Mathematical Modeling of the Kinematic Scheme Planetary Mixer Mechanism

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Abstract: Planetary mixer is presented, which uses drive mechanisms for the working bodies of the mortar mass mixture of a construction mortar mixer. The main objective of the study is to create a mathematical model in the mortar mixer mechanism of three different types of trajectory of the working blades with epicycloidal, hypocycloidal and vertical-circular lift of the mortar mixture from the bottom of the bowl to the upper level. To achieve this goal, a rotary screw auger is used for circulation with a central circular screw movement of the mortar mass mixture, which provides a vertical lift of the mixture mass for further mixing of the solution. The parametric equation of the screw conoid blade surface is obtained by an analytical method, and parametric equations of the epicyclic and hypocyclic motion of satellites in the planetary mechanism are determined. Methods: the article proposes theoretical developments of the device of planetary and rotary mechanisms, which were carried out according to the methodology of the main provisions of the theory of mechanisms and machines as applied to the technological processes of construction machines. The work is performed on the section of kinematic analysis of planetary mechanisms with determination of angular velocities of input and output links. Practical significance: providing multiple circulation of the solution mixture mass through planetary working blades and screw auger of several zones of different three types of trajectory of movement of mechanism links allowing intensive mixing of the mortar mixer. The discussion provides recommendations for further improvement of the developed planetary mixing mechanism.

1 INTRODUCTION

The study [1] presents the application of a mechanism for driving spindles in a cotton-picking machine using belt drives. Work on providing a compact design of devices mechanisms is given by Russian researchers [2], [3] in the food industry. Also in devices mechanisms drive transmissions of links are used for work on treatment facilities and reservoirs [4], [5], as well as in ventilation of wastewater treatment [6]. In works [7], [8] a structural synthesis and geometric analysis of planetary mechanisms of intermittent motion with elliptical wheels, as well as their kinematic motion are given. Kinematic research on the trajectory of motion of planetary mechanism satellites is given in works [9], [10]. In work [11] a planetary mechanism is investigated, where the satellites impart the required spatial movements to the working element simultaneously rotating around their axis and making a translational motion around the central sun wheel. The paper [12] presents experimental data on measuring the torque in a planetary gear, where the braking torques were measured on a setup with an input shaft speed n in the range from 1000 to 2800 rpm. The paper [13] presents the design of a composite link of a planetary gear transmission, where worn satellites can be easily replaced during operation. The paper [14] examines the design of a gearbox, where the gear ratio of a reducer is given at the maximum value of the gear ratio for each stage of a gear pair, and the gear ratio of a two-stage planetary type transmission was also investigated.

The paper [15] analyzes a planetary gearbox, in which the researcher determined that a planetary gear reduces the power consumption of a mechanism with respect to simple gears, and the properties of the lubricant in a planetary gearbox were also studied. The work [16] presents studies of a planetary mechanism of a state from two kinematic cycles, where opposite movements of the satellites of the epicyclic and hypocyclic trajectory of motion are performed, in which it is envisaged to use braking devices and synchronizers in the transition zones between two toothed segments for the smooth entry of the gear into the toothed engagement.

2 RESULTS AND THEIR DISCUSSION

The mixing device of the mortar mixer has a combination of two designs: a simple one - a rotary screw and a spatial one - a planetary mechanism. This device is called an epi-hypocyclic planetary mechanism with a rotary screw for driving the working bodies of the mixer blades of the mortar mixer. These two mechanisms perform two different functions: the radially located epi-hypocyclic working blades of the planetary mechanism mix and stir the masses of the mortar mixture, and the rotary screw vertically lifts this mortar mixture from the bottom of the tank to the upper level of the bowl. The planetary mechanism for driving the rotary screw and working blades (Fig. 1a) has peripherally located epi-hypocyclic working blades, and a rotary screw 9 is installed in the center of the mechanism.

When the planetary mixing mechanism is in operation, the rotors of the electric motor rotate with an angular velocity ω_p clockwise, then the paired gears 2 and 4 rotate with an angular velocity ω_2 (ω_4) counterclockwise, wherein gear 4 causes the rotation of the carrier 10 (N) ω_n clockwise, and gears 7 and 8 of the satellites, touching in engagement with the fixed central gear wheel 6, also perform movements, only with opposite directions of rotation, for example, gear 7 of the satellite, touching the external gear engagement of the central wheel 6, performs movement with an angular velocity ω7 counterclockwise, there is movement with an epicyclic trajectory, and gear 8 of the satellite performs movements with an angular velocity ω8 clockwise with a hypocyclic trajectory of movement. Simultaneously with the planetary gear carrier 10(H), the gear 2 causes the toothed wheel 3 to rotate, which exceeds the angular velocity of the carrier 4 and rotates the rotary screw 9 with an angular velocity ω_{sh} counterclockwise in the center of the mixer tank (bowl) with a helical trajectory of the circumference of the screw diameter. The technological process of preparing the solution mixture in the tank 11 (bowl) of the mixer occurs as follows: the rotation of the shafts of the carrier 10 (N) and the rotary screw 9 occurs simultaneously from the electric motor 1 through the paired installed gears 2 and 4 and the toothed wheels 3 and 5, as a result of which the blades 12 and 13 of the satellites perform opposite planetary movements - an epicycloidal and hypocycloidal trajectory around the carrier 6 along the periphery of the tank, and in the center of the installed rotary screw 9, due to the high angular velocity ωm of rotation, a turbulent rotation of the screw surface of the screw occurs, providing a vertical rise of the solution mixture from the lower part of the tank to the upper level of the mortar mixer, then with sufficient pressure created by the screw 9, the mass of the solution mixture rises up along the center of the tank and under the action of centrifugal force, the solution moves to the peripherally located blades 13 and 12. Here, there is an intensive movement of the mixture mass between two opposite rotating blades 13 and 12 of the satellites. Then, the solution mixture, due to its own weight, falls down to the bottom of the tank and gets to the rotary screw auger 9 and the technological process of the cycle, mixing the solution mixture, is repeated, which ensures multiple circulation through the zones of rotary and planetary intensive mixing of the solution mixture.

For continuous vertical lifting and mixing of the mass of the solution mixture, the drive of the mixer mechanism transmission is made with increased parameters of the angular speeds ω_m of the screw rotor auger 9 relative to the speed parameters of the planetary mechanism carrier 10(N). Therefore, the drive of the transmission of the toothed engagements of the rotary screw auger 9 and the carrier 10(N) is transmitted separately through gear wheels 2-3 and 4-5 with different gear ratios – $U_{sh} < U_n$, where U_{sh} is the gear ratio of the rotary auger 9, $U_n = Z_3/Z_2 = 2…3.15$; here Z_2 is the number of teeth of the drive gear 2; Z_3 is the number of teeth of the driven wheel 3, and U_n is the gear ratio of the carrier 10(N), $U_n = Z_5/Z_4 = 4…6.3$. Then the angular velocity ω_{sh} of the rotary screw 9 will be greater than the angular velocity ω_n of the planetary mechanism carrier 10(H) – $\omega_{sh} > \omega_n$.

To determine the trajectories of movement of various points of the satellites of the epi-hypocyclic planetary mechanism in Figure 2, the following radii are designated: R_{N8} - the radius of the axis of rotation of the satellite 8 installed on the planet carrier for the inner central wheel; R_{N7} - the radius of the axis of rotation of the satellite 7 installed on the driver for the outer central wheel; R''_{K6} - radius of the central wheel 6 with internal gearing; R''_{K6} - radius of the central wheel 6 with external engagement; r7 - radius of the point M_1 satellite 7 for external engagement of wheel 6 from its center of rotation axis and $r8$ - respectively the radius of the point M_2 satellite 8 for internal engagement of the wheel from its center of rotation axis. We will also designate the rotation angles: φ_H - for the driver H internal and externally located satellites 7 and 8, $\varphi 7$ - for satellite 7; $\varphi 8$ - for satellite 8.

Let us design the corresponding radii and angles of rotation of the mechanism links on the selected coordinate axes *YOX*. Then, at the initial moment of time, the points of the satellites of the internal 7 and external 8 positions M_1 And M_2 planetary gears are located on the axes *OY* And *OX*. In this movement, the instantaneous center of rotation of the satellites 7 and 8 always lies on the fixed central wheel 6, with which it is in gear engagement. To determine the trajectory of any point M_1 And M_2 satellites, we find the coordinates $M_1(x_1, y_1)$ And $M_2(x_2, y_2)$ these points for the moment of time when the driver H will start to turn at a certain angle φ_H.

The parametric equation of motion of the tooth point of satellites 7 and 8 in the planetary mechanism will be:

- for epicyclic movement of the point of the tooth of the satellite 7

$$\begin{cases} X = R_{H7} \cdot sin\,\phi_H - r_7 \cdot sin(\phi_7 + \phi_H) \\ Y = R_{H7}\, cos\,\phi_H - r_7 \cdot cos(\phi_7 + \phi_H) \end{cases}, \quad (1)$$

where R_{H7} – radius of the planetary gear carrier located at the centers of the satellite axis 7, mm; φ_H – angle of rotation of the planetary gear carrier, rad; r_7 – satellite radius 7 mm; φ_7 – angle of rotation of satellite 7, rad.

- for hypocyclic motion of satellite 8

$$\begin{cases} X = R_{H8} \cdot sin\,\phi_H - r_8 \cdot sin(\phi_8 + \phi_H) \\ Y = R_{H8}\, cos\,\phi_H - r_8 \cdot cos(\phi_8 + \phi_H) \end{cases}, \quad (2)$$

where R_{H8} – radius of the planetary gear carrier located at the centers of the satellite axis 8, mm; φ_H – angle of rotation of the planetary gear carrier, rad; r_8 – satellite radius 8 mm; φ_8 – angle of rotation of the satellite 8, rad.

(a) (b)

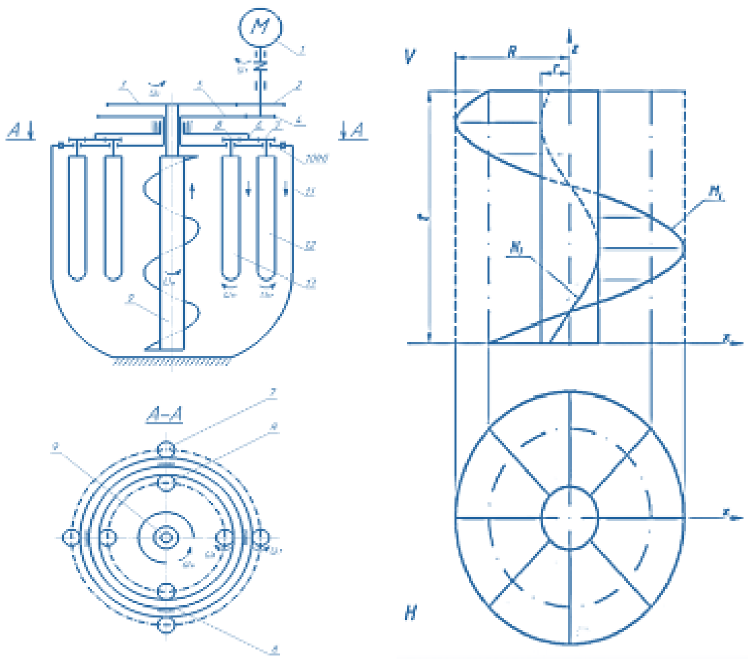

Figure 1: Kinematic diagram of the mechanism *a*) and part of the rotary auger assembly *b*).

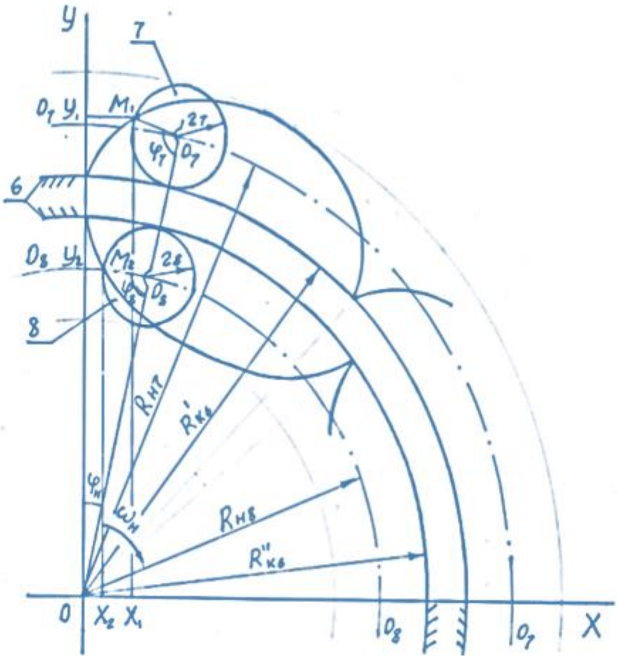

Figure 2. Kinematic diagram of the movement of satellites 7 and 8 planetary mixing mechanism in the YOX coordinate axis

Based on the data provided in Figure 2, we write the equality $\varphi_7 \cdot r_7 = \varphi_H \cdot R_{K7}$ and $\varphi_8 \cdot r_8 = \varphi_H \cdot R_{K8}$ from where $\varphi_7 = (R_{K7} / r_7) \cdot \varphi_H = i_{76} \cdot \varphi_H$, also $\varphi_8 = (R_{K8} / r_8) \cdot \varphi_H = i_{86} \cdot \varphi_H$,

where i_{76}, i_{86} – gear ratios from central wheel 6 to satellite 7, and also, accordingly, from central wheel 6 to satellite 8; $i_{76} = (R_{K7} / r_7)$; $i_{86} = (R_{K8} / r_8)$, R_{K7} and R_{K8} - pitch radii of the external and internal engagement of the fixed central wheel 6, respectively.

Substituting the obtained values φ_7 and φ_8 in (1) and (2) we obtain:

- for the hypocyclic curve of the satellite point 8:

$$\begin{cases} X = R_{H8} \sin \phi_H - r_8 \sin(i_{86} - 1)\, \phi_H; \\ Y = R_{H8} \cos \phi_H + r_8 \cos(i_{86} - 1)\, \phi_H; \end{cases} \quad (3)$$

- for epicyclical curve of point of satellite 7:

$$\begin{cases} X = R_{H7} \sin \phi_H - r_7 \sin(i_{76} + 1)\, \phi_H; \\ Y = R_{H7} \cos \phi_H + r_7 \cos(i_{76} + 1)\, \phi_H. \end{cases} \quad (4)$$

Given different numerical values $R_{H7} = 180мм$, $R_{H8} = 200мм$, $r_7 = r_8 = r_{sh} = 20мм$, $R^{`}_{k6} = 120мм$, $R^{''}_{k6} = 180mm$ and the angle of rotation $\phi_H = 0...6,28rad$ carrier with an interval of *i*=0.1746 rad we obtained (Fig. 3) a graph of the curve of the trajectory of the epicyclic and hypocyclic motion of the planetary gear satellite and the rotary screw. For the lower part of the carrier *H* planetary mechanism, with the overall dimensions of the same satellites 7 and 8 and working bodies - blades 12, 13 and 9, we obtained a similar picture of the trajectory of the curves for the working blades of the mortar mixer: epicyclic, hypocyclic and rotary circular.

Figure 1b shows a part of the rotary screw assembly of the mechanism, which has a profile of the curved line of the annular screw conoid, formed by rotating the screw along a circular line on a horizontal plane, while the trajectory of the curve simultaneously moves from the lower base along a vertical line to the upper part of the tank.

The installed rotary screw performs the function of a screw conveyor for lifting the mass of the solution mixture. Here, the screw design consists of two parts: a vertically suspended fixed rod and a screw tape petal blade. The petal blade of the rotary screw consists of two trajectories of curvature: internal *N* and external *M*.

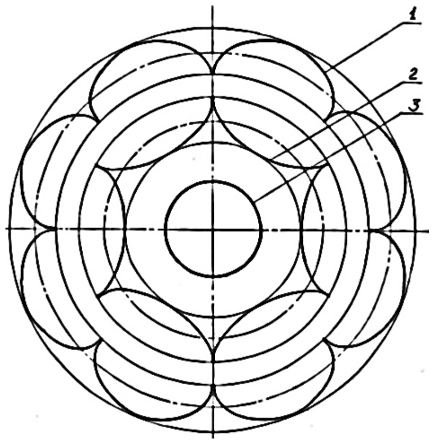

Figure 3: Graph of the curve of the epicyclic 1), hypocyclic 2) and rotary-circular 3) trajectory of movement of the blades 12, 13 and 9 of the mortar mixer.

The parametric equation of movement along the internal trajectory of curvature N of the rod has the form:

$$\begin{cases} X = r \cdot \cos\alpha\,; \\ Y = r \cdot \sin\alpha\,; \\ Z = 2\pi \cdot r \cdot \alpha, \end{cases} \quad (5)$$

where r is the radius of the rotary rod of the screw auger; α is the angle of elevation of the screw helical line, here, 2πrα is equal to the pitch t of the helical line: t=2πrα.

The outer trajectory of curvature M of the petal blade has the form:

$$\begin{cases} X = R \cdot \cos\alpha\,; \\ Y = R \cdot \sin\alpha\,; \\ Z = 2\pi \cdot R \cdot \alpha, \end{cases} \quad (6)$$

where R is the radius along the outer blade helical line of the auger.

From the (5) and (6) we have the total parametric equation of the surface of the petal blade, then in general it will look like:

$$\begin{cases} X = (R - r) \cdot \cos\alpha + r \cdot \cos\alpha\,; \\ Y = (R - r) \cdot \sin\alpha + r \cdot \sin\alpha\,; \\ Z = 2\pi \cdot R \cdot \alpha. \end{cases} \quad (7)$$

When subtracting the outer radius R of the screw turn from the radius r of the rotary rod, we obtain the surface area of the petal blade of the turn: $\ell = R - r$ – to calculate the movement of the material particle of the solution mass along the surface of the formed shelf and the angle α of the movement of the solution mass along the screw helical line. From here we select the average radius R_1, along the surface of the screw helical line, which is equal to: $R_1 = (R - r) \cdot 0{,}5 + r$. Then the final form of the parametric equation of the petal line will be:

$$\begin{cases} X = R_1 \cdot \cos\alpha + r \cdot \cos\alpha\,; \\ Y = R_1 \cdot \sin\alpha + r \cdot \sin\alpha\,; \\ Z = 2\pi \cdot R_1 \cdot \alpha. \end{cases} \quad (8)$$

3 CONCLUSIONS

This research introduces a mathematically modeled and kinematically examined planetary mixer mechanism that incorporates an epi-hypocyclic blade system alongside a central rotary screw auger to improve the mixing of construction mortar. The resulting parametric equations for the satellite blades' movement verified the creation of eight epicyclic and six hypocyclic arcs, illustrating intricate, multidirectional paths that guarantee total coverage of the mixing volume. At the same time, the rotary screw auger, represented by a conoid surface equation, generates a vertical-circular transport route, facilitating the steady upward movement of the mortar from the mixing bowl's bottom to its top. The determined gear ratios for the transmission system, U_{sh} = 2.0–3.15 for the screw and U_n = 4.0 to 6.3 for the carrier produced a greater angular velocity for the screw $\omega_{sh} > \omega_n$, promoting enhanced lifting and circulation. A kinematic diagram of an epi-hypocyclic planetary-mixing mechanism with a rotary screw for driving a construction mortar mixer is proposed. The analytical method is used to obtain parametric equations of motion of the point of the satellites of the epicyclic and hypocyclic trajectory, as well as a parametric equation of the surface of the petal blade of the screw conoid of the rotary screw.

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