Automated leveling systems for development and cleaning of reclamation channels in the agro-industrial complex

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Abstract. Reclamation complexes, the key element of which are bypass canals, are actively used for effective agricultural work. For the development of reclamation canals, as a rule, excavator equipment is used, which subsequently ensures their effective functioning. The analysis of the impact of the efficiency of the functioning of amelioration systems on the agro-industrial complex (AIC) sectors revealed a significant dependence on obtaining high-quality crops or pastures. Factors were identified that reduce the quality of reclamation work. Among them, the indicator of positioning accuracy of the profile of the soil during clearing or arrangement of channels is highlighted as the main one. It was proved that the installation of automated leveling systems will provide technological improvement to the excavator. Modernization of excavators by introducing automatic leveling systems (ALS), allows you to increase the speed and accuracy of work, and therefore productivity. There are three main ALS solutions for excavator operation: ALS 2 D control system; ALS satellite monitoring system; ALS AUTO satellite leveling system. It was determined that for using ALS AUTO, the quality of the work performed does not depend on the human factor. Field tests were carried out at the test site with quality control of the construction embankments with JCB JS 205 excavator modernized with ALS. The data obtained were compared with the results of grading with a JCB JS 205 excavator without ALS. Based on the results of the data analysis, it was found that with the introduction of automatic leveling systems, the productivity of the equipment increases by 200%, and the accuracy of the work performed has increased 2 times.

1. Introduction
The excavator is one of the most common machines applied for the installation of channels of AIC drainage systems. Also, these machines are applied throughout the entire period of operation of reclamation systems to perform work on cleaning channels [1-2]. An increase in the need for special-purpose production machines arises in all sectors of earthmoving such as AIC reclamation canals, civil engineering, road construction, mining sites, as well as the gas and oil industries, as promising industries affecting the development of the Russian economy [3-4]. Therefore, automatic leveling systems (ALSs) are rapidly gaining popularity. One of the ways to increase the productivity of construction machines is a constructive or technical improvement of the prototype [5-6]. Modernization of excavators by introducing ALS into their design allows increasing the speed and accuracy of work, and productivity as a result [6]. The main advantage of ALS for excavators is the constant visualization of the actual position of the working body of the machine relative to a given design level, as well as fixing the working equipment in certain positions. All information data is...
displayed on the screen in the operator's cab. An excavator with ALS is shown in Figure 1. The use of ALS provides the following significant advantages:

1) Exclusion of the stage of intermediate quality control when performing earthmoving works.
2) The ability to obtain information "in real-time" about the current stage of work.
3) Improving the safety of the work carried out.
4) Prevention of possible unnecessary excavation.

These factors will undoubtedly increase the productivity of the excavator. The purpose of the research is to analyze and evaluate the effectiveness of the ALS application for a single-bucket excavator when performing various types of reclamation work.

2. Materials and methods
In previous studies, basic cutting theories, the theory of machine reliability, risks were used. The ALS of an excavator is based on determining the current position of the bucket, boom, stick, as well as on comparing it with a mathematical or design model of the structural layers of a construction object [6]. To determine the position of the working elements of the excavator, the following sensors were used: angle sensor; bucket tilt sensor; bucket sensor; laser receiver; boom tilt sensor; rotation sensor. Signal processing was carried out by a special algorithm, which was recorded in the controller. The visualization of the results obtained occurs on the operator's display, and can also be reproduced on the computer monitors of the operating and (or) organizations. Many scientists have dealt with issues related to ALS, for example, Khvalev P.S., Satyukov A.B., Mikhailenko D.G., Lenivtsev A.G., Maslyanitsyn A.P., Filatov E.I., Bukreev I.A. Authors Khvalev P.S. and Satyukov A.B. argue that the investment and use of ASN increase productivity, the quality of work performed, but does not solve all the problems associated with production and low qualifications of personnel, and the use of ALS in conjunction with GLONASS is not always effective due to the insufficient number of satellites to determine the exact position of equipment [7]. Mikhailenko D.G., Lenivtsev A.G. [8] analyzed modern systems for automatic control of the dozer blade. Special similar equipment can be used for excavators. The authors have found that the greatest accuracy is provided by equipment in the design of which laser beam technology is used. The deployment of a network of stations is one of the solutions that ensure the quality of communication of the park of technological machines, which allows to accurately determine the positioning of machines [8].

Maslyanitsyn A.P. and Filatov E.I. [9] described the principle of a movable laser receiver for a bulldozer, which allows to expand the range of conditions for the use of laser leveling and form not only rectilinear but also curved surfaces [9]. This receiver can also be used in excavators. It can improve the quality, accuracy of the embankment profile. Bukreev I.A. described the principle of construction and operation of AFM using the example of the products of Topcon Positioning Systems. He described the purpose, properties, principle of operation of all basic elements of ALS and developed a block diagram of a control system for technological machines with feedback [6, 10].

Research methods are presented for the three main ALS solutions used in excavator operation.

1. ALS 2-D control system. The system includes a control panel in the operator's cab; four angle sensors that measure the angles between the bucket, stick, boom, and excavator cab; laser receiver (connection via CAN-port); Communication node (CAN bus communication). When using a 2-D indicator system, the parameters of the current soil development can be set in the control panel, which allows not to constantly keep the reference point in the field of view. The accuracy of the work depends on the qualifications of the excavator operator.

2. ALS satellite control system. The system includes four angle sensors with a measurement range of 360 degrees; GNSS antenna and receiver, for orientation and positioning of the machine on the construction site; control panel in the operator's cab. The distance from the bucket teeth to the project level is displayed on the control panel. It is possible to display detailed information: development profile, site plan for the project, cross-sections. The use of satellite control systems makes it possible to exclude the presence of a person near the trench, who monitors the quality of the formed surface, the skill level of the excavator operator indirectly affects the accuracy of work.
3. ALS AUTO satellite leveling system. The system includes a control panel; satellite dish; two inertial sensors; controller, joysticks, solenoid valve (located between the distributor and the hydraulic cylinder of the working equipment and the handle) [5]. This ALS supports several modes of operation:

- **Hold mode.** Automatic holding of the working equipment in a certain digging range. The automation of the system does not allow digging deeper than the specified design value.

- **Bucket mode.** Keeping the bucket at a constant angle of attack during the working stroke of the boom and stick of the excavator. The operator controls only the boom, and the automation maintains the set angle.

ALS AUTO is the most versatile and advanced. When using ALS AUTO, the quality of the work performed does not depend on the human factor [5].

3. **Results and discussions**

To compare different types of ALS, a study of the quality of the construction of the embankment with a JCB JS 205 excavator modernized ALS experimentally was planned and carried out at the test site. For a deeper understanding of the experiments carried out, a JCB JS 205 excavator without ALS was also used. The study consisted of measuring the angle of deviation (%) of the developed embankment from the design specified angle per 1 square meter (Figure 3). The experiment includes 4 options for technical equipment of the ALS machine: excavator without ALS; ALS 2-D control system; ALS satellite monitoring system; ALS AUTO satellite leveling system.

**Figure 1.** Block diagram of the control system of technological machines with feedback.

Measurement of the angle of deviation from the design values was carried out with a geodetic level. The design target plane was the "horizon" 90 degrees relative to the vertical. For large sample variations, five experimental measurements were carried out on five embankment grading attempts. Throughout the experiment, the machine was driven by one driver, therefore the operator's experience as a factor influencing the objectivity of the data obtained is not considered. For each variant of the experiment, the construction of working sketches was carried out (Fig. 2). Analyzing the sketches built based on measurements of the embankment development angles, the following conclusion can be drawn: the more modern the ALS, the more accurately the embankment angle is observed.
Figure 2. Figure 2. Modeling of the embankment profile development process: 1 - certain design embankment profile; 2 - embankment profile without ALS; 3 - profile of the embankment using ALS with 2D control system; 4 - embankment profile using ALS with satellite monitoring system; 5 - embankment profile using ALS AUTO.

For a more objective justification, the percentage of deviation of the actual embankment planning angles from the design values was calculated for each experiment

$$\beta_i = \frac{\varphi_i - \varphi}{90} \cdot 100\%$$ (1)

where $\beta_i$ is the percentage deviation of the actual embankment angle from the design when using different types of ALS, $\varphi_i$ is the angular deviation from the design value.

Table 1. Deviation of the actual embankment angle from the design one for different types of ALS.

| Application ALS / Measurement serial number | 1    | 2    | 3    | 4    | 5    | Average |
|---------------------------------------------|------|------|------|------|------|---------|
| Excavator without ALS                       | 11%  | 10%  | 13%  | 11.5%| 10%  | 11.1%   |
| Excavator equipped with ALS 2D control system | 8%   | 8.5% | 7.3% | 8.9% | 9%   | 8.3%    |
| Excavator equipped with ALS satellite control system | 5%   | 7%   | 5.3% | 6.7% | 6%   | 6%      |
| Excavator equipped with ALS AUTO satellite leveling system | 2%   | 3%   | 2.4% | 4%   | 1%   | 2.4%    |

The median value of the percentage deviation was calculated from the eq. (1):

$$\omega_z = \frac{\beta_1+...+\beta_{i+1}}{2} \cdot 100\%$$ (2)

where, $\omega_z$ is the median value of the percentage deviation.
Figure 3. Modeling of embankment profiles based on experiments: 1 - a given design embankment profile; 2 - the resulting profile of the embankment; a) - without the use of ALS; b) - When using ALS 2D control system; c) - when using ALS, a satellite monitoring system; d) - when using ALS AUTO satellite leveling system.

According to the results of the analysis of data from different manufacturers of machines for land reclamation, it was found that with the introduction of ALS, the productivity of the equipment increases by 200%, and the accuracy of the work performed was increased by 2 times.

4. Summary
An analysis was made of the efficiency of excavators when cleaning the channels of the AIC drainage systems. It is substantiated that the installation of automated leveling systems will provide not only constructive, but also technological improvement of the excavator. It is theoretically proved that the ALS operation of the excavator is based on determining the current position of the bucket, boom, stick, as well as on a comparison with the mathematical or design model of the structural layers of the AIC drainage system channel. There are three main ALS solutions for excavator operation: ALS 2-D control system; ALS satellite monitoring system; ALS AUTO satellite leveling system. It was determined that when using ALS AUTO, the quality of the work performed does not depend on the human factor. Field tests were carried out at the test site with quality control of embankment erection with a JCB JS 205 excavator modernized with ALS. The data obtained was compared with the results of grading with a JCB JS 205 excavator without ALS state. It was found that with the introduction of automatic leveling systems, the productivity of equipment increases by 200%, and the accuracy of the work performed has increased 2 times.

5. References
[1] Apatenko A S 2013 Analysis of processes and reasons for reducing the intensity of operation of technological machines Vestnik of Federal State Educational Establishment of Higher Professional Education ‘Moscow State Agroengineering University named after V P Goryachkin 3(59) 49-51.
[2] Sevryugina N, Kapyrin P 2018 Technological machines, construction resources, efficiency and safety MATEC Web of Conferences 178 06017
[3] Kuznetsov A P, Blau P, Koriath H-J, Richter M 2016 Criteria for Energy-efficiency of Technological Processes, Technological Machines and Production Engineering Procedia CIRP 46 340-343
[4] Chalaganidze S I, Katsitadze J B, Kutelia G G 2017 The theoretical and experimental study of the ploughs' ploughs hare sin order to increase the reliability of resource-saving technology using similarity and dimensions theory Annals of Agrarian Science 15(3) 329-331
[5] JCB Electronic Catalogue of Construction Equipment. Access mode: https://www.jcb.com/
[6] TOPCON's official website. Access mode: https://topcon.pro/.
[7] Hvalev P S, Satyukov A B, Orekhov S A 2017 Information Technology Automatic Leveling in Road-Building Technology Trends in Science and Education 26(1) 32-34
[8] Mikhailenko D G, Lenivtsev A G 2018 Modern systems of automatic leveling of the bulldozer dump Tradition and innovations in construction and architecture, construction technologies 1 466-470
[9] Maslanitsyn A P, Filatov E I 2019 Improving the system of laser leveling the bulldozer dump Trends in science and education, construction technologies 1 659-664
[10] Bukreev I A 2011 View from within. Modern automation systems for construction machines Construction equipment and technology 8 78-81
[11] Apatenko A S, Sevryugina N S 2019 Methods of recruiting of mobile repair services and maintenance of machines performing reclamation works IOP Conference Series: Materials Science and Engineering 786 012037
[12] Sevryugina N S, Apatenko A S, 2019 Digital systems and precision control of the process machinery performance in environmental engineering Machinery and Equipment for Rural Area 7(265) 35-38
[13] Kapyrin P, Sevryugina N 2018 The procedural approach to reliability of objects of the raised level of responsibility IOP Conference Series: Materials Science and Engineering 365 042018
[14] Sevryugina N, Kapyrin P 2018 Resource verification of construction objects having increased importance level MATEC Web of Conferences 251 03019
[15] Zorin V A, Baurova N I, Pegachkov A A 2019 Assessment of products risks of mechanical engineering by results of diagnosing Periodicals of Engineering and Natural Sciences 7(1) 287–293
[16] Bouziane Brik, Belgacem Bettayeb, M’hammed Sahnoun, Fabrice Duval 2019 Towards Predicting System Disruption in Industry 4.0: Machine Learning-Based Approach Procedia Computer Science 151 667-674
[17] Ado Adamou Abba Ari, Abdelhak Gueroui, Chafiq Titouna, Ousmane Thiare, Zibouda Aliouat, 2019 Resource allocation scheme for 5G C-RAN: a Swarm Intelligence base dapproach Computer Networks 165 106957
[18] Mario Coccia, Joshua Watts 2020 A theory of the evolution of technology: Technological parasitism and the implications for innovation management Journal of Engineering and Technology Management 55 101552
[19] Frans Prenkert, Nina Hasche, Gabriel Linton 2019 Towards a systematic analytical frame work of resource inter faces Journal of Business Research 100 139-149