Algorithm for determining the unbalances of continuous mixers rotors

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Abstract. The paper presents a design model of a continuous mixer, which employs working shafts with kneading and scraping blades as the equivalent rotors. The rotors are represented in the orthogonal system x, y, z. An algorithm for reducing a three-dimensional system to flat ones using three-dimensional simulation is proposed to simplify further calculations. The inertia and the mass moments of the rotors' structural elements were determined for the specific parameters of the parts obtained by blanks casting taking into account the accuracy classes. The conducted research allowed developing recommendations for choosing rational methods for manufacturing parts of continuous mixers and optimal parameters for the operation of the mixer.

1. Introduction

Dynamic loads that occur during the movement of the machine links are a source of additional friction forces affecting the elements of kinematic pairs, as well as causing additional stresses in them. Besides, periodically changing inertia forces cause fluctuations of individual machine components on the foundation [1-7]. The masses of the links whose inertia forces cause dynamic loads on the supports are considered unbalanced masses. The elimination or reduction of dynamic loads on the supports is achieved by balancing the masses [8-16]. In this paper, this process is considered on the example of a continuous mixer (a kneading machine for pasta dough) (Figure 1).

The machine is designed for mixing the crumbly dough mass in order to evenly distribute moisture and swell the starch. The working chamber is made of stainless steel sheet, its length is 2300 mm and width is 950 mm. The chamber has the shape of two semi-cylinders connected to each other. Inside the chamber, there are two parallel working shafts (rotors) with kneading blades (30 on each shaft) and scraper blades (2 on each shaft) installed horizontally. The rotation of the shafts with a frequency of 60 to 100 min⁻¹ is carried out from an individual drive consisting of an electric motor with a V-belt transmission and a system of gear cylindrical wheels operating in an oil bath. The top of the agitator is covered with two plexiglass lids, which provide safety and control over the kneading process. In one
of the end walls of the chamber there is a through discharge hole connected by a vacuum gate to the loading hole of the vacuum mixer. The crumbly dough mass moves along the working chamber of the mixer for 20 minutes to form the finished dough. About 300-400 kg of the mixture is constantly in the working chamber during the operation of the mixer. In the event of the machine forced stop, the mixture is quickly compacted, which leads to certain difficulties when restarting the mixer mechanism. Since the working shafts have a significant length, there is a need to balance them.

![Figure 1. Kinematic scheme of a continuous mixer:](image)

1 – working chamber; 2 – blade; 3 – working body; 4 – gear wheel (z=88, m=5); 5 – gear wheel (z=23, m=4); 6 – gear wheel (z=28, m=4); 7 – coupling; 8 – single-pass worm (m=6.3); 9 – worm wheel (z=30, m=6.3); 10 – plate; 11 – gear wheel (z=19, m=5); 12 – gear wheel (z=47, m=4); 13 – gear wheel (z=18, m=4); 14 – driven pulley (D=230 mm); 15 – driving pulley (D=150 mm); 16 – electric motor

In addition, large technological loads and aggressive environment lead to an intensive decrease in the performance characteristics of the kneading blades and, as a result, they require replacement. The low accuracy of these actuator elements leads to a change in the inertial mass parameters of the working shaft (rotor). Consequently, there is a need to develop recommendations for the manufacturing accuracy of the working body elements as well as their dynamic balancing.

2. Materials and methods

A system of three-dimensional solid-state simulation was used to determine the values and positions of the centers of mass of the working shafts elements. It allowed determining the masses of 30 kneading blades located on each shaft \(m_1, m_2, ..., m_{30}\), as well as the distances from the axis of rotation to the position of the centers of mass \(e_1, e_2, ..., e_{30}\).

The \(A\) plane was chosen as the main plane relative to which the calculations were made. On the basis of [17] we obtain the values of imbalances defined by distances from the plane \(A\) to the axes of blades \(a_1=70, a_2=140, ..., a_{30}=2100\) mm (Figure 2, a), as well as the angles of the blades between the axis \(OY\) \(\varphi_1=\varphi_5=...=\varphi_{29}=0^\circ, \varphi_2=\varphi_6=...=\varphi_{30}=90^\circ, \varphi_3=\varphi_7=...=\varphi_{27}=180^\circ, \varphi_4=\varphi_8=...=\varphi_{28}=270^\circ\) (Figure 2, b):
\[ \vec{D}_i = e_i \cdot m_i, \]

where \( e_i \) is the distance to the centers of mass of the working shaft elements.

**Figure 2.** Design model of the working body (rotor) of a two-shaft continuous mixer of an automatic pasta production line: a - spatial system of imbalances; b - the layout of the correcting imbalances vectors

Since the working shafts of the kneading machine are identical, it is not necessary to balance both shafts. Therefore, in further calculations, we used one equivalent shaft (Figure 2).

Since the equivalent design element is represented by the working shaft, which is a rotor, such systems allow balancing the entire assembly completely, and not each element included in it [17].

For further study of the working shafts, we selected two reference planes located at the beginning and end of the rotor (planes \( A \) and \( B \). Figure 2). These planes correspond to the location of the axes of the scraper blades, the centers of their masses are marked \( S_{cA}, S_{cB} \), with a distance between them \( l = 2170 \text{ mm} \).

Determining the values of the imbalances requires recalculating the values of the imbalances of each element taking into account the location of the reference planes.

Then, the imbalances are determined taking into account the reference planes:

\[ \vec{D}_{iA} = \frac{D_i \cdot b_i}{l}, \quad \vec{D}_{iB} = \frac{D_i \cdot a_i}{l}, \]

where \( b_i \) is the size from the \( i^{th} \) element of the assembly to the reference plane \( B \); \( a_i \) is the size from the \( i^{th} \) element of the assembly to the reference plane \( A \), \( l \) is the distance between the planes \( A \) and \( B \).

Determining these indicators at the nominal values of the elements included in the assembly is a necessary condition for studying the values of imbalances, both of the elements and of the entire working shaft. Such values are presented in [18].

Every part included in the assembly has a tolerance for its manufacture. Obviously, the more parts in the assembly, the greater the accumulated errors. Therefore, this work comprises three-dimensional simulation of the assembly elements manufactured with different accuracy. Thus, we took the blanks obtained by casting from the first to the third accuracy classes. The tolerances for obtaining blanks are within the range of \( IT6 \) to \( IT18 \).
3. Results and discussion
The results of the simulation are shown in the Table 1.

| IT Grades | Nominal dimensions | $D_{\text{min}} \text{ mm-g}$ | $D_{\text{max}} \text{ mm-g}$ |
|-----------|--------------------|-------------------|-------------------|
| IT6       | 67070.72           | 67062.74          | 67122.40          |
| IT7       | 67036.52           | 67010.80          | 67148.62          |
| IT8       | 66949.36           | 66853.16          | 67174.34          |
| IT9       | 67036.52           | 66949.36          | 67235.78          |
| IT10      | 66695.38           | 66536.52          | 67331.98          |
| IT11      | 66369.54           | 66064.36          | 67489.76          |
| IT12      | 65438.07           | 64409.04          | 68120.78          |
| IT13      | 65328.31           | 64230.83          | 68747.07          |
| IT14      | 59230.83           | 50822.26          | 70896.83          |
| IT15      | 50822.26           | 74954.31          | 83362.88          |

Considering [19], the presented system of imbalances (Figure 2) is reduced to the system shown in Figure 3. The total values of the imbalances are determined in accordance with the expressions:

$$
\overline{D}_A = \sum D_{\text{IA}} , \quad \overline{D}_B = \sum D_{\text{IB}} .
$$

In this case, the unbalance of the working shaft assembly is determined by the vectors $\overline{D}_A$ and $\overline{D}_B$, which are described as crossing ones.

**Figure 3.** The imbalance plan
(at the nominal dimensions of the working shaft elements)

Based on [17] full balancing is written as $\overline{D}_{\text{IA}} = -\overline{D}_A$ and $\overline{D}_{\text{IB}} = -\overline{D}_B$. 
As a result of the calculations, we obtained the values of the correction vectors $D_{kA} = D_{kB} = 47516.9$ mm·g with the angular coordinates $\varphi_{kA} = 137°$ and $\varphi_{kB} = 134°$ shown in Figure 2 and 3.

Since we were given the task of determining the correction vectors taking into account the manufacturing accuracy of the working shafts elements, using 3D modeling we found the values of the coordinates of the centers of mass and the correction vectors for the grades from $IT6$ to $IT18$, which are designated as $D'_{kA}$ and $D'_{kB}$.

The conducted theoretical studies found that the grades up to $IT9$ do not make significant changes to the positions of the elements centers of mass and therefore further studies were carried out for the grades $IT10$ - $IT18$. As the accuracy grades increase, their deviations increase relative to their initial (nominal) values $D_{kA}$, $D_{kB}$ (see Figure 4). This figure shows a sample diagram that reflects the characteristic pattern of deviation of the correction vectors.

![Figure 4](image.png)

**Figure 4.** Typical correction vectors of imbalances with reduced manufacturing accuracy of the working shaft elements

The data obtained as a result of theoretical studies are shown in Figure 5, where the IT grade values are represented on the $X$ axis, and the deviations of the correction vectors (imbalances) on the $Y$ axis; the values are represented as a percentage of the nominal ones.

Based on [19], the unbalance of the assembly elements negatively affects the dynamic loads of the machines. This fully applies to the mixer, which includes a shaft with blades located on it.

In this regard, the unbalance of the working shaft can exert additional pressure on its supports, which can lead to increased loads on the bearings.

![Figure 5](image.png)

**Figure 5.** Dependence of the values deviations correcting IT grades imbalances.
Based on this statement, the power and cyclic characteristics of the bearings can serve a criterion for choosing the accuracy of the rotor elements manufacturing. To identify these factors, we created 3D models of kneading shafts assembled with blades whose permissible deviations range from IT6 to IT18 using the ANSYS software. The order of the blades placement was chosen by random numbers. The obtained data allowed selecting the maximum values for each of IT grades and adjusting their results with a special TableCurve 3D software. In the final form, these results are represented in Figure 6. The results were differentiated for each of the intended sides of the working shaft.

![Figure 6](image)

**Figure 6.** The dependence of the reaction in the supports on the rotor speed of rotation and on the accuracy of the elements manufacture: a – for fixed supports and b – for movable supports

The images shown in Figure 6 enable determining the frequency range of the rotor rotation, which is deferred on the X axis, the loads on each of the supports are given on the Z axis and the accuracy of the assembly execution (IT) on the Y axis.

4. **Conclusion**

The following results are obtained.

1. We obtained a three-dimensional mathematical simulation of the mixer working shaft whose working bodies are shafts (rotors) with blades manufactured with different accuracy.

2. The presented mathematical model allows, if necessary, to move from a three-dimensional coordinate system to a two-dimensional one, which simplifies the calculations and yields specific numerical values. The calculated imbalance value for the sixth IT grade of blades manufacturing is (minimum) 67062.7 mm·g, the maximum is 67122.4 mm·g. With the accuracy of manufacturing blades according to the eighteenth IT grade, maximum is 50822.26 mm·g, minimum is 83362.88 mm·g.

3. The reactions in the rotor supports depend on the precision of its elements manufacturing and, as a result, on the rotor balancing. Thus, if the blades are manufactured with the sixth IT grade, the reactions in the supports can reach values of 407-432 N, and when the accuracy is reduced to IT18, they are 424-452 N.

4. We have developed nomograms that allow choosing efficient parameters of the mixer operation, including the rotation speed of the working shaft (rotor) and the accuracy of the working shaft elements manufacturing.
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