DETERMINATION OF RATIONAL VALUES OF INCLINATION ANGLES OF STRAW WALKER SECTIONS

Dainius Steponavicius, Sigitas Petkevicius, Rolandas Domeika
Lithuanian University of Agriculture
dainius.steponavicius@lzuu.lt

Abstract. Crop yield has been harvested by combine harvesters where threshed grain has been separated from straw by the straw walkers or rotary straw separators. The conventional combine harvesters consist of four, five, six or eight straw walkers with stepped surface. The number of steps, their height and the inclination angle of straw walkers sections (screens) are differed in the straw walkers of various producers. In this study the impact of the inclination angle of the sections of straw walker on grain separation through the straw layer has been tested. About 20 % of the grains threshed and unseparated through the concave of the threshing device have still remained trapped in the straw layer fed on the straw walkers. It has been defined that the greatest number of grains has been 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 four straw walkers was 2.58 (the rotational speed of the crankshafts was 215 min^{-1}). The rational inclination angle of the first straw walkers section was 22º, the second one was 10º, and the third one was 18º, when the straw feed rate on the straw walkers was 2.08 kg $(s{\cdot}m)^{-1}$. The intensity of grain separation can be controlled using the rotational speed of the crankshafts or the inclination angle of the straw walker sections.

Keywords: combine harvester, straw walker design, grain separation, grain loss.

Introduction

The qualitative indices of straw walker operation mostly depend on the walker design, their inclination angle, the amount of the grain in the supplied straw layer, plant species, their characteristics, etc. The kinematics regime coefficient or Froude-number ($k = r{\cdot}\omega^2{\cdot}g^{-1}$), i.e., the ratio of inertia and gravity, is one of the most important indexes of the estimation of straw walker operation. It depends on the straw walker crankshaft radius r and the angular rotation speed ω [1], but these values remain constant in combine harvesters.

Straw walkers limit the efficiency of the self-propelled combine harvesters [2; 4], thus special attention is given to their design development. Grain separation through the straw layer supplied via the section surface in modern combine harvesters is activated by modernizing the design of straw walker assembly, changing the technological parameters, and installing straw mat agitators over the walker surface [2].

The tests have shown that the grain separation in various places of the walker length is uneven [1; 3]. The steps on the walker surface increase the grain separation [1; 5], and the most intensive it is when the straw falls down from the step onto the successive section [3; 4]. Besides, the number and height of the steps depends on the agitator installation place and its design. It has been determined, that the influence of the length and inclination angle of the first section of the straw walker on the separation process is greater than that of other sections. Gusev [5] has stated that the optimization of the inclination angles of the straw walker sections increased the grain separation intensity about 15 % and the adjustment of the parameters of the beater and straw walker position in relation with each other increased the grain separation intensity about 30 %. But insufficient research has been made on the impact of various inclination angles of straw walker sections on the grain separation through the straw layer, and their rational values.

The investigation objective is to determine the rational values of inclination angles of straw walker sections.

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 the walker rotational speed and by optimizing the walker design. The test rig (Fig. 1) consisted of two band conveyors: one for straw 2 and another for grain 1, drum-type straw feeder 3 and the assembly of four individual straw walkers. Weighed straw samples were spread on the band conveyor 2, the grain samples were spread on the band conveyor 1. The conveyor 2 fed the straw into the drum-type straw feeder 3 at the speed of 1 $m \cdot s^{-1}$. The grain fell from the band conveyor 1 onto the supplied straw. The drum supplying unit pushed the straw through the smooth surface of the concave 4, and the beater 7 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 12 powered by an electric motor. The radius of the crankshafts was 0.05 m. The straw walker bottoms made 6° angles with horizontal line. The rotational speed of the crankshafts was altered by the variator within the range of 205 min^{-1} (Froude-number k=2.35) to 225 min^{-1} (k=2.83). On each straw walker, there were four permeable 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 walker steps height allowed the inclination angle of the first, second and third sections 8 of the examined straw walkers to be altered in a range of 6° to 33° (Table 1). It was varied by the screws 10. 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.

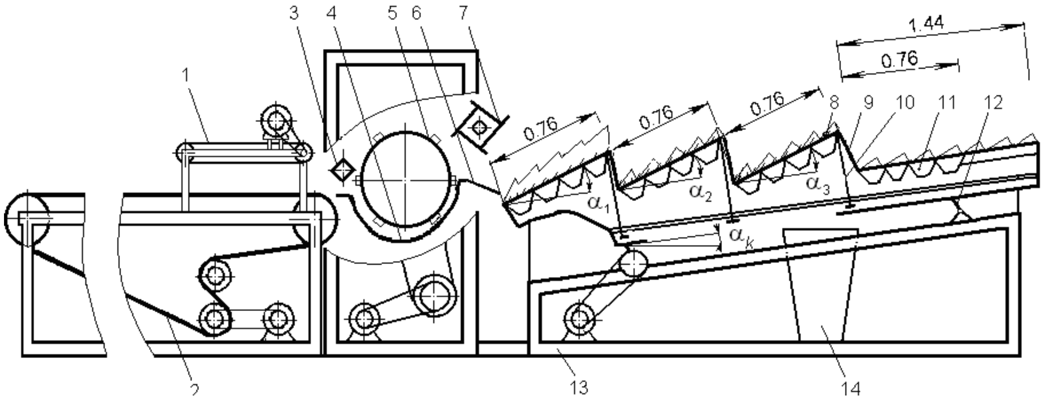

Fig. 1. **Test rig scheme of grain separation:** 1 – band conveyor for grains, 2 – band conveyor for straw, 3 – feeder, 4 – concave, 5 – threshing cylinder, 6 – grate bars, 7 – beater, 8 – sections of straw walker, 9 – steps of straw walker, 10 – inclination control screws of the straw walker sections, 11 – sample bags, 12 – crankshafts, 13 – straw walker frame, 14 – grain collection bag, α_1, α_2, α_3 – inclination angle of the first, second and third straw walker sections, α_k – inclination angle of straw walker (α_k=6°)

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.

During the investigation three replication tests were made. The straw layer was fed on the straw walker at the rate 2.08 kg $(s \cdot m)^{-1}$ and the grain feed rate was 0.42 kg $(s \cdot m)^{-1}$. The straw layer thickness (h) was calculated when it moved along the surface of the straw walker at the speed of 0.35 $m \cdot s^{-1}$. When the supplied straw feed rate (m) was 2.08 kg $(s \cdot m)^{-1}$ the straw layer thickness was 0.43 m. The straw moisture content was 8.2±0.4 %. The grain part separated through the straw walker screens was calculated having in mind the grains (20 %) which reach the straw walker (80 % grains were separated through concave). When the inclination angle of the section (screen) of straw walkers was 6°, it was in mind, that then the inclination angle of the section was 0°.

Table 1

The impact of inclination angle of straw walker sections (L_1=L_2=L_3=0.76 m) of on the step height

Indices	Values							
Inclination angle of first, second and third straw walker sections α_1, α_2, α_3 (°)	0	6	12	18	24	27	30	33
Height of steps H_1, H_2, H_3 (m)	0	0.08	0.16	0.23	0.31	0.35	0.38	0.41

All experiments in this study were repeated in triplicate or more. Differences among means were compared by the one way Analysis of Variance (ANOVA) and using *t*-test with 95 % confidence. The columns in figures followed by the same letter are not significantly different at 5 % level according to *t* post hoc test.

Results and discussion

The inclination angle of the first sections of the straw walker. The impact of the inclination angle of first sections of straw walkers on the grain separation through the straw layer supplied via their surface and sections has been determined. When the inclination angle of the surface of the first sections of straw walkers (α_1=0°) coincided with the straw walker position angle α_k (straw walker without steps) and when the crankshaft rotational speed was changed from 205 to 225 min^{-1}, the grain separation through the first sections decreased from 20 % to 9 %, and behind the three sections (2.28 m) of the straw walkers amounted from 37 % to 46 % of unseparated grain in the straw layer (Fig. 2). The inclination angle of the first sections had positive impact on grain separation through the straw layer. When the walker crankshaft was rotated at the speed of 225 min^{-1} the greatest amount of unseparated grain remained in the straw, because they moved via the straw walker surface at the speed of 0.68 m·s^{-1}, and when the crankshaft rotational speed was 205 min^{-1}, the straw velocity was 0.51 m·s^{-1}, and the straw layer received less strokes.

When the inclination angle of the first sections was increased, the amount of unseparated grain in the straw layer decreased. Its amount depended on the crankshaft rotational frequency. The least amount of grain remained in the straw when the crankshaft was rotated at the frequency of 215 min^{-1} and the first sections were tilted at the angle of 22 degrees (Fig. 2). Then the grain amount equaled to 15.6 % of the grain supplied onto the straw walkers or 3.12 % of the whole grain supplied into the threshing apparatus remained in the straw behind the three sections of the straw walkers (L_{3d}=2.28 m).

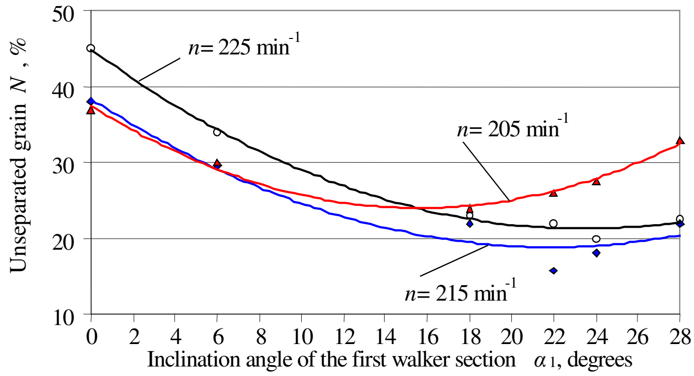

Fig. 2. **The impact of the inclination angle of the first sections (α_1) of the straw walker and the crankshaft rotational speed (n) on the grain amount (N) remaining in the straw behind the three sections of the straw walkers (L_{3d}=2.28 m), when: α_2=α_3=0°**

The test showed that the first sections retarded the straw movement thus 40 % of grain were separated from the straw through the sections. The intensity of the grain separation is determined by the crankshaft rotational frequency. It has been defined that the straw accumulated on the surface of the first sections when crankshafts were rotated at the speed of 205 min^{-1} and when the inclination angle of the first sections of the straw walkers was greater than 18°. Furthermore, the thickness and density of the straw layer also maximized and less grain could pass not only through the first but also through the rest two sections of the straw walkers. The optimum inclination angle of the first sections of straw walkers was 16° when the crankshafts were rotated at the frequency of 205 min^{-1}.

When the rotational speed of the crankshafts was maximized to 225 min^{-1}, the least amount of the grain remained in the straw, when the first sections were tilted at the angle of 24°. The analysis of the filmed material disclosed that when the crankshaft was rotated at the speed of 225 min^{-1}, the straw movement duration was longer, thus their passage speed through the surface of the sections tilted at the angle of 24 degrees was almost the same as the one when the inclination angle was 16 degrees (when n=205 min^{-1}). The test result estimation revealed that when the crankshafts of the straw walker assembly were rotated (at greater than 225 min^{-1} speed), the first sections could be tilted by more straight angles.

When the first sections of the straw walkers were tilted by 6° angle, the separation of the grain maximized by 8 %, as when the inclination angle was α_1=0 degrees (Fig. 3). The optimum inclination angle of the first sections was 22°, because 42 % of the grain was separated through the sections from the straw, and through all three sections of the straw walkers even 84.4 % of the grain was separated. The most intensive grain separation was when the straw fell down from the steps. When the first sections were tilted at the greater than 22° angle, even if the grain separation increased insignificantly (from 41 % to 43 %), but it decreased significantly through the second ones (from 38 % to 30 %), because the straw layer became thicker when the straw moved through the surface of the first sections. The research helped to conclude that the optimum inclination angle of the first sections of the straw walkers was 22°, when the rotation frequency of the crankshafts was 225 min^{-1}. The most intensive grain separation occurred when the straw fell from the first sections of the straw walkers and onto the surface of the second sections.

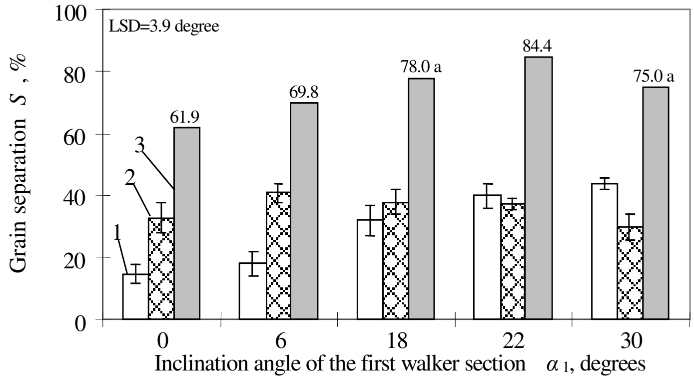

Fig. 3. **The impact of the inclination angle of the first sections (α_1) of the straw walker on the sum grain separation (*S*) through the first (1) and the second (2) sections, and the three sections (3) of the straw walkers (L_{3d}=2.28 m), when:** n=215 min^{-1}, $\alpha_2=\alpha_3$=0°

The impact of the inclination of the second and the third sections on the grain separation. The grain separation through the length of the second and the third sections depended on the inclination angle of the second sections. The tests disclosed that when the inclination angle of the second sections was increased from 0 to 12 degrees, the grain separation through the straw layer in the front part (0.76 m) of the straw walker remained almost constant (only 38 % of the grain was separated). With the further increased of the angle α_2 the separation minimized, as decreased the height of the straw downfall from the first sections onto the second ones. But it was impossible to tilt the second sections by less than 12 degree angle because the grain separation through the sections of the third steps minimized because of that. When the above mentioned sections were tilted by the angle of 12 degrees, the greater amount of grain (45 %) was separated through the second and the third sections, and through all three sections of the straw walkers 89 % of the grain was separated (Fig. 4).

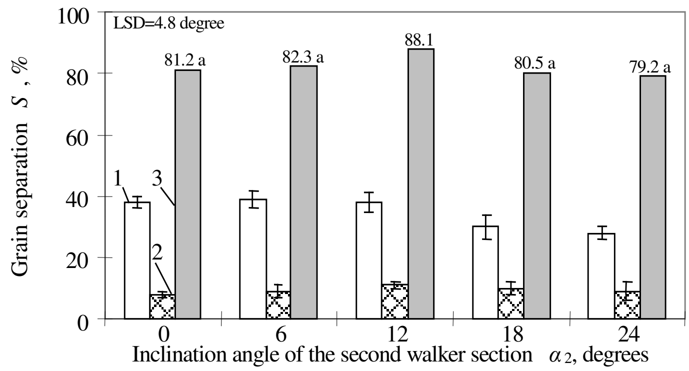

Fig. 4. **The impact of the inclination angle of the second sections (α_2) of the straw walker on the sum grain separation (*S*) through the second (1) and the third (2) sections, and the three sections (3) of the straw walkers (L_{3d}=2.28 m), when:** n_k=215 min^{-1}, α_1=22°, α_3=0°

The optimum inclination angle of the second sections was determined after the estimation of the value of the grain separation efficiency coefficient E, i.e., the ratio of the amount of the grain separated through the sections with the amount of the supplied grain. The maximum value of the coefficient E was α_2 at the limit of 6° and 12° (Fig. 5). The grain separation through the third sections was the most efficient when the second sections were tilted by the angle from 8° to 18°. Thus the second sections of the straw walker should be inclined at the angle of not less than 9 degrees and not more than 13 degrees. Besides, the second sections were almost twice as effective (E=0.65) for grain separation if compared with the effectiveness of the third sections (E=0.38) when α_2 was optimum and equaled to 10°.

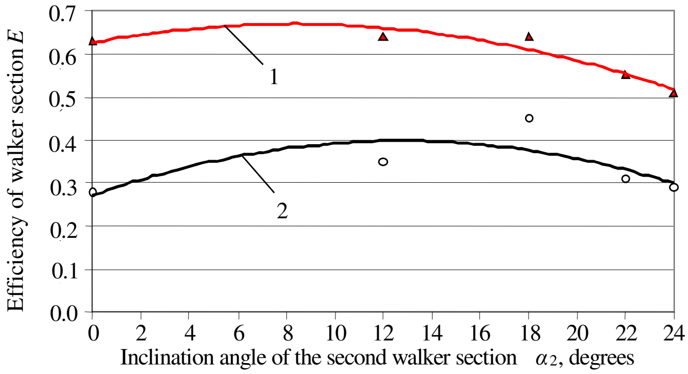

Fig. 5. **The impact of the inclination angle of the second sections (α_2) of the straw walker on the efficiency coefficient (E) of the second (1) and the third (2) sections, when:** n_k=215 min^{-1}, α_1=22°, α_3=0°; 1 – the efficiency coefficient of the second sections, $E = -0.0006\alpha_2^2 + 0.010\alpha_2 + 0.63$; R^2=0.92; 2 – the efficiency coefficient of the third sections, $E = -0.0008\alpha_2^2 + 0.020\alpha_2 + 0.27$; R^2=0.84

When the inclination angle of the third sections was varied, the grain separation through the length of the sections remained almost unchanged (Fig. 6). Approximately 10 % of the grain from the straw walker surface was separated via the third sections. To determine the optimum inclination angle of the third sections the grain separation was also tested in the fourth sections length of 0.76 m. When α_3 was increased from 0 to 18°, the amount of the grain separated through the 0.76 m segment of the fourth sections of the straw walker increased from 3.5 % to 4.5 %. The grain separation stopped to increase at further maximizing the inclination angle of the third sections. After the grain separation was calculated in the segments of the third and the fourth sections of the straw walker, and the sections effectiveness was estimated (Fig. 7), it was determined that the optimum inclination angle of the third sections was 18 degrees. Then 14 % of the grain that were supplied to the straw walker were separated through both sections.

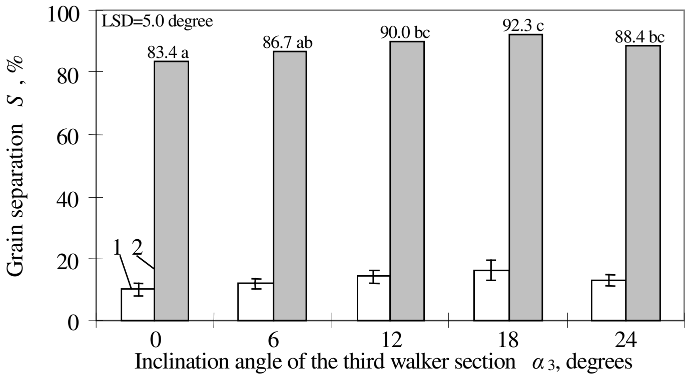

Fig. 6. **The impact of the inclination angle of the third sections (α_3) of the straw walker on the sum grain separation (S) through the third and the fourth (1), and the three sections (2) of the straw walkers (L_{3d}=2.28 m), when:** n=215 min^{-1}, α_1=22°, α_2=10°, α_4=0°

When the inclination angles of the front part (L_{3d}=2.28 m) of the sections of the straw walker were optimized, more than 90 % of the grain supplied to the surface of the straw walker could be separated from the dry straw. Besides, when the inclination angle of the sections of the straw walker was increased, the step connecting the sections also maximized, thus it also positively influenced the grain separation through the successive sections of the straw walker. The tests helped to reveal that the grain separation through the straw walker assembly minimized, so it was appropriate to install the straw agitator next to the third steps.

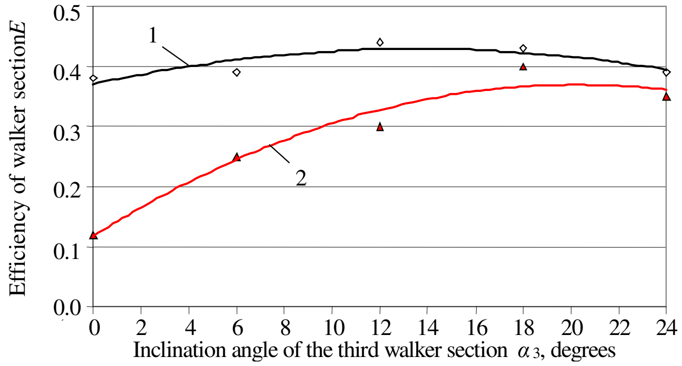

Fig. 7. **The impact of the inclination angle of the third sections (α_3) of the straw walker on the efficiency coefficient (E) of the third (1) and the fourth (2) sections, when:** α_1=22°, α_2=10°, α_4=0°;
1 – The efficiency coefficient of the third sections, $E = -0.0003\alpha_3^2 + 0.0086\alpha_3 + 0.37$; R^2=0.91;
2 – The efficiency coefficient of the fourth sections, $E = -0.0006\alpha_3^2 + 0.0249\alpha_3 + 0.12$; R^2=0.95

Conclusions

1. The intensity of the grain separation through the straw layer and the first sections of the straw walker can be adjusted with the crankshaft rotation frequency and the inclination angle of the sections, when α_1=16°, the crankshafts should be rotated at the speed of 205 min^{-1}, and when α_1=24°, at the speed of 225 min^{-1}, and about 2 kg/s·m of the straw should be supplied to the straw walker.
2. The optimum inclination angle of the first sections of the straw walker is 22°, that of the second ones is 10°, and the third ones is 18°. After optimization of the inclination angles of the three sections of the straw walker, in the part (L_{3d} = 2.28 m) of the straw walker length the grain separation exceeded 90 % of the grain supplied to the straw walker.
3. Through the supplied straw layer and the first sections of the straw walker 44 %, through the second sections 65 %, and through the third sections 38 % of the grain were separated, when the inclination angles of these screens were optimum (α_1=22°, α_2=10°, α_3=18°). As the grain separation via the length of the straw walker sections minimizes, it is considered appropriate to install the straw agitator next to the third steps.

References

1. Зубков В. И. Основы механики среды дискретных частиц (Basics of the mechanic the medium of discrete particles). Rostov na Donu: DGTU, 1996. 167 p. (In Russian).
2. Kutzbach H.D., Wacker P., Böttinger S. Grain Harvesting. Combine Harvesters. Yearbook Agricultural Engineering. VDI Verlag, Düsseldorf, Bd. 18, 2006, pp. 143-153.
3. Steponavičius D., Špokas L., Petkevičius S. The influence of the first straw walkers section on grain separation. Agronomy Research, Vol. 6 (Special issue), 2008, pp. 377-385.
4. Špokas L., Steponavičius D. Impact of wheat stubble height on combine technological parameters. Journal of Food, Agriculture & Environmental, Vol. 8, Nr. 2, 2010, pp. 464-468.
5. Гусев А. П. Обоснование параметров рабочих поверхностей и режима работы соломотряса зерноуборочного комбайна (Design and setting of straw walker of combines). Совершенствование почвообрабатывающих машин: Труды МИИСП. Москва, 1987. pp. 76-80. (in Russian).