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ANALYSIS OF THE WORKING MODES OF INERTIAL VIBRATORS

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ABSTRACT

The paper analyzes the energy consumption of an inertial vibrator in two operating modes, resonance and post-resonance. We used MATLAB software to solve the differential equation of motion of the vibrator system and to find the energy consumed.

KEYWORDS:resonance, postresonance, vibration, MATLab

1. INTRODUCTION

Inertial vibrators (Figure 1) are devices used to generate and control vibrations in various industrial applications, from vibrating conveyors to compaction and structural testing systems. These devices operate on the principle of inertia, using eccentric masses and electric motors to produce controlled oscillating forces.{1]

Figure 1. Inertial vibrator

An essential aspect in the operation of inertial vibrators is the operating mode, which can be classified into resonance mode and post-resonance mode. Resonance is the condition in which the excitation frequency of the system coincides with its natural frequency, causing a significant amplification of the vibration amplitude. This phenomenon is exploited in numerous applications due to its increased energy efficiency and the possibility of obtaining large amplitudes with minimal energy consumption.

On the other hand, the post-resonance mode refers to the operation of the system at frequencies higher than its natural resonance frequency. This mode of operation allows for more precise vibration control and reduces the risk of structural damage caused by excessive amplitudes. The choice of the operating mode depends on the specific application and the performance requirements of the system used.

In this paper, the operating principles of inertial vibrators, the characteristics of each operating mode, and their specific fields of applicability will be analyzed in detail.

2. OPERATING PRINCIPLES

Inertial vibrators operate by converting mechanical energy into controlled vibrations using an assembly consisting of an electric motor, eccentric masses, and an elastic support. When put into operation, the electric motor drives the eccentric masses, generating a variable centrifugal force that causes the system to oscillate.

The frequency and amplitude of the vibrations are influenced by the characteristics of the system, including its mass, stiffness, and damping.[1] The balance between these elements determines the performance of the vibrator and its operating regime. The factors that influence these parameters are:

The mass of the vibrator – the greater it is, the lower the natural frequency of the system;

The stiffness of the elastic support – determines the oscillatory behavior and the frequency range in which it can operate effectively;

The damping coefficient – influences the energy dissipation and the stability of the vibrations.

In the resonance regime, the vibrations are amplified due to the coincidence of the excitation frequency and the natural frequency of the system. This leads to a significant increase in the amplitude of the oscillations with a reduced energy consumption. For this reason, many industrial applications exploit resonance to obtain maximum efficiency. However, excessive increases in the amplitude can lead to damage to mechanical components and require protective measures, such as dampers or stroke limiters.

In contrast, in the post-resonance regime, the system operates at frequencies higher than the resonance frequency, which allows for more precise control of the movement. This operating mode is preferred in applications where greater vibration stability and reduced risk of mechanical damage are required. However, operation in this mode requires higher energy consumption, as the system must exceed the resonant frequency and maintain oscillations in a higher frequency range.

By choosing the right operating mode and system parameters, inertial vibrators can be used effectively in a wide range of industrial and technological applications, such as soil compaction, vibrating conveyors, and material sorting and separation processes.

3. RESONANCE WORKING MODE

The resonance regime is the state in which an inertial vibrator reaches its maximum amplitude of oscillations, due to the coincidence of its excitation frequency and the natural frequency of the system. This condition determines the increase in energy efficiency and is used in a variety of industrial applications.

For a system to reach resonance, the frequency of the excitation force must be equal to its natural frequency. In addition, it must be designed with minimal damping, so that the amplitude of the oscillations is maximum. Also, the supporting elements and mechanical connections must be optimized to reduce energy losses, thus ensuring efficient vibration transmission and maintaining stable behavior of the system in the resonance regime.

One of the main advantages of using resonance is high energy efficiency, since it requires a reduced amount of energy to generate large amplitude vibrations. The resonance phenomenon also allows for the amplification of vibrations, making it particularly useful in applications that require intense oscillations, such as structural testing systems. In addition, the resonance regime is frequently used in various industrial processes, including material separation, soil compaction, and vibro-transport technologies, where it contributes to optimizing operational efficiency and reducing energy consumption.

Resonance is widely used in various industries due to its ability to optimize processes and improve energy efficiency. In the mining industry, this phenomenon is applied in crushers and material separators, contributing to the fast and efficient processing of resources. In the field of structural testing, resonance is used to analyze the behavior of materials and structures at different vibration frequencies, allowing the assessment of their strength and durability. Also, in industry, vibratory transport systems are used for the efficient handling of bulk materials, facilitating production processes, and reducing operational costs.

Despite its many advantages, the use of resonance also involves certain risks and negative effects. One of the main problems is the damage to components, as high amplitudes can lead to material fatigue and cracking. Also, under certain conditions, vibrations can become uncontrollable, generating instability in the system. In addition, high levels of vibration can create ergonomic and acoustic problems in industrial environments, leading to discomfort and noise pollution. Therefore, careful design and the use of appropriate measures to minimize these negative effects are essential.

4. POST-RESONANCE WORKING MODE

The post-resonance regime is characterized by the operation of the inertial vibrator at frequencies higher than its natural frequency. This allows for more precise vibration control and reduces the risk of damage to mechanical components.

In the post-resonance regime, the operating frequency exceeds the natural frequency of the system, which allows for improved control over the amplitude of oscillations. This feature makes the systems more stable and easier to tune for specific applications. However, maintaining vibrations in this regime requires higher energy consumption, since additional energy is needed to compensate for the losses caused by damping and to maintain the excitation force at an optimal level. This fundamental difference makes the post-resonance regime preferable in applications where stability and precision are essential, at the expense of the maximum energy efficiency offered by the resonance regime.

To prevent the destructive effects of excessive vibrations, various control methods are used. One of the most effective solutions is the integration of dampers and shock absorption systems, which reduce the amplitude of vibrations and protect structures from damage. Also, continuous monitoring of vibration parameters is essential for early detection of potential problems and for adjusting operating conditions. Another important aspect is adjusting the operating frequency of the system to avoid mechanical overloads and ensure optimal and safe operation of the equipment.

Examples of use

• Vibrating compaction machines – used in construction;

• Controlled vibration conveyors – used in the food and pharmaceutical industries;

• Mechanical component durability testing systems.

5. ANALYSIS

We used the MATLAB application to simulate the motion and energy consumption of the vibrators in the two cases.[2]

We simulated the vibrator motion by solving its equation of motion.

In the process of analyzing and modeling the vibrator system, the geometric representation of the components was achieved using parametric geometric modeling principles. This allows for the rapid adjustment of shapes and dimensions depending on the system parameters, contributing to a more accurate simulation of the dynamic behavior[3].

To create three-dimensional models of the vibrator system and its related components, Solid Edge 2024 software was used. This tool provides a high-performance environment for computer-aided design (CAD), allowing for an efficient integration between geometric modeling and functional analysis[4].

For an inertial vibrator with elastic damping and sinusoidal external force, the equation of motion is[2]:

$$m \cdot \ddot{x} + \lambda \cdot \dot{x} + k \cdot x = F_0 \cdot \sin(\omega t)$$

where:

m is the mass of the vibrator (kg),

$\ddot{x}$ is the acceleration,,

γ is the elastic damping coefficient (kg/s),

k is the elastic constant (N/m),

$\dot{x}$ is the velocity (m),

x is the displacement (m),

F_0 is the amplitude of the external force (N),

ω is the frequency of the external force (rad/s),

t is the time.

To calculate the energy consumed we used the following formula:

$$E = \int_0^T F_0 \cdot \sin(\omega t) \cdot \dot{x}(t) dt$$

We generated the code for the MATLAB application using the formulas and obtained the following results:

In the first case, we have the simulation in the resonant mode of the vibrator. The simulation resulted in the following graphs for the amplitude achieved (figure 2) and the energy consumed by the system (figure 3). We can observe high amplitudes and low energy consumption.

Figure 2.Displacement performed in resonance mode

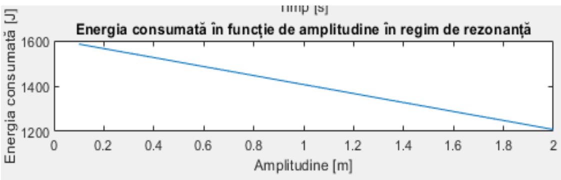

Figure 3. Energy consumed in resonance mode

For operation in post-resonance mode (figures 4 and5) we obtained lower amplitudes with high energy consumption.

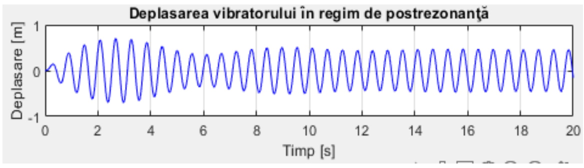

Figure 4. The displacement performed in post-resonance mode

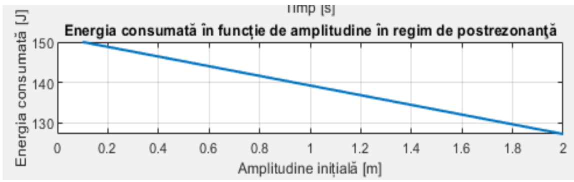

Figure 5. Energy consumed in post-resonance mode

6. CONCLUSIONS

In the resonance regime (ω≈ω0), the energy supplied by the external force is efficiently transferred to the system, which leads to maximum oscillation amplitudes. The energy consumed in the resonance regime is relatively low compared to the amplitudes obtained, since the external force is applied in a synchronized manner with the vibrator’s movement.

In the post-resonance regime (ω>ω0), the frequency of the external force exceeds the natural frequency of the system, which causes a significant reduction in the oscillation amplitudes compared to the resonance regime. This phenomenon is due to the fact that the system can no longer accumulate energy in an optimal way, and the applied external force is no longer synchronized with the vibrator’s movement. The post-resonance regime causes lower amplitudes but higher energy consumption compared to the resonance regime. This regime is preferable in applications where excessive oscillations must be avoided, such as in the case of structures subjected to periodic vibrations or mechanical equipment that requires strict control of the motion to prevent premature wear.

In the analysis of the vibrator behavior, it was highlighted that the resonance regime maximizes the amplitudes for a relatively low energy consumption, but can lead to destructive effects if not managed properly. In contrast, the post-resonance regime determines lower amplitudes but requires higher energy consumption to maintain the oscillations, making it useful in applications where excessive vibrations must be limited.

Establishing an optimal balance between damping, external force frequency, and energy consumption is essential for optimizing the system performance in various engineering applications.

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