Effective equipment and technology for building highways

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Abstract. Modern road building machines at a high level of mechanization do not meet the increased quality indicators of building highways. One of the main reasons for such poor quality is the lack of compaction of all the structural layers of the road pavement. The existing technology of compacting road-building materials is based on compression deformations, a significant portion of the air remains in the volume of the compacted material and leads to the formation of uneven surfaces (wheel tracks, transverse waves). The new technology of the compaction of road-building materials is based on shear deformations and compression deformation, thus creating a dense, rigid and unchangeable material structure. The article considers the peculiarities of the technology of laying road-building materials and proposes a technical solution for obtaining high-density structures from composite materials. It presents a comparison of the existing and the new technology of compacting road-building materials. The technical solutions of the new devices of the machines’ working elements (new equipment and technology) provide a higher coefficient of compaction for various road-building materials.

1. Introduction

Large volumes of road building works can be performed at the increased quality requirements, provided that there is effective equipment and technology based on the latest achievements of science and technology.

When building highways, road building materials (road metal, gravel, asphalt concrete, cement-concrete mixtures, etc.) are in a loosened state and their density, and, consequently, strength are insufficient to ensure a normal passage of high-speed and heavy vehicles. As a consequence, the laid materials require an artificial compaction, which is performed by different machines. The main technological task of compacting bulk layers of various mixtures of materials is to bring it into a flow state in order to fill a set geometric volume or shape, and to maximally reduce their porosity by removing entrapped air and excess process fluid (water, bitumen) from it.

Some experts believe that more powerful equipment is needed for a better compaction of road building materials, for example, the weight of road rollers should be increased to 200 tons or more (now the maximum weight is 25 tons), but new approaches can be found to solve this problem [1, 2].

A new approach to the technology and equipment for compacting road-building materials is needed to solve the task in a comprehensive manner. Currently, it is impossible to obtain extremely dense structures by the existing road-building equipment. To increase the material density, researchers
recommend to increase the number of passes of rollers on one and the same site from 8 to 12 times up to 24 ... 30 times, but this is a "costly way" for solving the set task [3].

2. Comparison of the existing and new equipment and technology of compacting road building materials

According to the standard operating procedures, surface or deep compaction is performed depending on the location of the working element with respect to the compactible materials. The main methods of mechanical compaction of road building materials are rolling, pinning, vibrocompaction and the combined method [4].

The most widespread type of machines for compacting road building materials is rollers. It is explained by the fact that they are easy to manufacture and operate. When materials are compacted by rollers, it is necessary to know the maximum stress that appears on the surface when the roll contacts the material, which continuously changes in connection with the change in the rheological properties of the multiphase structure of soils, concretes, and asphalt-concretes. This requires the use of non-stationary compaction modes, which is rather difficult to implement in practice, and considering the nature of the pressure change under the contact surface of the roller (Figure 1), one should expect a low efficiency of the air phase displacement process and reduce the porosity of the system.

![Figure 1. Pressure diagram. Traditional technology of compaction on the prepacked material.](image)

The South Ural State University proposes to change the conditions for the migration of air formations by means of technical solutions using not only compression, but also shear deformations. The task is successfully solved using the working element of the tamping machine based on the Archimedes lever (Figure 2), which has a fixed hinge support at one end, and an external force, which moves the lever "up and down", is applied to the other end.

The pressure diagram for elementary particles of the material, depending on the current coordinate "a", varies according to the hyperbolic law, which allows us to have the entire pressure spectrum from \( q_{\text{min}} \) to \( q_{\text{max}} \) (near the fixed support) on the working element. This creates conditions for an organized movement of the gaseous phase (air) in the horizontal direction (from the maximum pressure area towards the minimum).
The combined effect of vertical and horizontal loads contributes to the formation of structures with a denser packing (Figure 3).

Force $Q_{com}$, acting on the particle, which is introduced to the volume of the compactible material, is calculated as follows:

$$Q_{com} = P k_1 k_2$$  \hspace{1cm} (1)

where: $P$ represents the driving force; $k_1$ and $k_2$ represent the gain coefficients.

The principle diagram of the mechanism using the Archimedes lever effect is shown in Figure 4. The mechanism drive is made in the form of flat compound-lever arrangements (Figure 5) [5,6].
The gain coefficient $k_1$ is determined from the parallelogram of forces with the angle $\alpha$ between the levers (Figure 5)

\[ \frac{P}{2} = T \cos \frac{\alpha}{2} \]  \hspace{1cm} (2)

\[ T = \frac{P}{2 \cos \frac{\alpha}{2}} = Pk_1 \] \hspace{1cm} (3)

where:

\[ k_1 = \frac{1}{\cos \frac{\alpha}{2}} ; \quad k_1 \gg 1 \]

The gain coefficient $k_1$ tends to an infinitely large value at the angle $\alpha$ approaching 180 °, since $\cos \frac{\alpha}{2}$ tends to zero.

The gain coefficient $k_2$ is determined from the equality

\[ Q_{com} = \frac{b}{a} T = Tk_2 \] \hspace{1cm} (4)

where:

\[ k_2 = \frac{b}{a} ; \quad a \text{ represents the distance from the elementary particle of the material to the fixed hinge support; } b \text{ – radius (length) of the platform plate.} \]

A force analysis of (1) ... (4) shows that the technological concept of "hard-to-deform" materials in many cases loses its meaning. For example, for concrete mixtures with a low water-cement ratio with the predominant dry friction, a beneficial effect for a dense packing of particles is provided by the possibility of a relative shear of the layers and a mutual rotation of the solid filler particles.

Modern concrete placing machines with a sliding formwork, using vibrocompaction of cement-concrete mixtures, work with materials, which have a water-cement ratio in the range of 0.45 ... 0.5, and the use of the new mechanism is 0.3 ... 0.4, which will allow us to significantly improve the physical and mechanical properties of concretes, such as strength, frost resistance, abrasion [7].

Load tests of the pilot sample of a concrete-forming machine conducted in the laboratory of "Road-Building Machines" of the South Ural State University confirmed the predicted effectiveness of the new mechanism for compacting concrete mixtures in the manufacture of control samples with the
following dimensions in millimeters: 120 x 250 x 65. The compression strength of the test samples is 1.2 ... 1.3 higher than that of similar samples compacted on a standard vibro-bench.

The consumer properties of concrete pavers can be significantly expanded if the working element is constructed according to the improved scheme based on the RF patent for utility model No. 176735 [8]. In this case, the concrete paver acquires three executive functions in one mechanism:

- Supply of the material into the work area;
- Effective compaction of the mixture;
- Grouting of the working surface to create roughness and pore closure in the concrete layer in service.

The Ministry of Road Industry and Transport of Chelyabinsk Region notes the attractiveness of the proposed equipment and technology for compacting hot asphalt mixtures, whereas a complex mechanization of road construction with the existing equipment offers a time-extended compaction cycle with the use of 3 ... 4 machines: an asphalt paver and 2 ... 3 standard sizes of road rollers (RR). It is explained by the fact that the deformation properties of the asphalt-concrete mixture significantly depend on the temperature: when laying the mixture using viscous and liquid oil and road bitumen, the temperature of the material should not be less than 120 °C [9].

In practice, the total operating time of the asphalt paver and all three rollers often exceeds the recommendations of the temperature regulations specified in SP 78.13330.2012, which leads to undercompaction of asphalt-concrete and to a decrease in the physical and mechanical properties of the pavement [10,11].

The use the proposed equipment for compacting asphalt-concrete mixtures will allow us to refuse from rollers and perform the technological process by one asphalt paver in one pass.

Laying and compaction of the asphalt-concrete mixture according to the existing technology are performed by the link of road-building machines, and in this case the compaction coefficient reaches 0.98-0.99 (EMT), and according to the new technology (NET) - by one modernized asphalt paver - 1.05-1.10 (Figure 6) [12-14].

3. Conclusion
The South Ural State University has developed new technical and technological solutions based on the effect of the Archimedes lever, which creates a differential pressure in the neighbouring points of the compactible material. Under such conditions, there is a simultaneous use of compressive and shear deformations, at which the phase is displaced in the volume of the material with a lower pressure, which provides a denser packing of the components of road-building mixtures.

The new working elements of the compacting systems are made in the form of plates that perform angular vibrations, which are driven by crank mechanisms or other pulsators. The introduction of the new equipment and technology will allow the builders to solve many problems of improving the quality of hard-coated highways in a new and efficient manner.
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