Calculation of energy parameters of fixed drum concrete mixer with helicoid-type blades

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Abstract. Currently, one of the most important areas in the construction industry is the production of high-quality concrete and construction mixes used in the manufacture of reinforced concrete products and structures, road, foundation, monolithic works, as well as used in the laying of bricks, blocks, etc. Concrete mixes are able to ensure high quality of the resulting products and structures when solidified. The scope of their use is the most extensive of all building materials, and production volumes are among the largest. The practice of using concrete in world and domestic construction has shown that it is effective, i.e. it has a number of advantages over new types of building materials, provides high productivity during construction work, is universal and easy to obtain. Initial components for the production of concrete are very common, easily accessible and transportable over long distances, which allows for the production of concrete mix in remote locations using mobile plants. To date, the enterprises of building industry is the production of equipment of various designs and principles of operation used for mixing. In the construction industry, a variety of mixing machines with both advantages and disadvantages have been used in the production of concrete mixes.

1. Introduction

Every year, the volume of production of concrete and construction mixes, as well as the requirements for them, increases. Recently, both in Russia and in other countries [1], various promising developments of mixing equipment used in the production of concrete and construction mixtures have found their application. In modern economic conditions, the issue of efficiency of technological equipment for producing concrete and building mixes, reducing the energy intensity of production, as well as improving the technological properties of finished concrete is very important. The result of the analysis of long-term theoretical and experimental studies has shown that it is possible to increase the efficiency of mixing equipment and increase the uniformity of the resulting construction mixes, while reducing energy consumption and technical and economic costs, due to the rational mode of loading large aggregate into the mixer and creating an intensive circulation of the mixed components under the influence of the blade device. At the present stage of development of construction materials production, when solving problems to improve the mixing efficiency, it is necessary to take into account the properties and behavior of the components to be mixed, as well as to apply modeling of processes occurring in the mixer. To date, the enterprises of building industry is the production of equipment of various designs and principles of operation used for mixing. In the construction industry,
a variety of mixing machines with both advantages and disadvantages have been used in the production of concrete mixes. Despite the large number and variety of different designs of mixers used in the production of concrete mixes, still the most common in enterprises are fixed drum mixers with a vertical rotor. The existing mixing equipment of foreign and national manufacturers does not meet the increasing requirements for improving the uniformity of concrete and construction mixes and, consequently, the quality of finished concrete. Mixers that have become widespread in the construction industry have low energy efficiency, a long mixing time and do not provide the required level of quality of the finished product in the modern world. Various methods of intensification used in existing mixers can improve the quality of the finished concrete mix, but at the same time complicate the design of the equipment, reduce its reliability and increase the level of energy consumption. [1, 2, 3].

2. Materials and methods
Analysis of fixed drum rotary mixers for concrete production, as well as their technological and design parameters showed that increasing the efficiency of the mixing process of the initial components can be achieved by improving the design of the mixing apparatus of the machine (blades) and increasing the efficiency of the loading process of the initial components [4, 5, 9, 10, 11, 12].

In order to increase the efficiency of the mixing process, which consists in reducing energy consumption and improving the quality of the finished concrete (strength, uniformity, etc.), the design of a fixed drum rotary mixer with a modified shape of the mixing device blades is proposed.

![Concrete mixer diagram](image)

**Figure 1.** Concrete mixer:
1 - case; 2 - mixing bowl; 3 - boot device; 4 - electric motor; 5 - reducer; 6 - vertical shaft; 7 - bracket; 8 - rotary sprocket; 9 - blade; 10 - slide gate of the unloading device.

In a mixing bowl 2 console, in the bearing assembly, a vertical shaft 6 is mounted. On it there is a rotary sprocket 8, on which, with the help of adjustable brackets 7, the blades of the helicoid type 9 are fixed. The blades have a curved surface, which when moving in the mass of the blend components allows to give the motion of the particles of materials (gravel, sand, cement and water) a spiral trajectory [3, 4]. The angle of the blades varies from 23° to 69°. To load the initial components, a loading device 3 is installed on the mixing bowl. The device is attached to the cover on guides that allow changing the loading location of the source components. In the lower part of the mixing bowl for unloading the finished concrete mix, there is a discharge hatch, which is closed by a slide gate 10.
The concrete mixer (figure 1) works as follows: the initial components are fed through the loading device 3 installed on the lid of the mixing bowl 2 and get inside the installation, where they fall down under the influence of gravity and accumulate on the bottom of the mixing bowl.

![Concrete Mixer Diagram](image)

Figure 2. Concrete mixer mixer: 1, 2, 3, 4, 5, 6 – mixing blades of the helicoid type.

After the end of loading the initial components into the bowl, an electric motor 4 is turned on, which, through a belt transmission, transmits torque to the gearbox 5, which rotates the vertical shaft 6 with a rotary sprocket 8, brackets 7 fixed to it and blades of the helicoid type 9. As a result of rotation of the vertical shaft 6, the blades 9 act on the mixed components, giving them a helical trajectory in the vertical plane, and lift solid and dense particles from the bottom of the mixing bowl. As the blades are installed at different angles to their trajectory, the components to be mixed start moving not only in the vertical plane, but also in the horizontal plane, providing radial-axial circulation from the outer wall of the mixing bowl and back. This allows intensifying the mixing process when getting the finished concrete mix.

Thus, the developed design of the fixed drum rotary mixer will improve the quality of the resulting concrete and construction mixes by giving the mixed components multiple convective trajectories of material particles that intensify mixing of the mixture components in both horizontal and vertical planes inside the mixing bowl of the installation [6, 7, 8].

To determine the power of the mixer, we use the dependency:

$$ N_0 = N_{\text{тр}} + N_{\text{тр}} + N_{\text{тр}}W. $$ (1)

We calculate the power value $N_{\text{тр}}$, which must be spent on overcoming the friction force when the concrete mixture moves along the helicoid surface of the $i$ blade:

$$ N_{i,\text{тр}} = A_{i,\text{тр}} \cdot \omega_i W. $$ (2)

There $A_{i,\text{тр}}$ the amount of work spent on overcoming the friction force when moving along the helicoid surface of the $i$-th blade. The value of this work is determined by the following ratio:
\[
A_{i,\text{TP}} = \int_{0}^{\pi - \varphi_k} \cdot F_{i,\text{TP}} \cdot dl, \quad (3)
\]

where \( dl \) - element of length equal to:

\[
dl = R_0 \cdot d\varphi. \quad (4)
\]

The value of the friction force is determined by the ratio:

\[
F_{i,\text{TP}} = P_i \cdot f, \quad (5)
\]

where \( f \) – coefficient of friction of the concrete mix on the surface of the blade; \( P_i \) – the value of the normal pressure force on the surface of the \( i \)-th blade, equal to:

\[
P_i = f_{ul} + P_a(\varphi), \quad (6)
\]

\[
P_i = M \cdot \omega_i^2 \cdot R_0 + M \cdot g \cdot \cos \varphi, \quad (7)
\]

Substituting (7) in (5) gives the following expression for the friction force:

\[
F_{i,\text{TP}} = f \cdot M \cdot \left( \omega_i^2 \cdot R_0 + g \cdot \cos \varphi \right), N, \quad (8)
\]

then:

\[
N_{i,\text{TP}} = f \cdot M \cdot R_0 \cdot \omega_i \cdot \left[ \omega_i^2 \cdot R_0(\pi - \varphi_k) + g \cdot \sin \varphi_k \right], W. \quad (9)
\]

Based on the ratio (9), we find that the amount of power spent on overcoming the friction force of the mixture on the helicoid surface of all the mixer blades will be determined by the ratio of the form:

\[
N_{\text{TP}} = \sum_{i=1}^{z} N_{i,\text{TP}}, \quad (10)
\]

where \( z \) – number of mixer blades.

Substituting (9) into formula (10) allows getting the following results:

\[
N_{\text{TP}} = f \cdot \gamma \cdot R_0^3 \cdot l \left( \pi - \arccos \frac{H_0 \cdot \psi - R_0}{R_0} \right) \cdot \frac{\pi}{S} \cdot \Omega \cdot \\
\sum_{i=1}^{z} R_i \left[ \frac{4 \cdot \pi^2 \cdot R_i^2 \cdot \Omega^2 \cdot R_0 \cdot \left( \pi - \arccos \frac{H_0 \cdot \psi - R_0}{R_0} \right)}{S^2} + \\
g \cdot \sqrt{1 - \left( \frac{H_0 \cdot \psi - R_0}{R_0} \right)^2} \right], W. \quad (11)
\]

Thus, the obtained ratio (11) shows the amount of power spent on overcoming the friction force of the concrete mixture on the surface of all the mixer blades (figure 3), taking into account their length and the speed of rotation of the rotor.
Figure 3. The graph of the dependence of the power $N_{TP}$, which must be spent on overcoming the friction force when the concrete mixture moves along the surface of the blade on the blade length $l$ and the rotor speed $n$.

3. Results

The analysis of the obtained dependence showed that when the rotor speed increases by 1.7 times, the power spent on overcoming the friction force when using blades of the minimum length (0.14 m) increases by 2.6 times. And when using blades of the maximum length (0.18 m) increases by 2.4 times, which is 1.27 times less than when using blades of the minimum length at the maximum speed of the rotor, and for the minimum frequency by 1.4 times.

To calculate the amount of power spent on bringing the concrete mixture into rotational motion on the surface of the $i$-th blade, we use the following ratio:

$$N_{i, BP} = T_i \cdot \omega_i, W,$$

where $T_i$ – kinetic energy of rotational motion, the value of which is equal to:

$$T_i = \frac{m \cdot U_i^2}{2}, J,$$

here $U_i$ - the speed modulus, the value of which is determined by the formula.

The total power spent on bringing the concrete mixture into rotational motion along the helicoid surfaces of all the blades will be determined by the ratio:

$$N_{BP} = \sum_{i=1}^{z} N_{i, BP},$$

Converting expression (14) results in the following:

$$N_{BP} = \frac{4 \cdot \pi^4 \cdot R_0^4 \cdot l \cdot \gamma \cdot \Omega^5}{S^3} \left[ 1 + \left( \frac{S}{2 \cdot \pi \cdot R_0} \right)^2 \right] \sum_{i=1}^{z} R_i^3, W.$$

The resulting ratio (15) determines the power spent on bringing the concrete mixture into rotational motion on the surfaces of all the blades, depending on the design and technological parameters. The analysis of the obtained dependence (figure 4) showed that with an increase in the rotor speed from 0.32 s$^{-1}$ to 0.55 s$^{-1}$, the power spent on bringing the mixture into rotational motion will increase by 1.2 times when using blades with a length of 0.14 m compared to blades with a length of 0.18 m.
Figure 4. The graph of the dependence of the power spent on bringing the mixture into rotational motion $N_{wp}$ on the length of the blade $l$ and the rotor speed $n$.

The amount of power spent on overcoming the shear resistance of the $i$-th blade of the mixer will be equal to:

$$N_{c,i} = A_i \cdot \Omega, W,$$  \hspace{1cm} (16)

$$N_{c,i} = 2 \cdot \pi \cdot \tau \cdot l \cdot \Omega \cdot (2R_{k,i} + l) \cdot R_i, W.$$  \hspace{1cm} (17)

Based on (17), the total amount of power spent on overcoming the shear resistance of all blades is determined by:

$$N_c = \sum_{i=1}^{n_0} N_{c,i},$$  \hspace{1cm} (18)

Substituting (17) in (18) we finally can get the following expression:

$$N_c = 2 \cdot \pi^2 \cdot \tau \cdot l \cdot \Omega \cdot \sum_{i=1}^{n_0} (2R_{k,i} + l) \cdot R_i, W.$$  \hspace{1cm} (19)

Figure 5. The graph of the dependence of the power $N_c$, spent on overcoming the force of resistance to shear of the material along the lateral edges of the blade on the blade length $l$ and the rotor speed $n$.

Analyzing the dependence of the power consumed by the mixer (figure 5) to overcome the shear resistance of the material along the side faces of the blade on the blade length and rotor speed, it can be concluded that when the rotor speed increases from 0.32 s\(^{-1}\) to 0.55 s\(^{-1}\) when using blades with a length of 0.14 m, the power increases by 1.7 times, reaching 1.85 kW, and by 1.7 times reaching 1.4
kW when using blades with a length of 0.18 m, which is 1.3 times less than with blades with a length of 0.14 m.

![Graph showing the dependence of the total power on the blade length and rotor speed.](image)

**Figure 6.** The graph of the dependence of the total power \( N_0 \) on the blade on the blade length \( l \) and rotor speed \( n \).

Analysis of formula (1) allows concluding that the first two terms are proportional to the mixer speed \( n \) in the third power, and the last one is directly proportional to \( n \).

4. **Discussion**
The obtained dependence (1) allows determining the total power consumed by the mixer depending on its technological and design parameters. Analysis of the dependence of the total power consumed by the rotary mixer when changing the values of the rotor speed and the length of the used blades showed that:
- the minimum power value of 850 W is achieved when using blades with a length of 0.18 m and a rotor speed 0.32 s\(^{-1}\);
- the maximum power value of 1.86 kW is achieved when using blades with a length of 0.14 m and a speed of the rotor rotation 0.55 s\(^{-1}\);
- at increasing the length of the blades by 1.2 times consumption of the mixer capacity reduced by 1.3 times, while increasing the rotor speed by 1.7 times consumed by the mixer capacity increased by 1.8 times.

5. **Summary**
Thus, a ratio is obtained that allows determining the total power consumed by the mixer depending on its technological and design parameters. Its analysis shows that:
- the maximum power value of 1.86 kW is achieved when using blades with a length of 0.14 m and a speed of the rotor rotation 0.55 s\(^{-1}\);
- the minimum power value of 0.85 kW is achieved when using blades with a length of 0.18 m and a rotor speed 0.32 s\(^{-1}\);
- at increasing the length of the blades by 1.2 times consumption of the mixer capacity reduced by 1.3 times, while increasing the rotor speed by 1.7 times consumed by the mixer capacity increased by 1.8 times.

6. **References**
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