Mathematical simulation of kinematic capabilities of mechanisms in agro-industrial complex applications

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Abstract. Many modern machines, including agriculture, food and mining and processing industries, use the oscillatory movement of the working body. At the same time, not only the frequency and amplitude of the oscillations, but also their shape, that is, the law of motion, are important. When solving some practical problems, it is optimal to move with distances, change the idling speed compared to the working stroke, etc. The article proposes gear eccentric system (GES) and discusses a mathematical model of kinematic capabilities for various modifications.

1. Introduction
To obtain oscillations, the simplest kinematically closed four-link mechanisms are mainly used, the links of which are able to move relative to each other. The vast majority of such mechanisms convert the uniform movement of the driving link into uneven movement of the driven link and refers to mechanisms with a nonlinear function of the position of the driven link. These include crank-slider, crank-rocker or sinus-cosine, in which the movement of the driven link (slider) in the guide is actually proportional to the sine of the rotation angle of the driving link (crank). The range of change in the sinusoidal law of motion of the slave link due to the geometric characteristics of such mechanisms remains small.

A wide range and modification of the patterns of movement of the output link are provided by cam mechanisms. Their disadvantages are the sliding of working surfaces with a poppet pusher, or the high contact stresses of the load on the roller in the highest kinematic pair, or the large dimensions of the roller and the entire structure. The required modification of the law of motion of the working element of the machine can be obtained by using a gear eccentric system (GES).

2. Eccentric mechanism with additional harmonics
Eccentric mechanism [1] in figure 1 is a type of GES [2] without modification of the law of movement of the working element of the machine. The mechanism contains driving shaft 1, gear 2 fixed on it with eccentricity $e_b$ of gears, a driven member (slider) 3, a connecting crank rod 4 hingedly connected to it, having a rim 5 with internal teeth, and gear rolling bodies (satellites) of different diameter 6. Rolling bodies are located in closed space between driving gear 2 and rim 5. This arrangement allows the eccentricity $e_h$ of links 2 and 5 to be obtained. In the axial direction, the teeth of the gear wheels 2 and 5 are located between two cylindrical treadmills, the diameters of which are equal or close to the corresponding initial diameters of the gear rims. When driving shaft 1 rotates at angular speed $\omega_b$, rolling bodies 6 roll along rim 5 of connecting rod 4. Their axes make such a movement in space as if they were united by a carrier. In this case, the average angular velocity is according to the formula:

$$\omega_h = \frac{\omega_b}{i_{bh}}.$$
Where $i_{bh} = 1 + Z_5/Z_2$ is the gearing ratio the driving shaft to the imaginary carrier; $Z_5$ is the number of teeth of crown 5; $Z_2$ is the number of teeth of the driving gear wheel 2.

Driven link (slider) 3 reciprocates with frequency $\omega/2\pi$. This eccentric mechanism functions as a reduction gear, eccentric and rolling support simultaneously. The law of motion of the slave link (slider), determined by the rotation of the imaginary carrier, is close to the harmonic function (sinusoid).

Another eccentric mechanism circuit (figure 2) works in the same way. The structural difference is that the driving wheel 2 is in direct engagement with the wheel 5. Note here that rolling gear bodies 6 fill free space between links 2 and 5 to interact therewith. Gear ratio from shaft to «carrier»:

$$i_{bh} = 1 - Z_5/Z_2$$

Where $Z_5$ is the number of teeth of crown 5; $Z_2$ is the number of teeth of driving wheel 2.

Figure 1. Eccentric mechanism with gearing ratio $i_{bh} = 3$.

Figure 2. Eccentric mechanism with gearing ratio $i_{bh} = -0.5$.

3. Assembly condition

The presence of the eccentricity of the driving shaft $\epsilon_n$ adds an additional, high-frequency harmonica to the law of motion of the driven member.
The mathematical model of the GES with eccentricity of the driving shaft is shown in figure 3. The model contains the following parameters: \( \phi_h \) is the rotation angle of the system of rolling bodies (that is, the «carrier») relative to the fixed member; \( \phi_w \) is a connecting rod angle of rotation; \( e_h \) is the eccentricity of rolling body system; \( l_w \) is the length of connecting rod; \( l_h = l_w + S \) is the distance from shaft axis to slider hinge; \( S \) is the displacement of the slider from the central position. Kinematic analysis of the mechanism was carried out by a method similar to those used by the authors of works [3-5].

The closedness equation of vector mode will be:

\[
\vec{e}_b + \vec{e}_h + \vec{l}_{sh} - \vec{l}_p = 0
\]

The final dependence of the analytical decision on \( S \) will be:

\[
S = e_b \cdot \sin \phi_b + e_h \cdot \sin \frac{\phi_b - C}{l_{bh}}
\]

Where \( \phi_b \) is the angle of rotation of the leading shaft; \( C \) is the initial value of the angle to the drive shaft.

Figure 3. Mathematical model of GES with additional harmonics.

Visualization of the mathematical model of the law of motion of the driven member with additional harmonics is shown in figure 4.

The law of movement of the slave link must meet the requirements of the technological process for which the mechanism is designed. The analysis of possible combinations of parameters of two harmonics made it possible to identify certain variations thereof, corresponding to the movement with distances, accelerated reverse travel and other modifications. The conditional motion diagram of the slave link is shown as a cyclogram in figure 6.

An additional advantage of a drive comprising an eccentric mechanism is that it itself provides reduction, that is, it eliminates the need for a separate reduction gear. Thus, the metal capacity of the structure is reduced.

4. Use of GES in agro-industrial complex

Studies [6] show that the waveform can affect the efficiency of the grain cleaning process in rexman screen. Oscillations of the working element of the vibration-centrifugal grain separator [7] with certain values of amplitude and frequency together with rotary motion contribute to increase of separation efficiency, which is relevant for separation of difficult-to-separate mixtures. In vibration-centrifugal separators oscillating motion of working element is communicated in most cases from eccentric or crank mechanism [8].
Having analyzed literary sources, it is seen that the application of vibration technology in seed preparation is the most promising [9-10]. The capabilities of this technology and the scope of its application are very wide. Numerous studies of vibration grain cleaning machines have shown that the main parameters that determine the efficiency of separation of grain mixtures and the productivity of the plant as a whole are the amplitude, frequency of oscillations and angular speed of rotation of the working element [9]. Besides, in order to ensure the most efficient process of grain mixture separation, smooth control of amplitude and frequency of oscillations must be provided depending on the type of cultivated culture [11].

The larger the grain particle, the greater the effect on its average velocity is the increase in oscillation amplitude.

Calculations were made and the design of the experimental model of the rexman screen was developed (figure 6). Like any mechanical device, the separator is driven by an electric motor. Then rotation is transferred to double crank 1 and through connecting rods motion is transmitted to lower and upper screens 2, 3. This movement has an oscillatory character. At that frequency and amplitude of sieve oscillations is determined by dimensions of crank 1. Crank 1 is made using two toothed gear eccentric systems with offset drive gear wheel.

**Figure 4.** The cyclogram of the slider movement $S$ on the rotation angle of the driving shaft $\phi_b$ (curve 1) and its components: curve 2 corresponds to the rotation speed of the imaginary carrier; curve 3 corresponds to drive shaft.

**Figure 5.** Options for modifying the law of movement of the driven member.
The modification did not entail a complication of the design. The expected effect (according to [2]) is an increase in the productivity of the rexman screen 10 - 20 percent.

5. Conclusions

Thus, the use of gear eccentric system with additional harmonics in the separation of grain mixtures is quite interesting. For further, wider use of grain separators at agricultural enterprises, further study of the technology, design of separators, their drives is necessary, which will significantly improve the quality of the technological process, increase the efficiency of separation of grain mixtures and the life of machines.

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