Planetary adjustable vibratory exciter with chain gear

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Abstract. The paper is devoted to the problem of generation for periodic mechanical force and construction of its generator. The problem is vital for numerous fields of technics dealing with transmission of vibration energy to mechanical objects. The problem was solved in the framework of classical mechanics for calculation of inertia forces in rotational system of special type. New method of generation of periodic mechanical oscillations was acquired as well as the construction of the new type of vibration generator. The force being generated by the device is a result of inertial forces which occur during special planetary motion of unbalanced massive bodies on the rotating shaft with chain gear. Analytic and graphic representations for dependences of periodic force on time are presented in the article

1. Introduction

Problems of energy efficiency enhancement for process of soil compaction demand for wide spectrum of control parameters for the force which produce contact pressure necessary for the compaction. The main type of devices providing the periodic force is a group of vibration generators of different nature. Vibration as a particular type of periodic action is effectively used in different types of road construction machines. In case of compacting machines (rollers) energy of vibration is used to change the structure of material along with plastic deformation.

Devices for generation of periodic dynamic action are widely used in numerous fields of technics and industry. According to [1] they may be classified by the principle of construction, magnitude of periodic force, type of time dependence of the force, connection with the object of energy transmission etc. Such generators are used in industry, agriculture, construction for different purposes.

One of the main physical principles of generation of periodic dynamic action is rotation of unbalanced masses around the axis which does not coincide with their centers of mass.[2, 3] The advantage of these systems is simplicity of design but at the same time low energy efficiency and low coefficient of directed action.

Technical applications of generators of periodic force are not restricted to the problems of construction. Here must be mentioned original designs of vibratory exciters used for solution of technical problems in oil production [4], for excitation of specific oscillation in gyroscopic systems [5] and serving for special types of metrological problems [6].

Special place among vibration exciters is taken by the planetary type of the device. They may provide periodic type of the force different from purely harmonic. Usually construction of planetary exciter includes massive roller that travels along the rail of the shape different from the circular [7]. It gives wider spectrum of types of periodic force but demands for solution of certain technical problems. The
main problems are how transmit the force to the axis of exciter and how to avoid the slipping of travelling roller while in moves along the rail. These problems may be solved by implementation of strict kinematic link between roller and rail. Other approaches to the design of vibratory exciters combine circular and linear types of oscillations in order to provide more complex [8].

2. Formulation of the problem
The main technique of generation of periodic force is rotation of unbalanced masses around the axis which does not coincides with their centers of mass. If point mass \( m \) rotates with constant angular velocity \( \omega \) at distance \( R \) from the axes then centripetal inertial force is generated

\[
F_m = m R \omega^2,
\]

which can be interpreted as consequence of Huigens-Steiner theorem for point mass. In this case vertical projection of the force is periodic and can be found as

\[
F_m = m R \omega^2 \sin(\omega t + \phi_0),
\]

where \( \phi_0 \) – is initial phase.

The most widespread type of unbalanced systems in vibration exciters are eccentric weights. Their obvious advantages are simple design and high sustainability during operation which allow to produce forces of high magnitudes. Eccentric mass exciters are common elements for vibrational drums of road rollers. Technical applications demand for the vibration exciters with adjustable parameters for control and regulation of produced force. The main purpose of given paper is development of design for vibratory exciters with wider spectrum of parameters for control and adjustment of the force.

3. Theory
Similar technical solution for planetary exciters with strict kinematic connection is presented by the device for generation of periodic force according to Russian Federation patent № 2381078 [9]. It contains gear crown, shaft and satellite gear with inertial element. Satellite contacts with crown and rotates with the motion of the shaft.

Drawbacks of given device are disability of force magnitude control other ways then by increase of angular frequency of the shaft and position of inertial element. Also there is a restriction for the type of time dependences for produced force which are represented with family of hypocycloids. Technical requirements for manufacturing and adjustment precision of the device are also high due to use of crown gear which may occur unacceptable for application.

All of the above makes it necessary to develop new prospective designs of vibratory exciters for realization of energy efficient regimes of dynamic actions of soil compaction. For that purpose given device was designed. It provides wider spectrum of periodic forces suitable for cyclic surface action appropriate in cases of compaction of soil layers (Fig. 1, 2).
Vibration exciter consists of shaft 1, which may rotate 2, position of the shaft may be regulated by the attaching fitting 3. Shafts 1 are supplied with eccentric masses 9 and 10 mounted on satellite rollers 5 and 6 which can rotate around axis 7 and 8 respectively. Satellites are connected by the gear chain 4, which provides strict kinematic link between them through motionless sprocket 10. Rotation of the shaft 1 around axes 2 causes rollers 5 and 6 to perform additional rotation around axis 7 and 8. Rotation of the shaft 1 is transmitted to the rollers by the gear 4 through motionless sprocket 10. Angular velocities of the rollers are determined by the position of the axes 2 in respect to the center of the shaft which is adjusted by the attaching fitting 3 and angular velocity of the shaft rotation.

Centripetal acceleration of points of rollers’ centers of masses and direction of inertial force are defined by the positions and velocities of the rollers

\[ F = F_{sh} + F_r = m_{sh} \ddot{x}_{sh} + m_e(\ddot{x}_r + \ddot{y}_r), \]

since that vertical component (projection on \( y \)-axes) can be found as

\[ F_{vert} = (m_{sh} \ddot{x}_{sh} \cdot \vec{e}_y + m_e(\ddot{x}_r \cdot \vec{e}_y + \ddot{y}_r \cdot \vec{e}_y)). \]

where

- \( m_{sh} \) – shaft’s mass (considered being concentrated in the center of mass);
- \( \ddot{x}_{sh} \) – full acceleration of the center of shaft’s mass;
- \( \vec{e}_y \) – unit vector of direction of \( y \)-axes;
- \( \vec{e}_r \) – unit vector of direction of exciter’s action.

Taking into account the number of parameters to control the action of the exciter, the magnitude of the force can be varied in wide ranges. Necessary view of periodic force may be achieved by the choice of initial positions of the shaft and rollers.

\[ \vec{r}_{sh} = \frac{1}{2}(R_{sh} \cos(\omega t + \varphi_{sh}), R_{sh} \sin(\omega t + \varphi_{sh})), \]

where \( R_{sh} \) is a distance between axes 2 and center of mass of the shaft.

Law of motion of any roller will be more complicated and radius-vector of the eccentric mass of the roller will look as follows

\[ \vec{r}_r = (R \cos(\omega t + \varphi_{sh}) + R_r \cos(\omega_r t + \varphi_{cor}), R \sin(\omega t + \varphi_{sh}) + R_r \sin(\omega_r t + \varphi_{cor})), \]

where \( R \) – length of shaft from axes of exciter to roller’s axes 5; \( \varphi_{sh} \) – initial phase of shaft rotation.

\[ \text{Figure 1. Planetary adjustable vibration exciter with chain gear} \]
\[ R_e \] – distance of eccentric mass of the roller from the axes of rotation;
\[ \varphi_e \] – initial phase of the roller;
\[ \omega_e \] – angular frequency of roller sprocket defined as \[ \omega_e = \omega \frac{R}{R_0} \], where \( R_0 \) – roller’s sprocket radius.

Since that positions of roller’s masses, shafts and initial positions (phases) can provide any configuration intermediate between shown on Fig.2. That set of parameters may be used for control and adjustment of maximum value and direction of the force produced by the device. Fig.4 shows views of vibratory exciter. Position of rotation axes of 1 of shaft 7 is shifted in respect to its center and fixed by the attaching fitting 3.

**Figure 2.** Planetary adjustable vibration exciter with chain gear in eccentric position

Fig. 2 shows positions of eccentric masses of rollers which provides maximal magnitude of produced periodic force in given direction.

**Figure 3.** Planetary adjustable vibration exciter with chain gear in asymmetric position

4. Results of numeric experiments
The result of developed design of vibratory exciter is possibility to generate a set of periodic forces being produced by single device without need of crown gear which requires high precision of manufacturing and adjustment. The result is achieved by use of pair of sprocket rollers with
unbalanced eccentric masses on the rotating shaft. The position of sprockets in respect to the axes of shaft rotation is adjustable.

5. Discussion
Acquired technical result demands for theoretical consideration in order to investigate the details of the inertial force produced by the device. Consider the example of the force produced by the exciter with one shaft and roller under following conditions:

Shaft mass  \( m_s = 10 \text{ kg} \)
Roller mass  \( m_r = 0.5 \text{ kg} \)

Radius of the center of mass of the shaft  \( R_{sh} = 0.125 \text{ m} \)
Shaft radius  \( R = 0.25 \text{ m} \)
Radius of rotation of eccentric mass of the roller  \( R = 0.1 \text{ m} \)
Angular frequency of the shaft  \( \omega = 20 \pi \text{ s}^{-1} \)
Angular frequency of the eccentric mass of the roller  \( \omega = 100 \pi \text{ s}^{-1} \)

Fig. 4 shows the dependence of radius-vector of roller’s eccentric mass. Normal acceleration produced by the motion of roller causes the inertia force applied to the axes of the shaft rotation. Given configuration provides the ratio of angular velocities equal to 1/5.

![Figure 4](image)

**Figure 4.** Dependence of roller’s eccentric mass radius-vector  
\[ r = (R \cos(\omega t + \phi_s) + R_r \cos(\omega_r t + \phi_r), R \sin(\omega t + \phi_s) + R_r \sin(\omega_r t + \phi_r)) \]  
on shaft angular coordinate.

Energy efficiency of the device has simple explanation. Eccentric mass of the roller rotates with frequency which is several times greater than leading frequency of shaft rotation. Since that generated force is applied to the material more frequently. Time dependence of generated force is presented on Fig.5. That impulse-like type of force provides more efficient energy transmission to materials under deformation.

![Figure 5](image)

**Figure 5.** Dependence of force generated by the exciter on angular coordinate for one period of shaft rotation.
6. Conclusion
The main result of developed construction of vibratory exciter is that frequency of generated force differs from the angular frequency of shaft rotation. Taking into account deformational properties of the active volume of soil layer at the dynamic regimes of compaction given vibratory exciter can be recommended as a mean for energy efficiency improvement for heavy types of static rollers. The work was supported by the RFBR and Omsk region government grant № 18-48-550005 p_a.

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