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Kinematics of Soil-Tilling Vibrational Mechanisms

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Abstract: This scientific article presents a structural analysis of vibrational mechanisms designed for soil tillage. Vibrational mechanisms play a crucial role in enhancing the efficiency of agricultural machinery. They are used for soil loosening, weed elimination, and improving the fertility layer of the soil.

Keywords: vibrational mechanism, soil tillage, structural analysis, vibration exciter, amplitude, frequency.

Introduction

The working bodies of a vibrational machine designed for surface soil treatment aim to enhance the efficiency of processing the upper layers of the soil. These working bodies perform oscillatory movements, helping to reduce energy consumption during soil treatment. During the structural analysis of the vibrational machine, the function of each component and the operation of the entire system are examined. This analysis enables improvements in the machine's efficiency and optimization of its working principles [1].

A substituted mechanism is a new design created by replacing one or more links of an existing mechanism with another type of mechanism. Such mechanisms are typically developed to address mechanical limitations, improve operational efficiency, or reduce complexity. In general, substituted mechanisms are implemented through various structural modifications or adjustments to the elements of the original design.

The replacement of mechanism links is often related to the need to simplify complex movements of the mechanism or to create mechanisms with simpler structures to perform a specific task. In this way, substituted mechanisms improve the practical use process of the system. This process is referred to as the "substituted mechanism" concept [2].

Research method

During the structural examination of this mechanism, substituted links were utilized. A fixed frame and a movable frame were connected using a compressive spring. Instead of the spring, piston and cylinder links were installed (as shown in Figure 1).

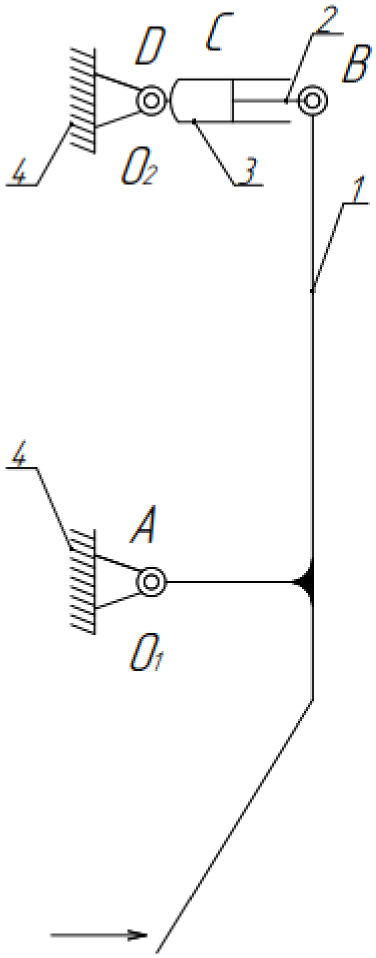

Figure 1. Structural diagram of the vibrational mechanism for surface soil treatment

1 — rocker arm, 2 — piston, 3 — cylinder, 4 — support frame

The mobility degree of the vibrational mechanism for surface soil treatment is determined using P.L. Chebyshev's formula:

$$w = 3n - 2P_5 - P_4. \qquad (1)$$

where:

n - the number of moving links;

P_5- the number of fifth-class (lower kinematic) kinematic pairs;

P_4- the number of fourth-class (higher kinematic) kinematic pairs;

The main purpose of P.L. Chebyshev's formula is to determine how the mechanism moves between its connections and elements. At the same time, this formula is used to calculate the degree of freedom for various types of mechanisms [3; p. 48, 4; p. 41].

In this mechanism, there are a total of three moving links and one fixed link, namely 1 — rocker arm, 2 — piston, 3 — cylinder, and 4 — support frame, so n=3n = 3n=3. In the mechanism's structure, there are four fifth-class lower kinematic pairs, i.e., P5=4P_5 = 4P5=4, and there are no fourth-class higher kinematic pairs, i.e., P4=0P_4 = 0P4=0. Thus, the degree of mobility of the mechanism is calculated as follows:

$$w = 3n - 2P_5 - P_4 = 3 \cdot 3 - 2 \cdot 4 - 0 = 1 \qquad (2)$$

Here, w=1w = 1w=1, meaning that only one driving link is sufficient to obtain the desired motion of all the links in the kinematic mechanism. In this case, the first link, i.e., the rocker arm, is considered the driving link. Its motion influences the motion of the other links in the mechanism and drives them. This is explained by the theory of kinematic pairs and the degree of freedom. In the kinematic chain, one driving link transmits energy to the other parts of the mechanism, ensuring their ordered motion. The motion of the driving link determines the kinematic parameters (such as angular velocity, acceleration, etc.) of the remaining links. Through the control of the driving link, the motion of all the other links is regulated.

Research result and discussion

For analytically determining the velocity and acceleration in the motion of a vibrational mechanism, its mathematical expressions must be derived. Since the mechanism's oscillatory motion is sinusoidal, its fundamental equations are as follows [5; 6]:

$x(t)=A\sin(\omega t+\varphi)$

Where:

- x(t) is the displacement as a function of time,
- A is the amplitude of the oscillation,
- ω is the angular frequency (in rad/s),
- t is time,
- φ is the phase angle.

To find the velocity and acceleration, we differentiate the displacement equation:

1. **Velocity:**

$$v(t) = \frac{dx(t)}{dt} = A\omega\cos(\omega t + \varphi)$$

2. **Acceleration:**

$$a(t) = \frac{dv(t)}{dt} = -A\omega^2\sin(\omega t + \varphi)$$

These equations describe the sinusoidal motion of the vibrational mechanism, where the velocity and acceleration are related to the displacement, angular frequency, and amplitude of the oscillation.

Inertial Vibrator's Kinematic Analysis

An inertial vibrator is a rotary mechanism where the mass is displaced from the center, causing it to rotate. It is used to generate oscillatory movements. When the masses rotate, they create a centrifugal force that results in the oscillation. In this type of mechanism, the rotational movement of the mass generates an eccentric force that is responsible for producing vibrations. These vibrations can be controlled by adjusting the speed of rotation, the mass distribution, and the mechanical parameters of the system.

The kinematic analysis of the inertial vibrator involves determining the rotational speed, angular displacement, and the resulting linear acceleration at the point where the vibration is transferred to the working body of the mechanism. The mechanism's performance depends on the balance between the centrifugal force and the resistance provided by the system's damping elements.

In this soil treatment vibrational mechanism, the basic structure of the inertial vibrator that generates the vibration consists of the following components:

- **Rotor** (the main part of the inertial vibrator),

- **Frame** (the static or non-moving part),
- **Eccentric mass** (the load displaced from the center) (as shown in Figure 2).

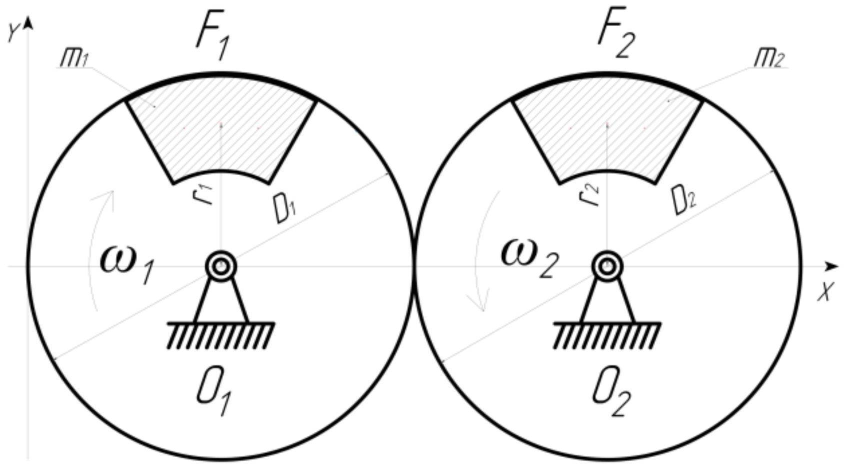

Figure 2. Kinematic diagram of the inertial vibrator

$m_1 m_2 -$ **Debalanced mass on the rotors** refers to the mass that is deliberately shifted away from the center of rotation in an inertial vibrator mechanism. This offset creates a centrifugal force during the rotor's rotation, which generates vibrations. The size and position of the debalanced mass are crucial for controlling the amplitude and frequency of the vibration. In the context of the kinematic analysis, the debalanced mass plays a key role in determining the magnitude of the vibration and how it is transferred to the working body of the mechanism. The greater the displacement of the mass from the center of rotation, the larger the centrifugal force and, therefore, the stronger the vibrations produced;

$r_1 r_2 -$ **Debalanced radii** refer to the radius at which a mass or debalanced mass is displaced from the center in gear wheels or other mechanisms. The debalanced mass is used to generate rotational motion in the system, and its radius directly influences the magnitude of the centrifugal force generated in the system;

$\omega_1 \omega_2 -$_**Angular velocity of gear wheels** is the quantity that expresses the speed of rotation of the gear wheel around its axis. The angular velocity primarily depends on the moment, force, and other parameters affecting the rotational movement of the gear wheel.

$D_1 D_2$- **The diameter of gear wheels** refers to the full width of the gear from its center to the outer edge. The diameter of a gear is crucial in determining the number of teeth, how they mesh with each other, and the efficiency of the mechanical system. The diameter also affects operational parameters such as the transmission ratio and speed;

$F_1 F_2 -$ **Centrifugal forces** refer to forces that are directed outward from the center in rotating objects or systems. They arise in rotating bodies and act against the center, pushing outward. These forces are inertial forces, indicating the tendency of objects to move away from the center during rotational motion.

In an inertial vibrator, a centrifugal force arises. The centrifugal force plays a crucial role in generating vibrations in the vibrator.

To calculate this centrifugal force, we use the general formula: [7]

$F = m \cdot r \cdot \omega^2$ (1)

where:

$F -$ is the centrifugal force; H,

$m -$ is the mass of the rotating object; кг,

$r -$ is the distance from the center (radius) of the object; м

$\omega -$ is the angular velocity of the object; рад/с.

This inertial vibrator consists of a two-rotor unbalance system. The first rotor has a total unbalance mass of 2.043 kg, and the distance from the center of the rotor to the unbalance center is 0.047 m. The rotational frequency of the rotor is 20 Hz. The second rotor also has an unbalance mass of 2.043 kg, a distance of 0.047 m from the rotor center to the unbalance center, and a rotational frequency of 20 Hz.

The angular velocity of each toothed wheel in the inertial vibrator is determined using the formula $\omega = 2\pi f$ [8]. where fff is the rotational frequency in 1/s.The angular velocity is calculated as:

$\omega = 2\pi f = 94.2$ rad/s.

The centrifugal force arising in the rotor unbalance of the inertial vibrator is calculated using the following formula (1):

$F_1 = m \cdot r \cdot \omega^2 = 852{,}05$ H.

In an inertial vibrator, the centrifugal forces arising in each rotor's unbalance will be equal to each other, i.e., F1=F2.

This means that the centrifugal forces generated by both rotors, despite being in separate parts of the system, will be balanced in magnitude, ensuring consistent vibration performance.

Summary.

Development of the Constructive Scheme of the Mechanism Generating Forced Vibration, Its Structural and Kinematic Analysis

This chapter focuses on the development of the constructive scheme of a mechanism designed to generate forced vibrations and the analysis of its operational principles. The main objective is to analyze the working principles of the mechanism and ensure efficient coordination of the various elements of the system.

1. Development of the Constructive Scheme:

The primary aim in developing the constructive scheme of the mechanism is to determine the role of each component and how they interact. This involves defining the function of each component, ensuring their interrelationship, and aligning them with the overall operational principle of the system. During the development of the constructive scheme, various structural changes and optimizations are introduced to achieve higher efficiency.

2. Structural Analysis:

Structural analysis focuses on studying the individual components of the mechanism, their mutual balance, and how they operate together. This analysis looks at the dynamic effects between the elements, the materials' ability to withstand external forces, and the overall efficiency and durability of the system. The structural analysis focuses on key elements such as mobility, imbalance mass, and force distribution, ensuring optimal performance.

3. Kinematic Analysis:

Kinematic analysis helps to determine the movement patterns of the mechanism. This analysis calculates the angular velocities, accelerations, and interactions of the different mechanical elements, identifying the degree of freedom of the system. Kinematic analysis is essential for calculating the individual movement parameters of each part of the mechanism, ensuring the system operates optimally.

4. Improving the System’s Efficiency:

Based on the results of the constructive and kinematic analysis, proposals are made to enhance the efficiency of the mechanism. These could include improving energy efficiency, ensuring the effective movement of the working components, and maintaining stability during operation. This may require the addition or improvement of elements or mechanisms.

Conclusion:

The constructive and kinematic analysis of forced vibration mechanisms was carried out. These analyses are crucial for improving the system’s efficiency, stability, and operational comfort. By analyzing the relationship between each component and their interactions, along with their governing parameters, the system’s energy efficiency and operational performance can be significantly improved.

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