CONSIDERATIONS REGARDING THE GRANULAR MATERIAL MOVEMENT ON THE VIBRATING INCLINED SCREEN'S SURFACE

CONSIDERAŢII ASUPRA MIŞCĂRII A MATERIALULUI GRANULAR PE SUPRAFAŢA SITEI CIURULUI VIBRATOR ÎNCLINAT

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Rezumat. *În vederea optimizării eficienţei procesului de cernere şi a productivităţii ciurului vibrator inerţial înclinat, au fot elaborate studii teoretice şi practice privind comportarea materialului granular pe suprafaţa sitei vibratoare. Lucrarea prezintă o serie de aspecte teoretice, rezultatele teoretice prezentate fiind analizate şi comparate cu cele obţinute pe cale experimentală, pe un ciur vibrator înclinat de 7,5 m^2 din cadrul unei balastiere.*
Cuvinte cheie: *proces de cernere; sort de material; faze de cernere; ciur vibrator inerţial*

Abstract. *In a view of optimizing the efficiency of the screening process and the productivity of the inertial inclined vibrating screen, there were accomplished theoretical and experimental studies regarding the behaviour of the granular material on the sieve's vibrating surface. The paper presents some theoretical aspects, he theoretical results being analysed compared with the experimental results obtained in a gravel pit on a 7,5 m^2 inclined vibrating screen.*
Keywords: *screening process; sort of material; screening stages; inertial vibrating screen*

1. INTRODUCTION

The concrete preparation process with mineral binders supposes the absolute presence of heavy mineral aggregates as a base element. Therefore, the aggregates extracted from the gravel pits and quarries impose certain previous operations, such as: washing, crushing and screening.

From all screening methods (mechanical, hydraulic, pneumatic, filtration), **the mechanical one** (sorting/sieving/screening) has the greatest using weigh in construction material industry, generally applicable to granular materials having dimensions between 0,2...500 mm [2].

Vibrations used in sieve's driving, directly influence the performance of the aggregates sieving process on **vibrating screens**, in comparison with other constructive alternatives that are not using vibration movement in driving the working element.

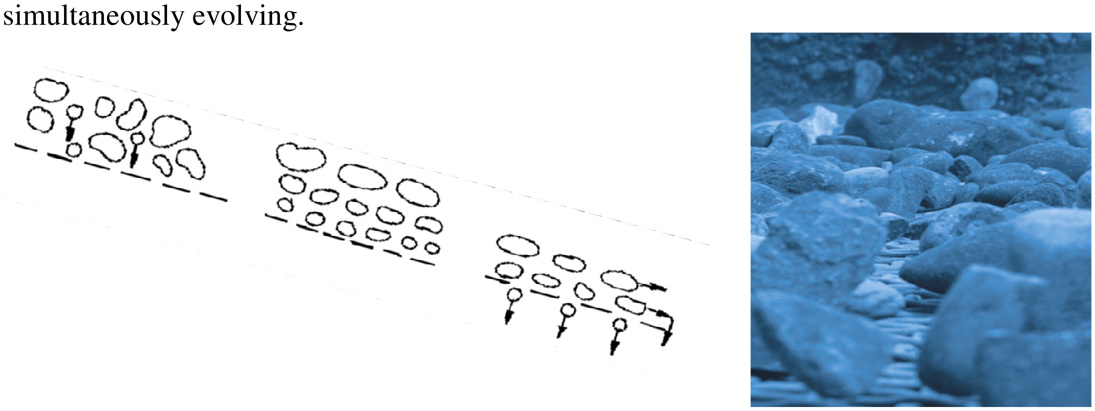
Nowadays, vibrating screens have replaced almost all screens having sieves that are not driven through vibrations.

2. GENERAL DESCRIPTION OF MECHANICAL SIEVING PROCESS TAKING PLACE ON THE VIBRATING SCREENING SURFACE

No matter the vibrating screen constructive alternative, the sieving process consists in some essential stages taking place following the vibrating movement of the working element, simultaneously with the interaction between the grains of material supplied and between these ones and the sieving surface. Sorting aims the mineral aggregates separation in fraction according to the imposed technological process.

The sort of aggregates is conventionally symbolised by a pair of numbers corresponding: first to the sieve's mesh dimension on which the aggregates entirely remain ($d_{s,\min}$) and the second to the sieve's mesh dimension through which aggregates entirely pass ($d_{s,\max}$). For example: 8-16; 16-31,5.

The process of grains' passing through the sieve's mesh imposes to be running along three main stages presented apart in figure 1- in reality (fig. 1 d), these stages are simultaneously evolving.



a *b* *c* *d* [4]

Fig. 1. Main stages of the sieving process
a – stratification; b – separation; c – passing; d – stages "in situ"

Material's stratification (fig. 1 a) represents fine grains' movement through material layer de material until they get contact directly with the screen's sieve.

Fine grain's separation, meaning the proper sieving (fig. 1 b), represents a permanent process of comparison between the grain's dimension (d) and the sieve's mesh dimension (d_s).

Fine grains' passing through sieve's mesh, if their transversal section doesn't exceed the free section of the sieve's mesh and if the grains are falling on the surface having the greater passing through probability (fig. 1 c).

The sieving process completion imposes the material's relative movement towards the sieve's surface.

The granules' passing through sieve's mesh is indirectly influenced by the parameters of the vibrating movement imposed through screen's vibrating generator. For example, in the inertial vibrating screen case (figure 2), the vibration amplitude is variable and depends on some factors , such as: the sieve-carrying movable frame (m_c), the eccentric mass speed (n), the perturbing force (P_c), the vibrations frequency (ωt), the elastic bond stiffness (k), mass of supplied material (m_a).

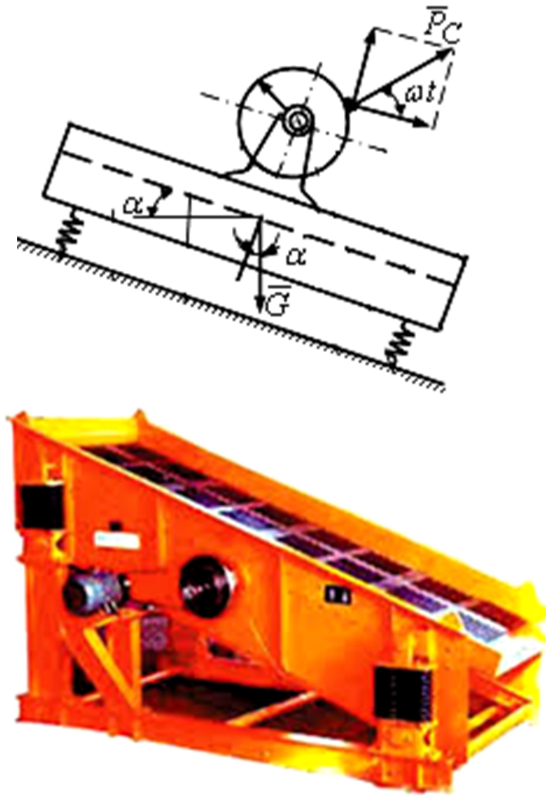


Fig. 2. Ciur vibrator inerţial înclinat [1],[4]

The sieve-carrying movable frame of the screen (fig. 2) is running under free vibrations having variable amplitude, which is dependent also on material falling on the sieve. When supplying great quantities of material, the amplitude is decreasing; in case of lower quantities of material, the amplitude is increasing. On this line, the inertial vibrating screen is able to auto protect itself against super- charges.

Using vibrating sieves is indirectly influencing the material layer thickness in a positive way, meaning a better grain repartition on the entire screening surface.

3. THE GRANULAR MATERIAL MOVEMENT DIAGRAM THROUGH POP-SLIDING

From the theoretical and experimental studies regarding the aggregates grain's movement on the vibrating sieve, three movements are representative:

- the pop movement
- the sliding one movement
- the pop and sliding movement.

This paper focuses the pop and sliding movement usually met in situ.

The study of the grain's jump established the existence condition of this kind of movement and the pop and sliding movement's graphic has been plotted (figure 3).

At a given moment, the position of a *sieve's point* reported to a fixed reference system $\xi O_1 \eta$ is given by the following coordinates [1]:

$$\begin{cases} \xi = a \cdot \sin(\omega t + \varepsilon) \\ \eta = b \cdot \sin \omega t \end{cases} \tag{1}$$

where *a*, *b* are the vibrations' amplitudes along the fixed reference system's axes attached to the sieve; ω – the frequency of vibrating movement; ε – the phase difference; *t* – the time.

The trajectory's equation described by the point considered above:

$$\left(\frac{\xi}{a}\right)^2 + \left(\frac{\eta}{b}\right)^2 - 2\left(\frac{\xi}{a}\right) \cdot \left(\frac{\eta}{b}\right) \cdot \cos \varepsilon = \sin^2 \varepsilon \tag{2}$$

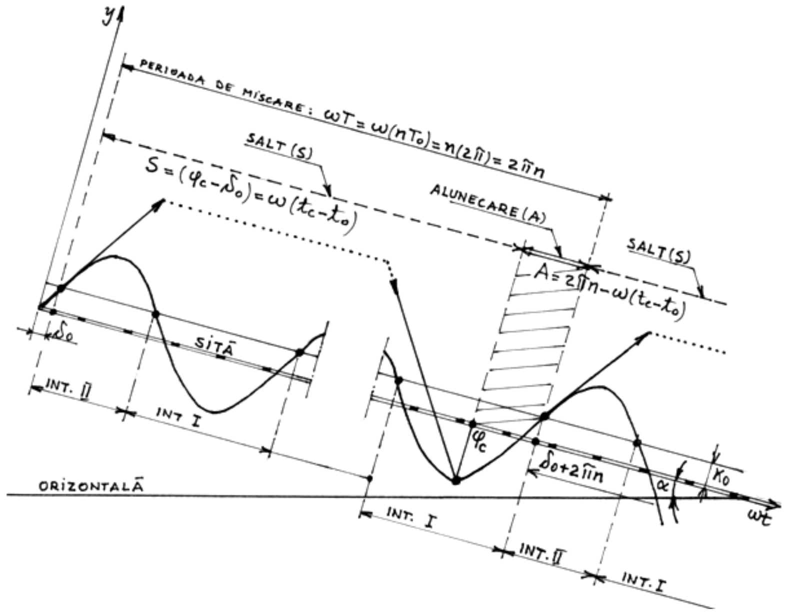


Fig. 3. The pop and sliding movement of the grain on the sieve's vibrating surface
S –pop; *A* – sliding; *INT* – interval; α – the sieves' inclination angle;
t_0 – moment of grain's detachment from the sieve; t_C – moment of grains' fall on the sieve [3]

The differential equations of a *material grain's movement*, on the vibrating screen's sieve, reported to a movable reference system *xOy*, are [1]:

$$\begin{cases} m\ddot{x} = ma\omega^2 \cdot \sin(\omega t + \varepsilon) - mg \cdot \sin \alpha - F \\ m\ddot{y} = mb\omega^2 \cdot \sin \omega t - mg \cdot \cos \alpha + N \end{cases} \tag{3}$$

where *m* is the material grain's mass; *F* – the friction force at sieve's surface; *N* – the normal force on the sieve's surface.

Considering that the grain rests on the sieve the normal force can be determined:

$$N = N(t) = mg \cdot \cos \alpha - mb\omega^2 \cdot \sin \omega t \tag{4}$$

As long as the grain is on the sieve, the normal force can be positive or null:

$$\frac{g}{b\omega^2} \cdot \frac{\cos \alpha}{\sin \omega t} \geq 1 \tag{5}$$

The minimum value of the vibrations accelerations' proportion is:

$$K_0 = \frac{g \cdot \cos\alpha}{b\,\omega^2} = \frac{1}{C} \tag{6}$$

where K_0 is the screen's constructive coefficient; C – the grain's throwing coefficient.

When $K_0 < 1$ the grain's detachment from the sieve takes place.

4. THE GRAIN'S POP-SLIDING USUAL MOVEMENT

Grain's popping. To study the grain's jump on the sieve's surface, we have to consider that at the initial moment t_S the material grain is still on the sieve ($y = 0$).

Closing the coordinate system's origin just in the material grain, which movement is studied, the initial conditions necessary for the jump are:

$$\begin{cases} \xi(\tau_\Sigma) = 0\ ;\ \ \dot{\xi}(\tau_\Sigma) = \dot{\xi}_\Sigma \\ \psi(\tau_\Sigma) = 0\ ;\ \ \dot{\psi}(\tau_\Sigma) = \dot{\psi}_\Sigma \end{cases} \tag{7}$$

In the equation system (3) the friction force F and the normal force N are null:

$$\begin{cases} \ddot{x} = a\,\omega^2 \cdot \sin(\omega t + \varepsilon) - g \cdot \sin\alpha \\ \ddot{y} = b\,\omega^2 \cdot \sin\omega t - g \cdot \cos\alpha \end{cases} \tag{8}$$

The integration of system (8) using the initial conditions (7) leads to:

$$\begin{cases} \dot{x}(t) = -g(t - t_S) \cdot \sin\alpha - a\omega\left[\cos(\omega t + \varepsilon) - \cos(\omega t_S + \varepsilon)\right] + \dot{x}_S \\ x(t) = -\frac{g}{2}(t - t_S)^2 \sin\alpha + \omega a(t - t_S)\cos(\omega t_S + \varepsilon) - a\left[\sin(\omega t + \varepsilon) - \sin(\omega t_S + \varepsilon)\right] + \dot{x}_S(t - t_S) \end{cases} \tag{9}$$

$$\begin{cases} \dot{y}(t) = -g(t - t_S) \cdot \cos\alpha - b\omega(\cos\omega t - \cos\omega t_S) + \dot{y}_S \\ y(t) = -\frac{g}{2}(t - t_S)^2 \cos\alpha + b\omega(t - t_S)\cos\omega t_S - b(\sin\omega t + \sin\omega t_S) + \dot{y}_S(t - t_S) = 0 \end{cases} \tag{10}$$

The systems (9) and (10) describe the grain's movement from the initial moment (t_S) up to grain's fall moment (t_C).

The fall moment t_C is the smallest root of the equation:

$$\begin{aligned} y(t_C) = &-\frac{g}{2}(t_C - t_S)^2 \cos\alpha + b\omega(t_C - t_S)\cos\omega t_S - \\ &- b(\sin\omega t_C + \sin\omega t_S) + \dot{y}_S(t_C - t_S) = 0 \end{aligned} \tag{11}$$

Notations: $\varphi_C = \omega t_C;\ \delta_S = \omega t_S;\ b_S = \dot{y}_S / b\omega$ (12)

Replacing in equation (11), results the following equation:

$$\frac{K_0}{2}(\varphi_C - \delta_S)^2 + \sin\varphi_C - \sin\delta_S - (\varphi_C - \delta_S)(\cos\delta_S + b_S) = 0 \tag{13}$$

The grain's movement on the sieve is stabile if the grain's passing moments through certain characteristic points reiterate after a certain period of time equal to sieve's movement period, or multiple of this one:

$$T = n \cdot T_0 \ , \quad n = 1, 2, 3\ldots \tag{14}$$

where: T_0 is the sieve's movement period; T – the grain's jump period on the sieve.

Grain sliding after its popping. The existence condition of pop and sliding movement is (figure 3):

$$(2n-1)\pi - \delta_0 \le \varphi_C \le 2\pi n + \delta_0 \tag{15}$$

where $\delta_0 = \omega t_0$ is the phase angle when pop movement starts.

In equation (13) we make the replacement $\delta_S = \delta_0$

$$\frac{K_0}{2}(\varphi_C - \delta_0)^2 + \sin\varphi_C - \sin\delta_0 - (\varphi_C - \delta_0)(\cos\delta_0 + b_0) = 0 \tag{16}$$

At the beginning of the jump: $\dot{y}_0 = 0; b_0 = 0$ and $K_0 = \sin\delta_0$. So:

$$\frac{\sin\delta_0}{2}(\varphi_C - \delta_0)^2 + \sin\varphi_C - \sin\delta_0 - (\varphi_C - \delta_0)\cos\delta_0 = 0 \tag{17}$$

So, the limit values of the phase angle $\boldsymbol{\delta_0}$, the screen's coefficient $\boldsymbol{K_0}$ or the grain's throwing coefficient ***C*** can be established, corresponding to $T = T_0$ or $T = nT_0$.

5. CONCLUSIONS

Experiments were done in a gravel pit on a inclined vibrating screen with 7,5 m^2 surface. The vibrations' amplitude and acceleration were measured in four different working situations: no-load running - with and without aggregates washing and load running - with and without aggregates washing.

The conclusion was that, for $\mathbf{1 < C < 3,29}$, the material makes a jump each oscillation of the sieve $S = \omega(t_C - t_0)$ followed by sliding $A = 2\pi - \omega(t_C - t_0)$.

The theoretical values were experimentally confirmed. In time the grain's movement was deviated from the theoretical trajectory, but in limits, ± 5%.

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