USING HYDRAULIC PARAMETRIC VIBRATION EXCITER IN AGRICULTURAL ENGINEERING

T. Gaponyuk, R. Kirchuk*, L. Zabrodotska

Lutsk National Technical University, Lutsk, Ukraine

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****Corresponding author:***
ruslan-mail@ukr.net

ABSTRACT

Vibration technology is widely used in mechanical engineering, construction, road building and different sectors of the manufacturing. In agriculture, it is used for dosing feed, cleaning and sorting seeds, digging up root crops, planting potatoes, and transporting bulk materials. Vibrations make the mechanical system more stable in relation to external force disturbances and do not change the technological properties of materials during its movement along the working surfaces. Also, the material passing through the vibration zone is not damaged. A wide range of frequency and amplitude of vibrations provides the possibility of vibration regime varying, and the characteristics of the movement of agricultural plant material on the vibrating working bodies. The analysis of possibility of application of vibrating hydraulic drives as elements of transmission of movement to working bodies of agricultural machines is executed. A historical excursion was conducted and the first mentions of the use of hydraulic drives were pointed out. The estimation of technological processes in agricultural production where it is expedient and possible to use vibration and vibrating drives is made. At the present stage of development of agricultural engineering, using vibrating hydraulic drive is accorded to the basic trends of agriculture machinery development. The stand for conduction of studies of amplitude-frequency characteristics of the vibrating drive with regulated perturbations is offered. A mathematical model is presented, which generally describes the course of the vibration process and estimates the stiffness of the mechanical system. The hydraulic parametric vibration exciter is recommended to use for studying and determination the conditions for the occurrence of parametric vibrations in working body of agricultural machines. Also, using a hydraulic drive makes it possible to simplify the kinematics, reduce metal consumption, increase accuracy, reliability and level of automation of working bodies of agricultural machines.

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ВИКОРИСТАННЯ ГІДРАВЛІЧНОГО ПАРАМЕТРИЧНОГО ВІБРОЗБУДЖУВАЧА В СІЛЬСЬКОГОСПОДАРСЬКОМУ МАШИНОБУДУВАННІ

Т.О. Гапонюк, Р.В. Кірчук*, Л.Ю. Забродоцька

Луцький національний технічний університет, Луцьк, Україна

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АНОТАЦІЯ

Вібрація широко використовується в машинобудуванні, будівництві та різних галузях виробництва. У сільському господарстві вібрація використовується для дозування кормів, очищення та сортування насіння, збирання коренеплодів, садіння картоплі, транспортування сипких рослинних матеріалів. Вібрація робить механічну систему більш стійкою відносно зовнішніх силових збурень і не зумовлює зміни технологічних властивостей матеріалів під час їх руху робочими поверхнями. Рослинний матеріал, що проходить через зону вібрації, не пошкоджується. Широкий діапазон зміни частоти та амплітуди вібрації забезпечує можливість варіювання вібраційного режиму і особливостей руху сільськогосподарського рослинного матеріалу на робочих органах. У статті проаналізовано можливості застосування вібраційних гідроприводів як елементів передачі руху робочим органам сільськогосподарських машин. Також проаналізовано технологічні процеси у виробництві сільськогосподарської продукції, де доцільно і можливо використовувати вібрацію та вібраційні приводи. У сільськогосподарському машинобудуванні використання вібраційного гідроприводу є одним із основних напрямів його розвитку. Запропоновано стенд для проведення досліджень амплітудно-частотних характеристик вібраційного приводу з регульованими збуреннями. Представлено математичну модель, яка в загальному вигляді описує перебіг вібраційного процесу і оцінює жорсткість механічної системи. У статті для дослідження умов виникнення параметричних коливань робочих органів машин рекомендовано використовувати гідравлічний параметричний віброзбуджувач. Використання гідроприводу дозволяє спростити кінематику, зменшити металомісткість, підвищити точність, надійність і рівень автоматизації робочих органів машин.

Ключові слова:
вібрація в сільськогосподарському машинобудуванні, віброзбуджувач, гідропривод, параметричні коливання, жорсткість

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****Автор для листування:***
ruslan-mail@ukr.net

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INTRODUCTION AND PROBLEM STATEMENT

Agriculture is the most ancient sphere of human activity. Since ancient times, on a subconscious level, a person has used oscillations processes in the production of food, without even comprehending the essence of the physical process. The appearance of water and wind drives made it possible to mechanize technological operations using oscillations and vibration. One of the first references to vibrating machines is in the scientific journal (*The London Journal of Arts, Sciences and Manufactures, and Repertory of Patent Inventions, 1849*) without careful explanations and references to the authors. A detailed analysis of the historical aspects of using vibration machines is made by *Lanets* (*2008*). At present, impulse and vibration technology is widely used in mechanical engineering, construction, road building and different sectors of the manufacturing. In agriculture, it is used for dosing feed, cleaning and sorting seeds, digging up root crops, planting potatoes, and transporting bulk materials. The principle of vibration is also used in the development of sowing devices. The main advantages of using vibration are as following (*Povidaylo, 2004; Pogorilec & Volyansky, 2011*):

- vibrations make the mechanical system more stable in relation to external force disturbances;
- vibrations and fluctuations do not change the technological properties of materials during its movement along the working surfaces;
- the material passing through the vibration zone is not damaged;
- a wide range of changes in the frequency and amplitude of vibrations allows us to vary the vibration regimes, and consequently, the characteristics of plant material movement.

The study of the parameters of vibration processes, their analysis and synthesis of energy and motion transmission systems allow us more efficient design of the working bodies of agricultural machines based on working with hydraulic drives.

The Goal of the Study is to analyze the possibility of using vibration hydraulic drives in the working bodies of agricultural machines, to analyze and develop the stand for studying the amplitude-frequency characteristics of a hydraulic drive with disturbing elements.

MATERIALS AND METHODS

The study was carried out by using the developed experimental stand. The technique for analyzing the parameters of the vibrational process of the hydraulic drive was based on the methods of analytical mechanics and hydraulics.

RESULTS AND DISCUSSION

At present, the study of vibrations is very important according to the rapid increase in the capacity of agricultural machines and the speed of movement of their units and mechanisms, the reduction in relative weight, the increase in durability and reliability, and the stability and controllability of mechanical systems. In some cases, the parameters of mechanical systems, such as rigidity or mass, do not remain unchanged, but they are functions of the time. If the equilibrium state of such a system is disturbed, then peculiar oscillations will be made: on the one hand, they cannot be called free, since the system is not autonomous and experiences this external influence in the form of a change in the parameter, and on the other hand, the external influence does not manifest itself in the form of this system strength. These fluctuations are called parametric and, depending on the properties of the system and the nature of the changes in parameters, they can have limited or increasing peak values over time. This is called parametric resonance.

Parametric oscillations can occur where the stiffness of the system and (or) the mass of moving elements that determine the natural frequency of the agricultural machine system periodically changes ω_0:

$$\omega_0 = (C / m)^{0.5}, \qquad (1)$$

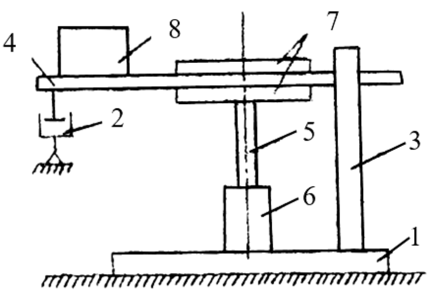
where C is the stiffness of the system; m is the mass of moving elements of the system.

This indicates that parametric oscillations can occur where the frequency of the oscillatory system periodically changes ($\omega_0 \pm \Delta\omega_0$).

In the studies of *Pogorilec and Volyansky* (*2011*), *Gaponyuk* (*1998*), *Kuzmin and Gaponyuk* (*1997*), parametric oscillations in machines, aggregates and other mechanisms are considered undesirable.

In a practical sense, these studies are aimed at determining the conditions for the occurrence of parametric oscillations and eliminating their harmful effects. For the purpose of practical using in vibration machines and technologies, the schemes of parametric vibration exciters will be considered.

The parametric vibration exciter shown in **Fig. 1** contains an elastic element of changeable bending stiffness, which is made in the form of a cantilever beam and non-circular disks. Non-circular disks are connected to the drive shafts. One end of the cantilever beam is rigidly attached to the rack, and the second is connected to the hydraulic damper. During rotation of the disks, the length of the beam periodically changes from the minimum to the maximum value. In this case, the bending stiffness of the elastic beam changes, which causes its parametric bending vibrations and, consequently, vibrations of the object fixed at the end of the beam. The device disadvantage is a narrowly limited range of disturbing frequencies and a decrease in operating efficiency due to the violation of parasitic oscillations.



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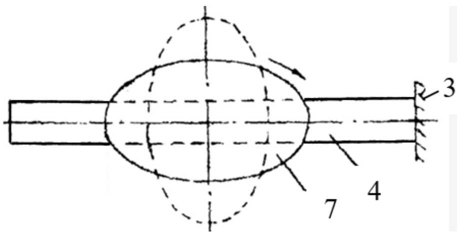

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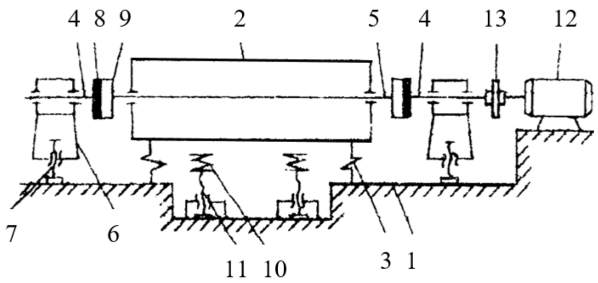
Fig. 1 – Parametric vibration exciter (a) with an elastic element of variable bending stiffness (b):
1 – base; 2 – hydraulic damper; 3 – rack;
4 – cantilever beam; 5, 6 – drive shaft;
7 – non-circular disks; 8 – beam

The parametric vibration exciter shown in **Fig. 2** contains a base and working unit, which is mounted on elastic support elements. The vibration exciter is made in the form of three coaxial shafts. The two extreme shafts are installed on platforms equipped with lifting mechanisms. Elastic elements are fixed on shafts and connected by means of coupling halves with shaft mounted on the working unit. Between the base and working unit buffer elements and the gap adjustment mechanism are located. The shaft rotation is made by the engine through the clutch.

Due to the different stiffness of the elastic elements in compression and bending, during shaft rotation the stiffness of the vibration device system periodically changes in the vertical direction. For one revolution of the shafts, the change in stiffness occurs twice. When certain frequency ratios are met, in particular, when the frequency of stiffness pulsations is twice the natural frequency of the system, the parametric oscillations of the working unit are disturbed.



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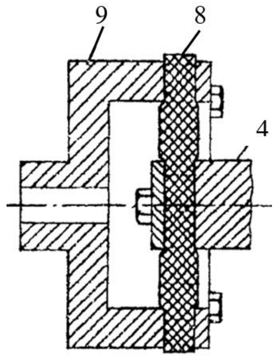

b

Fig. 2 – Parametric vibration exciter
with elastic support elements (a)
and elastic support elements (b):
1 – base; 2 – working unit; 3 – elastic support elements; 4, 5 – coaxial shafts; 6 – platforms;
7 – lifting mechanisms; 8 – elastic elements;
9 – coupling halves; 10 – buffer elements;
11 – gap adjustment mechanism; 12 – engine;
13 – clutch

The parametric vibration exciter shown in **Fig. 3** contains two levers, the arms of which are located at an angle, and the central hinges are connected to the base. The elastic element of exciter can bend. The device has a pin with multidirectional threads. The pin is placed along the axis of the table and is connected to the elastic element and the crossbar.

Depending on the required perturbation frequency, the corresponding initial longitudinal force is set by rotating the pin, which acts on the elastic element, that determines the frequency of its oscillations. When the drive rotation of the thrust is turned on, the two-arm lever moves. The different direction of movement of the levers is provided by the thrust. With such a movement of the two-arm levers, a periodic change in the stress state of the elastic element occurs, which leads to the parametric oscillations of the table. The disadvantages of such parametric vibration exciters include low efficiency due to the complexity of the design and the impossibility of regulating the system during operation.

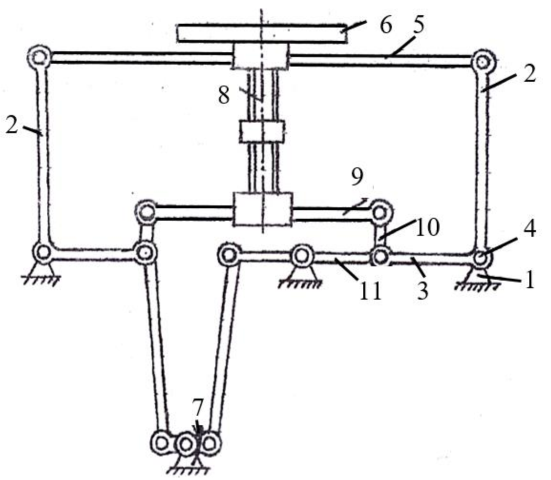

Fig. 3 – Parametric vibration exciter with adjustable parameters:
1 – base; 2, 3 – arms; 4 – central hinge;
5 – elastic element; 6 – table; 7 – drive; 8 – pin;
9 – crossbar; 10, 11 – thrusts

During operation of the parametric vibration exciter, which is shown in **Fig. 4**, its efficiency can be expanded by providing the ability to regulate the elastic system. The vibration exciter consists of a base, vibration table and elastic system consisting of longitudinal bending elastic elements. The mechanism for adjusting the elastic system and the drive are made in the form of an electromagnet. The unit of the electromagnet is fixed in the middle part of the elastic element, and the anchor is fixed on the middle part of the opposite elastic element in such a way that the longitudinal axis of the electromagnet is perpendicular to the direction of movement of the vibration table. The elastic elements are made in the form of plates, which are pivotally based with the displacement of the centers of hinges relative to the average plane of the plates. The vibration exciter is equipped with additional elastic elements, the characteristics of which are adjustable. Element for testing is installed on the vibration table, the mass of which causes longitudinal deformation of the elastic elements. At the same time, their middle parts move towards each other. The oscillations of the system are supplied with an alternating voltage supply to the coil. The magnitude of the amplitude of voltage fluctuations determines the amplitude of vibrations of the vibration table. By supplying voltage to the electromagnet, it is possible to adjust the deflection of the elastic elements.

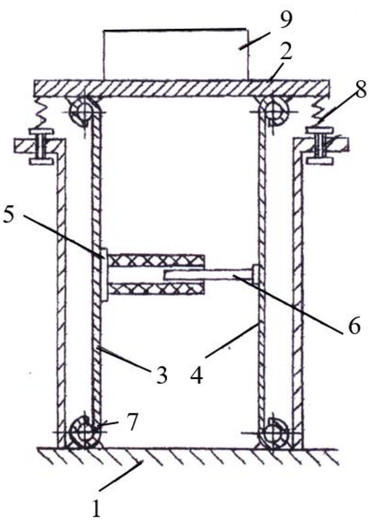

Fig. 4 – Parametric vibration exciter with adjustable elastic system:
1 – base; 2 – vibration table; 3, 4 – elastic elements; 5 – unit of the electromagnet;
6 – anchor; 7 – hinges; 8 – additional elastic elements; 9 – element for testing

The hydraulic parametric vibration exciter is shown in **Fig. 5**. Between the fixed unit and the working movable element, four elastic support elements, which are elastic high-pressure hoses pre-compressed to an elliptical shape, are clamped and connected by means of hydraulic lines to the cavities of hydraulic cylinders. Plungers are also installed. Conventionally, to simplify the description of the parametric vibration exciter, hydraulic cylinders with plungers, a profiled cam and parts of hydraulic lines can be combined into one concept as an oscillation generator. And the elastic support elements of the movable working element and the fixed unit can be combined into one concept as the actuator (working element).

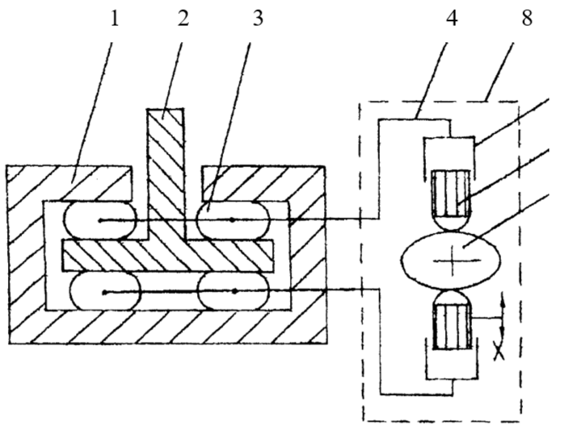

Fig. 5 – Hydraulic parametric vibration exciter:
1 – fixed unit; 2 – working movable element;
3 – elastic support elements; 4 – hydraulic lines;
5 – hydraulic cylinders; 6 – plungers;
7 – profiled cam; 8 – oscillation generator

Total stiffness C_Σ of executive mechanism is determined by the equation:

$$C_\Sigma = C_ш + C_{p0} + C_\delta + C_p, \qquad (2)$$

where $C_ш$ is self-stiffness of the hose under pressure $p_0 = 0$; C_{p0} is stiffness depends on pressure p_0; C_δ is additional stiffness associated with an increase in the average pressure in the hoses; C_p is stiffness of the «hydraulic spring» of mechanism.

It can be seen from equation (2) that the total stiffness of the system depends on several parameters, but the most important is the average pressure, which can be easily changed according to any law, including the harmonic one with frequency θ.

When the profiled cam rotates (**Fig. 5**), the plungers push the working fluid out of the cavity of the hydraulic cylinders and supply it through the hydraulic lines to the elastic support elements. In this case, the average fluid pressure increases from the minimum to the maximum value in the elastic elements. This changes the stiffness of the elastic support elements in the vertical direction. For one revolution of the profiled cam, the change in stiffness occurs twice. When certain frequency ratios are met, in particular, when the frequency of the liquid pulsation is twice the natural frequency of the system, there is a violation of the parametric oscillations of the working body.

The mathematical model of the parametric vibration exciter will correspond to the Mathieu equation with dissipative term (*Gaponyuk, 1998*):

$$X(t) + 2\varepsilon \ddot{X}(t) + \omega_0^2 (1 - 2\mu \cdot \cos(\theta t)) X(t) = 0, \qquad (3)$$

where X is coordinate along the X axis; ε is damping coefficient; μ is perturbation coefficient; t is time.

The perturbation coefficient is determined by the equation (*Kuzmin & Gaponyuk, 1997*):

$$\mu = \frac{\pi}{4} \cdot \frac{LEW_1}{C_\Sigma W_0}, \qquad (4)$$

where L is hose tightening length; E is total modulus of elasticity; W_1 is volume of fluid supplied by the pulsator; W_0 is volume of the working cavity of the actuator (working body).

At certain ratios between the frequency ω_0 of free (natural) oscillations of the movable working body and the frequency of pulsation θ, the form of equilibrium turns out to be unstable and oscillations of the movable working body arise with a sharply increasing amplitude.

Equation (3) has an increasing solution only for sufficiently large values of the parameter μ. So, for the zone of resistance, the equation is as following:

$$\theta = 2\omega_0 \sqrt{1 + \sqrt{\mu^2 - \left(\frac{\Delta}{\pi}\right)^2}}, \qquad (5)$$

where Δ is self-oscillation damping decrement.

The self-oscillation damping decrement is determined by the equation:

$$\Delta = \frac{2\pi\varepsilon}{\omega_0}. \qquad (6)$$

It follows from the equation (5) that instability is possible only under the condition for the perturbation coefficient:

$$\mu > \mu^* = \frac{\Delta}{\pi}. \qquad (7)$$

The uncontrollability of the characteristics of the frequency and amplitude of the pulsations are the disadvantage of parametric vibration exciter. This shortcoming can be easily eliminated if the hydraulic parametric vibration destroyer is converted according to the scheme, which is shown in **Fig. 6**.

The parametric vibration exciter includes adjustable pump, adjustable hydraulic motor and oscillation generators. Oscillation generators are connected with an adjustable clutch, and are also connected by hydraulic lines with the actuator on the hoses.

Theoretically, a hydraulic drive using an adjustable pump and hydraulic motor has an unlimited range of output speeds of the hydraulic motor (*Bashta, 1974*), and hence the pulsation frequencies of oscillation generators. An infinitely small pulsation frequency corresponds to an infinitely small working volume of the pump at the maximum working volume. And an infinitely large pulsation frequency corresponds to an infinitely small working volume of the hydraulic motor at the maximum value of the working volume of the pump. To adjust the amplitude of the pulsating volume, the adjustable clutch is used.

CONCLUSIONS

The parametric vibration exciter has advantages such as: the simplicity of the design, the relatively simple adjustment of the frequency and amplitude of vibrations during the operation of the vibration exciter, the absence of friction pairs, low sensitivity to distortions, the high quality of the vibrations of the system. So, it makes possible to use the parametric vibration exciter to study and determine the conditions for the occurrence of parametric vibrations in units and other working body of agricultural machines.

The hydraulic drive is an effective means of transmitting movement to the working bodies of agricultural machines. Using a hydraulic drive makes it possible to simplify the kinematics, reduce metal consumption, increase their accuracy, reliability and level of automation. With the help of a hydraulic drive, translational, rotary and rotating movements of the executive bodies are carried out.

Agricultural engineering is one of the consumers of hydraulic systems. The hydraulic is one of the main trend in the development of agricultural machines, which supports in increasing the number of working bodies, ensuring the movement of working bodies in relation to the machine and the machine itself in relation to the power source with which it is aggregated, automating technological operations to increase productivity and improve working conditions.

The active use of the hydraulic drive in agriculture is determined by its well-known advantages, which, however, can only be realized with proper design and operation.

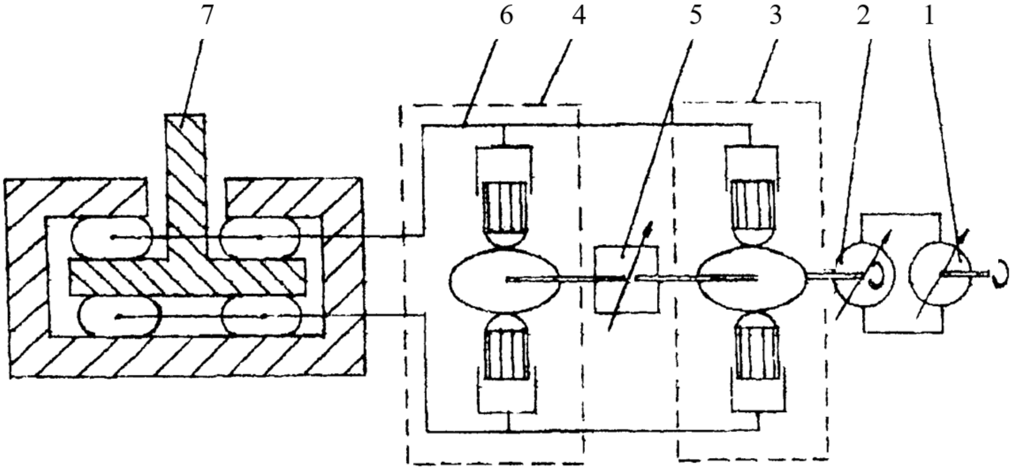

Fig. 6 – Hydraulic parametric vibration exciter with parameter adjustment system: 1 – adjustable pump; 2 – adjustable hydraulic motor; 3, 4 – oscillation generators; 5 – adjustable clutch; 6 – hydraulic lines; 7 – profiled cam

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