DETERMINATION OF THE REAL VALUES OF KINEMATIC INDEX CORRESPONDING TO THE MECHANICAL SEPARATION PROCESS

EMILIAN MOȘNEGUȚU*[1], VALENTIN NEDEFF[1], MIRELA PANAINTE-LEHĂDUȘ[1], NARCIS BÂRSAN[1], DANA CHIȚIMUȘ[1], DRAGOȘ RUSU[1]

[1]Department of Mechanical Engineering and Environmental Engineering, "Vasile Alecsandri" University of Bacau, Calea Marasesti 157, Bacau, 600115, Romania

Abstract: This article presents the methodology for determining the real values of kinematic indices which characterizes the mechanical separation of a mixture of solid particles. Mechanical separation of a mixture of solid-solid on surface provided with holes is the most common method of separation. To optimize equipment that performs this operation, both theoretical and practical characteristics are determined. Kinematic indices are part of the theoretical characteristics, helping to identify behavior of solid particles on a surface flat swing. Starting from an experimental batch, real values of the kinematic indices corresponding to up, down and sideways movement on the sieve were determined for the following types of real particles: grain, large grain beans, small grain beans and soybeans.

Keywords: particle motion, flat oscillating surface, real values of kinematic index, mechanical separation

1. INTRODUCTION

The separation process on a flat oscillating surface is a very common process in different industries, such as food industry, chemical industry, metallurgical industry, pharmaceutical industry etc. [1, 2].

Within this process, the separation of a solid particles mixture can be achieved by taking into account the two dimensions of the particle, its width and thickness. In order to make this process more efficient, the working surfaces, provided with different holes of different shapes, undergo certain simple of complex movements [3].

Since the screening separation process is a complex process, in order to understand it, a series of methods have been applied:

- theoretical method [4-7]:
  - the behavior of a solid particle has been determined through mathematical expressions.
  - through different models of simulations programs analyzing the behavior of a solid particles mixture as well as the movements on the working surface;
- experimental method [8-11]:
  - through different types of experiments to make the mechanical separation effect more efficient;
  - by analyzing different techniques: taking images and video files by using high-speed video-cameras.

To optimize this process are determined some parameters, such as:

* Corresponding author, email: emos@ub.ro
© 2016 Alma Mater Publishing House

- Real parameters - using different methods to measurement: the efficiency of the separation process, constructive parameters of the separation equipment which are used (inclination angle of the working surface, the shape of the working surface, active surface of the working surface, oscillation amplitude and frequency, time of separation process, etc.) [12-17];
- Theoretically parameters - using different relations, take into account type o equipment, relations which are designed to determine: the solid particle velocity on the working surface, kinematic index which describe the separation process [18, 19].

Following the theoretical approaches of the mechanical separation process, the kinematic indices have been determined. These indices can help us to identify the moving direction of a solid particle on the oscillating working surface [8, 20-22].

Specialty literature is poor in articles aimed at determining the real value of this parameter. The majority of articles aimed at determining the theoretically values of kinematic index for different types of separators [23-26].

Since the kinematic indices represent only theoretical features, this article, following a series of experimental analyses, has the purpose to determine their real value for different types of real particles.

2. THEORETICAL BACKGROUND

Two situations have been considered, one in which the particle moves down the sieve and one in which the particle goes up the sieve.

Following the two actual situations, Figure 1 and Figure 2 show the directions of the forces acting on a solid particle on an oscillating surface, and the calculation relations of the kinematic indices corresponding to the movements have been determined [27]:

- down the sieve k_j (equation 1);
- up the sieve k_s (equation 2),

relations corresponding to a 3D distribution of forces.

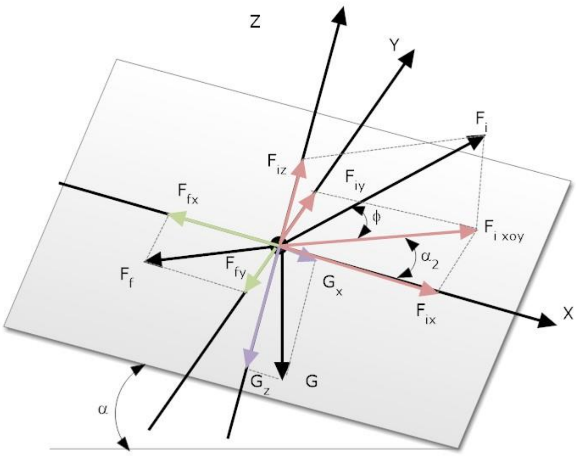


Fig. 1. Moving of the particle down the sieve [27].

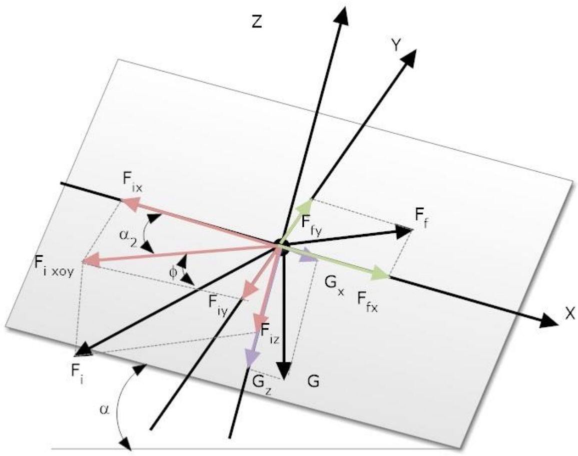


Fig. 2. Moving of the particle up the sieve [27].

$$k_j = \frac{\sin\alpha + \mu \cdot \cos\alpha \cdot \cos\alpha_2}{\cos(\omega \cdot \mathrm{t}) \cdot \cos\alpha_2 \cdot \cos\phi + \mu \cdot \sin\phi} \tag{1}$$

$$k_s = \frac{\mu \cdot \cos\alpha \cdot \cos\alpha_2 - \sin\alpha}{\cos(\omega \cdot t) \cdot \cos\alpha_2 \cdot (\cos\phi - \mu \cdot \sin\phi)} \tag{2}$$

By changing the 3D display into a 2D one (often seen in professional literature), i.e. angle α_2=0 and for ω=0, equation (1) and (2) become:

$$k_j = \frac{\sin\alpha + \mu\cdot\cos\alpha}{\cos\phi + \mu\sin\phi} \tag{3}$$

$$k_s = -\frac{\sin\alpha - \mu\cos\alpha}{\cos\phi - \mu\sin\phi} \tag{4}$$

Following the same display, we could determine a new kinematic index, k_l, which characterizes the sideways move of the particle on the oscillating surface (equation 5).

$$k_l = \frac{\mu\cdot\cos\alpha}{\cos(\omega\cdot t)\cdot(\cos\phi + \mu\cdot\sin\phi)} \tag{5}$$

Through the three aforementioned relations, starting from the actual analysis of the behavior of a solid particle on a flat oscillating surface, the real value of these indices has been determined.

3. EQUIPMENT AND MATERIALS

Within the experimental measurements, a laboratory stand has been used (Fig. *3*) for the analysis of the process of separation of a mixture of solid particles according to their dimensions, which is an oscillating sieve operated by a rotating slider crank mechanism. Working surface was suspended on frame with help of elastic which have 7 mm oscillation, in relation with the vertical axes. The oscillation motion of working surface it is made by an electric engine which send a motion to the crankshaft, with help of transmission belt drive, and after that the motion are taken by a connecting rod.

In order to determine the real value of the kinematic indices corresponding to a solid particle, the following modifications have been made on the mechanical separation process [27]:

- The working surface has been modified, from a sieve with holes into a blind sieve on the surface of which a series of marking lines have been traced;
- In order to determine the value of the kinematic indices on the working surface, only one real particle has been used.

Fig. 3. Laboratory stand used for the analysis of the behavior of a solid particle on a flat oscillating surface [27].

In order to determine the value of the kinematic indices, a series of parameters must be determined, such as [27]:

- construction characteristics of the laboratory stand: the gradient of the working surface with regard to the horizontal line, $\alpha = 10^o$ (inclination work surface was constructed so as the supply area is higher than the discharge area);
- characteristics of the solid particle used within the experimental measurements: friction coefficient, μ;
- characteristics of the movement of the solid particle on the working surface: the angle α_2 made by the projection of Fi force to OX axis; the angle ϕ made by the projection of F_i to OZ axis.

If α and μ can be determined by different devices and equipment, α2 and ϕ must be determined analytically. To do so, the following are to be determined:

- The projection of the solid particle's trajectory on the surfaces of the XOY and XOZ planes ;
- The real value of the angles α_2 and ϕ must be known, angles to be obtained from the projection of the F_i force on XOY and XOZ planes.

Two video cameras have been used, in order to determine the spatial trajectory of the solid particle on the flat oscillating surface, with a 25frames/sec recording speed. With the purpose to follow the movement of the particle on planes the cameras are placed on two perpendicular planes (Fig. *4* 4 and Figure 5), [27]:

- XOY – video camera number 1;
- XOZ – video camera number 2.

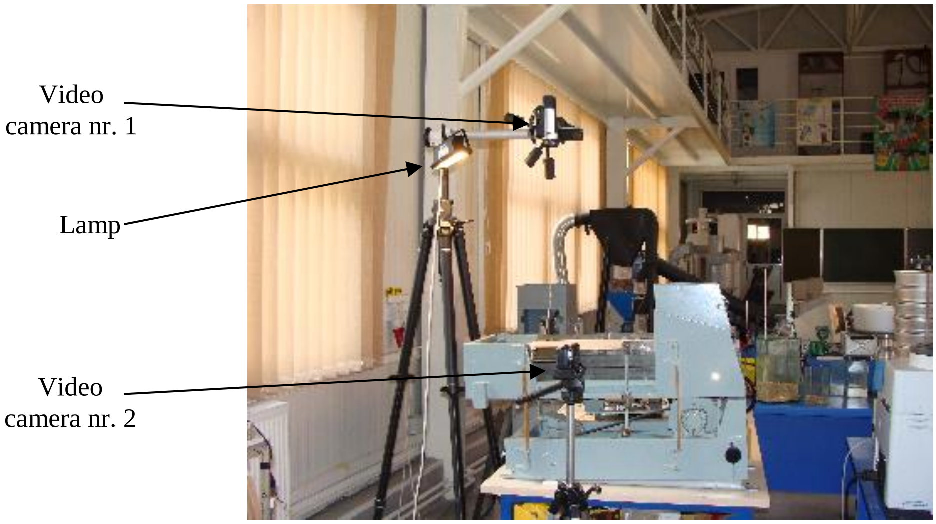


Fig. 4. Video camera positioning [27].

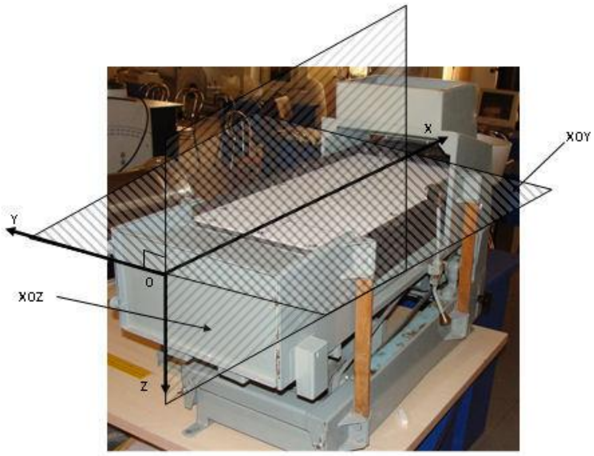


Fig. 5. The reference planes [16].

The rotation of the eccentric shaft was determined with help of laboratory equipment, *Vibrotest 60*, and for this study was choose 240 rpm the working rotation.

The purpose of this article is to demonstrate the possibility to determining the index corresponding to the kinematic separation process on the flat screen with oscillating movement. To this end, in order to eliminate some defects as the construction work surface, it was chosen as it is a blank screen inclined from the horizontal surface (Figure 6). On this surface was limited the distance that was monitored the movement of the solid particle by tracing a chalk lines. This marker, from the work surface, has taken into account the displacements on XOY plan that solid particle makes:

- 265 mm It's the tracking length of solid particle;
- To emphasize the lateral movement of the solid particle was drawn a longitudinal line in the middle of the working surface.

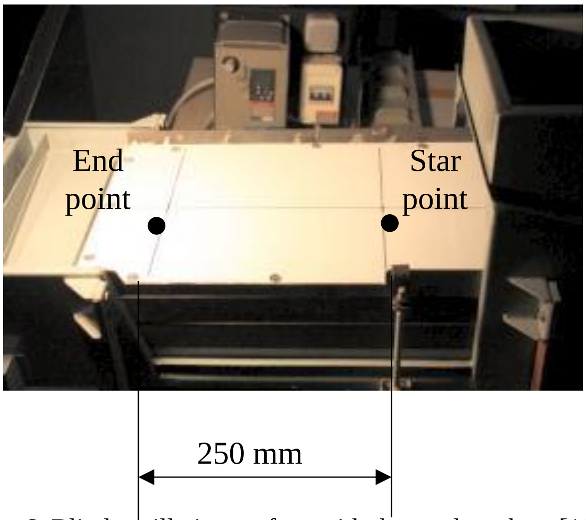


Fig. 6. Blind oscillating surface with the used markers [16].

In the experimental determinations there have been used real particles which form are differs from the ideal shape. To determine the real value of kinematic indices what use one real particle, respective the next particles: grain; large grain bean; small grain bean and soybean.

In order to determine the value of kinematic indices of the solid particles, the following working methodology has been used (Fig. *7*) [27].

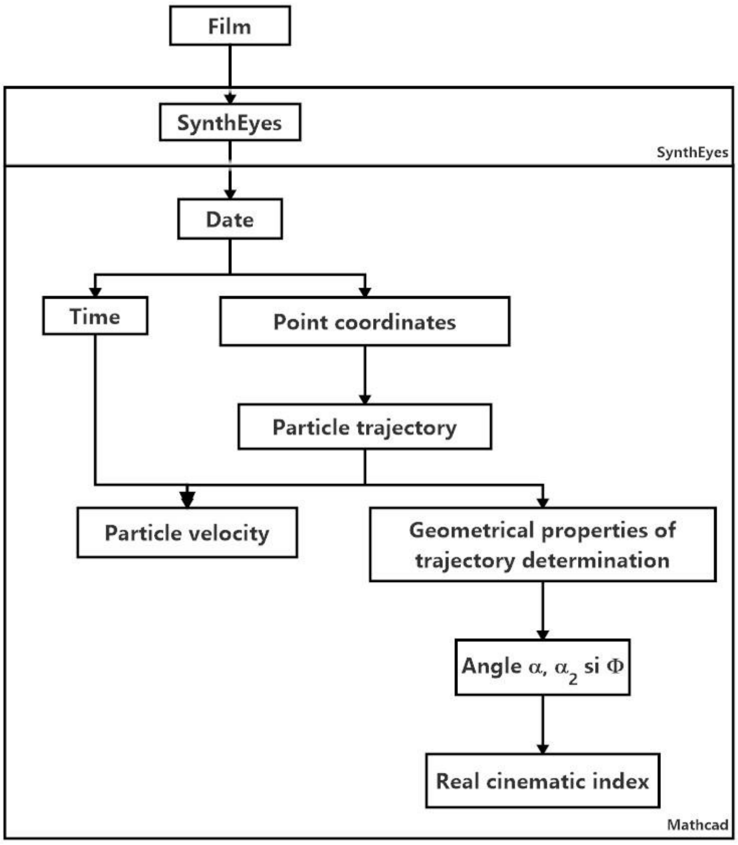


Fig. 7. Working methodology.

Software used to study the behavior of the solid particles on a flat surface are:

1. *SynthEyes 3-D Camera Tracker* It is a tool that will analyze 2D video motion [28]. In this way are obtained the particle coordinates and with help of them it is possible to determine the particle path.
2. *Mathcad* is a very complex software that can solve algebraic equations, algebraic equations systems, function graphs can represent many other operations [29].

Since within the experimental measurements intended to obtain the real value of the indices, the following real types of solid particles have been used: soybeans, grain, small grain beans and large grain beans, the characteristics of which are presented in Table 1.

Table 1. Characteristics of solid particles [27].

Nr.	Particle type	Solid particle dimensions, mm			Roundness	Weight (g)	Friction coefficient, μ
		Length (mm)	Width (mm)	Thickness (mm)			
1.	grain	20.30	13.43	8.46	0.65	1.25	0.49
2.	Large grain bean	19.03	12.93	8.77	0.67	1.19	0.48
3.	Small grain bean	12.70	8.19	7.44	0.72	0.48	0.39
4.	Soybean	7.32	6.40	6.29	0.91	0.22	0.37

To achieve the experimental study on the working surface was put only one solid particle, and for that particle was determined the real value of the kinematic index.

4. OBTAINED RESULTS

Following the experimental measurements and complying with the working methodology, it has been determined, first, the trajectory covered by the solid particle on the flat oscillating surface (Fig. *8*).

After analyzing the graphical representations of solid particles trajectories, it can be said that they don't have the same rate, and this due to characteristics of the solid particles.

The starting point of the movement of the solid particle on the working surface is the same for all types of particles, this being (250; 0) (coordinates on OX and OY). The trajectory of the solid particle ends at 0 on OX axis, but for all 4 types of analyzed particles, the final coordinates of the particle's trajectory on OY axis are not the same, as the results are as following:

- grain particle: 0.98;
- large grain bean particle: 9.1;
- small grain bean particle: 11.6;
- soybean particle: 78.4.

In conclusion, the highest deviation from the linearity of the trace, which is from the 0 value of OY, it was obtained for the soybean particle, and the lowest deviation for the grain particle.

Also, after measuring the trajectory generated by the solid particle, it shows that the particle of:

- Grain moved on the working surface 0.272 m;
- Large grain bean moved on the working surface 0.321 m;
- Small grain bean moved on the working surface 0.289 m
- Soybean moved on the working surface 0.32 m.

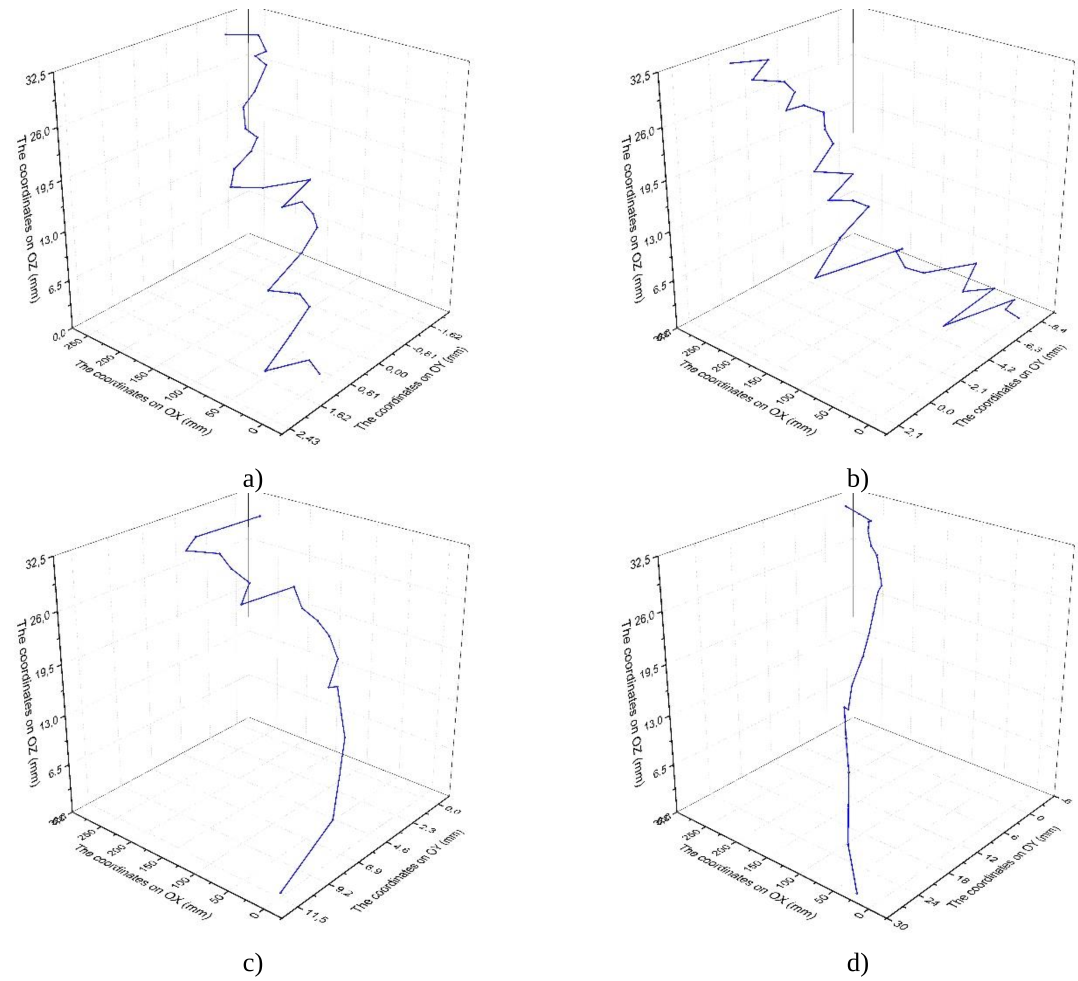


Fig. 8. Solid particles trajectory charts:
a) grain; b) large grain bean; c) small grain bean; d) soybean.

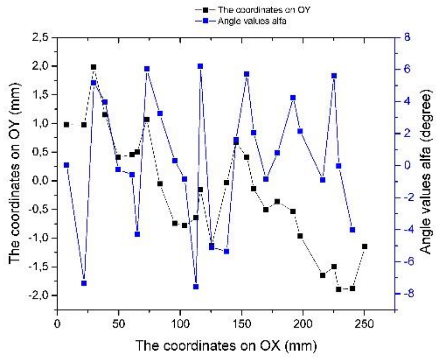
Given that in order to determine the value of the kinematic index one must know also other characteristics, Figure 7 shows the α_2 variation according to the projection of Fi with regard to XOY plane, with regard to OX axis, and to the trajectory of the solid particle on XOY plane. In order to find out the relation existing between α_2 angle and the particle's trajectory, the same graphic shows the projections of the trajectory on XOY plane (Figure 9).

Through calculation equations (3), (4) and (5) the real value of the kinematic index can be determined, describing the behavior of the solid particle on the oscillating surface (Figure 10).

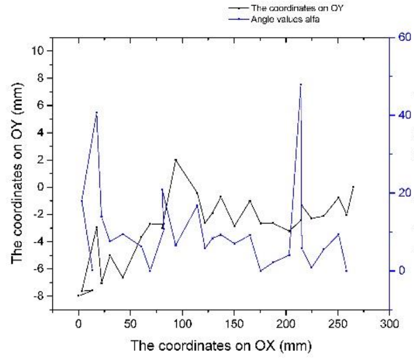
By analyzing the kinematic indices variations, the following conclusions can be reached:

- The rates of variation of kinematic indices k_l and k_j are identical, these being offset from each other, and generally $k_j>k_l$;
- In most of the situations, the shape of variation of kinematic index corresponding to upward movement on the working surface k_s is opposed to the variation of the kinematic index k_j;
- The shape of variation of the three characteristics is the same with the trajectory of the solid particle or, to be exactly, with its movement down the working surface, up the working surface and sideways on the working surface.

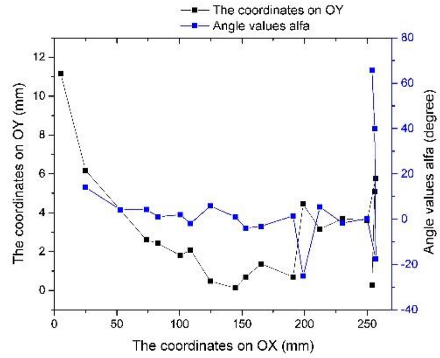
Following the analysis of previous charts, it shows that for any change of direction of the solid particle, the value of α_2 angle changes also, its positive or negative values depending on the position of the particle with regard to 0 value of OY axis.



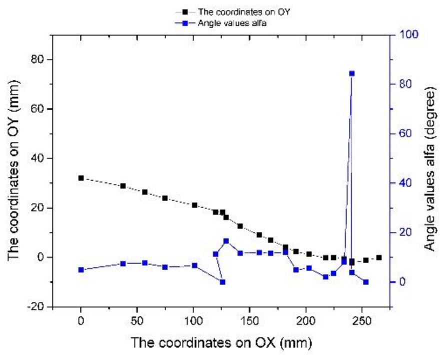
a)



b)

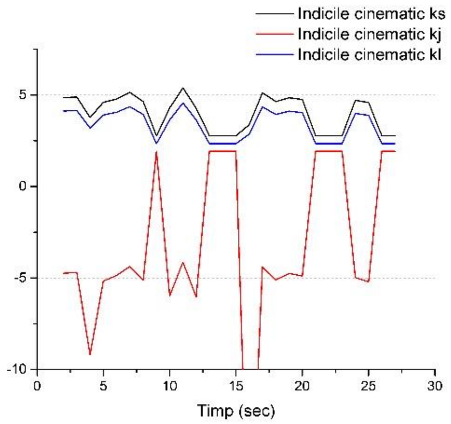


c)

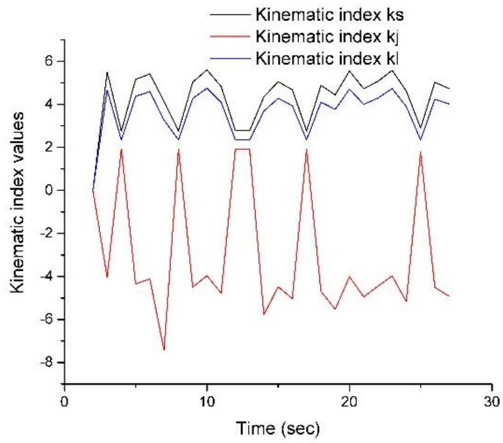


d)

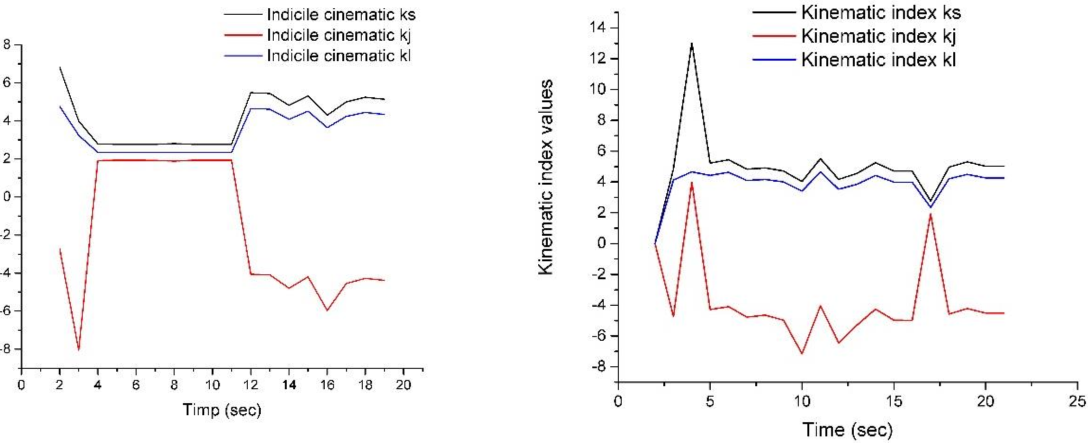
Fig. 9. the trajectory of the solid particle in function by α_2 variation for:
a) grain; b) large grain bean; c) small grain bean; d) soybean.



a)



b)



c) d)

Fig. 10. The variation of kinematic index according to the trajectory of the solid particle for: a) grain; b) large grain bean; c) small grain bean; d) soybean.

5. CONCLUSION

The most commonly used method of mechanical separation of a heterogeneous mixture of solid particles is the separation by size or separation on site.

The separation process is characterized by the side kinematic index, parameter that describes the movement of the swing plane on the surface of the solid particle.

Because in the literature is presented only flat distribution of forces acting on the solid particle on a flat oscillating surface, in this article was aimed how the same forces, but acts within the spatial movement of solid particles, thereby achieving equations of motion for two movement directions of particles or kinematic indexes of the particle movement on the sieve (k_j and k_s), taking into account the three forces projection on planes XOY, XOZ and YOZ.

From the new general motion equations we determined the kinematic indexes for sideways movement of solid particle on the oscillating flat surface k_l and we found that regardless of how solid particle movement on the oscillating flat surface that is up or down, on this relationship k_l index calculation is the same.
Following the experimental determination of the behavior of a solid particle on a flat oscillating surface, a number of parameters could be theoretical determined, such as angle α_2 of the projection of force F_i in relation to the OX axis; angle ϕ of the projection of force F_i in relation to the OZ axis.

With calculation relations determined for kinematic indexes we found the real value of these parameters.

From the results representation it appears that irrespective of the particle type used in the experimental determinations, kinematic indexes value is not constant, their variation is closely related to the behavior of solid particle oscillating surface.

BIBLIOGRAPHY

[1] Bontas, O., Nedeff, V., Mosnegutu, E., Panainte, M., Study of factors influencing the solid particles on a flat inclined surface, Journal of engineering studies and research, vol. 18, no. 1, 2012, p. 39-46.
[2] Bontas, O., Nedeff, V., Mosnegutu, E.F., Panainte, M., Tîrțoacă Irimia, O., Behaviour of solid particles on a flat oscillating surface, Environmental engineering and management journal, vol. 12, no. 1, 2014, p. 17-22.
[3] Moşnegutu, E., Nedeff, V., Panainte-Lehăduş, M., Bontaş, O., Barsan, N., Tomozei, C., Chiţimus, D., Studies and research concerning the displacement of solid particle on an oscillatory flat surface, Applied mechanics and materials, vol. 659, 2014, p. 521-526.

[4] Stoicovici, D.I., Ungureanu, M., Ungureanu, N., Bănică, M., A computer model for sieves vibrations analysis, using an algorithm based on the false-position method, American journal of applied sciences, vol. 5, no. 12, 2008, p. 48-56.
[5] Li, J., Webb, C., Pandiella, S.S., Campbell, G.M., Discrete particle motion on sieves - a numerical study using the DEM simulation, Powder technology, vol. 133, no. 1-3, 2003, p. 190-202.
[6] Xiao J., Tong X., Particle stratification and penetration of a linear vibrating screen by the discrete element method, International journal of mining of science and technology, vol. 22, 2012, p. 357-362.
[7] Dong, K.J., Yu, A.B., Brake, I., DEM simulation of particle flow on a multi-deck banana screen, Minerals Engineering, vol. 22, no. 11, 2009, p. 910-920.
[8] Moşneguţu, E., Nedeff, V., Bontaş, O., Bârsan, N., Chiţimuş, A.D., Possibilities to determining the solid particle trajectories on an oscillating separation screen, Journal of engineering studies and research, vol. 20, no. 3, 2014, p. 63-70.
[9] Xie, S., Or, S.W., Lai Wa Chan, H., Kong Choy, P., Chou Kee Liu, P., Analysis of vibration power flow from a vibrating machinery to a floating elastic panel, Mechanical systems and signal processing, vol. 21, no. 1, 2007, p. 389-404.
[10] Szymański T., Wodziński P., Screening on a screen with a vibrating sieve, Physicochemical problems of mineral processing, vol. 37, 2003, p. 27-36.
[11] Tsakalakis K., Some basic factors affecting scree performance in horizontal vibrating screens, The european journal of mineral processing and environmental protection, vol. 1, 2001, p. 42-54.
[12] Кролевец, Р.Л., Процесс очистки семян мелкосеменных культур от трудноотделимых засорителей методом фрикционного разделения, ТЕХНИЧЕСКИЕ НАУКИ, 2012, p. 52-57.
[13] Myoung, H.K., Seung , J.P., Analysis of broken rice separation efficiency of a laboratory indented cylinder separator, Journal of biosystems eng., vol. 38, no. 2, 2013, p. 95-102.
[14] Constantin, G.A., Voicu, G., Ştefan, M.E., Influence of cinematic regime and quantity of material on efficiency of sifting process, In: 3 nd International conference of thermal equipment, renewable energy and rural development, University "POLITEHNICA" of Bucharest, 2014, no. Issue, pp. 199-204.
[15] Shevtsov, I.V., Beznosov, V.A., Приводное устройство решетных станов зерноочистительных машин, Аграрный вестник Урала, vol. 120, no. 2, 2014, p. 43-45.
[16] Ivan, G., Nedelcu, M., Theoretical study of pile displacement on the straw walker of conventional combine harvesters (part three) INMATEH - Agricultural engineering, vol. 33, no. 1, 2011, p. 43-48.
[17] Ilea, R., Tonea, C., Drăgoi, G., Popa, D., Piloca , L., Experimental researches on flat sieve working processes, Research journal of agricultural science, vol. 41, no. 2, 2009, p. 438-442.
[18] Ilea, R., Tonea, C., Popa, D., Drăgoi, G., Mechanical models of the mixture layer from the cleaning system of harvesting combines, Journal of horticulture, forestry and biotechnology, vol. 15, no. 2, 2011, p. 138-142.
[19] Ivan, G., Nedelcu, M., Theoretical study of pile displacement on the straw walker of conventional combine harvesters, INMATEH – Agricultural engineering, vol. 36, no. 1, 2012, p. 33-40.
[20] Jansen, M.L., Glastonbury, J.R., The size separation of particles by screening, Powder technology, vol. 1, 1967, p. 334-343.
[21] Soldinger, M., Transport velocity of a crushed rock material bed on a screen, Minerals engineering, vol. 15, no. 1-2, 2002, p. 7-17.
[22] Kostas, T., Some basic factors affecting scree performance in horizontal vibrating screens, The european journal of mineral processing and environmental protection, vol. 1, 2001, p. 42-54.
[23] DonguaI, A., Rodríguez, A.M., Software for calculation of parameters in vibratory plane surfaces, Revista ciencias técnicas agropecuarias, vol. 23, no. 4, 2014, p. 82-87.
[24] Arturo, M.R., Software for calculation of parameters in vibratory sieves under criteria of limit speed of particles Revista ciencias técnicas agropecuarias,, vol. 18, no. 1, 2009, p. 41-45.
[25] Letoşnev, M.N., Maşini Agricole, Editura agro-silvică de stat, Bucureşti, 1959.
[26] Ene, G., Echipamente pentru clasarea și sortarea materialelor solide polidisperse, Editura Matrix Rom, București, 2005.
[27] Bontas, O., Posibilităţi de optimizare a procesului de curăţire şi sortare a produselor agricole vegetale granulometrice după lăţime şi grosime, Teză de doctorat, Universitatea "Vasile Alecsandri" din Bacău, 2013.
[28] xxx, SynthEyes 3-D Camera Tracker, https://library.creativecow.net/articles/holt_karl/syntheyes.php (26.11.2016).
[29] xxx, Mathcad, https://www.unf.edu/~mzhan/chapter1.pdf (26.11.2016).