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Development of a stripper-header for grain harvesting

A. Strakšas

Institute of Agricultural Engineering Lithuanian University of Agriculture,
Institute St. 20, LT-54132 Raudondvaris, Kaunas r., Lithuania; e-mail: anicetas@mei.lt

Abstract. Crop stripping technology has not been investigated in Lithuania until 2000 as there were no devices for this technology. The paper includes the scheme of a designed and manufactured experimental device (hereinafter 'stripper'), applied to crop ear stripping technology, and describes its operation principle. The results of operation and comparative tests are presented. Energetic indices of traditional and ear stripping technology were defined. It was determined that when the operating speed of the harvester with a stripper increased, the grain losses of wheat and barley stripping decreased. When stripping and threshing wheat, the operating speed of the harvester has no impact on grain threshing-separating losses. When stripping barley, it has a small impact: if the speed increases, the losses also increase insignificantly but do not exceed the permissible limit. When comparing ear stripping technology with the traditional crop harvesting one, the harvester output is twice as high as that in the first technology: 40% of fuel is saved.

Key words: stripper, combine, output, grain losses, fuel consumption, energetic efficiency

INTRODUCTION

In foreign countries, wider tests of stripping crop ears were started in the nineties of the 20th century, and nowadays various stripping devices are produced and widely implemented in numerous countries. The UK company *Shelbourne Reynolds Engineering* Ltd is the leader in this field. Investigations are carried out in Germany, Italy, Canada, Austria, Russia, Belarus, Latvia, Ukraine and other countries as well. In scientific literature, a lot of articles have been published on stripping issues. Beginning from 1987 (Klinner, 1987), the investigations have been carried and are continued at present (Vlasenko, 2004).

The firm *Shelbourne Reynolds Engineering LTD*, Great Britain, manufactures strippers with 3–9.8 m operating width and sells them to different countries. It has an especially great input in the harvesting-stripping of different cereals. The strippers operate with harvesters of different types: *New Holland, Claas, John Deere, Massey Ferguson, Fortschritt* and others. Using ears combing technology, only 20% of straw get into the harvester, thus the harvester can work faster. Operation output increases and fuel consumption decreases.

When grain harvest is taken with strippers, the straw is left on the soil. The straw can be taken in differently depending on the height, straw demand, available technique. Many countries widely apply straw ploughing after combing. Ploughed straw becomes an organic fertiliser. Ploughing the chopped straw is applied in

England, Germany and other countries. According to investigations carried out by English researchers (Patterson, 1983; The pros and ..., 1984), if the straw is incorporated correctly, the yield of wheat and barley increases, but when badly incorporated, the yield decreases, especially, during the first year after ploughing. German researches indicate that when ploughing up to 6 t ha^{-1} of straw, it should be inserted in the depth of 10 cm, when ploughing up to 12 t ha^{-1} of straw, it should be inserted in the depth of 20 cm. It is necessary to spread about 10 kg of nitrogen per 1 t of straw also (Probleme..., 1986). Russian researchers state that 1 t of straw with 10 kg of nitrogen is equal to 3.5 t of manure (Sharikov, 1999). Germany also uses another type of straw management technology when crop fields are cultivated after combing by big powerful combined aggregates '*Combi–Disc–Cutter'*.

The goal of the investigations is to create an ear stripping technology and a stripper, to determine agrotechnical indices of crop combing and straw management, trying to decrease energy consumption and production costs.

MATERIALS AND METHODS

After the analysis of stripping, patents and inventions devices – three worldwide patents of *Shelbourne Reynolds Engineering LTD,* Great Britain, (PCT/GB/WO 92/08339, 1992; PCT/GB/WO 89/00073, 1989; PCT/GB/WO 93/13642, 1993), were chosen for the stripper construction scheme and comb form. The scheme of the experimental stripper is presented in Fig. 1. The stripper consists of an octagonal rotor 1 with plastic combs 2, regulated front cowl 3, top cover 4, fixed pan 5 and two passive dividers 6. When the harvester passes through a crop field, the rotor combs moving clockwise cut the ears (part of them are threshed) and throw them into the auger 7. Then the technological process goes according to the traditional scheme when cutting crop. The stripper is mounted on the combine *SR 500* instead of a harvester cutting device and reels.

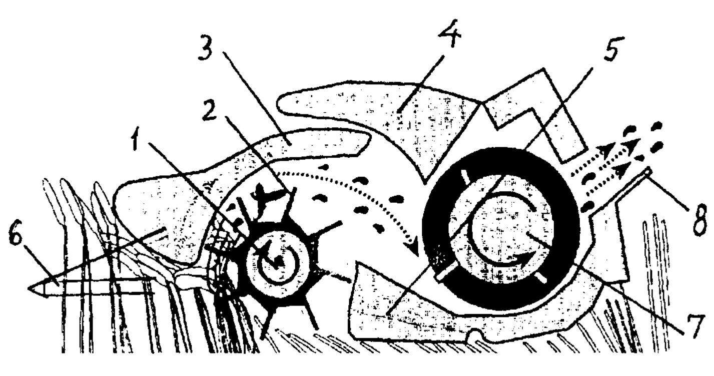

Fig. 1. Scheme of the stripper: 1 – rotor; 2 – plastic combs; 3 – regulated front cowl; 4 – top cover; 5 – fixed pan; 6 – exterior divider; 7 – combine auger; 8 – slanting chamber.

Technical description of the stripper header is presented in Table 1, specification of the combine *SR* 500 – in Table 2. It is noteworthy that the cereal ear stripper is 1.4 times heavier than a conventional combine cutter with reels. This can be problematic when working on wet soils, as the driving wheels of the combine receive a higher pressure.

Table 1. Technical specification of the stripper header.

Title	Measure units	Meaning
Aggregation (make of a combine)		*SR* 500
Working width	m	2.30
Working speed	km h^{-1}	1.5–8.1
Capacity	ha h^{-1}	1.5
Service staff / number of people		1
Diameter of stripping rotor with comb	mm	540
Step of comb (teeth)	mm	40
Revolutions of stripping rotor	rpm	340–1050
Distance from soil surface to comb of rotor (at the bottom)	mm	30–700
Dimensions:	m	
length		1.9
width		3.1
height		0.9
Total weight	kg	600
Number of drives:		
belt		1
chain		1
reductor		1

Table 2. *Sampo Rosenlew 500* technical specification.

Title	Measure units	Meaning
Table		
Cutting width	m	2.28
Cutting height	m	–0.07+0.84
Knife speed	stroke min^{-1}	1020
Threshing Device		
Cylinder width/Diameter	cm	86/50
Cylinder speed range	rpm	600...1320
Concave area	m^2	0.40
Concave wrap angle	degrees	105

Continuation of Table 2

Title	Measure units	Meaning
Straw Walkers		
Number	pcs	4
Area, separating	m^2	2.91
Type		Cassette turn walker
Cleaning Device		
Top sieve area	m^2	0.84
Grain sieve area	m^2	0.80
Total separating	m^2	1.64
Fanning mill, speed range	rpm	2500
Grain Tank		
Capacity	cbm	2.1
Unloading height	m	2.7
Engine		
Type		3 cylinder diesel
Model		Valmet 311 DL
Power	kW/HP	47/64
Fuel tank capacity	l	100
Transmission		
Speed	km h^{-1}	1.5...19.8
Weights and Dimensions		
Height	m	2.75
Width	m	2.76
Length (in transport)	m	7.4
Weight with 2.3 m table	kg	4000

Crop characteristics and technological features were determined according to the standard method (Strakšas, 1992, 1995). Harvester operation indices in the base technologies and in the technology of ear stripping were estimated taking into account combing, cutting and threshing-separation grain losses (Strakšas, 1992; Strakšas & Jurpalis, 2000;). The straw of combed crop was inserted into the soil with the knife harrow *BNV*–3, with the disk harrow *BDT*–3 and the composite straw shave '*Ražienis*–3' constructed in our institute. Energy consumption and energetic efficiency of crop combing technologies were estimated according to methodological recommendations (The methodical ..., 1989) and test results of our experiment. In order to determine fuel consumption for the combine *SR* 500, the device of new design was used operating according to the principle of communicating vessels.

Table 3. Indicators of adjusting working parts of the combine *SR* 500.

Indicators	Measure units	Meaning	
		wheat	barley
Revolution rate of threshing drum	min^{-1}	1000	1100
Gaps between drum and concave (front/end)	mm	10/5	10/5
Revolution rate of fan impeller	min^{-1}	2500	2500
Gaps between upper sieve chaffer	mm	12	14
Gaps between upper sieve extension plates	mm	12	12
Diameter of bottom sieve holes	mm	12	12
Fan rod of damper	position	9	9
Fan air stream direction rod of shield	position	6	6

The main indicators of adjusting working parts of the combine *SR* 500 during harvesting of the *'Almari'* variety wheat and the *'Ula'* variety barley are presented in Table 3. During the test, we measured the experiment field length, trial duration, working widths of the stripper and combine header and fuel consumption.
Experimental data were processed according to the statistical method recommended by the international standard ISO 7256/1.2 and literature (Dospechov, 1985). The average values of the data and their validity intervals $[\bar{x} \pm (t_{05} \times S_x)]$ are presented. In order to establish correlation of two factors, the curvilinear correlation coefficient η^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

Some biometrical indicators and technological characteristics are presented in Table 4. Operation indices of the stripper with the combine *SR* 500, when combing wheat and barley, are given in Fig.2.

Fig. 2 reveals that operating speed of the combine has a great impact both on wheat and barley combing grain losses: the higher is the speed, the lower are the grain losses. However, the operating speed is limited by technical facilities of the harvester itself. The maximum operating speed of the combine *SR* 500 reached in our tests was only 7.5 km h^{-1}, and this corresponds to the maximum speed of the second gear (the third gear is transport). The second and forth curves in Fig. 2 indicate that operating speed in crop combing technology both in wheat and barley threshing-separation has a small influence on grain losses. They tend to increase a little but under normal crop harvesting conditions the grain losses do not exceed the limit. In comparative experiments, traditional technology wheat and barley harvest was cut with the combine *SR* 500 of serial production.

Table 4. Wheat and barley characteristics and technological qualities.

Indices	Measure units	Meaning	
		wheat	barley
Plant density	unit m^{-2}	525±4	713±5
Weed infestation	%	0	0
Height of plant	cm	75.75±0.14	70.05±0.19
Plant lodging	%	4.08±0.08	16.19±0.27
1000 grains weight	g	39.52±0.03	41.61±0.04
Grain yield	t ha^{-1}	6.14±0.07	6.13±0.66
Grain and straw proportion		1:1.34	1:0.75
Moisture:	%		
grain		11.25±0.01	13.55±0.02
straw		24.08±0.11	28.68±0.32
chaff		10.49±0.09	14.65±0.14

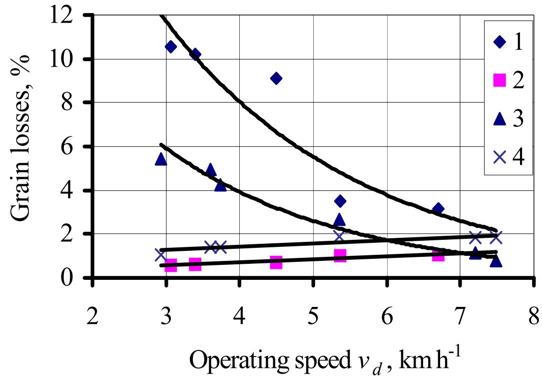

Fig. 2. Dependence of combing R_s and threshing-separation $R_{k\text{-}s}$ grain losses on combine *SR* 500 operating speed v_d: 1– wheat combing grain losses R_{s1}; 2–wheat threshing-separation grain losses $R_{k\text{-}s(1)}$; 3 – barley combing grain losses R_{s2}; 4 – barley threshing-separation grain losses $R_{k\text{-}s(2)}$.

$$R_{s1} = 36.7e^{-0.38v_d} \qquad \eta_1^2 = 0.86$$

$$R_{k-s(1)} = 0.14v_d + 0.14 \qquad \eta_2^2 = 0.92$$

$$R_{s2} = 20.34e^{-0.41v_d} \qquad \eta_3^2 = 0.97$$

$$R_{k-s(2)} = 0.15v_d + 0.8 \qquad \eta_4^2 = 0.79$$

Fig. 3 shows the impact of crop cutting and threshing-separation grain losses on combine operating speed.

Using traditional technology, the combine operating speed in barley field is limited not only by increase of threshing-separation grain losses (Fig. 3, curve 4), but also by combine operation as working at a higher speed than 3.5–3.8 km h^{-1}, the technological process of the harvester breaks down, i.e. the auger of the reaper and the threshing device get chocked. According to the permissible threshing-separation grain losses in Fig. 3, it can be determined that a rational operating speed of the combine *SR* 500 in barley field is 3.2 km h^{-1}, and in wheat field – a little higher. When summarising the data of Fig. 2 and 3, it could be stated that, comparing the crop combing technology with traditional one, the combine operating speed is achieved twice as high as in the first technology than in the second one while the output also increases.

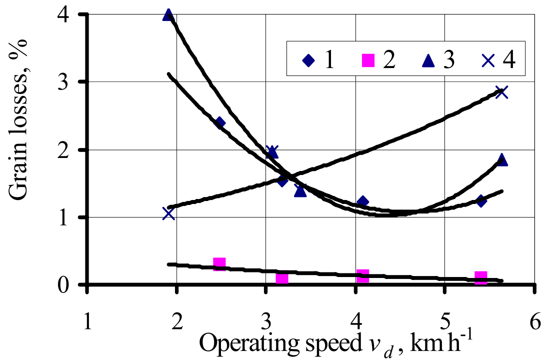

Fig. 3. Dependence of cutting $R_{pj.}$ and threshing-separation $R_{k\text{-}s}$ grain losses on combine *SR* 500 operating speed v_d: 1– wheat cutting grain losses $R_{pj.(1)}$; 2 – wheat threshing-separation grain losses $R_{k\text{-}s(1)}$; 3 – barley cutting grain losses $R_{pj.(2)}$; 4 – barley threshing-separation grain losses $R_{k\text{-}s(2)}$

$$R_{pj.(1)} = 0.28v_d^2 - 2.59v_d + 7.05 \qquad \eta_1^2 = 0.98$$

$$R_{k-s(1)} = -0.22\ln(v_d) + 0.45 \qquad \eta_2^2 = 0.62$$

$$R_{pj.(2)} = 0.5v_d^2 - 4.37v_d + 10.53 \qquad \eta_3^2 = 0.99$$

$$R_{k-s(2)} = 0.71e^{0.25v_d} \qquad \eta_4^2 = 0.82$$

During experimental tests of a stripper header, it was established that rational frequency of revolutions of a stripping rotor is 500–600 min^{-1} when stripping wheat and 600–650 min^{-1} when stripping barley.

The quality indices of both cereal harvesting technologies are presented in Table 5.

Table 5. Quality indices of cereal harvesting technologies.

Title of indices	Measure units	Value of indices			
		Technology			
		Stripping-threshing		Cutting-threshing	
		wheat	barley	wheat	barley
Grain losses:	%				
of combing		2.8	0.5	–	–
of cutting		–	–	1.5	1.3
of threshing-separation		0.5	0.7	0.2	1.8
total		3.3	1.2	1.7	3.1
Germinating power	%	90.5±0.31	90.5±0.21	88.0±0.44	86.0±0.26
Control[1]		89.5±0.24	89.0±0.44	89.5±0.24	89.0±0.44
Germinating ability	%	96,5±0.24	95.5±0.21	95.0±0.24	89.5±0.19
Control[1]		99.5±0.07	92.5±0.27	99.5±0.07	92.5±0.27

[1] The ears of wheat and barley threshed manually

Technologically, barley straw could be ploughed after the combing without any additional technological operations. From the agrotechnical point of view, the stubble should be shaved before ploughing. Ploughing the combed straw of high wheat, the higher or lower volume of straw is left on the surface of soil (see Table 6). It depends on the fact whether long straws were cultivated with a disk harrow or not and what plough was used. Volumetric value of straw left on the soil surface after its ploughing is not significant and makes: 8–14.6 kg ha^{-1} when the stubble was shaved and up to 59.7 kg ha^{-1} when the stubble was left unshaved.

Table 6. Residue of wheat straw on the surface of ploughed soil, percentage.

Shaved stubble		Not shaved stubble		
plough *MF* 715	plough *PN*–3–35	plough *MF* 715	plough *PN*–3–35	plough *PN*–3–35[1]
0.08	0.15	0.31	0.60	0.24

[1] – with a beam before a plough

Data in Table 6 reveal that when ploughing the straw of wheat not shaved with a plough *PN*–3–35 and having a massive wooden beam hung under the tractor to bend the straw before the ploughing, straw residue on the surface of ploughed soil is 2.5 times lower. There were no technological problems during the experiments because of combed straw neither during the ploughing nor spring cultivating.

Consumed and saved energy per hectare was estimated. The average grain and straw yield, grain losses, factual output of traditional and combing technologies, fuel consumption and other starting data were taken from the results of our experiments. When estimating the energy saved in production, the energy of straw inserted into the soil (with 10 kg t^{-1} of straw nitrogen added) was calculated as follows: barley straw would amount to 14.35 t ha^{-1} of manure and wheat straw would amount to 28.70 t ha^{-1} of manure. The energetic equivalent of manure is 0.4 MJ kg^{-1}. The summary of energetic indices is presented in Table 7. Its data reveal that the coefficient of energetic efficiency is 5.1–6.4, i.e. putting 1 MJ of energetic input gains 5–6 MJ of energy. Diesel fuel consumption has a great impact on overall energy consumption. Actual fuel consumption, when harvesting wheat and barley according to the combing technology, is shown in Fig. 4; Fig. 5 shows fuel consumption using traditional technology. The figures apparently prove fuel economy of 37–42%, gained while combing and threshing only crop ears (compared to traditional technology).

Table 7. Summary of energetic indices.

Title of indices	Measure units	Wheat		Barley	
		combine *SR* 500		combine *SR* 500	
		serial	with stripper	serial	with stripper
Direct energy input, t.no.:	MJ ha^{-1}	16680	16417	14817	14464
diesel		3671	3408	2820	2467
fertilisers, seeds, herbicides, other chemicals		13009	13009	11997	11997
Energy consumption	MJ ha^{-1}	1471	1121	1181	878
Labour input	MJ ha^{-1}	10.2	9.2	7.4	6.5
Overall energy input	MJ ha^{-1}	18161	17547	16005	15348
Energy saved in production	MJ ha^{-1}	93030	91213	100508	98069
Coefficient of energetic efficiency (α_e)		5.12	5.20	6.28	6.39

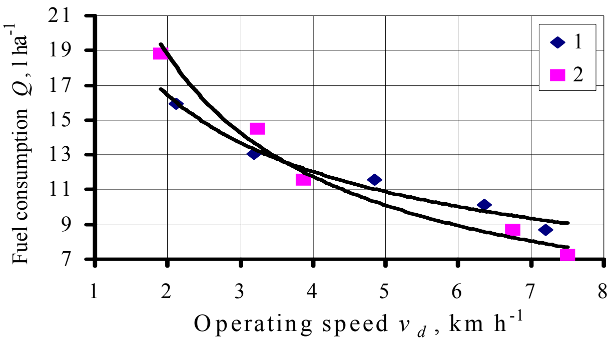

Fig. 4. Dependence of combine *SR* 500 fuel consumption Q on operating speed v_d in crop combing technology: 1 – wheat; 2 – barley

$$Q_1 = 22.47 v_d^{-0.45} \qquad \eta_1^2 = 0.96$$

$$Q_2 = 30.01 v_d^{-0.68} \qquad \eta_2^2 = 0.98$$

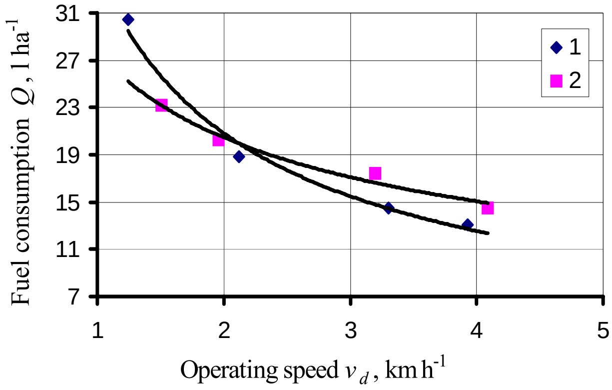

Fig. 5. Dependence of combine *SR* 500 fuel consumption Q on operating speed v_d in basic technology: 1 – wheat; 2– barley

$$Q_1 = 34.53 v_d^{-0.73} \qquad \eta_1^2 = 0.99$$

$$Q_2 = 27.77 v_d^{-0.44} \qquad \eta_2^2 = 0.97$$

CONCLUSIONS

1. The designed experimental stripper for the cereal combine *SR* 500 provides good results in harvesting wheat and barley. Increased combine operating speed reduces grain stripping losses.

2. When combing and threshing wheat, combine operating speed has no impact on threshing-separation grain losses; when combing and threshing barley, it has a small impact: when operating speed is increased the losses increase though not significantly and do not exceed the permissible limit. Rational rate of stripping drum revolution for wheat is 500–600 min^{-1}, and for barley – 600–650 min^{-1}.

3. In barley combing technology, grain total losses are 2.58 times less than those of cutting-threshing, but total grain losses of wheat stripping-threshing technology are 2.75 times greater than traditional technology losses at harvesting wheat by a combine of mass production – *SR* 500.

4. From the technological point of view, barley straw combed can be ploughed without stubble shaving. Wheat straw could be ploughed after stubble shaving (inserting long straw) with a knife, disk harrow or other aggregates. Then after ploughing, very little of straw is left on the surface of the soil (0.08–0.15%), and this does not hinder the further soil cultivation operations.

5. When comparing the stripping-threshing technology with traditional crop harvesting technology, the output of combine in the new ears combing technology increases twice, the fuel economy is 37–42%.

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