The influence of position of the first straw walker´s section on grain separation

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Abstract. The impact of the inclination angle of the first section (screen) of straw walkers on grain separation through the straw layer of various thicknesses has been tested in the laboratory. The straw feed rate on the straw walkers and the Froude number of the straw walkers (rotational speed of the walker crankshafts) was changed during the test. About 20% of the grains threshed and unseparated through the concave of the threshing device remained trapped in the straw layer fed on the straw walkers. It has been defined that the inclination angle of the first section of straw walkers were related to the straw throughput and the rotation speed of the walker crankshafts. The greatest number of grains was separated through the straw layer when it fell from the first section of straw walkers onto the second one. The optimum value of Froude number of the fourth straw walker assembly was 2.58 (the rotational speed of the crankshafts was 215 min^{-1}), the inclination angle of the first straw walkers section was 22º, a step height was 0.28 m, the permissible limit straw feed rate on the straw walkers of dry straw (moisture content 9.8%) was 2.08 kg $(s\ m)^{-1}$ on the layer with 0.43 m thickness because then only 3% of unseparated grains reach the fourth section of straw walkers with the straw. The intensity of grain separation can be controlled using the rotational speed of the crankshafts or the inclination angle of the first section of straw walkers.

Key words: combine harvester, straw walker design, grain separation

INTRODUCTION

Crop yield has been harvested by combine harvesters where threshed grain has been separated from straw by straw walkers or rotary straw separators (Rademacher, 2007). Some combines have axial threshing-separation devices. The conventional combine harvesters consist of four, five, six or eight straw walkers with a stepped surface. The number of steps, their height and the inclination angle of straw walkers sections (screens) vary with the producers. Tests showed that the straw walker limited the combine throughput mostly because it did not completely shake off the grains from the straw when it was on the conveyor (Zubkov, 2002; Hübner, 2007). In modern combine harvesters grain separation is activated by improving the design of straw walkers, by changing their technological parameters and by installing the active rotary elements that brake the straw mat on the straw walker's surface (Kutzbach et al., 2006).

One of the most important indices of straw walkers operation estimation is the Froude number ($k = r\,\omega^2 g^{-1}$), i.e. ratio of inertial and gravitational forces. It depends on the crankshafts radius r of the straw walker and the angular velocity ω (Zubkov, 1996) but their parameters are not varied in combine harvesters.

From 10–30% of the grains unseparated in the threshing device reach the straw walker with the straw. Only 0.5% of unseparated grains (walker losses) can remain in the straw when it falls out of the rear of the combine (Mahoney, 1988). Tests disclosed that grain separation varied on walker sections' length (Gregory & Fedler, 1987; Böttinger, 1993 et al.). The greatest portion of the grain was separated through the first section (screen) of the straw walkers (Herlitzius, 1995) and when the straw fell from the first section onto the second section of the straw walkers (Kirste & Kühn, 1983; Clauss, 1992; Špokas & Steponavičius, 2001).

The straw from the threshing drum and the beater drum is directed onto the beginning of the straw walkers. The straw conveying speed should be lower at the beginning of the straw walkers to separate more grains (Zubkov, 1996). The speed of the straw layer at the beginning of the straw walkers is stopped by the inclined first sections of the walker, the inclination angle of which should be substantiated (Gusev, 1987). The straw should not accumulate on the first section of the straw walkers, thus the collision of the straw thrown from the beater drum with the walkers surface should be tested (Schneider, 1983; Büermann, 1996) and the inclination angle of the first section of straw walkers should be substantiated.

Summarizing the test results of other authors the conclusion can be made that the straw walker's design and the crop properties have the greatest influence on grain separation from the straw layer moving along surface of the straw walkers (Srivastava et al., 1990; Zubkov, 1996; Neale et al., 2003). But research tests have not defined the impact of the inclination angle of the first section of straw walkers and the first step height on the grain separation through the straw layer.

The investigation goal is to relate the Froude number (rotational speed of crankshafts) of the assembly of four straw walkers with the inclination angle of the first section of straw walkers.

MATERIALS AND METHODS

At the Agricultural University of Lithuania, in the Laboratory of Agricultural Machinery investigations on the straw walker itself have been accomplished which pursued the goal of reducing the losses and increasing the throughput of a straw walker by coordinating walker rotational speed and by optimizing the walker design. The test rig (Fig. 1) consisted of two band conveyors – one for straw 1 and another for grain 2, drum-type straw feeder 7 and the assembly of four straw walkers. Weighed straw samples were spread on the band conveyor 1 and grain samples were spread on the band conveyor 2. The conveyor 1 fed the straw into the drum-type straw feeder 7 at the speed of 1 m s^{-1}. The grain fell from the band conveyor 2 onto the supplied straw. The drum supplying unit pushed the straw through the smooth surface of the concave 6, and the beater drum 9 directed them to the beginning of the straw walkers (1.2 m width and 3.72 m length).

The straw walkers were mounted on two crankshafts 15 powered by electric motor. The radius of the crankshafts was 0.05 m. The straw walker bottoms made 6^{o} angles with horizontal line. The rotational speed of the crankshafts was altered by the variator within the range of 205 min^{-1} to 225 min^{-1}. On each straw walker, there were four walker sections (screens with holes). The first three walker sections had a length of 0.760 m each, and the fourth section was 1.444 m long. The adjustment of the walkers first step height allowed the inclination angle of the first section 10 of the examined straw walkers to be altered in a range of 6° to 33° (Table 1). It was varied by the screws 13. The inclination angle of the other three sections of straw walker coincided with the angle (α=6°) of walker assembly inclination. The examined walker sections had screens with ellipse-shaped (60×20 mm) holes. The active separation area of straw walker sections comprised 47% of the whole straw walker area.

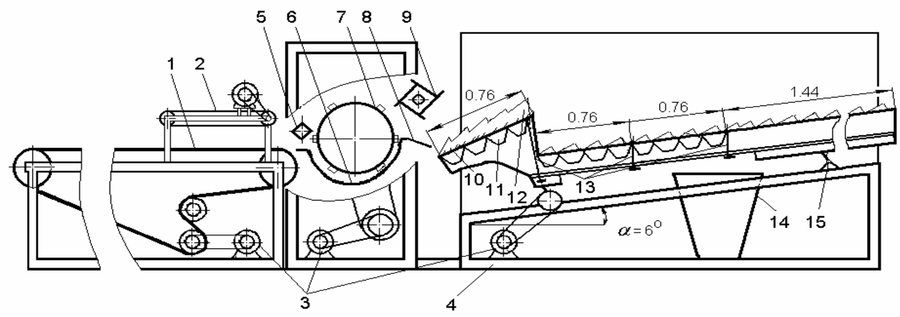

Fig. 1. Test rig scheme of gain separation:
1 – band conveyor for straw; 2 – band conveyor for grains; 3 – drives of conveyors and straw walkers; 4 – straw walker frame; 5 – in take; 6 – concave; 7 – feeder; 8 – grate bars; 9 – beater drum; 10 – assembly of four straw walker; 11 – sample bags; 12 – middle saw tooth plates of the first sections of straw walker; 13 – inclination control screws of the first, second and third straw walker sections; 14 – grain collection bags; 15 – crankshafts.

Underneath each of the first three walker sections examined, four equally sized frames with grain bags 11 were installed. In each grain bag, grains, chaff, and straw parts which were separated by the 0.19×0.25 m section area were caught. The mixture of grain and chaff separated by the fourth walker section fell into the grain bags 14. The chaff gathered from the bags was cleaned; the grains and admixtures were weighed separately (scales SPO 5, record accuracy 0.01 g). Grain separation was calculated through the first, second and third straw walker sections because the trajectory of the free fall of straw was longer when the straw fell from the higher first step onto the second straw walker section. Then the straw did not fall on the beginning of the second straw walker section.

During the investigation three replication tests were made. The straw layer was fed on the straw walker at the rate of 1.25 kg $(s\,m)^{-1}$ to 2.92 kg $(s\,m)^{-1}$ and the grain feed rate was from 0.25 kg $(s\ m)^{-1}$ to 0.58 kg $(s\ m)^{-1}$. The straw layer thickness (h) was calculated when it moved along the surface of the straw walker at the speed of 0.35 m s^{-1}. When the supplied straw feed rate (m) was increased the straw layer thickness varied from 0.17 m to 0.60 m, and the straw load of the straw walker varied from 2.38 kg m^{-2} to 8.33 kg m^{-2} respectively. The straw moisture content was 9.8±0.5%.

The grain that separated through the straw walker screens was estimated to be from 0.25 kg $(s\ m)^{-1}$ to 0.58 kg $(s\ m)^{-1}$. This was calculated having in mind the grains (20%) which reach the straw walker (80% grains was separated through concave).

Table 1. The impact of inclination angle (α_1) of first sections (l=0.76 m) of straw walker on the step height (H).

Indices	Values							
Inclination angle of first sections of straw walker α_1 (º)	0	6	12	18	24	27	30	33
Height of step H (m)	0	0.08	0.16	0.23	0.31	0.35	0.38	0.41

The grain trapped in the straw falling at the beginning of the fourth straw walker section (unseparated grain) was estimated to be from 1.25 kg $(s\,m)^{-1}$ to 2.92 kg $(s\,m)^{-1}$. This was calculated taking into account the grains fed into the threshing apparatus. When the inclination angle of section (screen) of straw walkers was 6º, the inclination angle of the section was considered to be 0º.

Experimental data were processed according to the statistical method recommended by the international Standard ISO 7256-1.2. The average values of the data and their validity intervals are presented. In order to establish correlation of two factors, the curvilinear correlation coefficient R^2 was calculated. The curvilinear correlation of two factors was established according to the Fisher criteria. In order to establish the direction and size of factor correlation, the regression equations were made.

RESULTS AND DISCUSSION

Straw feed rate. The straw feed rate on the straw walker and the inclination angle of their first section was changed when the Froude number of the straw walker was 2.58. The grain separation through the first section of straw walkers and the grain part (walker losses) that fell together with the straw on the fourth section of straw walker were established.

When the straw feed rate on the straw walker was increased from 1.25 kg $(s\,m)^{-1}$ to 2.92 kg $(s\,m)^{-1}$, the height of the straw layer moving on the walker's surface increased from 0.26 m to 0.60 m (Fig. 2). The grain penetration through the higher straw layer was slower. When the inclination angle of all sections of the straw walker was 0º (coinciding with the angle of walker assembly inclination α=6º), increasing the feed rate, the grain separation through the first section of the straw walker decreased by 10 percentage units. When the inclination angle of the first section of straw walker was increased to 28º the grain separation through the straw layer of 0.43 m height increased still more. When the higher straw layer was fed the limit inclination angle of the first section of the straw walker should be increased to 22º (Fig. 2, curves 4 and 5) to avoid straw accumulation on the beginning of straw walker.

The grain separation on the walker length is related not only with the inclination angle of the first section of the straw walker but the step height as well, because the straw falls farther from the higher steps and further onto the second section of the straw walker. The conclusion was made (Fig. 3) that the optimum inclination angle of the first section of the straw walker was 22º and the permissible height of the dry straw layer should be 0.43 m.

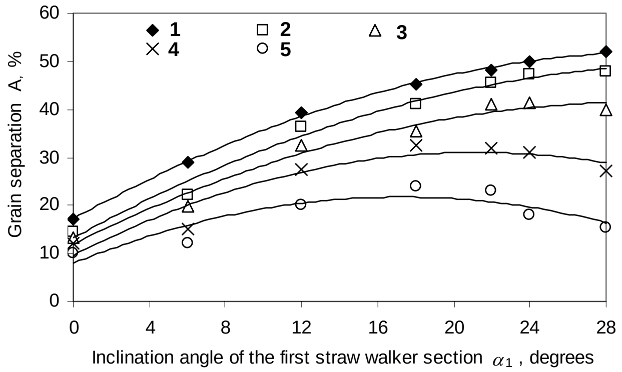

Fig. 2. The impact of the inclination angle of the first section of straw walkers (α_1) and the straw feed rate on the straw walker (m) on the grain separation through the first section of the straw walkers (A), when k=2.58, n=215 min^{-1}:

1 - $h = 0.26$ m, $m = 1.25$ kg$(\text{s m})^{-1}$; $S = -0.034\alpha_1^2 + 2.19\alpha_1 + 17.17$, $R^2 = 0.97$;

2 - $h = 0.34$ m, $m = 1.67$ kg$(\text{s m})^{-1}$; $S = -0.032\alpha_1^2 + 2.15\alpha_1 + 13.24$, $R^2 = 0.98$;

3 - $h = 0.43$ m, $m = 2.08$ kg$(\text{s m})^{-1}$; $S = -0.033\alpha_1^2 + 1.97\alpha_1 + 11.91$, $R^2 = 0.97$;

4 - $h = 0.51$ m, $m = 2.50$ kg$(\text{s m})^{-1}$; $S = -0.048\alpha_1^2 + 2.03\alpha_1 + 9.55$, $R^2 = 0.92$;

5 - $h = 0.60$ m, $m = 2.92$ kg$(\text{s m})^{-1}$; $S = -0.046\alpha_1^2 + 1.60\alpha_1 + 7.92$, $R^2 = 0.85$

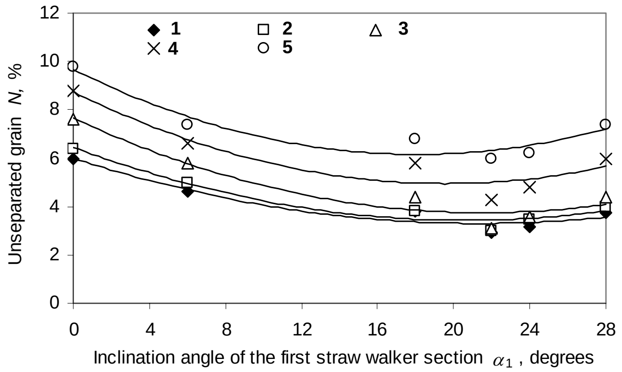

Fig. 3. The impact of the inclination angle of the first section of straw walkers (α_1) and the straw feed rate on the straw walker (m) on the grain amount in the straw at the beginning of the fourth section of straw walkers (N), when k=2.58, n=215 min^{-1}:

1 - $h = 0.26$ m, $m = 1.25$ kg$(\text{s m})^{-1}$; $N = 0.006\alpha_1^2 - 0.25\alpha_1 + 5.99$, $R^2 = 0.93$;

2 - $h = 0.34$ m, $m = 1.67$ kg$(\text{s m})^{-1}$; $N = 0.007\alpha_1^2 - 0.29\alpha_1 + 6.45$, $R^2 = 0.96$;

3 - $h = 0.43$ m, $m = 2.08$ kg$(\text{s m})^{-1}$; $N = 0.008\alpha_1^2 - 0.36\alpha_1 + 7.65$, $R^2 = 0.94$;

4 - $h = 0.51$ m, $m = 2.50$ kg$(\text{s m})^{-1}$; $N = 0.010\alpha_1^2 - 0.38\alpha_1 + 8.76$, $R^2 = 0.90$;

5 - $h = 0.60$ m, $m = 2.92$ kg$(\text{s m})^{-1}$; $N = 0.011\alpha_1^2 - 0.39\alpha_1 + 9.66$, $R^2 = 0.92$

Froude number of straw walker (rotational speed of crankshafts). Its change has an impact on the momentum of straw detachment from the walker surface, the rise height and fall trajectory. The greatest portion of the grains penetrates through the straw layer when it is detached from the walker surface because then it is more porous.

When the Froude number of the straw walker is reduced to 2.35 (205 min^{-1}), the grain separation through the first section of the straw walker began to decrease at an inclination angle of 16° and the straw feed rate was more than 2.08 kg $(s\ m)^{-1}$. When the crankshafts of the straw walker are rotated more slowly the inertial force exerted by the walker on the straw layer is less, thus it rises less after the detachment from the walker surface and more often collides with the walker. Despite the fact that the straw exerts more walkers' pulses they move more slowly through the walker surface, the straw mat is denser, and the conditions for grain separation are worse.

After the estimation of the grain amount remaining in the straw at the beginning of the fourth straw walkers section, the conclusion was made that in spite of the straw feed rate onto the straw walker the smallest amount of grains remained trapped in the straw layer when the first section of the straw walker was at an inclination of 16°. When the Froude number of the straw walker was reduced from 2.58 to 2.35 fewer grains were separated through three straw walker screens when the straw feed rate on the walkers was greater than 2.50 kg $(s\ m)^{-1}$.

Decreasing the Froude number of the straw walker (rotational speed of crankshafts) to ensure the same grain separation on the walker's length the inclination angle of the first straw walker section must be reduced to 16° and the straw feed rate on the walkers should be minimized.

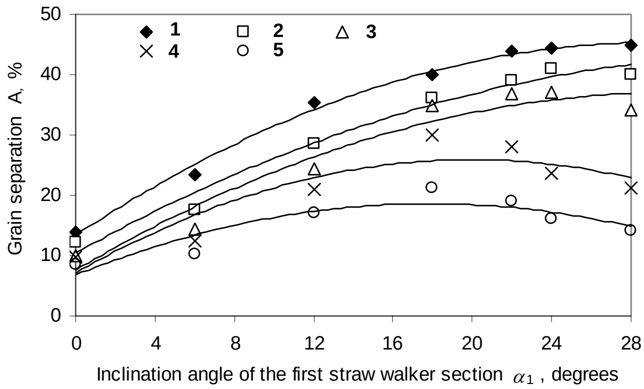

Fig. 4. The impact of the inclination angle of the first section of straw walkers (α_1) and the straw feed rate on the straw walker (m) on the grain separation through the first section of the straw walkers (A) , when k=2.83, n=225 min^{-1}:
1 – h=0.26 m, m=1.25 kg $(s\ m)^{-1}$; 2 – h=0.34 m, m=1.67 kg $(s\ m)^{-1}$; 3 – h=0.43 m, m=2.08 kg $(s\ m)^{-1}$; 4 – h=0.51 m, m=2.50 kg $(s\ m)^{-1}$; 5 – h=0.60 m, m=2.92 kg $(s\ m)^{-1}$,
∗ the grain separation change characteristics are similar to those, when k=2.58, n=215 min^{-1} (Fig. 2), thus equations are not presented.

Increasing the Froude number of the straw walker from 2.58 (215 min^{-1}) to 2.83 (225 min^{-1}), fewer grains were separated through the first straw walker section (Fig. 3) despite the fact that the straw layer received greater inertial forces from the walkers. Under the impact of the walkers the straw jumped high from the straw walker surface. Before the straw collided with the same walker again the crankshafts rotated by 720^o angle (2 rotations) and the straw layer in all conveying time received two times fewer walker strokes. Approximately 1.1 percentage unit more grains occurred on the fourth straw walker section together with the straw (Fig. 4) thus the optimum Froude number of the straw walker was 2.58, an inclination angle of the first straw walker section was 22^o, the step height was 0.28 m, and the straw feed rate on the walkers was 2.08 kg (s m)$^{-1}$.

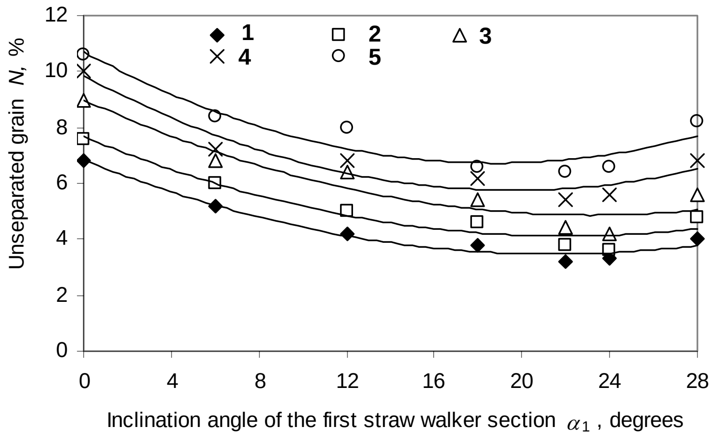

Fig. 5. The impact of the inclination angle of the first section of straw walkers (α_1) and the straw feed rate on the straw walker (m) on the grain amount in the straw at the beginning of the fourth section of straw walkers (N), when k=2.83, n=225 min^{-1}:
1 – h=0.26 m, m=1.25 kg (s m)$^{-1}$; 2 – h=0.34 m, m=1.67 kg (s m)$^{-1}$; 3 – h=0.43 m, m=2.08 kg (s m)$^{-1}$; 4 – h=0.51 m, m=2.50 kg (s m)$^{-1}$; 5 – h=0.60 m, m=2.92 kg (s m)$^{-1}$
* the unseparated grain change characteristics are similar to those, when k=2.58, n=215 min^{-1} (Fig. 3), thus equations are not presented.

Grain separation along the length of straw walkers. The grain separation change through the three sections of straw walkers was tested by changing the inclination angle of the first straw walker section (Fig. 6), when the Froude number was 2.58 (n=215 min^{-1}) and the straw feed rate onto the straw walker was 2.08 kg (s m)$^{-1}$. The greatest number of grains was separated through the three straw walker sections (screens) when the inclination angle of the first section was 22^o (Fig. 6, curve 2).

The most intensive grain separation was when the straw fell from the first straw walker section onto the surface of the second section. When the straw mat moved on the walker surface the grain separation decreased and only 15% of unseparated grains with the straw reached the fourth straw walker section, i.e. 3% of all the grains that fed into the threshing apparatus. Decreasing the angle of the first section of the straw walker to 0^o the beater drum threw the straw further onto the walkers thus the grain intensive separation zone occurred at the middle of the second section of the straw walker, and 8% of grains remained trapped in the straw layer (Fig. 6, curves 1).

Increasing the inclination angle of the first straw walker section up to 24° the straw layer became thicker and 5.2% of grains remained in the straw because the straw accumulated on the walker surface; fewer grains were separated not only through the first straw walker section but through the remaining two sections as well (Fig. 6, curve 3).

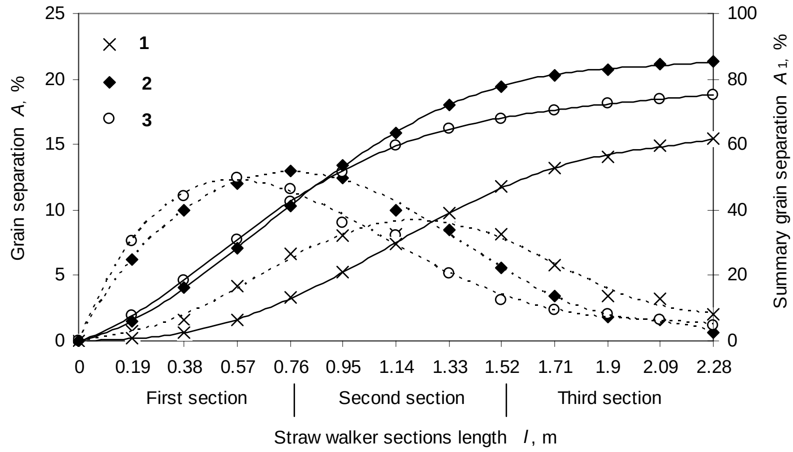

Fig. 6. The impact of the inclination angle of the first section of straw walkers (α_1) on grain separation (A) along the length of straw walkers (l), when k =2.58, n = 215 min^{-1}, h = 0.43 m, m = 2.08 kg (s m)$^{-1}$:
1 – α_1=0°, 2 – α_1=22°, 3 – α_1=24°

Test results of the grain separation on the walker length validated the previous conclusions that the optimum inclination angle of the first straw walker section must be 22° when the Froude number of the straw walker was 2.58.

CONCLUSIONS

The Froude number of the straw walker (rotational speed of the crankshafts) has an impact on the momentum of the detachment of the straw layer from the walker surface, the straw layer rise height, and the falling trajectory. The first step of the walker reduces the initial conveying speed of the straw layer on the walker surface.

The optimum Froude number of the four straw walkers is 2.58 (revolution of the crankshafts 215 min^{-1}), the inclination angle of the first straw walker section is 22°, the permissible limit straw feed rate on the walkers is 2.08 kg (s m)$^{-1}$, and the straw layer height is 0.43 m.

At the optimum Froude number of the straw walkers and the inclination angle of the first straw walker section, the most intensive grain separation from the straw layer was when the layer fell from the first section onto the second. At that time there are approximately 3% of not-separated grains reaching the straw layer of the fourth straw walker section.

Grain separation through the straw layer conveying on the walker surface can be increased by changing the Froude number of the straw walkers or by varying the inclination angle of the straw walker sections.

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