Constructive solutions for upgrading of the drive of processing equipment

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Abstract. This paper presents the results of studies to assess the efficient use of the equipment with flexible thrust coupling used as working bodies. Such mechanisms are known as wave mechanisms, where the transformation of motion is carried out due to the deformation of the flexible link. A number of constructive diagrams of wave gears and the kinematics of the movement of their working bodies were analyzed in the work. On the basis of an asymmetric diagram of the motion law of flexible coupling, the basic design of an inertial conveyor with a spring tab has been developed by equation.

1. Introduction
At present, the processing equipment with flexible thrust coupling or working bodies of considerable length is used in mechanical engineering [1-4]. In addition to the equipment considered in the article, various types of research in different fields are also conducted in parallel [5-21]. The complex movement patterns of actuation device, speed, impulsivity of the working cycle require the search for fundamentally new technical solutions to upgrade this equipment, namely in the drive system. In modern technology, wave mechanisms, so-called coaxial mechanisms, in which the transformation of motion is carried out by deforming the flexible link are widely used [22-24].

2. Objects and research methods
In figure 1a the working scheme of the wave transfer mechanism is presented. The mechanism I includes a full rotary crank 1 with an end roller 2 mounted on a drive shaft 3, bearing pulleys 4 and 5, a bypass circle 6 and a flexible coupling 7, 8 fixed at points 9.

When turning the crank 1, for example, clockwise with an angular frequency \( \omega_k \) at an angle \( \phi = \pi \), any point of the straight-line segment of the flexible coupling 7 is shifted to the left by the amount \( \Delta S = AB_0C - ABC \) (figure 1a). During the subsequent movement \( \phi = 2\pi - \pi \), the crank releases flexible coupling by the same value \( \Delta S \), which can be compensated either by a spring compensator (figure 1a) or by an identical mechanism with a crank operating in relation to the crank 1 with a shift the phase of rotation at an angle \( \pi \) (figure 1b). In the latter case, with continuous rotation of the cranks mounted on a common drive shaft 3, the linear section of the flexible coupling performs a reciprocating impulse movement with amplitude of \( \pm \Delta S \).

The wave transfer mechanism can be designed as follows (figure 1b). The axis of the fixed pulley 4 and the axis of the drive shaft 3 of the crank 1 of the mechanism I are combined. The crank 6 of the II mechanism is also mounted on the shaft 3 at an angle \( \pi \), and the flexible coupling is made in
the form of an endless belt 7, 8. When the crank 1 rotates counter clockwise, the roller 2 with the center of rotation at point a, touching the upper branch, begins to form a “corrugation” ABC (flexible coupling waves). The lower roller 2 of the crank 6 with the center of rotation at the point b produces the release of the previously formed “corrugation” ABC, while, during the angle of rotation of the crank φ = 2π, the flexible coupling moves by an amount ΔSк = ABC - AC. Driven pulley 5 is rotated, respectively, at an angle Δθ = 0.5·ΔSк·π·r2-1. Then the first roller carries out free ferrying of the “corrugation” along the fixed pulley 4, and the second roller moves in the space between the branches of the flexible coupling. The marked period of movement is accompanied by a dwell operation of pulley 5.

Figure 1. The basic diagrams of the wave pulse mechanisms with flexible coupling:
   a) diagram of the mechanism of lever-roller reversal of flexible coupling;
   b) diagram of the wave non-axial transmission.

Thus, this mechanism provides (with a uniform rotation of the crank 4) pulsed rotation of the pulley 5 with an amplitude ΔS of one sign along the neutral line of the flexible connection and oscillation of the branches of this connection in the vertical plane with a variable length of the flexible connection with amplitude ± Δvar [25-27].

The speed of the linear displacement of the flexible coupling of the dual reciprocating mechanism, if x₁ = x₂, r₁ = r₂ = r (figure 1a), is found from the expression

\[ v_\phi = 0.5·\Delta S·\omega·\sin\phi + F(\phi), \]  

where \( F(\phi) \) is a function of the angle of the crank rotation, depending on the geometric parameters of the mechanism. For normal operation of the mechanism, it is necessary to observe the self-compensation condition of flexible coupling branches

\[ |v_\phi| = |v_\phi + \pi|. \]  

In the general case, the lever-roller reversal mechanism does not provide a speed diagram \( v_\phi \) corresponding to condition (2), which follows from figure 2:

\[ |v_{\phi 1}| \neq |v_{\phi 1 + \pi}|. \]

The self-compensation condition corresponds to a special case of the mechanism with the law of speed change of flexible coupling, which is close to a sinusoidal one (figure 2):

\[ v_\phi = 0.5·\Delta S·\omega·\sin\phi. \]

In this case, the condition of self-compensation is ensured by the introduction of a cam corrector into the kinematic chain [24].

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The maximum displacement of the flexible coupling for the double lever-roller reversal mechanism is determined by the transcendental expression (if $x_1 = x_2$, $r_1 = r_2 = r$) [28].

Shown in figure 1b the wave gear is out of line pulsed transmission with external rolling of the flexible coupling along the fixed pulley. This gear can work both by engaging the flexible coupling with the pulleys, and by frictional contact [3, 4]. The speed of movement of the branch of the flexible coupling of this gear in the period of the pulse is found from the expression:

$$v_u = \omega_k \cdot y \{\sin(\varphi_0 + \varphi) - (r_1 - r)y^{-1}\},$$

where $y$ is the circle radius of the centers of the rollers; $r_1$ is the radius of the fixed pulley; $r$ is the radius of the rollers; $\varphi_0$ is the angle of rotation of the crank, corresponding to the moment of contact of the roller and the leading branch of the flexible connection:

$$\varphi_0 = 0.5 - \alpha; \quad \alpha = \arccos[(r_1 - r)y^{-1}].$$

The distance of movement of the flexible coupling within one pulse is calculated by the expression:

$$\Delta S_k = 2y[\sin\alpha - \alpha(r_1 - r)y^{-1}].$$

The average and instantaneous values of the gear ratio for the wave pulsed transmission are determined by formulas (5) and (6) respectively

$$i_{avg} = \pi r_2 z^{-1} \left\{\left[y^2 - (r_1 - r)^2\right]^{0.5} - (r_1 - r) \cdot \arccos[(r_1 - r)y^{-1}]\right\}^{-1},$$

$$i_{\varphi} = r_2 y^{-1} \left[\sin(\varphi_0 + \varphi) - (r_1 - r)y^{-1}\right]^{-1},$$

where $z$ is the number of leading crank rollers; $r_2$ is the radius of the driven pulley.

The angle of the crank rotation corresponding to the dwell of the driven pulley is $\varphi = 2(\pi z^{-1} - \alpha)$.

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Figure 2. Motion-velocity graph.

Analysis of expressions (5) and (6) shows that the wave out of line transmission can perform the functions of a variator with positive infinitely variable (frictional principle) or stepped (gearing) variation of the speed of movement of the driven link by controlling one of the parameters $y$, $r$ or $r_1$ [24].
The mechanism of lever-roller reversing found the industrial use in the drives of wire-chain saws for cutting rock salt during borehole blasting of the salt massif. The saw drives used provide the reversal of flexible connections (ropes) due to the impulsive (up to 1500 cycles per hour) switching of a hydraulic or pneumatic electric drive, which is accompanied by the frequent failures and breakdowns of the control system elements. The proposed mechanism of the saw moving excludes the use of any control gear of the reverse. Another advantage is the simplicity of construction, due to the fact that the traction rope serves as a working unit of the mechanism, which also simplifies the structural layout of the feed and cutting drive of the saw.

The installation scheme with the drive of the saw type HSD is shown in figure 3a. The saw 1 is driven from the drive mechanism 2 by means of the flexible coupling or the traction ropes 3 through the support rollers 4. The chamber filings are made from the upper hooking.

![Figure 3a](image1)

**Figure 3.** Scheme of installations with the wave pulse drives:

a) with the drive of the saw type HSD;

b) the basic design of the inertial conveyor with a spring compensator.

Using of an asymmetric diagram of the law of motion of the flexible coupling, according to the equation, the basic design of an inertial conveyor with a spring compensator was developed (figure 3b). The load-carrying and traction body of the conveyor is a flexible link – a vibrating carpet 1, receiving reciprocating movement from the drive mechanism 2. The vibrating carpet moves without detachment from the support rollers 3, i.e. with constant pressure load on the gutter. The advantage of this conveyor is the absence of metal inertial boxes and the simplicity of the drive mechanism [29].

3. Conclusions

1. The wave pulse mechanisms with flexible connections allow for the reciprocating movement of the working body with a uniform rotation of the driving link without using the switching equipment.
2. To ensure equality of speeds of movement of parallel branches of the flexible working body (in accordance with the self-compensation condition), it is necessary to introduce a cam-adjusting device into the kinematic chain of the mechanism.
3. The wave impulse mechanisms with the flexible connections make it possible to develop the reciprocating drives with a simple structural design, for example, for the wire saws of impulse action or the swing conveyors.
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