the study are:



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- establishing relations between energy-force parameters realized at the cutting edge of the bucket and operating parameters of the main actuating mechanisms;
- developing an algorithm to calculate the operating parameters of the main mechanisms for a specific law of bucket movement.

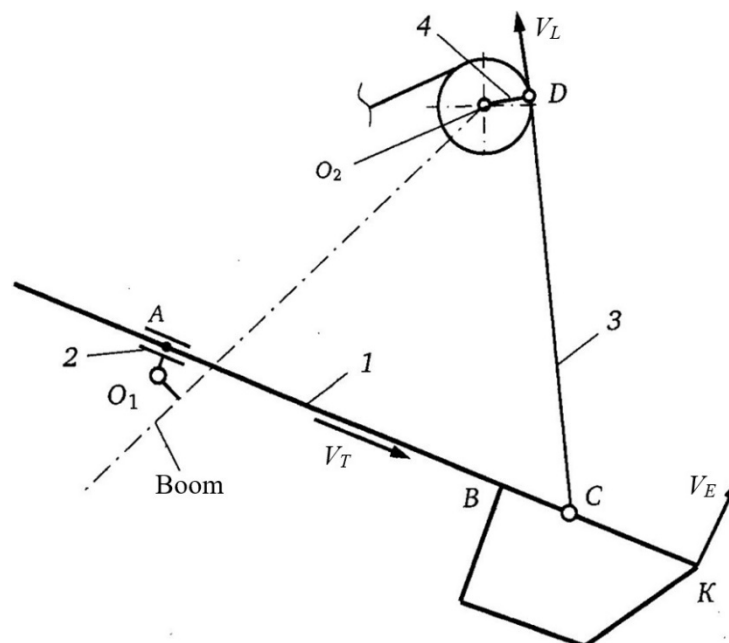
### 3. Solution to the problems

The research studies both a leverage mechanism of an excavator and a common transmission mechanism of its main drives (which includes its main mechanisms and the leverage).

The object of the research is the analysis of behavior patterns of the main mechanisms during excavation.

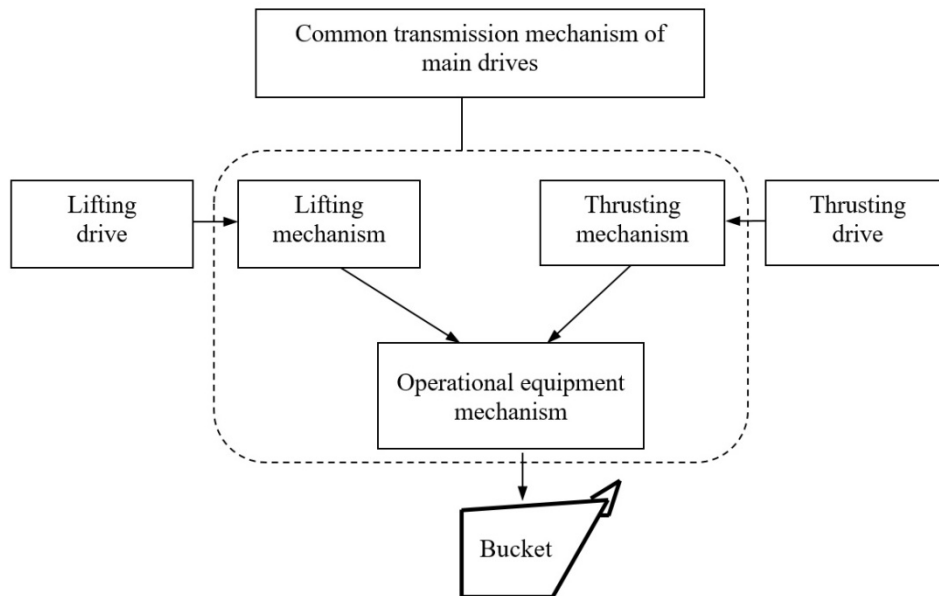
As a testing method, a computational experiment was chosen, based on a model which imitates a front-shovel excavation process [6]. For algorithm-based models, such an experiment is identical to evaluating output characteristics for specified input variables and constants, i.e. substituting specific numbers into the algorithm and calculating using certain formulas. Enumeration of alternate solutions is carried out with a given variation step. During calculation and calibration, the mathematical model helps to accumulate data on functionality of various designs of the operational equipment. Thus, a simulation modeling consists of reiterating operations of a studied system (reproducing its behavior) on the basis of a mathematical model. The result of the modeling is a set of values which characterizes the analyzed process.

The process of excavation involves the formation of a leverage mechanism (figure 1), which connects the main mechanisms of an excavator with its bucket and includes some elements of the thrusting mechanism (rack gear and saddle bearings), lifting mechanism (head block of its boom and lifting rope) and operational equipment (bucket and stick).



**Figure 1.** Leverage mechanism scheme: 1 – «stick-bucket» link; 2, 4 – cranks; 3 – lifting rope.

The head block and lifting rope are kinematically equivalent to rods which form revolute pairs in relation to each other, the bucket and main stand. It leads to the formation of a common transmission mechanism of the main drives (figure 2), which consists of the main (lifting and thrusting) mechanisms and their leverage. The transmission mechanism functions in accord with kinematic properties of the leverage.



**Figure 2.** Structural scheme of electromechanical digging system of an open-pit excavator.

A flow chart was developed to calculate the operating parameters of the main mechanisms for specified energy-force parameters realized at the cutting edge and paths which the bucket follows within the working area of an excavator.

A computational experiment was held to calculate the operating parameters for an EKG-20A excavator manufactured by JSC «Uralmashplant». Tangential excavation-resistance force  $P_{01} = 325$  kN, excavation velocity  $V_E = 1$  m/s, bucket mass  $M_B = 40$  t were initially set.

The results calculated for the operating parameters of the main mechanisms at different angles of bucket movement path (70, 60 and 50 degrees) are given in table 1.

The data cited demonstrates that the operating parameters change depending both on the angle of bucket path and the excavation height ( $Y_K$  coordinates).

**Table 1.** Operating parameters of main mechanisms at different angles of bucket path.

| №                            | Coordinates of cutting edge (m) |       | Lifting velocity (m/s) | Thrusting velocity (m/s) | Gravity of loaded bucket (bucket + rock) (kN) | Lifting force (kN) | Thrusting force (kN) | Power of lifting force (kW) | Power of thrusting force (kW) | Efficiency |
|------------------------------|---------------------------------|-------|------------------------|--------------------------|---|--------------------|----------------------|-----------------------------|-------------------------------|------------|
|                              | $X_K$                           | $Y_K$ |                        |                          |   |                    |                      |                             |                               |            |
| Path angle $\psi = 70^\circ$ |                                 |       |                        |                          |   |                    |                      |                             |                               |            |
| 1                            | 14                              | 0     | 0.91                   | -0.74                    | 400   | 732                | -295                 | 667                         | 218                           | 0.37       |
| 2                            | 15.5                            | 4     | 0.81                   | -0.52                    | 500   | 799                | -327                 | 646                         | 169                           | 0.40       |
| 3                            | 17                              | 8     | 0.68                   | -0.12                    | 600   | 959                | -300                 | 649                         | 35                            | 0.48       |
| 4                            | 18.5                            | 12    | 0.70                   | 0.34                     | 700   | 1179               | -234                 | 829                         | 80                            | 0.36       |
| Path angle $\psi = 60^\circ$ |                                 |       |                        |                          |   |                    |                      |                             |                               |            |
| 5                            | 14                              | 0     | 0.87                   | -0.61                    | 400   | 801                | -195                 | 696                         | 119                           | 0.40       |
| 6                            | 16.3                            | 4     | 0.76                   | -0.30                    | 500   | 876                | -183                 | 662                         | 56                            | 0.45       |
| 7                            | 18.6                            | 8     | 0.66                   | 0.13                     | 600   | 978                | -59                  | 645                         | 8                             | 0.50       |
| 8                            | 20.9                            | 12    | 0.59                   | 0.50                     | 700   | 1093               | 296                  | 640                         | 148                           | 0.41       |
| Path angle $\psi = 50^\circ$ |                                 |       |                        |                          |   |                    |                      |                             |                               |            |
| 9                            | 14                              | 0     | 0.80                   | -0.46                    | 400   | 853                | -103                 | 681                         | 48                            | 0.45       |
| 10                           | 17.4                            | 4     | 0.66                   | -0.06                    | 500   | 940                | -20                  | 618                         | 1                             | 0.53       |
| 11                           | 20.8                            | 8     | 0.51                   | 0.36                     | 600   | 1062               | 271                  | 537                         | 98                            | 0.51       |
| 12                           | 24.2                            | 12    | 0.17                   | 0.64                     | 700   | 1285               | 917                  | 221                         | 590                           | 0.40       |

For example, it follows from the above that the lifting velocity decreases both with a decreased angle and increased excavation height.

The thrusting velocity depends on the direction of stick movement: it lessens when the stick is retracted while the path angle decreases (indicated by minus sign for thrusting velocities in the table) and rises when it is extended.

The lifting and thrusting forces are hardly affected by the angle of bucket path except when the thrusting force reaches its maximum at the angle  $\psi = 50^\circ$  of bucket path.

Thus, the flow-chart developed for calculating the operating parameters of the main mechanisms allows to determine, at any given point of the working area and for a specified angle of bucket path, the correlation (functional) between energy-power parameters realized on the bucket and operating parameters of the main mechanisms.

#### 4. Conclusion

Developing a digital control system for the main drives of an open-pit front-shovel excavator based on an algorithmic description of the excavation process has a major potential when it comes to increasing the efficiency of excavating.

#### References

- [1] Ivanov I Y 2011 *Justification of Rational Parameters for Operational Equipment of Open-Pit Excavators with Closure of Working Loads: PhD Diss.* (Yekaterinburg: Ural State Mining University)
- [2] Fedorov L N 2009 *J. Mining Equipment and Electromechanics* **7** 45
- [3] Khoroshavin S A 2014 *J. Mining Equipment and Electromechanics* **11** 3
- [4] Komissarov A P, Lagunova Y A, Lukashuk O A and Shestakov V S 2018 *Excavator «Gorniy»* (Russia, patent 178976, bul. 12, publ. 24.04.18)
- [5] Gafurianov R G, Komissarov A P and Shestakov V S 2009 *J. Mining Equipment and Electromechanics* **6** 40
- [6] Koriukov A A 2013 *J. Mining Data-Analysis Bulletin* **4** 302
- [7] Bender F A and Sawodny O A 2014 *Proc. 13th Intl. Conf. on Control, Automation, Robotics and Vision (Singapore)* 187
- [8] Berns K, Proetzsch M and Schmidt D 2010 *Proc. IEEE Intl. Conf. on Robotics and Automation (Anchorage)* 5108
- [9] Frimpong S, Hu Y and Chang Z 2003 *Proc. Summer Computer Simulation Conf. (Montreal)* 133
- [10] Geu Flores F, Kecskemethy A and Pottker A 2007 Workspace analysis and maximal force calculation of a face-shovel excavator using kinematical transformers *Proc. 12th IFTOMM World Congress (Besancon)*
- [11] Lee B and Kim H J 2014 *Proc. 14th Intl. Conf. on Control, Automation and Systems (Seoul)* 716
- [12] Park B 2002 *Development of a virtual reality excavator simulator: a mathematical model of excavator digging and a calculation methodology: PhD diss.* (Blackburg: Virginia Polytechnic Institute and State University)
- [13] Talmaki S A 2012 *Real-Time Visualization for Prevention of Excavation Related Utility Strikes: PhD Diss.* (Michigan: University of Michigan)
- [14] Tao N 2008 *IEEE Conf. on Robotics, Automation, and Mechatronics* 889
- [15] Babakov S E and Pevzner L D 2012 *J. Mining Equipment and Electromechanics* **9** 8
- [16] Pevzner L D 2014 *Automated Control of High-Duty Single-Bucket Excavators* (Moscow: Mining)
- [17] Malafeev S I and Tikhonov Y V 2013 *J. Automation in Industry* **10** 33
- [18] Malafeev S I and Serebrennikov N A 2018 *J. Coal* **10** 30