Tomasz SZYMAŃSKI[*], Piotr WODZIŃSKI[*]

CHARACTERISTICS OF SCREENING IN SCREENS WITH VIBRATING SIEVES[**]

A method of description of a classification process performed in membrane screens with vibrating sieves is presented in the paper. It is characteristic of these screens that the sieve, stretched on an immobile riddle, is induced pointwise to vibrate. Consequently, the amplitude distribution takes place on the vibrating surface. A result is a separation process that is different than in other screens. Results of studies on the height of material layer on a vibrating sieve surface are discussed in the paper. This is a next project in the research series dedicated to material classification on screens with vibrating sieves performed in the Technical University of Łódź.

Key words: vibrating sieve, screening, model of screening, mass balance

INTRODUCTION

Screens with vibrating sieves are designed primarily for screening of fine- and very fine-grained materials. They have relatively high dynamic factors. That is why these machines are characterised by good segregation of the layer on the sieve and high efficiency of screening, especially the so-called undersize efficiency, i.e. the ratio of the amount of screened off grains to the quantity of undersize grains in the feed (Banaszewski, 1900).

$$\eta = \frac{\text{undersize fraction which passed through the sieve}}{\text{undersize fraction in the feed}}$$

Screens with vibrating sieves have high frequency of vibrations and small amplitudes. In the screen tested by the authors, the frequency was 50 Hz and

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[*] Technical University of Łódź, Faculty of Process and Environmental Engineering
Department of Process Equipment, Granular Material Classification Group

maximum amplitude 2 mm. The angle of sieve inclination to the level could be changed in the range from 20 to 35°, i.e. a twice as big inclination was obtained as that in the classical screens. Such high angles and accelerations cause that material velocity on the sieve is significant, 0.5-1.0 m/s (Wodziński, 1997).

The process of screening on screens with vibrating sieves is carried out in the so-called thin layers. In this process, the authors tried to exchange the exponential discharge function by a function in the form of a straight line. However, a number of studies carried out at the Technical University of Łódź indicate that it would be a too far reaching simplification. On the other hand, these studies proved that application of the classical discharge function was not possible either. The present paper refers to these observations.

DESIGN FEATURES OF THE MEMBRANE SCREENS

Experiments were performed on a membrane screen equipped with a vibrating sieve with a driving frame (Fig. 1). The screen was designed and constructed at the Technical University of Łódź. The system with a driving frame is a universal solution where with no significant changes in the construction, various drives can be applied to provoke frame vibrations. Vibrations are transmitted from frame (R_n) by means of pushing rods (P) onto sieve (S). In this construction, the mass incited to vibrations is much smaller than in the classical screens, where the sieve vibrates along with the riddle. In the described construction, riddle (R_z) remains immobile.

The process was driven by one electromagnetic vibrator, two electromagnetic vibrators placed on two edges of the driving frame, and two engines with unbalanced shafts. Results presented in the paper refer to the latter solution.
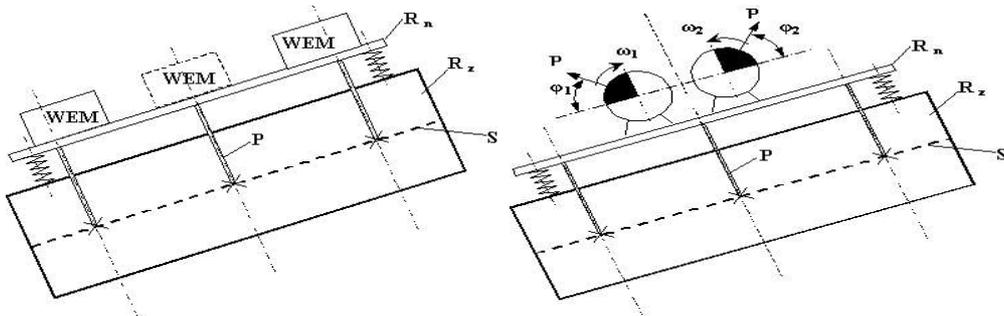

Fig. 1. Frame screen with a vibrating sieve

The rotary vibrators, or in other words, the engines with unbalanced shafts, work in counter-current self-synchronisation mode. This driving system guarantees a linear trajectory of vibrations, the trajectory being perpendicular to the sieve surface, i.e. also to the driving frame (Szymański, Wodziński, 2001).

THE PROCESS OF SCREENING ON SCREENS
WITH VIBRATING SIEVES

A characteristic method for transferring vibrations, and consequently, uneven distribution of amplitudes on the vibrating sieve surface, causes that screening proceeds according to different rules than in the classical screens. Screening in thin layers is caused by the fact that material (layer) on the vibrating sieves moves at high velocity, which means (at the same flow rate of the feed to the screen) that the layer thickness decreases. In these conditions, no resistance of screening segregation is observed. At the same time, specific movement of grains on the sieve (Fig. 2) causes that it is impossible to apply mathematical tools used specifically to a single grain. Owing to this, very favourable classification conditions can be obtained, which enable very high efficiencies reaching 100% (Szymański, Wodziński, 2002).

It is obvious that sieves in the discussed screens move only in the space perpendicular to the sieve surface. However, the amplitude of vibrations is not the same in every point. Due to mounting the sieve in an immobile riddle, not the whole sieve surface takes part in translational motion. To consider this phenomenon in the model calculations, it is necessary to introduce some calculation factor (Szymański, Wodziński, 2001).
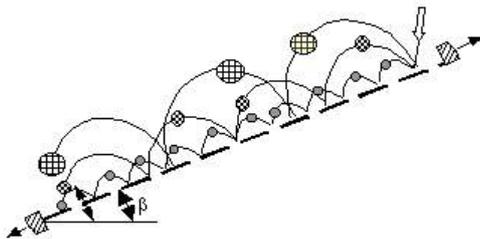

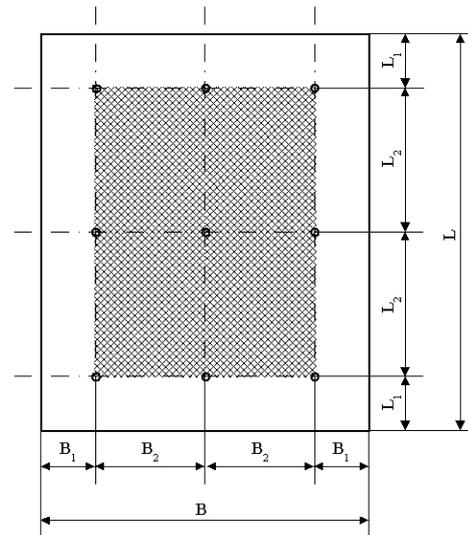Fig. 2. Movement of grains on vibrating sieves in a thin layer

Fig. 3. The surface taking part in screening

This role can be played by surface modulus m_p. It provides information which part of the sieve performs the translational, linear vibrations. This value is the ratio of the surface subjected to forcing to the total sieve surface.

$$m_p = \frac{F_d}{F_s}$$

where F_d – vibrating surface
          F_s – total surface

$$m_p = m_l \cdot m_b$$

where m_l – longitudinal modulus
m_b – transverse modulus

Taking notation in Fig. 3, the formulae describing the above values have the form:

$$m_l = \frac{(n_l - 1)l_2}{L}$$
$$m_b = \frac{(n_b - 1)b_2}{B}$$

where n_l – number of pushing rods in longitudinal direction
n_b – number of pushing rods in crosswise direction

In conclusion, the surface modulus of the screen with vibrating sieves has the form:

$$m_p = \frac{(n_b - 1)b_2 \cdot (n_l - 1)l_2}{B \cdot L}$$

The above values b_2 and l_2 depend on process parameters, particularly on the mesh size and layer thickness on the sieve.

Observations made during the investigations confirm that not the whole sieve surface takes part in the screening process. Transport and screening of material on the sieve occurs in the region marked by a broken line in Fig. 3.

ASSUMPTION FOR THE MODEL OF SCREENING ON A MEMBRANE SIEVE

To investigate the rate of changes in the whole material layer thickness on the sieve and the shape of the upper edge of the layer, one should consider the mass balance of elementary sieve surfaces (sieve sections). To do this, the undersize fraction container was divided in a way shown in Fig. 4.

In the Figure above, also the feeding site on the sieve is marked. The first section (the one to which material is fed) is wider that the others. It was assumed that along this segment, the layer on the sieve was formed.
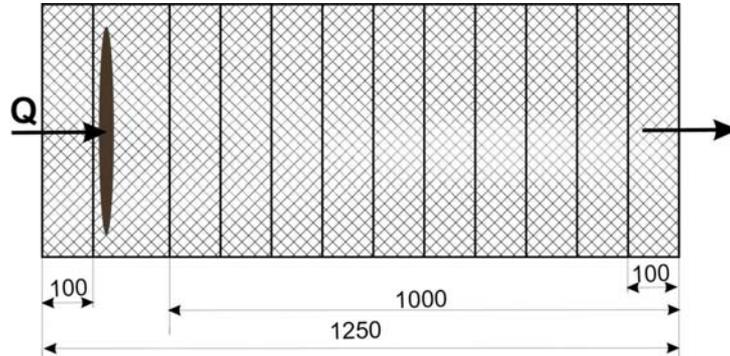
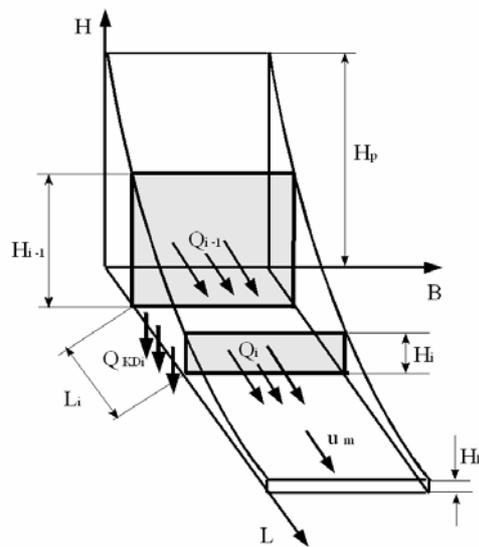Fig. 4. Division of the sieve into sections

Fig. 5. Mass balance of particular screen sections

The previously mentioned mass balance is shown in Fig. 5. According to symbols presented in this figure, we obtain the layer height at the end of the i-th section:

$$Q_i = H_i \cdot B \cdot \rho_n \cdot u_m \Rightarrow H_i = \frac{Q_i}{\rho_n \cdot B \cdot u_m}$$

where:

Q_i [kg/s] – rate of outflow from the i-th section,

$$Q_i = Q_{i-1} - Q_{KDi}$$

Q_{i-1} [kg/s] – rate of inflow to the i-th section,

$$Q_{KDi} = \frac{m_{Di}}{t_{p1}}$$

Q_{KDi} [kg/s] – rate of undersize fraction outflow from the i-th section,
m_{Di} [kg] – mass of undersize fraction screened off in time t_{p1} from the i-th section,
t_{p1} [s] – process time,
H_i [m] – layer height on the sieve at the end of the i-th section,
B [m] – sieve width,
ρ_n [kg/m³] – bulk density of the layer,
u_m [m/s] – mean velocity of the layer calculated from the relation:

$$u_m = \frac{L}{t}$$

L [m] – sieve length,
t [s] – time in which material passes the sieve length.

   Mass balance for whole screen is given by the formula:

$$Q_0 = \Sigma Q_{KDi} + Q_K$$

where:
Q_K [kg/s] – the rate of outflow from the last section, equal to the stream of oversize
          product,
Q_0 [kg/s] – feed flow rate.
   On the basis of feed stream size Q_0, the initial height of layer H_p can be determined:

$$Q_0 = H_p \cdot B \cdot \rho_n \cdot u_m \Rightarrow H_p = \frac{Q_0}{\rho_n \cdot B \cdot u_m}$$

   Further on, the subsequent layer heights (over consecutive sections, from i = 1 to k) are determined by the relations:

$$Q_1 = H_1 \cdot B \cdot \rho_n \cdot u_m \Rightarrow H_1 = \frac{Q_1}{\rho_n \cdot B \cdot u_m}$$

where: $Q_1 = Q_0 - Q_{KD1}$, $Q_{KD1} = \frac{m_{D1}}{t_{p1}}$, and next:

$$Q_2 = H_2 \cdot B \cdot \rho_n \cdot u_m \Rightarrow H_2 = \frac{Q_2}{\rho_n \cdot B \cdot u_m}$$

$$Q_2 = Q_1 - Q_{KD2}, \qquad Q_{KD2} = \frac{m_{D2}}{t_{p1}}$$

the layer height at the end of the last section:

$$Q_K = H_K \cdot B \cdot \rho_n \cdot u_m \Rightarrow H_K = \frac{Q_K}{\rho_n \cdot B \cdot u_m}$$

$$Q_K = Q_{K-1} - Q_{KDK}, \qquad Q_{KDK} = \frac{m_{DK}}{t_{p1}}$$

where:
Q_{KDK} [kg/s] – rate of undersize fraction outflow from the k-th (last) section,
m_{DK} [kg] – mass of undersize fraction screened off in time t_{p1} from the k-th section [kg].

The final layer height on the sieve H_K is closely related to screening process efficiency. On this basis we can determine if the process was long enough (the sieve length was appropriate), to reach the desired effect of screening, i.e. the assumed total stream of undersize fraction.

STUDIES OF LAYER HEIGHT ON THE SIEVE IN THE MEMBRANE SCREEN

Experiments were made in a frame screen driven by two engines with unbalanced shafts (Fig. 6). Supporting structure 1 is the machine frame. In the frame, at different angles there is riddle 2, which remains immobile during the screen operation. Sieve 3 is stretched on the riddle. The riddle is equipped with flat springs 4 on which driving frame 5 is placed. To the frame inertial vibrators 6 are connected. It is also possible to apply a vibrator or electromagnetic vibrators. The driving frame is connected to the sieve by means of rigid pushing rods 7. Feed to the screen is supplied from container 8 with gate valve 9 controlling the discharge orifice. The oversize fraction is collected in container 10, while the undersize fraction in container 11. This container is divided into sections as shown in Fig. 4.
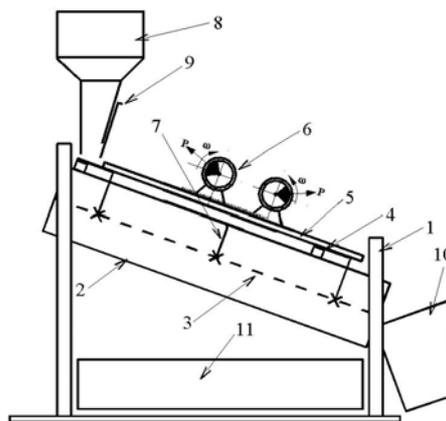

Fig. 6. Experimental set-up

RESULTS AND DISCUSSION

Changes of material layer height on the sieve were calculated according to the scheme presented in Section 4. The sieve width was taken as a distance between the pushing rods, as assumed in Section 3. Observations of the material moving along the sieve confirmed the statement concerning the membrane sieve geometry. The material was transported along the sieve in the region limited by the pushing rods.

Diagrams illustrate the real height of material layer along the sieve and the height calculated on the basis of a discharge function. The method of calculation of the discharge function will not be discussed here because this relation was frequently presented in literature (Sztaba, 1993, Wodziński, 1997) and according to the authors of this paper, it need not to be recalled.

The material was in the form of properly prepared mixtures of sand, agglomerate and agalite with a different content of the undersize fraction in the feed and various contents of grains difficult to screen. These are the grains which can block the mesh, and as follows from earlier studies, for a sieve with mesh size 0.63 mm these are the grains of size ranging from 0.5 mm to 0.8 mm. The material was dry and contained no transient moisture. Grains exceeding 2 mm were screened off from the material, because at the mesh size 0.63 mm they have practically no effect on separation.

In this paper results of studies are presented in the form of diagrams for three materials mentioned above in the following process conditions:
− angle of sieve inclination to the level $\propto$ = 20° (Figs. 7 to 9) and $\propto$ = 25° (Figs. 10 to 12),
− feed flow rate Q = 1 kg/s,
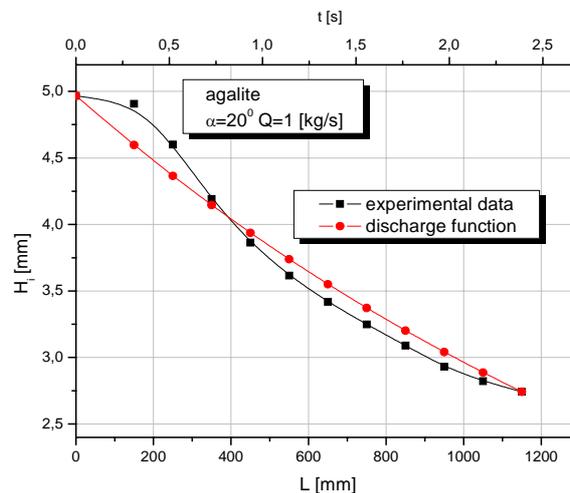− mixture composition: 50% undersize fraction, 50% grains difficult to screen.

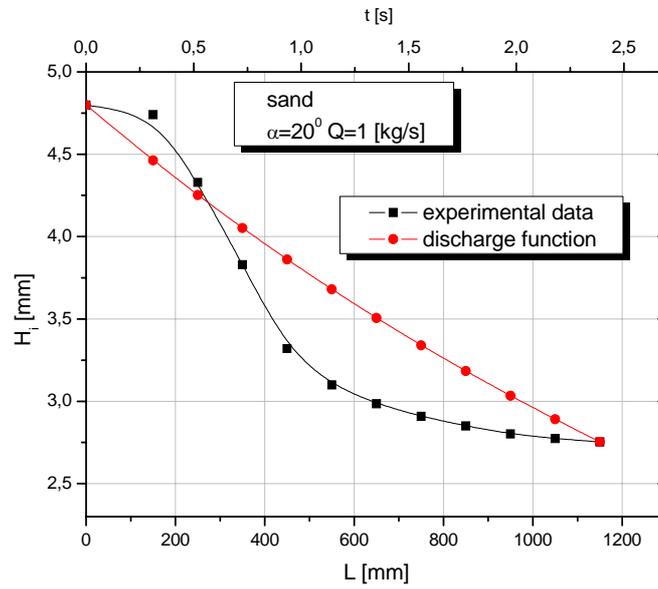Fig. 7. Distribution of agalite layer height at the angle $\propto$ = 20°, Q = 1 [kg/s]

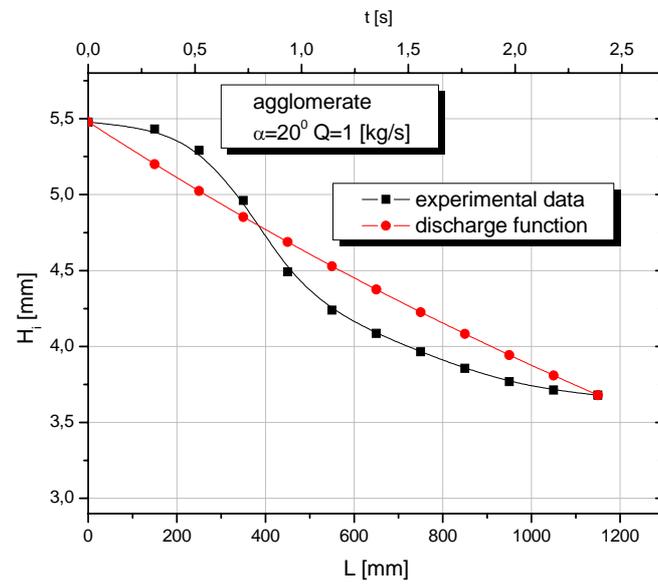Fig. 8. Distribution of sand layer height at the angle $\propto = 20°$
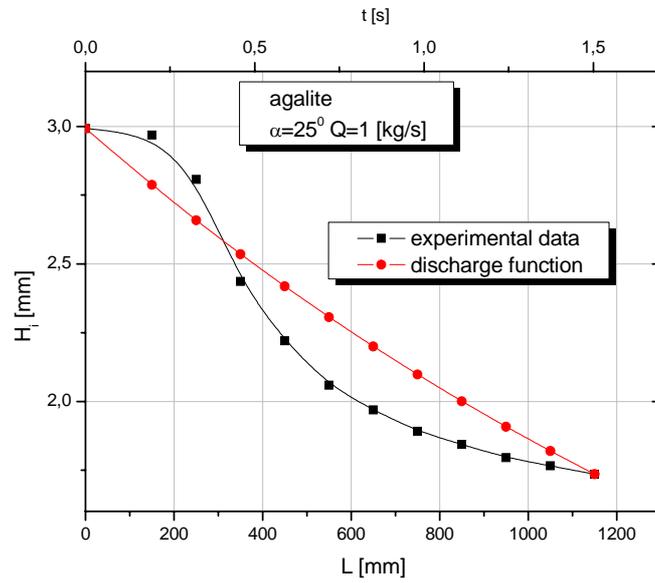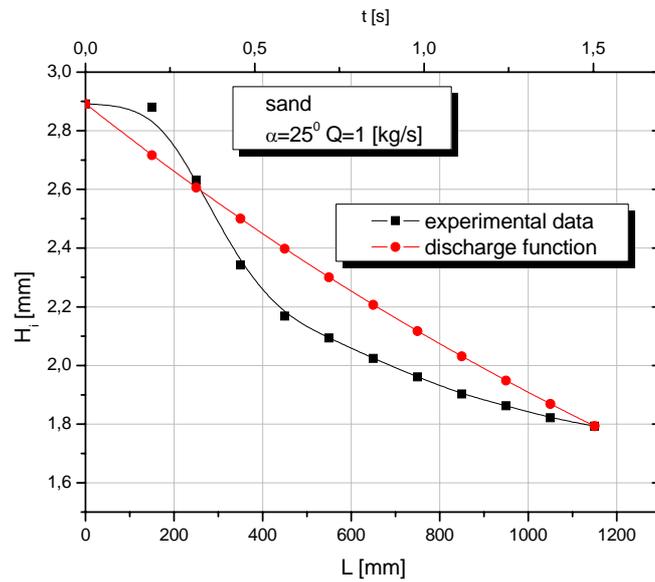

Fig. 9. Distribution of agglomerate layer height at the angle $\propto = 20°$

Fig. 10. Distribution of agalite layer height at the angle ∝ = 25°

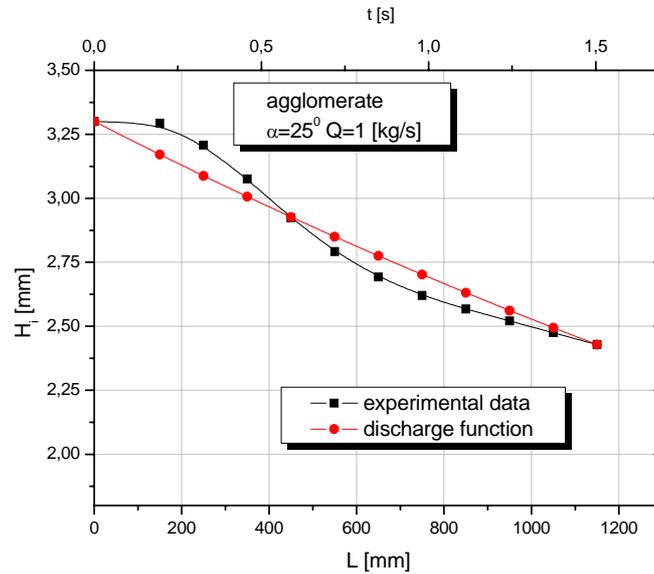Fig. 11. Distribution of sand layer height at the angle ∝ = 25°

Fig. 12. Distribution of agglomerate layer height at the angle $\propto = 25°$

CONCLUDING REMARKS

The aim of research presented above was to determine experimentally the operating parameters of a frame screen equipped with a vibrating sieve in the process of industrial screening of loose materials with model particle shapes. In the study only results for one mixture and one feed flow rate are presented. The subject of research were two parameters, the mass of screened material and the height of material on the sieve calculated on this basis. The knowledge of these values is a basis for calculations related to designing of sieve surface size necessary for a given screening process.

Analysis of the results leads to the following detailed conclusions:
1. Material supplied on a vibrating sieve should pass a certain distance to form a layer characteristic of screening in such machines. This can be clearly seen in the form of an initial segment of the material layer screened off along the sieve length.
2. After adjustment to the conditions characteristic of vibrating sieves, the material layer on the sieve has a classical shape specific for the discharge curve. After passing about 30 cm, the layer can be presented in the form of an exponential curve.
3. As follows from Figs. 7 to 12, approximation of the shape of material layer in thin-layer screening by a straight line would be a too far-reaching simplification.
4. Screens with vibrating sieves are very suitable for screening of materials that contain even very large amounts of grains difficult to screen, that cause sieve

blocking. This is due to the fact that the continuous sieve motion resulting from point-wise forcing of vibrations causes a fall-out of blocked particles, i.e. the phenomenon of sieve self-purification.

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W pracy przedstawiono metodę opisującą proces klasyfikacji realizowany na membranowych przesiewaczach z wibrującymi sitami. Cechą charakterystyczną tych przesiewaczy jest to, że sito rozciągane na nieruchomej ramie, podane jest wibracji. W wyniku tych działań, ustala się określona dystrybucja drgań wibrującej powierzchni. W wyniki tego proces separcji na wibrujacych sitach jest inny niż na innych (typowych) sitach. W pracy przedyskutowane zostały wyniki badań nad zmianą wysokości warstwy materiału umieszczonego na wibrującym sicie. Praca jest następnym projektem badawczym, który jest poświęcony klasyfikacji materiału na sitach, i który realizowany jest przez Politechnikę w Łodzi.