Structural synthesis and geometry analysis of planetary intermittent motion mechanisms with elliptical gears

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Structural Synthesis and Geometry Analysis of Planetary Intermittent Motion Mechanisms with Elliptical Gears

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Abstract. Mechanisms with intermittent movement of the output link are widely used in drives of automatic and semi-automatic machines. Currently, the most widespread are the mechanisms of a permanent structure with one-way coupling (ratchet, anchor mechanisms) and mechanisms of a variable structure (Maltese mechanisms, star mechanisms, incomplete gears), however, they are characterized by high loads on the links due to impacts that occur at the beginning or end of the phase movement. The aim of this work is the structural synthesis of actuators, in which the rotational motion of the input link is converted into intermittent motion of the output link, while the kinematic chain does not open during the cycle of the mechanism. As a synthesis method, a structural mathematical model is used in the form of a system of equations that describes the relationship between the quantitative and qualitative composition of the links and kinematic pairs of the future mechanism, its mobility, the number of connections to the rack and other structural parameters. Based on the results of structural synthesis, planetary gear schemes with elliptical gears are constructed, which, with certain gear sizes, allow intermittent motion of the output shaft. A geometric analysis of the mechanisms with elliptical gears is carried out, as a result of which the principle of their action is shown, link position plans are constructed and the output shaft rotation angle functions are obtained. Since the motion with stops is carried out without breaking the kinematic chain, the developed mechanisms are more reliable and compact in comparison with existing analogues, and can be recommended for wide practical application. Possible structural designs of the synthesized mechanisms and examples of use as part of a conveyor and mixer drive with intermittent movement of the impeller are shown.

INTRODUCTION

The design of actuating cyclic mechanisms that ensure the stopping of the output link is an important practical task, since such mechanisms are used in various branches of mechanical engineering [1-3]. They provide rotational or translational motion with stops of the working body with uniform rotation of the input link. The most common at present are two types of mechanisms: permanent structure mechanisms with one-way coupling (ratchet, anchor mechanisms) and variable structure mechanisms (Maltese mechanisms, star mechanisms, partial gears).

Intermittent motion in these mechanisms is ensured by breaking the kinematic chain, so they cannot be used in high-speed machines due to shocks that occur at the beginning or end of the movement phase. To eliminate this drawback, lever [4] and gear-lever mechanisms [5, 6] with stops of the output link are developed. A large number of works are devoted to their structural synthesis [5], kinematic [4] and dynamic analysis [6]. However, their synthesis and design are a rather difficult task, while the use of linkage mechanisms increases the dimensions of the transmission.

Recently, geometry, kinematics, as well as the possibilities of practical application of gears with non-circular gears have been widely studied [7, 8]. The inclusion of non-circular wheels in the planetary gear scheme allows to obtain mechanisms with uneven rotation of the output link [9], the rotationally reciprocating motion [10, 11] and the intermittent motion [7, 8, 12]. Thus, various laws of motion of the output link are realized with a uniform rotational movement of the input link.

The aim of this work is the structural synthesis and geometric analysis of planetary intermittent motion mechanisms with elliptical gears, in which the movement with stops is carried out without breaking the kinematic chain.

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STRUCTURAL SYNTHESIS OF PLANETARY MECHANISMS WITH ELLIPTICAL GEARS

To synthesize the structural scheme of the mechanism, we apply the structural mathematical model, which has the following form [13]:

$$\begin{cases} p = \frac{1}{2}\left(\sum_{t=T-j}^{2} t n_t + S\right); \\ n = \sum_{t=T-j}^{2} n_t; \\ W = \sum_{i=1}^{\Pi-1} i p_i - k\Pi; \\ k = p - n; \\ p = \sum_{i=1}^{\Pi-1} p_i; \\ T \le k+1, \end{cases} \tag{1}$$

where n is the total number of movable links; n_t is the number of movable links with t vertices; p is the total number of kinematic pairs; p_i is the number of kinematic pairs of the i-th mobility; T is the number of vertices of the base link; k is the number of independent closed circuits; Π is the mobility of the space in which the mechanism is synthesized; W is the mobility (DOF) of the mechanism; S is the number of connections to the racks; i, j are integer indices.

Structural synthesis is carried out under the following initial conditions. Let the future mechanism exist in a three-DOF space (Π = 3), have two closed loops (k = 2), one three-vertex base link (n_3 = 1, T = 3), one- (p_1) and two-DOF (p_2) kinematic pairs. Substituting the synthesis conditions into the system of equations (1), we obtain:

$$\begin{cases} p = \frac{1}{2}(3n_3 + 2n_2 + S); \\ n = n_3 + n_2; \\ 1 = 2p_2 + p_1 - 2\cdot 3; \\ 2 = p - n; \\ p = p_1 + p_2; \\ 3 \le 3. \end{cases} \tag{2}$$

When solving the system of equations (2), the following integer roots can be distinguished:

$$p_1=1,\ p_2=3,\ p=4,\ n_3=1,\ n_2=1,\ n=2,\ S=3; \tag{3}$$

$$p_1=3,\ p_2=2,\ p=5,\ n_3=1,\ n_2=2,\ n=3,\ S=3; \tag{4}$$

$$p_1=5,\ p_2=1,\ p=6,\ n_3=1,\ n_2=3,\ n=4,\ S=3; \tag{5}$$

$$p_1=7,\ p_2=0,\ p=7,\ n_3=1,\ n_2=4,\ n=5,\ S=3. \tag{6}$$

To select one of the solutions (3) – (6), we introduce restrictions on the number of two-DOF kinematic pairs ($p_2 \le 2$) and the total number of kinematic pairs ($\sum p \le 5$). These restrictions are rational in terms of simplicity and reliability of the synthesized mechanism. The set conditions are met by solution (4), which corresponds to a two-row planetary mechanism with two external gears. This transmission is well known and, depending on the size ratio of the gears, can act as a multiplier or reduction gear. The inclusion of non-circular gears in the transmission scheme allows to obtain various types of motion of the output shaft [10], including intermittent motion [12]. Consider planetary mechanisms using elliptical gears (Fig. 1).

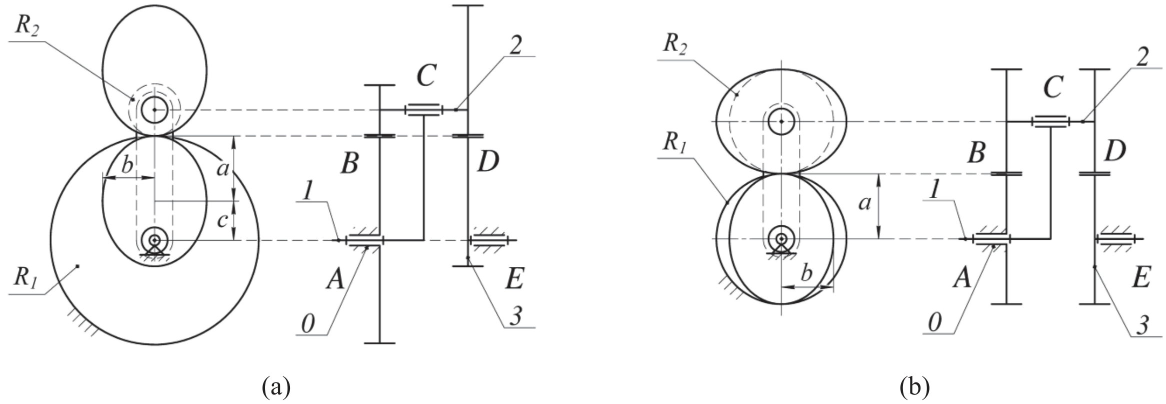


FIGURE 1. Planetary intermittent motion mechanisms with elliptical gears: (a) axis of rotation in focus of the pitch ellipse; (b) axis of rotation in centre of the pitch ellipse

The mechanism consists of three single-DOF (A, C, E) and two two-DOF kinematic pairs (B, D); one three-vertex (link 2) and two two-vertex links (links 1, 3); three connections to rack 0 (S = 3). Thus, the structural schemes of the mechanisms in Fig. 1 correspond to solution (4). Replacing the spur gears on non-circular does not change the structure of the mechanism.

GEOMETRY ANALYSIS OF INTERMITTENT PLANETARY GEARS

The synthesized mechanisms are distinguished by the use of various types of elliptical gears: a pair of gears with rotation axes in the focus of the pitch ellipse (Fig. 1, a) and in the center of the pitch ellipse (Fig. 1, b). To ensure intermittent movement of the output link of the mechanism according to Fig. 1 (a), it is necessary to provide the following values of the spur gears radii:

$$R_1=a+c; \tag{7}$$

$$R_2=a-c, \tag{8}$$

where a and b are the major and minor axes of the pitch ellipse, c is the focal distance of the pitch ellipse.

Consider a mechanism with the following geometric parameters: a = 25 mm, b = 20 mm, c = 15 mm, R_1 = 40 mm, R_2 = 10 mm. Let us construct plans of the positions of mechanism for one revolution of the cylindrical satellite wheel (Fig. 2).

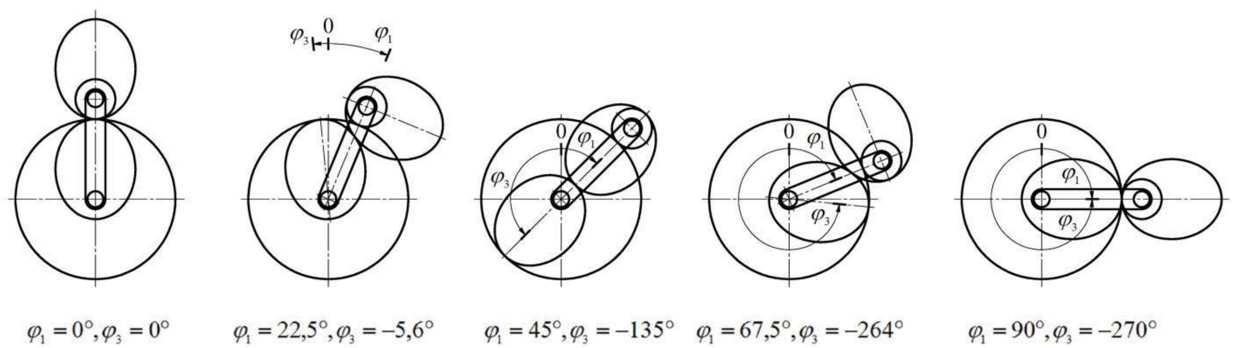


FIGURE 2. Plans of the positions for the mechanism with the elliptical wheels axis of rotation in the focus of the pitch ellipse

Intermittent movement of the output link of the mechanism according to Fig. 1, b is provided with the following values of the radii of the cylindrical wheels:

$$R_1=a; \tag{9}$$

$$R_2 = b. \tag{10}$$

We analyze the mechanism with the following geometric parameters: a = 25 mm, b = 20 mm, R_1 = 25 mm, R_2 = 20 mm. Let us construct plans of the positions of mechanism for one revolution of the cylindrical satellite wheel (Fig. 3).

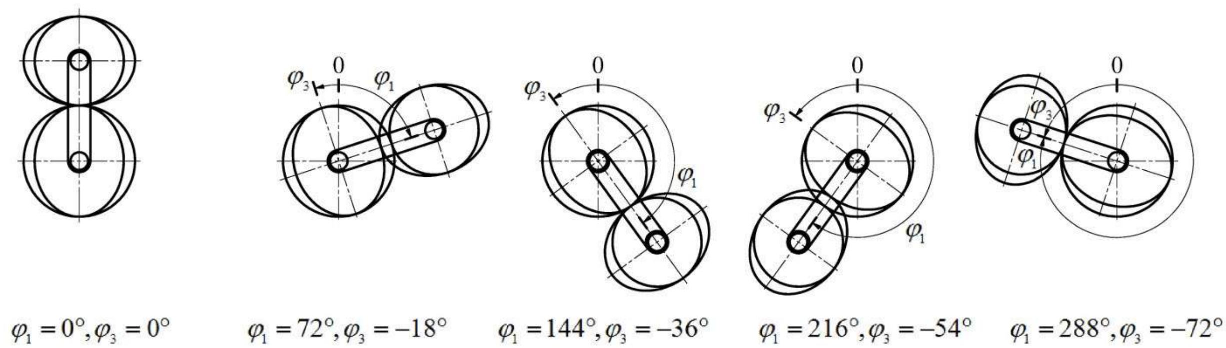


FIGURE 3. Plans of the positions for the mechanism with the elliptical wheels axis of rotation in the centre of the pitch ellipse

Having built position plans at intermediate points and measured the rotation angles of the input and output shafts, we obtain the position functions of each mechanism (Fig. 4).

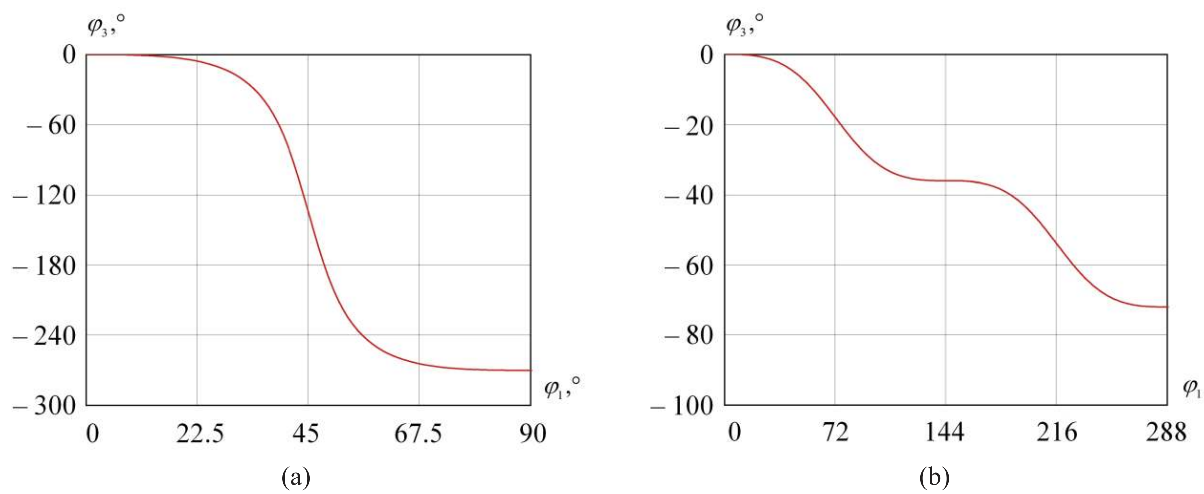
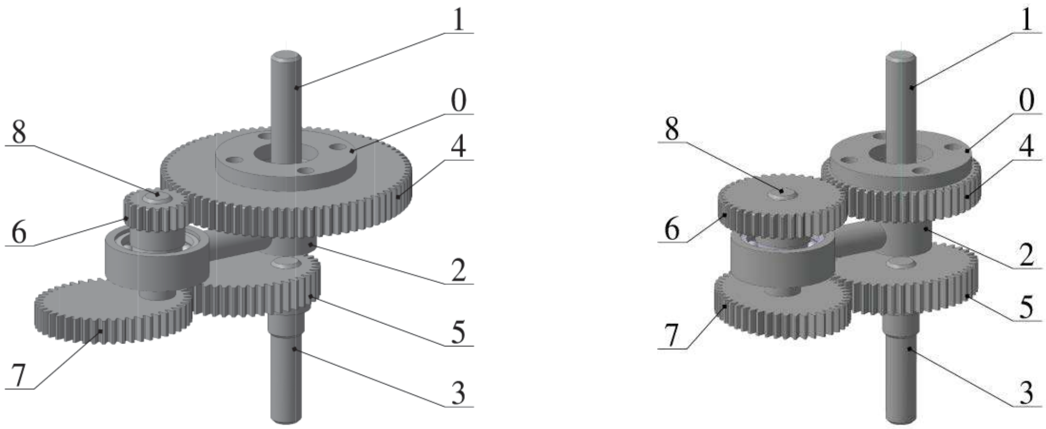


FIGURE 4. Position functions of intermittent movement mechanisms with elliptical gears: (a) axis of rotation in focus of the pitch ellipse; (b) axis of rotation in centre of the pitch ellipse

As can be seen from the graphs, for one revolution of the satellite, the output shaft of the mechanism with the rotation axis in the focus of the pitch ellipse makes one stop, and the output shaft of the mechanism with the rotation axis in the centre of the pitch ellipse makes two stops. The angle of rotation of the input shaft, for which the satellite shaft makes one revolution, is determined by the gear ratio of the cylindrical gears.

PRACTICAL APPLICATION OF PLANETARY INTERMITTENT MOTION MECHANISMS WITH ELLIPTICAL GEARS

The geometric analysis of the synthesized mechanisms showed that the use of elliptical wheels with specified dimensions ensures the movement of the output link with stops during continuous movement of the input link. The design of planetary mechanisms according to Fig. 1 is shown in Fig. 5.



(a) (b)

FIGURE 5. Design of planetary gears: (a) axis of rotation in focus of the pitch ellipse; (b) axis of rotation in centre of the pitch ellipse

The developed mechanisms operate as follows. The input shaft 1 performs rotational motion, which is transmitted to the carrier 2, so that the spur gear 6 rolls around the stationary gear 4. The rotational movement of the spur gear 6 is transmitted to the satellite shaft 8 and the elliptical gear 7, which drives the elliptical gear 5 and, respectively, output shaft 3. At the time when the gear ratio of the pair of elliptical wheels is equal to the gear ratio of the pair of cylindrical wheels, the output shaft 3 is stopped. Further, the speed of the output shaft increases to the maximum value, then again decreases to zero. This provides intermittent movement with stops of the output link.

Intermittent movement mechanisms are mainly used in conveyors of automatic lines. An example of using a synthesized mechanism in a conveyor drive system is shown in Fig. 6.

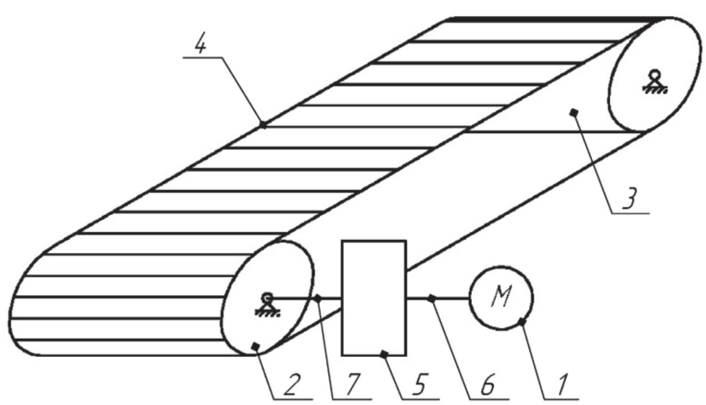


FIGURE 6. Discrete conveyor drive: 1 – motor, 2 – driving pulley, 3 – driven pulley, 4 – conveyor belt, 5 – planetary intermittent motion mechanism, 6, 7 – input and output shafts of the mechanism

Also, the developed gears can be used as the actuator of the stirred tank (Fig. 7). By connecting the motor shaft with the input shaft of the planetary mechanism, and placing the impeller on the output shaft, we obtain a stirred tank with intermittent motion of the impeller.

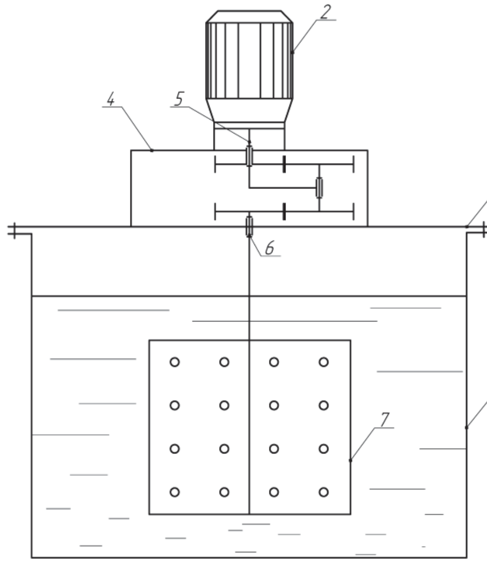


FIGURE 7. Stirred tank with intermittent motion of the impeller: 1 – reactor, 2 – motor, 3 – reactor cover, 4 – actuator, 5, 6 – input and output shafts of the actuator, 7 – impeller

Many researchers note [14-18] that traditional mixers with a constant speed of rotation of the impeller do not allow maximum efficiency of the mixing process. The use of the mechanism of intermittent motion in the drive system of the stirred tank will increase the velocity difference of the processed liquid, which will increase the intensity of mixing and eliminate stagnant zones in the reactor.

CONCLUSION

As a result of structural synthesis, planetary mechanisms with elliptical gears were obtained, the variable gear ratio of which allows the implementation of various types of motion of the output shaft. Geometric investigations have shown that the developed gears with certain sizes of gearwheels allow for intermittent movement of the output shaft with continuous uniform rotation of the input shaft. Since during the work cycle there is no rupture of the kinematic chain, the obtained mechanisms can be recommended for wide practical application.

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