UDC 621.3.011(075.8)
DOI: 10.15587/2312-8372.2019.189057

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ANALYSIS AND SYNTHESIS OF CREATION OF VIBRATION MACHINES WITH AN ESTIMATION OF THEIR EFFICIENCY AND RELIABILITY

Розглянуто аналіз процесів, що протікають в середовищі під дією вібраційних сил. Здійснено синтез отриманих результатів для розробки нового класу вібраційних машин, які забезпечують критерії ефективності та надійності. Основним критерієм оцінки ефективності прийнята функція амплітуди і частоти коливань, яка визначає швидкість або прискорення процесу ущільнення. При цьому доведена логіка стадійного розгляду процесу ущільнення. Перший з них – процес переукладання складових суміші – інтенсивно протікає тільки при відсутності яких-небудь значних зовнішніх навантажень. Реалізується цей процес забезпеченням машиною низької швидкості, тобто великої амплітуди та малої частоти коливань. Другий – це процес зближення частинок суміші із більш щільним, компактним укладанням складових цієї суміші між собою. Він протікає при наявності значних динамічних навантажень, збільшення яких до певної межі дає позитивний ефект. На цій стадії реалізуються малі значення амплітуд коливань та висока частота. Одним з найбільш проблемних місць у вирішенні такого підходу є відсутність не тільки загальноприйнятих методів оцінки цих властивостей, але навіть і єдиного погляду на її природу. В новоствореній вібраційній машині зазначені процеси досягаються за рахунок цілеспрямованого використання удару і вібрації. Конструктивно це забезпечується застосуванням обмежників коливань. Об'єктом дослідження є вібраційні та віброударні процеси в машинах для ущільнення будівельних сумішей в дорожньому та будівельному виробництві. Визначено зокрема відповідний підбір жорсткості обмежників коливань, здійснено вибір раціонального співвідношення часу удару і періоду коливань. Завдяки цьому виявлені нові явища при реалізації стадійних режимів роботи із встановленням декількох стійких режимів. Аналіз надійності вібраційних машин здійснювався методами якісного та кількісного аналізів. Простота конструкції машини забезпечує надійність її роботи. Зменшується в два рази режим ущільнення бетонної суміші у порівняні із існуючими параметрами вібраційних процесів.

Ключові слова: *вібраційна машина, процес ущільнення, стадії режимів ущільнення, будівельна суміш, амплітуда та частота коливань.*

Received date: 11.09.2019
Accepted date: 03.10.2019
Published date: 30.12.2019

1. Introduction

An analysis of a number of works [1–3] shows that the existing vibration technique does not fully satisfy the modern requirements of efficiency and reliability. Similar results were obtained in the authors' own studies [4]. It is noted that neither the amplitude of the vibration, nor the speed, nor the acceleration, taken separately, is a parameter for evaluating the effectiveness of the compaction process. Therefore, these parameters taken separately do not ensure the achievement of the necessary density and strength of the finished product. The process will be effective only if the speed of movement of the components of the mixture is sufficient to reduce the forces of internal friction [5]. For concrete of this composition with a constant duration of vibration, there is a limit speed beyond which density and strength slowly increase or remain unchanged. This is due to the fact that in a concrete mixture with the plastic-viscous properties of the cement test, structural bonds are destroyed at low vibration frequencies [6]. In this case, amplitude deformations arise in the mixture, which are able to create the necessary conditions for rearrangement and compact packing of aggregate grains. The physics of the compaction process defined in this way is a prerequisite for the formulation of the idea of creating a new machine to determine the parameters of this machine, providing criteria for efficiency and reliability. The main criterion for evaluating the effectiveness is adopted function of the amplitude and frequency of vibration, which determines the speed or acceleration of the compaction process. Moreover, the logic of the stage-by-stage examination of the compaction process is proved [7]. The first of them – the process of reconnecting the components of the mixture is intensive only in the absence of any significant external loads. This process is realized by providing a machine with a low speed, that is, large amplitude and a low frequency of vibrations. In the presence of significant forces of comprehensive compression or in cramped conditions, the process of renegotiation develops weakly or does not occur at all. The second is the process of convergence of the particles of the mixture with a denser, more compact conclusion of the

ISSN 2226-3780

components of this mixture with each other. It proceeds in the presence of significant dynamic loads, the increase of which to a certain limit gives a positive effect. This process is determined by the optimum ratio between the static and dynamic components of the total pressure on the mixture. At this stage, small values of the vibration amplitudes and a high frequency are realized [7]. The process of achieving high efficiency depends on two completely dissimilar factors. These are the true characteristics of the mechanical properties of the mixture (ultimate shear resistance and viscosity) and the characteristics of the type and intensity of the dynamic effect on the mixture. The reason for this situation is the complexity of the process of shaping (flowing) the mixture. The process must be considered as a dependence on two completely dissimilar factors. That is, the true characteristics of the mechanical properties of the mixture (ultimate shear resistance, viscosity). As well as the characteristics of the type and intensity of dynamic effects on the formation of the future product. It can be a concrete roadbed or a concrete product. In other words, with the vibrational formation of products, we are not dealing with the true, but with the effective or vibrational viscosity of the mixture. This paper does not talk about effective shear resistance, since it is practically not manifested when using modern vibration molding machines. The process of achieving high efficiency depends on two completely dissimilar factors. These are the true characteristics of the mechanical properties of the mixture (ultimate shear resistance and viscosity) and the characteristics of the type and intensity of the dynamic effect on the mixture. One of the most problematic places in taking these factors into account is the lack of not only generally accepted methods for assessing these properties, but even a single view of its nature. Thus, the urgent is the problem of qualitative and quantitative analysis on the basis of which structural synthesis is formed, and is a prerequisite for the development of a new design of a vibration machine. *The object of research* is vibration and vibration shock processes in machines for compaction of building mixtures in road and construction industries. The subject of research is the analysis and synthesis of vibration machines for the implementation of compaction processes. And *the aim of research* is development of new designs of vibration machines that will provide high efficiency and reliability during their operation.

2. Methods of research

Reliability analysis methods are used to predict reliability, maintainability, availability and measures to ensure the safety of a vibration machine, as well as to compare the consequences of forecasting with specified requirements [8].

The task of reliability analysis and its volume depend on the stage of the life cycle of a vibration machine, taking into account the entire process of use up to its decommissioning [9]. You should also consider the depth of mining assembly units and the condition of the vibration machine as a whole [10]. Important investigated components of reliability are the assessment of the consequences of failures and its ultimate states [11]. Analysis of the reliability of the system and solving optimization problems in the elements of structural synthesis is carried out by the following methods [12]:

1) qualitative analysis (determination of types of malfunctions, failure mechanisms of elements and their consequences for the system, analysis of the functional diagram of the vibration machine, analysis of the maintenance and repair system, construction of structural diagrams of the system reliability);

2) quantitative analysis (building mathematical models of the reliability of elements and systems with dynamic parameters).

The analysis of the literature and the results of previous studies [4] allows to determine the effectiveness criteria (Table 1).

Table 1

Criteria for evaluating the effectiveness of the processes of compaction of building mixtures

No.	Criterion name	Analytical dependence
1	Intensity of vibration exposure:	$u = A^2 \cdot f^3$
	– for sinusoidal vibrations (product of speed and acceleration)	$u = \frac{\alpha \cdot A}{4\pi^2 T} \cdot \frac{\left(1+kn\right)^2}{2}$
	– for dual frequency vibration	$u = \frac{\alpha \cdot A}{4\pi^2 T} \cdot \frac{\left(1+\sum k_i n_i\right)^2}{2}$
	– for multi-frequency vibration	$u = \frac{\alpha \cdot A}{4\pi^2 T}$
2	Efficiency of using the power of the base machine	–
3	Specific productivity	$\Pi = \frac{\Pi}{N}$
4	Dynamic load intensity	$I = \sigma_0 \cdot \omega$
5	Averaged core height intensity	$n_{av} = \frac{1}{h}\int \sigma(h) \cdot \upsilon(h) dh$
6	Specific vibration compaction	$\bar{A} = \bar{P} \cdot t$
7	Specific power for building compaction seals	$\bar{P} = \frac{k \cdot k_d \cdot x_{av} \cdot a_n \cdot \left(1+k_a\right)}{T \cdot k_a}$, $\bar{P} = k \cdot k_b \cdot x_0^2 \cdot \omega^3$

According to these criteria, parametric synthesis is carried out – part of the research process of solving the problem of determining the main structural (geometric and mechanical) parameters of machines in general, its individual mechanisms, devices and working bodies [7]. The structural synthesis of the vibration machine is carried out according to the block hierarchical principle. In accordance with it, at each level of research and development, a certain rank of the system is synthesized. At the first stage – the general scheme, then the functional scheme and elements of functional systems (the units are prefabricated units), then – the individual functional elements and parts that are part of the prefabricated units [4]. New vibration platforms with the implementation of the subresonance regime have been developed; see Fig. 1, and the implementation of the super-resonance regime in Fig. 2.

The task of developing new vibration machines with high efficiency and reliability is considered as a task, it involves the consistent solution of the following subtasks:

1. The selection and justification of criteria for evaluating the effectiveness of the parameters of the working process of compaction of building mixtures and energy-saving mode.

2. The search for such structural solutions of elements and vibration machines as a whole, which, when specified in the statement of the general problem, ensure the reliability of their work.

3. Development of the design of vibration machines with the implementation of the multi-mode spectrum of their working process of compaction of building mixtures.

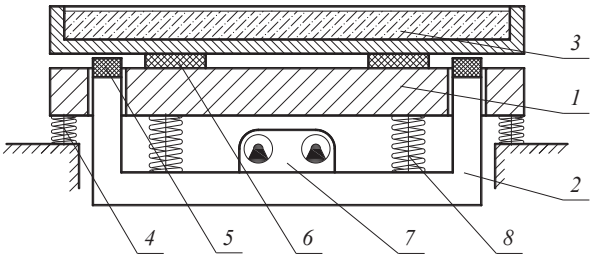

Fig. 1. Vibration shock pad with sub-resonance mode of operation: 1 – frame; 2 – drummer; 3 – form with a compacted mixture; 4 – vibration isolating supports; 5 – drummer buffer; 6 – additional buffer; 7 – vibration exciter

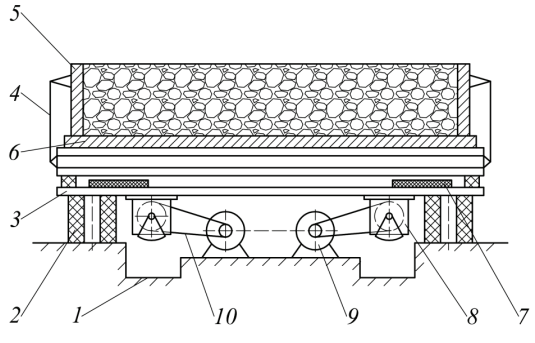

Fig. 2. Resonant vibration pad with super-resonance operation mode: 1 – submotor frame; 2 – vibration mounts; 3 – working frame; 4 – bracket; 5 – onboard equipment; 6 – pallet; 7 – vibration limiter; 8 – vibration blocks

3. Research results and discussion

The studies and the consistent solution of these subtasks allow to formulate a solution for the development of effective modes and the creation of reliable vibration machines for compaction of building mixtures:

1. Creation of machines with harmonious excitation on the product, which is formed by a multicomponent spectrum of vibrations with the following parameters: amplitude of vibrations in the horizontal plane – 0.85–1.2 mm; in the vertical – 0.35–0.45 mm; vibration frequency – 25 Hz.

2. Development of multi-purpose machines, combining the processes of conclusion, distribution and compaction of building mixtures.

3. Development of vibration machines operating in an area close to resonance with vibration impact on the sealing medium when the following parameters are implemented: semi-range of vibrations – 0.75–0.95 mm; vibration frequency – 15–20 Hz.

4. Development of vibration machines with non-linear characteristics, which use the effects of sub- and super-resonances.

The analysis and parametric synthesis makes it possible to propose criteria for evaluating the determination of energy-saving modes and parameters of the working process of vibration machines (Table 1).

In the developed vibration machines, the problem of implementing these processes is achieved through the targeted use of shock and vibration. Structurally, this is ensured by the use of vibration limiters.

The improvement of machines is aimed at creating such constructive solutions that would preserve the advantages of resonant-type machines and ensure reliability and stable operation in a given mode.

4. Conclusions

In the course of the study, in particular, the appropriate selection of the rigidity of the vibration limiters is determined, and a rational choice is made of the ratio of the impact time and the vibration period. Thanks to this, new phenomena are discovered during the implementation of staged modes of operation with the installation of several stable modes. The simplicity of the machine design ensures its reliability. The mode of compaction of the concrete mix is reduced by half in comparison with the existing vibration parameters.

The obtained research results can be effectively used in the research and development of vibration technology and for other technological processes of their application.

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