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Research paper

Means to Enhance Operating Efficiency of the Concrete Mixer Trucks with the Purpose of Highly-Homogeneous Concrete Mix Preparation

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Abstract

Option shall be considered to create concrete mixer trucks for preparation not only of high-flow but also of low-slump and dry type concrete mixes. With these aims it is offered to transfer operation to the cascade mode being characterised by combination of two principles on concrete mix preparation: gravitational and forced action.
Design solution of the concrete mixer truck of gravitational-forced operation with spiral-blade shaft has allowed to liquidate available free places in the drum. The dependencies for calculation and arrangement of mix particles motion in the workspace of the machine drum are provided. Graphic performance confirms the absence of free zones.
There is description of dependency for determining the homogeneity degree obtained on the basis of the experimental investigation findings.

Keywords: *concrete mixer truck of gravitational-forced operation, spiral-blade shaft, degree of homogeneity, degree of homogeneity.*

1. Introduction

1.1. Relevance

Capacity to prepare dry and extra dry concrete mixes in the concrete mixer trucks not only high-flow but also of low-slump, dry and extra dry types of concrete mixes provide for a design development of the working machines and intensification of the mixing working processes of mix ingredients.
Concrete mix preparation is the most important scope in the total amount of the construction works. A potential level of concrete features is formed on this stage.
For the time being, it is significant to perform an in-depth study of common factors, bounding concrete properties with its structure and parameters of technology involving contemporary views of physicochemical mechanics, rheology, thermodynamics, colloid chemistry, elasticity theory, etc.
The outputs of these works are essentially of phenomenological nature and may not, as a rule, provide a full qualitative assessment of the prepared concrete mixes features correlation influenced by the machines' constructive peculiarities, in particular, which are used for their preparation. Thus, in practice it is continued to be guided, first of all, with the general regularities established by an experimental approach. Improving of current and creating of new designs of mixers is one of the main trends among the focal points in theory and practice of high-performance mixing equipment creation.
Low balancing capacity both at macro level and micro level is a major disadvantage of the work of the current concrete mixer trucks.
In order to enhance efficiency of the concrete mixer trucks operations it is required to introduce new approaches into their design, one of which is a cascade operation mode of the machines.
Almost the whole capacity of their body become working during the machines' cascade operation mode. The design peculiarities of these machines ensure displacements of the concrete mix components during their movement along the composite paths, where free fall is available from above the blades of the machine actuating element, which is typical for gravity mixing method, and then, in the lower body of the mixer upon getting on the blades of running blade shaft the free -falling mixture components are involved in forced mixing [1].
The combination of two types of mixing components movement in the workspace of the concrete mixers under specific rotation frequencies of its working parts allows creating cascade motion of the mix particles throughout the length of the blending machine ensuring their axial displacement. Such motion of mix particles significantly intensifies the process of their blending under identity of conditions along the entire capaciousness of the mixer body (drum) and increases the volume efficiency кзо up to 0.7…0.75. Application of cascade mode for the mixer's operation under the mixing particles free fall from above and their following forced lifting up allows obtaining a high degree of homogeneity of the preparing building mixtures of not only high-flow but also of low-slump, dry mixes of different purpose, building mortar. This principle of machine operation produces high-degree of homogeneity of preparing concrete mixes. Such principle of operation is estab-

lished in the concrete mixers of new design solutions [2, 3] being patented in Ukraine.

1.2 Source Analysis

New principle of the concrete mixer trucks operation has been established in series of known patents [4, 5, 6]. All these concrete mixer trucks are equipped with auxiliary spiral blades with screw winding on the cover surface [4], or interior auxiliary spiral blade inside the drum [5], or auxiliary blending shaft inside the mixing drum [6]. The spiral blades are fixed on the internal surface of the drums at all listed designs of the concrete mixer trucks.

In addition, the design solutions of the working parts of the analysed machines are characterized with free zones availability in the drum, which do not provide an appropriate mix components blending.

However, a sufficient design disadvantage is peculiar for all above mentioned concrete mixer trucks: additional auxiliary blades or blade shaft occupy only the part of machine drum workspace. Therefore, there are no arranged identical conditions for mix components blending along the entire workspace in the drum of the concrete mixer truck. Hence, no conditions are arranged to prepare concrete mixes with high-degree of homogeneity.

The concrete mixer truck, the basic chart of which is shown on the Figure 1, is worth noticing from these positions [7].

1.3 The Aim

The purpose of these investigations lies in the elaboration of a universal concrete mixer truck hydraulically driven allowing preparation of concrete mix of various flowability and different assignment with an option to change macine performance in a wide range.

2. Main Body

The concrete mixer truck (Fig.1) is composed of a base motor-car 1 and mixing drum 3 with feed bin 9 and discharging tray 11. Spiral blades 7 are fixed on the internal surface of the drum, and shaft 4 is equipped with a spiral tape 6 and blades 5. The drum and spiral-blade shaft have unit drives 2 and 10 in the form of "hydraulic motor – reduction gear", which expands the performance capabilities of the concrete mixer trucks: performance is adjusted both by changing rotation frequency of the machine body and rotation frequency of the spiral-blade shaft.

The operation principle of the concrete mixer truck is the following. The dosed mixture components in factory environment are loaded into the drums. First, the drum shall be put into operation in 15…20 minutes before arrival to the building site, and then the spiral-blade shaft, and water is fed. The drum and spiral-blade shaft rotate in all directions. The ready-made concrete mix is unloaded by the rotating spiral-blade shaft

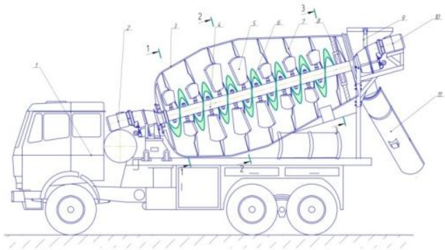

Fig 1. The concrete mixer truck of gravity-enforced action with the spiral-blade shaft

1 – base motor-car; 2 – hydraulic drive of drum control; 3 – drum; 4 – shaft; 5 – shaft blades; 6 – spiral auger; 7 – spiral blades on the drum body; 8 – supports for spiral-blade shaft fastening; 9 – feed bin; 10 – hydraulic drive of spiral-blade shaft ; 11 – discharging tray

Universal nature of such concrete mixer truck of gravity-enforced action allows to use it in concrete mix preparation of different purpose considering the needs of the sites under the construction. Such concrete mixer trucks can be efficiently used in the technological complexes when performing by cement gun works by wet-method.

The offered construction of the spiral-blade shaft should ensure liquidation of the zones in the drum being free of outworking by the working part. It may be validated by the research results of the concrete mix particles' motion path in the workspace of the concrete mixer truck.

It is required to build up the concrete mix particles' motion path when descending from the blades of the rotating drum as well as the blades and spiral turns of the running shaft.

The absolute velocity of concrete mix particles descending from the

1. drum blades of the concrete mixer truck:

$$V_{1\ абс} = \sqrt{V_{1\ окр}^2 + V_{1\ отн}^2} = \frac{\pi \cdot n_1 \cdot R_1}{30}\sqrt{2 - \frac{R_2^2}{R_1^2}}, \quad (1)$$

where $V_{1\ окр}$ – peripheral rotation speed of the concrete mixer truck's drum, m/s;

$V_{1\ отн}$ – relative velocity of concrete mix particles motion along the drum blades, m/s;

n_1 – rotational speed of the drum, rad/s;

R_1 – inner radius of the drum on the attaching point of the spiral blades, m;

R_2 – drum radius along the end of its blades, m.

2. spiral-blade shaft:

$$V_{2\ абс} = \sqrt{V_{2\ окр}^2 + V_{2\ отн}^2} = \frac{\pi \cdot n_2 \cdot R_2}{30}\sqrt{2 - \frac{R'^2_2}{R'^2_1}}, \quad (2)$$

where $V_{2\ окр}$ – peripheral rotation speed of the spiral-blade shaft, m/s;

$V_{2\ отн}$ – relative velocity of concrete mix particles motion along the spiral-blade shaft, m/s;

n_2 – rotational speed of the spiral-blade shaft, rad/s;

R'_1 – maximal radius at the ends of the spiral turns, m;

R'_2 – minimal radius of the shaft, m.

In order to construct the motion path of the concrete mix particles upon descending from the spiral blades of the concrete mixer trucks' drum without regarding the environmental resistance the following simultaneous equations may be applied:

$$y(x) = \left[x \cdot tg\alpha_{Ш} + \frac{g}{2 \cdot \omega_1^2 \cdot R_1^2 \cdot \left(1 - \frac{R_2^2}{R_1^2}\right) \cdot cos\alpha_1^2}\right] \cdot cos\alpha_{Н.Б.}, \text{ m} \quad (3)$$

$$x(t) = [V_{1\ абс} \cdot t \cdot cos\alpha_{Ш}] \cdot cos\alpha_{Н.Б.}, \text{ m} \quad (4)$$

where $\alpha_{Ш}$ – an angle, from which free falling of mix particles started from the auger end of the drum being rotated; $\alpha_{Н.Б}$– inclination angle of the concrete mixer truck's drum to the horizontal plane.

The motion path of the concrete mix particles being formed by means of the dependencies (3 and 4) considering the maximum angular rotation speed of the drum's mixer ω_1 = 1,8…2,0 s^{-1} and the angle of its inclination $\alpha_{Н.Б}$ = 10…15^0 in three different sections of the drum, is demonstrated on the Fig. 2.

The above equitation's (3, 4) allow constructing the motion path of the concrete mix particles after the drums' auger descends, spiral and the blades of the rotating shaft. The results of the motion path construction are shown on the Fig.2.

The motion path of the concrete mix particles upon descending from the spiral blades of the concrete mixer trucks' drum without regarding the environmental resistance may be defined by means of the dependency:

$$y(x) = \left[E\frac{x}{V_{1\ абс} \cdot cos\alpha_{Ш}} + \frac{E^2}{g} ln\left\{\frac{\beta_{(1)} + exp\left[\left(-\frac{2g}{E}\right) \cdot \frac{x}{V_{1\ абс} \cdot cos\alpha_{Ш}}\right]}{\beta_{(1)} + 1}\right\}\right] \cdot cos\alpha_{Н.Б.}, \text{ m} \quad (5)$$

$$x(t) = [V_{1\ абс} \cdot t \cdot cos\alpha_{Ш}] \cdot cos\alpha_{Н.Б.}, \text{ m} \quad (6)$$

where $\beta_{(1)} = \frac{1+\frac{V_{1\,абс}}{c}sin\alpha_{ш}}{1-\frac{V_{1\,абс}}{c}sin\alpha_{ш}}$; $E^2 = \frac{m_ч \cdot g}{k_ч \cdot S_ч}$; $m_ч$ – mass of the concrete mix particle; $S_ч$ – projection of the particle section on plane, m;

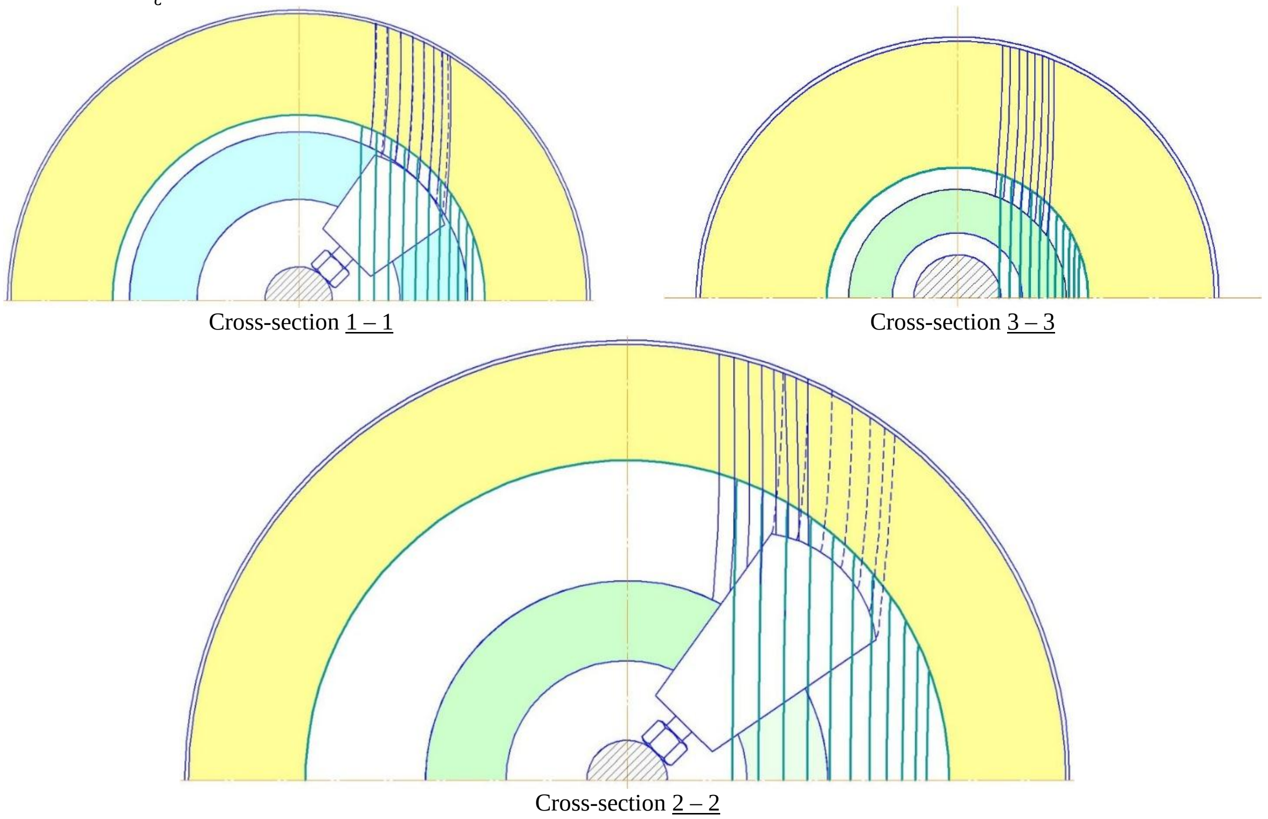

Fig. 2 The motion path of the concrete mix particles when descending from the screw blades of the drum and spiral-blade shaft of the concrete mixer truck not tacking into account the environmental resistance in three different section of the drum

– motion path of the particles from the spiral; – motion path of the particles from the shaft blades; – motion path of the particles from the drum auger

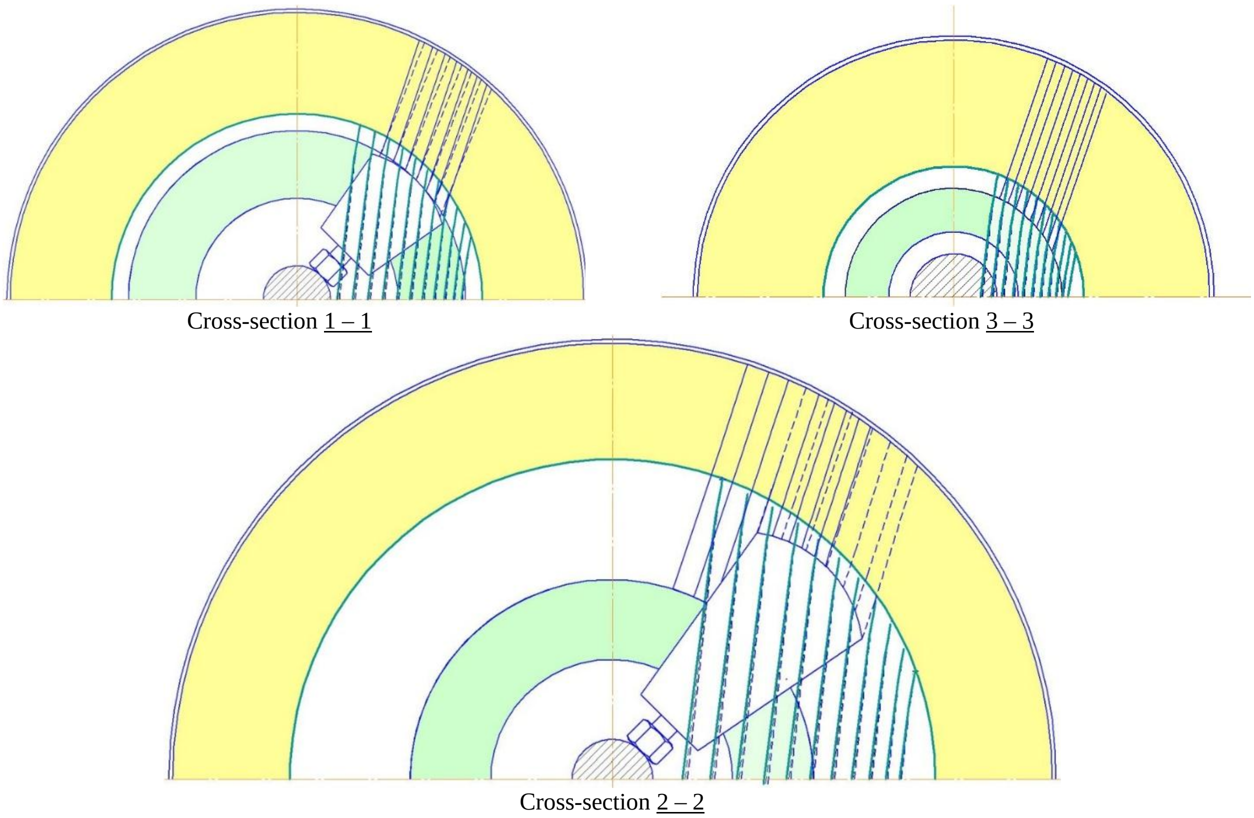

Fig. 3 The motion path of the concrete mix particles when descending from the screw blades of the drum and spiral-blade shaft of the concrete mixer truck not tacking into account the environmental resistance in three different section

– motion path of the particles from the spiral; – motion path of the particles from the shaft blades; – motion path of the particles from the drum auger

$k_ч$ – coefficient considering environmental resistance, which tests the mix particles; c – coefficient taking into account the mix changes by its mobility.

The motion path of the concrete mix particles considering the environmental resistance are formed by means of the dependencies (5 and 6), taking into account angular speed of the mixer's drum rotation $\omega_Б$ = 1,8…2,0 c^{-1} and inclination angle of the drum α Н.Б = 10…150 in three different sections of the drum, shown on the Fig. 3.

In order to construct the motion path of the particles descend from the spiral-blade shaft, the equitation's (5) and (6) have been applied. Thus, the design peculiarities of the concrete mixer truck have been taken into account. The obtained motion paths are shown on the Fig.3.

From the analysis of the graphical dependencies on the Fig. 2 and 3 it is clear that if the concrete mixer truck operates in the cascade mode the particles of the concrete mix are thrown off the screw blades surfaces of the rotating drum into the action zones of the shaft blades. Such situation occurs both during the period of environmental resistance mix particles discharge and without it.

In addition, free space between each pair of the shaft blades and drum (Fig.1) due to the available spiral on the shaft, also becomes an active workspace.

Also, it is apparent that the particles of concrete mix are discharged from the spiral-blade shaft to the action zone of the rotating drum's spiral blades.

Hence, the obtained motion paths demonstrate the availability of the cascade operation mode of the concrete mixer trucks, and its design peculiarities allow significantly to expand the workspace, so that prepare concrete mix with high degree of homogeneity in identical conditions of components mixing along the entire area of the drum.

Thus, the availability of spiral-blade shaft in the mixer's drum liquidates weak zones of components mixing and allows arranging stable conditions in order to prepare concrete mixes with high degree of homogeneityThe most efficient mixing and best use of all capacities of the system "mixer – mixture" requires supply of the exponential process being achieved by setting rational frequencies of the concrete mixer truck's drum rotation and spiral-blade shaft, proper form and layout of the blades on the drum and shaft, the greatest possible machine loading by concrete mix and mixing as low as practicable for prearing mix to be of high homogeneity.

Rheological model of mixing in the advanced concrete mixer truck is complicated and is called a elastic-plastic Bingham's (Shvedov's) model, the principal rheological feature of which is a specific resistance of path of ribbon spiral' turns and blades in the mixture, depending on its flowability, on features of fine and coarse aggregate included into composition of mortar composition.

The main quality index of mixture preparation in the concrete mixer trucks is its degree of homogeneity being considered as a function $С = f\ (V,\ t,\ \delta, ф,\ ш)$, where V – the rotation speed of the concrete mixer truck's operation part; t – mixing time of source components; δ – grain size composition; ф – grain shape; ш – waviness assessment.

Aiming to obtain high degree of homogeneity the particles of the source components shall be reported these motion paths, which are to ensure the greatest possibility of their intersection in the workspace if there are no zones having no such intersection. The velocity of mixing degree change in time dY/dt is a universal criterion of mixing intensity [9]. Thus, the mixture homogeneity characterises the degree of its approaching to the material with some ideal order of such mixture components in it [10].

There are investigations known in the field of homogeneity degree [11, 12], illustrating complicated ones enough for dependencies use. There are investigations known in the field of determining the homogeneity degree of mixture, which do not completely reflect the process of their preparation. Frequently, there is no any opportunity to consider specific process conditions in preparing building mixtures of different assignment.

Thereat, the following formula is offered [13, 14] to determine the homogeneity degree, which is obtained on the basis of the results of experimental investigation on the researching the capabilities of efficient use of one of the mixtures for building mixtures preparation being operated in the cascade mode – three-shaft concrete mixer.

$$С = \left| \frac{\sum_{i=1}^{n}(f_{cp} - f_i)}{\sum_{i=1}^{n}(\rho_{0\ cp} - \rho_{0\ i}) \cdot V^2} \right| \cdot k_{пр} \cdot k_{ф}, \quad (7)$$

where f_{cp} – an index of average compression strength of cube concrete test specimen, MPa;

f_i – index of compression strength of i-concrete specimen, MPa;

$\rho_{0\ cp}$ – index of compression strength of concrete specimen, kg/m3;

$\rho_{0\ i}$ – index of compression strength of i-concrete specimen, kg/m3;

V – peripheral rotation speed of the concrete mixer truck's drum, m/s;

$k_{пр}, k_{ф}$ – accordingly the coefficient reflecting deviation of compression strength indexes of the concrete specimen and coefficient depending on the grain shape of coarse aggregate; ($k_{ф} = \frac{f_{i\ ф}}{f_{cp\ ф}}$;

$f_{i\ ф}$ – compression strength of i-concrete specimen; $f_{cp\ ф}$ – average compression strength of i-concrete specimen, moulded on the concrete mixes with coarse aggregate of specific shape (flaky, cube-like, needle shaped).

Consequently, dependency (7) allows defining the homogeneity degree of preparing mixes directly considering design peculiarities of advanced construction and features of concrete mix test specimen used for formation.

3 Conclusions:

1. The actuality of concrete mixer truck creation for a new design solution has been demonstrated.
2. Statement of reasons has been performed as to creation of the concrete mixer truck operating in the cascade mode.
3. Improvement of operational efficiency of working machines has been proven on the basis of the example of concrete mix particles motion path's investigation in the workspace of the concrete mixer truck
4. Dependency for determining the homogeneity degree obtained on the basis of the experimental investigation findings has been offered.

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