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Experimental testing of load kinematics in mixers with deformable chambers and vertical working tools

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Abstract. Application of mixers with deformable chambers and vertical working tools has been justified as well as possibility to regulate particles translation inside the mixer chamber, which allows using maximal number of freedom action degrees on the material that provides necessary particle translation and necessary quality of the mixture. A kinematic model of a load point translation in the view of principles of continuous medium mechanics has been created. It has been determined that particles translate in cross- and longitudal sections along helix trajectories. The experimental studies of components particles translation in longitudal and cross sections with the use of models with transparent walls proved the choice of the theoretical model for the material point kinematics for determining forces and power.

1. Introduction

One of the possible ways for improving mixing equipment for granular material is [1,2] mixture installations with ability to regulate particles translation inside the mixer's chamber, which fulfils maximal number of action freedoms of the material that provides necessary particles translation and achieving necessary quality of mixture. That is why possibility to control the process of mixing, structure simplicity, fast and quick re-arrangement of the mixer for different grained materials is topical today. One of the perspectives is application of mixers with deformable chambers [3].

If we analyze powder mixture kinematics [4] we can analyze forces, acting on the mixture in the chamber, and calculate power consumed for mixing.

2. Theoretical studies of load kinematics

The main peculiarity of grained material movement in the continuous mode is dependence of particles speed on their coordinates in the cross section of the chamber in layered movement. That is why using principles of the mechanics of solids [4] we can explain mechanical processes inside the deformable chamber in the form of a hemi-sphere which is deformed with the eccentricity d_e relative to axis OX (Figure 1) taking the following assumptions:

1. The studied medium (component mixture) is uniform through the whole volume.
2. Drive rotation speed, and consequently a vertical working tool, which consists of a pivot with blades, is constant that meets the required mixer modes of operation and medium movement.
3. The system of reference is the axis of the deformable chamber and particle movement relative to this system of reference is taken as absolute.

Let's study kinematics of the point M [4] at its even translation along the axis OX in the working chamber in the form of a semi-barrel (Figure 1a) which is deformed by rotation with the eccentricity

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due to the action of the mixing blade onto it. Movement analysis of every blade shows that due to drive rotation any point, contacting the blade or acted by it will fulfill the movement in longitudal section along the sphere with the radius r (Figure 1a) [4], changing in the range $0 \le r \le d_e$ (relative translation).

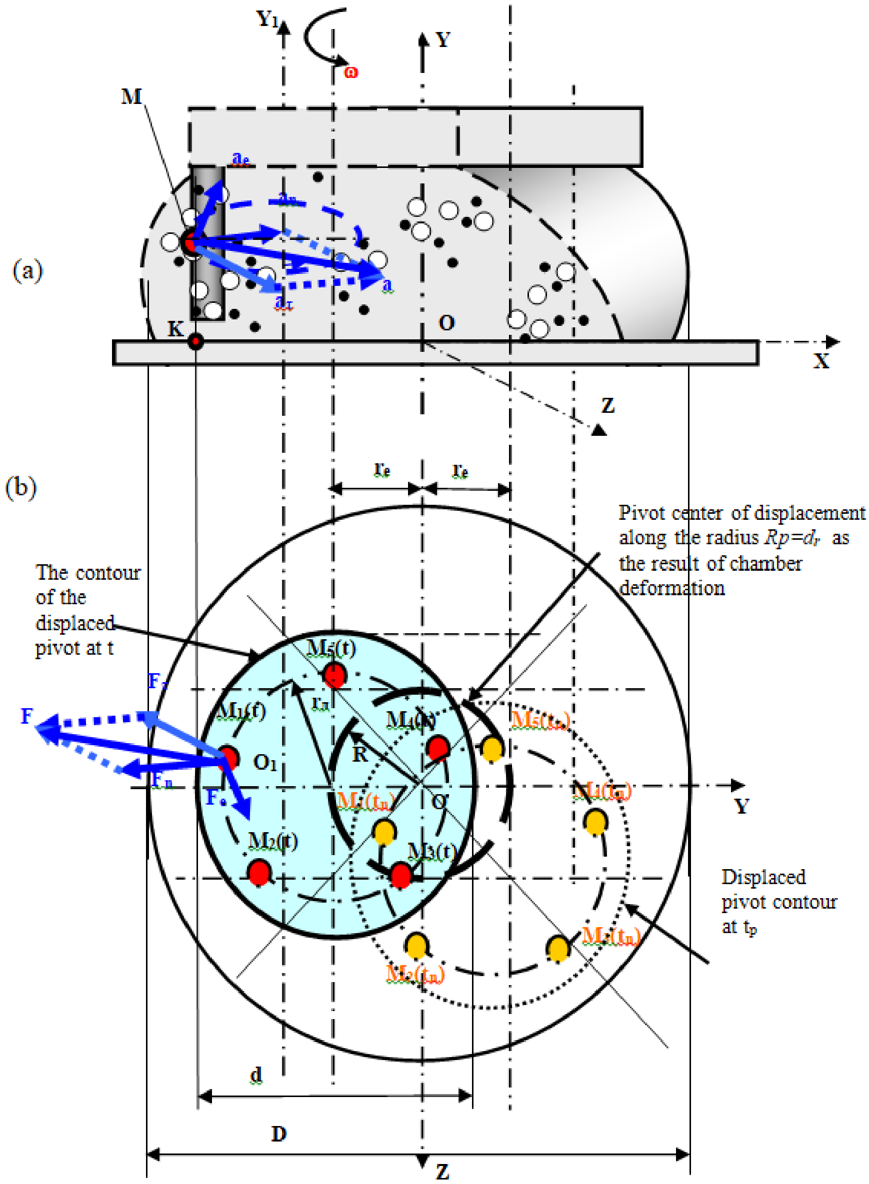

Figure 1. Calculating scheme for determining forces acting onto the point *M*.

Due to irregularity of the working chamber along the section as a result of its deformation point *M* fulfills some movement (translational) along the case. To describe the movement of load particles let's introduce polar coordinates $r(0 \le r \le d_e)$, $\varphi(0 \le \varphi \le 2\pi)$ in the plane Y_1OZ, where polar angle φ is determined from the positive direction of axis Y_1 (Figure 1a). Its change in time is determined by the linear function of time $\varphi = \omega_0 t$, here ω_0 is an angular speed of rotation of the point.

Suppose, that in this type of the point displacement the equations of its movement in general will be determined:

$$z = r\cos\varphi; \qquad y = r\sin\varphi; \qquad x = \frac{a_e t^2}{2} \tag{1}$$

where y, z are Cartesian coordinates of the point at t;

ω_0 is own frequency of particle rotation;

$\varphi = \omega_0 t = \frac{\varepsilon_u t^2}{2}$, is a polar angle here, ε_u is angular acceleration;

$\vartheta_e = a_e t$ is particle speed during translational movement from the state of rest;

a_e is acceleration during translational movement along axis OY_1.

Movement trajectory in plane Y_1OZ can be determined,* excluding time from the two first equations of the point movement (1), we will receive:

$$z^2 + y^2 = r^2, \tag{2}$$

It is circle equation in plane *YOZ*, where projection *K* of the point *M* onto this plane moves. Hence, point *M* moves on the surface of the round cylinder with the resulting, parallel axis *Z* (along the circle). Pivot center O_1 is displaced from the center axis of the chamber *O* for the eccentricity size. During operation the blades rotate each along its trajectory with radius d_e. *As Z* coordinate of point *M* is proportional to the angle of φ radius rotation drawn to the point K, then the trajectory of the point *M* is a helix [4].

The point speed can be determined by its projection onto the coordinate axis

$$\begin{aligned} \vartheta_z &= \dot z = -r\dot\varphi\sin\varphi = -r\varepsilon_u t\sin\varphi; \\ \vartheta_y &= \dot y = r\dot\varphi\cos\varphi = r\varepsilon_u t\cos\varphi; \\ \vartheta_x &= \dot x = a_e t \end{aligned} ; \tag{3}$$

$$\vartheta = \sqrt{\vartheta_x^2 + \vartheta_y^2 + \vartheta_z^2} = \sqrt{r^2\dot\varphi^2 + a_e^2 t^2} = t\sqrt{r^2\varepsilon_u^2 + a_e^2}\,. \tag{4}$$

Total acceleration can be determined, knowing the projections of accelerations onto the axes of Cartesian coordinate system, which are first time derivatives on the relation (4).

$$\begin{aligned} a_z &= d\vartheta_z/dt = -r(\dot\varphi^2\cos\varphi + \ddot\varphi\sin\varphi) = -r\varepsilon_u(\varepsilon_u t^2\cos\varphi + \sin\varphi); \\ a_y &= d\vartheta_y/dt = r(-\dot\varphi^2\sin\varphi + \ddot\varphi\cos\varphi) = r\varepsilon(-\varepsilon_u t^2\sin\varphi + \cos\varphi); \\ a_x &= d\vartheta_x/dt = a_e; \end{aligned} \tag{5}$$

$$apol = \sqrt{a_x^2 + a_y^2 + a_z^2} = \sqrt{r^2\varepsilon_u{}^2(1+\varepsilon_u{}^2 t^4) + a_e^2}\,. \tag{6}$$

Tangential acceleration is determined by formula

$$a_\tau = |d\vartheta/dt| = \sqrt{r^2\varepsilon_u{}^2 + a_e^2} = const. \tag{7}$$

Point normal acceleration is determined by the circular and tangential accelerations

$$\begin{aligned} a_n &= \sqrt{a^2 - a_\tau^2} = \sqrt{r^2\varepsilon_u{}^2(1+\varepsilon_u{}^2 t^4) + a_e^2 - (r^2\varepsilon_u{}^2 + a_e^2)} = \\ &= \sqrt{r^2\varepsilon_u{}^4 t^4} = r\varepsilon_u{}^2 t^2 \end{aligned}. \tag{8}$$

The received acceleration coincides with normal acceleration of projection *K* along the circle which is calculated

$$a_{nN} = \frac{\vartheta_N^2}{r} = \frac{\vartheta_z^2 + \vartheta_y^2}{r} = \frac{r^2\dot\varphi^2\sin^2\varphi + r^2\dot\varphi^2\cos^2\varphi}{r} = r\varepsilon_u{}^2 t^2. \tag{9}$$

Radius of curvature is determined from formula $a_n = \vartheta^2/\rho$

$$\rho_\kappa = \frac{\vartheta^2}{a_n} = \frac{t^2(r^2\varepsilon_u{}^2 + a_e^2)}{r\varepsilon_u{}^2 t^2} = \frac{r^2\varepsilon_u{}^2 + a_e^2}{r\varepsilon_u{}^2} = r + \left(\frac{a_e}{\varepsilon_u}\right)^2 \Big/ r \; ; \qquad \rho_\kappa > r\,. \tag{10}$$

Value ρ_κ does not depend on time, as helix curvature in all points is the same. The main normal along which vector $\vec{a}_n$ is directed in every point *M* of the helix is parallel to radius *OK* (Figure 1).

Basing on this scheme of load particle translation we can calculate the forces of reaction to the feed movement.

3. Experimental grounding of load kinematics in mixers

Experimental tests were conducted with the laboratory installation (Figure 2), which consists of the chamber 1 with the volume 3 liters, fixed to the footing 2 with the ring 3. Chamber 1 is fixed by screws to the hollow journal 4, with the driver 5 and bearing joint 6. Feeding is done through the hole 7 in the hollow journal, unloading is done with a sliding shutter 8.

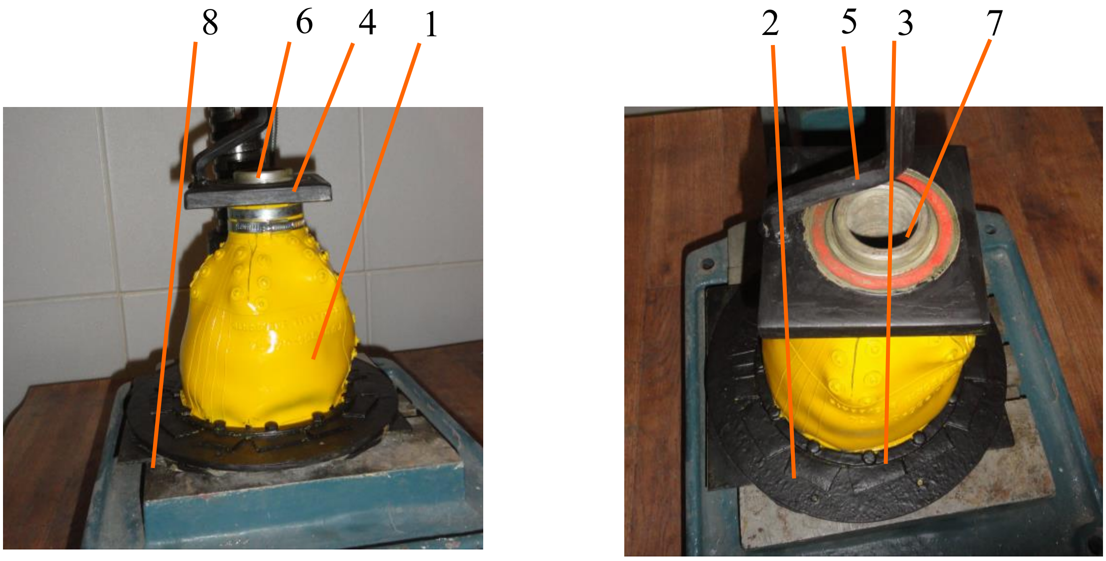

Figure 2. Sample of the mixer with a deformable chamber.

Blades 9 are fixed to the hollow journal 4, in the footing 2 there are holes 10 for unloading, whose width is 6 mm. Their size is determined by that when it is necessary the chamber is filled with grinding bodies 6.5 mm in size and more and the installation can function as a grinder for fine grinding.

When the quality of components mixing has been studied in cross- and longitudal sections of the deformable chamber a transparent chamber was used and translation of the mixture with blades was imitated. The blades were fixed to the hollow journal in the material 10 mm thick (light is sand, dark is earth) (Figure 3), particles translation was fixed gradually.

(a) (b)

Figure 3. Studying the quality of the components mixing in cros- (a) and longitudal (b) sections.

Mixture movement was fixed in 2, 5 and 20 rotations of a hollow journal in the chamber with transparent walls in the crossections (Figure 4) in longitudal and cross-sectional sections in 2, 5, 20, 50 rotations of the hollow journal (Figure 5). The photos prove correctness of the applied calculation

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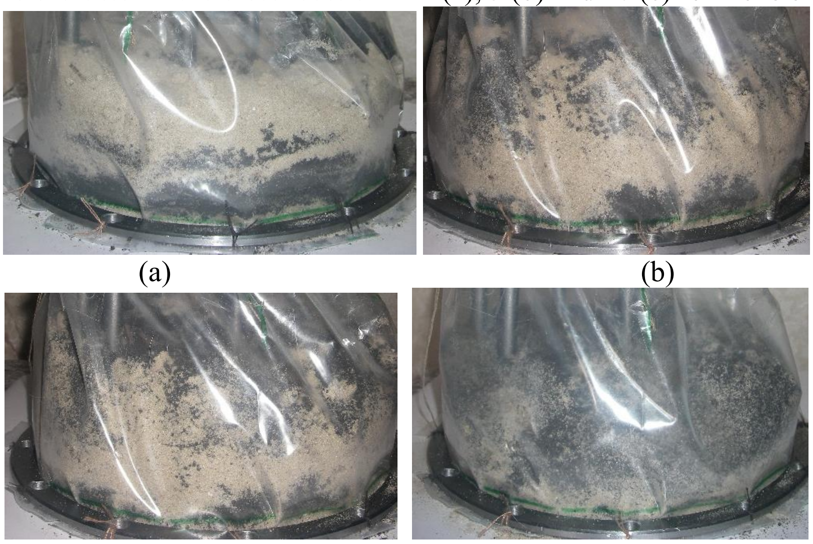
scheme for the material point translation M (Figure 1) and further, for determining resistant forces acting on it during materials mixing and power consumed for overcoming these forces. According to picture 1 b in cross section the material point M_1 rotates together with the blade along the radius r_l and together with the journal whose center translates relative to the chamber axis with the radius equal $Rhj = d_d$, as a result every blade and materials particles involved must rotate along the circle, which is proved by photo of the picture 4 a [5].

(a) (b) (c)

Figure 4. Mixture character in the cross- section in 2 (a), 5 (b) and 20 (c) rotations of the journal.



(a) (b)

(c) (d)

Figure 5. Mixing character in longitudal section in 2 (a), 5 (b), 20 (c) and 50 (d) rotations of the hollow journal.

In further mixing bordening particles are involved. So, after a certain number of journal rotation nearly all the particles, boardening the blades of the cross-sectional layer are mixed, picture 4 shows unmixed areas, that can be elliminated by aditional blades, located closer to the journal center. According to figure 1, a material point M must be translated in the cross section due to deformation of the chamber, that can be seen on the photos of picture 5. Herewith, it is not necessary to place additional blades in the chamber of the laboratory chamber, as unmixed areas are eliminated by particles translation in longitudal section by chamber deformation.

4. Conclusion

Kinematics analysis proved that a material point moves in cross-section circular, and due to chamber curvature and hollow journal rotation with eccentricity, in general along a complex helix trajectory.

The conducted tests of mixture particles translation longitudal and crosssectional sections with application of natural models with transparent walls proved correctness of the chosen theoretical model of a material particle kinematics for determining forces and power for mixing. It has been determined that particles move along helix trajectories in cross-sectional and longitudal sections.

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