New rotator dynamic models

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Abstract. The advantages of drilling with the superposition of torsional vibrations and features of a pulsed rotator design to reduce friction losses during transmission of the uniform rotation by the links of vibrators are considered in this paper.

1. Introduction
The creation of new constructive solutions of technological machines provides for the greatest use of the supplied energy to perform the required amount of useful work. Energy losses occur in the working machine mechanisms and in the transformation process of the material being machined. In mechanisms, energy is dissipated by friction in kinematic pairs, unreasonable location, displacement velocity and acceleration of links in the kinematic chain, unavoidable side effects (temperature, specific pressure, etc.)

The maximum energy absorption for the given useful work performance is determined by physical properties and optimal interaction with the working member of the machine.

Thus, the set-up parameters of the mechanisms are coordinated with the demand for the processing of materials.

Dynamic impact is traditionally used in the processing of materials (well drilling, concrete and mineral drilling) by the pneumatic, mechanical and other vibrators with the pulse direction along the working tool rotation axis.

The experiment results on the mineral destruction by compression and cleavage have shown a significant reduction in the cleavage fracture force (10 ÷ 12 times). Until now, industrial machines and mechanisms have not been created to use this property of materials and torsional vibration modes have not been determined for the entire range of technological processes.

2. Experiment and rationale of vibrator designs
The constructive solution rationale is possible after the determining of the optimum vibration effect on the material being processed. A positive factor of the impulse action along the tangent to the trajectory of points of the rotating working member can be considered as the application of pulsed drilling during metal processing as the loads on compression and metal cold-hardening are eliminated.

It has been experimentally established that the speed of the "static" cutting is much less than the dynamic speed with various tool feeding force onto the material being processed.
The rotator power decreases with impulse action and changes from the feed force less intensively. The vibrator drive consumes 20 ÷ 30% of the rotator power. The change of the speed and power in a dynamic mode depends on the amplitude-frequency characteristic and the time-determining impulse action. The oscillation frequency improves the dynamic process parameters more intensively.
The optimal combination of power and speed changes lies in the range of $50 \div 80$ Hz and determines the necessary design parameters of the torsional vibration exciter. The choice of kinematic schemes of excitors provides for the fulfillment of conditions for their optimal operation, minimum dimensions and forces in kinematic pairs. Slider-crank mechanisms [2] were used in experimental installations and their dimensions did not correspond to the planned industrial rotators.

3. Kinematic drive circuits. The study of regularities

An additional degree of freedom by separating the driven shaft was introduced in the design of the wedge-shaped device for the oscillation excitation.

![Figure 3. The motion summation scheme](image)

The impulse rotator design [3] uses the summation of uniform and periodic motions. Body 1 of the device with cams 2 is stationary, wedge-shaped pusher 3 is moving in a seesaw mode due to the profile curvature and the resilient member. Evenly rotating shaft driving part 4 with its left surface carries a pusher moving along the body profile and the right surface sums the uniform and oscillating rotation of driven part 5 of the working member shaft.

Angle $\alpha$ of the pusher surface inclination is limited by the friction cone and allows for a small change in the displacement of driven part 5. Displacement gain increases the frictional losses and may cause the mechanism jam.

The method of oscillation creation [4] with the help of a rotary cam-pusher (Fig. 4) reduces friction losses in kinematic pairs and allows a large range of the oscillation amplitude.
In contrast to the wedge-shaped device for the oscillation excitation, the acting forces are directed perpendicular to the perception plane of their reaction in this method. The force from cam 1 of body 3 acts on cam-pusher 2 perpendicular to its surface and rotates it on axis 5 until the lower part of the cam-pusher contacts surface 4 of the driven shaft part.

4. Conclusion

The magnitude of pressure angle $\alpha$ of the link is determined at the tangency point of the cam-pusher with the surface of the shaft driven part provided that it is moved in a translational motion. In view of the small relative displacement of the shaft, the driven part from the applied impulse force and characterized by the angles of a large rotation radius of the tangency point, the assumption of rectilinear motion of point A is comparable with the error in the gaps of the kinematic pairs.

In Figure 4, the cam-pusher axis is mounted on the shaft driven part and stationary relative to the shaft. One of the most important design parameters, the pressure angle of the driven member determines the frictional losses and even the jamming of the mechanism. The kinematic pair and the contact surfaces arrangement were designed with allowance for the minimum value of this angle. In the considered torsion oscillator, the force in the cam-pusher is determined by the magnitude of the working member torque and significantly affects the possible losses of the supplied energy.

The effect of angle $\alpha$ on the cam mechanism operation can be represented by the components of force $Q'_{12} = Q'_{121} + Q'_{122}$ in the projections on the axis along the tangent to the contact surface of the cam-pusher and the shaft driven part, characterized by angles $\alpha$ and $\varphi$ and perpendicular to the tangent:

\[
Q'_{12} = Q_{12} \cos(\alpha + \varphi_{112}),
Q''_{12} = Q_{12} \sin(\alpha + \varphi_{112}).
\]

Components $Q'_{12}$ perform useful work. $Q''_{12}$ causes losses of applied force on friction. With increasing force $Q''_{12}$, the force proportional to it increases $F_f = F_{32} = f Q''_{32}$ in the cam contact zone of the shaft driven part. In the contact zone of the second cam-pusher arm with the body, force $Q_k = Q_{N2} \frac{I_{k1}}{I_{k2}}$ depends on the ratio of the cam-pusher arms and causes increased wear of the sliding pair and heating.

The formula for determining pressure angle $\alpha$ in mechanisms with translational motion of the pusher:
$\tan \alpha = \frac{V_{B2} + e}{\omega_1 S_{B2} + r_0^2 + e^2}$, where

- $V_{B2}$ – speed of relative motion
- $\omega_1$ – rotation speed of link 1
- $S_{B2}$ – analogue of speed
- $r_0$ – initial cam profile radius
- $e$ – eccentricity

This determines the constructive ratio of dimensions and directions of the device links and facilitates the creation of an efficient kinematic scheme.

In the mechanisms with the rocker pusher, the value of the pressure angle is determined through the velocities:

$\tan \alpha = \frac{l_2 \frac{d\varphi_{23}}{dt}}{A \sin(\beta_0 + \varphi_{23})}$, where

- $l_2$ – link size
- $A$ – eccentricity characteristic
- $\beta_0$ – the initial angle to the tangency point of the cam-pusher

The experimental data results about the influence of amplitude and oscillation frequency on the productivity and power consumption have shown that the oscillation frequency improves the technological process more intensively.

In the constructions of torsional oscillation vibrators of the proposed method, the force of the cam-pusher on the body depends, with other things being equal, on the ratio of the cam-pusher arms $Q_{23} = \frac{Q_{12} l_1}{l_2}$, where $l_1, l_2$ are the cam-pusher arms.

The value of $Q_{12}$ is determined by the torque value of the working member shaft and radius $R$ to the tangency point of the cam-pusher $Q_{12} = \frac{M_{sr}}{R}$.

Friction force losses $F_f = f Q_{12}$ and the heating of the body surface were reduced due to an increase in the number of cams and the installation of a discharged resilient member [7,8]. Based on the experiment results, it is established that frictional losses reduce the operational reliability of the vibrator operation.

5. Conclusion
An analysis of the work results shows the need to reduce the friction loss in the mechanisms of oscillation excitation by replacing the sliding friction by the rolling friction or by creating a kinematic scheme capable of redistributing forces in kinematic pairs.

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