Test stand equipped with a polyharmonic vibration source to study compaction of dispersed material in an enclosed volume

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Abstract. The vibration effect on materials to be compacted was analyzed. The design scheme is substantiated for the test stand, intended to study consolidation of a granular material under the polyharmonic oscillations of a working member.

1. Introduction
Compaction of granular materials is an important operation in a good deal of technological processes in different industries. Compaction quality influences durability and reliability of a final product and, as a consequence, the production cost efficiency being of specific value in view of ever-increasing energy resource costs.

Machinery designed to provide consolidation is regularly up-dated with more and more complication of its influence modes on materials under treatment [1–4]. However, the attempts to produce a maximum-density package at relatively low energy consumption, as a rule, failed in spite of a variety of methods and facilities, available and practiced. The appreciable improvement of the compaction process performance requires new comprehensive knowledge about regularities of the process, its usage in combination with experience background in view to develop principally novel technologies.

The researchers working for Institute of Mining, SB RAS, developed the process for vibration compaction of dispersed and powder materials in an enclosed volume and received RF Patent [5]. Experimental tests of the process on the finely dispersed material compaction yielded high results. The rational vibroeffect parameters: amplitude-frequency specification and vibration angle were determined.

From Russian and foreign experience in the vibration effect utilization to compact granular materials it is obvious that there is the optimal frequency range for different vibration intensity and particle sizes of a material to be compacted [6–8]. Some researchers recommend to handle a material containing particles of less size with vibration of a higher frequency with the purpose to compact it efficiently. The idea of multi-frequency vibration arose in relation to compaction of concrete mixture containing particles of a wide size range from few micron to few score of millimeters. As the researchers set forth, the presence of two-frequencies in resultant oscillations leads to increase in a velocity of particle motion, hence, higher efficiency of the process.

One of commonly known ways to realize poly-harmonic oscillations of the working member is employment of two or more centrifugal vibroexciters, mounted on the working member, mechanically
connected with one another and rotating at different angular velocities. However, the mechanical transmission really complicates a vibration device structure and aggravates its reliability.

The objective of the present research work is to design and manufacture a test stand to generate a polyharmonic high-frequency oscillation mode of the working component operation in a vibration device intended to compact a finely-dispersed material in an enclosed volume.

2. Compaction research on test stand equipped with a polyharmonic vibration source

The idea of a superharmonic vibration drive (as a polyharmonic version) is proposed in publication [9] and rests on practical use of rotation irregularity of eccentric mass in a centrifugal vibroexciter. The reasons for such irregularities can be different, including variable gravitational moment of d eccentric mass relative to rotation axis, given that it is not vertical; variation in resistance to eccentric mass rotation because of design or exploitation factors. Thereto, oscillations of the executive member are characterized with higher harmonics; amplitude of one of them is appreciably enhanced. The resultant polyharmonic oscillations contain a comparable-in-amplitude high-frequency harmonics along with the principal frequency.

The application of low-frequency centrifugal vibroexciter to generate high-frequency oscillations has certain advantages as compared to a high-speed vibrodrive: less power loss in eccentric mass bearings, lower operational noise, and high reliability of vibrodevices.

Figure 1a demonstrates an oscillogram of the working member oscillations in a vibrodevice generated by centrifugal vibroexciter; Figure 1b shows a respective frequency spectrum, thus indicating the presence of higher harmonics in frequency spectrum, but their amplitude is substantially lower than that of basic frequency oscillations. Theoretically it is feasible to enforce any of harmonics, but in practice there is a technical opportunity to do this only with the second or third harmonics.

![Figure 1.](image)

A scheme to realize superharmonic oscillations, presented in Figure 2, is taken as the basis to design a test stand [9]. The presented system with one degree of liberty has support frame 1 connected through buffer damper 2 and spring 3 to the working member 4. When eccentric masses 5 of a centrifugal vibroexciter rotate, the ideal constraints 6 provide only forward movement of the working member. Tuning of this system to generate resonance in vicinity of the third harmonics leads to increase in its amplitude.
Figure 2. Vibrodrive scheme: 1—support frame; 2—buffer damper; 3—spring; 4—working member, 5—debalances of a vibroexciter; 6—ideal constraints.

The test stand (Figure 3a) consists of a vessel 1 of rectangular cross-section (500×500 mm), filled with a granular material, and vibration device 2 designed to compact it. Their internal surfaces are made of an elastic material in order to diminish the vibration effect of vessel walls on high-density compaction.

Vibration device includes sealing metallic plate 3 (Figure 3b) and centrifugal directed-action vibroexciter 4, mounted on base 5, connected to a sealing plate through elastic elements 6. The stiffness of the elastic elements is selected based on design calculation in view to provide resonance in the vicinity of the third harmonics of the basic frequency. The strictly vertical motion of the vibrodevice in the operation process is provided due to rigid connection of sealing plate 3 to guiding-frame 7, where mounted rollers 8 are moving along guide 9 creating one degree of liberty to the vibrosystem.

Figure 3. Test stand to study the process for compaction of a dispersed material in an enclosed volume: 1—vessel; 2—vibration device; 3—sealing plate; 4—vibroexciter; 5—base; 6—elastic element; 7—guiding frame; 8—rollers; 9—guide; 10—sensor.

Basic (low) frequency is selected in the range of 30–50 Hz. At this frequency range, based on earlier research evidence, the efficiency of the dispersed material compaction is the best [10]. Three frequencies of vibroexciter rotation of 30, 40, and 50 Hz (the third harmonics corresponding to them having frequencies of 90, 120, and 150 Hz) are suggested for experimental evaluation of the influence of the complicated superharmonic vibroeffect on the material to be compacted.
In the oscillation system with one degree of liberty the eigen oscillations frequency $\omega_0$ is determined by formula [1]:

$$\omega_0 = \sqrt{\frac{c}{m}},$$

where $c$—cumulative stiffness of the elastic element system; $m$—total oscillating mass of the vibration device.

After preliminary determination of mass $m$ (70 kg) the stiffness of elastic elements, responsible for generation of resonance at frequency of the third harmonics, were calculated for each of selected basic frequencies. Numerical stiffness values versus frequency are: 30 Hz — 5.61 MN/m; 40 Hz—9.97 MN/m; 50 Hz—15.6 MN/m.

Three sets of such elements were made of rubber technical plate of 20 mm thickness and Young’s modulus of 8.14 MPa. As it is rather complicated technically to generate a resonance mode exclusively by changing parameters of elastic elements, the design of the test stand allows a fine tuning of the system in terms of resonance by varying the basic vibroexciter frequency within a narrow range using a frequency transducer.

The performance of the test stand was verified under the following conditions: the used set of elastic elements had the total stiffness of 10 MN/m, the frequency of a vibrosource, viz., a centrifugal vibroexciter with directed inducing force Pendulum Vibrator type A 200/600, KNAUER ENGINEERING Co. was 40 Hz, expectant frequency of enhanced third harmonics was 120 Hz.

Vibrovelocity of the executive organ – a vibrosealing plate was measured by using piezoelectric accelerometer; its signal passes through charge amplifier and analogue-digital transducer to a personal computer. Information storage and data processing was performed be means of ACTest© software system.

In Figure 4 presenting a fragment of oscillogram of sealing plate oscillations and the respective frequency spectrum it is obvious that both low frequency $f_1 \approx 42.5$ Hz and its third harmonics $f_3 \approx 128$ Hz, ratio of vibrovelocity amplitude $v_3 / v_1 = 1.26$ are present in the resultant polyharmonic oscillation.

Figure 4. (a) Fragment of vibrovelocity oscillogram and (b) respective frequency spectrum of the sealing plate.

Deviation of frequency values from the calculated values are explained by rough manufacture of the elastic elements.

The follow-on research stage is experimental evaluation of influence of parameters of a superharmonic vibroeffect mode on performance of compaction process.

3. Conclusions

Realization of the polyharmonic mode of the working member operation enabled to generate its oscillations characterized with frequency threefold exceeding frequency of eccentric-mass rotation at
comparable amplitude. This makes it feasible to utilize serial commercial vibroexciters with less frequency of eccentric shaft rotation and as a consequence to perform compaction of finely dispersed materials at less energy consumption and mechanical loads on the mechanism, thus appreciably improving the reliability of vibrodrive operation. The new-proposed mode of compaction of finely dispersed materials in an enclosed drive volume is expected to improve qualitative and quantitative parameters of the process.

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