Study of a dual frequency vibration press for the formation of concrete elements

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Abstract. The article presents the results of a study of a planetary drive dual frequency vibration press for the formation of concrete elements. Mathematical modeling of the movement of the working bodies (matrix and punch) has been carried out, analytical dependences have been obtained to determine the parameters of a vibration press. The results of the study indicate the ability to control the nature of the movement of working bodies, which expands the technological capabilities. The obtained dependences make it possible to improve the methodology for calculating the parameters of a planetary drive dual frequency vibration press.

1. Introduction

For current construction needs, the manufacture of such concrete materials as paving slabs, bricks, curly paving elements, blocks, etc., is relevant.

Technological sets of equipment for the formation of concrete elements by vibration pressing are widely represented on the world market by such companies as Hess, Masareport, Rosacometta, Zenit, Besser, etc. [1-7].

Sets of equipment for the manufacture of concrete products by vibrocompression occupy relatively small areas. For example, the Spanish line "Kompakta-2000" occupies a span of 18×60 m in the workshop and produces tiles of 600 ... 900 thousand m²/year (or 5 ... 8 million concrete blocks), which is equivalent to a brick plant with a capacity of 35 ... 50 million bricks per year.

Vibration equipment of technological complexes for the production of building materials has an important place. These machines include vibration presses, the improvement of which is reflected in the quality of the formation of concrete products.

Presses have been developed and used for the manufacture of paving slabs, floor slabs, figured paving elements and other small products. The process of molding products on vibration presses is carried out due to the complex action of vibration and static pressure on the entire volume of the compacted mixture.

For the production of paving slabs, rigid concrete mixtures are used, because otherwise there is adhesion on the surface of the lower and upper voids of the punches.

The rigidity of the concrete mix leads to a decrease in density and frost resistance, if the intensity of the vibration action is not increased, which can be achieved, for example, by introducing dual frequency drives in the design of presses.

The duration of the vibration process affects performance. However, excessively prolonged vibration may, instead of a positive effect, lead to a deficiency through the delamination of the concrete mixture.

The main directions of improvement of equipment for molding concrete products by vibration pressing are:

- development of new designs and calculation methods for the formation of units;
- introduction of regulated modes of vibration and vibration pressing;
- the use of computer and laser technologies during the design and manufacture of equipment.

The works [1-7] are devoted to the analysis of achievements in the field of design, manufacture and supply to the market of technological sets of equipment for the manufacture of concrete elements by vibration pressing. In works [7-9] data on the ways of improvement and research of vibration presses are given.

Options for improving the designs of vibration press units, including working bodies and drives, are given in the sources [4, 7, 9].

The articles [8, 9] consider the issues of expanding the technological capabilities of vibration presses (creation of machines with combined and regulated modes of operation, development and research of presses with dual frequency drives).

The analysis of studies and publications shows that to ensure high strength, wear resistance and frost resistance of concrete products made by vibration pressing, it is necessary to use rational molding modes based on the results of analytical and experimental studies. These research results are the basis for the creation of methods for calculating the parameters of vibration press systems, taking into account the properties of the processed materials [10-11].

The aim is to study the dynamics and develop a calculation methodology for a dual frequency vibration press for the formation of concrete elements.

The purpose of the research include the establishment of dependencies for determining the parameters of the movement of the working bodies of a planetary drive dual frequency vibration press based on the creation of a mathematical model of the vibration system of the press, which takes into account the static pressure on the formed concrete mixture and its rheological characteristics.

2. Materials and methods

A vibration press was adopted as an object of research, which includes a matrix, a punch, a dual frequency planetary vibration drive of the matrix (Figure 1) and a hydraulic drive for creating static pressure on the concrete mixture [7].

The design diagram of the two-mass system "vibrating table - medium - punch" is shown in Figure 2.

![Figure 1. Scheme of a planetary drive dual frequency vibration press: 1 – case; 2, 3 – gear pair of internal gearing; 4, 7 – shafts; 5, 6 – unbalances; 8 – bearing.](image)

![Figure 2. Physical two-mass model of the vibrational system of a vibration press.](image)
Mathematical model of the "vibration press-concrete mix" system.

The differential equations of motion of a two-mass vibration press system, without considering the forces of energy dissipation, are written in the form:

\[
\begin{cases}
\ddot{y}_1 + \omega_{11}^2 y_1 + \omega_{12}^2 (y_1 - y_2) = \frac{F_1}{m_1} \sin \omega t + \frac{F_2}{m_1} \left(\cos[(u-1)\omega t] - \cos[(u+1)\omega t]\right), \\
\ddot{y}_2 + \omega_{22}^2 (y_2 - y_1) = 0
\end{cases}
\]

(1)

where \( m_1 = m_a + m_s + m_v \); \( m_m, m_c, m_s \) – respectively, the mass of the matrix, concrete mix and matrix vibrator; \( F_1 = m_b \cdot r_o \cdot \omega^2 \); \( F_2 = \frac{1}{2} \cdot m_p \cdot r_o \cdot (u\omega)^2 \) – exciting forces of the main and additional imbalances of the vibrator; ratio; \( m_2 \) – mass of vibrating parts of the block of punches; \( C_f \) – stiffness coefficient of elastic matrix supports; \( C_2 = \frac{(P_a + P_p)^{1+\kappa} \cdot S_k}{F_a h_p \Pi_c} \) – concrete stiffness coefficient; \( P_a, P_p \) – respectively atmospheric pressure and static pressure on the concrete mix; \( k \) – adiabatic exponent; \( h_c \) – concrete bed height; \( S_k \) – contact area of punches with concrete mix; \( \omega \) – angular velocity of rotation of the main unbalance; \( t \) – time.

\[
\omega_{11}^2 = \frac{C_1}{m_1}; \quad \omega_{12}^2 = \frac{C_2}{m_1}; \quad \omega_{22}^2 = \frac{C_2}{m_2}.
\]

Particular solutions of the system of equations (1) were obtained in the form (2):

\[
\begin{align*}
\dot{y}_1 &= a_1 \sin \omega t + b_1 \cos[(u-1)\omega t] + d_1 \cos[(u+1)\omega t]; \\
\dot{y}_2 &= a_2 \sin \omega t + b_2 \cos[(u-1)\omega t] + d_2 \cos[(u+1)\omega t].
\end{align*}
\]

(2)

The amplitudes of the composite vibrations are found in the form:

\[
\begin{align*}
a_1 &= \frac{F_1 \left(C_2 - m_v \omega^2\right)}{(C_1 + C_2 - m_m \omega^2) \left(C_2 - m_m \omega^2\right) - C_2^2}; & b_1 &= \frac{F_2 \left(C_2 - m_v \omega^2 (u-1)^2\right)}{T}; \\
a_2 &= \frac{F_1 \cdot C_2}{(C_1 + C_2 - m_m \omega^2) \left(C_2 - m_m \omega^2\right) - C_2^2}; & b_2 &= \frac{F_2 \cdot C_2}{T}; \\
T &= (C_1 + C_2 - m_m \omega^2 (u-1)^2) \cdot (C_2 - m_v \omega^2 (u-1)^2) - C_2^2; & d_1 &= \frac{F_2 \left(C_2 - m_v \omega^2 (u+1)^2\right)}{K}; \\
K &= (C_1 + C_2 - m_m \omega^2 (u+1)^2) \cdot (C_2 - m_v \omega^2 (u+1)^2) - C_2^2; & d_2 &= \frac{F_2 \cdot C_2}{K}.
\end{align*}
\]

(3)

3. Discussion

Relative displacements of the die and the punch \( \Delta y = y_1 - y_2 \), m. for the following values of the vibration system parameters are shown in Figure 3:

\( m_1 = 300 \text{ kg}; \quad F_1 = 6800 \text{ H}; \quad P_a = 0.1 \text{ MPa}; \quad S_k = 0.15 \text{ m}^2; \quad \omega = 157 \text{ sec}^{-1}; \)
\( m_2 = 100 \text{ kg}; \quad F_2 = 2300 \text{ H}; \quad P_{pa} = 0.07 \text{ MPa}; \quad u = 2. \)
Figure 3. Graphs of the relative displacements of the matrix and punch for different values of the thickness of the layer (h, m) of the concrete mixture.

The dependences obtained on the basis of mathematical modeling for evaluating the parameters of the movement of the working bodies of the vibration press, which allow us to evaluate the effect of the thickness of the column of concrete mixture and the ratio of the frequencies of the pathogens on the nature of the relative vibrations of the matrix and punch.

The analysis of the graphs (Figure 3) shows that due to the dual frequency drive, it is possible to change the nature and range of the relative oscillations of the working bodies, expands the technological capabilities of the vibration press for the manufacture of concrete products. Based on the results of the factorial experiment carried out on the laboratory bench, a regression equation was
obtained, which describes the dependence of the strength of concrete samples in compression on the following factors: the second (high) vibration frequency, static pressure and molding time.

Revealed rational ranges of parameters of the process of vibration pressing of concrete samples (for example, at a fundamental vibration frequency of 50 Hz, it is recommended to assign a high frequency value of 73 ... 75 Hz; static pressure 0.05 ... 0.06 MPa; molding time 7 ... 8 sec.).

Methodology for calculating the parameters of a planetary drive dual frequency vibration press:

1. Calculations of the productivity of a vibration press as a cyclically operating machine, m²/h:

\[
\Pi \frac{3600}{T_c} \cdot S_c ,
\]

where \(T_c\) – time of one cycle of vibration press operation, sec.; \(S_c\) – the number of products that are manufactured in one cycle, m².

2. Frequency range selection. For molding products from fine concrete mixtures with a height of 40 ... 200 mm, a frequency range of 100 ... 50 Hz is recommended, respectively.

3. The choice of static pressure and its strength. Rational value of static pressure on concrete mix:

\[ P_{st} = 0.05...0.1 \text{ MPa.} \]

Required static load force: \( F_{st} = P_{st} \cdot S_k \).

4. Hydraulic pressing force of punches, H:

\[
F_{hyd} = P_a \cdot S_k - (m_{pun} + m_{rod}) \cdot g .
\]

5. The required limiting oscillation amplitude of the elements, or half-span, for dual frequency oscillations according to models (1) – (3):

\[
A_{bound} \leq h_k \cdot \Pi_c \left( 1 - \frac{P_u}{P_u + P_{cm}} \right) .
\]

6. The required total vibration force (taken from the ratio):

\[
F_{vibe} \approx \frac{F_{st}}{(0.5...0.55)} .
\]

7. Required maximum total static moment of mass of unbalanced vibrators:

\[
S_p \sum m_i = m_i - A_{gr} .
\]

The vibrators are selected according to the found static moment of the unbalance mass.

8. Required force on the hydraulic cylinder rod:

\[
F_{hyd} = F_{hyd} - m_2 \cdot g .
\]

9. Required piston diameter at hydraulic line pressure \(p_{hyd}\):

\[
d \geq \frac{4 \cdot F_{hyd}}{\pi \cdot p_{hyd}} .
\]

10. Estimated power consumed by the concrete mix from the vibroblock:

\[
N_1 = 12 \cdot S_k \cdot \omega_2 \cdot A_{prel} .
\]

11. Dimensions of rubber elastic supports for the matrix. Total stiffness of \(n\) supports:
\[ C_M \sum_{i=1}^{n} = \frac{m_i \cdot \omega_i^2 \cdot \left( \frac{1}{30} \cdots \frac{1}{60} \right)}{n_M}. \]

Stiffness coefficient of one elastic support:

\[ C_{M1} = \frac{C_M \sum_{i=1}^{n} \omega_i^2}{n_M}. \]

For cylindrical rubber supports with a radius \( R \) and a height \( h \), the dimensions are related by a ratio that takes into account the properties of the material:

\[ h = \frac{3 \cdot \pi \cdot G_s \cdot R^2}{C_{M1}}. \]

For rubber grade 2959 with modulus of elasticity \( G_s = 1.6 \times 10^6 \) Pa = 1.6 MPa, a graphical dependence of the stiffness coefficient of a rubber support on its height was constructed for the given other parameters (Figure 4).

**Figure 4.** Dependence for determining the height of a cylindrical rubber support from its radius and stiffness coefficient.

The rational dimensions of the elastic elements are selected taking into account the shear modulus of a particular brand of rubber.

### 4. Conclusions

1. It was proposed, as a press drive, to use a planetary vibration drive, which makes it possible to increase the vibration intensity due to the generation of dual frequency vibrations and expands the technological capabilities.

2. The dependences were obtained on the basis of mathematical modeling, allowing to evaluate the effect of the thickness of the concrete mixture column and the ratio of the frequencies of vibration exciters on the nature of the relative vibrations of the matrix and punch of the vibration press.

3. A refined method for calculating the parameters of a vibration press with a dual frequency drive has been compiled.

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