Classification of Impulse Rotators with Kinematic Excitation of Oscillations

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Abstract. The kinematic torsional vibration exciters ensure that the material to be processed is required in the specified parameters. The structure of the Assur groups involved successive manufacture and testing of a device for practical assessment of motion possibilities, nature of change in process forces, structural reliability and maximum useful application of the supplied energy for destruction of the processed material. Analysis of operation results of laboratory and industrial samples showed their advantage in comparison with existing drives due to expansion of application field, reduction of specific energy consumption of a production unit, quality improvement of technological processes and operation time. The varied influence of torsional oscillations on properties variety of the processed materials has led to the development of an impulse rotators (IR) class of required technical characteristics. In order to increase rotators consistency parameters with materials properties, individual property IR designs are currently being developed.

1. Introduction

The intensity of destruction of material when drilling, boring, milling is defined not only by the engine capacity of the rotator and effort of giving, but also by properties of the processed material. Minerals and concrete of increased strength are not destroyed by traditional drilling. Method of destruction of such materials is borrowed from rolling or impact-rotary drilling machines.

Soviet scientists investigated effective machines and mechanisms with an active working tool. The first drilling experiments in 1934 were started by Doctor of Technical Sciences, Professor E.F. Epstein [21]. The vibration action along the rod axis on compression of the material to be processed was the only way of carrying out works and was successfully used until the early 1950s.

Researches on destruction of materials when drilling at institute of mining of Skochinsky, at Tomsk and Chelyabinsk polytechnical institutes, at Karaganda research institute of coal, in Japan, etc. showed advantage of minerals destruction when imposing power impulses on torque on material shear fracture, decrease of destruction efforts 10÷12 times and energy consumption per a unit of production [2, 3, 4, 5, 6, 7].
Properties variety of materials and technological processes of transportation, mixing, compaction etc with the application of torsional oscillations investigated by the authors set the task of possibilities matching of pulse action methods and devices on the processed material.

The Lagrange equation of the second kind [1] defines the motion of the system by

\[ \frac{d}{dt} \left( \frac{\partial T}{\partial q_j} \right) - \frac{\partial T}{\partial q_j} = Q_j \quad (j = 1, 2, \ldots S) \]

where

- \( T \) is kinetostatic energy of the system;
- \( Q_j, q_j, \dot{q}_j \) are generalized forces, speed, coordinates.

design features of rotator (left part of equality) and change regularities of generalized force [2]

\[ Q_j = \frac{\delta A_{q_j}}{\delta q_j} = \frac{\sum P_i \delta S_i \cos(p_i \delta S_i)}{\delta q_i} \]

where

- \( A_{q_j} \) is elementary work of forces \( P_1, P_2, \ldots, P_n \);
- \( \delta q_i \) is increment of generalized coordinate;
- \( \delta S_i \) is movement.

Elementary operation of forces is multi-factor dependence of physical and mechanical properties of processed material, direction of action and regularity of efficient use of supplied energy. Random combination of properties of processed material determines variety of methods and devices of work performance for different operating conditions [9, 10, 11, 20, 24].

On the basis of theoretical and experimental studies the problem of impulse rotators (IR) development of various interaction possibilities with the processed material is solved.

In authors opinion, the variety of considered devices and the given classification will help to choose concretization direction of IR.

The first device (1967) of industrial type with superimposition of power pulses from eccentrically arranged masses on satellites of planetary reduction gear (dynamic vibration exciters) confirmed the perspective of research and development of such mechanisms, and demonstrated a number of disadvantages in the possibility of creating a picture of optimal pulse [1, 2, 6, 7, 8, 11, 14].

Kinematic torsional vibration exciters ensure that the material to be treated is required in preset parameters. The structure of the Assur groups provided for successive manufacture and testing of the device for practical assessment of motion possibilities, process forces change, structural reliability and maximum useful application of the supplied energy for destruction of the processed material [3, 4, 10].

Analysis of sample operability was evaluated by effort of power pulse, friction losses, thermal mode, relative speeds in kinematic pairs units, efficiency and specific energy consumption per unit of product. The investigated values were determined analytically by registration of the desired values or accompanying manifestations of the device operation factors.

Device ("Drive of miner actuator," author's certificate No. 433282, published 25.06.74, bulletin № 23; "Drive of the executive element of the mining combine," author's certificate № 759716, published 30.08.80, bulletin No. 32 etc.) copied the method of creating torsional oscillations, replacing dynamic excitation with kinematic one. Additional devices of cam or crank mechanisms with independent drive significantly complicated the structure of the rotator and increased the influence of inertial forces.

The proposed "Method of creating torsional oscillations" (Patent No. 2018618, published 30.08.94, Bulletin No. 16), which provides for separation of the output shaft into two parts and installation of a torsional oscillations vibrator between them, has shown the possibility of creating rotators with application of torsional oscillations of the IR with a slight change in the design of rotation drive of the working member. Between two surfaces of the driving and driven parts of the shaft the Assur group of zero or first classes was installed or the profile of the kinematic pair of shaft parts interaction was changed.

The authors solve the task of consistent consideration of kinematic possibilities of the vibration exciter, constructive realization and research of movement nature of IR working body.
2. Methods, constructions

The first "Impulse rotator of working body of the car" (the patent for invention No. 1802112 is published 15.03.93, bulletin No. 10) based on the offered way of oscillations creation at experimental pattern research showed efficiency drilling of minerals, concrete and steels and defined ways of design change for possibilities expansion of IR.

A significant advantage of using rotators with application of torsional oscillations is obtained by drilling steels. With currently common electric reels with axial dynamic load, their use in steels is not rational, as dynamic loads on compression of steels produce tilting and complicate destruction. An experiment in a drilling machine with IR showed 1.5-2.5 time increase in productivity with improved surface quality. Force measurements on the cam of the rotator housing, wear of friction surfaces, thermal mode, supply force, amplitude of vibration and power consumption determined the capabilities of the proposed design and weak assemblies. The variation in vibration amplitude was limited by the wedging angle as the cam moved over the shaft surface and its value was limited by the theoretically possible angle of inclination of the rotational transmission force. The variable value of the cam contact plane with the shaft plane was eliminated by an additional degree of freedom and according to the authors is not economically confirmed.

On the basis of device operation analysis the new "Creation way of torsional oscillations" (invention patent No. 2335676, published 10.10.2008, bulletin No. 18) allowing to vary amplitude-frequency characteristic, by effort in kinematic pairs is developed. Replacement or possibility of rational replacement of kinematic pairs of sliding friction with rolling friction increases device efficiency and reduces heat load.

Requirements of processed material in certain modes of torsional oscillations are satisfied by different design versions of impulse rotators. The authors proposed several copyright solutions (about 30 patents) of pulsed rotators, each of which is preferred for specific operating conditions. New methods of creating torsional oscillations are also proposed by changing some kinematic pairs without additional links and bearing assemblies; creation of a set of torsional, axial and spare oscillations.

Reasonable selection of impulse rotators, according to preliminary assessment of the requirements of the processed material, will help to classify the IR by design characteristics (see Figure 1).

The offered classification is made by results of a research of pulse impact on materials when drilling, boring, milling of minerals and metals, cuttings minerals, hashing and screw transportation of liquid and loose materials. For processed materials with different physical and mechanical properties and processing tasks, the authors have developed, manufactured and tested 17 varieties of torsional oscillation exciters.

Theoretically based design solutions [3,4,10] were clarified during the experiment on selected materials and possible changes in subsequent technical solutions were predicted. Power characteristics of oscillation excitation device were changed by structures of Assur groups, kinematic properties of interaction at relative movement of links, installation of elastic elements etc.
Amplitude of oscillations depends on geometrical dimensions of cams of rotator housing, "cam-pPushers" and driving and driven parts of output shaft. Vibration frequency can be controlled in two ways:

- number of cams on rotator housing or on follower cam;
- rotation of device body about the axis of working tool.
The useful application of pulse energy is determined by force value, organized structural feature of the impulse rotator and the ability of the processed material to perceive energy for carrying out specified amount of work.

Three properties options of the processed material in processes of drilling (boring), screws transportation of loose and viscous liquid materials are considered.

Figure 2 shows the change in momentum force along the convex line oa, the straight line cb, and the concave de. Increasing intensity is determined by properties of processed material, segments a’c, b’d depend on periodicity and application of pulses required for the material to be treated. When material of this property is broken by drilling, it is able to absorb almost completely the energy of the pulse.

At points o, c, d interaction of cutting tool pulse with surface of processed material starts.

Nature of pulse change and time of its action are determined by the design of vibration exciter according to demand of the material to be treated. When loose materials are transported or mixed, the pulse energy perception pattern changes (see Figure 3).

Loose materials contact the working member over the whole surface. Pulse force operation coinciding with uniform rotation performs useful work.

Side surfaces of working member are held by friction forces and their overcoming is loss of force pulse. In addition, with a dense mass of transported material, the movement of the rear portion of the screw overcomes the force of the formed vacuum.

Figure 3 shows the nature of pulse force change on contact areas of the cam-pusher and the driven part of the shaft of vibration excitation mechanism. Pulse energy losses on non-working planes of vibrator links are characterized by 01 and 02 sections for maximum and minimum value of supplied energy losses on the first pulse and 0c1 and 0c2 on the second pulse.

Figure 3. Image of impulse force perception during loose materials transportation:
- - - effort of full work;
- - - effort of losses.

Considerable vacuum force during transportation or mixing of liquid and substances of increased viscosity creates losses of energy of torsional oscillations pulse up to 50% and more. Figure 4 shows a
picture of the perception of impulse force during transportation and mixing of liquid and substances of increased viscosity.

Energy losses to overcome vacuum $o a_1$ in value are comparable to total energy loss of pulse $o a$ during transportation of liquid materials and substances of increased viscosity.

In case of high resistance force ($o a_1$, Fig. 4) value of energy consumption of useful work is determined by segment $a a_1$, which often does not provide positive effect in case of impulse excitation on processed material.

At significant values of harmful resistance forces the mechanism can be jammed. The authors have developed a device (patent for the invention "Screw conveyor of viscous substances" № 2682899, published 22.03.2019, bulletin No. 9) to reduce the negative impact of harmful resistances.

![Figure 4. Picture of perception of pulse force during transportation and mixing of liquid and substances of increased viscosity.](image)

### 3. Conclusions

Analysis of operation results of laboratory and industrial samples showed their advantage in comparison with existing drives due to expansion of the field of application, reduction of specific energy consumption of a unit of production, improvement of technological processes quality and operation time.

The varied influence of torsional oscillations on properties variety of the processed materials has led to the development of a class of impulsed rotators of the required technical characteristics. In order to increase consistency of rotators parameters with materials properties, individual properties IR designs are currently being developed.

The authors consider it necessary to determine parameters of processed materials and to classify them according to machining requirements with application of torsional oscillations.

At the same time, the possibility of creating a pulse rotator of universal use in various technological processes is investigated.

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