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К ВОПРОСУ ОПРЕДЕЛЕНИЯ МОЩНОСТИ ВИБРОВОЗБУДИТЕЛЯ

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В настоящий момент вибровозбудители, отличающиеся разным исполнением, широко применяют для осуществления всевозможных технологических операций. Использование вибрации позволяет снизить трудоемкость и уменьшить себестоимость производственных затрат. В данном исследовании представлены результаты изучения механизма возбуждения вибрационных колебаний, из которого очевидно, что на величину мощности вибровозбудителя влияют размеры корпуса, бегуна и принятый эксцентриситет. Приведены результаты по величине корпуса, эксцентриситета и величины неуравновешенной массы – бегуна, – перемещающегося по внутренней поверхности цилиндрического корпуса и возбуждающего при перемещении вибрационные колебания. Определена максимальная мощность вибровозбудителя, зависимая от того, будет ли бегун прижиматься центробежной силой к цилиндрической внешней поверхности вибровозбудителя на протяжении всей длины поверхности. Если бегун центробежной силой не сможет быть прижат к цилиндрической поверхности виборовозбудителя, то на рабочих скоростях вала отбора мощности (750 и 1000 об./мин) будут участки поверхности, по которым бегун будет прижат к поверхности и оказывать вибрационные колебания. На остальной поверхности бегун станет скользить мимо цилиндрической поверхности, вызывая стук, и не будет возбуждать вибрационные колебания. Определены участки поверхности, где бегун не будет возбуждать вибрационных колебаний. Стук относится к вибрационным колебаниям бегуна. Он возникает у бегуна, не набравшего максимальной скорости и поэтому не прижатого к корпусу цилиндрической формы. Передача энергии вибрации на корпус вибровозбудителя происходит от энергии бегуна. Бегун, касаясь корпуса, испытывает воздействие инерционных сил на корпус и возбуждает внешние силы, передающие энергию вибрации на вибровозбудитель.

Ключевые слова: глубокорыхлитель, вибровозбудитель, вибрация, амплитуда, рабочие скорости, вал отбора мощности

ON THE QUESTION OF DETERMINING THE VIBRATION EXCITER POWER

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At the moment, vibration exciters of different designs are widely used for all kinds of technological operations. The use of vibration makes it possible to reduce labor intensity and the cost price of manufacturing costs. This paper presents the results of a study of the mechanism of excitation of vibrational motion, from which it is obvious that the size of the body, the runner and the adopted eccentricity affect the value of the power of the vibration exciter. The results on the size of the body, the eccentricity and the value of the unbalanced mass - a runner - moving on the inner surface of the cylindrical body and exciting vibration oscillations during movement are presented. The maximum power of the vibration exciter, depending on whether the runner will be pressed by centrifugal force to the cylindrical outer surface of the vibration exciter over the entire length of the surface, is determined. If the runner cannot be pressed to the cylindrical surface of the vibrator by centrifugal force, then at the working speeds of the PTO (750 and 1000 rpm) there will be areas of the surface where the runner will be pressed against the surface and exert vibratory oscillations. On the remaining surface, the runner will slip past the cylindrical surface, causing a knock, and will not excite vibratory oscillations. The surface areas where the runner will not excite vibratory oscillations were determined. The knock refers to the vibratory oscillations of the runner. The knocking occurs in a runner who has not gained maximum speed and therefore is not pressed against a cylindrical shaped body. Transmission of vibration energy to the vibrator body comes from the energy of the runner. The runner, touching the hull, experiences the impact of inertial forces on the hull. The runner excites external forces that transfer vibration energy to the vibration exciter.

Keywords: deep loader, vibration exciter, vibration, amplitude, operating speeds, power take-off shaft

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INTRODUCTION

At present, vibration exciters of different designs are widely used to excite mechanical vibrations, which are used to perform a variety of technological operations. At the same time, special vibrating machines are created, in which energy from the vibration exciter is transferred directly to the working body, which uses vibration (in particular, in agriculture) for destruction of various soils compacted by running systems of machines, non-moldboard deep tillage, plowing. Application of vibration enables to considerably raise labor productivity, reduce labor input and prime cost of the executed works. Vibration exciters, which excite mechanical vibrations of the working bodies of machines, are quite widespread in many areas of the economy and in everyday life.

High opportunities for the use of vibration exciters will appear when it will be possible to create designs with maximum power, readjustment of frequencies and amplitudes of mechanical vibrations. An important value for vibration machines is the change in the power of the vibration exciter, which allows to change the amplitude of mechanical vibrations and, accordingly, the amplitude of oscillations of the working bodies, affecting the layer of soil, breaking the monolithic structure of the anthropogenic compacted soil after the passes of heavy machines, which affect the subsoil horizon with the propulsion systems[1] [1-6].

Excitation of mechanical vibrations is a process of conversion of the source energy into vibrating fluctuations. According to I.N. Petryagin [7], it is possible to increase the power of the vibration exciter by shifting the rotor from the center of the body. I.N. Petryagin theoretically and experimentally justified that the increase in the rotor displacement relative to the center of the body allows you to increase the maximum power of the vibration exciter. This statement was proved in practice by determining the power of vibration exciter on the running-in-brake stand. Experimental values of vibration exciter power exactly fit the calculated characteristic, so for a long time it was believed that theoretical and calculated values [7] derived by I.N. Petryagin and experimental dependences are flawless and applicable to the development of vibration exciters of other designs[2]. We made a vibration exciter with the calculated values of I.N. Petryagin, in

[1]Trofimov I.V. Justification of design-mode parameters of vibrating cultivator for pre-sowing tillage: Ph. Orenburg, 2018. 116 p.
[2]Patent № 2578745, B06B1/16 (Russian Federation). Vibration exciter / S.G. Shchukin, V.V. Alt, M.A. Nagayka, V.A. Valkov. Application. 15.12.2014; publ. 27.03.2016. Bulletin no. 9.

which shock loads inside the body were found, which were not reported in the work[3].

There was a process of occurrence of shock loads from a cylindrical-shaped part, called a runner, when it moved along the inner cylindrical surface of the body under the influence of the rotor, whose center of rotation was shifted from the center of the body by the value of eccentricity.

Vibration exciter was driven by hydraulic motor GMSH-50, standardly installed in T-150K, driven by hydraulic motor of standard drive by hydraulic pump GMSH-50.

It is assumed that the runner does not reach the top of the inner surface of the vibrator body. The assumption was made that if we increase the rotor rotation speed, the impacts on the inside of the cylindrical body would not be heard, because the runner would run around the entire inner surface of the body. However, increasing the rotational speed from 750 to 1000 rpm did not change the process taking place, the force of the internal shock only increased.

The purpose of the work is to improve the mechanical vibration exciter to obtain its maximum power through the motion of the rotor, the center of rotation of which is displaced from the center of the body with an unbalanced mass - a runner - on the inner surface of the body.

The object of the study is the process of moving the rotor, mounted with an offset from the center of the body, unbalanced mass - runner, which excites the vibrating motion of the vibration exciter body.

The subject of the study is the determination of the vibration exciter power depending on the offset of the rotor spinning axis by the eccentricity e from the center of the body.

Research objectives:

– determination of vibration exciter design parameters, at which there is no knocking at different rotor speeds (v = 750 and 1000 rpm);

– numerical determination of the value of the rotor offset from the center of the exciter body (eccentricity e), at which the runner will touch the entire surface of the exciter body when rotating;

– determination of the magnitude of the acting centrifugal force on the runner rotated by the rotor;

– determination of the maximum eccentricity value e_{max}, at which the runner will touch the exciter body at all points (see Fig. 1).

The design and technological scheme of maximum power vibration exciter according to I.N. Petryagin [7] was made and verified in the experiment. Diameter of vibration exciter body D = 120 mm, diameter of the runner d = 72 mm, eccentricity of displacement of the rotor from the center of the body e = 15 mm. The claimed power at 1000 rpm by I.N. Petryagin [7] is N = 0.299 kW. In the presence of knocking the vibrating exciter was tested on a deep loosener GV-1,8, the following qualitative indicators of crumbling the structure of the cultivated soil were obtained (see table).

Let's consider the position of the runner 3 relative to the axis of rotation C_v, displaced on

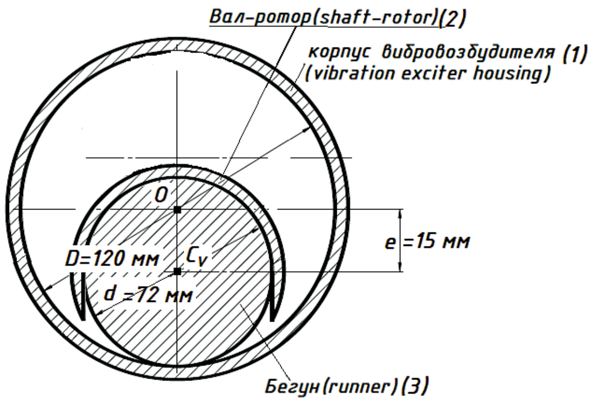

Рис. 1. Конструктивно-технологическая схема «бегункового» типа вибровозбудителя максимальной мощности (по И.Н. Петрягину [7])

Fig. 1. Structural and technological scheme of the "runner" type vibration exciter of maximum power (according to I.N. Petryagin [7])

[3]A.s. 1681979, MKY3B06 B 1/16 (USSR). Vibration exciter / I.N. Petryagin; No. 4386471/28. Application. 02.03.88; publ. 07.10.91. Bulletin № 37.

the value e of eccentricity (see Fig. 2), and describe the character of its movement, taking: S_b - center of mass of the runner 3; R - distance |OK| from the center of body O, in which the runner 3 rotates, to point K on the line |OK|, which is the contact point of the runner 3 with the surface of body 1 (see Fig. 3). The distance from the center of the runner to the axis of rotation C_v = 9 mm.

The outer diameter of the cylindrical runner d = 0.072 m (72 mm); r is the distance $|C_vS_b|$ from the center (aka center of mass) of the runner to the center of rotation Cv of the leading link.

The offset of the center of rotation C_v from the center of the inner circle of the body O is 15 mm (eccentricity e = 0.015 m (15 mm)).

When the runner is located at the lower point of the exciter (the beginning of the deflection angle φ = 0) the distance $|C_vS_b|$ = 0.009 m (9 mm);

$$\frac{D}{2} - \frac{d}{2} - e = 0{,}009.$$

The diameter of body 1 is 0.12 m (120 mm), R = 0.06 m (60 mm).

The leading link 2 begins to rotate the runner 3 (see fig. 4) in a vertical plane inside the case with the center O relative to the center of rotation C_v with a constant rotation frequency (see fig. 3) ωv = 750 rpm.

Агротехнические показатели обработки почвы при различных режимах работы ГВ-1,8 (по данным, полученным М.А. Нагайка [9])
Agrotechnical indicators of tillage at different modes of operation of GV-1.8 (based on the data obtained by M.A. Nagayka [9])

Mode of operation of GV-1,8			Agrotechnical indicator, %		
Runner mass, kg	Running speed, km/h	Oscillation amplitude (estimated), 10^{-3}m	Lumpiness	Ridgeness	Stubble field preservation
Control*	9	–	26	21	52
4,55	9	1,06	21	20,5	56
4,55	3	1,06	14	18	68,5
9,1	9	4,53	8	11,5	81
9,1	3	4,53	3	8	92

* Without the use of vibration.

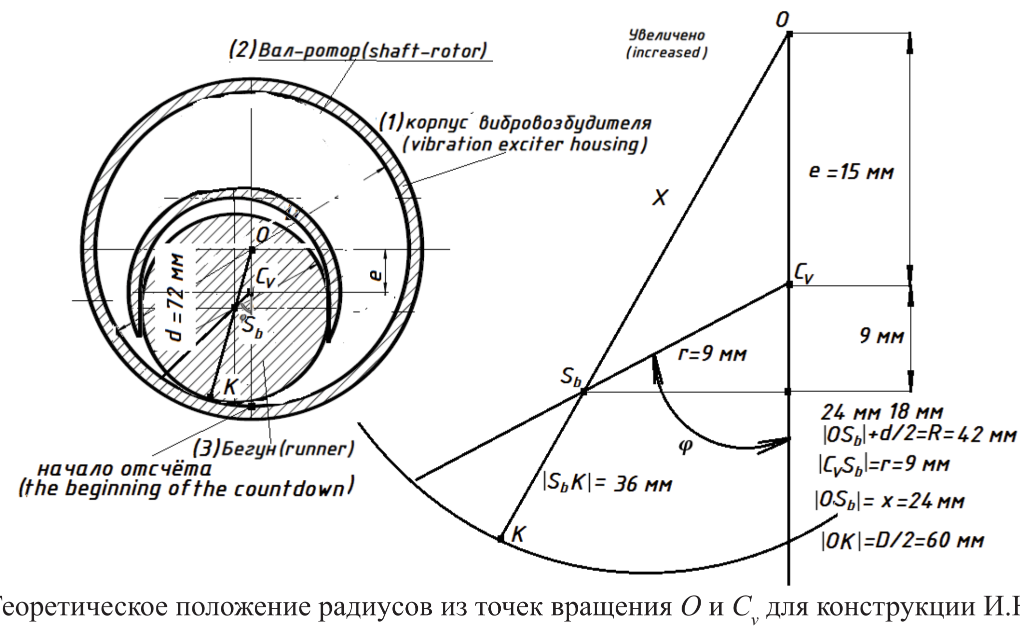

Рис. 2. Теоретическое положение радиусов из точек вращения *O* и C_v для конструкции И.Н. Петрягина [7]

Fig. 2. The theoretical position of the radii from the points of rotation O and C_v for the construction of I.N. Petryagin [7]

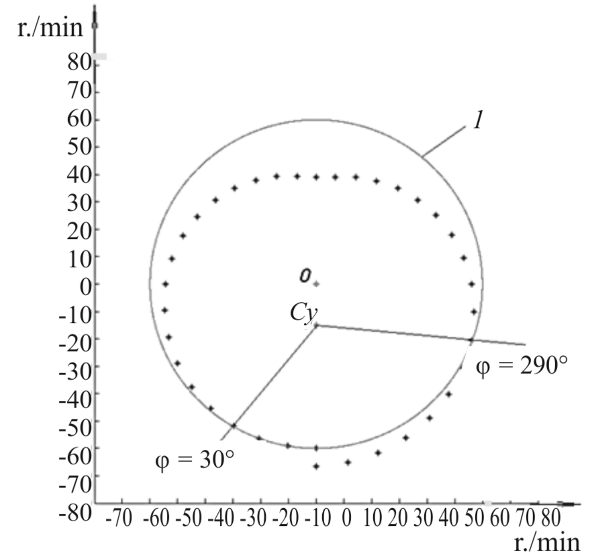

Рис. 3. Теоретическое положение точки *К* (точка касания бегуном *3* внутренней поверхности вибровозбудителя) в зависимости от поворота вокруг центра вращения C_v на величину угла φ
Fig. 3. The theoretical position of point K (the point where the runner 3 touches the inner surface of the vibration exciter) depending on the rotation around the center of rotation Cv by the value of angle φ

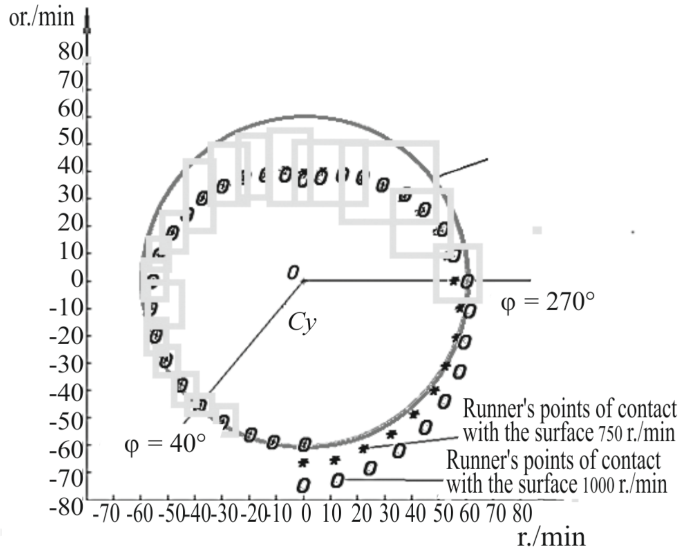

Рис. 4. Графическое решение уравнений для разной частоты вращения вала (750 и 1000 об. /мин)
Fig. 4. Graphical solution of the equations for different shaft speeds (750 and 1000 rpm)

Theoretically, the runner 3 with the center of mass at the point Sb should, when rotated by the leading link 2, touch the surface 1 of the body of the diameter D at the point K (see Fig. 2). Since there is a clearly audible impact, let us consider the position of the runner based on the physics of the process.

The point of contact K of the runner 3 and the inner surface of the vibration exciter with the center of the circle O is located on the line OK, passing through the center Sb of the runner 3. The distance from the center O to K is $|S_bO| + 1/2d$, where d = 0.072 - the larger diameter of the runner. Let's take $|OS_b|$ as X.

Then at any point of contact of the runner with the inner surface of the vibration exciter the value X is constant. At the lower point X = e + r (φ = 0), where e is the eccentricity and r is the distance from the center of the runner S_b 3 (see Fig. 4) to the center of rotation C_v, which is (see above) 0.009 m (9 mm).

Let us express X through r. In the general case

$$X^2 = (e + r \cdot \cos \varphi)^2 + r^2 \cdot \sin \varphi. \quad (1)$$

from here it follows that

$$X = \sqrt{(e^2+2r \cos\varphi + r^2) \cos\varphi^2 + r^2\sin\varphi^2} = \\ = \sqrt{e^2+2r \cos(\varphi) + r^2}. \quad (2)$$

Now let's find r at each point of the runner's position when rotating around the axis of rotation C_v based on the formulas for the acceleration and rotational motion of the body around the axis (see Fig. 2).

$$r_{i+1} = r_i + \Delta r_i = r_i + \frac{a_i \Delta t^2}{2}. \quad (3)$$

In our case, the rotating link 2 transmits to runner 3 the centrifugal acceleration, $a_i = \omega^2 \times r_i$. Taking into account the free-fall acceleration g = 9.8 m/s^2, the general formula will look like

$$r_{i \times 1} = r_i + \frac{(\omega^2 r_i + q \times \cos\varphi)\Delta t^2}{2}. \quad (4)$$

Since r depends on the angle of rotation φ, for calculations we will take the step (Δφ) equal to 10 degrees. In this case we express the time Δt through the rotational frequency

$$v = 750 \text{ rpm} = 12{,}5 \text{ cps}; \quad (5)$$

$$\Delta t = (10/360)/12{,}5 = 1/450 \ c^{-1}; \qquad (6)$$

$$\Delta t^2 = (1/450)^2 = 1/202500 \ c^{-2}. \qquad (7)$$

Let us also determine the angular velocity of the driving link 2, it is also the angular velocity of the runner 3. It is constant and equal to ω = 2πν. ν = 750 r./min = 12,5 r./s. Hence ω = 2 × 3,1416 × 12,5 = 78,54 (rad/s) and ω^2 = 6168,5316 $(rad/s)^2$. By substituting these values into the formula

$$r_{i+1} = r_i + \frac{(\omega^2 r_i + q \times \cos\varphi_i)}{2}, \qquad (8)$$

we get the expression

$$r_{i+1} = r_i + \frac{(6168{,}53 r_i + 9{,}8 \times \cos\varphi_i)}{2 \times 202500}, \qquad (9)$$

where $\varphi_i = \varphi_0 + \frac{2 \times \pi \times 10}{360} \times i.$ (10)

After that using numerical methods with Microsoft Excel we calculate X_i through previously obtained in the same way r_i. Adding to the value X_i half of the runner diameter, we obtain the radius-vector from O to the theoretical point of contact K of the runner 3 with the inner surface of the vibration exciter. The calculation is shown in Fig. 3.

Thus, the graphical representation presented in Fig. 3 graphical image gives a complete picture of the cause of excitation of sound vibrations (shock): it is a detachment of the runner 3 from the body 1, its acceleration without contact with the body 1 and contact at φ = 290 deg., causing a shock (knock), the sound of which is heard during operation of the vibration exciter. We investigated two practical modes of operation at speeds of 750 and 1000 rpm.

The stars and circles in Fig. 4 represent the points K and their position relative to the body with an angle of φ = 0.1745 radians (10 degrees).

Circle 1 indicates the position of the body. If the stars and circles are located inside the body 1, the trajectory of movement indicates the action of insufficient centrifugal force. On the contrary, if the stars and circles are located outside the body 1, the action of the centrifugal force in practice leads to contact of the runner with the body, which is the cause of impact of the runner on the body and excitation of oscillations. The graph of the process (see Fig. 3), shown by the asterisks, indicates that the runner 3, moving at a speed of 750 rpm, breaks away from the body at φ > 30 degrees and returns to contact with the body at φ = 290 degrees, so it affects the body at 290 < φ < 30.

The process shown by the circles in Fig. 4 indicates that the runner 3, rotating at 1000 rpm, detaches from the body at φ > 40 degrees and returns to contact with the body at φ >270 degrees and therefore interacts with the body at 270 < φ < 40. The remaining surface of the body is not in contact with the runner.

Let's define the total energy from the rotating runner as the sum of kinetic and potential energies from different types of motion inside the body of the vibration exciter. When the runner moves in a circular motion, it is the kinetic energy of the runner ΔK, and when the runner is raised and lowered, it is the potential energy ΔP. The total energy, the sum of the kinetic and potential energies, will be defined as ΔE = ΔK + ΔP. Provided the speed of rotation of the runner is practically constant (ΔK = 0 if ω is const), we define the magnitude of the change in potential energy as $\Delta\Pi = vmg\Delta h = vg\left(2\left(\frac{D}{2} - \frac{d}{2}\right)\right)$.

Thus, the maximum work produced by the vibration exciter will be equal to A = ΔP = vg (D - d) m, where v is the speed of revolutions per second.

In the work of I.N. Petryagin [7] it is noted that the maximum efficiency of the vibration exciter is achieved when the ratio of the runner diameter d to the internal diameter of the body $\frac{D}{2}$ = 0,6.

Let's estimate the mass of the runner based on the size and density

$$m = \pi\frac{d^2}{4}\rho l = \frac{1}{4}\rho\pi l d^2. \qquad (11)$$

Let's take *S* - area of the runner, L - length of the runner, ρ - density of the material used, i.e. steel, 7800 kg/m^3, g -9.80665 m-s-2. Let us differentiate the expression and equate the derivative to zero:

$$\Delta\Pi = vg\rho\pi\frac{d^2}{4}L(D-d) = \frac{1}{4}vg\rho\pi L(d^2D-d^3) = k(d^2D-d^3); \quad (12)$$

$$k\times(2dD-3d^2)=0 \text{ или } k\times d\times(2D-3d)=0. \quad (13)$$

Let's consider $2D–3d = 0$.

From here we get

$$d = \frac{2}{3}D. \quad (14)$$

From this it follows that the maximum work can be done when the ratio D and d is equal to $d = \frac{2}{3}D$, which is very close to the ratio obtained by I.N. Petryagin [7], but calculated in a different way.

Fig. 5 shows the design of the vibration exciter, taking into account the results of work on obtaining its maximum power and operation without knocking. An invention application has been filed for the proposed variant.

There is a back side plate 10 with a hole 8 in it displaced by the eccentricity value e, the rotor shaft 3 rotates the runner 1 inside the body of the vibration exciter. The bearing stop 19 provides a free rotation of the cylindrical disc 3, from the rotation of which, through the rotor shaft 3, the rotation is transmitted to the runner 1, moved inside the cylinder of the vibrating exciter body [9, 10]. The views are given: a - from the inner side to the plate 10, on which a slot 6 is made with a cylindrical tube of the vibration exciter body 1 placed in the slot, along the inner side of which the runner 3 moves clockwise, pressed by the centrifugal force in the tube window 15 to the vibration exciter body 1; b - rear view of the plate 10, on which the drive spacer 17 is made, placed on the studs fixed in the holes 9 of the side plate 10; there is a through hole 14 for pouring lubricant into the inside of the exciter on the drive spacer 17; through the holes 9 the hydraulic motor is fixed with studs.

The claimed vibration exciter is assembled. Between the side back plate 10 and the back plate 11 there is a cylindrical tube 15 forming the vibrating exciter body, along the inner part of which the runner 1.

The proposed calculation method, used in the work, allowed to determine the value of ec-

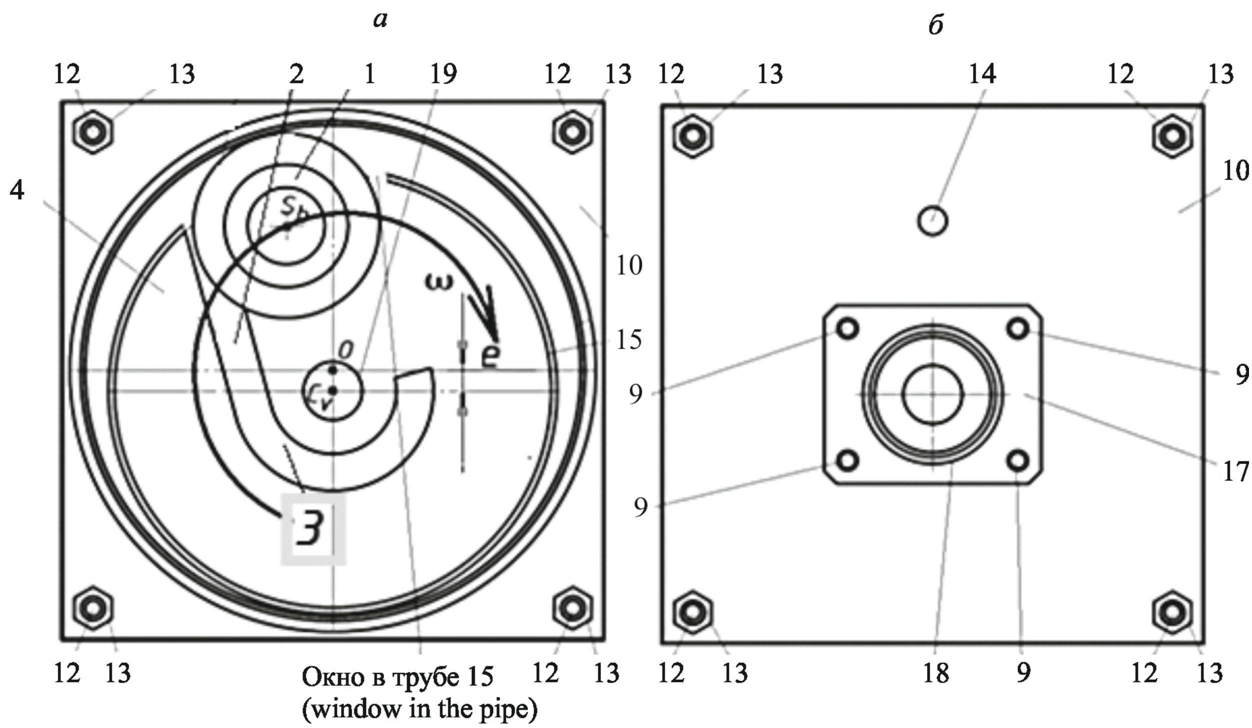

Рис. 5. Устройство боковых плит и ротора, перемещающего бегун внутри корпуса предлагаемого вибровозбудителя с мощностью [8]

Fig. 5. Fig. 5. The device of the side plates and the rotor moving the runner inside the housing of the proposed vibration exciter with power [8]

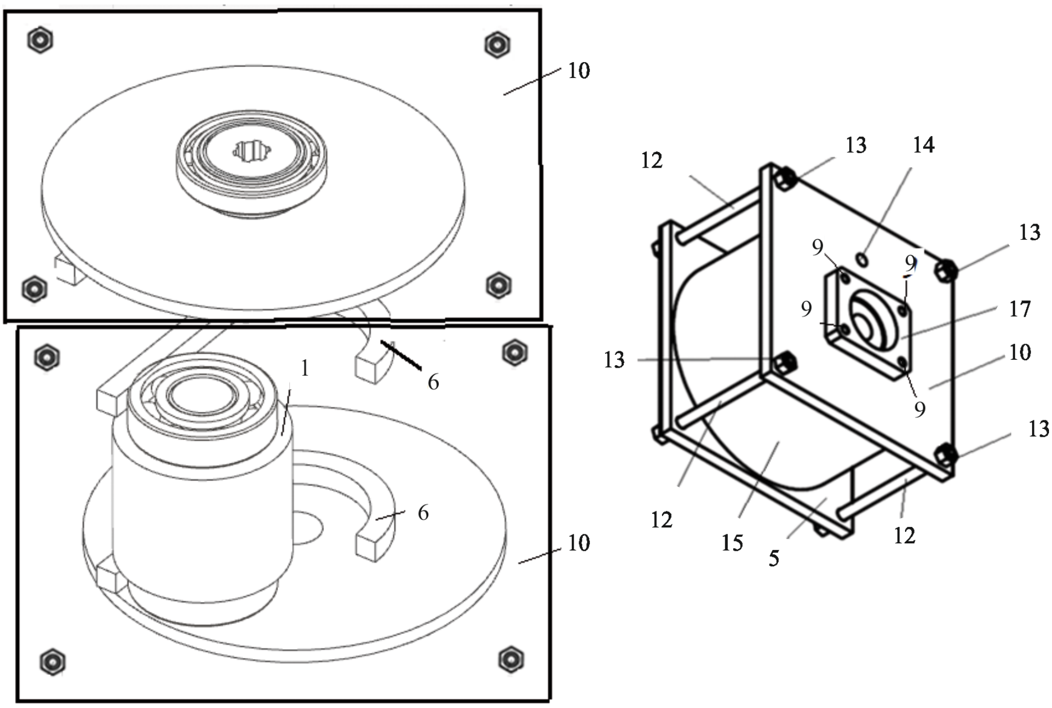

Рис. 6. Внешний вид вибровозбудителя максимальной мощности
Fig. 6. Maximum power vibration exciter appearance

centricity, at which the runner touches all points of the inner surface of the exciter. Changing parameters (rotation frequency and diameter of the runner), it was found that for the runner to touch the whole surface of the exciter body, for eccentricity e the following condition must be fulfilled:

$$16{,}11(\text{при } v - 500\ \frac{\text{об.}}{\text{мин}}) \le \frac{D-d}{e} \le$$

$$\le 17{,}06\ (\text{при } v - 1500\ \frac{\text{об.}}{\text{мин}}). \qquad (15)$$

Patent values, at which the maximum power of the claimed vibration exciter is achieved, correspond to the conditions of the diameter ratio as d = 23 D, where D - diameter of the cylindrical body, d - diameter of the runner is 72 mm, the eccentricity value is 17.06 mm.

CONCLUSIONS

1. The mechanism of excitation of vibration oscillation has been studied, which showed that the size of its body, runner and adopted eccentricity have a significant influence on the magnitude of the power of the vibration exciter.

2. On the example of calculations carried out by the numerical method, the design and technological scheme of the inertial type vibration exciter is substantiated and the results, at which its maximum power

$$W = vg(D - d)m,$$

where v is the rotation frequency of revolutions per second, are given.

A patentable solution on the necessary value of eccentricity emax, at which the runner will touch the exciter body at all points is obtained (see Fig. 1).

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