Test bench to study drying of geomaterials in vibratory conveying

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Abstract. The authors review vibrating machines used to convey and dry different geomaterials. The article describes the structural layout of a vibrating device with an elastic operating component designed at the Institute of Mining, SB RAS for the simultaneous conveying and drying of loose materials. The experimental test bench is applicable to studying influence of dynamic parameters of the elastic conveying component on the efficiency of drying of granular materials.

1. Introduction

Mineral mining involves many operations connected with extraction, haulage, blending, washing and beneficiation of rocks, which need special equipment and take certain time.

Loose rocks from open pits are stored in dumps in the open air and become dampened due to exposure, which results to intense adfreezing during haulage and storage in winter. For another thing, mineral dressing sometimes involves separation with watering [1]. In this respect, processing of geomaterials is added with the operation of dehydration. Dehydration is associated with heat exchange and mass exchange between a heating sources and moisture of the material being dried. The heating sources may be furnace gases, heated air, or their mixtures, etc.

Processing plants widely use convective driers driven by smoke fumes [2]. Atmospheric air is boosted into a furnace and enters the drying box from the fee side of a wet material which is continuously mixed to make its particles steadily contact with smoke fumes. For example, in cylinder drier (Figure 1), a granular material is simultaneously subjected top mixing and gravity flow inside the rotating cylinder. The dry product is outlet to a discharging chamber.

Operation of such equipment is associated with high temperatures of hot gases (700…800 °C) and feed particles to 250 mm in size. The equipment is heavy and large while only 15–25% of the drying box volume is occupied by the feed during drying. Moreover, wet material sticks to the inner surface and nozzles of the drying cylinder, which reduces the machine capacity and requires cyclic process downtimes.

The volume of the drying box can be diminished through the use of vibratory displacement of the dehydrated material.

Vibrating transporters have simple designs and ensure health condition, operating safety as well as automation. The mode of transport with tossing of particles [3] so that they hop off the conveying surface makes it possible to mix the material with hot air inside a relatively small volume.
Figure 1. Gas drying cylinder [8]: 1—welded cylinder; 2—clip bands; 3—ring gear; 4—discharging chamber; 5—tappet rollers; 6—drive; 7—furnace; 8—feeding hole.

Out of more than 50 types of vibrating transporting machines actually known are designed for specific plant facilities. The structure of almost all these machines includes a rigid actuating element, a system of elastic couplers to the substructure and a vibration exciter [4]. This is used as an engineering framework for the equipment for dehydration of granular materials in the course of vibratory movement and using various methods of heat source feed to the drying box. For example, vibration drier SVIK (Figure 2a) [5] features power supply in the infrared band EM field, and granular material flows in the vibrating boiling bed. Heating and dehydration are implemented using UV halogen lamps mounted on the inner surface of the body. The drying time and moisture content of the end product are adjusted through the change of vibration parameters and the material layer thickness. Such driers ensure enhanced heat exchange inside the drying box, with the flow of granular materials without spraying and dispersion of particles from the body. On the other hand, these machines have a complex design and feature temperature constraints due to infrared sources.

Figure 2. Vibratory dryers (a) SVIK (Russia) and (b) CarrierDelta-PhaseDrive (USA).

Another example is vibrating fluid bed Carrier Delta-Phase Drive shakeout machines (Figure 2b).[6]. The heat source is smoke fumes fed to the drying box via the channels of distribution. Exhaust gases are ejected through the system of filters. As compared with SVIK driers, these shakeout machines feature a simple design. At the same time, cohesive materials adhere to the conveying surface and walls of the drying box. Moreover, drying consumes much energy.

The common disadvantage of drying machines with a rigid vibratory conveying element is high labor content of assembling, installation and precommissioning, as well as the need to use thick understructures which are exposed to high loads due to dynamic unbalance.

2. Vibrating machines with an elastic conveying element

The vibrating machines designed at the Institute of Mining, SB RAS is free from the elastic elements to connect the understructure and the conveying member [7]. The latter is a low later-rigidity steel
sheet placed on the substructure at an angle of 10–15°. Conveying takes places as a wave flow, which allows implementation of various transportation modes as against conventional vibrating machines. The new-designed machines are small and light. The elastic conveying element can be curved, which enhances its efficiency in operation under heaps of granular materials.

The advantages of such vibrating conveyors allow using them to design light, structurally simple and energy-saving dehydration facilities. Figure 3 depicts the construction diagrams proposed by the Institute of Mining, SB RAS [8]. Drying of granular material occurs in the chamber formed by the conveyor, walls of the frame, housing and the self-regulating flap gates.

![Figure 3. Vibrating device for conveying and drying of materials: 1—conveying member; 2—frame; 3—safety element; 4—vibration source; 5—flap gate; 6—hole; 7—plates; 8—high pressure chamber; 9—heat-resistant elastic plates; 10—connection; 11—air heater; 12—vibration exciter; 13—housing; 14—steam ejection pipe; 15—intake socket; 16—granular material.](image)

Elastic conveying element 1 of the vibrating device can be divided into three conventional branches. The loading branch takes the highest load from the inlet wet material. For better conveying, this branch is curved and elastically fixed on the frame. In the central branch, dehydration takes place. To that effect, this branch has through holes 6 to ensure contact of the material with hot air fed under pressure from chamber 8. From above, holes 6 are covered with thin elastic plates 7 fixed on one of the side to the surface of the conveying element. The discharging branch provides outlet of the dry material. Aimed to accelerate the granular material flow in this branch and to prevent heat energy loss, this branch is curved so that its angle is 70–80 deg at the level of the discharge edge.

The drive includes two inertia vibration sources with their eccentric masses rotating at the same velocity in the direction of the granular material flow. For the self-synchronization of the sources, they are placed at a spacing divisible by the half length of the elastic wave generated by the conveying element [9]. The material flow velocity is adjusted using the frequency of the driving force application.

Engineering and behavior assessment of such machines require studying the influence of the structural and dynamic constants of the conveying element and the hot air feed method on the treatment efficiency of different granular materials.

With this end in view, the authors designed a test bench and determined the structural constants and the dynamic behavior of the vibrating device intended for conveying of materials while dehydrated. The engineering analyses used the known procedures [10].
Rigidity $EI$ of the conveying element was assumed from the condition of its wave motion under the action of the driving force and from sufficient strength under impacts [11]:

$$l_w = 2\pi \sqrt{\frac{\alpha}{\omega}} \leq l,$$

where $l_w$ and $l$ are the lengths of the wave and conveying surface, respectively; $\alpha$ is a coefficient ($\alpha = \frac{EI}{m}$, where $m$ is the mass of the conveying element with the material); $\omega$ is the vibration frequency.

Vibration amplitudes generated by two sources along the conveying element (Figure 3) were calculated from the numerical modeling in ANSYS. The full transient analysis used the implicit direct integration scheme with respect to time based on the Newmark method [12].

The conveying element is made as an elastic beam (Figure 3), with its loading branch arch-wise curved with the downward camber and the discharging branch arch-wise curved with the upward camber.

Granular material was modeled as an added mass spread along the beam in accordance with loading of the conveying surface during operation.

The beam was applied with two equal driving forces concentrated at two points in the central straight branch, directed normally to it and changed as per the law of sine:

$$P = P_{\text{max}} \sin \omega t,$$

where $P_{\text{max}}$ is the amplitude of the driving force; $t$ is the time.

The beam freely contacted with the elastic understructure fixed at the face opposite to the contact face. In case of zero driving force, the contact was ensured only by the weights of the beam and added mass. The major energy loss in this vibration system is associated with external dry friction on the contact faces, which allowed neglecting internal friction.

The coordinate origin was assumed to be at the left end of the straight branch of the beam.

In the plane problem, all displacements, velocities and the clearance between the conveying element and the elastic understructure were assumed as zero at the initial time.

The input data were: the sizes of the beam and elastic understructure; the coordinates, amplitude and frequency of the driving forces; the material properties of each element in the model (density, elastic modulus, Poisson’s ratio) and the gravitational acceleration.

From the calculation results, we plotted the transverse vibration amplitudes versus the conveying element length at different rigidities of the element and at different driving force frequencies. Figure 4 presents the plots for the conveying element at $EI$ of 2.16 kN·m$^2$ and vibration frequency of 25 Hz.

Figure 4. Vibration amplitudes generated by different driving forces along conveying element: 1—25; 2—30; 3—37; 4—49 kN.
Figure 5. Test bench model: (a) general view (profile); (b) supporting element of charging branch; 1—conveying element; 2 and 3—elastic steel plates; 4 and 5—elastic rubber blankets; 6 and 7—clamp elements; 8—frame; 9—vibration source; 10—elastic plates; 11—higher pressure cell; 12—housing; 13—elastic gaskets to prevent spill; 14—flap gate; 15—cyclone.

The studies make it possible to select vibration sources capable to ensure vibration of the conveying element for the granular material flow with tossing [3]:

\[
\frac{A \sin \alpha}{g} = \Gamma,
\]  

where \( \Gamma \) is the mode factor (in the mode of vibration and boiling, \( \Gamma \geq 1 \)); \( A, \omega \) are the amplitude and frequency of vibrations, respectively; \( \alpha \) is the angle of the conveying element; \( g \) is the acceleration by gravity.

Based on the calculations, drawings were plotted for a test bench including a frame, a housing and a conveying element 5 m long and 0.6 m wide (Figure 5a).

The welded frame includes the elements to support the conveying element in the design position. In the center, the frame has walls to lace heaters and pressurized air feeders. With the installed conveying element, this central portion makes pressurized air cell 11. The sealing of the cell is ensured by the elastic heat-resistant plates fixed at the upper edges of the frame and supporting the central branch of the conveying element at the same time.

The conveying element is replaceable as per the wanted flexural rigidity. The central branch of the element is straight and has through holes covered with thin steel plates. The curved charging branch is fixed to the frame using an elastic element (see an example in Figure 5b). This supporting element consists of elastic steel plates 2 and 3, rubber blankets 4 and 5, and clamps 6 and 7 to fix the plates to the conveying element and to the frame, respectively. The discharging branch is curved toward the outlet so that to provide the maximum material velocity at the outlet from the drying box. The back face of the conveying element is freely supported on the elastic elements of the higher pressure cell and on the safety rollers.

Two vibration sources are mounted in the central branch outside cell 11. Their spacing is varied as per the test conditions. For the experiment, we selected series-produced vibration sources MVE 3000/15 manufactured by OLI, Italia, having the force of 30.6 N and rotation frequency of 25 Hz.
The vibration frequency is adjusted using an electronic frequency changer. Housing 12 with hinged self-regulating flap gate is rigidly fixated to the frame, embraces the conveying element and forms the drying cell. In order to prevent spraying of granular materials, the steam-eject pipe is connected with cyclone 15.

3. Conclusions
1. In the conditions of higher production output in mineral mining and processing, the end product time can be shortened by means of synchronization of some operations, for instance, transport and dehydration of granular materials.
2. Vibrating conveying devices allow maximal reduction in metal consumption of the equipment and enables automation of vibratory dehydration.
3. Vibrating machines with an elastic conveying element, designed at the Institute of Mining, SB RAS feature a simple structure and ready assembly, and can be effectively used in the structure of drying equipment.
4. Based on the useful model patented by the Institute of Mining, the engineering paperwork is developed for the test bench to study the influence of the design and dynamic behavior of the vibratory conveying device and the hot air feed method on the performance efficiency of dehydration of various granular materials.

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