Method for determining the reduced parameters of the mixer gear drive

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Abstract. The article presents the method of determining the reduced moments of a mixer mechanism with an epicyclic gear and a rocker arm. The method consists of using a mathematical model of the mechanism; determining the change of process load on the device working shaft; determining the dependence of the moments change on inertia forces and their values and reducing them to the main shaft of the device. It also includes determining the dependence of the change in the total moments values on the forces of useful resistance and on the moments of inertia forces and reducing them to the main shaft of the device.

1. Introduction

Existing designs of continuous mixers operate mainly in a stationary mode, i.e. at a constant angular velocity of the work member.

When preparing bulk mixtures, the coincidence of the mixture movement speed and that of the work member may result in components deposits in the mixing zone, which leads to the final product quality deterioration. At the same time, the production time, as well as energy consumption, increases [1-3].

The production of liquid and low-viscosity mixtures in paddle mixers is also associated with the gradual alignment of the mixture movement speeds and those of the mixer's work member paddle. As a result, the mixture moves in layers, i.e. there is a laminar flow mode, in which the mixture layers do not mix with each other, which negatively affects the quality.

In both cases, a variable rotation speed of the mixer's working shafts solves these problems.

When a variable angular velocity is transmitted to the working body, the actual instantaneous velocity of the mixture (liquid or bulk) \( \omega_m \) consists of the time-average value of the mixture velocity \( \omega_{av} \) and the deviation of the actual velocity from the averaged \( \Delta \omega \).

\[
\omega_m = \omega_{av} + \Delta \omega, \tag{1}
\]
In this case, the deviation of the actual speed from the average value is an increment of the work member rotation speed, which will be different in value and direction. This will lead to turbulent phenomena, i.e. the transition of elementary mixture masses from one layer to another, which contribute to improving the quality and intensity of the mixing process [2, 4–6].

The turbulent mode of particle motion allows achieving uniformity of the mixture. Thus, the use of continuous mixers with the work member variable angular rotation speed is the most efficient method to achieve a high-quality final product. The lever and gear drive mechanisms can transmit the specified type of the work member movement providing for the set objective.

Increasing the performance of mixers is possible both by changing the geometric parameters of the working chamber and by increasing the speed of the actuators within the requirements of the manufacturing process. Increasing the speed modes of the kneading device work members with a significant length (2 m or more) has a considerable impact not only on the kinematics, but also on the dynamics of the mechanism, which imposes higher requirements on individual elements and units of continuous mixers. Determining the dynamic characteristics of the synthesized mechanism [2] requires knowing the moment of useful resistances, the driving moment, and the inertia forces moment. During downtime of the mixing equipment, some mixtures change their chemical, biological, physical and mechanical properties; therefore, the load on the work member increases over time which leads to the electric motor overloads, as well as to the damage in the elements of the actuating and transmission mechanisms. Lowering the starting torque before restarting the mixer requires releasing the working chamber from the mixture (often done manually), which leads to additional loss of time and possibly raw materials. When a mixer comes into regular operation after a downtime, accelerating the unit and filling the working chamber with mixed raw materials takes certain time, which affects the performance and, consequently, the efficiency of the equipment. The research into determining the reduced parameters of inertia and useful resistances forces components will help establishing the energy costs for the useful operation of the mixer. The objective of the study is to increase the performance of food mixing equipment.

2. Theory and methods

The kinematic scheme of the unit is shown in Figure 1.

![Kinematic diagram of a mixer driven by an epicyclic transmission](image)

**Figure 1.** Kinematic diagram of a mixer driven by an epicyclic transmission: 1 - electric motor \((P = 11 \text{ kW}, \ n_m = 1460 \text{ min}^{-1})\); 2 - driving pulley \((D = 140 \text{ mm})\); 3 - driven pulley \((D = 560 \text{ mm})\); 4 - gear wheel \((z = 19, \ m = 4)\); 5 - gear wheel \((z = 71, \ m = 4)\); 6 - driver; 7 - gear wheel \((z = 44, \ m = 4)\); 8 - planet gear \((z = 22, \ m = 4)\); 9 - slot stone; 10 - rocker arm; 11 - gear drive \((z = 88, \ m = 5)\); 12 - kneading shaft; 13 - blade; 14 - loading hopper; 15 - discharge hole.
The mechanism workflow: the V-belt transmission 2-3 transmits the movement from the electric motor shaft 1 to the shaft with gear 4. From it, via a gear cylindrical transmission 4-5, the movement is transmitted to the driver which moves the planet gears 8 along the fixed solar wheel 6. On the planet gears, there are fixed axes that carry slot stones 9, which engage with the slots of the rocker arm 10 and turn it at a certain angle. The shaft carrying blades 13 rotates together with rocker arm. The second shaft of the mixer is rotated by a gear drive 11.

For technical tasks, the graphic form is the most convenient one for representing the reduced moment of resistance forces. The work of the reduced resistance forces can be represented by the expression

\[ A_{Mr} = \int_0^{\phi} M_r \cdot d\phi, \]

with \( A_{Mr} \) being the resistance forces work; \( M_r \) - resistance forces moment; \( \phi \) – angle of the main shaft rotation.

The work of the reduced resistance forces is determined by the product of the area bounded by the curve \( M_r = M_r(\phi) \) and the axis \( \phi \) by the angle \( \phi \), taking into account their scales.

In this view, the most acceptable form of research is to describe the behavior of the system through kinetic energy. In this case, the expression \( T = T(J_{red}) \) establishes the dependence of the kinetic energy on the reduced moment of inertia.

In the article, the reduced process load was determined at different angles of the blades placing [2]. It is the sum of the process loads on each blade placed in a separate row. The typical graphs of the reduced process load on each row of blades are shown in Figure 2.

The obtained data is the basis for plotting the change in the total loads from each row of blades reduced to the main shaft depending on the rotation angle of the working shaft. A typical graph is shown in Figure 3.

Figure 2. Graphs of changes in process loads reduced to the main shaft for each row of blades depending on the rotation angle of the working shaft at a speed of 120 min\(^{-1}\): 1, 2, 3, 4 are the loads on the corresponding rows of blades

Figure 3. Graph of changes in the total load on the working shaft reduced to the main shaft depending on the rotation angle of the working shaft at a speed of 120 min\(^{-1}\)

The reduced moment of inertia was determined in accordance with the kinematic scheme shown in Figure 4 and the calculation formula:

\[ M_i = J_{red} \frac{d\omega}{dt}, \]

where \( J_{red} \) is the reduced moment of inertia, kg\(\cdot\)m\(^2\); \( \omega \) is the angular velocity of the main shaft, s\(^{-1}\).

The angular velocity of the main shaft is a variable value and is substantiated in [2, 7–14].
To determine the reduced moment of inertia of the masses, we used the kinetic energy theorem [3, 7, 14]:

\[
T_{\text{red}} = T_{\text{mr}} + T_{1} + T_{2} + T_{3} + T_{4} + T_{5} + T_{6} + T_{7} + T_{8} + T_{9} + T_{10} + T_{11},
\]

where \( T_{\text{mr}} \) – kinetic energy of the electric motor rotor; \( T_{1} \) – kinetic energy of the drive pulley; \( T_{2} \) – kinetic energy of the driven pulley; \( T_{3} \) – kinetic energy of the gear shaft; \( T_{4} \) – kinetic energy of the driven wheel; \( T_{5} \) – kinetic energy of the driver; \( T_{6} \) – kinetic energy of the planet gear and slot stone; \( T_{7} \) – kinetic energy of the rocker arm; \( T_{8} \) – kinetic energy of the drive wheel for the first working shaft; \( T_{9} \) – kinetic energy for the first working shaft; \( T_{10} \) – kinetic energy of the drive wheel for the second working shaft; \( T_{11} \) – kinetic energy for the second working shaft; \( T_{12} \) – kinetic energy of the slot stone caused by its translational motion.

The reduced moment of mixture inertia for the entire device reduced to the main shaft was determined in accordance with the expression:

\[
J_{\text{red}} = \frac{1}{2} \left( J_{\text{mr}} + J_{1} \right) \omega_{a}^{2} + \frac{1}{2} \left( J_{2} + J_{3} \right) \omega_{a}^{2} + \frac{1}{2} \left( J_{4} + J_{5} \right) \omega_{a}^{2} + \frac{1}{2} \left( J_{6} \right) \frac{\omega_{a}^{2}}{\omega_{a}^{2}} + \frac{m_{6} \cdot V_{\text{pl.}}^{2}}{\omega_{a}^{2}} + \frac{m_{\text{sl.st.}} \cdot V_{\text{sl.st.}}^{2}}{\omega_{a}^{2}}.
\]

In expression (3), all notations correspond to the notation of the kinetic energies represented in formula (2), with the exception of the expression \( \frac{m_{\text{sl.st.}} \cdot V_{\text{sl.st.}}^{2}}{\omega_{a}^{2}} \), where \( m_{\text{sl.st.}} \) is the mass of the slot stone; \( V_{\text{sl.st.}} \) is the speed of the slot stone; \( \omega_{a} \) is the angular velocity of the drive shaft.

3. Results and discussion

In accordance with the mentioned expressions and the design methodology for continuous mixers described in [3, 5, 7, 8, 10–14], the process load at the rotation angles of the working shaft equal to 45, 135, 225, 315 degrees was reduced to the main shaft of the mechanism presented in [2]. Taking into account the gear ratio, the process load is reduced to the main shaft. For one revolution of the work member, the motor shaft makes 16,069 revolutions. The results of the calculations are shown in Figure 5.

We obtained the inertial mass characteristics of the proposed mechanism's components to determine the reduced moments of the inertia forces (Table 1).
Figure 5. Process load reduced to the main shaft.

Table 1. Inertial mass characteristics of the working shaft drive components of the double agitator.

| Name                              | Indication in Figure 4 | Weight, m, kg | Moment of inertia, J, kg⋅m² |
|-----------------------------------|------------------------|--------------|-----------------------------|
| The rotor of the motor            | \( J_{mr} \)           | 83.500       | 0.183957                    |
| Drive pulley (D = 140 mm)         | \( J_1 \)              | 8.032        | 0.019629                    |
| Driven pulley (D = 560 mm)        | \( J_2 \)              | 37.333       | 2.122987                    |
| Shaft gear (m = 4, z = 19)        | \( J_3 \)              | 6.327        | 0.003069                    |
| Gear wheel (m = 4, z = 71)        | \( J_4 \)              | 27.587       | 0.329693                    |
| Driver                            | \( J_5 \)              | 10.139       | 0.096606                    |
| Planet gear (m = 4, z = 22)       | \( J_6 \)              | 2.751        | 0.002739                    |
| Rocker arm                        | \( J_7 \)              | 15.466       | 0.130923                    |
| Slot stone                        |                        | 0.454        | 0.000317                    |
| A gear wheel (m = 5, z = 88)      | \( J_8 \), \( J_{10} \)| 56.524       | 1.457055                    |
| Mixer’s shaft                     | \( J_9 \), \( J_{11} \)| 65.405       | 0.041337                    |

The nature of the change in the mechanism’s reduced moment of inertia is shown in Figure 6.

The angular velocity of the main shaft, taking into account the gear ratio, was determined by the formula \( \omega_{\text{red}} = \omega_c \cdot \left( \frac{I_a}{I_a + \epsilon} \right) \).

Considering [2] and bearing in mind that \( \epsilon(\phi) = \frac{d}{d\phi} \omega(\phi) \), we get the following dependence of angular acceleration which is graphically shown in Figure 6.

As a result, the reduced moment of forces calculated by the formula (1) has the following form (Figure 6).

Figure 6. Graph of the change in: 1 - moment of inertia reduced to the main shaft; 2 - angular acceleration; 3 - reduced moment of inertia.
Summing up the graph of changes in the reduced moment of forces (Figure 6), and the graph of changes in the process load (Figure 5) yields a graph of changes in the total load reduced to the main shaft (Figure 7).

![Graph of changes in the total load on the main shaft.](image)

**Figure 7.** Graph of changes in the total load on the main shaft.

### 4. Conclusion

We performed the study of the reduced parameters of the epicyclic transmission drive with a rocker arm for the following engine parameters. The reference diameter of the larger wheel was $d_1 = 176$ mm; the reference diameter of the small wheel was $d_2 = 88$ mm. The gear ratio of epicyclic transmission was $i = 0.5$; the driver length (center distance) was $l = 132$ mm; the eccentricity was $e = 14$ mm. The detailed substantiation of these parameters is presented in [2].

The paper presents a method for determining the reduced moments of the epicyclic transmission drive with a rocker arm, including:

- a mathematical model of the mechanism that allows calculating the reduced moment of inertia for the drive masses. The maximum values of the reduced moment of the masses inertia were 0.359 kg·m², the minimum – 0.357 kg·m²;
- determining the nature of changes in the process load acting on the working shafts of the device; determining the values and nature of the reduced moments of these forces to the main shaft of the device. The maximum values of the total moment of the useful resistance forces were 44-47 N·m, the minimum – 22-24 N·m; the values depend on the blades placing angle on the working shafts;
- determining the dependence of the moments changes on the forces of inertia and their values and reducing them to the main shaft of the device. The maximum values of the inertia moment were 2.4 N·m, the minimum – 2.4 N·m;
- determining the dependence of changes in the total values of moments on the useful resistances forces as well as the dependence of moments on the inertia forces and reducing them to the main shaft of the device. The maximum values of the total moment of inertia forces were 45 N·m, the minimum – 22 N·m.

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### References

[1] Mudrov A G 1999 *Development of spatial mixing devices of a new generation used in agriculture and industry* (Al'nopress Publ.) p 44

[2] Martynova T G et al 2020 *IOP Conf. Ser.: Mater. Sci. Eng.* **843**(1) 012006

[3] Hsieh J F 2014 *Mechanism and Machine Theory* **81** 155-165

[4] Podgornyi Y I et al 2017 *IOP Conf. Ser.: Earth Environ. Sci.* **87** 082039

[5] Antipov S T 2001 *Machines and equipment for food production* (High School Press.) p 703
[6] Martynova T G et al 2018 IOP Conf. Ser.: Earth Environ. Sci. 194(2) 022022
[7] Zhoua C, Hua B, Chenb S and Mac L 2016 Mechanism and Machine Theory 104 118-129
[8] Myszka D H 2012 Machines & Mechanisms: Applied Kinematic Analysis (Pearson Publ.) p 576
[9] Podgornyj Y I et al 2019 Obrabotka metallov 21(4) 47-58
[10] Vulfson I 2015 Dynamics of Cyclic Machines (Springer Int. Publ.) p 390
[11] Podgornyj Y I, Skeeba V Y, Kirillov A V et al 2016 Obrabotka metallov 4 24-33
[12] Podgornyj Y I et al 2019 IOP Conf. Ser.: Earth Environ. Sci. 378(1) 012025
[13] Matyashin A V 1998 Justification of the parameters and operating modes of the feed mixer of periodic action (KGSKhA Publ.) p 24
[14] Mott R L 2013 Machine Elements in Mechanical Design (Pearson Publ.) p 816