ANALYSIS OF GRANULE LAYER IMPACT INTERACTION ON VIBRATING 2D PRISM

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Abstract. The impact of granules which are of various form, size and densities against a vibrating prism is analyzed. The analysis is performed in a two-dimensional plane (2D), assuming that the prism perpendicular to the plane is symmetric with the given constant height. In the description of the interactions, classical mechanics are used to describe the impact of granules or granule flow against a moving obstacle (vibrating prism). The air viscosity is not taken into account and thereby the present work offers simplified analytical solutions for engineer calculations through a straight forward mathematical model. In the interaction of granules with the obstacle, the impulse restitution coefficient is applied in the normal direction. The no-slip rule or the dry friction coefficient for slip, respectively, is applied to the interaction in the tangential direction. The analysis uses the superposition principle for individual airflow and for each granule fraction. As a result, for a continuous environment, it is possible to divide the interaction by the center of mass of several layers in the region of motion. The results obtained show the distribution of fractional flows, taking into account that there is a suction zone just behind the prism. Despite the complicated interactions of the components of the environmental fractions, the developed analytical method allows analytical prediction and calculation of the separation motions. The equipment for the experiments is 3D printed, and the experiments were performed to measure the flow speed of the medium using a bottom open cone container.

Keywords: granules, separation, fractional flow, transport.

Introduction

Various multi-material fraction separation and transport equipment are widely used in grain harvesting and treatment in the field of agriculture, artificial fertilizer spraying in the countryside, as well as a variety of other bulk substances, transport and handling as technological processes in everyday life.

The problem of separating the light fractions and the dust from the main fractions plays an important role in fractional separation. The mathematical models for solving this problem have not yet been fully developed. This is because the interaction of the individual fractions (particles) is described by one-sided (non-supporting) holonomic (non-geometric) constraints [1]. In their motion, the flying particles collide with each other and then fall apart. Collisions produce normal and tangential interactions, which direction depends on the relative velocity direction and magnitude of the contact point. Even a spatial collision of only two particles cannot be analytically resolved [2; 3]. Similarly, the collision of two particles in plane motion has a complicated description: there are seven collisions, which depend not only on the velocity and angular velocity of the moving particle centers, but also on the position of the contact point against the particle mass centers [4; 5].

Despite these problems, there are a number of successful studies that have been validated in practical applications. For example, four kinds of threshing principles including impact, rubbing, combing and grinding interactions are investigated [6]. Here four types of contact models between grain and threshing components have been constructed. One theoretical model by means of which processes of classification and separation occur in suspended-layer vortex granulators with variable-height cross-section is described in [7]. Possibilities to separate particles with difficult dust properties from gases are described in [8]. Additional changes to the Discrete Element Method (DEM) in order to be suitable for the simulation of grain-straw separation, which is one of the most critical processes in the combine harvester, are given in [9]. Entering rice grain model parameters into the EDEM program to simulate rice separation by observing two main contact parameters – static friction coefficient and rolling friction coefficient – is discussed in [10].

In view of the foregoing, this work extends the research in this direction by proposing a method for describing a multi-fractional environment roughly by applying the classical mechanics rules of the interaction of a moving medium as a mechanical system with a fixed barrier in the form of a prism. Simplified tasks are solved in analytical form, which allows us to understand the nature of larger, more complex tasks. Illustrative results of numerical modeling and experimental studies on the influence of vibrations on the motion of multi-fractional media are also given and discussed in detail.

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Materials and methods

1. Model of 2D prism interaction calculation analytical method

The model of non-stationary flow of granules and the vertical interaction with a vibrating prism is described in Fig. 1. The model describes the vertical drop motion of several fractional particles and the interaction of the impact with a vibrating triangular prism. Here, it is not possible to use fundamental fluid dynamics relationships to describe the impact interaction [11; 12]. This is because particles of different fractions are not continuous fluid. For this purpose, here is described the particle layer mass interaction with a solid prism with the classical mechanical momentum change theorem in differential form [13-15]. Accordingly, additional correlations following the rules of impact motion can be obtained from impulse recovery relationships, knowing their restitution coefficients and slip friction coefficients [4; 5].

Applying the superposition principle to each individual particle in the prism collision, we obtain the following equations (1):

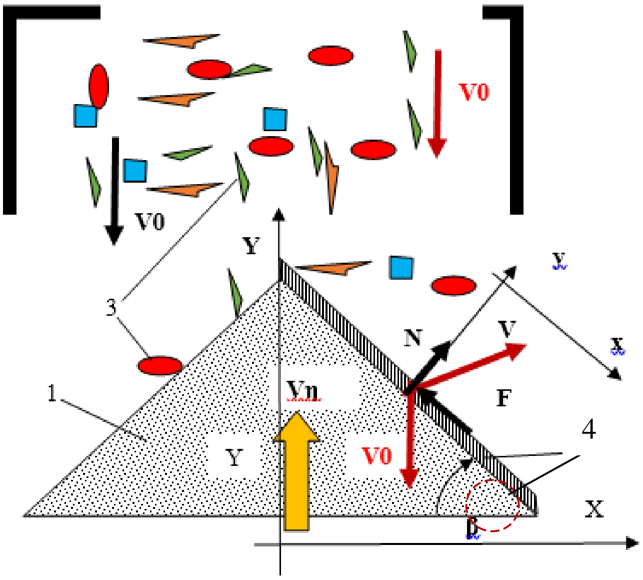

Fig. 1**. Model of granule first vertical interaction with triangular prism:** 1 – triangular prism; 2 – boundary layer; 3 – granules; 4 – separation point

$$\begin{aligned}
&m \cdot Vy - [-m \cdot (V0 + V\eta) \cdot \cos(\beta)] = N \cdot dt; \\
&m \cdot Vx - [-m \cdot (V0 + V\eta) \cdot \sin(\beta)] = -F \cdot dt; \\
&F = f \cdot N; \\
&Vy = R \cdot (V\eta + V0) \cdot \cos(\beta); \\
&m = (V0 + V\eta) \cdot \cos(\beta) \cdot dt \cdot A \cdot \rho,
\end{aligned} \tag{1}$$

where β – a prism flat angle;
$V0$ – the downwards vertical velocity of flow;
$V\eta$ – the vertical velocity of prism;
N – the boundary layer normal interaction force;
F – the boundary layer tangential interaction force;
dt – the infinitely small time t interval;
m – the boundary layer mass in small time interval dt;
f – the dry friction coefficient;
R – the normal impulse restitution coefficient;
A – the area of prism interaction one side.

Here $A = L \cdot B$, where L is a triangle diagonal; B is a width of the prism.

From the system of five equations (1), five unknowns *Vx*, *Vy*, *N*, *F* and *m* can be found out. After finding them, the next interaction parameters can be found again after investigation of flying or slipping motion.

For instance, components of velocity after impact in the system along x,y directions are given in (2):

$$\begin{aligned} vx &= (V0+V\eta)\cdot[\sin(\beta - f\cdot\cos(\beta)\cdot(1+R)]; \\ vy &= (V0+V\eta)\cdot R\cdot\cos(\beta). \end{aligned} \tag{2}$$

Fractional separation will occur at the far end of the prism edge, when the shock interaction ends. From the end of the shock interaction, considering from that point, free fall graphs, without air interactions are shown in Fig. 2-4.

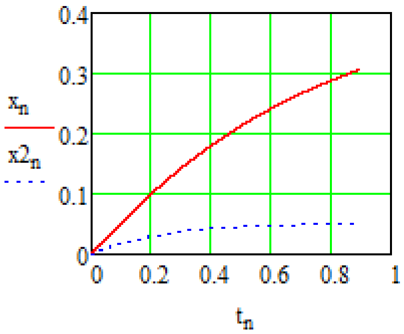

Fig. 2. **Horizontal displacements of two different granules after vertical interaction with vibrating triangular prism:** t_n – integration time; x_n – horizontal displacement

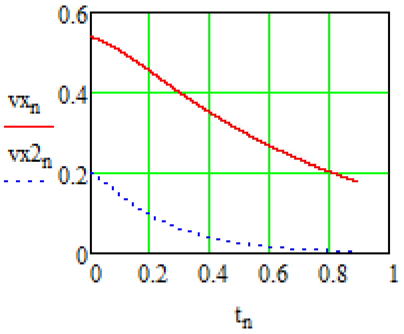

Fig. 3. **Horizontal velocity of granules after vertical interaction with vibrating triangular prism:** t_n – integration time; vx_n – horizontal velocity

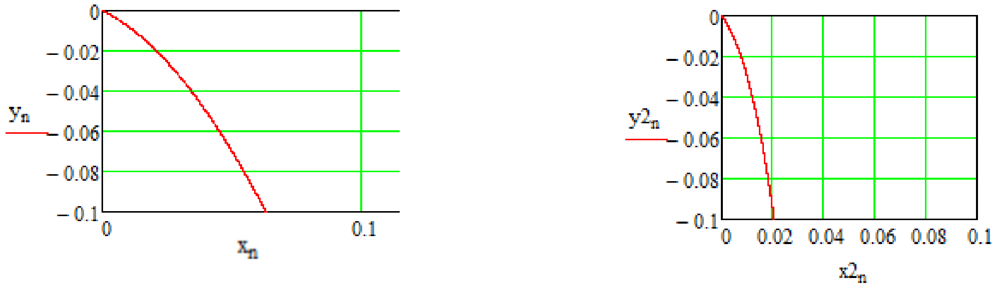

Fig. 4. **Vertical displacements of granules after vertical interaction with triangular prism:** t_n – integration time; y_n, $y2_n$ – vertical displacements for two different fractions; x_n, $x2_n$ – horizontal displacements

The results of numerical modeling (Fig. 2-4.) allow drawing the following conclusions.

1. After the last collision with the prism (after the separation point in Fig. 1), the horizontal displacements of the two particles differ significantly (even three times) at a small drop height (about 0.1m).
2. Primary particle separation can be simply performed on an inclined vibrating prism plane.
3. The trajectories of further movement of the separated particles can be further modified by adding an additional air stream or an additional barrier.

2. Numerical investigation method of granule interactions using Working Model 2D

In this case, the results of modelling are shown in Fig. 5, 6.

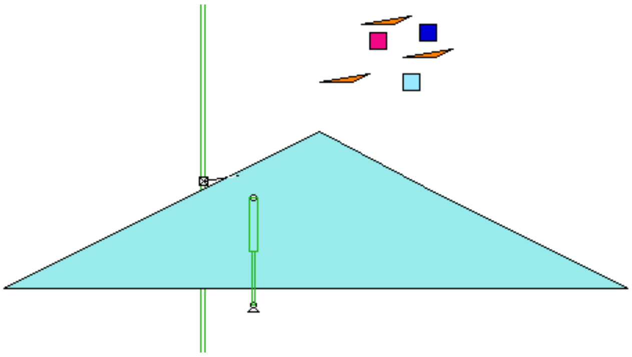

Fig. 5. **Initial rest position of two different granules**: 1 – granule with soft (dust) parameters; 2 – granule with hard (grain) parameters

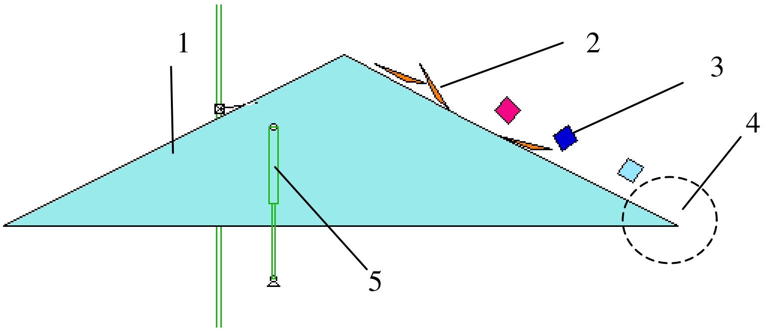

Fig. 6. **Granule displacements along vibrating surface:** 1 – prism; 2 – soft granule; 3 – hard granule; 4 – separation point; 5 – harmonica actuator

From the modeling images in Figs. 5, 6, it can be concluded that really soft and hard particles move on a vibrating prism with different laws. It can be used in particle separation. For example, if the airflow forms with the falling particles, a suction zone with reduced pressure is created behind the triangle or rhombus prism (Fig. 7). This example is discussed in more detail in paper [13].

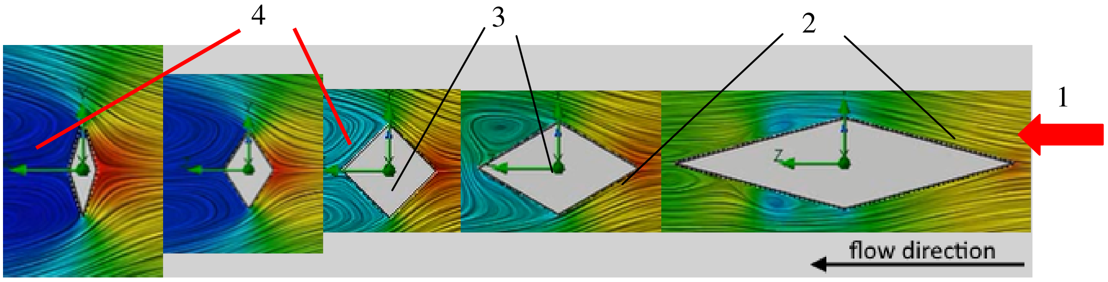

Fig. 7. **Stream lines and pressure distribution for diamond (rhombus) body [8]:** 1 – air flow direction (vertical) ; 2 – pressing zone; 3 – rhombus; 4 – suction zone (see here Fig. 1, 6, separation point 4)

3. Experimental investigations

The purpose of the pilot studies was to start the development of an experimental device to test the theoretical calculations of granule interactions with vibrating bodies. The development took into account the already known basic studies found in the works [16-18].

For this purpose, a conical funnel with an open outlet was created. 3D printing technology was used to make the experiments with different cone funnels. The funnel drawing and photograph are shown in Fig. 8, 9. A universal electromagnetic vibrator was used to shake the conical funnel. The walls of the funnel have a matte finish of unknown roughness value, but no interlocking with the surface of the funnel and the particles is observed or expected. This allows to change the rules of the oscillation movement in a variety of forms. Basic experiments were performed under mono harmonic excitation. The motion parameters were measured with an accelerometer. For the sake of accuracy within this experiment, the acceleration values Γ are kept below 3.5, as it becomes difficult to measure the finalization of the emptying of the cone with larger acceleration values due to a number of some agitated particles still bouncing off the walls of the cone while the bulk mass has already exited. The experiments have been carried out using the following sine frequencies: 5 Hz, 10 Hz, 15 Hz, 20 Hz, 30 Hz, 35 Hz.

The physical properties of the particles are as follows: material – glass microbeads; size of particles – 1.1 mm to 1.3 mm; density – 2500 kg·m^{-3}; starting mass of particles – 35 g (approximately 20 ml).

The results of one global experiment, in which the granules are not trapped in the effluent, are shown in Fig. 10. There

$$\Gamma = \frac{a \cdot \omega^2}{g},$$

where a – the vibration amplitude;
ω – the vibration angular frequency;
g – the free fall acceleration.

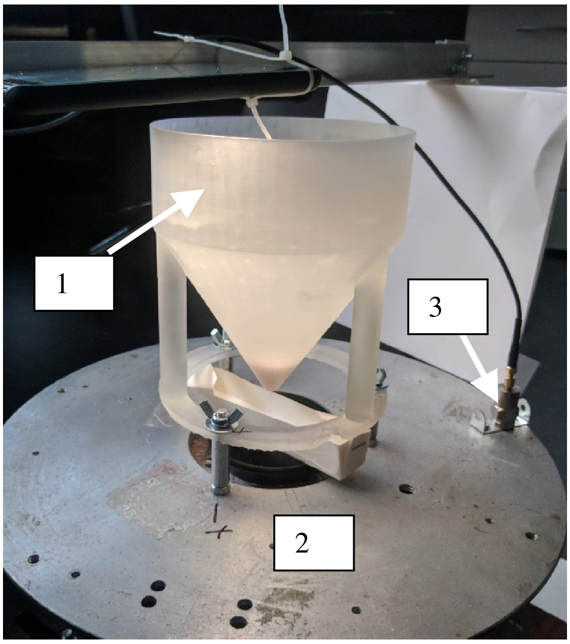

Fig. 8. **Experimental device:** 1 – conical funnel; 2 – table with universal electromagnetic vibrator; 3 – accelerometer

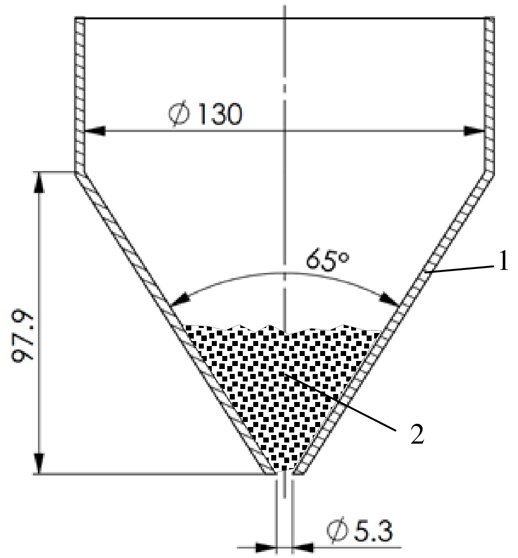

Fig. 9. **Conical funnel:** 1 – conical funnel; 2 – granule material

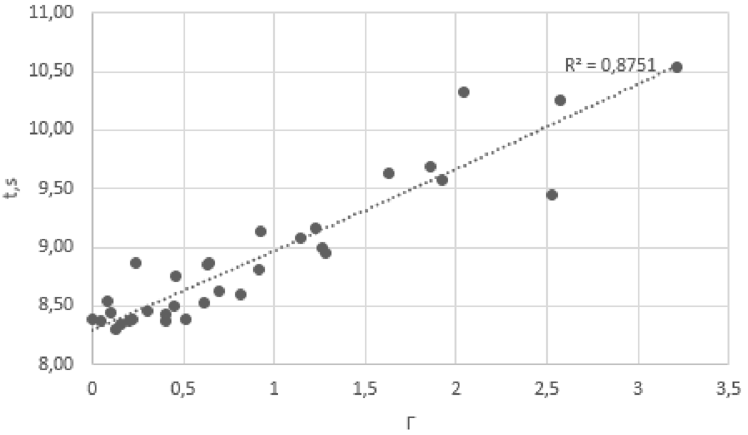

Fig. 10. **Yield of mono harmonic experiment:** Γ – parameter of mono harmonic relative acceleration; t – initial volume release time in seconds (productivity).

The following conclusions can be drawn from the experiment.

1. With 3D printing technology, experimental models for experimental study of pellet motion can be produced quickly and easily.
2. Electro-magnetic vibration tables are desirably used in experimental research.
3. The application of vibrations to a given internal discharge surface increases the discharge time.

Results and discussion

Despite the complicated interactions of the components of the environmental fractions, the developed analytical method allows analytical prediction and calculation of the separation motions. The analytical method is based on the principle of superposition for individual air flow and each granule fraction, regardless of their small geometric configuration. The primary impact interactions with the vibrating prism can be used in the future with the addition of airflow or the next impact barrier. The paper provides comments and illustrations that the air stream together with the bulk material forms a suction area on the backside of the prism to be used for separation. Efficient modeling of discrete element computer modeling and experimental research can be used as proof of theory. It has been proposed by other authors that the speed of flow correlates positively when increasing vibration intensity, measured in unit less peak acceleration.

Conclusions

1. The elemental analytical separation method proposed in the first part of the article is used in similar calculations, where it is decided to use the external and internal prism collision surfaces that vibrate.
2. The method is obtained by using fundamental mechanics of the relation of the amount of movement of the layer in the differential form.
3. As a result, analytical formulas have been obtained that allow for the analysis, optimization and synthesis of various labyrinths of bulk motion.
4. Computer-aided modelling of discrete particles, such as Working Model 2D, can be used effectively in different particle separation.
5. The question of how to obtain surface vibrations was not discussed here, as it goes beyond the scope of this article.

Acknowledgements

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