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CONTEMPORARY COMBINE HARVESTERS IN CORN HARVESTING

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SUMMARY
The goal of the investigation was to analyze parameters and indicators of performance for modern combine harvesters in corn harvesting, as a basis to review the possibility for improved performance, productivity, as well as decrease of fuel consumption per product unite.
Relevant parameters and indicators were established, according to investigations results. Fuel consumption was 14.04 l/ha, and 58.97 l/ha for efficiency of 24.2 ha/h and average working speed 8.0 km/h.
The utilization range of investigated harvesters was 70%, with a considerable potential for improvement, through better harmonizing of the working regime and the working conditions.
KEY WORDS:
contemporary harvesters, corn, speed, energy, losses, efficiency

1. INTRODUCTION

Short duration of optimal time for harvesting is very important limitation factor. The period in which the grain is in optimal condition for harvesting takes 5 to 15 days. From this fact can be concluded that harvesting process should take very short period or should be finished very fast. This is particularly important in cereals harvesting, which are suffering of significant losses caused by falling of, hectoliter weight decrement (increased early morning air moisture and rainfalls), and difficulties in mowing because of weeds and laid crop. The losses increase exponentially five to ten days after the full technological maturity stage.

Wheat harvesters, same as the other agricultural machines, have the capacity that should be maximally exploited, in certain exploitation conditions, with the purpose of minimal working expenses to be achieved. This is possible with the simultaneous efficiency increment and fuel consumption decrement.

The purpose of this investigation is analysis of parameters and indicators of harvesters work in corn harvesting, as a base for consideration of all the possibilities for optimization of harvesters work in harvesting, as well as organization of harvesting process, harvester's maintenance and operators training and education.

2. MATERIAL AND METHOD

Investigation comprehended several types of harvesters from different manufacturers, with accent on the model Claas Lexion 450 with the fallowing technical characteristics:

Adapter: 6-rows, Conspeed 6 -70 FC

- Working width 4.3 m with the stalk chopper
- Working width 4.1 m without the stalk chopper
- Leading chains - length 1216 mm
  - links number 38
  - link length 32 mm
- Linear speed - 3.81 km/h
- Sliver rollers - 285 rpm
- Stalk chopper - 1800 rpm
- Engine "Cummins" - 220 kW

The harvester Claas-Lexion 450 was tested during the period from October the 7th to October the 10th, 2003. at the corn fields of PKB Corporation. All the methods applied during the investigation are designed and elaborated at the Institute of Agricultural Engineering of the Faculty of Agriculture in Belgrade. The harvester No. 111 was tested at the field unit No. 59 of the PKB farm "Lepušnica".

Because of the drought, the harvesting in PKB started much earlier then usually. Nevertheless, an average corn yield of 6.9 t/ha was recorded. During the investigation, different influencing factors were recorded and analyzed, also.

Air temperature rated from 8 °C (morning temperature) to 10 °C (daily), with the air humidity of 68 to 75 %.

Crop characteristics were the fallowing:

- Corn hybrid - SK 677
- Stalk height - 200 cm
- Height to the cob - 75 cm
- Plant density - 57.000/ha
- Row distance - 70 cm
- In-row distance - 20 - 25 cm
- Yield - 8.3 t/ha
- Grain moisture - 17%
- Cob - length 20.17 cm
  - thickness 4.5 cm
- Mass – 366.8 g
- Cob : stalk ratio - 1 : 1.2
- Kernel : cob : husk ratio - 1 : 0.15 : 0.06
- Crop stage - standing
- Weeds - 15%

Harvester work was fallowed from the early morning e.g. from the beginning of the regular morning maintenance and harvester daily work preparation, to the end of daily work and return of the harvester to the parking place in the farm yard.

The investigation has included the fallowing parameters:

- Speed on the distance of 30 m.
- Harvester efficiency.
- Fuel consumption.
- Working width.
- Cutting height, e.g. stalk residue height after the harvester passage.
- Kernel mass (from the bunker) from the distance of 30 m (mass flow).
- Mass of kernel and stalk chops collected on the measuring cloth (losses).
- Time structure of the working process.

For the measurements were used: stop-watch, length strip, marks, measuring cloth, cloth hose, bunker, balance etc.

Before the testing, harvester needed to be prepared. To the back side of the harvester was mounted the measuring cloth for collecting the stalk residues together with the husk and possibly lost kernel. At the outlet auger was mounted the cloth hose for directing the kernel into the bunker, which was used for mass flow measurement.

3. RESULTS AND DISCUSSION

Threshing/detaching the kernels from the ears or pods is accomplished by a combination of impact and rubbing action. While the conventional tangential threshing unit threshes mostly by impact, other threshing devices like rotary threshing units act more by rubbing. A survey of a number of threshing devices is given by Caspers. Rotary threshing units in which the crop is fed axially or tangentially into the rotor are becoming more popular (Fig. 1).

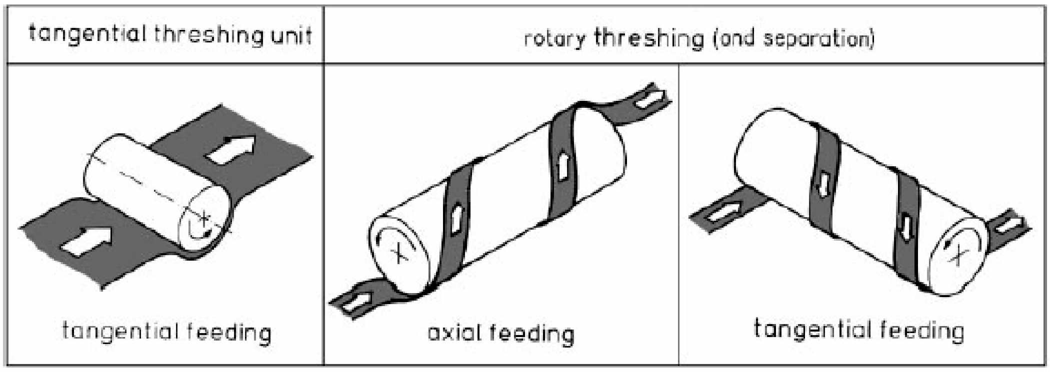

Fig. 1. Feeding of threshing cylinders

Additional tasks of the threshing units are the separation of the grain through the concave and transferring the straw to the straw walker or separating section. In rotary combines, generally, the front part of the one or two rotors threshes and the rear part separates the grain from the straw, making use of higher *g*-forces without the need for gravity-dependent walkers.

Increment of threshing cylinder peripheral speed decreases threshing loses. Some typical peripheral speeds are shown in Table 1. To adjust speed, the threshing cylinder is driven by a variable-speed power belt drive or hydrostatic transmission, often in association with a reduction gearbox for speed-sensitive crops like peas or soybeans.

Table 1. Typical conventional rasp bar cylinder settings for a range of crops

Crop	Peripheral Speed [m/s]	Clearance [mm] Front	Clearance [mm] Rear
Barley	27 - 34	10 – 18	3 - 10
Beans	7 - 20	20 – 35	10 - 18
Maize	10 - 20	25 – 30	15 - 20
Oats	27 - 35	12 – 20	3 - 10
Peas	7 - 18	20 – 30	10 - 18
Rapeseed	15 - 24	20 – 30	10 - 20
Rye	25 - 35	12 – 20	3 - 10
Rice	20 - 30	14 – 18	3 - 6
Wheat	24 - 35	12 – 20	4 - 10

Additional separation cylinders may be placed behind the beater (New Holland, MF, Fiatagri, Deutz-Fahr) or in front of the threshing cylinder (Claas). Between the drums the material is loosened up for improved grain penetration. In hard work conditions, power supply for additional separation cylinders and rotors, placed at any position (in front or behind of the main cylinder), increases and requires the more powerful engine.

Separation efficiency of straw-walkers decreases rapidly with increasing MOG throughput because the straw layer cannot be loosened enough and grain gets caught in the straw. To improve separation efficiency of straw walkers, a range of walker auxiliaries have been tried and some are in commercial use. Crop path can be tangential. In this case several drums are necessary to get sufficient separation length (CS, Claas). With an axial separator, the crop moves in axial and tangential direction along a helical path. Thereby the separation length will be long enough for nearly complete separation of the remaining grain, using one or two rotors (TF, New Holland; CTS, John Deere; Lexion, Claas). The characteristic grain separation versus length of the concave can best be described by an exponential function. Detachment of grain from ears can also be described by an exponential function:

$$f_1(x) = \lambda e^{-\lambda x}$$

The proportion of unthreshed grain s_n is given by:

$$s_n = 1 - \int_0^x \lambda e^{-\lambda x} ds = e^{-\lambda x}$$

For a constant throughput, at every cross-section of the threshing unit, the sum of proportion of unthreshed grain s_n, free grain s_f, and separated grain s_s is:

$$s_n + s_f + s_s = 1$$

With the assumption that the frequency of grain separation s_d is proportional to the amount of free grain:

$$s_d = \frac{ds_s}{dx} = \beta s_f$$

The cumulative proportion of separated grain S_s is:

$$s_s = \frac{1}{\lambda - \beta}\left[\lambda\left(1 - e^{-\beta x}\right) - \beta\left(1 - e^{-\lambda x}\right)\right]$$

and the frequency of grain separation s_d is:

$$s_d = \frac{\lambda\beta}{\lambda - \beta}\left(e^{-\beta x} - e^{-\lambda x}\right)$$

Figure 2. shows unthreshed grain s_n, free grain s_f, cumulative separated grain S_s, and frequency of grain separation s_d plotted against rotor length. For tangential and axial threshing units, there are different values of L, λ and β.

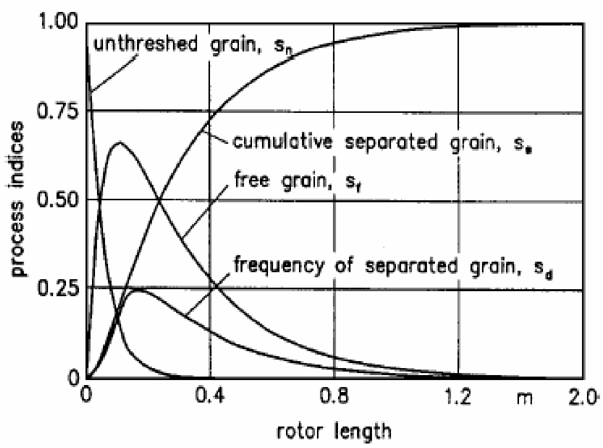

Fig. 2. Grain separation versus separation length (winter barley, total throughput 5 kg/s)

The linear rate of threshing λ is given by:

$$\lambda = k_t\,(\rho v^2 LD)\ /\ (q_p\,\delta_m\,v_{ax})$$

where: ρ = bulk density of MOG [kg/m³]
v = peripheral speed of the rotor [m/s]
v_{ax} = crop speed [m/s]
L = cylinder (rotor) length [m]
D = cylinder (rotor) diameter [m]
q_p = throughput of MOG [kg/s]
δ_m = concave clearance [m]
k_t = threshing factor

Threshing factor k_t relates to: machine type, crop variety, moisture content, etc.

The rate of separation β is proportional to the probability of a kernel passage through an opening in the concave and depends on the ratio of kernel diameter to opening size.

The main cleaning device (cleaning shoe) takes care of the final separation of grain from other crop material such as chaff, broken straw pieces, dirt, or weed seeds. Separation of clean grain on the cleaning shoe occurs due to differences in the terminal velocities and dimensions respectively of grain, broken straw pieces, and chaff material under the action of both mechanical forces (oscillation of the sieves) and pneumatic forces (direction and air velocity). To some extent mechanical and pneumatic forces are exchangeable. For sufficient purity, however, a minimal air velocity is essential (Fig. 3). One parameter for mechanical performance is the flight number $Fr_v = a\omega^2 \sin(\beta - \alpha)\ /(g \cos \alpha)$, where a, $\omega = 2\pi f$, and β are oscillating amplitude, frequency, and direction; α is sieve inclination, and g the gravity constant.

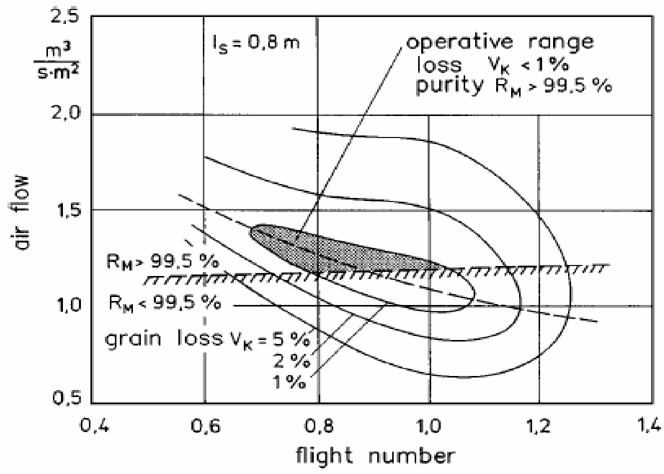

Fig. 3. Interaction of mechanical and pneumatic parameters

Flight number is the relationship between components perpendicular to the sieve, oscillating acceleration and gravity. For modern cleaning shoes the flight number is about Frv = 1. Typical values for the mechanical parameters are: a = 17-38 mm, f = 4,3 - 6 Hz, α = 0-5^0 and β = 23 – 33 ^{0}.

Pneumatic parameters play an important role in cleaning shoe performance. Airflow should be even across the width of the sieve and decrease strongly from front to rear of the sieve. The airflow should ideally be angled as steeply as possible, i.e., 30° in the winnowing steps and 20–30° on the sieve; in practice, however, it is smaller. Values for the air velocity in the winnowing steps a re 6–8 m/s, 5 m/s at the beginning of the loaded sieve, and about 3 m/s at the end. A mathematical model for the grain/chaff separation on grain pan and cleaning shoe is based on physical laws. Diffusion leads to a well mixed grain/chaff layer. With the force of gravity acting on the kernels, they penetrate the mat towards the sieve surface in a process which may be described by the physical law of convection.

In the basic equation of segregation, the distribution function of the grain mass *u*(*y*; *t*) is determined by the diffusion component with the diffusion constant ***Dy*** and the convection component with the average sinking speed ***vy*** .

$$\frac{\partial}{\partial t}u(y, t) = D_y \frac{\partial^2 u}{\partial y^2} - \nu_y \frac{\partial u}{\partial y}$$

Since the sieve is effectively an obstacle to grain separation, a stochastic separation model is combined with the convection-diffusion model. All model parameters depend on process parameters of the grain pan or cleaning shoe. For a standard set of cleaning parameters, Fig. 4 shows typical values of the average sinking speed and the diffusion constant.

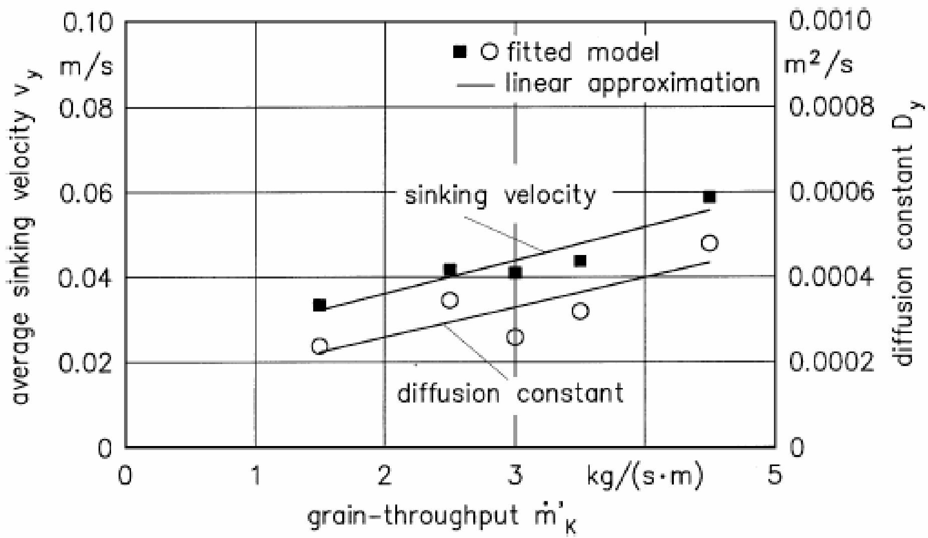

Fig. 4. Effect of grain throughput (wheat) on average sinking speed and diffusion constant for typical cleaning parameters

Threshing losses were directly dependent on the working speed and are presented in the Table 2. Manufacturer recommended adjustment was optimal, but the losses didn't correlate with the working speed and the 6 row adapter. Non balanced work of adapter with the basic machine working regime directly influenced the losses increment rate, as well as impossibility of higher capacity achievement, which determined the harvester final efficiency. From this fact was derived the conclusion that the basic machine charge was only 69.44 % from its nominal capacity. Declaration about the capacity we have defined stays valid for 1% of total losses.

The recorded losses are not significant, because the harvester was not optimally loaded.

The adapter efficiency in laid crop was not estimated because of luck of proper conditions for that kind of research. All the crops were in standing position during the research.

Working quality was estimated according to the results of the analysis of the 1st class kernel from the bunker. Very high purity was found. With the adjustments recommended from the manufacturer, very high kernel breakage of over 10% was obtained. This was result of high working speed of the separation cylinder (500 rpm) and relatively low kernel moisture content (17%). During the further trials, cylinder speed was decreased to 450 rpm, which has significantly reduced the kernel breakage rate. The results are presented in Table 2.

Tab. 2 – Operating quality parameters of harvester Claas Lexion 450

Trial No.	Cylinder speed (rpm)	Working speed (km/h)	Quality parameter (%)			Cob breakage (%)			
			Whole kernel	Broken kernel	Impurity	Whole	1/2	1/3	Chopped cobs
1	500	6.62	86.17	13.47	0.36	91	6	3	0
2	500	6.55				91	5	4	0
3	500	9.25	85.82	12.95	1.23	86	8	6	0
4	500	8.72				88	7	5	0
5	450	10.96	91.76	6.83	1.41	97	3	0	0
6	450	10.36	93.41	6.30	0.29	96	4	0	0
7	450	10.11				95	5	0	0

At higher speeds was noticed higher presence of impurities in the bunker, which means that the harvester is pulling in higher quantity of stalk chops from the 6 row adapter. Thrashing quality, which determines the cob breakage rate, indicates exceptionally good trashing and excellent harvester adjustment. This conclusion is confirmed by the fact that there were not found any chopped cobs (Table 2).

According to the performed tests, 6 row adapter "Conspeed 6 - 70 FC" which was aggregated with the harvester Claas Lexion 450 showed a lot of weaknesses. The main problem is non balanced kinematics regime of the adapter with the function and capacity of the main machine, especially because this relation can not be regulated. Any working speed increment over 10 km/h results with high losses of felt cobs, especially on lateral sections 1 and 6, which is a limitation factor for the successful operation of the whole aggregate, in terms of it's capacity (low linear speed, 3.81 km/h) and total losses, which raise over 2%.

Average cutting height of 290 mm is in acceptable range, but an uneven cut at the cutting height was noticed. Stalks are actually lacerate (no fine cut), which means that 1800 rpm is not enough for the applied working regime. Installing of cutter is enabling much better results in main soil tillage, because the percent of uncultivated plant residues is reduced to minimum.

All the mentioned parameters emphasize the fact that the tested adapter is not able to fallow the technical capacity of the main machine. The final conclusion in this part is that the harvester Claas Lexion 450 needs to be aggregated with the 8 rows adapter.

Efficiency and the obtained working regime were continuously recorded by the computer, and the processed data are presented in Table 3.

Tab. 3. – Records of Claas Lexion 450 work

Date	Working time	Surface	Total grain mass	Humidity	Fuel	Ratios			
	h	ha	t	%	lit.	ha/h	t/h	t/ha	lit/ha
13.10	6.97	30.283	180.71	20.3	389.0	4.35	25.94	5.97	12.85
15.10	5.02	18.011	131.68	16.9	281.0	3.59	26.25	7.31	15.60
16.10	5.58	23.020	153.96	16.6	315.0	4.12	27.57	6.69	13.68
Total	17.57	71.314	466.35		985.0	4.02	26.58	6.66	14.04

4. CONCLUSIONS

According to the presented results, the harvester Claas Lexion 450 in corn harvesting achieved the fallowing results:

1. Optimal capacity of the harvester Claas Lexion 450 with the accepted losses of 1% can be declared on 12.5 kg/s, at the working speed of 8 km/h.
2. Maximal capacity of the harvester Claas Lexion 450 with the accepted losses of 1% can be declared on 14 kg/s, at the working speed of 10 km/h.
3. Recognized limitation parameters for the capacity in relation to the losses were:
    a. 6 rows adapter
    b. yield over 8 t/ha
    c. kernel moisture content of 17%
4. Threshing losses were negligible, which was explained with the precise operation of the automatic control. The most significant losses were noted in the adapter.
5. Working quality is on the upper threshold value (6% kernel breakage), which could be reduced by increment of concave clearance to 28-30 mm, depending on grain humidity.
6. Quality of threshed mass is extremely high, which is the result of very aggressive operation of APS system and good separation action, and approved with the percent of chopped cob.
7. Bunker unloading is very efficient, auger is full and with the constant flow.
8. Harvester efficiency of 4.02 ha/h is relatively low, which was limited with the limited movement and limited percent of losses to 1%.
9. Average productivity of 26.58 t/h, compared to the theoretical value of 35 t/h is the result of non balanced working regime and the working speed, which is directly influencing the harvester efficiency of 70%.
10. Fuel consumption of 14.04 l/h is extremely low, which correlates with the engagement of working parts and working efficiency.
11. Control of the board computer function showed that the increased working speed was indicated. Increment was about 10% over the real working speed.

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