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Original article

JUSTIFICATION OF THE VIBRATION PLATE INSTALLATION TYPE OF THE HOPPER OF FERTILIZER APPLYING MACHINE

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Abstract

Background. The main units of an agricultural machines for subsoil fertilizer application are the hopper and metering unit, which provides uniform fertilizer supply to all sowing working bodies. As a result of the main research, a hopper and metering device with a vibratory plate operating in forced oscillation mode was proposed, and in this paper installation types of vibratory plate on a chamber have been theatrically investigated. The main goal of the study is to define more effective type of installation. The vibratory plate was modeled as a flexible rod with two fixed ends and one degree of freedom, then the vibration amplitudes and frequencies for 4 types of mounting were investigated. According to theoretical studies, a rational model for fixing the vibrating plate is a fixed rod with two ends fixed pivotally.

Purpose. The aim of the present study is to perform the justification of the vibration plate installation type of the hopper of the fertilizer applying machine.

Materials and methods. Figure 1 presents the scheme and experimental example of the proposed hopper. To simulate the fastening scheme of the AB plate ends, 4 ways of fixing are proposed in Figure 3. As a result, we calculate the frequency for each circuit, compare them with real frequencies and select one of the four ways of fixing. During the research, it has been calculated the frequency for each circuit, compare them with real frequencies and select one of the four ways of fixing. To solve the problem described above, in the first approximation, the oscillation of the AB plate is modeled as the oscillation of an elastic system with one degree of freedom presented in Figure 4. The unknown parameters are determined by boundary conditions.

Results. The effective installation type of the vibratory plate has determined by modeling it as a flexible plate with two ends fixed with one degree of freedom. Vibration amplitudes and frequencies for the 4 ways of fixing the plate as vibrations of an elastic system were determined. By modeling a fixed vibrating plate with two ends that is a one-dimensional continuous system, amplitude problems and frequency equations of specific and involuntary vibrations of the plate were obtained. According to results it concluded that the rational model of a vibrating plate is a fixed plate with two ends hinged. The specific frequency of the plate was approximately the same as the results of the calculation of the body model identified earlier.

Conclusion. The studied data is required for further analysis using computational fluid dynamics (CFD) and discrete element method (DEM).

According to the general search, it should be noted that the seeding device with the proposed compensating chamber provides 4.37–6.63% seeding unevenness and 5–5.8% seeding instability.

Keywords: amplitude; seeder hopper; oscillation; fertilizer; subsoil

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Научная статья

ОБОСНОВАНИЕ ТИПА УСТАНОВКИ ВИБРОПЛИТЫ В БУНКЕРЕ МАШИНЫ ДЛЯ ВНЕСЕНИЯ УДОБРЕНИЙ

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Аннотация

Обоснование. Основными узлами сельскохозяйственных машин для подпочвенного внесения удобрений являются бункер и дозатор, которые обеспечивают равномерную подачу удобрений ко всем рабочим органам сеялки. В результате основных исследований был предложен бункер-дозатор с виброплитой, работающей в режиме вынужденных колебаний, а в данной работе театрально исследованы типы установки виброплиты на камеру. Основной целью исследования является определение более эффективного типа установки. Виброплита моделировалась как гибкий стержень с двумя фиксированными концами и одной степенью свободы, затем были исследованы амплитуды и частоты колебаний для 4 типов установки. Согласно теоретическим исследованиям, рациональной моделью крепления виброплиты является неподвижный стержень с двумя концами, закрепленными шарнирно.

Цель. Целью настоящего исследования является обоснование типа установки виброплиты в бункере машины для внесения удобрений.

Материалы и методы. На рисунке 1 представлена схема и экспериментальный пример предлагаемого бункера. Для моделирования схемы крепления торцов пластин АВ на рисунке 3 предложены 4 способа крепления. В результате мы рассчитываем частоту для каждой цепи, сравниваем ее с реальной частотой и выбираем один из четырех способов крепления. В ходе исследования были рассчитаны частоты для каждого контура, сравнены с реальными частотами и выбран один из четырех способов крепления. Для решения описанной выше задачи в первом приближении колебания пластины АВ моделируются как колебания упругой системы с одной степенью свободы, представленной на рисунке 4. Неизвестные параметры определяются граничными условиями.

Результаты. Эффективный тип установки виброплиты был определен путем моделирования ее как гибкой пластины, два конца которой закреплены с одной степенью свободы. Определены амплитуды и частоты колебаний для 4-х способов крепления плиты как колебаний упругой системы. При моделировании неподвижной вибрирующей пластины с двумя концами, представляющей собой одномерную непрерывную систему, получены амплитудные задачи и частотные уравнения собственных и вынужденных колебаний пластины. По результатам сделан вывод, что рациональной моделью вибрирующей пластины является неподвижная пластина с двумя шарнирно закрепленными концами. Удельная частота пластины примерно совпала с результатами расчета модели тела, определенной ранее.

Заключение. Исследованные данные необходимы для дальнейшего анализа с использованием вычислительной гидродинамики (CFD) и метода дискретных элементов (DEM).

По результатам общего поиска следует отметить, что высевающий аппарат с предложенной компенсационной камерой обеспечивает неравномерность высева 4,37-6,63% и нестабильность высева 5-5,8%.

Ключевые слова: амплитуда; бункер сеялки; колебания; удобрения; почва

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Introduction

The main component of agricultural units for intra-soil fertilizer application is the presence of a hopper and dosing device, which ensures uniform fertilizer delivery to all working bodies. However, most machines cannot efficiently allocate and apply the fertilizer in the soil. One of the problems faced by farmers and fertilizer machines operators is vaulting in hoppers; the accumulation and sticking of fertilizer in the corners and low parts of the hoppers, the formation of vaults (clogging) above the seeding windows [1-4]. It makes difficult to dose fertilizer evenly and, by disrupting the technological process of fertilizer application it leads to a reduction of agronomic efficiency [5-7]. In this regard, a hopper-dosing machine that operates under forced vibration was developed. The hopper equipped with a vibrator and compensation chamber [8; 9] to induce a vibration. The main work component is the vibrating plate that mounted in the compensation chamber. Currently, the known types of hopper vibrator designs are suspended rigid vibration drive, crank vibration drive, pulley vibration drive, recessed vibration driver, etc. The design of the vibration motor, which is usually installed on the hopper, depends on the size, shape and design of the body, the angle of inclination of the base, the thickness of the walls, the strength of the supports, as well as many factors, such as the design of the vibration motor. Vibrators are divided into electromechanical, electromagnetic, hydraulic and pneumatic actuators [10-13]. Vibratory thrusters are also characterized by complexity in design, control and maintenance. Energy consumption is only insignificant. Vibration from the vibration actuator is transmitted to the wall of the hopper or directly to the material. At the same time, a significant disadvantage of these actuators is that vibration not only loosens the material, however also contributes to the compaction of the material [14; 15].

On the proposed design the vibrating motor installed independently and influences to the vibrating plate that according to owned amplitude and according to its property vibration condition multiples. The connection type of the vibrating plate to the chamber walls is very important to obtain the required vibration amplitude and its rising. The vibratory plate was modeled as a flexible rod with two fixed ends and one degree of freedom, then the vibration amplitudes and frequencies for 4 types of mounting were investigated. The main *purpose* of the study is to determine and theoretically substantiate the most acceptable type of installation of the vibratory plate.

Materials and methods

Figure 1 presents the scheme and experimental example of the proposed hopper. The bulk of the fertilizer in the hopper (1) falls into the chamber (3) under the action of the conic-helical spring. The vibrating plate (5) ensures that the fertilizer falls continuously and evenly onto the belt, which then guides the fertilizer into the pipes. The connection type (6) of the vibrating plate to the chamber walls is very important to obtain the required vibration amplitude that provide fertilizer fall-flow without any vaulting problems.

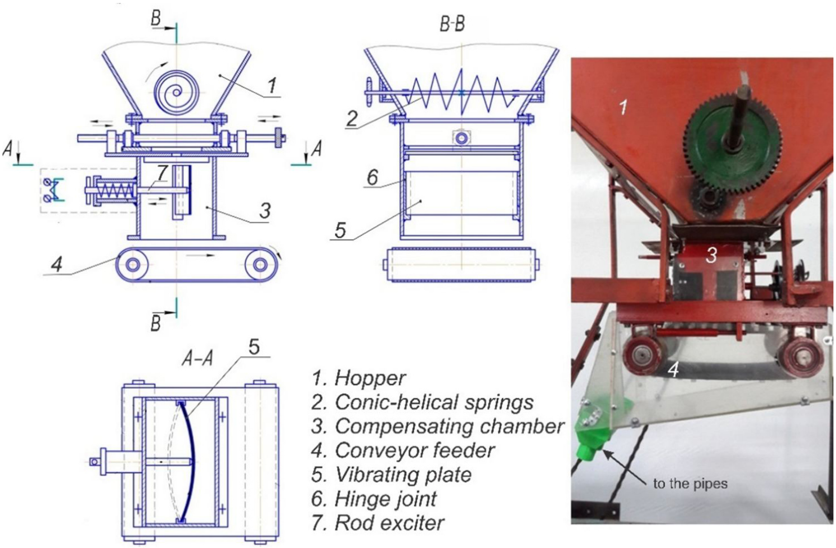


Fig. 1. The scheme and experimental example of the proposed hopper

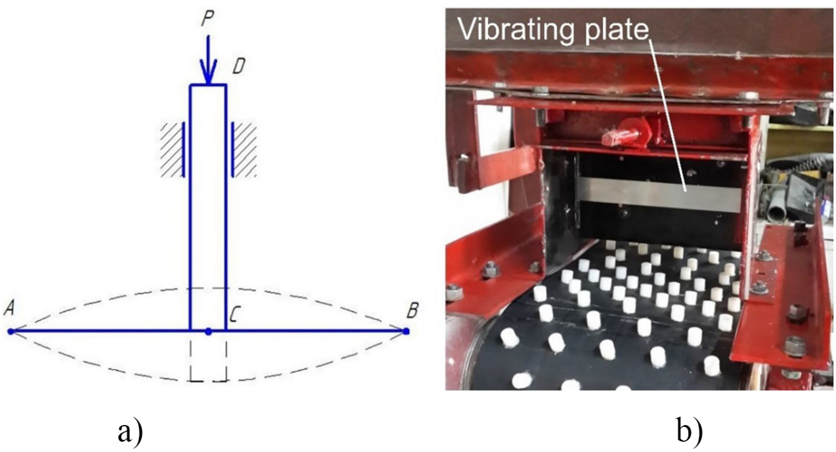
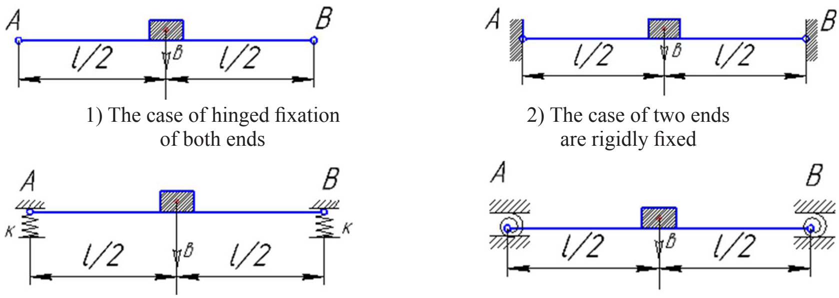


Fig. 2. The scheme of the plate and pole position

The AB ends of the thin elastic vibrating plate are fixed on the chamber wall. The rod exciter DC is perpendicularly fixed with the end C on the center of the plate AB. In this case, the plate AB makes horizontal vibrations [8; 9] (Fig. 2).

To simulate the fastening scheme of the AB plate ends, 4 ways of fixing are proposed (Fig. 3). As a result, we calculate the frequency for each circuit, compare them with real frequencies and select one of the four ways of fixing. During the research, it has been calculated the frequency for each circuit, compare them with real frequencies and select one of the four ways of fixing.



1) The case of hinged fixation of both ends

2) The case of two ends are rigidly fixed

3) The case of the two ends are fixed by springs

4) The case of two ends are secured by swing springs

Fig. 3. Ways of fixing the plate ends (AB)

To solve the problem described above, in the first approximation, the oscillation of the AB plate is modeled as the oscillation of an elastic system with one degree of freedom (Fig. 4). Consider the specific oscillation of a plate with two ends rigidly fixed. The plate is affected by the elastic force $\overrightarrow{F_c}$ and gravity $\vec{G}$.

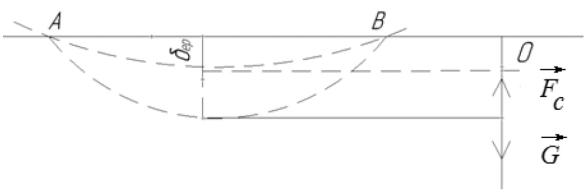


Fig. 4. Forces acting on the bent plate element

If the plate is affected by an elastic force F_c, then the load is in free swing along with the plate. The specific cyclic frequency can be found using the formula:

$$\omega = \sqrt{\frac{c}{m}}, \tag{1}$$

where, c – is the springiness of the plate,

m – is the given mass of the plate, which takes into account the mass of the load on the plate and the mass of the plate.

The specified mass of the plate using the coefficient of adjustment K_m:

$$m = \frac{G}{g} + K_m \rho l. \tag{2}$$

The kinetic energy of the plate and the kinetic energy of the additional mass oscillating with the load are determined by equation [16].

$$K_m = \frac{2}{\delta_{\text{ст}}^2} \int_0^{1/2} y^2 d\xi. \tag{3}$$

where, K_m – is the plate mass reduction factor, y is the plate bending function depending on the coordinates of the plate points, $\delta_{\text{ст}}^2$ is the maximum static bending of the plate.

Then, the cyclic frequency of the system – ω and the period – τ are calculated using the following equations:

$$\begin{cases} \omega = \sqrt{\frac{g}{\delta_{\text{ст}}} \cdot \frac{1}{1+K_m \frac{\rho g l}{G}}}, \\ \tau = 2\pi \sqrt{\frac{\delta_{\text{ст}}}{g}\left(1 + K_m \frac{\rho g l}{G}\right)} \end{cases}. \tag{4}$$

As can be seen from the equation (2.28), to calculate the frequency and period, it is necessary to know the static bending and the given mass coefficient, depending on the ways of fixing the plate. To determine the static bending of the plate, we use the method of initial parameters [16], (Fig. 5). The bend of the plate can be written as:

$$y = y_0 + \theta_0 x + \frac{1}{EI}\left[M_0 \frac{x^2}{2!} + Q_0 \frac{x^3}{3!} - G \frac{\left(x - \frac{l}{2}\right)^3}{3!}\right], \tag{5}$$

where y_0 and θ_0 – is the angle of bending and bending of the plate at point O;

E – longitudinal elastic module of the plate;

J – the inertial moment of the cross section of the plate;

M_0 and Q_0 – bending moment and horizontal force at the point O;

x – longitudinal axis of the plate.

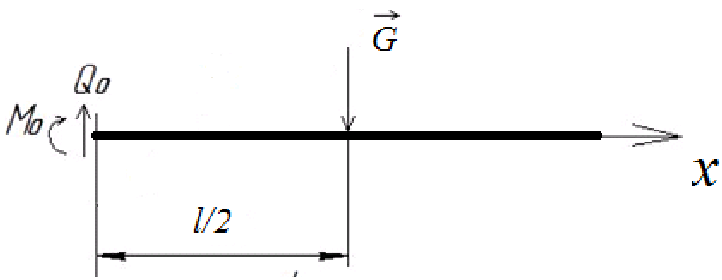


Fig. 5. Diagram of the force acting on the plate

The center of the plate is affected by gravity $\vec{G}$. The bending moment M_0 and the transverse force Q_0 at point O are equal to the reverse effect of the fixing moment and the support at the left end of the plate, respectively. They, in turn, are determined from the equilibrium conditions of known statics.

Table 1.

The opposite effect of supports in different ways of fastening the plate when gravity falls on the center of the plate

Types of fixing the ends of the vibrating plate	Equations
1. The case of hinged fixation of both ends	$M_0 = 0; \quad Q_0 = \frac{G}{2}$
2. The case of two ends are rigidly fixed	$M_0 = -\frac{Gl}{8}; \quad Q_0 = \frac{G}{2}$
3. The case of the two ends are fixed by springs	$M_0 = -\frac{Gl}{8}; \quad Q_0 = \frac{G}{2}.$
4. The case of two ends are secured by swing springs	$M_0 = -\frac{Gl}{2^3(\mu+1)}; \quad Q_0 = \frac{G}{2}$

The boundary conditions for the 4 ways of fixing the plate ends are given in Table 2.

Table 2.

Boundary conditions for fixing plate ends

Types of fixing the ends of the vibrating plate	Equations
1. The case of hinged fixation of both ends	$y\|_{x=0} = 0; \quad \left.\frac{d^2y}{dx^2}\right\|_{x=0} = 0.$
2. The case of two ends are rigidly fixed	$\left.\frac{dy}{dx}\right\|_{x=0} = 0; \quad y\|_{x=0} = 0.$
3. The case of the two ends are fixed by springs	$\left.\frac{dy}{dx}\right\|_{x=0} = 0; \quad EI\left.\frac{d^3y}{dx^3}\right\|_{x=0} - k \cdot y\|_{x=0} = 0.$
4. The case of two ends are secured by swing springs	$\left.\frac{d^2y}{dx^2}\right\|_{x=0} - \frac{k_1}{EI} \cdot \left.\frac{dy}{dx}\right\|_{x=0} = 0; y\|_{x=0} = 0.$

where k is the spring stiffness, k_1 is the torsion spring stiffness (Fig. 3).

The unknown parameters y_0 and θ_0 are determined by boundary conditions. If set the equation (5) to the conditions given in Table 2, it allows to obtain the above parameters. The results are presented in Table 3.

Table 3.

Initial conditions of y_0 and θ_0 for the ways of fixing the plate ends

Types of fixing the ends of the vibrating plate	Equations
1. The case of hinged fixation of both ends	$y_0 = 0; \quad \theta_0 = -\frac{1}{EI}\frac{G}{4}l^2.$
2. The case of two ends are rigidly fixed	$y_0 = 0; \quad \theta_0 = 0.$
3. The case of the two ends are fixed by springs	$y_0 = \frac{G}{2k}; \quad \theta_0 = 0.$
4. The case of two ends are secured by swing springs	$y_0 = 0; \quad \theta_0 = -\frac{Gl}{2^3 k_1(\mu+1)}.$

As a result, according to those given in tables 1 and 3, the unknown quantities in the equation (5) the y_0 and θ_0, the M_0 and Q_0 were determined for all fixing types. Further, from the equations (3) and (5), we find the static bending and the given mass coefficient for all four ways of fixing the plate ends. The results are presented in Table 4.

Table 4.

The equations and values of the $\delta_{ст}$ the static bending and K_m – the plate mass reduction coefficient for 4 ways of fixing the plate ends.

Types of fixing the ends of the vibrating plate	Equations
1. The case of hinged fixation of both ends	$\delta_{ст} = y_{max} = \frac{Gl^3}{48EI}$ $K_m = \frac{17}{35}$
2. The case of two ends are rigidly fixed	$\delta_{ст} = y_{max} = \frac{Gl^3}{192EI}$ $K_m = \frac{13}{35}$
3. The case of the two ends are fixed by springs	$\delta_{ст} = y_{max} = \frac{Gl^3}{3\cdot 2^6 EI}(3\cdot 2^5 r - 1)$ $K_m = \frac{2^5}{(3\cdot 2^5 r-1)^2}\left(3^2\cdot 2^5 r^2 - 3r - \frac{3}{7\cdot 7\cdot 2^5}\right)^2$

4. The case of two ends are secured by swing springs	$\delta_{\text{ст}} = y_{max} = -\frac{Gl^3}{2^6 \cdot 3EI} \cdot \frac{4\mu+1}{\mu+1}$ $K_m = \frac{3 \cdot 2^4 \delta_{\text{ст}}(\mu+1)}{4\mu+1}\left[-\frac{\mu}{2^3(\mu+1)} \cdot \frac{1}{2^3} - \frac{1}{2^6 \cdot 3(\mu+1)} + \frac{1}{3 \cdot 2^6}\right]$

where $\mu = \frac{2}{l}\frac{EI}{k_1}$, $r = \frac{EI}{k \cdot l^3}$.

Suppose that the return force F_c acts on the plate as the resistance force $R = -a\dot{y}$ and the forcing force $S = H \sin \rho t$. Here, the plate involuntarily oscillates, where α is the coefficient of resistance of the external environment, H is the amplitude of the acting force, p is its cyclic frequency. Here, the movement of the load can be written with this differential equation. Involuntary oscillation is an independent solution to the differential equation of plate oscillation:

$$\ddot{y} + 2n\dot{y} - \omega^2 y = h \sin pt, \quad (6)$$

where $2n = \frac{\alpha}{m}$; $\omega^2 = \frac{c}{m}$; $h = \frac{H}{m}$.

The independent solution of the equation in case $n < \omega$ (6) is written as:

$$y_{\text{дерб}} = \frac{h}{\sqrt{(\omega^2-p^2)^2+4n^2p^2}} \sin\left(pt - \tan^{-1}\left(\frac{2np}{\omega^2-p^2}\right)\right). \quad (7)$$

According to the equations of Table 4 and Eq. (4), the theoretical values of the frequency are determined (Table 5).

Table 5.

Theoretical frequency values for different types of fixing

Methods of fastening of plate ends	The case of hinged fixation of both ends	The case of two ends are rigidly fixed	The case of the two ends are fixed by springs	The case of two ends are secured by swing springs
Frequency, Hz	3.45	4.069	2.005	2.022

Results and conclusion

The effective installation type of the vibratory plate has determined by modeling it as a flexible plate with two ends fixed with one degree of freedom. Vibration amplitudes and frequencies for the 4 ways of fixing the plate as vibrations of an elastic system were determined. By modeling a fixed vibrating plate with two ends that is a one-dimensional continuous system, amplitude problems and frequency equations of specific and involuntary vibrations of the plate were obtained. According to results it concluded that the rational model of a vibrating plate is a fixed plate with two ends hinged. The specific frequency of the plate was approximately the same as the results of the calculation of the body model identified earlier.

The studied data is required for further analysis using computational fluid dynamics (CFD) and discrete element method (DEM).

According to the general search, it should be noted that the seeding device with the proposed compensating chamber provides 4.37–6.63% seeding unevenness and 5–5.8% seeding instability.

Conflict of interest information. The authors declare that they have no conflict of interest.

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