STUDY OF MASS MOTION ON VIBRATING DEVICE: DESIGN AND PROCESS SIMULATION

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The simulation of mass motion using a vibrating device that was laboratory designed was the main idea of the work. The construction of an experimental vibrating device and the associated measuring station along with the measurement of dynamic properties of the vibrating device depending on preselected input parameters of the device of bulk material on this experimental model is presented. The simulation of the general behavior of particles on an experimental vibrating device at rotational frequencies of 20 Hz, 25 Hz and 35 Hz, and the rotation of contact vibrators at 30°, 45° and 75° by mass flow modeling using software ROCKY DEM is done. It was observed that the particles were moving at the fastest speed at 45° and at 35 Hz and that the top layers fall to the bottom especially at higher rotational frequencies, which may ultimately cause aeration of the particulate matter, thus reducing the angle of internal friction of the bulk material.

KEYWORDS

Vibrating device design, bulk material, powdered particles, simulation, mass motion.

1 INTRODUCTION

The oscillation of machines intended for the transport of particulate matter investigated in [Oujezdský 2015, Chandravanshi 2017, Al-Saif 2011] has been a topic, which has often been discussed in recent years not only in professional circles in [Hickersko 1967, Kruelle 2007, Slíva 2019, Di Maio 2012]. The variability of the materials developed nowadays is forcing engineers to design new transportation devices where adaptation of such means is simple, economic and environmentally friendly in [Mucchi 2013, Dvorský 2011]. Vibration transport represents a significant share in the transport of lump, bulk and powdered/nanostructured materials presented in [Peters 2018, Slíva 2019, Sliva 2003, Simha Martynková 2021, Imole 2016, Ommen 2012, Auffan 2009]. Understanding fundamentals of vibration and their influence on bulk materials handling is gaining an increasing importance in the economies of scale. However, at present there appears to be no accurate and sufficient description of various phenomena observed in a granular material affected by vibration. This paper presents a concise review of physical phenomena observed in bulk granular materials affected by vibration, taken here as mechanical oscillations of relatively low amplitude and relatively high frequency [Cleary 2009, Yan 2022, Zhang 2018]. Particulate matter is transported with the assistance of so-called microjumps, which are in most cases produced by an oscillator (electromagnetic exciters, mechanical exciters, pneumatic exciters, etc.) as is written in [Yan 1996].

Energy savings/low-maintanence (low-wearing) of an existing equipment is given to working in the natural frequency of the equipment. The natural frequency is a key parametr, which plays important role on vibration control, optimalizating design and especially to material mass flowability as mentioned in [Yurteri 2002]. The equipment working on a very closed to its natural frequency provided stable mass flow of the material depending on a dynamic characteristics. Mass flow is defined a state in which the entire volume of transported material is in motion. The individual layers of bulk material flow evenly over the entire cross section of the equipment, which preserves it the time sequence of the transported material.

Recently, great emphasis has been placed on the energy savings of existing equipment, or on the construction of unique equipment capable of easily transporting a wide range of materials. These devices must be environmentally friendly and especially low-maintenance (low energy consumption, low wear, etc.) as depicted in [Tseng 2011].

The basic building element characterizing this type of transport is called a vibrating conveyor, sorter or feeder. These elements can handle almost everything, from fine powdered materials to large pieces of stone, without loss, environmentally friendly and minimal wear.

The vibratory feeder is a forced vibrating system mostly used in industries to feed material from hoppers, bins, silos and storage piles to belt conveyors. It is used to control the feed rate of material being transported. In this paper, dynamic analysis of the vibratory feeder is conducted theoretically, and the obtained results are validated with experimental values corresponding to the various operating frequencies of the feeder unit as is depicted in [Wang 2018, Wu 2013, Jaeger 1997, Wang 2016].

The vibrating devices are usually formed by a trough (most often wide letter (U or circular), which is flexibly mounted to the base. Their movement and construction can be quite complex, depending on the way of use and the type of material being transported as mentioned in [Čep 2013].

To predict the behaviour of the various type of particles the simulation using DEM software as in written in [Chadha 2018, Woschny 2021, Fermandez 2011, Saker 2019]. The software environment allows modeling of accurate particle shapes which includes custom 3D bodies, 2D shells and fibers which can be made rigid or flexible, Multibody Dynamics of equipment components to move freely in response to forces such as particle contacts, gravity, breakage modeling.

In this work we want to set the unique model for experimental device, where visual study of material flow on vibrating device would be possible. The crucial parameters such as stiffness of the spring that affects oscillation character and frequencies along with the angle of device is studied to assure the best conditions for various type of particular matter. To simplify the complex system the particles with spherical shape were selected.

2 EXPERIMENTAL DEVICE MODEL SETTINGS

An experimental model (Fig. 1) was constructed for a basic study of material movement under different conditions of material movement on a vibrating device consisting of a transparent trough designed for visual study of material flow

(1), a supporting structure (2), which is connected to the trough by means of springs (3). The source of the vibration motion in this case is a set of two vibration exciters (4) controlled by frequency converters and other electrical accessories.
Operation of the vibratory machine may be described by combination of following parameters: the way of oscillation (= shape of oscillation); working frequency (= rotation speed, angular frequency); maximum value of shift (= amplitude of oscillation); angle of working plane.

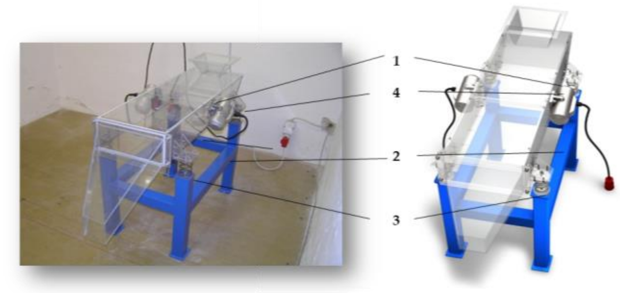

Figure 1. Real model-device of vibration equipment. 1. transparent trough, 2. supporting metal constructure, 3. springs, 4. set of two vibration exciters

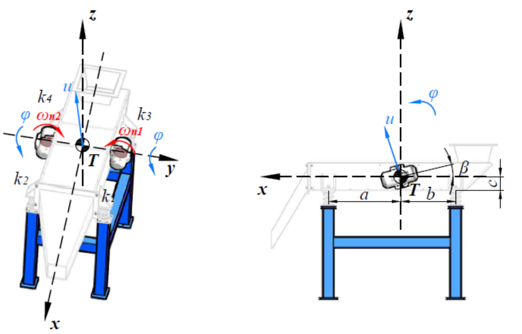

Figure 2. Modelling of vibration equipment: two views with denoted controlled parameters. T -centre of gravity, an origin of a coordinate system, a,b,c -dimensions for the center; k_1, k_2, k_3, k_4 – stiffness of springs for vibrational device; ω_{n1} and ω_{n2} - angular velocity of imbalances; β , φ– angles of turning of the attached vibrators; u- vector shift

After the construction of the experimental vibration equipment (Fig. 1), its input properties were measured and the input parameters were set (Table 1). The weight in a closed and open state (without a cover and a mask), the coordinates of the center of gravity, and the moment of inertia etc. were all determined for the experiment. Great emphasis was placed on measuring the spring stiffness in all directions (Fig. 2). Due to the fact, that the stiffness of the springs significantly affects the oscillation character, the springs were measured at VŠB-TUO in laboratories of the Department of Applied Mechanics of the Faculty of Mechanical Engineering.

Weight closed trough m_{tc} [kg]	Weight open trough m_{to} [kg]	Center of gravity coordinates T [mm]	Dist. r [mm]	Moment of inertia closed state Jzu [kg · mm²]	Moment of inertia open state J_{zu} [kg · mm²]
17.504	15.707	a=497 b=503 c=59.4	12	1463307	1439852

Table 1. Input parameters of real vibrating equipment.

The measurements show that the stiffness of the springs differs slightly from the expected values, so the vibration pattern may differ from facts assumed above.

Stiffness k_{1z} [N / mm]	Stiffness k_{1x} [N/mm]	Stiffness k_{2z} [N/mm]	Stiffness k_{2x} [N/mm]
16.667	10.867	16.021	10.124
Stiffness k_{3z} [N / mm]	**Stiffness k_{3x} [N/mm]**	**Stiffness k_{4z} [N/mm]**	**Stiffness k_{4z} [N/mm]**
15.42	9.536	15.693	9.843

Table 2. Measured parameters of the tested cylindrical compressive springs k_1, k_2, k_3 and k_4 in given directions x and z according to Figure 2.

Since the stiffness of the springs slightly differs from the above assumption, there are different values of oscillation parameters, especially at natural frequencies, from the assumed values (Table 2). The springs have different stiffness in different directions due to the connection to the supporting metal constructure, and the overall design of the vibration equipment device.
Based on Ansys Workbench method, there were natural frequency and shapes of the open vibrating device determined (Table 3).

Natural frequency [Hz]			
	0°	15°	30°
Natural frequency F_{n1}	7.445	7.443	7.439
Natural frequency F_{n2}	7.970	7.969	7.969
Natural frequency F_{n3}	9.989	9.989	9.99
Natural frequency F_{n4}	11.75	11.777	11.798
Natural frequency F_{n5}	12.048	12.014	11.972
Natural frequency F_{n6}	16.309	16.309	16.309
Natural frequency F_{n7}	29.106	29.052	29.035
Natural frequency F_{n8}	58.048	57.466	56.404

Natural frequency [Hz]				
	45°	60°	75°	90°
Natural frequency F_{n1}	7.435	7.430	7.425	7.425
Natural frequency F_{n2}	7.969	7,969	7.969	7.969
Natural frequency F_{n3}	9.991	9.990	9.990	9,988
Natural frequency F_{n4}	11,8	11.767	11.711	11.662
Natural frequency F_{n5}	11.94	11.934	11.956	11.985
Natural frequency F_{n6}	16.309	16.309	16.309	16.309
Natural frequency F_{n7}	29.05	29.007	29.099	29.071
Natural frequency F_{n8}	55.004	52.833	50.339	49.097

Table 3. Natural frequencies of entire device of real vibrating equipment.

The experimental research of the behavior of particulate matter on a vibrating device were carried out switching on the accelerometer control interface on the PC, starting the sensing elements with remote controls and the vibrating device. After pouring the bulk material into the collection container, the experimental vibrating device, the sensing elements and the accelerometer were switched off. This was followed by saving the results from the graphical interface of the accelerometers to a PC. After completing eight measurements, the results from the camera and digital camera were also saved to a PC, where they were further modified. Thus, four measurements were made in two days for a rotational frequency of 20 Hz, 25 Hz and 35 Hz when the attached vibrators were turned to 30° and 75° when the conveyor trough was filled from 10 %, 25 % and 50 % (Fig,4).

From the measured visual observations, the layer of material formed by the glass balls at an angle of rotation of the connected vibrators of up to 30° reached, as expected, with a higher frequency of rotation at a higher speed. At lower rotational frequencies, the material layer did not show the expected continuous movement in the direction of transport, which could be caused by partial synchronization of the connected vibrators. In the place from the vibration exciters, there was an obvious reduction in the advancing speed, which resulted in the accumulation of a larger volume of material at the landfill site. It is also clear from visual observation that the bottom layer is always some time before the layer above it. There is a delayed transfer of energy between the particles, i.e. the lower layer is shifted towards the discharge, while the upper layer is only in suspension. As the frequency of rotation increased, the upper layers began to sink into the lower ones. The particles reached higher kinetic energies, which caused more stress on the lower part of the trough and an excessive increase in noise of the experimental equipment. In the place from the vibration exciters, there was also an evident decrease in the advancing speed, which resulted in the accumulation of a larger volume of material at the dump site. This phenomenon is most likely caused by a slight tilt of the experimental equipment, where the particles are ejected from the end of the trough to the discharge with less acceleration.

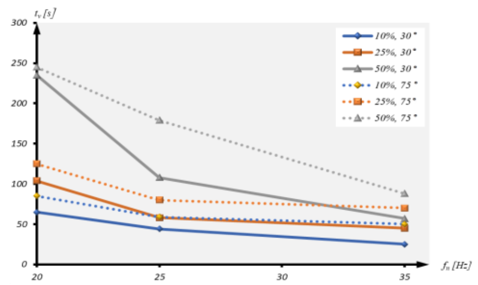

Figure 3. Example of the measured values of the empty flour emptying time t_v at the angle of rotation of the attached vibrators at 30 ° and 75°.

3 SIMULATION STUDY OF THE PARTICULATE MATTER MOVEMENT ON A VIBRATING DEVICE

Since the motion of particles is very complex and its analytical definition using standard mathematical equations is very complicated, it is necessary to find a tool that would be able to simulate and capture the behavior of some properties of bulk material in transport and processing. Many discrete element software (DEM) software platforms are currently used. In fact, these are computational programs that allow the import of the default model from existing CAD systems, where boundary conditions (translation, rotation, load, etc.) can be defined for the imported model.

In the next step, it is relatively easy to assign a particle weight to the general imported model. Here, too, the boundary conditions (shape, granulometry, coefficient of internal friction, coefficient of external friction, etc.) can be easily assigned to the individual particles. When calculating the software, it works with the information of individual particles. After the calculation is performed, the required results (speed, energy spectrum, etc.) can be plotted as needed.

For simulation purposes, the above mentioned computer model was exported to the Rocky DEM calculation program. Rocky DEM quickly and accurately simulates the flow behavior of bulk materials with complex particle shapes and size distributions.

This was followed by the assignment of boundary conditions to the simulation model of the vibration device (mass, moment of inertia, creation of pouring gradients, input of vibration parameters to the simulation model).

The actual movement of the simulation model with its set properties approximates the rotation speed of 20 Hz, 25 Hz, 35 Hz and the angle of rotation of the surface vibrators in the range of 30°, 45° and 75°. This was followed by the formation of spherical particles having general properties of 10 mm. In the next step, the transport element was filled with the above-mentioned spherical particles in three different color layers (Fig. 4).

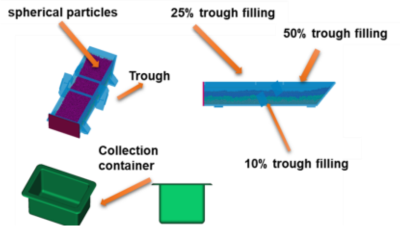

Figure. 4. Demonstration of filling of the simulation model with spherical particles.

After completing the pouring process, the actual movement of the particulate matter on the conveyor trough for pre-defined entry conditions was simulated. First, the motion of particles was simulated, with trough frequencies corresponding to 20 Hz, 25 Hz and 35 Hz at an angle of 30°. At the end of the simulation, the data of the input values of the simulation model corresponding to the rotational speed of 20 Hz, 25 Hz and 35 Hz at an angle of rotation of the surface vibrators to 45°, was processed.

After entering these input values, the simulation was started again. At the end of the process, the input values corresponding to the rotational speed of 20 Hz, 25 Hz and 35 Hz were again reset at 75° at the angle of the vibrators (Fig. 3). After completing the simulations, the results of the actual movement of the simulated particulate matter were processed (Fig. 5 and Fig. 6), where t=10.7 s is considered the shortest modelled time to discharge a given particle mass under defined conditions.

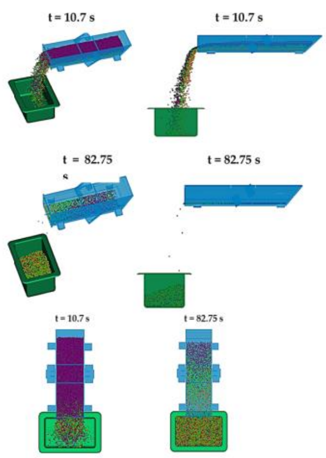

Figure 5 Demonstration of spherical particle simulation on vibrating device at 20 Hz and angle of contact vibrators to 30°

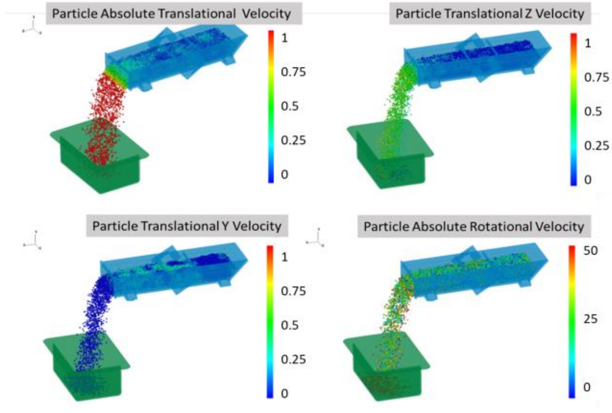

Figure 6 Spherical particle velocity on a vibrating device at a rotation speed of 20 Hz and an angle of rotation of the surface vibrators to 30° at time t = 10.7 s

Rotate of vibration exciters	30°		
Frequency of rotation f_n [Hz]	20	25	35
Pouring time t [s]	112.5	101.1	89.5
Average speed v_{Tp} [m·s^{-1}]	0.3	0.4	0.48
Average speed v_{zp} [m·s^{-1}]	0.26	0.35	0.42
Average speed v_{yp} [m·s^{-1}]	0.15	0.2	0.24

Rotate of vibration exciters	45°		
Frequency of rotation f_n [Hz]	20	25	35
Pouring time t [s]	105.6	98.4	86.2
Average speed v_{Tp} [m·s^{-1}]	0.38	0.42	0.52
Average speed v_{zp} [m·s^{-1}]	0.31	0.29	0.37
Average speed v_{yp} [m·s^{-1}]	0.22	0.29	0.36

Rotate of vibration exciters	75°		
Frequency of rotation f_n [Hz]	20	25	35
Pouring time t [s]	115.6	108.7	115.6
Average speed v_{Tp} [m·s^{-1}]	0.27	0.37	0.27
Average speed v_{zp} [m·s^{-1}]	0.26	0.36	0.26
Average speed v_{yp} [m·s^{-1}]	0.07	0.09	0.07

Table 4. Demonstration of selected parameters obtained from simulations using computational software Rocky Dem vibrators at 30° at time t = 10.7 s

4 DISCUSSION

It is evident from the simulation that the layer of spherical particle material displayed higher progressive velocities at a higher oscillation frequency (the emptying time of the trough was smaller). The particles were moving at the fastest speed at 45° and at 35 Hz when simulating the rotation of the external vibrators (Fig. 5). It is also evident from the simulation that the top layers fall to the bottom especially at higher rotational frequencies, which may ultimately cause aeration of the particulate matter, thus reducing the angle of internal friction of the bulk material. The selected angle will be very important in case of practical application where the fast movement of the particles is required, e.g. in waste management, where mechanical recycling is recommended for plastic waste or other granulates mentioned in [Wu 2013].

It should also be noted that, when the vibrators are rotated to 30°, the average velocity of the particle in the z direction is higher than in the y direction, depending on the rotational speed of the vibrators (Fig. 5 and Fig. 6). When the oscillators are turned to 45°, the average velocity of the particles in the z and y direction is approximately the same. When rotated to 75°, the vibration pattern of the trough itself changes, i.e. the average particle velocity in the z direction is higher than in the y direction. From this, it can be concluded that the material layer moves more slowly due to an insufficient decrease in the internal friction angle of the particulate matter (Table 4). Thus, discharge time reaches relatively higher values than in the above examples. The experiment accompanied with simulation evolve important characteristics that could be used for many industries area, especially the very fine particles with spherical such as pharmaceuticals, powdered food, and chemicals with respect to health and safety.

5 CONCLUSIONS

Movement of particulate material on vibratory equipment depends on method of the excitation. To save power, can be propose a method of the excitation, which will not burden the machine. For example it could be a sound or a magnetic levitation. The construction of a vibratory equipment can be fitted with regulators. The regulators then kept constant acceleration during operation of the equipment, depending on the loading trough.

It would also be appropriate explore the speed of movement particular materials on a vibratory equipment. From speed of movement particular materials can be derived transport capacity and energy consumption. It would be interesting to monitor the pressure and other parameters in a conveyed material during transport.

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