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Impact of Electronic-Hydraulic Hitch Control on Rational Exploitation of Tractor in Ploughing

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Regulacija trozglobne poteznice
Traktor
Učinak
Utrošak energije

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Preliminary note

The aim of the investigation was to compare and unveil efficiency of electro-hydraulic control (EHR) system to mechanical three point hitch regulation in mouldboard ploughing. Increase of working velocity and three point hitch automatic regulation activity decreased depth of ploughing at both regulation systems but electro-hydraulic system done it more accurately since deviation from default value was 10 % less than at mechanical regulation system. Electro-hydraulic three point hitch control system decreased wheel slip up to 30 % in comparison to mechanical regulation system. Net energy requirement at mechanical three point hitch regulation system spent 3 % more energy than electro-hydraulic control system. If wheel slip reduction influenced by electro-hydraulic control system would be added one could account on greater energy savings than previously mentioned value. The greatest working rates were achieved at the greatest working velocity (8,0 km h^{-1}), while exactly at that velocity the greatest working rate increase of 3,8 % influenced by electro-hydraulic three point hitch control was noticed.

Utjecaj elektroničko-hidrauličke regulacije trozglobne poteznice na racionalno iskorištenje traktora u oranju

Prethodno priopćenje

U radu je prikazana usporedba učinkovitosti elektroničko-hidrauličke regulacije trozglobne poteznice s klasičnom mehaničkom regulacijom i to u oranju. Porastom radne brzine agregata i utjecajem automatske regulacije poteznice smanjuje se dubina oranja. Odstupanja od zadane dubine s EHR sustavom bila su do 10 % manja od onih sa sustavom mehaničke regulacije. EHR sustav regulacije smanjio je klizanje pogonskih kotača traktora do 30 % u usporedbi s mehaničkom regulacijom. Utrošak energije za oranje smanjen je korištenjem EHR sustava do 3 % u odnosu na mehaničku regulaciju, no ukoliko dodamo uštedu energije koja proizlazi iz smanjenog klizanja kotača uštede su i veće. Najveći učinci ostvareni su pri najvećoj radnoj brzini (8,0 km h^{-1}), a upravo je pri toj brzini zabilježeno i najveće povećanje učinka do 3,8 % djelovanjem EHR sustava regulacije.

1. Introduction

In spite economical-energetic disadvantages (high labour and energy expenses) mouldboard ploughing is even today the most common way of primary soil tillage. Although the ploughing expenses are considerably higher in comparison to the different systems of reduced tillage without ploughing [1], this type of soil inversion tillage has several important advantages: good soil loosening, easier seed bed preparation, which enables proper sowing and good weed control. Today, approximately 85 % of the arable land of the Middle Europe is ploughed, while forecasts showed that in the next twenty years decrease of this portion to close 60 % is expected [2].

At the beginning of the tractor development, the engine power was used only for drafting implements, transporting and for stationary machines driving via pulley transmission. Tractor ploughs were similar to the horse-drawn, and the tractor-plough link was without any possibility of adjustment. Older versions of tractors without three point hitch drawbar were not only unable to control implements work, but in case when plough came to the obstacle in the soil, couldn't prevent the

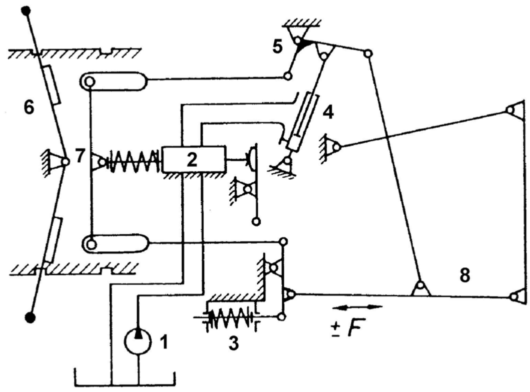
Symbols/Oznake

a	- ploughing depth, cm - dubina oranja	G_{ad}	- normal reaction of soil, kN - normalna reakcija tla
B_r	- working width, m - radni zahvat pluga	M	- torque on drive wheel axle, Nm - zakretni moment na vratilu pogonskog kotača
δ	- drive wheel slip, % - klizanje pogonskih kotača traktora	μ	- pull coeficient - koeficijent vuče
k	- viscous damping coefficient, Ns/m - koeficijent viskoznog prigušenja	P_{pot}	- tractor pull power, kW - vučna snaga traktora
E_{spec}	- specific energy, MJ/ha - specifična energija	r	- drive wheel radius, m - radijus pogonskog kotača
F_D, F_L, F_G	- forces in linkages of three point hitch, kN - sile u polugama trozglobne poteznice	v	- working velocity, km/h - brzina kretanja agregata
F_{pot}	- tractor pull force, kN - vučna sila traktora	W_h	- work rate, ha/h - učinak
F_t	- tangential force on drive wheel, kN - tangencijalna sila na obodu kotača		

reaction moment and turning the tractor over its rear axle. Tractors equipped with the three-point hitch drawbar in case of the overload transmit part of the draft force over the upper lever to the front axle of the tractor preventing thus lifting off the tractor's front axle and turning-over. Described function contributes to the tractor operator's safety. For this reason tractor could have been lighter which indirectly meant energy savings as well.

Harry Ferguson in 1925 patented "Device for hydraulic regulation of the working depth of the various implements linked to the tractor" – three point linkage with control system based upon the measurement of the soil resistance over the upper lever. The prototype was assembled on the tractor called Black Ferguson. Ferguson's cooperation with Henry Ford in 1939 resulted in serial production of tractors equipped with hydraulic hitch with ploughing depth control system (model Ford 9N). In the middle of the sixties of the last century American Corporation John Deere modified this system changing the soil resistance measuring on the lower levers of the three-point hitch drawbar linkage and improved tractor hydraulic hitch-control introducing the force and position "signal mixing". Such system of the mechanical-hydraulic control (MHR) provided control of the three-point hitch drawbar on the basis of the draft force and implement position, as well as combined regulation with less or more influence to each component (Figure 1).

Control strategy development was strongly influenced by the development of the new types of sensors and controllers. Therefore, firstly the mechanical controllers were replaced by hydraulic elements while today the electronic controllers dominate (Figure 2).



1. Hydraulic pump / Hidraulička crpka
2. Regulation valve / Regulacijski ventil
3. Draft sensor / Senzor sile vuče
4. Lift cylinder / Podizni cilindar
5. Position sensor / Senzor položaja
6. Regulation lever / Upravljačka ručica
7. Mixing of signals / Miješanje signala
8. Lift arms / Podizne poluge

Figure 1. Mechanically actuated hydraulic three point hitch

Slika 1. Mehanički upravljani automatski hidraulični podizač traktora

Sensor types M1 and M2 were originally implemented on Ferguson tractors and they are even today used on cheaper low power tractors. The example E3 shows a bolt in the lower link point of the three-point hitch drawbar with integrated electronic force converter constructed at the Bosch factory in 1982.

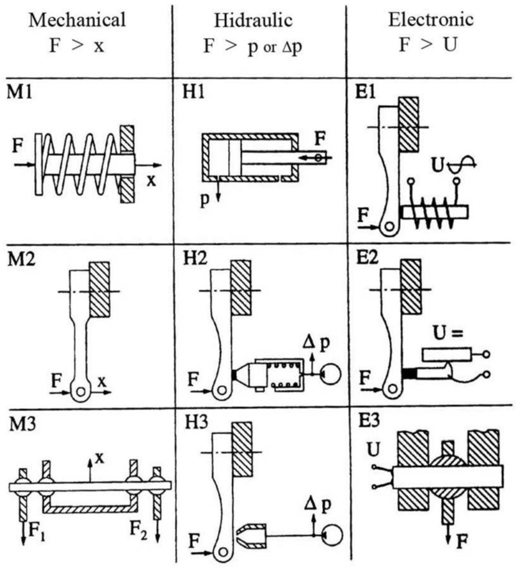


Figure 2. Mechanical, hydraulic and electronic draft sensors (Renius [3])

Slika 2. Mehaničke, hidrauličke i elektroničke izvedbe senzora vuče prema Reniusu

In the middle eighties intensive increase of the possibilities of the computer data processing provided application of the electronic sensors in the entire system of the automatic three point hitch drawbar linkage control. Hesse [4] pointed out the advantages of the electronic-hydraulic components for realizing and accurate force determining. Author considered application of the most used components in electronic-hydraulic interface-electronically controlled hydraulic valves and development of the control system in ploughing with higher power tractors. The influences of the Bosch three-point hitch drawbar linkage control system (Figure3) to drive wheels slip control has also been researched by Hesse [4]. The acceptable amount of wheel slip is maintained through the draft force and variations of the implement operating depth adjustment, which enables significant fuel and labour savings [5].

Improving the tractor three point hitch drawbar linkage regulation system Grubešić [7] in cooperation with the Zagreb Institute of Agricultural engineering has been carrying out testing of Torpedo RX120 tractor equipped with Bosch electronic-hydraulic controller regular exploitation conditions. Control was achieved with two sensors, linkage position sensor and draft force sensor. Testing was carried with mouldboard plough. Uniformity of the ploughing depth was presented by standard deviation. Testing showed that maximum average deviation of ploughing depth was 10 %. The drive wheels slip was mostly within the range of 10-20 % and even in the most unfavourable conditions never exceeded 25 %.

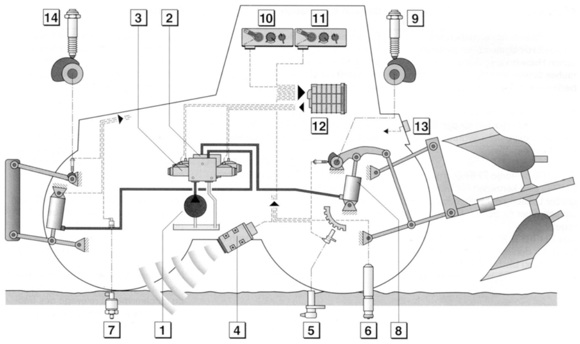


Figure 3. EHR system built in tractor (according to Bosch [6]): 1. Hydraulic pump; 2., 3. Regulation valve; 4. Radar sensor; 5. Speed sensor; 6. Draft sensor; 7. Presure sensor; 8. Lift cylinder; 9., 14. Position sensor; 10., 11. Control panel; 12. Control unit; 13. Rear (outside) controls

Slika 3. EHR sustav implementiran na traktor (po Boschu [6]): 1. Hidraulička crpka; 2., 3. Regulacijski ventil; 4. Radarski sensor; 5. Senzor brzine; 6. Senzor sile vuče; 7. Senzor tlaka; 8. Podizni cilindar; 9., 14. Senzor položaja; 10., 11. Kontrolna ploča; 12. Upravljačka jedinica; 13. Stražnje (vanjske) kontrole

The power P_d, or drawbar power is the product of the draft force F_d (in operation with constant speed it is equal to the total plough resistance) and tractor speed v in direction of the force:

$$P_d = F_d * v. \tag{1}$$

This power is always lower than the nominal engine power due to transmission losses, and tractor drive wheels slip losses. The largest draft force in field conditions was achieved under extremely high wheel slip of 50 – 60% [8]. However such wheel slip is not acceptable for regular working conditions. Long-term operation at the maximal draft force would cause higher energy consumption, excessive tyre wear, lower performance and soil damage. The greatest draft force of a tractor is limited by the engine power and tractive force - a force transferred to soil surface through drive wheels. The value of the tangential force F_t at the wheel radius determines the tractor's engine and transmission parameters and it can be expressed as follows:

$$F_t = \frac{M_e}{r}, \tag{2}$$

where: M_e is the torque on the drive wheel shaft in Nm and r drive wheel radius in m.

Effectiveness of the traction device-soil interaction is evaluated by draft coefficient μ, defined as ratio of the tangential force at the wheel radius and normal soil reaction Wt to drive wheels at agro-technical acceptable wheel slip ($\delta \leq 20$ %):

$$\mu = \frac{F_t}{W_t}. \tag{3}$$

Slip δ is usually expressed as the proportion of the tractor speed loss and peripheral drive wheel velocity:

$$\delta = \frac{v_o - v}{v_o}, \tag{4}$$

where: v is actual velocity in m s^{-1} and v_o is drive wheel peripheral velocity in m s^{-1}.

Since wheel slip directly influences rational exploitation of the tractor it is necessary to maintain the slip amount within limits of the best ratio between generated draft force and the tractive force. This relation McKyes [9] described as the traction efficiency corresponds to the highest traction in field conditions achieved within limits of the wheel slip from (10 – 15) %.

Energy-fuel consumption in soil tillage increases as utilization of the tractor engine power in certain operating conditions decreases. Depending on the surface type (ploughed or in some other way tilled or untilled soil-stubble) the least specific energy-fuel consumption is obtained at wheel slip range 10 to 30 % [10]. Analysing of the tangential force at tractor wheel radius and draft force at three-point hitch drawbar linkage Poje [11] determined that in ploughing rolling resistance and wheel slip requires approximately half of the total tractor's engine generated power (42,3 to 57,7 %), while the remaining half spends ploughing.

From the beginning of the mechanization implementation in agriculture main role of the tractor was implement towing. Later, with development of the three-point hitch drawbar, enables hydraulic control of implement in operation. The principle aim of the research was to evaluate efficiency of the electronic-hydraulic control (EHR) and mechanical three-point hitch drawbar control (MHR) in primary soil tillage where most obvious influence on rational exploitation of tractor was expected.

2. Materials and methods

Research of the EHR system efficiency in mouldboard ploughing was carried out on experimental fields of Laboratory of Agricultural Engineering and Process Technique in village Jable (46°05'N; 14°52'E), 10 km north from Ljubljana. Measurements were carried out on silty-clay soil with 20,2 % of clay, 42,0 % of silt and 37,8 % of sand. Soil water content was 17,8 %, porosity 32,1 % and soil density 1,54 g cm^{-3}.

Prior to tillage specific horizontal soil resistance was measured by electronic penetrometer developed at Agricultural institute of Slovenia. Specific soil resistance increased from 2.9 Ncm^{-2} at 20 cm up to 7.1 Ncm^{-2} at 40 cm depth. Measurement of the surface soil shear strength showed that cohesion of the soil was 0.29 Ncm^{-2}, average soil shear angle 20.8 ° and internal friction angle 36.2°. Measured values classify this soil in the group of semi-solid media [12]. In spite of low cohesion, due to large inner friction the soil was able to resist sufficiently large tangential force of tyres without excessive wheel slip, having thus good traction capabilities.

The experiment was performed with two Fendt tractors of equal characteristics. One was Favorit 612 LSA equipped with EHR system and other was Favorit 614 SL with MHR system of three-point hitch control. They are standard performance tractors with four wheels drive, 6000 kg mass and engine power of 100 kW. For exploration needs there were used two three-furrow reversible ploughs: A - Vogel Noot Euromat-Permanit LM 950 – plough of constant operating width 38 cm/plough body and B - Lemken EurOpal 5X-3L100 – –plough adjustable operating width on 33, 38, 44 and 50 cm/plough body. Plough width B_r was placed on 38 cm/plough body, so that both ploughs were set to total operating width of 114 cm. Operating depth of both ploughs was set to a = 30 cm.

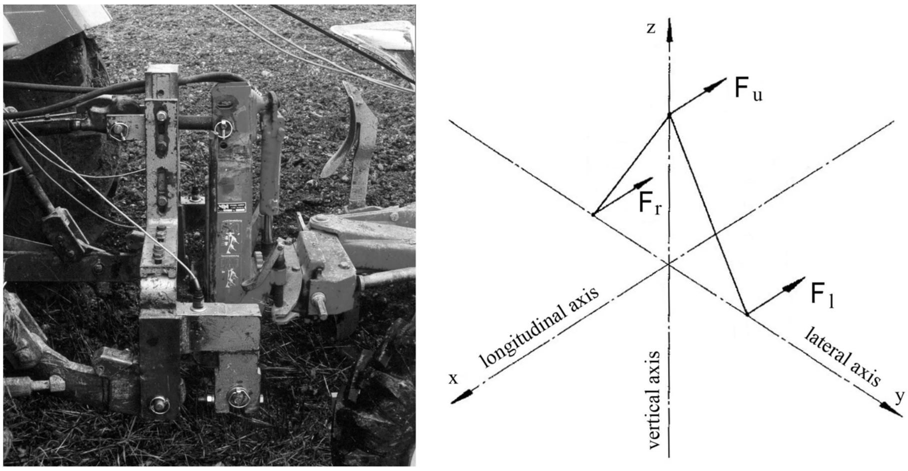


Figure 4. Attaching of dynamometer frame and direction of measured forces

Slika 4. Način priključivanja i djelovanje sila kod mjerenja dinamometarskim okvirom

Measurements were carried out at three movement speeds: $v_1 = 4,0$ km h^{-1}, $v_2 = 6,0$ km h^{-1} and $v_3 = 8,0$ km h^{-1}, and monitored efficiency factors of the EHR and MHR systems were:

- ploughing depth,
- tractor drive wheels slip,
- direct energy consumption,
- work rate.

Draught force in ploughing was measured by dynamometer frame of category III mounted to tractor's three-point hitch drawbar (Figure 4).

Measurements of the draught force components on right F_r, left F_l and upper lever F_u of three-point hitch drawbar were taken, while the total tractor draft force F_d is a sum of the particular components:

$$F_d = F_r + F_l + F_u. \tag{5}$$

Drawbar power P_d is calculated as product of the total draft force and tractor velocity according to equation (1).

The soil tillage energy requirement by ploughing is expressed by specific energy E_{spec}:

$$E_{spec} = 0.36 * \frac{P_d}{B_r \cdot v}, \tag{6}$$

where: P_d - drawbar power at the tractor hitch in kW, Br - working width in m and v - tractor velocity in m s^{-1}.

Measurement of actual tractor speed was performed by additional wheel attached to the plough's frame (figure 5). The additional wheel revolutions was registered by incremental transmitter (path crossed), in time interval (computer time database), and speed was calculated afterwards (off-line). On the basis of the calculated operating speed v and measured ploughing width B_r tractor efficiency in ploughing W_h was calculated according to expression:

$$W_h = 0.36 * B_r * v \tag{7}$$

In order to determine the wheel slip amount, the linear tractor velocity and tractor's drive wheel peripheral velocity are required. Inductive sensors - revolution counters mounted to all four tractor wheels (Figure 6) measured actual travelled distance, and slip was calculated according to expression (4) taking into account dynamic radius of the tractor tyres.

The measurement of ploughing depth performed by additional wheel attached on the plough's frame. The wheel was mounted on a separate frame that enables its vertical movement regardless of the main plough's frame (Figure 7). Applying an incremental optical sensor and chain transmission, wheel frame linear vertical motion has been converted to circular motion necessary for the operation of the sensor.

Measurement system consisted of three digital measuring amplifiers HBM Spider 8 connected to portable computer with the HBM software Catman 4.0 for data acquisition and processing. Source and calculated data were statistically processed by program SAS [13]. The significance of the influence of EHR system on researched factors was determined by analysis of variance (ANOVA) using the GLM procedure.

3. Results and discussion

3. 1. Ploughing depth

Results of testing EHR and MHR three-point hitch control regarding default ploughing depth sustaining are showed in Figure 8. EHR system in all tests enabled less deviation of the default ploughing depth than the mechanical control (MHR). The greatest deviation of average ploughing depth of 13.2 % was obtained at the highest operating speed of $v_3 = 8$ km h^{-1} with mechanical control, while EHR system provided deviation of barely 4,5 %. The analysis of variance of the experimental data showed that EHR system results of maintaining default ploughing depth are significantly different and better in comparison to results of the mechanical hitch control at the probability level of $p = 0,01$ for all operating speeds and both ploughs.

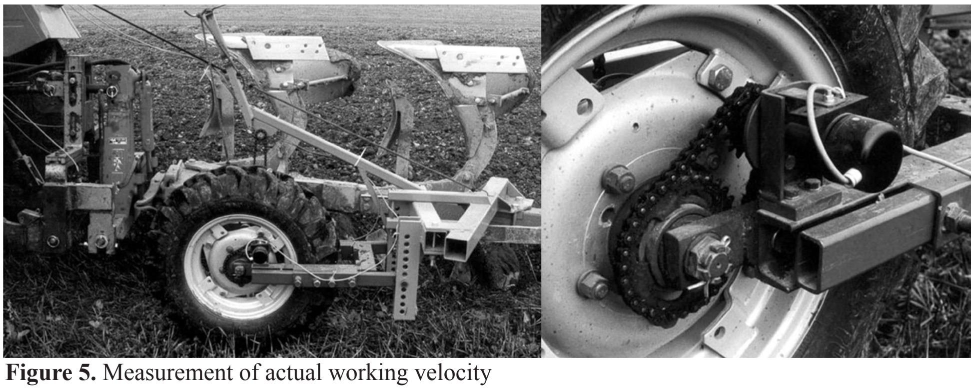


Figure 5. Measurement of actual working velocity

Slika 5. Mjerenje stvarne brzine kretanja agregata

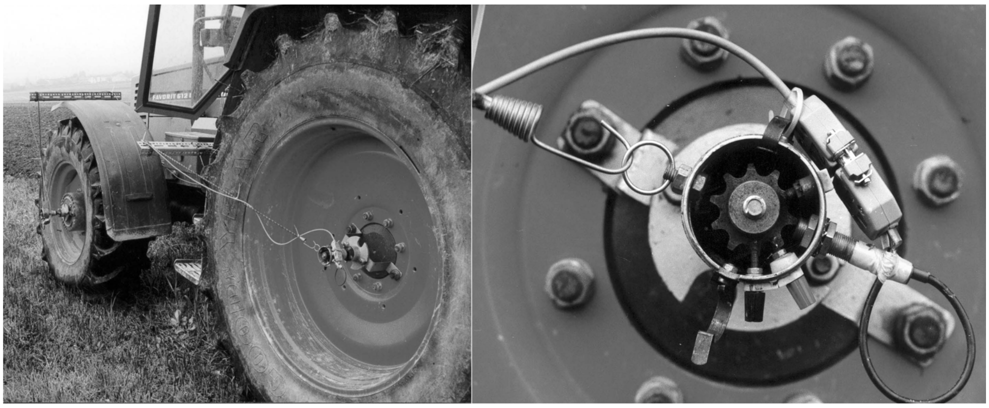


Figure 6. Inductive wheel revolution counter

Slika 6. Induktivni brojač okretaja kotača traktora

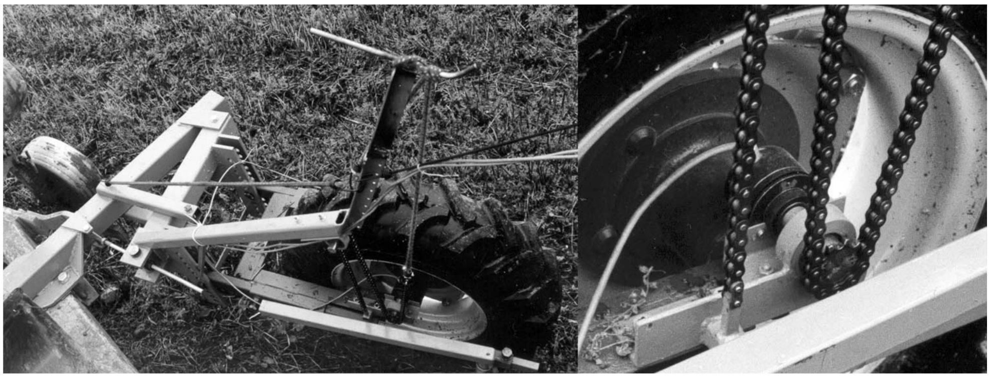


Figure 7. Measurement of ploughing depth

Slika 7. Mjerenje dubine oranja

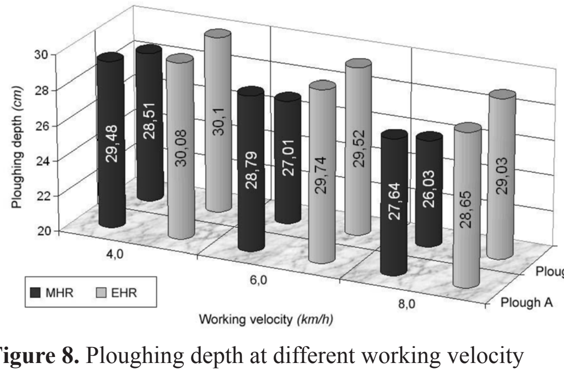


Figure 8. Ploughing depth at different working velocity

Slika 8. Dubina oranja pri različitim brzinama kretanja agregata

3.2. Wheel slip

The tractor drive wheels slip was significantly decreased due to control of the EHR system in comparison to the mechanical three point-hitch control (MHR). Recorded differences were presented in Figure 9. Statistically significant difference of wheel slip averages between EHR system and MHR system control is evident at the probability level of $p = 0.01$ for all working speeds and both ploughs. Tractor drive wheel slip while working with plough A due to EHR system resulted in 30 % decrease at all speeds. In working with plough B EHR system of tractor's three-point hitch control reduced slip of the tractor drive wheels for 8 % in comparison to the mechanical system control.

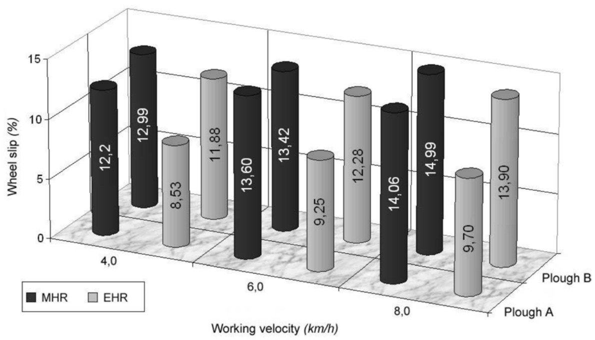


Figure 9. Drive wheels slip

Slika 9. Klizanje pogonskih kotača traktora

3.3. Energy requirement

Energy requirement differences influenced by EHR and MHR three-point hitch control systems are presented in figure 10. Ploughing with plough A at the lowest speed of v_1= 4,0 km h^{-1} the EHR system achieved statistically significant difference of energy requirement in comparison to the mechanical control system at the probability level of p = 0,05, while at speed of v_2 and v_3 achieved statistical difference at the probability level p= 0,01. Ploughing with plough B EHR system achieved statistically significant difference in energy requirement in comparison to the mechanical control system at all speeds (v_1 = 4,0 km h^{-1}, v_2 = 6,0 km h^{-1} and v_3 = 8,0 km h^{-1}) at probability level of p = 0,01.

Energy requirement in ploughing with EHR system equipped tractor resulted in 2 - 3 % savings comparing to the mechanical hitch control system. Since the EHR system also decreased wheel slip up to 30 % in comparison to the mechanical control system, this saving must also be taken into account to total energy savings.

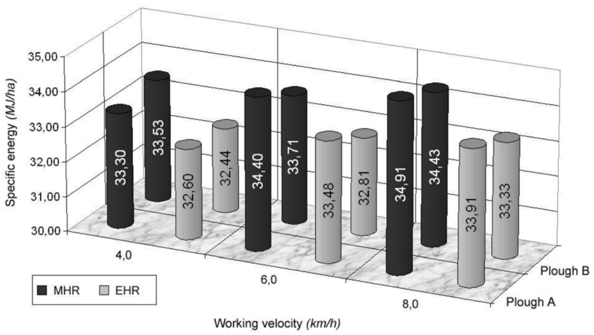


Figure 10 Energy requirement
Slika 10. Utrošak energije

3.4. Work rate

Figure 11 presents recorded differences of achieved work rate in ploughing induced by action of EHR and MHR three-point hitch control systems. At the lowest speed, v_1 = 4,0 km h^{-1} no significant differences of work rate appeared between EHR and mechanical control in operation with plough A, while with plough B the difference was statistically significant at the probability level of p = 0,05. At the speed of v_2 = 6 km h^{-1} the increase of the work rate due to the EHR appeared with both ploughs and is statistically significant at the level of p = 0,05, while at the highest speed, v_3 = 8,0 km h^{-1} differences were significant at the probability level of p= 0,01. The increase of the work rate with EHR system was mostly evident at the highest speed of v_3 = 8 km h^{-1} and was from 3,4 % at plough B to 3,8 % at plough A in average.

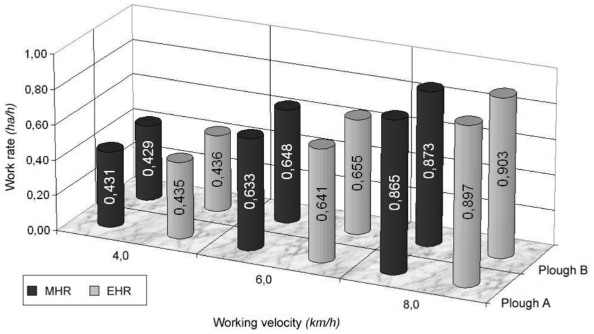


Figure 11. Work rate
Slika 11. Učinak

4. Conclusions

The research of the electronic-hydraulic and mechanical-hydraulic three-point hitch control efficiency to rational exploitation of the tractor in ploughing and statistical analysis of experimental data enables the following conclusions:

- The increase of the tractor velocity within range v = 4,0 – 8,0 km h^{-1} have been decreasing the average ploughing depth. All measurements proved the superiority of the EHR system of three-point hitch control to MHR control system since its less deviation of default ploughing depth. The largest deviations of 13,2 % with mechanical control and only 4,5 % with EHR system were registered at the highest operating speed v_3 = 8,0 km h^{-1}.
- Tractor drive wheels slip has been significantly decreased by EHR system within range 7,0 – 30,0 % in comparison to the mechanical control.
- EHR control system decreased energy requirement for 2 – 3 % in comparison to the mechanical control regardless to the energy savings by decreasing tractor drive wheels slip.
- Acting of EHR control system in all measurements obtained work rate increase in comparison to the mechanical three-point hitch control system. The greatest work rate increase of 3,4 % - 3,8 % was achieved at the highest speed of v_3 = 8,0 km h^{-1}.

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