Compaction of dispersed granular material by a vibratory compactor with polyharmonic oscillation exciter

AV Morozov* and VM Usoltsev**
Chinakal Institute of Mining, Siberian Branch, Russian Academy of Sciences, Novosibirsk, Russia
E-mail: *alex02@ngs.ru; **vovchik_big@list.ru

Abstract. This paper addresses problems connected with machine engineering for compaction of powder materials by vibration. The authors present an engineering solution of dispersed granular material compaction in one operating cycle of a compacting equipment. The structural layout of a vibratory compactor involves a polyharmonic oscillation exciter. Some research findings on the compaction process of granular material with the proposed facility are given, and its efficiency is compared with a compacter with a harmonic oscillation exciter. The research shows the promising nature of this method, while the polyharmonic oscillation exciter expands the application range of vibratory equipment in many industries.

1. Introduction
Machine engineering, metallurgy, chemical industry and construction widely use fine granular and powder materials which undergo compaction to ensure required characteristics and performance. The quality of compaction governs endurance and reliability of products, which is critical in the background of the increasing cost of energy resources.

Compacting mechanisms and machines undergo persistent improvement while modes of treatment are up-graded. The existing methods and tools meant for compaction of granular materials, although diverse [1–5], fail to produce maximum possible density of a packing at a comparatively low energy input. For enhancing efficiency of compaction, new knowledge on regularities of the process is required to be used in combination with available experience to create brand-new technologies.

According to many studies, compaction by vibration is an efficient and comparatively readily feasible method [1, 4–7]. Vibration influences behavior of a material under compaction, while the induced rheological effects change the forces of friction and cohesion between particles and reduce deformation resistance. This, given a sound choice of the vibration mode, can both enhance compaction efficiency and decrease its energy consumption.

The Institute of Mining, SB RAS has designed and licensed [8, 9] the vibration compaction method for granular and powder materials in a closed volume. The tests of this method produced good results. For the harmonic mode, efficient parameters of the vibrational impact (amplitude–frequency response, angle of vibration) were determined.

The domestic and foreign experience of compacting granular material by vibration [10–13] shows that there exists an optimal frequency range for every article size. Some researchers recommend treating smaller particles by higher frequency vibrations. The idea of multifrequency vibration started up when it was required to compact concrete containing particles from micron fractions to a few tens
millimeters in size. The presence of a number of frequencies in the resultant vibration results in increased velocities of particles, and the process efficiency grows.

Thus, it was decided to create a vibration mechanism for compaction of granular materials in a closed volume under the polyharmonic oscillation mode of a compactor. A simplest way to produce polyharmonic oscillations of the compactor is using two or more unbalance vibration exciters mechanically interlink and rotating at different angular velocities. However, the mechanical transmissions complicate the structure and lowers reliability of the vibration mechanism.

2. Experimental results

The idea of a superharmonic vibrating drive (a special case of polyharmonic vibration) was described by Bykhovskii [13]. This idea consists in taking advantage of the nonuniform rotation of the eccentric masses within a centrifugal vibration exciter. The causes of the nonuniformity may be various, in particular, a variable gravitational moment of the eccentric mass relative to the axis of revolution when the axis is not vertical, or change in the rotating resistance of the eccentric mass due to some structural or operational factors. In this case, vibrations of the compactor contain higher harmonics, and amplitude of one of the harmonics can be amplified. As a result, we obtain the polyharmonic vibration containing both the base frequency and the high-frequency harmonic of the comparable amplitude.

The low-frequency centrifugal vibration exciters (25 or 50 Hz) are advantageous over the high-speed vibrating drive in generation of high-frequency vibrations as the power loss in the bearings of unbalance shafts reduce, noise is abated, and overall reliability of the mechanism grows.

Figure 1 shows an oscillogram of the compactor vibrations generated by the centrifugal vibration exciter (Figure 1a) and the related frequency range (Figure 1b). High frequencies are present in the spectrum but their amplitudes are much smaller than the basic frequency has. Theoretically, amplification of amplitude of any harmonic can produce the required vibration mode, while practically, the simplest way is to use the second or third harmonic.

For implementation of that vibration mode, a test bench was designed based on the scheme [9] with one degree of freedom to ensure only progressive motion of compactor.

The test bench (Figure 2) includes container 1 with granular material and a vibrating compactor. Aimed to abate influence of vibrating container walls on the process of compaction, the inner surfaces of the walls are made of an elastic material.

The vibrating mechanism consists of compacting steel plate 2 and directional vibration exciter 3 (Pendulum Vibrator type A 200/600 by KNAUER ENGINEERING) mounted on basement 4.
connected with the compacting plate through the system of elastic elements 5 (Figure 2). Stiffness of the elastic elements is selected from calculations in order to ensure resonance at the third harmonic of the basic frequency. To make the mechanism displace strictly vertically, compacting plate 2 is rigidly connected with frame 7 fitted with rollers 7 intended to move along guide way 8 to provide one degree of freedom only.

The basic (low) frequency is selected from the range 30 to 50 Hz. This choice is explained by the earlier research findings on this frequency range being the most efficient for compaction of granular materials [14] for the experimental estimation of the influence exerted by the complex superharmonic vibration impact parameters on the material, three rotation frequencies were set for the vibration exciter: 30, 40 and 50 Hz; the related amplified third harmonics have frequencies 90, 120 and 150 Hz, respectively.

The vibrating mass of the test bench is known (70 kg); thus, for the frequency of 40 Hz, the stiffness of the elastic elements to ensure resonance at the third harmonic frequency was calculated as 9.97 MN/m.

The elastic elements were made of rubber sheet 20 mm thick with elasticity modulus of 8.14 MPa. It is highly technical to ensure resonance by only changing parameters of elastic elements; for this reason, the structure of the test bench allowed resonance adjustment through small-range variation of the basic frequency of the vibration exciter using a frequency converter.

The test conditions involved a set of elastic elements with total stiffness of 10 MN/m, the vibration exciter frequency was 40 Hz, and the expected frequency of the amplified third harmonic was 120 Hz.

The vibration velocity of the compactor was measured using a piezoelectric accelerometer, and its signal was fed, through amplifiers and an analog-to-digital converter, to a computer. The data acquisition and processing used the Experimental and Process Installation Automation Software System ACTest©.

In the series of tests aimed to assess influence of the polyharmonic vibration mode on efficiency of compaction, the measured parameters of vibration impact were: vibration frequency, static moment of eccentric masses and duration of the vibration treatment process. The density of the compacted materials...
material under the polyharmonic vibration was compacted with compaction density after operation of a compactor with harmonic mode of vibration, all other conditions being equal.

Figure 3 presents the experimental curves of the granular packing density and the impact force at the constant frequency and duration of vibration in the polyharmonic mode (curve 1) and harmonic mode (curve 2). The force was amplified by changing the static moment of the eccentric masses of the vibration exciter. It follows from the plot that compaction using the designed vibrating drive ensures an increase in the packing density by 10–15% at the same duration of the process and all other conditions being equal.

![Figure 3](image1.png)

**Figure 3.** Density of compaction versus impact force of vibration action at frequency of 42 Hz: 1—polyharmonic mode; 2—harmonic mode.

The estimate of the influence exerted by the vibration amplitude of the exciters operating in different modes on the density of compaction produced the same results for the harmonic and polyharmonic modes though the amplitude of the latter was half as much (Figure 4).

![Figure 4](image2.png)

**Figure 4.** Oscillogram of vibration velocity of compacting plate: 1—polyharmonic mode; 2—harmonic mode.

The earlier research into compaction of a granular material in a closed space by a compactor in the mode of the harmonic vibrations has found that the main compaction take place within the time to threshold of the vibration action. Subsidence of the packing over the entire surface is 45–50 mm. The
further increase in the time of the vibration action results in no essential change in the packing density. The subsequent re-compaction of the packing in the mode of the polyharmonic vibrations ensures the packing subsidence over the whole surface by 10–15 mm more, which enhances the packing density.

3. Conclusion
Summing up, implementation of the harmonic mode operation of the compactor provides vibrations containing frequency three times higher than the frequency of eccentric masses at the commensurable amplitude. This allows using the series-produced vibration exciters with lower rotation frequency of eccentric masses. As a consequence, compaction of granular materials can be performed at the lower energy inputs and mechanical loading on the mechanism, which essentially improves operational reliability of vibrating drives.

Acknowledgements
The study was supported in the framework of the Basic Research Program, Project No. AAAA-A17-117122090003-2.

References
[1] Lavendel EE (Ed) 1981 Vibration in Engineering. Handbook Vol 4: Vibration Processes and Machines Moscow: Mashinostroenie (in Russian)
[2] Blekhman II 2013 Theory of Vibration Processes and Mechanisms. Vibration Mechanics and Vibration Equipment Saint-Petersburg: Ruda Metally (in Russian)
[3] Bauman VA and Baykhovskii II 1977 Vibration Machines and Processes in Construction Moscow: Vysshaya shkola (in Russian)
[4] Zubkin VE, Konovalov VM and Korolev NE 2001 Hard-pressed rolling method and classical road-rollers Stroit. Dorozh. Mashiny No 3 pp 12–15
[5] Pivinskii YuE 2004 Shaped Refractories: Reference Book Book 1: Technological Generalities Moscow: Teploenergetik (in Russian)
[6] Sukhin NV, Bukin SL, Korchevakii AN and Reshevskii AP 1997 Vibromachines with antiresonance mode of operation—A new trend of mineral processing machinery improvement Advanced Technologies in Machine Building and the Contemporaneity: International Conference Proceedings Donets pp 240–241 (in Russian)
[7] Zakharenko AV 2005 Theretical and experimental investigation of soil and asphalt concrete compaction by rollers Dr Tech Sci Dissertation Omsk: SGADA (in Russian)
[8] Proshkin AV, Levenson SYa, Pingin VV and Morozov AV 2015 RF Patent No 2553145 Byull. Izobret. No 16
[9] Proshkin AV, Pingin VV, Timofeev VS, Levenson SYa, Gendлина LI, Eremenko YuI and Goldobin VA 2007RF Patent No 2296819 Byull. Izobret. No 10
[10] Garkovenko EE, Nazimko EI, Bukin SL et al 2011 Use of bi-harmonic vibration machinery in coal dresing Ugol Ukrainy May pp 41–44
[11] Bukin SL, Kondrakhin VP, Belovodskii VN and Khomenko VN 2014
[12] Shatalova IG, Gorbunov NS and Likhtman VI 1965 Physicochemical Framework of Vibratory Compaction of Powder Materials Moscow: Nauka (in Russian)
[13] Bykhovskii II 1968 Theoretical Framework of Vibration Engineering Moscow: Mashinostroenie (in Russian)
[14] Gendлина LI, Levenson SYa, Eremenko YuI and Vidanov VV 2011 Research data on vibration compaction of granular materials GIAB No 8 pp 255–259