Comprehensive control method of asphalt concrete compaction by road roller

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Abstract. The research results of the study of the system of continuous control of asphalt concrete compaction are presented. The comprehensive method for controlling asphalt concrete compaction based on the continuous measurement of key process parameters of the rolling process of the mixture: thermal condition, thickness of the laid layer, amplitude-frequency characteristics of the vibration roller system and asphalt concrete bed. The authors present the conditions for performing continuous control of asphalt concrete and the results of experimental studies of asphalt concrete rolling. The regularities of changes in the ultimate strength of mixtures are presented. The graphs of the speed and spectra of vibration acceleration of the drum of the vibratory roller have been obtained, graphs of the dependence of the integral indicators relative to the coefficients of compaction of asphalt concrete have been constructed. The acquired knowledge allows improving the methods for controlling the asphalt concrete mix. Based on the performed studies, the authors propose to use the method of continuous controlling the state of asphalt concrete pavement, as the difference between the specified parameters taken from the sensors, which provides the required compaction coefficient.

1. Introduction

The durability of the asphalt pavement is largely ensured by the homogeneity of the structure and the density of the asphalt concrete. The uniformity of the asphalt mix structure depends on the fractional composition and temperature of the mixture being laid. The density of asphalt concrete largely depends on the quality of compaction by rollers and compliance with the compaction technology. To increase the degree of asphalt mix compaction, rollers with vibrating drums are used. At the same time, there is a need to comply with the operating modes of the roller vibration in accordance with the granulophysical state of the mixture and the thickness of the asphalt concrete layer being laid.

According to modern construction technology, the quality of the asphalt concrete pavement is determined by static test methods. Samples are cut from the coatings and their strength is tested in laboratory conditions. This technology does not contribute to ensuring the specified durability of the asphalt concrete pavement, and therefore, unscheduled repairs are performed that require significant costs. At the moment, there is no information on the use of automated continuous monitoring of the state of the asphalt-concrete mixture during road works. Automated continuous monitoring is used in various industries (power supply, mechanical engineering, transport). In works [1-5] the results of studies of foreign scientists are given. The very phenomenon of temperature segregation of asphalt-concrete mixture is given in them to a sufficient extent. However, even in these works, there is not enough information on non-destructive testing of asphalt concrete. To implement the methods of continuous
non-destructive testing, experimental research and mathematical modeling of the ongoing processes are required. The results of computer simulation of the process of laying asphalt concrete mixture are given in the publication [6]. However, the previously developed mathematical models did not investigate the issues of thermal control of the asphalt-concrete mixture to exclude temperature segregation. Therefore, for continuous monitoring of the condition of the asphalt concrete pavement, an integrated automated system is required.

The aim of the research is to develop an integrated quality control system for rolling asphalt concrete with a road roller.

2. Methods and materials
The scheme for measuring the parameters of asphalt concrete rolling with a roller is shown in figure 1.

To control the parameters of the asphalt-concrete mixture rolling, the non-contact temperature sensors PC151LT-0 were used. The compaction rate of asphalt concrete was measured with an Analog Devices of the ADXL326 serie accelerometer. The control of the vibrational process of the roller was determined indirectly by the amplitude-frequency characteristics of the vibration equipment. In this case, the driving force of the vibrator was varied. The measurement accuracy is about ± 2%. The measurement range of the accelerometer covers frequencies from 800 to 50,000 min⁻¹, which corresponds to approximately 14-833 Hz. The thickness of the layer of the laid mixture was controlled by an ultrasonic sensor US-025A in accordance with the measurement scheme shown in figure 2.
3. Results

The goal function is adopted as a condition for performing continuous monitoring of the temperature state of the asphalt-concrete mixture:

\[ Ty - \beta(T_1; T_2; T_3; T_4)/0, \]

where \( Ty \) – temperature set by the set point of the controller; \( T_1; T_2; T_3; T_4 \) – the operating temperature of the asphalt-concrete mixture coming from the sensors installed on the roller.

The thermal state of the asphalt concrete mixture at any time is determined by the heat balance equation [7; 8]:

\[
(Q_{abc})d\tau = (Q_n)d\tau + c_i m_i dT + k_i F_i(T - T_0)d\tau.
\]

Where \((Q_{abc})d\tau\) – the amount of heat released by the asphalt concrete mixture during the time \(d\tau\); \((Q_n)d\tau\) – the amount of heat spent on useful work \(d\tau\); \(c_i m_i dT\) – the amount of heat spent on heating the structural elements at the temperature \(dT\); \(k_i F_i(T - T_0)d\tau\) – the amount of heat dissipated into the environment during the time \(d\tau\).

The condition for asphalt-concrete mix compaction is the transmission of vibration force from the drum to the asphalt concrete. The vibratory roller and the road surface form a coherent system during compaction. The coupled response is determined by the excitation frequency and the intrinsic vibrational modes of the coupled system. Variations in compaction will affect response and result in different drum vibration patterns. Therefore, the quality of the compaction can be assessed by comparing the vibration pattern and the degree of compaction.

Experimental studies of the temperature state of the asphalt concrete pavement have shown that the temperature in the central area of the pavement is 142.2°C (figure 3). In the process of placing the asphalt-concrete mixture on the roadbed, the temperature decreases. With the distribution of the asphalt-concrete mixture over the width of the laid pavement strip of 4-4.5 m, the maximum temperature was 124.4°C. At the edges of the strip, the temperature was 94.6°C, which is close to the critical value of the mixture. With an increase in the width of the laid strip up to 7.5 m, the temperature difference reaches up to 25°C. A decrease in temperature to 82.2°C causes the appearance of temperature segregation of the asphalt concrete mixture.

![Figure 3. Thermal state of asphalt concrete mix.](image)
When the mixture is rolled by the roller, the vibrations of the drum are transmitted to the layers of the asphalt concrete mixture. By adjusting the magnitude of the disturbing force of the vibrator, the optimal vibration mode was selected. Figure 4 shows the acceleration of the oscillatory process of the drum along the X-axis.

Figure 4. Measurement of small accelerations along the X-axis.

Experimental studies were processed by the method of correlation-regression data analysis. Figure 5 shows the dependence of the strength characteristics of an asphalt-concrete mixture under compression on temperature. As the temperature rises, the tensile strength of the rolled mixture increases.

Figure 5. Temperature dependence of compressive strength characteristics.

Table 1 presents the regression dependences of the distribution of strength characteristics in compression, where $R^2$ is the coefficient of accuracy of the approximation.

Table 1. Linear dependence of ultimate strength in compression on temperature.

| Material | Mathematical dependence | $R^2$ |
|----------|-------------------------|-------|
| B1       | $y = -0.0139x + 1.9127$ | 0.9481 |
| SMA15    | $y = -0.0113x + 1.5007$ | 0.9324 |
| SMA20    | $y = -0.0038x + 0.708$  | 0.9822 |
The obtained results of the approximation of the dependence of the ultimate strength on the temperature load confirm the possibility of using a first-order polynomial in order to draw up a regression equation for a full factorial experiment.

Having processed the graphical dependencies obtained when modeling the compaction coefficient of the asphalt concrete mixture on the ultimate strength, it is possible to represent the regularities of the change in the ultimate strength of the mixtures at 85°C and 100°C due to a decrease in the compaction coefficient (figure 6).

![Figure 6. Dependence of ultimate strength in compression on the coefficient of compaction of the mixture: a – at 85°C; b – at 100°C.](image)

Presented in figure 6 dependences of the ultimate strength of the asphalt concrete mixture on the compaction coefficient are expressed by linear functions. Table 2 shows the linear dependence of the tensile strength on the compaction coefficient.

| Material | Temperature 85°C | Temperature 100°C |
|----------|------------------|-------------------|
|          | Mathematical     | R²                | Mathematical     | R²                |
|          | dependence       |                   | dependence       |                   |
| B1       | y=11.254x-10.511 | 0.9407            | y=5.7627x-5.4131 | 0.8445            |
| SMA15    | y=5.8644x-5.4275 | 0.9966            | y=6.5763x-6.2183 | 0.9905            |
| SMA20    | y=5.6271x-5.2505 | 0.9690            | y=5.3559x-5.0554 | 0.9705            |

This table shows the mathematical equations for each type of mixtures at different temperatures and with the corresponding coefficient of determination R², which makes it possible to trace the relationship between the coefficient of compaction of a material and its ultimate strength. Using the obtained dependences, it is possible to determine the strength characteristics of the asphalt concrete mixture, which fluctuate depending on the acting factors.

4. Discussion
The comprehensive control method of the rolling of asphalt concrete is based on the simultaneous monitoring of the temperature state of the mixture, the vibration mode of the roller drum on the compacted mixture of the thickness of the asphalt concrete layer being laid, and comparing the actual values with the measured ones. In the process of rolling asphalt concrete, errors in technological parameters and deviations in the geometry of the layer to be laid are possible.

Measuring the temperature of the asphalt concrete mixture allows detecting discontinuities (cracks, porosity, foreign inclusions) in asphalt concrete, changes in the structure and physicochemical properties
of the material. The paper proposes a solution to the problem of increasing the efficiency of the process of monitoring the technical condition of a roller with a vibrating drum using a decision-making block, thereby providing an opportunity to switch to an adaptive strategy for monitoring the condition of asphalt concrete. In the process of placing the asphalt-concrete mixture on the roadbed, the temperature decreases. With the distribution of the asphalt-concrete mixture over the width of the laid pavement strip of 4–4.5 m, the maximum temperature was 124.4°C. At the edges of the strip, the temperature was 94.6°C, which is close to the critical value of the mixture. With an increase in the width of the laid strip up to 7.5 m, the temperature difference reaches up to 25°C. A decrease in temperature to 82.2°C causes the appearance of temperature segregation of the asphalt concrete mixture.

5. Conclusion
Thus, a method of automated continuous control of the compaction of an asphalt concrete pavement with a vibrating roller has been developed. The result is consistent with the results of previous studies [9]. The developed system of continuous control of the asphalt-concrete mixture with a vibrating roller improves the quality and durability of asphalt pavements.

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