Technological Capabilities of Impulse Rotators

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Abstract. In the article "Technological capabilities of impulse rotators" the results of use of impulse rotators in some technological processes, differential adjustment of their motion with kinematic and dynamic vibration exciter are considered. Equation of kinetic energy of impulse rotator allows to determine mutual influence of design elements on rational use of supplied pulse energy for useful work. Positive qualities of kinematic torsional vibration exciters are noted, the main of which is organization of force pulse regularity and its considerable force possibilities of pulse creation. A generalized graph of the change of productivity and wear of the working element of the pulse converter compared to the static one is given. Features of impulse rotators with kinematic excitation of torsional oscillations make it possible to change the mode of work performance, to apply low-energy processes of individual operations. Transportation way of destruction products by the screw with use of an impulse rotator on breeds above average fortress excludes use of the compressor. Machines with rolling and spring impact tools do not correspond to the screw method of destruction products discharge and require compressor use. In this case, the energy intensity of production unit increases more than twice.

1. Technological capabilities of impulse rotators
Optimization of production and operation of equipment is determined by rational use of technological properties of processed material, structural parameters of mechanisms and durability of their operation.
Dynamic impacts in many energy-intensive processes are the predominant and even the only possible modes of work.
Drilling of wells during mining, construction of building objects, roads and trenches etc is used in technological processes by force impact with application of force pulses, dynamic or kinematic methods of their creation [1,2,7,8,16,19].
Rolling, pneumatic, electric-impact and other methods of material destruction are actively used in industry for more than 100 years integration of uniform movement of working tool and short-term periodic application of pulse in direction of material compression. While the destruction of material on shear fracture is 10-12 times more effective.
In industry there are no devices for creation of dynamic loads on shear fracture. The proposal to use a mechanism with two or three degrees of freedom in the 1950s was the beginning for development of rotators of uniform and periodic movement, mainly dynamic and kinematic methods of excitation of torsional oscillations.
Design features of rotators with superimposition of torsional oscillations, impulsed rotators (IR) are determined by capabilities and needs of processed material to perceive specified modes of rotation and amplitude-frequency characteristics ensuring maximum productivity and minimum power consumption per unit of production.

Power consumption of a single pulse depends on structural features of production facilities, scientific-based methods of their use, consistency of capabilities of the object of production and properties of the processed material and change of operating modes of the working element according to the needs of the processed material under the specified operating conditions.

Studies of both dynamic and kinematic effects on the production process determine the efficiency of production. When the force pulse of the given value and direction is superimposed, its action time, loading pattern, repetition periodicity.

It has been experimentally determined that the oscillating motion of the working tool in the direction of shear fracture reduces the coefficient of friction by 2-6 times, the force of destruction up to 12 times, increases the mobility of the material up to 4 times etc.

Initially, centrifugal torsional vibration exciters were propagated by inertia forces of eccentrically arranged masses on planetary reduction gear, (dynamic excitation), perturbing force of periodic action of these rotators depends on debalance mass value, their position on satellites and rotation speed. Amplitude of vibration of such vibrator is determined by inertial forces of disturbance, ratio of mass of balance and uniform rotation, properties of processed material. The variable force on the working member affects the amplitude certainty, changing the loading pattern and pulse action time.

In kinematic method, vibration perturbation of pulse action time, loading pattern, displacement value for any characteristics of processed material depends on shape and arrangement of links and kinematic pairs. Movement of the working tool is guaranteed by vibrator material strength. Such vibration perturbation method fully ensures the need of material to be treated in dynamic exposure modes.

For the first time kinematic methods of pulse generation (Patent for invention "Method of vibration generation" № 2686518, published 25.04.19 bulletin No. 13, patent for invention "Creation way of of tortional fluctuations" No. 2584410, published 20.05.2016, bulletin No. 14, patent for invention "Creation way of tortional fluctuations" No. 2541569, published 27.02.2016, bulletin No. 6 etc.) are proposed in the optimum direction on shear fracture on the movement of working body or on a tangent of rotation points trajectory of the working tool.

Application of dynamic loads in optimal direction of pulse provides reduction of power consumption of destruction process, reduction of friction losses and increase of operating time of both working tool and all kinematic pairs of rotation drive [11,14,15].

Change of power consumption by elements of technological process of rock boring and drilling of minerals and steels determined possibilities of efficiency increase in many mechanisms with rotating working body. Preliminary experiments on drilling, screw transportation of loose materials, drilling and milling of minerals and metals, grinding, retarding, grain grinding etc. showed a significant improvement in the results of materials processing with application of torsional oscillations (impulse).

As torsional vibration exciter dynamic [16] and kinematic [17,18] methods of perturbation are used. Differential equation of rotator motion is compared with both perturbations. For example pulse rotators with two degrees of freedom in the Lagrange equation of the second kind can be considered in generalized coordinates \( \Phi_d \):

\[
\begin{align*}
\frac{d}{dt} \frac{\partial T}{\partial \Phi_d} - \frac{\partial T}{\partial \Phi_d} = \frac{\partial T}{\partial \Phi_d} - \frac{\partial T}{\partial \Phi_d} \\
\frac{d}{dt} \frac{\partial T}{\partial \Phi_a} - \frac{\partial T}{\partial \Phi_a} = \frac{\partial T}{\partial \Phi_a} - \frac{\partial T}{\partial \Phi_a}
\end{align*}
\] (1)

The inventors Devices of pulse rotators (about 30 patents) are proposed by the authors for different operating conditions differential equations of which are identical.

Kinetic energy of rotator links movement
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The sinusoidal pattern of satellites causes sinusoidal oscillations. Useful work of inertia forces is limited by mass of unbalance

An additional degree of mobility allows inertia forces to operate. In case of excess of force resistance degree of freedom are unable to change uniform rotation of working tool. The single excitation of oscillations.

with one degree of mobility similar to load in device with two degrees of freedom at dynamic exciters shows possibility of changing

Q when m is equal

T = J_a \frac{\dot{\phi}_a^2}{2} + n J_d \frac{\dot{\phi}_d^2}{2} + \frac{F u_a^2}{\varphi_{bc} D} + J_d \frac{\dot{\phi}_d^2}{2} + J_H \frac{\dot{\phi}_H^2}{2},

(2)
is different from centrifugal perturbation rotator \( \frac{F u_a^2}{\varphi_{bc} D} = \frac{m v_a^2}{2} \) where:

\( J_a, J_d, J_H \) are links inertia moments about rotation axis \( H \);
\( J_s \) is satellites inertia moment about axis;
\( \varphi_a, \varphi_d, \varphi_H \) are angular links speeds of uniform \( a \), excitation of oscillations of \( d \) and \( H \);
\( \varphi_{bc} \) are angular speeds of satellites;
\( v_i \) is satellites masses speed and application point of force \( F \);
\( F \) is disturbance force;
\( m \) is mass of satellite \( bc \);
\( D = 2 e \), \( e \) is eccentricity of masses and application point of force \( F \).

After determination of speeds \( \varphi_{bc}, \varphi_H \) and \( v_i \) expression of kinematic energy of a system with kinematic excitation of oscillations in the generalized coordinates will be received

\[ T = \frac{\dot{\phi}_a^2}{2} [A_1 + B_1 \cos(\varphi_0 - \varphi_d)] + \frac{\dot{\phi}_d^2}{2} [A_2 + B_2 \cos(\varphi_0 - \varphi_d)] + \varphi_0 \varphi_d [A_3 + B_3 \cos(\varphi_0 - \varphi_d)] \]

(3)

Where constant coefficients \( A_1, A_2, A_3 \) numerically equal to coefficients with dynamic excitation (when \( m \) is equal)

\[ A_1 = J_0 + J_H \left( i_{Hd}^d \right)^2 + n m e^2 (i_{id}^d)^2 + n m r_H^2 (i_{Hd}^d)^2 + n J_s (i_{sd}^d)^2; \]
\[ A_2 = J_1 + J_H (i_{Hd}^d)^2 + n J_s (i_{sd}^d)^2 + n m e^2 (i_{id}^d)^2 + n m r_H^2 (i_{Hd}^d)^2; \]
\[ A_3 = J_H + i_{Hd}^d i_{Hd}^a + n J_s i_{sd}^d i_{sd}^a + n m e^2 i_{id}^d i_{id}^a + n m r_H^2 i_{Hd}^a i_{Hd}^d; \]

(4)

Constant coefficients of kinematic excitation \( B_1, B_2, B_3 \) differ numerically by \( F \) and \( m e \varphi_{bc}^2 \)

\[ B_1 = 2 m n r_H i_{Hd}^d i_{sa} = \frac{2 F r_H}{i_{Hd}^d i_{sa}^d}; \]
\[ B_2 = 2 m n r_H i_{sa}^d i_{Hd} = \frac{2 F r_H}{i_{sa}^d i_{Hd}^d}; \]
\[ B_3 = 2 m e r_H (i_{sd}^d i_{Hd}^a + i_{sd}^a i_{Hd}^d) = \frac{2 F e}{a_{sd}^d} r_H (i_{Hd}^a i_{sa}^d + a_{sd}^d i_{Hd}^a). \]

(5)

Private derivatives of kinematic energy are determined by generalized coordinates and generalized \( Q_{ao} \) and \( Q_{od} \) forces are calculated at possible movements \( \delta \varphi_a, \delta \varphi_d \) and after transformations a final type of Lagrange equation is determined.

Analysis of motion regularity of working element with dynamic and kinematic torsional vibration excitors shows possibility of changing the design of rotary gear box.

Kinematic excitation method makes it possible to perform dynamic load (force pulse) in devices with one degree of mobility similar to load in device with two degrees of freedom at dynamic excitation of oscillations.

Impulse rotators with excitation of torsional oscillations by inertia forces (dynamic) with one degree of freedom are unable to change uniform rotation of working tool. The single-moving rotator system absorbs internal forces in the drive due to additional stresses in structural groups of the device. An additional degree of mobility allows inertia forces to operate. In case of excess of force resistance on working element, value of satellites inertia force is limited and efficiency of pulse action is significantly reduced. It should also be noted that rotation of masses eccentrically arranged on satellites causes sinusoidal oscillations. Useful work of inertia forces is limited by mass of unbalance and acceleration in direction of performed work, increase of which negatively affects structure of device. The sinusoidal pattern of impulse force variation does not always meet the needs of the material being processed.

Kinematic excitation of vibrations is able to organize force action according to the required loading pattern, action time and value. The amount of disturbance force is limited by the allowable strength of
assembly parts. Improvement of impulse rotator design with kinematic excitation provides clear advantage over dynamic ones.

Investigation of different technological processes with both principles of torsional oscillations excitation under compatible vibration conditions showed a general pattern of pulse drives use. A positive factor of work performance of impulsed rotator is increase of reliability and durability of their operation. The reliability of operation is explained by the reduction of dynamic drive with application of vibrations, friction coefficient, thermal mode. Durability of operation, in authors’ opinion, besides reduction of dynamic loads, is provided by reduction of power loads of technological processes by several times and increase of productivity.

Fig.1 shows the dependence of performance and wear of active zones of the working tool and rotator units for most technological processes studied by the authors. The horizontal scale determines the intensity of working process, the left vertical scale determines productivity, the right scale shows wear intensity. All key figures are in conditional relative units of measurement.

**Figure 1.** Dependence of performance and wear of working element of conditional technological process.
Significant reduction of force factors per unit of produced volume of work, reduction of possibility to adjust motion kinematics, specified nature of interaction of working tool and processed material allows to use pulse effect on materials in working processes of high-tech operations. For example, working with materials of limited force effect: glass, cereals, vegetables, fruit etc.

Figure 1 illustrates the possibilities of force limitation of works performance at the specified productivity, energy consumption per unit of production, general and specific wear of the device elements, productivity. For high energy intensive technological processes efficiency of use of pulse rotators is increased due to change of physical and technical properties of processed material and even change of some elements of technological process.

Use of impulse rotators:
on sealing rollers reduces friction between soil particles and changes the directions of their movement; on screw conveyors increases filling of housing volume; on washing machines a significant portion of the contamination is removed mechanically upon activation of relative movement of washing fluid and washing object etc.

2. Conclusion
Impulse rotators on drilling machines use rational direction of force pulse. This expands the use of cutting-type machines in drilling medium-strength rocks and can fundamentally change the delivery of destruction products compared to existing rolling and pneumatic impact machines. In this case, the slurry discharge compressor is excluded from the drilling process and energy consumption for production unit is reduced by two or more times.

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