651. Investigation of grain separation through straw layer over oscillating screen

D. Steponavičius, E. Jotautienė, S. Petkevičius, V. Butkus
Lithuanian University of Agriculture,
Studentu 15A, LT-53361, Akademija, Kauno distr., Lithuania
E-mail: *Dainius.Steponavicius@lzuu.lt, Egle.Jotautiene@lzuu.lt, Sigitas.Petkevičius@lzuu.lt, Vidmantas.Butkus@lzuu.lt*
Phone: +370 674 27721

(Received 2 July 2011; accepted 1 September 2011)

Abstract. Straw walker is a separator that separates grain from straw, and limits the efficiency of combine-harvesters therefore special attention is devoted to the development and improvement of its design and technological parameters. The most important parameter of walker operation is Froude-number k that depends on the amplitude of the straw walker movement in vertical direction, i.e., walker sieve oscillation amplitude r and angular velocity ω. High speed camera used in the investigation tests helped to determine not only the behavior of the straw layers on the oscillating sieve of straw walker but also the duration of grain penetration (separation) through the straw. With estimation of these parameters the rational values of Froude-number k were substantiated. It has been determined that at various ω and r combinations when k=const. sieve vertical accelerations when the crankshaft is rotated at the same angle are equal, but speeds and displacements are varied. For this reason the duration of grain separation is different. The rational angular velocity of the crankshaft is 22.5 s^{-1} (r=0.05 m), as then the straw layer when the crankshaft is rotated at the angle 2π, raised from the walker surface (sieve) the most early and strokes with it latest, i.e. the duration of free movement of the straw is 1.5 times longer and the grain separation about 15% more intensive than when ω=21.5 s^{-1}. The estimation of grain separation enabled to define critical value of crankshaft angular velocity equal to ω=23.5 s^{-1}. When this value is exceeded the top straw layers receive only one stroke when the crankshaft is rotated at the angle 4π, therefore the increase of crankshaft angular velocity and, simultaneously, sieve oscillation intensity above the critical value is inexpedient.

Keywords: grain separation, Froude-number, sieve oscillation amplitude, straw oscillation.

Introduction

Straw walker is used for grain separation from straw in combine-harvesters. Straw movement through the walker surface can be investigated in two stages: the first one is related with straw elasticity when the walker rises and the straw layer laying on its surface is pressed, the second one is the free movement of the straw when it separates from the walker surface and strike with the walker surface again. This way the straw is transported along the straw walker surface. Simultaneously under the gravitational force the grain is separated from the straw and penetrated through walker surface (sieve). Grain separation intensity is related with supplied straw flow and the quantity of grains in the straw, straw moisture content, its density, elasticity, etc. [1, 2, 3, 9]. Two hypotheses are widely adopted as decisive factors for grain separation from the straw. The first hypothesis states that the greatest influence on the separation process has the impact of the walker surface to the straw layer. The second hypothesis states that grain separation is related with the duration of the straw free movement and the increase of the porosity after the takeoff of straw from the walker surface [4, 6, 8]. The interaction of the free movement duration of the straw layer and the walker stroke impulse influencing the separation process has to be coordinated. The aforementioned parameters depend on the kinematic and dynamic parameters of the straw walker. The most significant index of the estimation of straw walker operation is the ratio of inertia and gravitational force or the kinematic regime coefficient, i.e., Froude-number *k*, ($k=r\omega^2 g^{-1}$). It depends on the amplitude *r* of the crankshafts of the straw walkers and the angular velocity of rotation ω [5].

The research goal is to define the impact of the Froude-number *k* of the straw walker on grain separation through the oscillating straw layer and to justify its rational values.

Methodology and means of the experiment

Tests of grain penetration through the elastic and viscous straw layer have been conducted in the laboratory of Hohenheim University in Germany. The test stand (Fig. 1) consists of the frame, motor with transmission, small frame, straw receptacle (shaker box), grain collection box, electronic scales, and grain box with sliding bottom.

The electric motor rotated the mechanism, whose lifter in the external side of the main frame moved between two pairs of the rollers, vertically up-and-down. The lifter was connected with the small frame, whose rollers leaned upon the main frame guides. The receptacle with transparent walls the base area of which was 0.38 m^2 was attached to the frame. The receptacle had a sieve bottom, and the straw sample was put on it. The electronic scales were installed on special supports under the straw receptacle, and the grain collection box was put on the electronic scales. The scales were connected with the computer. The box with the scale bottom used for the grain sample collection was installed on the top of the main frame. Electromagnetic switch was used to operate the scale position of the bottom. The computer program controlled the operation of the test stand.

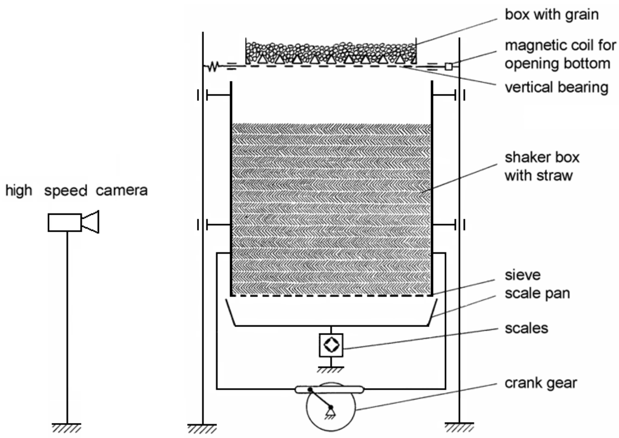


Fig. 1. Grain penetration test stand

Undamaged clean wheat grains, the 1000 grain mass of which was 45±3.2 g, were used in grain penetration tests. Straw average length was 187±7.1 mm; their moisture content was 8.6%.

Weighed straw sample was put into the receptacle. The load of the receptacle bottom (sieve) with straw was 3.3 $kg \cdot m^{-2}$, and that corresponded to the straw amount transferred onto the straw walker of combine-harvester, i.e., 1.5 $kg \cdot s^{-1}$. It was estimated that 80% of the grains transferred onto the threshing apparatus of combine-harvester would be separated through the concave grates, and 20% would fall onto the straw walker surface when the grain and straw ratio was 1:1. With this in mind, the amount of grains supplied onto the straw in the receptacle was 0.66 kg. Weighed grains were poured into the box on the test stand top. When the test stand transmission was switched on, and the frame with the straw began to oscillate up and down, the electronic scales were automatically switched, and the electromagnetic switch opened the scales of the grain box bottom. The grains that fell on the straw layer surface were penetrated through the straw layer, later through the sieve, and fell onto the grain collection box on the electronic scales.

Electronic scales measured grain mass and recorded the results every 0.9 seconds. When 95% of all the grains occurred in the box, the computer switched off the test stand transmission. The test data stored in the computer was recorded by the printer on the paper strip. Time ($t_{0.8}$) was the estimation index of grain separation through the straw, when 80% of the grain was separated from the straw. Research tests of grain separation had three replications.

Rotation frequency of the motor shaft was from 185 to 245 min^{-1}, and simultaneously the oscillation frequency of the receptacle with the straw was from 2.75 to 4.08 s^{-1} and it was changed by voltage frequency converter of the power network. Then the shaft angular velocity ω varied from 17.3 to 27.8 s^{-1}. The oscillation amplitude r of the receptacle with the straw oscillation in the vertical direction was changed from 0.030 to 0.060 m when the radius of the transmission eccentric was varied.

The motion of the separate straw layers in the receptacle was filmed with the digital high-speed camera KODAK HG, at the frequency of 750 frames per second or every 0.00133 s (Table 1). The filmed pictures were stored in the computer connected with the camera and recorded on CD. The filming process was controlled with the distance console.

The calibrated scale was pasted on the wall of the straw receptacle. The movement of the separate straw layers from the point of view of the receptacle bottom (sieve) was calculated. After 10.9 s the camera was automatically switched of when 8192 frames were made. To estimate the test results the straw layer was divided into three equal parts and the movement of the straw layer surface was also recorded.

Table 1. Indexes of the filming at the speed of 750 frames per second

Shaft angular velocity ω, s^{-1}	Shaft rotation frequency n, min^{-1}	Sieve oscillation frequency f, s^{-1}	Sieve oscillation period T, s	Frame number during sieve oscillation	Shaft rotation angle in one frame duration $\Delta\varphi$, degrees
19.4	185	3.08	0.324	243	1.48
21.5	205	3.42	0.293	220	1.64
22.5	215	3.58	0.279	209	1.72
23.6	225	3.75	0.267	200	1.80
24.6	235	3.92	0.255	191	1.88
25.7	245	4.08	0.245	184	1.95

After the visual material analysis of the straw oscillation in a receptacle the position of the top, middle and bottom straw layers was determined with respect to the immovable stand frame. When the values were recorded on the coordinate axes x (shaft rotation angle) and y (straw layer displacement), the absolute displacement curves of the individual straw layers were obtained.

The technique of experimental tests is unique because of the fact that the use of high-speed camera helped to disclose not only straw layer behavior on the oscillating straw walker sieve but also to determine the duration of grain separation, thus it was possible to establish the rational value of Froude-number k.

Results and discussions

To determine the rational values of Froude-number k the impact of sieve oscillation amplitude (from 0.03 m to 0.06 m) on the grain penetration through the straw layer was investigated. The rational sieve oscillation frequency f or the shaft angular velocity ω was determined at various sieve oscillation amplitudes r, when the duration of 80% grain penetration through the straw was the shortest (Fig. 2). The numeric value of Froude-number (Fig. 3) was calculated for each determined ω_{opt}.

The tests revealed that at ω=21.5 s^{-1} and r=0.055 m the rational value of Froude-number k was equal to 2.58 (Fig. 3). Then 80% of grains were separated from the straw in 7.4 s (Fig. 2). After the sieve oscillation amplitude was minimized up to 0.035 m, in order to keep the Froude-number k unchanged, the shaft angular velocity ω should be increased to 27.0 s^{-1}. It was determined that when the sieve oscillation amplitude was 0.035 m the most intensive grain separation was observed when the shaft angular velocity ω was equal to 25.7 s^{-1} and not ω=27.0 s^{-1}. Thus in this case the rational value of Froude-number k_{opt} is 2.35 but not 2.58 (Fig. 3). It was proved that after the reduction of the sieve oscillation amplitude its oscillation frequency should be comparatively less as Froude-number k_{opt} was less. It can be stated that ω and r impact on straw oscillation and grain separation was insufficient, i.e., at varied ω and r combinations when k=const. the sieve vertical accelerations when the shaft was rotated at the same angle, were equal and velocities and displacements were different. Thus the grain separation duration was varied. For this reason, Froude-number k could not be used to estimate grain separation.

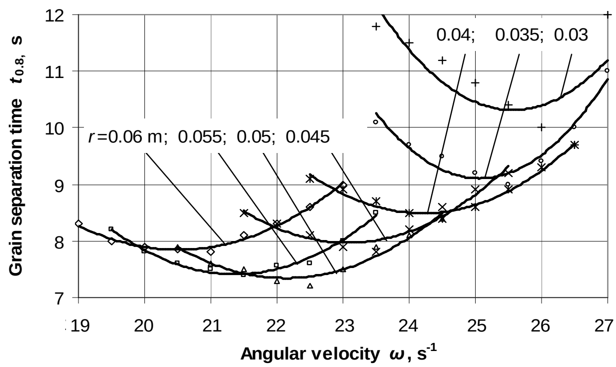


Fig. 2. Influence of crank-shaft angular velocity (ω) and oscillating amplitude (r) of sieve onto grain separation ($t_{0.8}$)

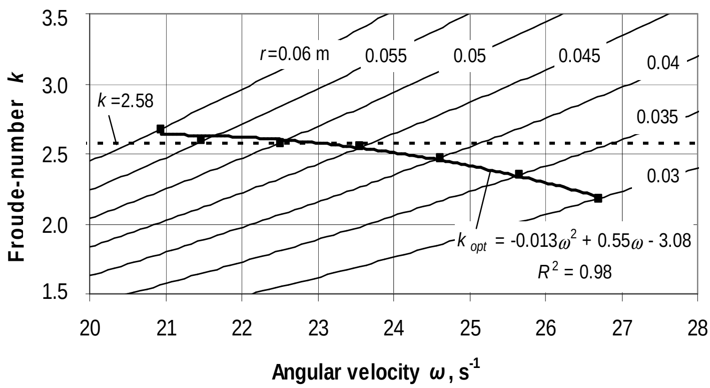


Fig. 3. Influence of crank-shaft angular velocity (ω) and oscillating amplitude (r) of sieve onto rational value of Froude-number (k_{opt})

Tests demonstrated that grain separation duration changed at the constant numerical value of coefficient k (k=2.58) (Fig. 4). It happened because at a constant k value, the sieve vertical displacements and velocities at straw risings and impacts moments were different. Thus the straw layer movement trajectories and straw free movement duration after loss of touch with oscillating sieve surface varied.

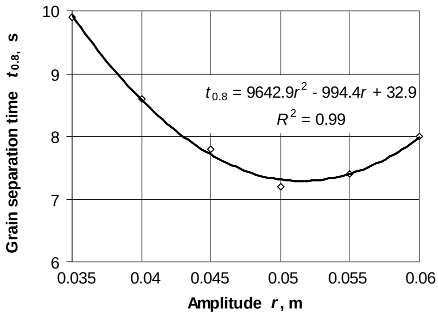


Fig. 4. Influence of oscillating amplitude (r) of sieve onto grain separation ($t_{0.8}$), when k=2.58=const.

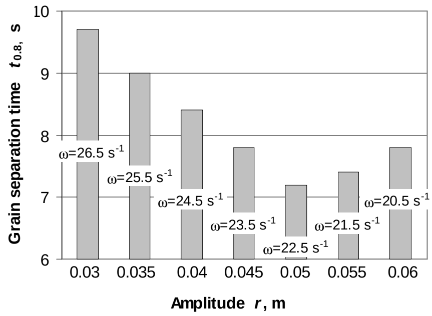
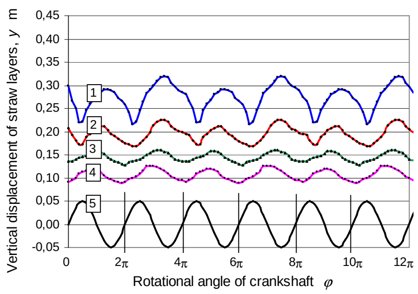


Fig. 5. Influence of crank-shaft angular velocity (ω) and oscillating amplitude (r) of sieve onto grain separation ($t_{0.8}$), when k_{opt}

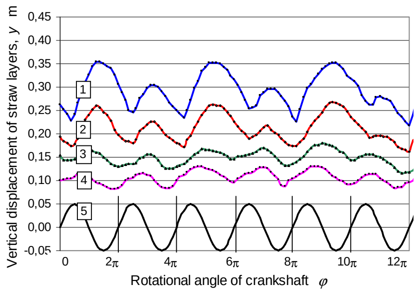
Grain separation duration $t_{0.8}$ at individual k_{opt} (Fig. 3) was also different (Fig. 5). Estimation of the impact of two kinematic parameters (ω and r) on the grain separation in vertically oscillating straw layer led to the conclusion that it was the most intensive when ω=22.5 s^{-1}, r=0.05 m (k=2.58). Then 80% of the grains were penetrated through the straw during 7.2 s. Very similar grain separation duration was at slightly less shaft angular velocity, i.e., up to ω=21.5 s^{-1}. Then the grains penetrated more intensively when the straw layer was started to shake but later on the grain penetration decreased and only 80% of grains were separated during 8 s. After investigation of the filmed material it was defined that when the shaft angular velocity was ω=22.5 s^{-1}(r=0.05 m) (Fig. 6b) the amplitude of the movement of lower layer (y=0.04 m) was identical, that of the middle layer was 0.01 m, and that of the top layer was by 0.03 m higher than at ω=21.5 s^{-1}(Fig. 6a). The straw layer became more porous after the loss of contact with the sieve surface. The grain penetration through the straw layer was also influenced by its free movement duration which, when ω=22.5 s^{-1}, was 1.5 times greater because the straw layer raised sooner and collided with the sieve later than at ω=21.5 s^{-1}. Besides at both shaft angular velocities and simultaneously at sieve oscillation angles of (f=3.42 s^{-1} and f=3.58 s^{-1}) respectively, all the straw layers received one stroke when the shaft was rotated at the angle 2π. This is obligatory condition for even operation of straw walker [6, 7].

Tests revealed that every separate straw layer moved differently above the oscillating sieve. When the sieve rises all the straw layers move down in regard to the sieve, i.e., are deformed till the entire straw layer becomes pressed spring. The lower layer is the first one to loose contact with the surface, later the middle layer is separated, followed by the top layer. But the free movement of the bottom straw layer that lost contact with the surface (sieve) was limited by the above layers. The upper straw layer starts its free movement the soonest because its movement meets no obstacles. The bottom straw layer is the first to descend meanwhile the above layers are still rising. When the sieve reaches the bottom limit, the whole layer slowly starts to fall down and the bottom layer together with the sieve starts to go up. When the sieve reaches the upper limit position the straw reaction force into the surface of sieve becomes equal to zero and they start to separate from the surface. But up to this moment part of the straw middle layer and all the top layer is still in the phase of the free movement (when ω=23.5 s^{-1}, n=225 min^{-1}). The rising bottom layer collides with the falling top layers. When the sieve starts its downfall movement, the bottom straw layer begins to fall down, because its accumulated energy is insufficient to outweigh the gravitational force of other falling straw layers.

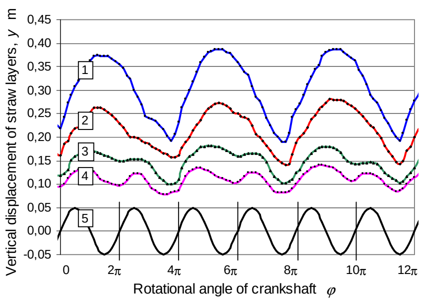
The investigation of filmed material revealed that the movement amplitude of the top straw layer was higher than the lower layers. Earlier it was affirmed [8] that the increase of the sieve oscillation frequency (when k=const., and r is reduced), the straw layer during the same time period received more strokes. But this statement is valid only when ω=23.5 s^{-1}, because when ω is greater than 23.5 s^{-1}, the top straw layer, and at still greater ω the middle straw layer received only one stroke of sieve when the shaft was rotated at the angle 4π (Fig. 6c). For some time the straw fell freely but the sieve stroke straw rarely, i.e., reoriented the straw and slowed the grain separation process. Theoretically the straw might get still more strokes when the sieve oscillation frequency increased but the sieve stroke the straw layer (particularly the top one) only every second period (Fig. 6d). The movement of straw layers with respect to each other became more passive, and the grain penetration time increased.



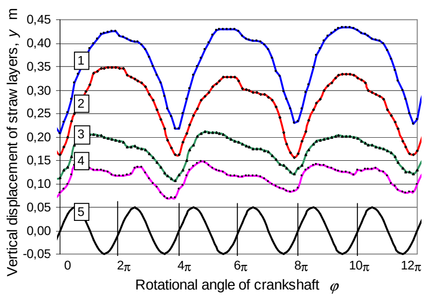
a) ω=21.5 s^{-1}; n=205 min^{-1}; f=3.42 s^{-1}; r=0.05 m; k=2.35



b) ω=22.5 s^{-1}; n=215 min^{-1}; f=3.58 s^{-1}; r=0.05 m; k=2.58



c) ω=23.5 s^{-1}; n=225 min^{-1}; f=3.75 s^{-1}; r=0.05 m; k=2.83



d) ω=24.5 s^{-1}, n=235 min^{-1}; f=3.92 s^{-1}; r=0.05 m; k=3.09

Fig. 6. Vertical displacement of different straw layers (1-4) over oscillating screen (5)

The reduction of the shaft angular velocity from the 21.5 s^{-1} limit still far decelerates the grain separation process (Fig. 5), as the height of the straw free movement trajectory and its duration decreases, and the straw movement trajectories assimilate.

Conclusions

When straw walker Froude-number k is constant, and the values of shaft angular velocity ω and the amplitude r are variable the grain penetration duration through the straw layer is not constant because accelerations of straw layer are equal, while the displacements are different.

The rational value of the Froude-number k has been determined by changing the sieve amplitude (from 0.03 to 0.06 m) and shaft angular velocity when the grain penetration duration through the straw layer is minimum: $k_{opt}=-0.013\omega^2+0.55\omega-3.08$.

Crankshaft rational angular velocity (r=0.05 m) is 22.5 s^{-1} (n=215 min^{-1}), because then the straw layer when the shaft is rotated at the angle 2π the soonest separates from the sieve and collides with it at the latest, i.e., the duration of the free straw movement is 1.5 times longer, the grain separation about 15% more intensive than at ω=21.5 s^{-1} (n=205 min^{-1}).

The critical value of the crankshaft angular velocity is 23.5 s^{-1} (n=225 min^{-1}), because when it is further increased the top straw layers receive the stroke only when the shaft is rotated at angle 4π thus the increase of the shaft angular velocity and, simultaneously, the intensity of the sieve oscillation above the critical is inexpedient.

References

[1] **Kutzbach H. D., Wacker P., Böttinger S.** Grain Harvesting. Combine Harvesters. Yearbook Agricultural Engineering. VDI Verlag, Düsseldorf, Bd. 18, 2006, p. 143 – 153.

[2] **Steponavičius D., Špokas L., Petkevičius S.** The influence of the first straw walkers section on grain separation. Agronomy Research, Vol. 6 (Special Issue), 2008, p. 377 – 385.

[3] **Špokas L., Steponavičius D.** Impact of wheat stubble height on combine technological parameters. Journal of Food, Agriculture & Environmental, Vol. 8, Nr. 2, 2010, p. 464 – 68.

[4] **Зубков В. И.** Основы механики среды дискретных частиц (Basics of the Mechanic the Medium of Discrete Particles). Rostov na Donu: DGTU, 1996, p. 167 [In Russian].

[5] **Steponavicius D., Spokas L., Kutzbach H. D.** Investigations of grain separation through the MOG layer on a straw walker. Engineering the future: Abstracts of International Conference of Agricultural Engineering. – Leuven (Belgium), 2004, Part 1, p. 460 – 461.

[6] **Босой Е. С.** Теория, конструкция и расчет сельскохозяйственных машин (Theory, Design and Sizing of Agricultural Machinery). Moscow. 1978, p. 568 p [In Russian].

[7] **Антипин В. Г.** Пропускная способность зерноуборочного комбайна (Throughput of Combine Harvester). Механизация и электрификация соц. сельского хозяйства. 1973, № 1, p. 9 – 11. [In Russian].

[8] **Kanafojski Cz.** Methoden und Theorie des Trennens der Feldfrüchte (Methods and Theory the Separation of Agricultural Materials). Grundlagen erntetechnischer Baugruppen. Berlin, 1973, p. 240–258. [In German].

[9] **Jasinskas A., Plieskis K., Šarauskis E., Sakalauskas A.** Grass silage thickening technology using centrifugal undirected action vibrator. Journal of Vibroengineering. 2010, Vol. 12, Issue 4, p. 621 –628.