Studying the dynamics of the automatic control system for the elevation position of a motor grader blade with an alternative position sensor

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Abstract. The existing problems of controlling the elevation position of a motor grader blade when leveling a roadbed, caused by arising measurement errors associated with both the operation of the control systems themselves and disturbing influences, are considered. It is shown that the optimally tuned regulators in the existing control system do not provide the required quality indicators for the operation of a construction machine. It is proposed to equip the automatic control system for the elevation position of the grader blade with an alternative position sensor, the signal from which is compared with the reference action and the difference is introduced as a correction to the control system. The developed system allows us to increase the accuracy of automatic elevation positioning of the motor grader blade up to the quality required by regulatory documents.

1. Introduction

One of the most important stages in road construction is the precise grading of the roadbed by motor graders. In the process of work, the spatial position of the grader blade should correspond as closely as possible to the longitudinal and transverse profiles of the road project design. The solution to this problem is carried out with the help of automatic control systems for the elevation position, angle and tilt and cutting of the blade in accordance with the project. There are several principles for constructing automatic blade control systems, among which the most effective is the use of the global navigation satellite system (GNSS). GNSS operation is subject to a lot of interference, therefore, in order to reduce the measurement error, the method of differential corrections is used, as a result of which the positioning accuracy according to the GNSS equipment manufacturers is 15-25 mm. The results of the conducted studies of the automatic control system for the elevation position of the motor grader blade (BEP ACS) Leica iCON grade 3D showed that the errors in measuring the spatial position of a stationary object using GNSS in Real Time Kinetic RTK-mode are significantly variable in time. They lead to a quasi-harmonic change in the ΔZ value of the measured coordinates Z. It has been experimentally established that the average value of the oscillation period ΔZ is 17 min, and their amplitude reaches 20-30 mm. Such indicators are unsatisfactory from the point of view of the arrangement of the roadbed with the quality required by regulatory documents. Therefore, the development of effective methods and means for controlling the elevation position of the motor grader blade, which provide the required performance of the construction machine, is relevant.
2. Mathematical model of the blade elevation sensor

In the mathematical modeling of the BEP sensor as a dynamic link of the system under study, we will take into account that the time of transmission of data obtained with the help of GNSS to the ACS BEP is on average 0.1 s [1]. Then the output signal \( Z_{oc} \) of the feedback sensor can be represented, in operator form, as a sum of signals \( Z'_{oc} \) and \( \Delta Z \) (Fig. 1)

\[
Z_{oc}(p) = Z(p)e^{-\tau_{u}p} + \Delta Z(p) = Z'_{oc}(p) + \Delta Z(p)
\]

(1)

where \( Z \) is the measured coordinate; \( \tau_{u} \) is the delay time; \( \Delta Z \) - quasi-harmonic interference; \( Z'_{oc} \) - feedback signal in the absence of interference. We assume that the \( \Delta Z \) signal is generated by some interference generator (IG).

![Figure 1. Block diagram of the mathematical model of the blade elevation sensor](image)

It is proposed to analyze the operation of the BEP ACS under the action of two types of signal \( \Delta Z \) coming from the interference generator (IG) (Fig. 1), which simulates the inaccuracies of the GNSS operation:

- type I

\[
\Delta Z(p) = A_{1} \cdot \frac{\omega_{1}}{p^{2} + \omega_{1}^{2}} + A_{2} \cdot \frac{\omega_{2}}{p^{2} + \omega_{2}^{2}};
\]

(2)

- type II

\[
\Delta Z(p) = A_{1} \cdot \frac{\omega_{1}}{p^{2} + \omega_{1}^{2}}.
\]

(3)

Here \( A_{1}, A_{2} \) and \( \omega_{1}, \omega_{2} \) are the amplitudes and frequencies of the first and second harmonics of the interference signal, respectively.

The conducted studies of the existing BEP ACS, taking into account the adopted model of the feedback channel [2], showed that the error \( \Delta Z \), summed up with the reference signal \( Z_r \), causes a mismatch between the position \( Z \) of the blade and the required elevation position \( Z_{r} \) even under the conditions of a correctly selected regulator. Furthermore, the maximum deviation from the nominal value of \( Z_{r} \) of the position of working body reaches 25 mm, which substantially exceeds the allowable indicators set by regulations.

3. Mathematical model of ACS of the hydraulic drive of a motor grader blade taking into account the correction device

To improve the accuracy of the automatic control system for the elevation position of the blade (BEP ACS) in conditions of large errors in the operation of the GNSS, it is proposed to use the technology of dynamic correction. Its principle is to periodically use a more accurate measuring device (alternative \( ASZ \) sensor) and calculate the difference between its reading \( Z_{AS} \) and the signal setting \( Z_{r} \) at certain time intervals \( T_{i} \):

\[
\Delta_{i} = Z_{r} - Z_{AS}(T_{i}).
\]

(4)

Subsequently \( \Delta_{i} \) is entered into the control system as a correction to the current measurements.
A functional diagram of the BEP ACS with a correction device has been developed (Fig. 2). A distinctive feature of the proposed approach to the construction of BEP ACS, different from the traditional one, is the discreteness of the calculation of the correction in combination with the use of a memory element, the function of which is the formation of a correcting signal in the time interval between connections to the reference device for measuring BEP. The approach under consideration makes it possible to carry out the technical implementation of the dynamic correction system (DCS), based on various types of sensors for measuring the spatial position of objects.

![Functional diagram of the BEP ACS with a correction device](image)

**Figure 2.** Functional diagram of the BEP ACS with a correction device: SD - setting device; R - regulator; EHC - electrohydraulic converter; HC - hydraulic cylinder; WB - working body (blade); IG - interference generator; ASZ - alternative sensor; W_{df} - dynamic filter.

4. **Studying the influence of the discreteness of information obtained from an alternative sensor of the position of the motor grader blade on the ACS error**

To assess the influence of the discreteness of data obtained from an alternative blade position sensor on the error of the BEP ACS in the Matlab software environment, its computational model was developed (Fig. 3). Here, the hydraulic drive model developed in [3-5] is used as a control object (CO). The correction device is modeled by a combination of a comparator, an adder, and Zero-Order Hold and Memory blocks. The reference signal is fed to the direct input of the comparator, and the signal from the alternative BEP sensor ASZ is fed to its inverse input. The memory block is modeled by elements of the Simulink library of the Matlab program – an adder, "Zero-Order Hold" and "Memory".

When simulating the operation of the BEP ACS with a correction device, it is assumed that the movement of the motor grader when leveling the roadway is constant and \( v_{mg} = 1 \) m/s, and the sampling step \( \Delta t \) of the difference signal \( \Delta \) is determined by:

\[
\Delta t = \frac{\Delta L}{v_{mg}}
\]

where \( \Delta L \) is the distance between alternative sensors.

During the research, the following options for the location of alternative sensors were taken \( \Delta L \in 10, 25, 50, 75, 100, 150 \) m. Then the sampling step, in accordance with (5), is \( \Delta t \in 10, 25, 50, 75, 100, 150 \) s.
Taking into account the accepted conditions mentioned above, it is proposed to conditionally divide computational experiments on the study of performance indicators of BEP ACS into two stages. At first stage we take into account the interference of the inaccurate operation of GNSS of the first type (2), at second stage - the type II interference (3).

To analyze the experimental results obtained at the first stage, let us select the most characteristic curves at $\Delta t = 10, 50, 100$ s, respectively (Fig. 4). Comparison of those presented in Fig. 4 characteristics shows a natural decrease in the magnitude of the error with a decrease in the magnitude of the sampling step $\Delta t$. In this case, the maximum deviation is 0.022 m (at $\Delta t = 100$ s), the minimum is 0.002 m (at $\Delta t = 10$ s).

Figure 3. Computational model of BEP ACS taking into account the correction device

Figure 4. The graph of the change in the position of the working body under the action of type I GNSS interference: 1 - in a system without a correction device; 2, 3, 4 - with a correction device at $\Delta t = 10, 50, 100$ s, respectively
Analysis of the results of computational experiments involving the second type of interference showed that, as with the type I interference, a decrease in the error value is observed with a decrease in the sampling step. The maximum deviation is observed at $\Delta t = 150$ s and is $0.018$ m, the minimum error ($0.0005$ m) corresponds to $\Delta t = 10$ s.

**Conclusion**

Summing up what has been said, the developed method for the dynamic correction of the BEP ACS of the motor grader and the analysis of the results of the experimental studies of the accuracy of the blade position on the created computational model of the ACS, in which the GNSS receiver is used. We showed satisfactory results and the expediency of its practical application to improve the accuracy of the elevation position of the motor grader blade.

**References**

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