J. Electrical Systems 20-11s (2024): 324-327

[1] **Vitaly Mikheyev***
[2] **Sergei Saveliev**

Highly Directional Design of Planetary Vibratory Exciter and Its Kinematic Analysis

Abstract: - Development of new techniques of controlled excitation for directed vibrations is actual engineering problem. The paper analyses properties of new design of vibratory exciter with highly directed force to be produced. The key feature of the generator is partially rotating planetary gear as a source of directed inertial force. The mechanical principle of force generation is based on composition of rotation motions of unbalanced massive body driven by the crank of special type. Use of this principle of mechanical drive allows to vary produced force and increase energy efficiency of the device. Kinematic properties of the generator are analyzed in the article and further applications of the device are recommended as well. The graphic presentation of time and directional behavior of produced force illustrates work regime of the exciter. The article also suggests new analytic characteristics which describe efficiency of vibration exciters in general.

Keywords: Vibration, Generator, Inertial Force, Vibration Exciter, Unbalanced Mass, Planetary Gear, Directional Oscillations

I. INTRODUCTION

Vibration as a mechanical phenomenon plays in technical applications various roles being both useful and undesirable sometimes. First of all, vibratory action (contact action of periodic force with different dependences on time, primarily harmonic) serves as an intense source of energy to be transmitted to objects or media. Secondly, vibration may be completely inappropriate if being caused by periodical technical processes impacts machines and humans. These two sides of one phenomenon often reveal themselves at the same time while one of them must be amplified and another in turn must be attenuated.

The most common and widespread type of vibration exciters is inertial type which produces periodic force by rotation of massive unbalanced body around axis located at certain distant from its center of mass. This design definitely has definite advantages but drawbacks as well. For instance, use of this type of exciter in road building machines requires implementation of vibration protection for operator [1]. Energy efficiency and orientation of periodic force are also unsatisfying for conventional inertial exciters. This is a reason for use of more sophisticated designs of vibratory machines. Here one must mention planetary exciters of variable types [2], [3],[4],[5]. The other way to enhance performance of vibratory exciter is to use crank type mechanisms [7], [8] which can produce periodic force of necessary type. Vibration exciters are widely used in road building, mining, material science, measurements etc.[5], [6], [7] Must be mentioned use of unbalanced mass mechanism for the purposes of energy storage [8]. Another question which often emerges when vibratory exciters are considered is a problem of driving principle of the device. Along with usual mechanical drives the drives based on hydrostatic [9] and electromagnetic [10] principles.

II. THEORETICAL CONSIDERATION OF DIRECTIONAL OSCILLATIONS SOURCES

Mechanical source of vibration excitation which is conventionally used in inertial type of the exciters is a centrifugal force caused by centripetal acceleration

$$\boldsymbol{a}_n(t) = \frac{v^2}{R_{curv}}\boldsymbol{n} = \frac{(\dot{\boldsymbol{\rho}}(t))^2}{R_{curv}}\boldsymbol{n}, \tag{1}$$

where R_{curv} is curvature radius of trajectory of center of gravity of the exciter's unbalanced mass;
$\boldsymbol{n}$ is normal vector to the trajectory of center of gravity of the exciter's unbalanced mass;
$\boldsymbol{\rho}(t)$ is radius-vector of center of gravity of the exciter's unbalanced mass.

Easily obtainable condition of orientation of periodic force $\boldsymbol{F}(t)$ with period T along direction of vector $\boldsymbol{e}$ looks can be expressed as follows

---

[1] Faculty of Radiotechnics, Omsk State Technical University, Omsk, Russia. E-mail: vvm125@mail.ru
[2] The Siberian State Automobile and Highway University (SibADI), Omsk, Russia

$$\int_{t_0}^{t_0+T} (\boldsymbol{F}(t)\cdot\boldsymbol{e})dt \neq 0 \quad . \tag{2}$$

In order to assess the level of orientation quantitively one can introduce **axial efficiency index** of the exciter

$$\lambda = \frac{\left|\int_{t_0}^{t_0+T} (\boldsymbol{F}(t)\cdot\boldsymbol{e})dt\right|}{\int_{t_0}^{t_0+T} \left|(\boldsymbol{F}(t)\cdot\boldsymbol{e})\right| dt} \quad . \tag{3}$$

It can be considered as a ratio of the force produced by the exciter and being pointed in the chosen axial dominant direction (determined by vector $\boldsymbol{e}$) in the total force which is produced during vibrations excited along chosen axis (including the direction opposite to $\boldsymbol{e}$).

If one needs an assessment of ratio of the force in dominant direction then another expression can be easily obtained:

$$\mu = \frac{1+\lambda}{2} \tag{4}$$

It means that mean modulus of force produced in dominant direction is μ smaller than mean absolute value of produced force along the direction of chosen axis.

III. SPECIAL DESIGN OF PLANETARY VIBRATORY EXCITER

Planetary exciters may have different designs and planetary motion of unbalanced mass may be caused by different types of mechanical transformation of forces and momentums. Along with regular sliding motion exciters [2], [3], wheel gear [11] and chain gear types [12] of planetary vibration exciters must be definitely mentioned.

Directional oscillation produced by energy effective crank type exciters [13], [14] are based on mechanical principle of transformation of crank motion into swinging of heavy unbalanced mass which mainly produces inertial force applied to the axis of rotation mainly directed along certain axis.

Here a new design of vibration oscillator is being introduced. It combines advantages of both crank type and wheel gear planetary vibration exciters and produces vibratory force directed mainly along vertical axis. Kinematic scheme of the machine is presented on figure 1. with following notations:

r is radius of rotation of bushing 2 mounted in crank 1;

d is distance between axis of rotation of crank 2 and swinging axis 4 of shaft 3;

R is radius of driving rod of planetary gear;

R_0 is radius of gearwheel of planetary gear;

r_0 is radius of rotation of total gearwheel mass of planetary exciter (center of gravity for the system “gearwheel – extra unbalanced mass”);

φ is angle of rotation of crank 1 with initial value φ_0

$$\varphi = \omega t + \varphi_0 = 2\pi f t + \varphi_0 ,$$

where f is linear frequency of rotation of crank 1, Hz;

$\Psi(t)$ angle of swinging of shaft 3 with dependence on φ

$$\Psi(t) = \arctan\left(\frac{r\cos(\varphi)}{d + r\sin(\varphi)}\right) ;$$

$\Phi(t)$ is angle of rotation of gearwheel 6 with initial value Φ_0

$$\Phi(t) = \frac{R_0 + R}{R_0} + \Phi_0 ;$$

$\boldsymbol{e}_x = (1,0), \boldsymbol{e}_y = (0,1)$ are unit vectors of coordinate axes as shown on Fig. 1.

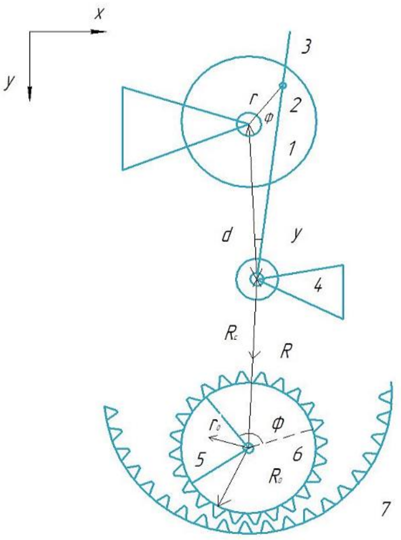


Fig.1 Kinematic scheme of vibratory exciter

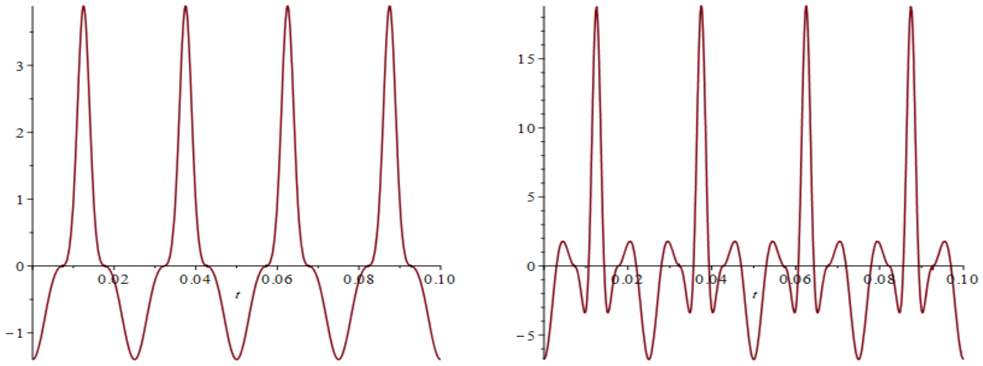
1 is rotating crank of special design;
2 is bushing insert with ability to rotate around its axis and provide sliding motion of the shaft;
3 is driving shaft; 4 is axis of rotation of shaft 3; 5 is extra unbalanced mass; 6 is gearwheel;
7 is ring gear

In given notation trajectory of unbalanced mass causing inertial force is described by following kinematic expression

$$\boldsymbol{\rho}(t) = (R + r_0 \sin\Phi(t), R + r_0 \cos\Phi(t))$$

Further calculations were performed in Maple computer algebra package.

Periodic force produced by the exciter is inertial force produced by the motion of unbalanced mass according to (1) is strongly directed along $\boldsymbol{e}_y = (0,1)$. Using the theoretical approach presented above one can easily obtain $\boldsymbol{a}_n(t)$ and its graphic representation is given on Figure 2. Dimensionless function $\frac{\boldsymbol{a}_{ny}}{(2\pi f)^2 r}$ shows the ratio between produced acceleration and initial acceleration on the crank 1 at the point of bushing 2. Figure 2 describes two cases which differ by the values of parameters determining geometric configuration of exciter



a) $\frac{R}{R_0} = 4$, $\frac{d}{r} = 4$

b) $\frac{R}{R_0} = 10$, $\frac{d}{r} = 4$

Fig. 2. Time graphs of function $\frac{\boldsymbol{a}_{ny}}{(2\pi f)^2 r}$, representing patterns of oriented vibration generated by the exciter for 4 periods of oscillations ($f = 40\ Hz$)

Presented exciter construction demonstrates higher level of orientation and **axial efficiency index** (3) in case a) on Figure 2 with value $\lambda = 0.2226$.

Ratio of the force concentration in dominant direction may be easily calculated and equals $\mu = 0.6113$. which means that the produced force predominantly oriented in positive direction of y axis.

This fact allows to make recommendation for possible use for the developed design of vibration exciter as a source of dynamic action on elastoviscoplastic media with different dynamic response depending on direction of load.

IV. Conclusion And Discussion

The design of new type of exciter of highly oriented vibrations demonstrates advantages of both crank type and conventional planetary exciters. It also allows to change patterns of the time dependence and direction of produced force by variation of geometric parameters of the construction. Impulse-like type of force is inherited from crank type exciter but has greater absolute values in chosen direction. This makes possible to use the device as the source of periodic mechanical action in soil compaction machines.

Additional advantages of suggested vibratory exciter design may be found in possibility of application of linear electric drives as an initial source of force. They may be presented by linear electric motors or moving core of electric magnet. This may give less losses due to the friction in moving parts and higher energy efficiency because of use of electric drives.

Acknowledgements

Research presented in the article was supported by the grant № 23-29-10010 «Development of road rollers for the enhancement of road construction efficiency in Omsk region» by Russian Science Foundation and Government of Omsk region.

References

[1] Korchagin P.A., Teterina I.A., Rahuba L.F., (2017) Improvement of human operator vibroprotection system in the utility machine. *J. Phys.: Conf. Ser.* 944 1-012059 https://doi.org/10.1088/1742-6596/944/1/012059

[2] Dudkin M.V., Planetary vibration exciter. (2004) In: Patent law of the Republic of Kazakhstan. Available via DIALOG. https://kzpatents.com/0-pp14541-planetarnyjj-vibrovozbuditel.html.

[3] Dudkin M.V., (2010) Planetary vibration exciter. (2010) In: Patent law of the Republic of Kazakhstan. Available via DIALOG. https://kzpatents.com/6-22221-planetarnyjj-vibrovozbuditel.html.

[4] Pluta J., Orkisz P., (2012) Bi-axial exciter of mechanical vibrations, Proceedings of the 13th International Carpathian Control Conference (ICCC), High Tatras, Slovakia, 2012, pp. 568-572, doi: 10.1109/CarpathianCC.2012.6228709.

[5] Korendiy V., Parashchyn O. et al. (2023), Kinematic analysis and geometrical parameters justification of a planetary-type mechanism for actuating an inertial vibration exciter. *Vibroengineering Procedia*. 52. 35-41. https://doi.org/10.21595/vp.2023.23728.

[6] Kachur O., Korendiy V. (2023), Dynamic Behavior of Vibratory Screening Conveyor Equipped with Crank-Type Exciter. *Vibroengineering Procedia*, Vol. 48, pp. 8–14, Feb. 2023 https://doi.org/ 10.1007/978-3-031-32774-2_5.

[7] Igumnov L.A., Metrikin V.S. et al (2017), On the theory of multi-pulse vibro-impact mechanisms. *J. Phys.: Conf. Ser.* 919 012005 https://doi.org/10.1088/1742-6596/919/1/012005.

[8] Rui-Jun L., Ying-Jun L., Lian-Sheng Z. et al (2018) High-precision and low-cost vibration generator for low-frequency calibration system. *Meas. Sci. Technol.* Volume 29, Issue 3, article id. 034008 https://doi.org/10.1088/1361-6501/aa9f6d.

[9] Nizhegorodov A.I., Gavrilin A.N., Moyzes B.B. (2016) Hydrostatic Vibratory Drive of the Test Stand for Excitation of the Amplitude-Modulated Vibrations. *J. Phys.: Conf. Ser.* https://doi.org/10.1088/1742-6596/671/1/012037.

[10] Zhang M., (2015) Dynamic optimization analysis of a stored energy motor with serious unbalanced mass distribution, 2015 IEEE International Conference on Information and Automation, Lijiang, China, 2015, pp. 2799-2802, doi: 10.1109/ICInfA.2015.7279762.

[11] Isaev I.K., Guerasimov M.D., (2010) Excitation method for directed mechanical oscillation and device for its realization. In: Federal Institute of Industrial Property. Available via DIALOG. https://yandex.ru/patents/doc/RU2381078C2_20100210.

[12] Mikheyev V.V., Saveliev S.V., (2019) Planetary adjustable vibratory exciter with chain gear. *J. Phys.: Conf. Ser.* 944 012079, https://doi.org/10.1088/1742-6596/1210/1/012097.

[13] Mikheyev V.V., (2018) New type of vibration generator with vibratory force oriented in preferred direction. *J. Vib. Eng. Technol.* 2018, 6(6), 1-6 https://doi.org/10.1007/s42417-018-0025-4.

[14] Mikheyev V.V., (2020) Generator of periodic inertia force concentrated in one direction. *J. Phys.: Conf. Ser.* 1441 012106. ASMD-2019. IOP Publishing. https://doi.org/10.1088/1742-6596/1441/1/012106.