Impulse Rotators with Kinematic Excitation of Oscillations

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Abstract. Increasing the efficiency of technological process is achieved by applying oscillations in the movement direction of the working tool active point. The proven advantage of the dynamic impact on the chip at energy-intensive technological processes, for example drilling, wasn't used because of the lack of appropriate mechanisms. The proposed mechanisms can be used in specific conditions. An analysis of their constructive changes allows to predict the development direction of impulse rotators and new ways for creating torsional oscillations and devices for their implementation with possibility of maximizing the use of the connected energy on work process and minimum losses in the rotation drive.

1. Introduction

The dynamic impact on the processed material expands the scope of machining, improves the quality of the process, increases productivity and reduces energy consumption per unit of output.

The direction of the force impulse along the tangent to the trajectory of the working tool of the rotating working body gives several advantages over oscillations along the axis of rotation in many technological processes, such as: components mixing; screw conveyor; grinding; washing and others. Torsional vibrations show the greatest effect in highly energy-intensive processes.

The destruction of rocks of medium and above average blast hole strength is carried out with the imposition of force pulses in roller cone bits and a special pneumatic impact device. The direction of the pulse in this process occurs perpendicular to the fracture surface and requires a significant effort of dynamic action with low beneficial use of supplied energy and a complex technological process for the pneumatic method of cleaning wells. The use of cutting drilling has several advantages in organizing the drilling of blast holes, but is limited by the strength of rocks. The efficiency of rock destruction when the pulse is directed to a cleavage tangential to the path of the cutting edge was proved in the 30-40s of the last century, but did not receive industrial application due to absence of torsional vibration exciters. The maximum use of the summed energy of a single impulse is possible when coordinating physical and technical properties of the processed material with rotators design of machines working bodies. For example, in the process of dynamic drilling, the efficiency of rock destruction is determined by both the amplitude-frequency characteristic and the time of the pulse, the process of loading, power parameters.

Pulse rotators, as a combination of a reducer and a dynamic exciter of torsional oscillations, appeared in the 70s of the twentieth century. Torque is applied to the driven shaft of the pulse rotator (PR).
\[
M = M_i \cdot i \cdot \eta + M_u
\]  \hspace{1cm} (1)

where \(M_i\) is the torque of the uniform rotation motor  
i - gear ratio  
\(\eta\) - drive efficiency  
\(M_u\) - moment of inertial momentum forces,

\[
M_u = 2 \cdot a \cdot m \cdot e \cdot \omega^2 \cdot \sin \omega t
\]  \hspace{1cm} (2)

where \(m\) is eccentric mass  
a - center-to-center distance between the sun wheel and satellites  
e - satellite eccentricity  
\(\omega\) is the angular velocity of satellites rotation

5. Differential equation of impulse rotator motion is composed using the Lagrange equation

\[
\frac{d}{dt} \left( \frac{\partial T}{\partial \dot{q}_i} \right) - \frac{\partial T}{\partial q_i} = Q\dot{\varphi}
\]  \hspace{1cm} (3)

The kinematic energy of eccentrically located masses determines the regularity of the pulse action and the pulse force factor. Exceeding the destruction force of the material being processed, the magnitude of the force impulse changes the nature of the dynamic action, especially in mechanisms with two or more mobility degrees. In such mechanisms it is difficult to maintain the specified parameters of dynamic effects.

Kinematic devices on pulsed rotators of various design solutions, which have several advantages over the dynamic mode of excitation, were proposed in 1972. The pattern of impulse point movement of the working body, for example, a crank-slider mechanism is determined by the structure and position of the kinematic chain links and the deviations are determined by the elasticity and strength of the links. The projection of the acceleration point analogue from the working body to the X axis:

\[
\dot{x}_c = -l_1 \left\{ \cos \varphi_1 + \frac{1}{\lambda} [\cos \varphi_2 \dot{\varphi}_2^2 + \varphi_2 \cdot \ddot{\varphi}_2] \right\}
\]  \hspace{1cm} (4)

where \(l_1\) is the leading link  
\(\varphi_1\) - angle of the leading link  
\(\lambda\) - link ratio  
\(\varphi_2\) - angle of link 2 rotation  
\(\ddot{\varphi}_2\) - link 2 acceleration

In the kinematic chain of the oscillations exciter, regularity of change in momentum is provided in the given parameters of devices with one degree of freedom. The sequence of creation of torsional vibration exciters provided for the device of minimal friction losses and optimization of uniform rotation transmission.

Initially, kinematic excitation of oscillations was installed on planetary gearboxes with two degrees of freedom: uniform rotation was summed up by vibrations of the crank mechanism or eccentric [1], with the possibility of automatic control of operating modes [2]. Sophisticated design made it difficult to manufacture and use this method of creating torsional vibrations.

2. Methods, constructions

The authors obtained a fundamental change in the torsional vibration exciters by dividing the shaft of the working body into two parts, between which the moving part of changing the uniform rotation of the shaft first part together with the working body was established. The pulse rotator of the working body of the machine [3] created oscillations of the shaft with the working body due to the reciprocating motion of the conical insert between the surfaces of the two shafts. The conical insert of the outer surface slid along the cam surface of the rotator housing. In this design, the change in the amplitude of the oscillation is limited by high loads in kinematic slip pairs with the possibility of jamming.
Figure 1 shows the principle of operation of the device for creating oscillations and mutually exclusive technical solutions for increasing the amplitude of oscillations. The first part of the shaft 1 rotates uniformly and transmits torque through the supporting surfaces 2 of the first shaft, the surface 3 of the cam 4, which rotates it through the supporting surface 5 of the cam 4 and the supporting surface 6 of the second shaft 7. The cam 4 moves along the inner surface of the rotator housing 8 and, when interacting with the cams 9 of this surface, moves to the center of rotation, imposing a pulse on the rotation of the second shaft.

The angle of inclination $\alpha$ of the surfaces 3 and 5 of the cam 4 limits the amplitude of the working body oscillation and the dynamic loads on the cams 9 with a small change in the amplitude of torsional vibrations.

$$\frac{dA}{R} = \frac{d\varphi_2}{2} = \frac{dS}{R} \tan(\alpha),$$
where

- $dA$ - oscillation amplitude of the contact point
- $\varphi_2$ - change in torsional oscillations
- $R$ – radius of the contact point
- $dS$ - cam 4 shift to the center
- $\alpha$ - inclination angle of the surfaces 3 and 5 and the cam 4

A decrease in the angle $\alpha$ increases the ratio $\frac{dS}{R} \frac{d\varphi_2}{2}$ and reduces energy losses, and cam jamming between the surfaces of the first and second shafts is not excluded. With an increase in the angle $\alpha$, it is possible that the vector of the displacement force enters the zone of the friction cone and may lose operability.

This design practically does not change the dimensions of the rotators, but its use is limited to devices of low intensity vibration and increased energy consumption.

The need for the material to be processed in a wide range of pulsed action control determined changes in the operation principle of torsional oscillation vibrators.

The method of creating torsional oscillations [4] on the shaft of the executive working body is based on the addition of uniform and oscillatory movements. The shaft is made of two parts, the first part rotates evenly, and the vibrational motion is superimposed on the second part by the interaction of the profiles of three kinematic pairs. Changing the frequency of cycles and their patterns in comparison with the harmonic movements of oscillations exciter shaft provides the technological need of the processed material in pulsed action, changing the amplitude-frequency characteristics of the disturbing force of each subsequent cycle, eliminating unwanted resonance phenomena in the drives by regulating the laws of relative motion of the parts of the working body shaft. The implementation of the claimed method is illustrated using the device in figure 2.
Figure 2. Device and method for creating torsional oscillations.

The device comprises a fixed cam 1, kinematic sliding pairs 3 and 4, cam follower 2, and a kinematic pair of rotation 5. When the first part of the shaft is rotated uniformly, cam 2 moves in relative motion when the cam glides on surface 3.

At the moment of touching the stationary cam 1, cam-pusher 2, it rotates on a kinematic pair of rotation 5 and transmits a pulse to the second rotating part of the shaft through surface 4.

The mutual working arrangement of surfaces 3 and 4, cam follower 2, fixed cam 1 and kinematic pair of rotation 5 excludes the possibility of jamming of the exciter of oscillations and allows a wide range of regulation of the amplitude-frequency characteristic.

The proposed method allowed to develop a number of devices of torsional vibrations excitors.

The first patent of a pulse rotator of an executive body of a machine [5] comprises a rotation drive; two parts of the shaft of the working body; a cam follower connected with parts of the shaft and fixed cams on the inner surface of the housing. The cam follower is made in the form of a two-shouldered lever with the axis of rotation on the first part of the shaft and is constantly in contact with one shoulder with the housing, the second with the thrust surface of the second part of the shaft of the working body, constantly transmitting the drive torque and periodically a tangential pulse. The pulse frequency is determined by the number of cams on the inner surface of the housing and in the following constructions by the number of cam followers, the amplitude of the oscillations and the loading pattern are determined by the angle of rotation of the cam follower, the position of the thrust plane of the second part of the shaft and the radius of rotation to the point of contact of the cam follower.

In this torsional vibration exciter, power loads are perceived by the working surfaces of the cam follower, housing, and the thrust surface of the second shaft part and are determined by the design capabilities of the device while preserving the amplitude-frequency characteristics of the optimal effect on the material being processed.

The analytical dependence of the vibration amplitude is determined for simplified rectilinear and cylindrical forms of the surfaces of kinematic pairs. The fixed surface of the body is a cylinder centered on the axis of the working body. When moving along this surface, the cam follower does not rotate relative to point O (Figure 3) until it touches at a point A the surface of the stationary cam of radius \( r_k \). If the center of the cam \( r_k \) is on the inner surface of the cam follower, then the maximum angle of rotation of the cam follower is \( \alpha = 2 \arccos \left( \frac{\Delta r_k}{2} \right) \). The movement of the point B in contact with the second arm of the cam follower \( \Delta S = OB \alpha \). The oscillation amplitude of the
point B $\Delta S = \Delta \varphi_2 R_2$ of the second part of the shaft $\Delta \varphi_2 = \frac{\Delta S}{R_2}$ is determined by the dimensions of the details of the pulse formation mechanism $R_2 = O_2$. Change in the shape of the contact surface of point A and point B is taken into account with the coefficients $\eta_A$ and $\eta_B$ respectively to the point $\Delta \varphi_2 = \frac{2OB \arccos\left(\frac{r_k}{2}\right)}{R_2}\eta_A\eta_B$. Linear displacement of any point $N_i$ on the working body $\Delta S_i = \Delta \varphi_2 r_i \eta_B$.

**Figure 3.** The cylindrical shape of the surface of kinematic pairs.

The greatest change in $\Delta S_i$, ceteris paribus, is provided by the direction of the contact surface of the second plane along the radius $R_2$ and the position of point B on the cam on the midline of angle $\alpha$. In this design of pulse formation mechanism loads in the kinematic pairs are significant. Especially the heating factor with the constant contact of point A for the transmission of both rotational and pulsed movements. Constant work of the surface at point A is excluded in subsequent devices [6] by the introduction of the sequential operation of several cams and the load at the nodes is reduced by the installation of elastic elements.

3. **Conclusions**

A further reduction in the loads in the kinematic pairs to increase the efficiency of the use of the pulse is provided for in the design change of the mechanisms of pulse formation according to the “Method for creating torsional vibrations” [7], where a bearing is mounted in the cam follower.

Each version of the pulse rotator is made and tested to determine rational design solutions. Industrial tests were carried out with electric drills, a milling machine, a lathe, an auger and other machines with a rotating working body.

Currently, along with increasing the reliability of machines, methods are considered for reducing negative vibrations and noise levels with an achieved productivity increase of 2-8 times for various materials and technological processes.
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