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Concept of a new method for continuous non-destructive control of asphalt road pavements compaction

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Concept of a new method for continuous non-destructive control of asphalt road pavements compaction

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Abstract. The article deals with the research results of a concept for a new method of continuous non-destructive control of asphalt road pavements compaction based on the analysis of the vibration and force state of working bodies of road construction machines as well as the corresponding algorithm for data conversion and intelligent prediction of compaction quality. The definition of the concept "cyber-physical road construction system" is proposed. A scientific problem as well as the corresponding purpose and objectives of the study are formulated. The theoretical background of the continuous compaction control method for pavers is considered. The structure of the considered cyber-physical road construction system is determined.

1. Introduction

The development of information technologies and computer networks helps to increase the technical level of construction industries. Ensuring the quality requirements for asphalt concrete coatings is possible through the introduction of digitalization and intellectualization of the road construction industry as well as the development of automatic control systems.

Taking into account modern achievements of scientific and technical progress and industry features, there is a section of science for the system solution of the problem of improving the efficiency of road construction. It is cybernetic physics studying physical systems using cybernetic methods [1, 2]. The engineering theory considers cyber-physical systems (CPS), which are formed at the junction of the Internet of people, things and services [3]. The technological basis of cyber-physical systems is the Internet of things (IoT) [4].

Based on the analysis of scientific publications during the existence of the CPS concept (since 2006, USA), an important conclusion can be formulated: a new unified system theory has not yet been created, instead several new application areas have appeared, each of which is rapidly developing its own theories: smart homes and smart cities, smart manufacturing and smart grids, the Internet of things, intelligent embedded systems, etc. [5].

An example of the CPS applied field is the scientific direction "Cyber-physical construction systems" by professor A. A. Volkov [6] developed in the industry of industrial and civil construction. Examples of the development of cyber-physical systems in the construction industry are as follows: intelligent neural network system for automatic control of the vibration roller [7], continuous compaction control (CCC) [8], intelligent compaction (IC) [9]. Improvement of CPS facilities (vibration rollers, pavers) is an actual scientific direction [10-13].

Summarizing the known scientific achievements during the period of CPS development, taking into account significant industry features, it is possible to predict the development of the applied direction on the topic "Cyber-Physical Road Construction System" (CPRCS). The following definition of a "cyber-physical road construction system" is proposed: it is a functional set of mobile and stationary technical automation tools that interact with each other, with the Internet and users, and are implemented in computer systems.

2. Problem formulation

The main stages of the construction process of the top asphalt concrete coating (production, transportation from the plant to the object, distribution, laying and compaction of the mixture) have an impact on the quality indicators of the coating. According to M. P. Kostelov, PHD in engineering, (VAD CJSC, St. Petersburg) and Professor Elk Richter from Erfurt Technical University (Germany), 50% of all defects and destructions of asphalt concrete pavement on the world's roads are caused by low, including non-uniform, compaction quality [14]. The compaction process is an increase in the density of road construction material due to the application of external forces. That is, due to high-quality compaction of the mixture with asphalt pavers and road rollers, it is possible to eliminate up to 50% of the road pavements limitations and increase their service life. Also, when the compaction coefficient increases from 0.99 to 1.02, the strength and durability of the asphalt concrete coating increases by approximately 35% and 40%, respectively [14].

One of the most pressing problems of road construction reducing the productivity and economic efficiency of construction, is the quality control of compaction. In the process of road construction, spot, selective non-destructive quality control is performed using devices (express method). The disadvantage of this method is that it is not possible to continuously monitor the compaction. Continuous and rapid measurement of the compaction is required. Known methods and control means [1, 2, 3, etc.] for rollers based on the calculation of compaction indicators according to the results of spectral analysis of accelerometer signals installed on the design of the roller vibration roll. Many researchers have established a relationship between the roll speeding and the characteristics of the asphalt concrete mixture [7-14, et al.].

Research [13, 17, etc.] testing the effectiveness of intelligent compaction on vibration rollers have shown that current indicators (CCV, CMV, RMV, Evib, etc.) have a significant error, and do not allow judging the efficiency and quality of the rolling process [14]. This is obviously due to the fact that current compaction indicators do not take into account variables having a significant impact on compaction. Thus, the development of a method for continuous, operational and reliable control of the rolling efficiency and compaction characteristics of the material within achieving the standard density, evaluating its stress-strain state, is a problem that needs to be solved [14].

With the traditional compaction technology of asphalt pavements for road construction, sets of machines are used including an asphalt paver, road rollers of light type, vibration rollers of medium type and rollers of heavy type. A significant reserve for improving the efficiency of road construction is the improvement of pavers to increase the compaction coefficient and reduce the size, number and number of rollers passes at the final phase of compaction of the road pavement. We know the results of tests of an asphalt paver with a highly efficient working body (ramming bar, vibration plate, two pressing bars), which provides obtaining a standard density of asphalt concrete mixture of type A (GOST standard 9128-97) at a speed of 3 m / min, and saving labor and energy resources by excluding the technological chain of medium and heavy road rollers [15]. Such models of working bodies are produced by VÖGELE (Germany).

The results of experimental studies of an asphalt paver with an effective working body (two ramming bars, a smoothing plate) in real road construction conditions [16] results that the compaction coefficient depends on the maximum force in the ramming bar pushers. The mixture resistance to compaction increases gradually and reaches maximum values after 4-5 impacts on the mixture with a ramming bar. The research was carried out at paver speeds of 1.6, 3.2, 4.8 m / min, and the rotation speed of the eccentric shaft from 1100 min^{-1} to 1700 min^{-1}. The force in the pushers F_{1m}, F_{2m}

(maximum values) was measured by load cells (figure 1). The amount of effort during compaction of type B asphalt concrete mixture with a layer thickness of 0.05 m, varied from 10 kN (compaction coefficient K_c=0.92) to 23 kN (K_c =0.99), as in figure 2.

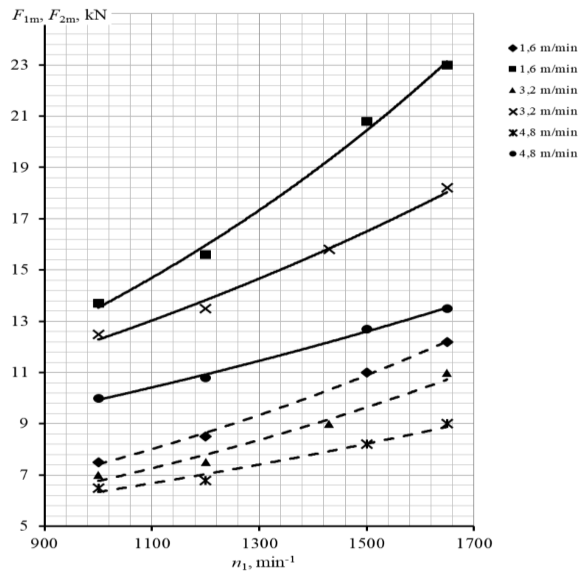

Figure 1. Relationship of the maximum forces from the rotation frequency eccentric shaft (F_{1m} - dotted; F_{2m} - continuous).

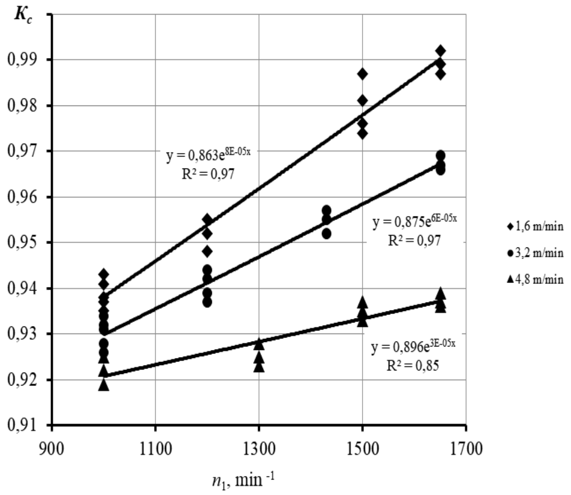

Figure 2. Relationship of the mix compaction coefficient from the rotation frequency eccentric shaft.

3. Solution methods

The purpose of this work is to develop the new and perfect the current methods of continuous non-destructive control of road pavements compaction using algorithmic as well as software and hardware tools for constructing simulation models of processes, using artificial intelligence methods that improve the automation of compaction control devices, determine the compaction coefficient, increase the productivity of road construction works, and reduce the cost of road pavements construction.

The results obtained by the authors [16] allow to propose the concept of a new method of continuous non-destructive quality control of compaction for pavers, based on processing data of operating modes (speed of movement, rotation frequency of the eccentric shaft of the ramming bar, vibration frequency of the plate vibrator), values of forces in the ramming bar pusher (bars), data on the vibration plate speeding. To improve the efficiency of predicting the value of the compaction coefficient, it is proposed to use artificial intelligence methods: artificial neural networks, hybrid neural networks, methods of spectral data analysis (Fourier transform), wavelet transform.

The concept of a new method of continuous non-destructive control of pavements compaction is proposed. The method is based on artificial intelligence technologies. The value of the compaction coefficient predicted by the system allows the paver driver to adjust the operating modes and send a radio signal to the vibration rollers to optimize their operating modes. The continuous monitoring system on the paver based on the well-known automatic control systems (filling the screw chamber, profiling, leveling, temperature control of the mixture in the hopper and the compacted coating, global navigation, documentation of the results of compaction and temperature measurement), significantly increases the level of automation and brings the machine to compliance with the concept of "smart paver". There are no similar or similar scientific and technical solutions available in open sources of information.

The cyber-physical road construction system includes machines (pavers, road rollers of medium and heavy type), sensors and information systems which are connected at all stages of road pavements construction (acceptance of the mixture from the dump truck, laying and pre-compaction by the paver's working body, compaction of layers by medium-sized vibration rollers, final compaction by static heavy-duty rollers) and continuously interact with each other using standard Internet protocols to predict the compaction coefficient and adapt to changes in the characteristics of the asphalt mixture and the environment (temperature and air speed).

A block diagram of a cyber-physical pavements construction system for continuous non-destructive control of asphalt pavement compaction with hierarchical layers (joining, transformation, cloud, study, and configuration) is shown in figure 3.

The "connection" layer is characterized by the selection and installation of measuring transducers (sensors). In the "transformation" layer, the signals from the sensors are analyzed and normalized, in which all input data goes through the process of "alignment", i.e., reduction to the interval [0, 1] or [-1, 1]. To align quantitative values, a linear shift of the attribute value interval is most often used. If normalization is not performed, the input data will have an additional impact on the artificial neuron of the next layer prediction system, which will lead to incorrect decisions.

Large amounts of current technological information are stored and processed on cloud servers. This allows for information flow and communication between road construction machines (pavers, road rollers) in online mode to optimize the process, taking into account the changing state of the environment and the characteristics of the compacted layer of the road pavement.

In the hierarchical "study" layer, the results of measurements and forecasts are determined, which are made available to interested specialists, and are used for theoretical analysis using a mathematical model of the object for further adjustment of optimal operating modes.

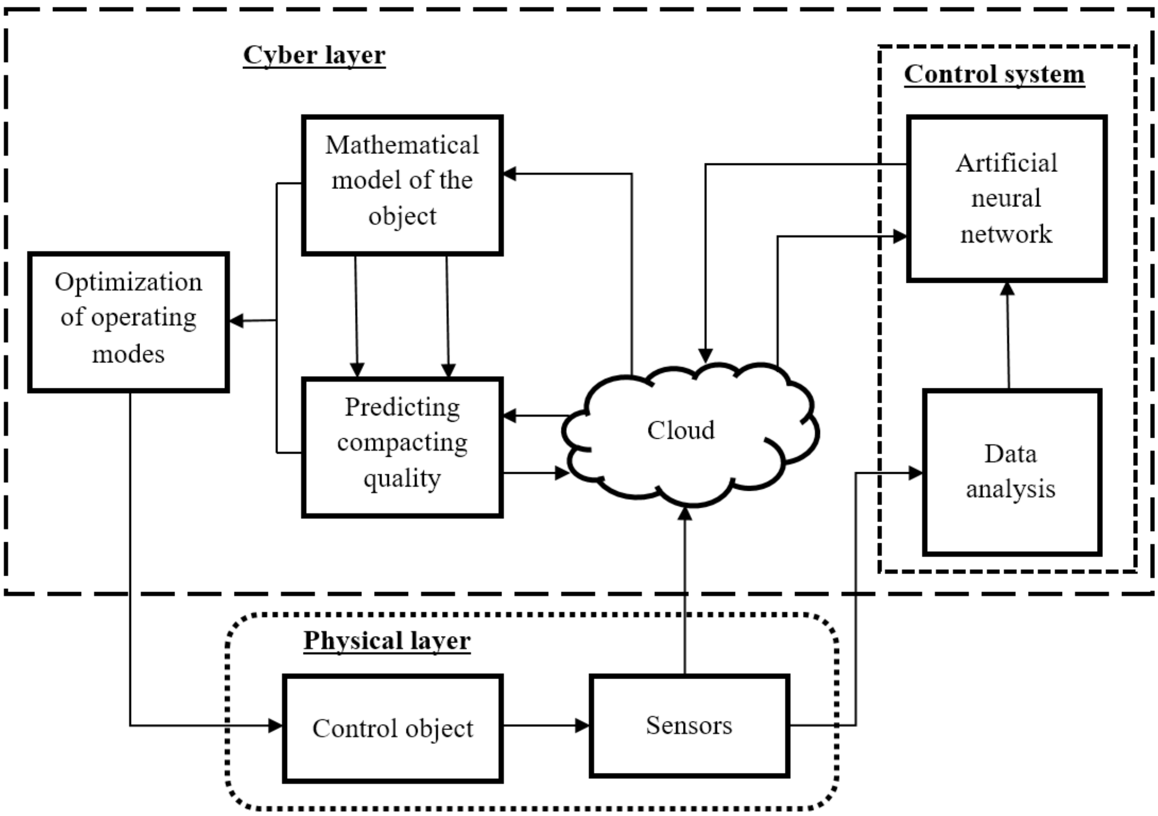

Figure 3. Cyber-physical system for continuous control compaction of the asphalt mixture.

Continuous monitoring systems for compaction of road pavements layers based on artificial intelligence technologies will significantly increase the efficiency of pavers and road rollers. Information links between road construction machines on linear objects via the Internet protocol allows to optimize the entire process of road construction depending on the state of the environment and the characteristics of the asphalt mixture. This helps to maximize productivity and reduce the cost of construction.

4. Conclusion

This article deals with the concept of a cyber-physical road construction system for continuous non-destructive quality control of asphalt pavements compaction based on artificial intelligence technologies. The definition of the concept "cyber-physical road construction system" is formulated.

Theoretical prerequisites for the neural network continuous compaction control method for asphalt pavers are considered. The structure of the system is determined.

To implement the method of continuous monitoring, artificial intelligence technologies are proposed for continuous forecasting of the values of the compaction coefficient of the mixture.

This method allows to determine the quality of the compaction at different operating modes, environmental conditions and condition of the road pavement being compacted.

The validity of the method is confirmed by the necessary amount of experimental research of the asphalt paver with an effective working body in real operating conditions.

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