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Research paper

Determination of Building Mortar Mixers Effectiveness

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Abstract

The peculiarities of building mortar mixes preparation in cyclic compulsory mixers of various designs have been considered in this article. The work of mixers with a horizontal shaft, a vertical shaft, beaters, screw straps, as well as planetary motion of mixing stars with beaters have been described in detail. The main attention here is paid to the constructive performance of machinery. A relative assessment is given to the manual bearing groups. The multi-purpose system of numerical indices necessary for the performance assessment of mixers' running efficiency is proposed and defined in this paper. The design of the mixers is considered in this research according to the number of components of the mixture particles motion, which arise from the constrained influence of the movable operating element. The indicators of net weight and area in the plan are attributed to the productivity. The general method of determining the coefficient for assessing the impact, exerted by the design of the mixers on their running efficiency, has also been developed by the authors of this scientific investigation. The obtained data will enable to investigate and improve the design of the mixers, finding the ways to increase their working efficiency.

Keywords: *efficiency, mixing action, compulsory mixer, mixer operating element, construction*.

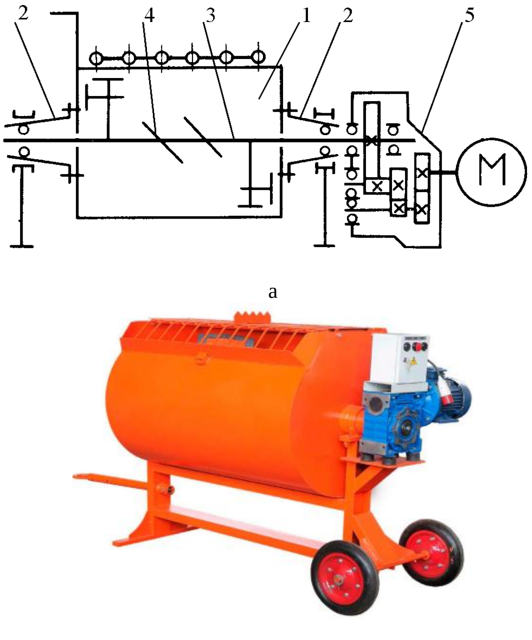
1. Introduction

The list of requirements to mixing equipment is quite wide. The main ones are: the ability to prepare good homogeneous mixture, relatively low values of energy intensity and metal intensity, high efficiency performance, simple design and ease of operation, utilization flexibility of mixers, without regard to rheological characteristics of the mixture being mixed, the type and properties of binding substances and filler materials. In addition, the quality of the obtained building materials directly depends on the type of the used mixer [1, 2, 3, 4]. And, therefore, the efficiency determination of the mixing equipment, in order to ensure as many of the examined requirements as possible, is considered to be a crutial task for choosing the rational mixer design for certain production conditions or for establishing upcoming and promising trends in the designing of new construction machines.
Existing mixer designs are very diverse [1, 3]. The most widely used are cyclic compulsory mixers, as they have proven themselves to be the most effective among the machinery for the building mixtures preparation. In its turn, among them paddle mixers and screw mixers with horizontal configuration of agitator shafts [5, 6, 7, 8] are used and investigated extensively, as well as paddle rotary mixing devices and planetary mixers - with the vertical arrangement of agitator shafts [9, 10]. Also, particular attention should be given to vertical mixers with screw elevators [11, 12], due to the fact that they have certain advantages over the aforementioned mixing plants. But it is rather difficult to determine how important the advantages of a separate type of mixer design are, how significantly they affect the final result of the work – the finished products, and how many resources have been used to achieve this result. Therefore, the issue of the cyclic compulsory mixers comparative analysis based on the efficiency of the implementation of the technological process of mixing construction mortar mixes is important and requires detailed consideration and continuous improvement to cover the maximum possible number of mixing machines varieties.
Research for this direction is known. This is an attempt to evaluate the mixers effectiveness by type, character and class of possible displacements of mixture particles [13]. This technique is approximate, with a relative comparison of mixers, and does not have quantitative mathematical justification.
The introduction of an absolute indicator for comparing the performance of specific costs per unit of finished product [14] adds objectivity to the solution of this problem. This performance indicator is the coefficient [14], which characterizes the mixer efficiency, depending on the location and geometry of its working body and blending hopper. But this technique has limited use through the description of the coefficient calculation only for machinery with the horizontal position of the agitator shaft.
Considering rapid development of technologies and machine building and the invention of new structures, it is necessary to respond appropriately to the possibilities of qualitative assessment of mixing equipment utilization efficiency. In order to achieve single-valuedness, it is important to have an indicator, or a suite of metrics that would take into account as many factors affecting the mixers efficiency as possible, would be multi-operated in their application to different types of machinery and would have a numerical quantitative assessment that is suitable for a particular comparison.
The goal of our research is to develop the general methodology that contains numerical indicators to determine the performance index of cyclic compulsory mixers used for the preparation of construction mortar mixes. Another objective of our investigation

is to carry out the analysis of the main advantages and disadvantages of different types of mortar-mixing machines.

2. The Principal Types of Building Mortar Mixers

Let's consider the working peculiarities of the most commonly used cyclic compulsory mixers. The mixers with horizontal configuration of agitator shafts (fig. 1) or with several shafts consist of a trough-like mixer hopper 1, at the butt ends of which there are manual bearing groups 2. Inside of the mixer hopper there is a shaft 3 (or several shafts), which rotates with the beaters 4 fixed on it from the mixer drive 5. Instead of beaters, it is possible to use a screw-type strap or a multiple-unit movable operating element, which has either a screw-type strap, or the beaters, as in the mixer ACG-4 (fig. 2), can also be used. Such mixers are easy maintainable and provide good mixing quality with the ability to move mortar mixes to the discharge door (dump door), have a simple design and a large variety of decisions on the manufacture of movable operating elements in order to provide the planned motion trajectories of mixture flows.



a

b

Fig. 1: The mixer RN-400 with a paddle lay shaft: a – function chart; b – physical form; 1 – blending hopper; 2 – manual bearing group; 3 – shaft; 4 – a beater; 5 – mixer drive

One of the most important shortcomings of mixers with a horizontal configuration of the shaft is the availability of sophisticated sealing glands to protect manual bearing groups. But despite the protection, the effective and useful work of shaft bearings is mainly shortlived. Thuswise, penetration of the construction mortar mixes into manual bearing groups occurs quite often, which leads to their accelerated wear and beakdown, and in some cases, causes seepage of mortar mix or water from them.

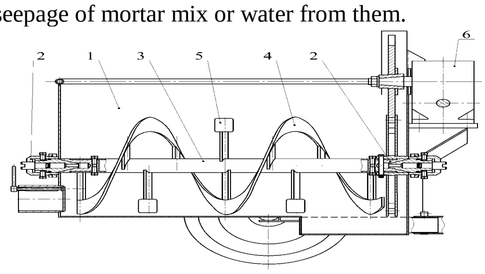


Fig. 2: The lay-shaft mixer with a screw strap and beaters ACG-4: 1 – a blending hopper; 2 – the manual bearing group; 3 – a shaft; 4 – a screw strap; 5 – a beater; 6 – a mixer drive

Vertical movable operating elements of mixers do not have this disadvantage thanks to either the knee-type (console) mounting of beaters on the rotor, or to the particular design of the lower support.

In particular, as the simplest variant, on the vertical worm shaft it is possible to use the design of the lower manual bearing group, located in the mortar mix shown in Figure 3. The worm shaft 1, using the chair 2 and the ball 3, bears on the toe end of the hopper 4 with spherical crater. Such a design allows to minify the intrusion of abrasive particles of the medium that is being mixed to the manual bearing group for a long period of service.

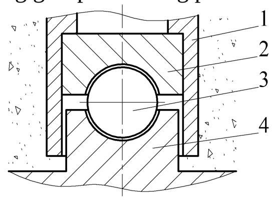
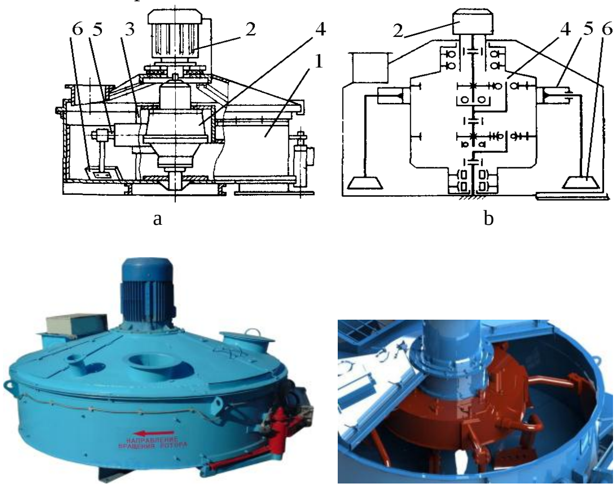


Fig. 3: The construction of the lower supporting manual bearing group in the vertical shaft with a screw: 1 – a shaft; 2 – a chair; 3 – a ball; 4 – the toe end of the hopper

Positive mixers with vertical shafts are the most omni-purpose machinery. The acceptable ratio of the mixer's empty weight to the hopper's net volume, the good quality and homogeneity of the prepared mixture, the ability to produce both easily workable mixes and slow-moving mixtures, as well as stiff forming solutions, make the mixers of this type the most common machinery for the preparation of building mortar mixes.

One of these mixers is the paddle rotary mixing device SB-146 (Fig. 4), which consists of a cylindrical mixer hopper 1, in the central part of which is the engine 2 and the cup 3. The cup is necessary only to avoid the zone of low-speed linear velocities of movable operating elements, since the beaters birl and within small radii from the axis of revolution their linear velocities will approach to zero. In order to make the best use of the created space, in this part the mixer drive elements are usually located, for example, the gearhead 4. The mixing part of the unit has several corbel pieces 5 with mixing and cleansing plates 6 mounted on them. Each beater body is executed at different length. The beaters move along the circular trajectory, moving the mortar mix into the operating area of the neighboring beater. Therefore, the solution mass flow occurs mainly in the horizontal plane, as in the vertical one the mortar mixture can only raise to the height of the beater, and it is low for these types of mixers. Accordingly, the height of filling the mixer with the mortar mix of is also low, and the mixer hopper itself in diameter is several times larger than its height. Due to this form of volumentric displacement of the mixer hopper, vertical paddle rotary mixing devices and planetary mixers are also called cup mixers.



a b

c d

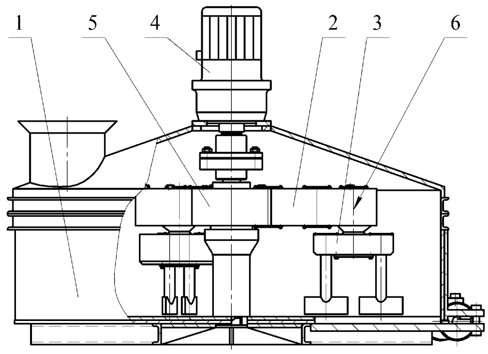
Fig. 4: Paddle rotary mixing device SB-146: a – overall view; b – function chart; c – physical form; d – mixer rotor; 1 – mixer hopper; 2 – engine; 3 – a cup; 4 – gear reducer; 5 – corbel piece; 6 – a beater

Planetary mixers also have exactly the same problem (as to small vertical component of the mixture). But planetary mixers, in comparison with rotary mixing devices, have a variety of significant and essential advantages. First and foremost, this is the ability to use in net volume the central zone, near the axis of racks rotation, providing the drive is located above the hopper. The movement of planetary beaters is complex and provides high intensity, efficiency, performance and excellent mixing quality. This is especially important for the mixing of high viscous mortar mixes, in which adhesion powers of the cement grout with the filler are greater than sticking forces, since under these conditions there is no equilibrium distribution of the cement grout on the surface of sand particles, which compromises the strength of the mortar stone. In such cases, as a rule, additional measures are required to increase the mixture homogeneity. Mixing is made in macrovolumes, and this disadvantage increases with the immobilization of construction mortar mixes mobility. One of the ways to overcome this problem is to use mixer plants where blending takes place in counter-current flows. Planetary mixers fulfill this condition.

All of this is achieved thanks to the working peculiarities of the planetary mixer. For example, the planetary mixer BP-750 (Fig. 5) has a cylindrical dished mixer hopper 1, and on hollow-bore drive rack 2 there have been installed mixing stars with beaters 3. The mixer drive, which consists of an engine 4 and gearbox 5, a mixing star with beaters 3 rotate about the movable axle 6, which, in its turn, rotates together with drive racks 2 around the axis of the mixer hopper 1. In these conditions, the rotation velocity of the star with beaters 3 is usually higher than the rotation velocity of the drive rack 2.

Planetary mixers are expensive, sophisticated and technically complicated installations. They also require good high-quality and regular service. In addition, they have an increased capacity of the drive (a 750-liter hopper mixer BP-750 requires about 18.5 kW).

The cantilever mounting of the beaters requires a solid and massive rotor design in the dish-shaped mortar mixer. For this reason and taking into account the aforementioned circumstances and considerations, taking cognizance of the need for an efficient and simultaneously inexpensive and simple construction of mixing equipment, it is important to consider the performance index and the expediency of using mortar mixers with vertical screw elevators. Such a design of the RZVSh-500 mixer (Fig. 6) was developed at Poltava National Technical Yuri Kondratyuk University. Along with this the movable operating element of such a mixer has an external screw strap with a heightwise variable moving line [12]. This is done to increase the number of directions (componental movements or submotions) of the enforcement and inducing effects on the mixture.



a

b

Fig. 5: The planetary mixer BP-750 design: a – overall view; b – physical form; 1 – mixer hopper; 2 – drive rack; 3 – mixing star with beaters; 4 – engine; 5 – gearbox; 6 – movable axle

It is known to everybody that when the mortar mix intersects with a vertical screw elevator and a screw strap, which have a moving line, perpendicular to the axis of rotation, the mixture particles are influenced to the move in the radial direction only from the axis of rotation from any height [12]. And if in the central operating area of the screw 5 (Fig. 6) it contributes to mixing, then in the outside radius zone of the mixer hopper, where the external screw strap 6 operates, this only slows down the mixing process. Since mixture particles can move radially to the axis of the mixer hopper only under the influence of gravitational forces, shifting to the center under the pressure of mixture components, which rise up the external screw strap. In this case, there is no compulsory action of the mixer’s movable operating element, which would direct the mixture particles to the axis of the hopper. Therefore, the agitation level will be relatively low.

To provide complex motion trajectories of mixture components flowing and the action of the vertical screw movable operating element, which would force the mixture to move to the axis of the mixer hopper, as well as to increase the intensity and quality of the building mortar preparation in machinery of this type; we have also changed the inclination angle of the moving line vertical external screw strap of the mortar mixer.

The mixer RZVSh-500 has a cylindrical hopper 1 (Fig. 6, a). The mixer drive 2 is above the casing and does not occupy counter space in the plan. The design of the mixer’s movable operating element has a vertical shaft 4 (Fig. 6, b) with a lower support to the manual bearing group 3 at the bottom of the hopper. The design of the manual bearing group 3 is shown separately in Fig. 3. In the center of the shaft, there is a screw 5 with the surface of an ordinary helicoid. Such a surface has a permanent moving line, perpendicular to the screw axis. On the mixer’s outside radius on corbel pieces 7 and 8 there are four screw straps 6 with moving lines that change the inclination angle heightwise in such a way that in the very bottom of the screw strap, the moving line is perpendicular to the screw axis, and with the upward movement of the screw strap, the moving line gradually increases its inclination angle up from the screw axis to the periphery in the vertical plane and reaches its crest value at the highest point. This crest value is equal to the angle α, at which the external screw straps have been installed to the horizontal plane. The changeable moving line by the height of the screw strap has been attained by executing it in the form of a flat surface. It also improves the manufacturability of producing an external screw strap, allowing it to be obtained from sheet material.

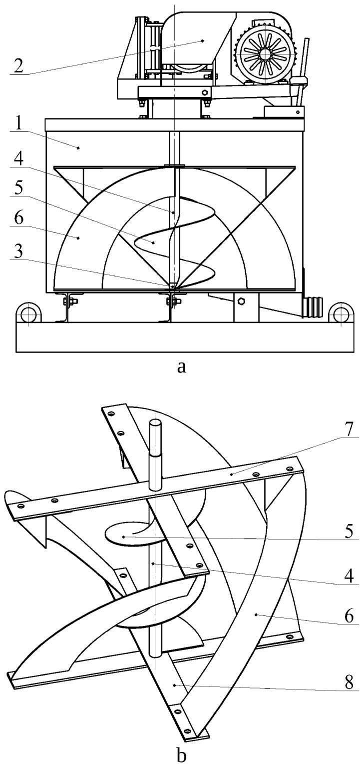


Fig. 6: The vertical screw mixer RZVSh-500 design: a – overall view; b – movable operating element of the mixer; 1 – mixer hopper; 2 – mixer drive; 3 – manual bearing group; 4 – vertical shaft; 5 – internal screw; 6 – an external screw strap; 7 – upper corbel piece; 8 – the lower corbel piece

3. Performance Indicators of Constructional Mortar Mixers

Comparison of the advantages and disadvantages of equipment is relative. In order to assess the impact of the applied construction solutions in various types of enforcement action cyclic mixers on the effectiveness of the building mortar preparation process, it is necessary to propose a general indicator that could be determined for the above-considered mixers types in the numerical value.

In this work, considering that the mixing process has a very complex physical nature, in order to determine the machinery efficiency we offer a number of indicators that should be considered on the system level. These indicators are:

1. The number of component motions of mixture particles, which arise from the forced influence of the mixer's movable operating element, N_m.
2. The ratio of the area (in terms of equipment) to its productivity, S_s.
3. The ratio of equipment mass to its productivity, m_s.
4. The efficiency coefficient of the mixer K_e, which is determined by the design parameters of the machinery.

Let us consider each of these indicators.

3.1. The Number of Mixture Particles Submotions, Which Arise from the Forced Influence of the Mixer's Movable Operating Element

As is known, the body in space (including the mixture atomic particle) has six degrees of freeness. Accordingly, there are six possible submotions that can be described by coordinate vectors: the three components v_x, v_y, v_z of the translational motion along coordinate axes and the three components v_{xy}, v_{xz}, v_{yz} of the rotational motion in coordinate planes [13].

The greatest mixing process efficiency is achieved in the mixers when all the six displacement components of the movement arise from the compulsory action of their movable operating elements on the mixture. After all, for intensive mixing, the mixture components have to be provided with such motions that their trajectories would have as many intersections and counter-current flows as possible. In practice, it is very difficult to create a mixing machine with five or six components of particles movement. But it is obvious that machines with more components, have an advantage in the efficacy. The combination of movements and movement behavior within a single component are also very important. In particular, cyclic variations in trajectories and motion speed in time contributes to the operational efficiency, which can be estimated by the method of distributing mixers into differentclasses [13]. Even so, the considered indicator is relative.

3.2. The Ratio of the Area (In Terms Of Equipment) to Its Productivity

This indicator affects the convenience of placement and transportation (mobility) of mixing machines within the boundaries of construction sites. Due to lesser specific equipment dimensions, there appear more opportunities for its use close to work places with ready-made mortar mixtures. And this contributes to increasing the efficiency of the technological processes implementation in construction, including the effectiveness of a particular mixer. The index can be defined numerically by the formula:

$$S_s = \frac{S_p}{P}, \tag{1}$$

where S_p – mixer surface area in the plan, m^2; P – mixer productivity, m^3/h.

3.3. The Ratio of Equipment Mass to Its Productivity

This indicator is important with relation to manufacturability, repairability, the mixer's manufacturing cost, affecting the shipping costs. It can be defined in the numerical expression by the formula:

$$m_s = \frac{m}{P}, \tag{2}$$

where m – mixer weight, kg; P – mixer effectiveness, m^3/h.

3.4. The Efficiency Coefficient of the Mixer K_e, Which Is Determined By the Design Parameters of the Machinery

The main factor that determines how rational the mixer design is and how efficiently it affects the workprocess is the homogeneity of the prepared mortar mixture. It can be estimated by different methods using the coefficient of mixture components density variation [1], the degree of mixture separation [15] or the boundary traction of the mixture shifting [16]. But it does not matter which technique would be used, as a part of the studies [1, 15, 16] it was established that the regularities of mixture formation in the process of constructional material preparation are subject to the exponential dependence. Such a dependence, par example, for the degree of mixture separation, S, can be written as follows:

$$S = S_{nom} + \left(S_{\max} - S_{nom}\right) \cdot e^{-K \cdot t}, \tag{3}$$

where S_{nom} is the bogey (nominal) value of separation degree, which corresponds to the fully ready-mix mortar; S_{max} – is the crest value of the degree of mixture separation, which corresponds to the mixing process beginning; K – is the coefficient which is at the same time the value that, in an integrated manner, characterizes the mixing process and depends on design factors and process parameters of the mixer and the type and condition (rheological properties) of the materials being mixed; t – is mixing time, s.

Depending on (3), the coefficient K is the complex value, so it requires separation into components, so as to take into account separately the impact on the mixing process efficiency on the part of the properties of the mixture and the mixer. Then we will get the following:

$$K = K_{rf} \cdot K_{ce}, \quad (4)$$

where K_{rf} – is the coefficient that takes into account the influence on the process of mixing the rheological properties of the materials being mixed; K_{ce} – is the efficiency coefficient of the mixer, which is determined by the design parameters of the machinery.

We propose to consider the K_{ce} indicator as the performance factor of the construction mixers design. And it is very important to develop the general methodology of its determination for different types of mud mixing equipment. To do this, you need to find out what the mixing conditions are, which work process requirements need to be provided, and what design features of the mixers qualitatively implement these requirements.

The qualitative process of homogenizing the building mortar must contain two types of physical transformations that occur in the mixture [17]. First, it is the ensuring of the maximum possible separation of the mass of all components into separate grains and drops to achieve their equilibrium distribution in the smallest individual parts of the total mixture volume. That is the implementation of micromixing. Secondly, it is providing the moving and replacing of relatively large mixture volumes within the mixer hopper. It must be accompanied by the change in the trajectory and the traverse speed of these volumes, the change in their position so that they would fall into different zones in relation to the influence of the mixing device's movable operating element (lifting or lowering of the mixture, dropping it outwards or into the center). That is, the implementation of macromixing. On completing the mixing, there will originate the symmetrical structure of the mixture with homogeneous distribution throughout its volume of grains of the binding components (cement, lime), filler components (sand) and water.

In connection with this, the efficiency coefficient of the mixer, K_{ce}, will be determined by multiplying two quantities. One of them will take into account the micro-mixing factor, in the form of the activity factor of the cutting action on the mixture, K_{ce1}, and the other will make allowance for macromixing – the activity factor of the mixture mass transferal, K_{ce2}:

$$K_{ce} = K_{ce1} \cdot K_{ce2}. \quad (5)$$

Micromixing requires constant cutting action that occurs on the edges of steel plate elements along the side surfaces of the beaters and screw straps. The larger the total length along the perimeter of the cutting lines l_{cut} is, the more preconditions for the components qualitative separation appear. If you want to estimate the degree of impact of the mixer's movable operating element on micromixing process to the best advantage, you should take along with l_{cut} to the total mixer volume for the loading of components, V_{com}, the value of the cutting surface area per unit time, S_{cut}, which is formed by the mixer's movable operating element during its movement along the lateral faces (side surfaces).

For the micromixing factor, the activity factor of the cutting action on the mixture will look like:

$$K_{ce1} = \frac{l_{cut} \cdot S_{cut}}{V_{com}}. \quad (6)$$

As for the K_{ce} indicator, it is necessary to reflect the degree of impact of the mixer's movable operating element on the macromixing process. We offer to evaluate it by the ratio of the total volume through which the units of the mixer's movable operating element per unit time, V_{wb}, to the total mixer volume for the loading of components, V_{com}. Then the activity factor of mixture masses transferal will be:

$$K_{ce2} = \frac{V_{wb}}{V_{com}}. \quad (7)$$

After all, the greater part of the mixer hopper volume will be subjected to coercive action, the more preconditions to qualitative mixing arise. In such a way, we will be able to take into account the influence of the geometrical dimension of beaters and screw straps of the mixer's movable operating element, their number and location relative to the rotation axis, the rotary velocity of the mixer's movable operating element.

If we consider movable operating elements of various types of mixers, one can distinguish separate excitation bands of the building mortar mixture that are of different nature. For example, for a mixer ACG-4: the beaters coverage, the screw strap coverage, the zone of mixture streams meeting which is free of direct influence of the mixer's movable operating element (Fig. 2). In order to take into account the displacement of the mixture between the zones of different influence, it is necessary to add to the K_{ce2} index a mathematical expression that describes the intensity of this phenomenon. When the angle of inclination α of the beaters or of a screw strap to its velocity vector (Fig. 7) is formed, there are preconditions for the mixture displacement. It is also evident that the limit value of the angle $\alpha = 0°$, together with the inevitable decrease of V_{wb}, makes this process impossible. The mixture will not move along the velocity vector of the part of the mixer's movable operating element. This can be described by the derivation of the mathematical expression (7) with $\sin\alpha$, which in such conditions will become zero, and in the opposite boundary value of the angle $\alpha = 90°$ $\sin\alpha$ will be the unity element that corresponds to the nature of the impact. Also, when $\alpha = 90°$ it is possible to suggest a model, when the movement will be only in the direction of motion, and there will be no movement to the side. Similarly, this can be described by the development of a mathematical expression (7) from $\cos\alpha$, which will become zero under such conditions. But it should be noted that, at a perpendicular position to the velocity vector, the mixture compression zone will appear [9] (Fig. 7, b) before the division of the mixer's movable operating element. Therefore, the effect will be equivalent, as at an angle of inclination $\alpha = 90° - \eta$. The angle η in this case is the angle of the mixture internal friction [7]. Then, with a sufficient echelon of accuracy, we can write the expression (7) in the following form:

$$K_{ce2} = \frac{V_{wb}}{V_{com}} \cdot \sin\alpha \cdot \left[\cos\left(\frac{\pi}{2} - \eta\right) + \cos\alpha\right]. \quad (8)$$

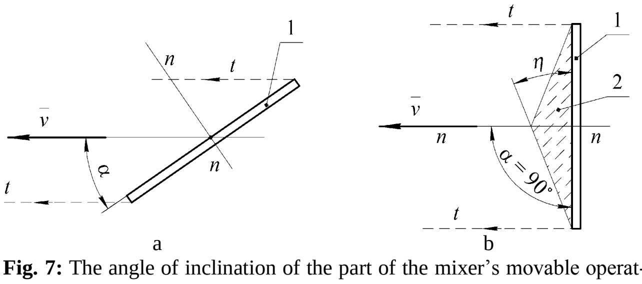


Fig. 7: The angle of inclination of the part of the mixer's movable operating element α: a – intermediate value of the angle α; b – limiting value of the angle $\alpha = 90°$; 1 – part of the mixer's movable operating element; 2 – the mixture compression zone; v – traverse speed vector; t-t – tangential component of the moving direction; n-n – surface normal of the part of the mixer's movable operating element; η – angle of the mixture internal friction

In view of the formation of the mixture compaction zones in front of the beaters and screw straps, where the motion of mixture components is naturally slowing down, we note that the coefficient K_{ce2} has a limit on the upper boundary that requires separate research and depends on the properties of the mixed medium.

Finally, we obtain an expression for determining the coefficient of the mixer's performance according to the design factors in the following form:

$$K_{ce} = \frac{l_{cut} \cdot S_{cut}}{V_{com}} \cdot \frac{V_{wb}}{V_{com}} \cdot \sin\alpha \cdot \left[\cos\left(\frac{\pi}{2} - \eta\right) + \cos\alpha\right], \quad (9)$$

or

$$K_{ce} = \frac{l_{cut} \cdot S_{cut} \cdot V_{wb} \cdot \sin\alpha \cdot \left[\cos\left(\frac{\pi}{2} - \eta\right) + \cos\alpha\right]}{V_{com}^2}. \quad (10)$$

For the complete characterization of the mixing process by the dependence (3), the K_{rf} coefficient, which takes into account the influence of rheological properties of the mixed materials on the mixing process, has to be determined experimentally. For homogeneous mixtures, it will have the same values.

Consequently, according to the expression (10), a numerical indicator of running efficiency of various types of mixers can be determined at equal initial conditions, depending on their design factors. The formulas for calculating the values of l_{cut}, S_{cut}, V_{wb}, are not the same for different types of mixers and depend on geometric characteristics of the movable operating element and the mixer hopper. Therefore, they have to be calculated separately for each type of machinery.

3.5. Generalization of Building Mixers' Performance Indicators

The obtained results of the building mixers' performance indicators and their main performance specifications are given in Table 1. With the help of these data it is possible to carry out the comparative characteristic of the equipment and to select the machines that may be used most effectively for the particular production conditions.

For planetary machines, the mathematical calculation of the mixer's running efficiency according to the design factors, K_{ce}, is very complicated. In addition, there is no special need in it, as the specific character of the operation of this mixer type enables to conclude that the coefficient K_{ce} value for it will be significantly higher than the value of the same coefficient for other types of machinery. This is also confirmed by the fact that the length of the building mortar preparation period for planetary mixers according to the design factors is significantly lower (Table 1).

Table 1: Performance spesifications and performance indicators of various cyclic compulsory mixers

Mixer trademark	RN-400	ACG-4	SB-146	BP-750	RZVSh-500
Characteristics of the design	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Total volume of the mixer for loading components, V_{com} , m^3	0.40	0.43	0.75	0.75	0.50
Technical effectiveness, P, m^3/h	7.5	8.5	21.0	27.0	12.0
Rotary velocity of the movable operating element, n , r/min	35	38	26	24	24
Mixing time (to readiness), t_{pr} , s	105–120	95–110	60–75	40–50	75–90
Engine capacity, P_{eng} , kW	3.0	2.2	18.5	18.5	7.5
Dimensional specifications, mm, length, width, height	1850 900 1350	1450 1215 1130	2500 2325 1760	2760 2320 1860	1360 1116 1595
Net weight, m , kg	410	380	2750	2500	395
Area in plan, S_p , m^2	1.67	1.76	5.81	6.40	1.52
Number of components of the mixture particles motion, N_m	2 (v_x, v_{yz})	2 (v_x, v_{yz})	3 (v_x, v_z, v_{xy})	3 (v_x, v_z, v_{xy})	3 (v_x, v_z, v_{xy})
Ratio of area in plan to the effectiveness, S_s, $\frac{m^2}{m^3/h}$	0.223	0.207	0.277	0.237	0.127
Ration of net weight to the effectiveness, m_s, $\frac{kg}{m^3/h}$	55	45	131	93	33
The activity factor of the cutting action on the mixture, K_{ce1}	56.555	70.854	36.240	–	25.264
The activity factor of the mixture mass transferal, K_{ce2}	0.120	0.109	0.346	–	0.431
The coefficient of the mixer's running efficiency according to design factors, K_{ce}	6.802	7.748	12.527	–	10.954

For planetary machines, the mathematical calculation of the mixer's running efficiency according to the design factors, K_{ce}, is very complicated. In addition, there is no special need in it, as the specific character of the operation of this mixer type enables to conclude that the coefficient K_{ce} value for it will be significantly higher than the value of the same coefficient for other types of machinery. This is also confirmed by the fact that the length of the building mortar preparation period for planetary mixers according to the design factors is significantly lower (Table 1).

Consequently, planetary mixers are the most effective machines in terms of impact on the mixture and the final quality of the finished products. But, along with this, they need increased drive power, have high cost, complicated and elaborate design, demanding of high-quality good service and scheduled engineering maintenance, larger ratio values of net weight and area in plan to the performance. Therefore, the utilization efficiency will be confirmed only in case when high requirements are set for the quality of the prepared construction mortar mixture. This suggests that the assessment of utilization efficiency of mixing equipment should be carried out exclusively on the indicators system. Moreover, the influence degree of each of them will be determined depending on the requirements for the technological process at the construction site.

In addition to planetary mixers, mixers with the constructive design, similar to the models RN-400, SB-146 are dominant in the market of construction machines. By performance coefficient, K_{ce}, the SB-146 model has shown itself better. But, taking into consideration such indicators as the simplicity of design, reliability of manual bearing groups, relatively small specific area in plan, low metal intensity, attention should be paid to the development of machinery with a vertical screw shaft and screw straps. Due to their high running efficiency, they have preconditions for low production costs.

4. Conclusion

The proposed methodology for the performance evaluation of cyclic compulsory mixers contains a number of numerical indicators that enable to perform an objective comparison of differently designed machinery. Some indicators, namely: the number of components of the mixture particles motion, which arise from the constrained impact of the mixer's movable operating element, N_m; ratio of area in plan, S_s, and net weight, m_s, equipment to its productivity; were known earlier. They are proposed to be used within the system together with the new indicator – the efficiency coefficient of the mixer's K_{ce} work operation, which depends on design factors of machinery. The method of its definition has been developed in this paper. Taking into account the application of this technique to existing mixer models (Table 1), it can be concluded that the assumptions regarding the impact, exerted by design factors of their movable operating elements on the running efficiency is legitimate. Because the calculation data K_{ce} are consistent with the time for the building mortar mixture preparation according to mixers' performance specifications, which was obtained during the production tests of these machines.

By operating the K_{ce} indicator, it is possible to investigate and improve the existing mixer designs, finding the ways to increase their efficiency. It should also be noted, however, that the proposed methodology for evaluating efficiency yields qualitative results when the mixer's movable operating element carries out a simple motion, that is rotation about the horizontal or the vertical axis.

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