Energy limitations of changes in construction of rotators

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Abstract. The paper considers the problem and its solution for the effective modification of the
impulse rotators construction. When applying torsional vibrations to the working tool, the
destruction of rocks occurs on the cleavage. The kinematic exciters of oscillations are able to
change the amplitude-frequency characteristic, the loading pattern, the quality of processing
according to the requirements of the material being processed. Constructive use of the
oscillation device contains links and kinematic pairs, which quantity and quality determine
additional drive energy losses.

The authors estimate the expediency of drive elements installed by the magnitude of losses and
the increase of effective work. The costs per output unit should not exceed the losses in the
existing structure after changing the rotation drive of the working element.

1. Introduction

The destruction of rocks during drilling is more effective when torsional vibrations are applied to the
working tool. The axial excitation of vibrations, which have become widespread in the mining
industry, works to compress the rock, while vibrators of torsional vibrations that have become
widespread in the last decade create a momentum of tangential force on the rotating working element
[1]. Dynamic [2] and kinematic mechanisms of impulse formation along the tangent to the mechanical
trajectory of the working element are created [3]. The number of links and kinematic pairs determines
the possible losses of the rotation drive. Thus, it is proposed to calculate the expediency of a
constructive solution application.

The energy consumption analysis of the technological process, using impulse rotators, determined
the change in the efficiency of construction solutions for the optimal energy consumption per output
unit, increasing productivity (Figure 1), improving mineral processing quality (Figure 2.).
Figure 1. Drilling rate: a - axial thrust of vibration; b - tangential force of vibration

Figure 2. Quality of marble processing while drilling: a - normal and b – impulse

2. Materials and methods
It has been experimentally established that when torsional vibrations are imposed, the energy intensity of the process is reduced and the productivity of the work increases from 1.7 ÷ 2 to 4 ÷ 5 times for various materials while drilling using the impulse method. At the same time, the dynamic loads on the rotation drive are reduced by a factor of 2 to 4 and it becomes possible to use the auger when the slurry is dispensed.

Two types of mechanical vibrators of dynamic and kinematic excitation have been created at present. The kinematic excitation pattern is given by the profile of the working surfaces and the arrangement of the links. The nature of the interaction of the working element with the material being processed
advantageously differs from the dynamic exciters of torsional oscillations by the possibility of creating a loading pattern according to the needs of the material being processed [4].

3. The study of regularities
In the kinematic exciters of torsional oscillations, an additional chain of links and kinematic pairs is required [5], which causes losses of the supplied energy to overcome the frictional force in the kinematic pairs and the inertness of the links. The constructive decisions of the exciters adopted by the authors made it possible to reduce the losses from inertial forces to a minimum and without taking them into account in the calculations. The friction losses in kinematic pairs are several times higher than the effect of inertial loads and are not taken into account in the calculations.

Efforts of friction arising in kinematic pairs are:

\[ F_{fr} = N f_{fr} Z, \]  

where
- \( N \) – standard pressure force;
- \( f_{fr} \) – friction ratio in dynamic conditions;
- \( Z \) – amount of kinematic pairs in the given kinematic chain.

Limitations on the organization of the kinematic chain of the oscillations drive exciter cause total friction losses which do not exceed the efficiency of the process. Let us take an increase in productivity while maintaining the quality of work and taking into account the total costs of fabricating the mechanism as the basis for the expediency of improving the construction.

As it was noted earlier, the application of torsional vibration exciters in the drilling of blasting holes increases productivity with a reduction in energy costs per output unit.

The imposition of torsional oscillations increases the volume of production per unit of time and reduces the energy consumption.

Elementary work of the force on a processed material is:

\[ dA = F_e^T R d\phi + F_e^{''} dh = M_{z_e} d\phi + F'' dh, \]

where
- \( F_e^T \) and \( M_{z_e} \) – force and moment of external impact on materials in the plane of the tool rotation;
- \( R \) – radius of the working element rotation;
- \( d\phi \) and \( dh \) – elementary movement in the direction of rotation and axial feed of the tool.

The volume of the work performed by a single pulse is increased by changing the physical and technical properties of the technological process. The productivity of the work increases with the improvement of technical and economic indicators. In this case, the drive energy of the working element can be divided into the energy used for the main rotation and the driver of the torsional oscillations. The change in the rotator construction is considered expedient if the losses in the kinematic chain of the vibration disturbance drive are less than the work increase.

\[ \Delta dA = \sum_{i=1}^n M_{z_i} d\phi_i + F_{e_i}^{''} dh_i. \]

The limit of economic feasibility of the impulse rotators construction can be determined using formulas 3 and 4:
\[ \sum_{i=1}^{n} (M_{2i}^{0} d \varphi_{i} + F_{2i}^{0} d h_{i}) - \sum_{i=1}^{n} N_{i} f_{fr} z k_{i} = 0. \quad (5) \]

Whence the aggregate of kinematic pairs in the exciter drive of torsional vibrations is:

\[ j_{i} = \frac{\sum_{i=1}^{n} (M_{2i}^{0} d \varphi_{i} + F_{2i}^{0} d h_{i})}{\sum_{i=1}^{n} N_{i} f_{fr} d S_{i}} \quad (6) \]

The formula 6 analysis allows one to determine the optimum drive circuit for the torsion oscillator at the stage of preliminary development of the impulse rotators construction.

4. Conclusion

The development and investigation of the impulse rotator [7] showed that it is necessary to provide for working conditions, excluding wedging in kinematic pairs, thermal conditions and maximum forces in bearing assemblies except the number of kinematic circuits in the construction.

The use of the regularities (6) and the result of the first sample experiment determined the directions of the construction change of the impulse rotator. The existing construction of the pusher cam in the created impulse rotator provided for the transmission of the torque with uniform and impulse rotations due to the contact with the fixed surface of the body and the movable part of the shaft of the working element. The cam-pusher with an external profile constantly slides over the body surface and causes significant losses for friction and heat loads. A new version of kinematic excitation [8] is a significant reduction in slip in the external profile by successive contact of three cam-pushers and a reduction in friction losses. The installation of the elastic element reduces the force in the kinematic pairs.

![Exciter of torsional vibrations](image_url)
Figure 3 shows a schematic diagram of the torsional vibrations exciter. The body 1 with the cams 2 remains stationary during the operation of the rotator. The outer part 3 of the cam of the pusher 4 slides along the inner surface 5 of the body 1, together with the first part of the shaft 6 and in contact with the cams 2 rotates and transmits the force impulse of the second shaft part 7. The resilient element 8 receives a portion of the torsional moment forces. The redistribution of forces in the exciter of torsional vibrations is analyzed, envisaged in further constructions and protected by patents. The change in the interaction of the working element with the material being processed in the separation of uniform and impulse rotations [9] provides for an independent change in the regularities of uniform rotation and the amplitude-frequency characteristic.

References
[1]  Kumabe D 2005 Vibrational cutting (Moscow, "Mashinostroenie") pp 34-40
[2]  Kittel Ch., Knight W, Ruderman M, Mechanics. Berkeley physics course (St. Petersburg-Moscow-Krasnodar) p 248
[3]  Yablonsky A A, Noreyko S S 1975 Course of the theory of oscillations (Moscow "Higher School") pp 69-74
[4]  Belokonev I M 1978 Mechanics of machines. Calculations using computers (Kiev "Higher School") pp 79-86
[5]  Crainera G V 1988 Dynamics of machines and machine control. Handbook edited by. (Moscow "Mechanical Engineering") pp 17-19
[6]  Skoibeda A T and others 1997 Applied mechanics:Under the Society (Ed. AT Skobedy-Minsk Higher School) pp 117-121
[7]  Antipina E S, Zhilin S N 2008 Impulse rotator of the executive body of the machine. Patent of the Russian Federation No. 2341636, publ. 20.12.2008, bul. No. 36
[8]  Antipina E S, Zhilin S N, Kukinova G V 2011 Impulse rotator of the working element of the machine. Patent of the Russian Federation No. 2413830, publ. 10.03.2011, bul. №7
[9]  Antipina E S, Zhilin S N, Kukinova G V 2015 Method of creating torsional oscillations. Patent of the Russian Federation No. 2541560, publ. February 20, , bul. №5