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IMPROVEMENT OF HARVEST SHARE RESISTANCE FOR SUGAR BEET RENOVATION

ZLEPŠENIE ODOLNOSTI VYORÁVACÍCH RADLÍC REPY CUKROVEJ RENOVÁCIOU

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This paper deals with results of welding-on materials tests applied at the harvest share for sugar beet. The most intensive abrasion is in first hard of harvest share. The results shown that the ledeburic material with the highest carbon capacity and chromium achieve the minimal lost of abrasion.

Key words: harvest share for sugar beet, abrasive resistance, renovation welding-on

Súčiastky pracujúce v pôdnom prostredí strácajú svoju funkčnú spôsobilosť pre abrazívne opotrebenie. Opotrebenie spôsobuje veľké straty materiálu súčiastok a z dôvodu nedostatku surovín na svetových trhoch je potrebné hľadať cesty ako zvyšovať životnosť výrobkov a tým dosiahnuť úsporu surovín, materiálov ale aj energie.

Pre stanovenie odolnosti materiálov proti opotrebeniu sa používajú skúšky prevádzkové, poloprevádzkové alebo laboratórne. Prevádzkové skúšky sú však značne ovplyvnené premenlivosťou prevádzkových parametrov, napr. druhom, vlhkosťou, utlačením pôdy atď., ktoré sa pri skúške menia. Preto majú prevádzkové skúšky význam pre konkrétne výrobné zariadenie (Brožek, 2003).

V oblasti prevencie proti opotrebeniu je najväčšia úloha pripisovaná technológiám, ktoré zvyšujú odolnosť aktívnou ochranou povrchovej vrstvy. Medzi technológie, ktoré to umožňujú patrí renovácia – naváraním.

Jednou zo súčiastok poľnohospodárskych strojov, ktoré sú vystavené silnému abrazívnemu opotrebeniu, je radlica na vyorávanie repy cukrovej. Kvalita práce vyorávacích radlíc závisí od pojazdovej rýchlosti, od nastavenia, ale aj od veľkosti opotrebenia. Pri príliš veľkom opotrebení nedochádza k dokonalému vytiahnutiu repy z pôdy, čím dochádza k zvyšovaniu strát. Vo veľmi suchých pôdach je dvojica radlíc opotrebovaná už po vyoraní 15 ha repy. O čo častejšie je ich potrebné meniť o to väčšie sú náklady na samotné radlice, vzrastajú náklady prestojov, predlžuje sa čas zberu repy cukrovej (Čičo a Tolnai, 2003).

Voľba optimálnej technológie navárania je závislá od poznaní špecifických vlastností a poznaní funkčnosti nástroja. Na naváranie sa používa široký sortiment technológií, zariadení a návarových materiálov, pomocou ktorých sa dajú dosiahnuť vysoko kvalitné návary s dobrými tribologickými vlastnosťami.

Zámerom tohto príspevku je poukázať na miesto najväčšieho opotrebenia a poukázať na možnosti predĺženia životnosti vyorávacích radlíc vyorávacieho stroja HOLMER naváraním tvrdonávarovými materiálmi a vyhodnotiť opotrebenie na základe prevádzkových skúšok.

Materiál a metódy

Na výrobu vyorávacích radlíc sa používa oceľ triedy 14 260, ktorú možno charakterizovať ako ušľachtilú zliatinovú oceľ. Oceľ je zušľachtená kremíkom a chrómom a je určená na silne namáhané a striedavo zaťažované súčiastky strojov.

Na naváranie vyorávacách radlíc A-A1, D-D1 boli použité návarové elektródy FIDUR 10-60, na naváranie vyorávacích radlíc označených B-B1, E-E1 boli použité návarové elektródy FIDUR 10-65, radlice C-C1 boli navarené elektródou HARD FRO V-1000. Posledný pár s označením F-F1 bol bez návaru a predstavoval etalón.

Chemické zloženie návarových materiálov a tvrdosť udávaná výrobcom je uvedená v tabuľke 1.

Návarové materiály, všetky tri druhy boli priemeru 2,5 mm a boli aplikované na pracovnú plochu vyorávacej radlice zváracím usmerňovačom AW-200 s naváracím prúdom 90 A.

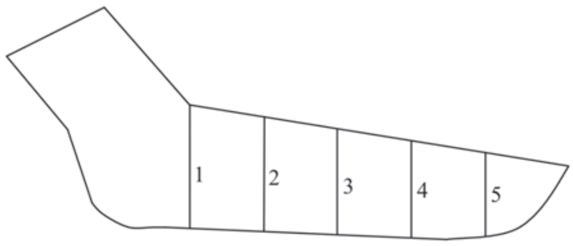
Návar bol vyhotovený ako jednovrstvový na čelnú plochu radlice v šírke 30 mm tak, aby boli dodržané správne technologické zásady s ohľadom na premiešanie so základným materiálom a prekrytím návaru. Po naváraní sa nevykonávali žiadne dodatočné úpravy.

Po navarení sa vyorávacie radlice označili. Na každej radlici sa vyznačilo päť meracích miest, na ktorých bol zisťovaný úbytok šírky radlice (obr. 1).

Tabuľka 1 Zloženie použitých materiálov a tvrdosť udávaná výrobcom

Návarový materiál (1)	Obsah prvkov v % (2)					Tvrdosť HRC (3)
	C	SI	Mn	Cr	Mo	
Fidur 10/60	3,8	0,9	0,4	33,0	–	57 – 60
Fidur 10/65	4,5	0,7	0,5	34,0	–	62 – 64
HARD FRO V-1000	4,0	–	1,1	35,0	0,9	58 – 61

Table 1 Composition of used materials and hardness presented by producer
(1) material of weld deposit, (2) content of elements, (3) hardness



Obrázok 1 Miesta merania
Figure 1 Measuring points

Pred naváraním a po naváraní bolo vykonané meranie tvrdosti podľa Rockwella (HRC).

Prevádzkové skúšky prebiehali v poľnohospodárskom podniku, na pozemkoch s hlinitou resp. hlinito-piesočnatou pôdou. Vlhkosť pôdy pri meraní bola 16 %.

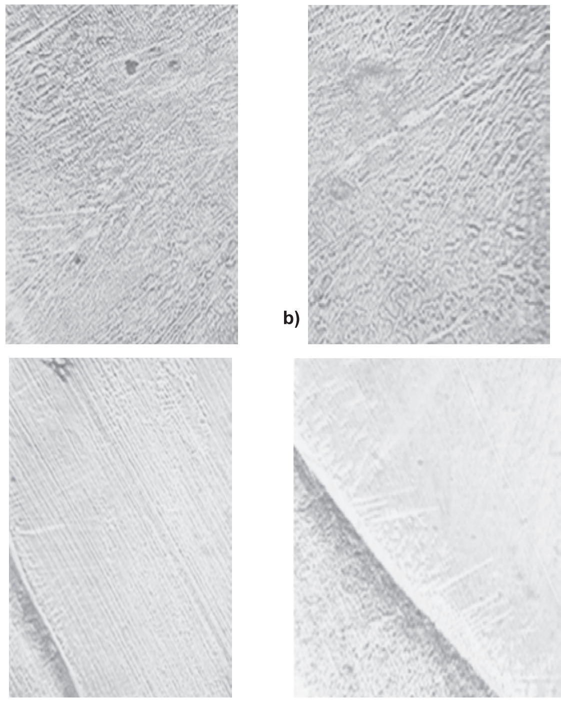
Výsledky a diskusia

Dosiahnuté výsledky úbytku šírky vyorávacej radlice po vyoraní 150 ha repy cukrovej sú v tabuľke 2 a grafické znázornenie na obr. 3 a 4.

Priemerné hodnoty tvrdosti navarených radlíc materiálom FIDUR 10/65 boli 51 HRC, materiálom FIDUR 10/60 boli 52 HRC, materiálom HARD FRO V-1000 boli 54 HRC, nenavarené radlice mali tvrdosť 45 HRC. Všetky návarové materiály patria do skupiny ledeburitických materiálov. Štruktúra návarov je zobrazená na obr. 2.

Zvýšený obsah chrómu spôsobuje zvýšenie pevnosti, tvrdosti a zlepšenie žiarupevnosti. Chróm patrí do skupiny feritotvorných prvkov, tvorí karbidy, ktoré zvyšujú odolnosť proti opotrebeniu. V ternárnych zliatinách Fe-Cr-C sa časť chrómu rozpustí v základnej kovovej matrici a časť tvorí s uhlíkom karbidy. Typ karbidov tvoriacich sa v chrómových oceliach závisí od obsahu chrómu a uhlíka. Mangán (≤0,5 %) a kremík (≤ 0,8 %) sú prítomné v oceliach ako základná dezoxidačná prísada. Mangán pri vyššom obsahu, kedy vzniká austenitická štruktúra, a hlavne za súčasného pridania chrómu, výrazne zlepšuje odolnosť voči korózii. Prísada kremíka netvorí v oceliach karbidy, ale rozpúšťa sa vo ferite a zväčšuje pevnosť v ťahu a tvrdosť zliatiny. Časť molybdénu obsiahnutá iba v návare Hard Fro V-1000 sa rozpúšťa vo ferite, ktorého tvrdosť zvyšuje, a časť molybdénu vytvorí karbidy. V spojení s ostatnými legujúcimi prvkami molybdén zvyšuje prekaliteľnosť, výrazne znižuje popúšťaciu krehkosť, odstraňuje náchylnosť k zhrubnutiu austenitického zrna a zlepšuje zvariteľnosť.

Vyorávacie radlice pracovali v ideálnych pôdnych podmienkach (16 % vlhkosti pôdy). Dosiahnuté úbytky opotrebenia, boli minimálne, nespôsobovali nekvalitné vyorávanie a po premeraní pokračovali v práci ďalej.



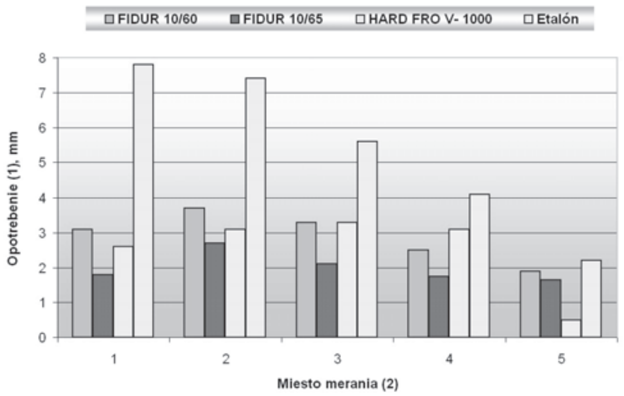
a) b) c)

Obrázok 2 Štruktúra návarov: a) Fidur 10/60, b) Fidur 10/65, c) HardFro V-1000
Figure 2 Structure of weld deposits: a) Fidur 10/60, b) Fidur 10/65, c) HardFro V-1000

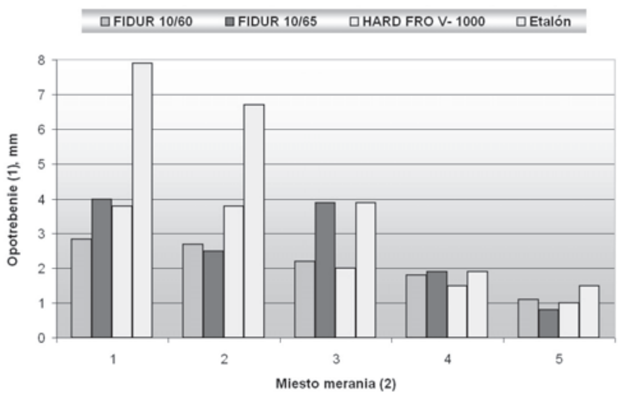
Tabuľka 2 Namerané úbytky šírky radlíc v jednotlivých miestach merania

Radličky (1)	Materiál (2)	Miesto merania (3) / úbytky šírky (4) v mm					Priemerná hodnota (5) v mm
		1	2	3	4	5	
Ľavé (6)	FIDUR 10/60	3,6	4,3	3,2	2,5	1,7	3,006
	FIDUR 10/60	2,6	3,1	3,4	2,5	2,1	2,74
	FIDUR 10/65	1,7	3,3	1,7	2,2	1,6	2,10
	FIDUR 10/65	1,9	2,1	2,5	1,3	1,7	1,90
	HARD FRO V-1000	2,6	3,1	3,3	3,1	0,5	2,52
	bez návaru (8)	7,8	7,4	5,6	4,1	2,2	5,42
Pravé (7)	FIDUR 10/60	3,1	3,0	2,6	1,9	2,1	2,54
	FIDUR 10/60	2,6	2,4	1,8	1,7	0,1	1,72
	FIDUR 10/65	2,3	2,0	1,8	1,0	0,4	1,50
	FIDUR 10/65	1,7	0,5	2,1	0,9	0,4	1,12
	HARD FRO V-1000	3,8	3,8	2,0	1,5	1,0	2,42
	Bez návaru (8)	7,9	6,7	3,9	1,9	1,5	4,38

Table 2 Measured lost of share width in individual measuring points
(1) skives (2) material, (3) measuring point, (4) width lost, (5) average value, (6) left, (7) right, (8) without weld



Obrázok 3 Úbytky šírky ľavých radlíc v jednotlivých miestach merania
Figure 3 Width lost of left shave in individual measuring points
(1) wear, (2) measuring point



Obrázok 4 Úbytky šírky pravých radlíc v jednotlivých miestach merania
Figure 4 Width lost of right shave in individual measuring points
(1) wear, (2) measuring point

Z dosiahnutých výsledkov je vidieť, nerovnomerné opotrebenie vyorávacích radlíc. Najmenšie abrazívne opotrebenie bolo v meranom mieste 5. Z dosiahnutých výsledkov je tiež vidieť, že ľavé radlice sa opotrebovávali intenzívnejšie ako pravé, v priemere asi o 29,7 %.

Najmenšie priemerné opotrebenie dosiahli radlice navárané materiálom FIDUR 10/65. Druhú najnižšiu priemernú hodnotu opotrebenia dosiahol materiál HARD FRO V-1000, ktorý z použitých návarových materiálov mal najvyššiu tvrdosť. Materiál FIDUR 10/60 dosiahol hodnotu opotrebenia len o niečo vyššiu ako HARD FRO V-1000. Najväčšiu priemernú hodnotu opotrebenia dosiahli radlice bez návaru, oproti radlice navarenej FIDUROM 10/65 až 2,95-násobnú. Z dosiahnutých výsledkov je vidieť, že preventívnym návarom sa dá životnosť predĺžiť niekoľkonásobne, záleží od použitého prídavného materiálu (druhu, štruktúry).

Súčasne s dĺžkovými úbytkami boli zisťované aj hmotnostné úbytky, výsledky však korešpondovali s lineárnymi úbytkami. Opotrebenie na šírke radlice však lepšie vystihuje a viac vplýva na kvalitu práce.

Z výsledkov vidieť, že dosiahnuté úbytky šírky nekorešpondujú priamo úmerne s nameranou tvrdosťou. Dosiahnutá tvrdosť po navarení nekorešponduje s tvrdosťou udávanou výrobcom, ale v našom prípade bol použitý len jednovrstvový návar a výrobca udáva tvrdosť čistého návaru. Tvrdosť návaru však môže byť ovplyvnená práve tepelnými vplyvmi pri naváraní, chladnutím návarov, ale aj premiešaním prídavného materiálu so základným ale hlavne štruktúrou a rozložením karbidov chrómu v návare.

Záver

Možno konštatovať, že najväčšiu odolnosť proti opotrebeniu dosiahol navárový materiál FIDUR 10/65 ledeburitickej štruktúry s karbidmi chrómu, ktorého makrotvrdosť dosiahla 51 HRC. Zvýšenie odolnosti proti opotrebeniu podmieňuje prítomnosť tvrdých štruktúr karbidu chrómu.

Dôležitú úlohu pri kvalite zberu repy cukrovej zohráva aj rovnomernosť opotrebovania vyorávacej radlice. Výsledky práce ukázali, že najväčšie opotrebenie je v prvej tretine vyorávacej radlice.

Dosiahnuté výsledky sú príspevkom k riešeniu problematiky opotrebenia vyorávacích radlíc vyorávačov repy cukrovej a naznačili možnosti v riešení tejto problematiky. Životnosťou radlíc sa bude potrebné ďalej zaoberať a hľadať nové možnosti predĺženia ich životnosti.

Súhrn

Príspevok sa zaoberá odolnosťou návarových materiálov aplikovaných na vyorávacie radlice repy cukrovej. Najintenzívnejšie sa opotrebovávala prvá tretina vyorávacej radlice. Dosiahnuté výsledky ukázali, že ledeburitické materiály s vysokým obsahom uhlíka a chrómu, s ktorými bol vytvorený preventívny návar na radlice vyorávača repy cukrovej, dosahujú lepšiu odolnosť proti opotrebeniu ako nenavarená vyorávacia radlica zo základného materiálu triedy 14, hoci tento materiál je zušľachtený.

Kľúčové slová: vyorávacie radlice repy cukrovej, abrazívne opotrebenie, renovácia naváranie.

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ELECTRICAL CAPACITY AND RESISTANCE MEASUREMENT OF BLUEBERRY CULTIVARS (*VACCINIUM CORYMBOSUM* L.)

MERANIE ELEKTRICKEJ KAPACITY A ODPORU PRI JEDNOTLIVÝCH ODRODÁCH ČUČORIEDOK (*VACCINIUM CORYMBOSUM* L.)

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Blueberries have become a product of interest in recent years due to their nutritional and health benefits. They are a rich source of vitamins (A and C), minerals and dietary fibre. The electrical measurements are utilized at appraisal of various fruits quality. The measurements were done on 15 cultivars of blueberries (*Vaccinium corymbosum* L.). At each frequency, we measured three values of capacity and resistance, after that we calculated average values from measuring data for each samples. Resistance has decreasing tendency with increasing temperature and frequency. Simultaneously, the higher was the temperature of measurement, the higher was the capacity at particular frequency of measurement.

Key words: blueberries, capacity, resistance, frequency

The origin of blueberries and the biggest tradition of their growing are in the North America, where their big fruit cultivars are also growing. The big plantation is also in the all Europe, Australia and New Zealand (Dierking and Dierking, 1993). On Slovakia, there does not exist a big tradition in growing of blueberries. Orava is the main producer of blueberries in Slovakia. The *Vaccinium corymbosum* L. is cultivated from traditional vegetation. Blueberry's fruits belong to the healthiest species on the world. They have got high biological and dietetic value (Šimala, 2000). From the nutritional point of view, blueberries have also high concentration of ferrum in compare with other species of small berrylike fruits. They are also very rich in carbohydrates, they have a low content of fat and a lot of vitamins from the category C, K, A, and magnesium. They are also rich source of fibre (Kováčiková et al., 1997). Because of a wide knowledge about their chemical structure, nutrition structure and their health effects, it is very interesting to fill in also knowledge about their physical properties.

From the microscopic and macroscopic point of view, we can classify biological materials as non – homogenous dielectrics. Inside of the cells, there are different solutions of organic and inorganic substances, which are electrolytes (conductors of 2nd type). This is the reason why there exists ion's type of electrical conductivity inside of them. The cell's membranes are not conductors, they are dielectrics. The biological capacitors are created by changing of conductive internal parts of cells and membranes as insulators. From the macroscopic point of view, the electrical properties of biological materials are influenced by their chemical composition, texture and by the deployment and arrangement of cells in them. The main factors are the moisture content and their non – constant distribution in the material, as well as various types of water bonds, and sorptive properties. The next factors are the air content inside of tissues and temperature (Hlaváčová, 2003).

The electrical measurements are utilized at appraisal of various fruits quality. For example Gordeev (1998) developed an apparatus for investigation the electrical parameters of fruit tissue, viz. polarization capacity and conductivity. Montoya et al. (1994) utilized a technique for measuring the electrical conductivity of intact fruits. They measured the electrical conductivity of avocado fruits during cold storage and ripening. The health state of some fruit can be observed on ground of their electrical properties. Than et al. (1996) investigated the effect of pineapple blackheart on electrical resistance of pulp tissues. The electrical resistance of pulp from harvested pineapples with blackheart was lower than that of tissue from healthy pineapples. Resistance decreased with increase in disease severity. The measurement of the electrical resistance thus provides a rapid and convenient method of diagnosing the blackheart. Hlaváčová and Hlaváč (2003) measured the electrical properties of apricot flesh. It was found that the decay of apricot flesh influences its electric conductivity, impedance and capacity, which are caused by damage of cell membranes. The impedance decreased on values from 250 Ω till 900 Ω for decayed apricots; on the contrary the impedance of flesh intact with decay attained the values more than 13 kΩ. Icier and Ilicali (2005) used temperature dependencies of the fruit puree conductivity at description of their treatment during ohmic heating.

Material and methods

The measurements were done on 15 cultivars of blueberries (*Vaccinium corymbosum* L.). The samples were from Research Institute of Grassed Growth and the Mountain Agriculture in Krivá on Orava. The experimental area where the individual cultivars are grown lies in altitude 700 m. o s., with geographical latitude 49° 17' n. l. and 19° 28.5' e. l. The average temperature over the year is 6 °C with yearly total amount of meteoric water (800 – 900) mm. The manual picking was realized on August 28 in 2009. Samples were stored in the fridge in laboratory at the temperature of 4 °C. Each sample has mass of 200 g. The moisture content was measured according to standards STN 5602 46 – Test methods for canned semi – products of fruit and vegetables. Determination of dry mater content (1984). The samples were dried in dryer during 4 hours at the temperature of 105 °C. After drying were cooled in desiccator and then were weighted. The moisture content wet basis was then calculated according to the following relationship:

$$\omega = \frac{m_1 - m_2}{m_1 - m_o} 100\ \% \qquad (1)$$

where:

m_1 – the mass of the moist sample and the drying dish

m_2 – the mass of the dried sample and the drying dish

m_o – the mass of the drying dish

Electrical capacity was measured by LCR meter Good Will 821 in frequency range from 50 Hz to 200 kHz. LCR meter was connected to personal computer. The parallel plate capacitor which was used during the measurement is created by two parallel electrodes. The each sample was filling into the parallel plate capacitor and connected with LCR meter. After that, each sample was measured three times. First time – immediately at that temperature after getting from the fridge, the second time – after longer time period and the third time – after reaching the temperature of laboratory. Samples with different temperatures were measured at the frequencies 0.05 kHz, 0.1 kHz, 0.2 kHz, 0.5 kHz, 1 kHz, 3 kHz, 10 kHz, 50 kHz, 100 kHz, 200 kHz. We measured three values of the capacity and resistance at each frequency, after it we calculated average values for each samples from measured data. We took into account regression equation for capacity and resistance for the evaluation of the results.

Results and discussion

The moisture content wet basis was calculated according to equation (1). Tab. 1 shows the cultivars covered a moisture range from 81.24 % to 88.10 %. The moisture content decreases from cultivar Blueray to cultivar Puru.

Table 1 The moisture content wet basis of particular cultivars

Cultivar (1)	Moisture content in % (2)
Blueray	88.10
Duke	87.18
Patriot	86.28
Bluejay	86.36
Pemberton	85.75
Bluecrop	84.75
Goldtraube 23	84.14
Chippewa	83.79
Berkeley	83.54
Polaris	83.25
Spartan	82.80
Sierra	82.48
Nelson	81.99
Sunrise	81.65
Puru	81.24

Tabuľka 1 Relatívna vlhkosť pre jednotlivé kultivary
(1) kultivar, (2) vlhkosť v %

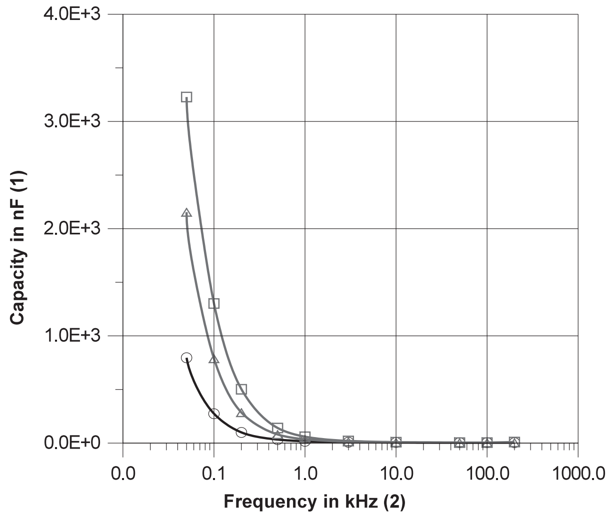

Figure 1 Frequency dependencies of capacity at three temperatures (○ – 4 °C, △ – 26 °C, □ – 29 °C)

Obrázok 1 Frekvenčná závislosť kapacity pri troch teplotách (○ – 4 °C, △ – 26 °C, □ – 29 °C)
(1) kapacita v nF, (2) frekvencia v kHz

We constructed the dependencies of measured and calculated physical quantities. Frequency dependencies of capacity at three temperatures for the illustration are shown on Fig. 1. Each point on Fig. 1 at particular frequency was calculated as average value from all measured values for all cultivars.

Based on the evaluated results, we found out that frequency dependencies of capacity have the character of decreasing power function, according to the formula:

$$C = C_o \left(\frac{f}{f_o} \right)^{-k} \qquad (2)$$

where:

C – capacity (nF)

C_o – capacity at the reference frequency (nF),

f – frequency (kHz)

f_o = 1 kHz

k – constant

On Figure 1 we can see the differences between the curves till frequency of 3 kHz. The highest values of capacity were obtained at the highest temperature, and the lowest values of capacity are at the lowest temperature. The values of capacity at highest frequencies than 3 kHz are the same for all temperatures. After the calculation of the coefficient of determination (R^2) for dependencies at particular temperature we found out, that the value for R^2 is between 0.871481 (4 °C) to 0.893422 (26 °C) and this is right for the correctness of regression. The coefficients of determination are placed in Tab. 2.

Table 2 Coefficients of determination for frequency dependencies of capacity at three temperatures

Dependency (1)	R^2 (2)
○ – 4 °C	0.871481
△ – 26 °C	0.893422
□ – 29 °C	0.880929

Tabuľka 2 Koeficienty determinácie závislostí kapacity od frekvencie pri troch teplotách
(1) závislosť, (2) koeficient determinácie R^2

We found out that the regression equation of the resistivity dependencies for the same samples has the similar shape:

$$R = R_o \left(\frac{f}{f_o} \right)^{-a} \tag{3}$$

where:
R – resistance (kW)
R_o – resistance at the reference frequency (kW)
f – frequency (kHz)
f_o = 1 kHz
a – constant

Fig. 2 shows that the resistance has the highest values at the lowest temperature and on the contrary the lowest values of resistance belong to the highest temperature. The frequency dependency of resistance at the temperature of 4 °C is decreasing rapidly than at the higher temperatures.

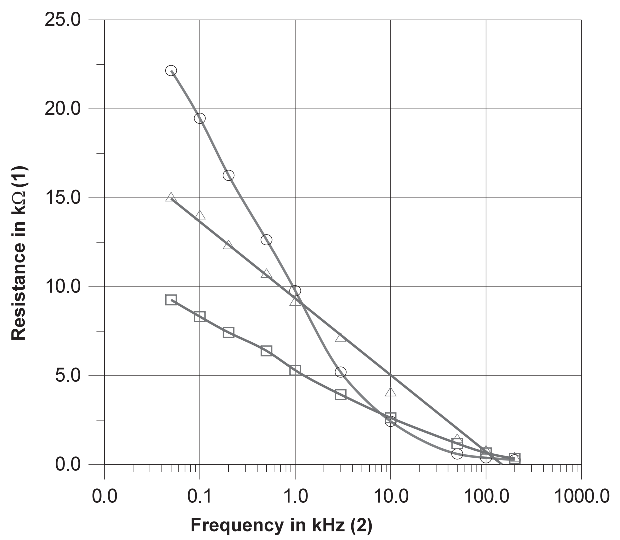

Figure 2 Frequency dependencies of resistance at three temperatures (○ – 4 °C, △ – 26 °C, □ – 29 °C)
Obrázok 2 Frekvenčná závislosť odporu pri troch teplotách (○ – 4 °C, △ – 26 °C, □ – 29 °C)
(1) odpor v kΩ, (2) frekvencia v kHz

The coefficients of determination of this equation have high value for all samples. Differences can be observed till the frequency 100 kHz. The values at higher frequencies for each sample are the same.

Table 2 Coefficients of determination for frequency dependencies of resistance at three temperatures

Dependency (1)	R^2 (2)
○ – 4 °C	0.966665
△ – 26 °C	0.919977
□ – 29 °C	0.931275

Tabuľka 2 Koeficienty determinácie pre frekvenčnú závislosť odporu pri troch teplotách
(1) závislosť, (2) koeficient determinácie R^2

Frequency dependencies of capacity for several cultivars are shown for the illustration on Fig. 3. For a better transparency, we put into Fig. 3 only 6 cultivars. We found out decreasing tendency of capacity in whole measured frequency

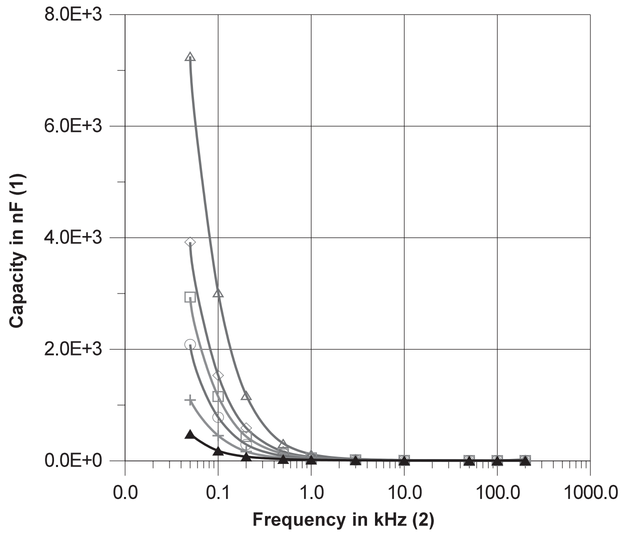

Figure 3 The frequency dependences of capacity for several cultivars (△ – Blueray, ◇ – Patriot, □ –Bluejay, ○ – Bluecrop, + – Goldtraube 23, ▲ – Puru) at the temperature of 29 °C
Obrázok 3 Frekvenčná závislosť kapacity pre niektoré kultivary (△ – Blueray, ◇ – Patriot, □ – Bluejay, ○ – Bluecrop, + – Goldtraube 23, ▲ – Puru) pri teplote 29 °C
(1) kapacita v nF, (2) frekvencia v kHz

range for each from 15 monitored cultivars of blueberries. The values of capacity at highest frequencies than 3 kHz are the same for all cultivars. We can notice that differences between the dependencies are occurred till frequency of 3 kHz. The capacity of several cultivars has lowest values than the cultivar of Blueray. The cultivar of Puru has shown the lowest values of capacity. The values of the capacity lowest than ones for cultivar Blueray are in this order: Duke, Patriot, Bluejay, Pemberton, Bluecrop, Goldtraube 23, Chippewa, Berkeley, Polaris, Spartan, Sierra, Nelson, Sunrise, and Puru. The differences could be caused by the moisture content of cultivars. The moisture content decreases from the cultivar Blueray to cultivar Puru. The capacity of cultivars is influenced by moisture content and cultivar particularity respectively.

Tab. 4 shows the coefficients of determination (R^2) for several cultivars. We found out, that the values for R^2 are between 0.852145 (Blueray) to 0.91379 (Goldtraube 23) and this is right for the correctness of regression.

Table 4 Coefficients of determination for frequency dependences of capacity for several cultivars

Cultivars (1)	Dependency (2)	R^2 (3)
Blueray	△	0.852145
Patriot	◇	0.897341
Bluejay	□	0.913578
Bluecrop	○	0.907516
Goldtraube 23	+	0.91379
Puru	▲	0.890594

Tabuľka 4 Koeficienty determinácie pre frekvenčnú závislosť kapacity pre niektoré kultivary
(1) kultivary, (2) závislosti, (3) koeficient determinácie R^2

Conclusion

We use electrical quantities in a lot of branches and specializations. The aim of this work was to determine the frequency dependencies of capacity and resistance for the 15 samples of blueberry's cultivars (*Vaccinium Corymbosum* L.). We can see (Fig. 1) that the capacity decreases with frequency in whole measured range according to regression Eq. (2) for all samples at all monitored temperatures 4 °C, 26 °C, 29 °C. Differences between curves can be observed till the frequency of 3 kHz. The capacity has the same values at the higher frequencies for each cultivar. We found out that the regression equation for the frequency dependencies of resistivity have the similar shape as for capacity (Eq. 3). The resistance has the highest values at the lowest temperature and on the contrary the lowest values of resistance belong to the highest temperature. The frequency dependency of resistance at the temperature of 4 °C is decreasing rapidly than at the higher temperatures (Fig. 2).

Further, we found out decreasing tendency of capacity in whole measured frequency range for each from 15 monitored cultivars of blueberries. The values of capacity at highest frequencies than 3 kHz are the same for all cultivars (Fig. 3). The capacity of several cultivars has lowest values than the cultivar of Blueray in this order: Duke, Patriot, Bluejay, Pemberton, Bluecrop, Goldtraube 23, Chippewa, Berkeley, Polaris, Spartan, Sierra, Nelson, Sunrise, and Puru. The moisture content decreases from the cultivar Blueray to cultivar Puru. The capacity of cultivars is influenced by moisture content (Tab.1) and cultivar particularity respectively.

Conclude, based on the measured electrical quantities, it is possible to use them at the quality of blueberry's cultivars (*Vaccinium Corymbosum* L.) determining.

Súhrn

Na základe merania elektrických vlastností sa zisťuje kvalita, zloženie potravín a zrelosť ovocia. LCR meter je jedným z vhodných zariadení, ktoré sa používajú na meranie elektrických vlastností. Merania boli uskutočnené na 15 odrodách čučoriedok (*Vaccinium Corymbosum* L.), ktoré pochádzali z Výskumného ústavu trávnatých porastov a horského poľnohospodárstva v Krivej na Orave. Vzorky boli merané pri troch rôznych teplotách 4 °C, 26 °C, 29 °C. Sledovali sa závislosti kapacity od frekvencie a odporu od frekvencie pri troch teplotách pre všetky kultivary. Následne boli zisťované závislosti kapacity a odporu od frekvencie pri troch rôznych teplotách aj pre jednotlivé kultivary. Zohľadnená bola relatívna vlhkosť jednotlivých meraných kultivarov (tab.1). Zistili sme, že frekvenčné závislosti kapacity pri troch rôznych teplotách, pre celý sledovaný súbor kultivarov, mali klesajúcu tendenciu (obr.1). Hodnoty odporu, pre celý sledovaný súbor, mali rovnako klesajúcu tendenciu v závislosti od narastajúcej frekvencie, čo bolo zistené pri všetkých troch teplotách (obr. 2). Rovnaké výsledky pre jednotlivé závislosti kapacity a odporu od frekvencie pri troch rôznych teplotách sa preukázali aj pri jednotlivých kultivaroch. Hodnoty kapacity pre jednotlivé kultivary klesali v nasledujúcom poradí: Blueray, Duke, Patriot, Bluejay, Pemberton, Bluecrop, Goldtraube 23, Chippewa, Berkeley, Polaris, Spartan, Sierra, Nelson, Sunrise, a Puru (obr. 3). Hodnoty nameranej kapacity ovplyvnila vlhkosť a aj odrodová rozdielnosť kultivarov. Koeficienty determinácie dosiahli vysoké hodnoty pri všetkých meraniach, čím sa potvrdila regresná rovnica (tab. 2, 3, 4).

Kľúčové slová: odrody čučoriedok, kapacita, odpor, frekvencia

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MECHANICAL PROPERTIES OF MULCHING MATERIALS
MECHANICKÉ VLASTNOSTI MULČOVACÍCH MATERIÁLOV

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The paper is oriented at the analysis of the plastic materials, which are used in the horticulture. Mulching plastic foils affected the environment by the absorption and reflection of the light by their surface and they change microclimate of the cultivated plants. We analyzed an endurance of the polyethylene Bralen RA 2-63, which was white and yellow colored by the concentrate Maxithen. We analyzed mechanical properties as are a strain at the strength limit, load force, modulus of elasticity and deformation. The results of the measurement of the material Bralen RA 2-63 showed that the biggest values of the modulus of elasticity we are obtained in the transversal direction at the yellow colored material. The values of the tensile strain were approximately the same for the all measurements. We found out the white colored material is more resistant than yellow colored at the impact measurement. The obtained results and conclusions can find wider application, which is next motivation at the solution similar problems.

Key words: modulus of elasticity, tensile strain, weight of the impact beater

Mulching is agro-technical measures, where we use covering of soil with different materials (organic, inorganic). We help by, inter alia, better water retention in the soil, warming or cooling of the soil, eliminating weed infest and soil erosion (Uher a i., 2009). Result of favorable conditions for growth and development is increasing of the yield, quality and earliness of realized production (Romic et al., 2003; Ibarra-Jimenez et al., 2006). This method of cultivation is mostly used for vegetables.

The plastic foils, which are used in horticulture, are of prime importance polyethylene film. Plastic mulch generally affect the radiation balance of the absorbing or reflecting light by surface of cultivated plants and change the microclimate. The color of mulch has an important role. Color affects the mulch temperature and the soil layer under the mulch. Partly reflect the wavelengths of solar radiation back into the vegetation and affect physiological processes of plants, especially on growth and photosynthesis, a process sensitive to the precise wavelength of light radiation. The plants can change length of internodes and date of flowering (Taber, 2004).

The success of cultivation by using plastics depends on of specific conditions of production in a particular location. Orzolek (2005) recommends plastic mulch in colder regions. The actual effect of mulching is by Kóňa (2007a) greater in worse climatic conditions of given year.

Material and methods

For different packing materials is operating risks of mechanical stress, especially in transportation, handling and storage. For plastic packaging, we design and build equipment for determination of impact resistance to free fall (Zeman, 2005).

A hemispheric head of pestle is made of aluminum with a diameter of 38 mm. The surface is polished and can not have scratches or other defects. Additional weights are made of aluminum. The test has two stages, preliminary and main. In a preliminary trial were used five samples, to the main trial at least 20 samples. The weight gain was chosen by force to puncture of test sample according to STN 77 O513. After the testing of 20 samples we determined the total number of damaged samples. Number of damaged samples must be at least 10 from a total of 20 samples.

Weight of a Mass needed to transfer shock „m_f“ is calculated by the equation:

$$m_f = m_o + \Delta_m \left(\frac{A}{N} - 0{,}5 \right), \text{ g} \quad (1)$$

where:
m_o – is the smallest total weight of to pestle which was damaged samples, g
Δ_m – constant weight gain, g

$$A = \sum_{i=1}^{k} m_i \cdot z_i \quad (2)$$

where:
m_i – number of perforated samples to mass m_i
z_i – number of possible weight gain from m_o to *mi*

The total number of perforated samples:

$$N = \sum_{i=1}^{k} n_i \quad (3)$$

The force required to perforate the sample:

$$F = m_f \cdot \frac{dv}{dt} \quad (4)$$

where:
v – the speed of falling, $m.s^{-1}$
t – time of falling, s

Tests of mechanical strength properties of the material was observed by tensile test, which is used to determine the ultimate tensile strength, modulus of elasticity in tensile stress and other characteristics depending on stress and strain. To measure the mechanical properties we used ripper machine

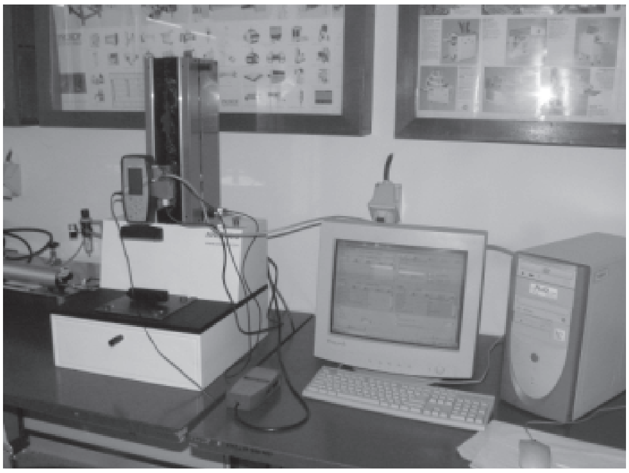

Figure 1 Test stand STENTOR ANDILOG
Obrázok 1 Trhací stroj STENTOR ANDILOG

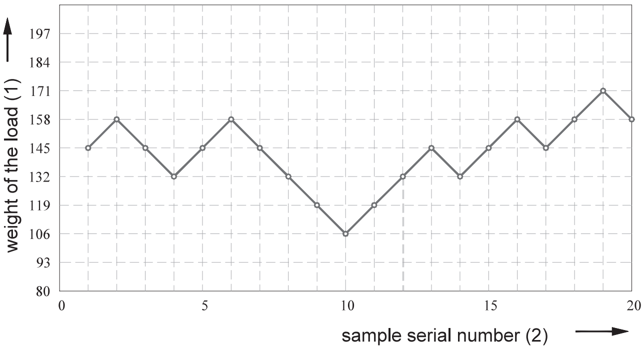

Figure 2 Dependency of the weight at the breaking of the material by the impact – Bralen RA 2-63 yellow coloured
Obrázok 2 Priebeh hmotnosti pri porušení materiálu rázom – Bralen RA 2-63 sfarbená do žlta
(1) hmotnosť závažia v g, (2) poradové číslo vzorky

Stentor ANDILOG, Figure 1. Sliding speed of clamping jaw was 200 mm.min^{-1}. Before carrying out tests, samples were prepared according to ISO 291.

The test conditions for determining the tensile properties of mulching plastics and plastic composites, we adapt to standards ISO 527-1, STN ISO 527-2 and ISO 527-3. Measurement methodology and evaluation of results is shown at work (Zeman, 2001).

To measure we used mulching film made of polyethylene type Bralen RA 2-63, which was dyed to concentrate Maxithen. Material thickness was 50 μm (microns). We evaluated two materials, which were colored as white and yellow.

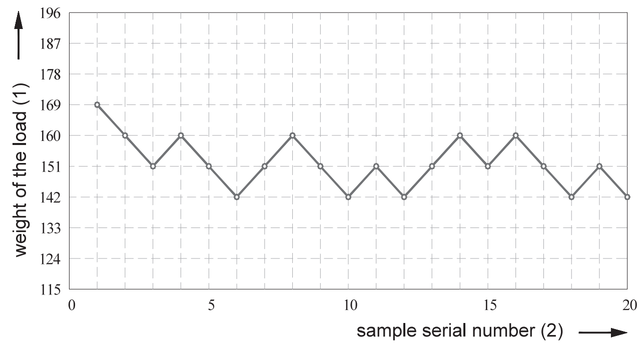

Figure 3 Dependency of the weight at the breaking of the material by the impact – Bralen RA 2-63 white colored
Obrázok 3 Priebeh hmotnosti pri porušení materiálu rázom – Bralen RA 2-63 sfarbená do biela
(1) hmotnosť závažia v g, (2) poradové číslo vzorky

Results and discussion

According to the methodology we have chosen a constant weight gain of 13 g. That weight gain was gradually added until breakthrough (damage) of the test material. The measured values for polyethylene film of type Bralen RA 2-63, dyed yellow (Fig. 2) show that of 20 test samples were damaged 10 samples. When placing the rider up to 0.66 m, the incident rate was 3.59 ms^{-1} and a time for falling off the material was 0.36 s. The difference in weight gain of pestle ranged from 106 g to 171 g, where there was a breakthrough shock of test sample. The total weight of pestle for shock breakthrough of polyethylene type Bralen RA 2-63 with dyed in yellow on the thickness of 50 μm according to equation (1) is 137.2 g. For this weight is required the force of 1.349 N (equation 4) and the energy for puncture of the test material by free fall of pestle was 0.09 J.

Measurement results for the impact resistance of polyethylene type Bralen RA 2-63 with dyed in white to 50 μm (micron) thickness are shown in Fig. 3. From these values shows that from total 20 samples 11 specimens reclassified shocks. For this sample the weight of pestle to puncture the material was significantly greater. The lowest weight at which the pestle was to puncture the sample was 151 g. In contrast, the highest mass reached a pestle in 169 g. Constant weight gain was 9 g.

Total recommended weight of pestle, when there is a perforation of the packaging material in 50 micron thickness is 158.78 g. By this weigh, needed is the force of 1.56 N. The resulting energy of the pestle free fall to perforate the material was 0.10 J.

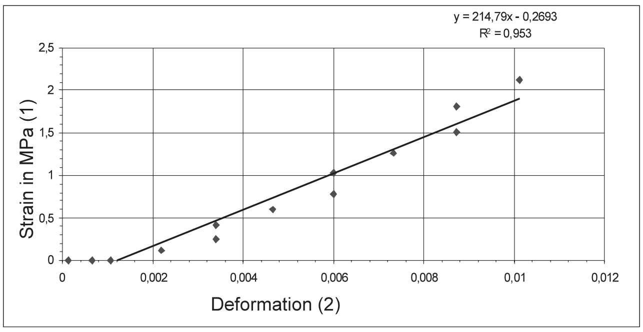

Figure 4 Regression line of the modulus of elasticity of material Bralen RA 2-63 white colored, cut in longitudinal direction
Obrázok 4 Regresná priamka modulu pružnosti pre materiál Bralen RA 2-63 s farbený do biela, vystrihnutý v pozdĺžnom smere
(1) napätie v MPa, (2) deformácia

The measured and evaluated the mechanical properties of mulching materials, which was excised in the longitudinal direction, we found that the tension strength was obtained in polyethylene type Bralen RA 2-63 colored white 13.2 MPa (Fig. 5) and modulus of flexibility was 214. 79 MPa. Regression line for determination the modulus of elasticity (Fig. 4) have the line equation y = 214.79x – 0.2693. Of 10 measurements of mechanical properties, we got an average tension on the strength of 13.51 MPa and elasticity modulus of 222.73 MPa.

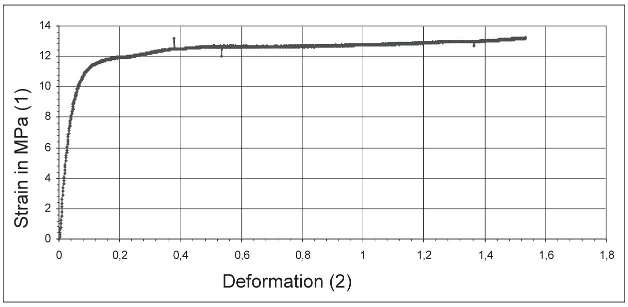

Figure 5 Tensile diagram of material Bralen RA 2-63 white coloured, cut in longitudinal direction
Obrázok 5 Ťahový diagram pre materiál Bralen RA 2-63 sfarbený do biela, vystrihnutý v pozdĺžnom smere
(1) napätie v MPa, (2) deformácia

Rupture of material occurred when the external force was from 9 to 9.8 N. Furthermore, we observed mechanical properties of the same material, but samples were cut in the transverse direction (Fig. 6, 7). Tensions between the strength we have reached 15.6 MPa at 10.5 N imposed on the strength and elasticity modulus of 210.24 MPa. Equation line of modulus is $y = 210.24x - 10.708$. Average tension on the strength of the 10 measurements we achieved 15.8 MPa and elastic modulus of 214.36 MPa.

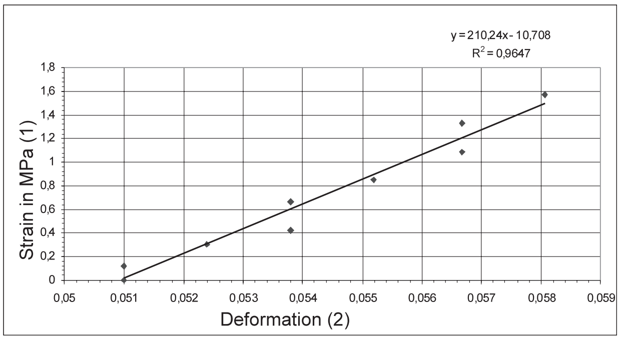

Figure 6 Regression line of the modulus of elasticity of material Bralen RA 2-63 white colored, cut in transversal direction
Obrázok 6 Regresná priamka modulu pružnosti pre materiál Bralen RA 2-63 sfarbený do biela, vystrihnutý v priečnom smere
(1) napätie v MPa, (2) deformácia

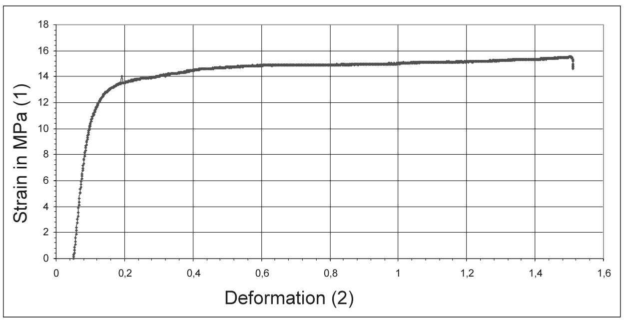

Figure 7 Tensile diagram of material Bralen RA 2-63 white coloured, cut in transversal direction
Obrázok 7 Ťahový diagram pre materiál Bralen RA 2-63 sfarbený do biela, vystrihnutý v priečnom smere
(1) napätie v MPa, (2) deformácia

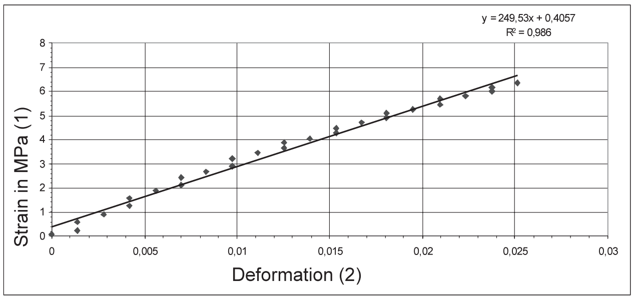

Figure 8 Regression line of the modulus of elasticity of material Bralen RA 2-63 yellow coloured, cut longitudinal direction
Obrázok 8 Regresná modulu pružnosti pre materiál Bralen RA 2-63 sfarbený do žlta, vystrihnutý v pozdĺžnom smere
(1) napätie v MPa, (2) deformácia

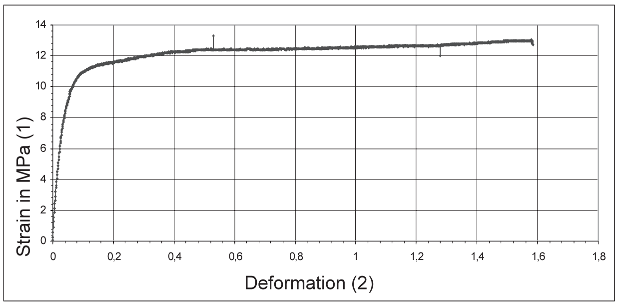

Figure 9 Tensile diagram of material Bralen RA 2-63 yellow colored, cut in longitudinal direction
Obrázok 9 Ťahový diagram pre materiál Bralen RA 2-63 sfarbený do žlta, vystrihnutý v pozdĺžnom smere
(1) napätie v MPa, (2) deformácia

The results of mechanical properties measurements of material Bralen RA 2-63 with dyed yellow which was cut out in the longitudinal direction is shown in (fig. 8, 9). We note that the rupture occurred when imposed on the strength of 8 to 9 N, a tensile stress reached a value of 13.2 MPa and elasticity modulus was 249.53 MPa. Regression line equation for the elasticity modulus is $y = 249.53x + 4\ 057$. Average tension on the strength of the 10 measurements was 12.73 MPa and elastic modulus was 250.92 MPa. When the test sample was loaded in the transverse axis, the sample occurred when imposed on the power of 7.8 ÷ 9.1 N. Tensions between the tensile strength of the tested material amounted to 12.2 MPa and elasticity modulus of 261.72 MPa. Regression line equation for the modulus was $y = 261.72x + 0.0058$. Average value of tension on the strength of the 10 measurements achieved 12.43 MPa and elastic modulus 270.41 MPa.

Conclusion

We evaluated selected materials in terms of mechanical properties. The experimental measurements, we performed impact tests and set dimensions of tension in strength and modulus of elasticity and regression lines for tested samples, which were cut in longitudinal and transverse directions. From the results we can conclude that white and colored material Bralen RA 2-63 with concentrate Mexithen was sturdier. The white polyethylene film in comparison with yellow material Bralen RA 2-63 withstands greater weight of pestle in a drop test about 21. 58 g (15.7 %).

The experimental measurement of the mechanical properties of materials based on plastics, we can conclude that the tension value of strength was roughly the same for both materials. In evaluating the modulus of elasticity, we found that the material Bralen RA 2-63 with yellow coloring achieved higher values of elasticity modulus of 16.1 ÷ 24.8%.

Súhrn

Príspevok je zameraný na analýzu plastových materiálov, ktoré sa používajú v záhradníctve. Mulčovacie fólie ovplyvňujú prostredie pohlcovaním a odrážaním svetla svojím povrchom a menia mikroklímu pestovaných rastlín. Analyzovali sme odolnosť polyetylénu typu Bralen RA 2-63, sfarbeného koncentrátom Maxithen na bielo a žlto. Z mechanických vlastností sme sledovali napätie na medzi pevnosti, zaťažujúcu silu, modul pružnosti a deformáciu. Výsledky merania pre materiál Bralen RA 2-63 ukázali, že najväčšie hodnoty modulu pružnosti sme dosiahli v priečnom smere pri materiáli zafarbenom na žlto, hodnoty ťahového napätia pri všetkých meraniach boli približne rovnaké. Z merania obalového materiálu proti rázu sme zistili, že materiál zafarbený na bielo je odolnejší ako materiál zafarbený na žlto. Získané výsledky a závery môžu nájsť širšie uplatnenie, čo je ďalšou motiváciou pri riešení podobných problematík.

Kľúčové slová: modul pružnosti, napätie v ťahu, hmotnosť tĺka rázom

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ECONOMIC BENEFIT OF THE AUTOMATED SATELLITE GUIDANCE OF THE FIELD MACHINES

EKONOMICKÝ PRÍNOS AUTOMATICKEJ SATELITNEJ NAVIGÁCIE V TECHNOLOGICKOM POSTUPE PESTOVANIA OBILNÍN

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The paper is focused on the issues related to using of satellite-based guidance system for navigation of machines in field operations. Benefits and economic effectiveness of the using of automated satellite-based guidance system were calculated by the mathematical model. The comparison with the manual steering of machines has been done. The model has allowed to calculate all types of savings achieved due to the higher accuracy of the machine passes (savings of labour hours, labour cost, equipment cost, crop care product cost, seed cost, fertilizer cost, fuel cost saving). For the 600 hectares farmed the payback period of the automated satellite guidance system is 2 years and 5 months, while the total guidance investment were 25 000 € and annual cost on guidance system were 1 400 €.

Key words: satellite guidance, guidance accuracy, economic effectiveness, machine capacity

Currently, farmers are facing a major requirement to increase the efficiency of technological processes. In particular, it relates to field processes in plant production. This objective can be achieved by increasing the accuracy of technological operations. The accuracy of technological operations carried out in the field largely depends upon the accuracy of machine passes. Improved accuracy of machine passes the utmost especially for those operations which involve the application of inputs (fertilizers, pesticides, seeds, etc.). Higher accuracy means higher economic efficiency of field technological processes. According to Heraud and Lange, 2009, steering a farm vehicle is an extremely demanding task. The operator must drive on the desired path so as to not run over crops while minimizing overlaps and skips and continuously monitoring the operation of the equipment. Modern equipments based on using of GPS guidance have brought a new level of accuracy of field operations. Attention of researchers focuses on the whole complex of problems concerning the use of guidance systems. Ehrl et al. (2004) have compared different satellite guidance systems and on the base on the results obtained they stated that the successful introduction of autonomous steering or guidance systems for standard tractors must be accounted as a first step towards completely independent field robots. For the whole range of this technology, the accuracy and therefore the quality of work is the most important factor for being successful in practice. Modern guidance systems can provide different accuracy of the machine passes. According to Borgelt et al. (1996) and Žitňák and Švarda (2011) for variable rate application and referencing of soil and yield data, an accuracy of one to several meters is generally sufficient. More accurate systems would be useful for vehicle guidance, to eliminate skips and overlaps with a fertilizer spreader or a chemical applicator. Global positioning system enabled navigation technologies such as light-bars and automated guidance systems have been commercially available for several years. Potential benefits include reduction in overlap, increased speed of field operations, workday expansion, and appropriate placement of spatially sensitive inputs, Griffin, 2009. Modern navigation systems have become part of the field of machinery, thereby affecting the price of the machinery itself, Watson and Lowenberg-DeBoer, 2003. In these circumstances it is important to know the economic aspects of the use of satellite-based navigation systems.

The main aim of our research was to analyze the potential and the possibilities of satellite navigation systems in the technological processes in crop production. From the theoretical knowledge as well as from many previous studies in this area, it was shown that the efficient use and quality of agricultural machinery work in crop production is closely linked with quality guidance and steering of machinery during all field operations.

The objective of the study was to evaluate the economic return and cost savings when automated satellite-based navigation system was used for the guidance of machines during operations of sowing, fertilization, soil cultivation, spraying and harvest.

Materials and methods

Calculations of the economic benefits of the automated satellite guidance system have been related to technology operations within cereals cropping system on the acreage of 600 ha. Before the calculations of the economic benefits it was necessary to measure the deviations of the machine passes from the ideal trajectory during individual technology operations with the automated satellite guidance system and without it (steering of the tractor fully depended upon the skills and ability of the operator).

Measuring of the accuracy of the automated satellite guidance system

Measuring of the accuracy of the automated satellite guidance system has been done during spring tillage provided by disc harrow KUHN Discover XM (working width 4.75 m) with the tractor JOHN DEERE 7820, which was equipped with the satellite guidance system JOHN DEERE AutoTrac using a correction signal StarFire 2 (±10 cm).

A B C

Figure 1 A – Stand with the laser distance meter, B – reflecting surface for the laser beam of the laser distance meter (front view and rear view), C – laser distance meter LEICA Disto classic 5a

Obrázok 1 A – statív s laserovým diaľkomerom, B – odrazová plocha pre laserový lúč diaľkomera (pohľad spredu a zozadu), C – laserový diaľkomer Leica Disto classic 5a

Before the measuring of the accuracy of the automated satellite guidance system on the AutoTrack monitor there was setup the spacing of the working passes on the value 4.65 m. Inaccuracies of the satellite guidance have been recorded by measuring of working width after two machine passes. We have obtained the information about the overlaps and skips caused by the machine guidance. Working overlaps (including 2 machine working widths) have been measured from the tracks of the side discs which have been created by the discs to the uncultivated soil surface.

For the measuring of the working width we have used the LEICA Disto Classic 5a laser distance meter (Fig. 1C), which has been located on the stand (Fig. 1A) and reflecting surface for the laser beam (Fig. 1B).

Measuring of the accuracy of the working passes and working width without using of a navigation system were performed in a similar manner. In this case, the accuracy of the steering was entirely dependent on operator skills and abilities.

Working hypothesis regarding economic effects caused by using of satellite guidance

Due to the higher accuracy of the machine passes as a result of using of satellite guidance of the field machine the following benefits can be achieved:

1. more effective application of the inputs: chemicals (pesticides), fertilizers, seeds,
2. smaller working width overlaps cause smaller wearing of the soil engage machine parts of the tillage equipment,
3. shortening of the total travelled distance causes decreasing of the fuel consumption,
4. increasing of the working speed,
5. increasing of the machine capacity.

The additional benefits can be achieved when the field machine is guided by the automated satellite guidance:

1. decreasing of the operator fatigue increases work safety,
2. extension of the time of working shift allows to perform the working operations also when the visibility is reduced, e. g. during foggy weather or during night.

Determination of a mathematical calculation model

In order to formulate the mathematical model for the calculation of the technical and economic effects of the using of satellite guidance system it is necessary to determine the financial return on invested funds related to guidance system purchase and its operation. The financial inputs must be compared with the cost savings caused by using of satellite guidance system. General procedure of the model composition:

1. formulation of the problem,
2. model creation,
3. model quantification,
4. calculations,
5. results obtaining,
6. application in practice.

In our mathematical model for the calculations of the technical and economical indicators we have considered the technology of the grain cereals cropping system with the following working operations:

- stubble loosening, 1×, working width 6 m,
- seedbed preparation (soil loosening) 1×, tillage equipment working width 6 m,
- application of the chemicals 3×, sprayer working width 24 m,
- fertilizing 2×, fertilizer spreader working width 24 m,
- seeding 1×, drill machine working width 6 m,
- harvest 1×, combine harvester working width 9.15 m.

The above operations represent year – round using of the satellite guidance system.

For the calculations of the economic benefits of the satellite guidance system the following input data must be used:

- area farmed,
- implement working width,
- overlaps without using of guidance system,
- overlaps with using of guidance system,
- % overlap reduction,
- machine operation speed,
- labour productivity without guidance,
- labour productivity with guidance,
- number of working operations performed during a year,
- machine capacity with the using of guidance system,
- machine work rate (without fuel),
- input costs (crop care products cost, fertilizer cost, seed cost),
- fuel consumption with/without using of guidance system,
- fuel price,
- machinery costs,
- machine capacity,
- labour costs.

To perform the calculation of return of investment it will be necessary to calculate the parameters characterizing the cost savings caused by the use of navigation:

- labour hours,
- labour cost saving,
- equipment cost saving,
- crop care product cost saving,
- seed cost saving,
- fertilizer cost saving,
- fuel cost saving.

For the final calculation the cumulative data will be determined:

- total annual return,
- total time saving,
- total guidance investment.

In order to calculate the total annual return and economic effectiveness it is necessary to calculate some input parameters characterizing the economic costingness of the individual seasonal operations.

Overlaps of the working widths

This parameter considers two values of the overlaps of the working width: overlaps of the working widths without guidance and overlaps of the working widths when guidance system is used. In the mathematic model we have used the following equation:

$$R_p = \frac{(P_b - P_s)}{B}, \quad \% \qquad (1)$$

where:
R_p – % overlap reduction
P_b – overlapping of the working widths without guidance, m
P_s – overlapping of the working widths with guidance, m
B – implement working width, m

The biggest differences of the overlaps occur in case of large size machine working widths (spraying and fertilizing).

Machine capacity (P_p)

This indicator characterises hectares-per-hour machine capacity related to individual operations (tillage, spraying, fertilizing, etc.).

$$P_p = (B - P) \cdot v_p \cdot 0.1, \quad \text{ha/h} \qquad (2)$$

where:
P_p – machine capacity, ha/h
v_p – machine operation speed, km/h
B – implement working width, m
P – overlapping without/with guidance, m

In the next step it is necessary to calculate for all operation used in cropping system the values of input indicators. It will allow to using these indicators in mathematic model for the purpose of determination of all kinds of savings and total annual return when satellite guidance system is used.

As a first parameter we have considered the **labour hours**, which characterises the amount of working time necessary to perform given field operation. The following equation can be used:

$$P_{pr} = \frac{V_f \cdot I_{pr}}{P_p}, \quad \text{h} \qquad (3)$$

where:
P_{pr} – labour hours, h
V_f – area farmed, ha
P_p – machine capacity, ha/h
I_{pr} – number of field operations performed during a year

In the next step of the calculation it is necessary to calculate the labour cost, which is connected with the payment of the staff salaries. The labour cost is effected by labour hours, agreed hourly wage and also the cost related to machine operation without fuel cost.
Labour cost can be calculated by the following equation:

$$C_p = H_m \cdot P_{pr}, \quad € \qquad (4)$$

where:
C_p – labour cost, €
H_m – unit labour cost (hourly wage, including fund contributions), €/h
P_{pr} – labour time, h

For the calculation of the parameter **machine operation cost without fuel** we can use the similar equation:

$$C_N = S_p \cdot C_S \cdot n_p \qquad (5)$$

where:
S_p – hectares worked annually, ha/year
C_S – machine work rate without fuel, €/ha
n_p – number of operations worked per year

Among the other parameters entering the calculation belongs the cost of each material input in production processes (crop care products, fertilizers, seed). This cost is calculated by multiplying the price of the commodity, application rate per hectare and total area.

Annual savings then will be defined as the difference between the costs related to implementation of the field operations with and without the use of satellite guidance system.

For the calculation of the **economic benefit** achieved due to the using of guidance system we can use the following equation:

$$E_E = (R_ú \cdot n_{pr}) - \left[N_{vst} + (N_{pr} \cdot n_{pr})\right], \quad € \qquad (6)$$

where:
E_E – economic benefit, €
$R_ú$ – annual savings, €
N_{pr} – cost related to operation of guidance system, €
n_{pr} – operational life of the guidance system, years

Results and discussion

Accuracy of the navigation of field tractor-machine set

The aim of this part was to measure the accuracy of the navigation of field tractor-machine set when JOHN DEERE AutoTrack automated satellite guidance system has been used and to compare occurred deviations with the deviations when manual steering of the field tractor-machine set was used for navigation. The data obtained have been used for calculations of the economic benefits of implementation of the automated satellite guidance system.

For both methods of field tractor-machine set navigation there were done 100 measurements of the accuracy of machine trajectory. The field was cultivated in runs parallel to each other (pass to pass). Fig. 2 and Fig. 3 present the histograms of distribution of the measured deviations. From the point of methodology the overlaps and the skips are presented in positive values.

When using the satellite guidance system the 89 % of the readings was in a tolerance zone, which is guaranteed by the manufacturer. The mean value of the deviation was 0.092 m. In case of manual steering of the tractor-machine set the largest part of the deviations (38 %) was located within the range 0.5 – 0.75 m. The mean value of the deviation was 0.65 m.

On the base of data obtained it is possible to state that for the model calculations of the economic benefits of the automated satellite guidance system the value of overlap 0.5 m can be used for manual guidance of tractor-machine set used for stubble loosening and seedbed preparation. In case of automated satellite guidance system with the AutoPilot we can use the value of overlap 0.1 m (AutoTrack – StarFire 2 signal).

Similarly, there were performed the measurements of accuracy of the tractor-machine set trajectory when manual steering was used. It was found that for the field operations fertilizing and spraying the mean value of the overlaps and skips were higher (fertilizing: 2.45 m, spraying: 1.75 m) due to the bigger working widths of the machines (24 m).

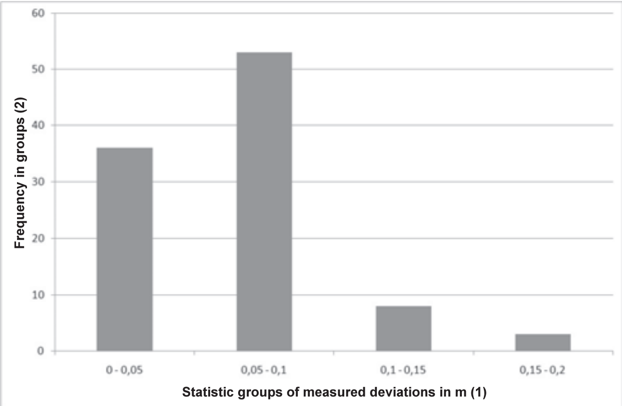

Figure 2 Frequency's distribution bar chart of measured deviations of machine trajectory with satellite guidance system
Obrázok 2 Histogram rozdelenia nameraných odchýlok pri satelitnej navigácií
(1) štatistické triedy nameraných odchýlok, (2) početnosť výskytu v jednotlivých triedach

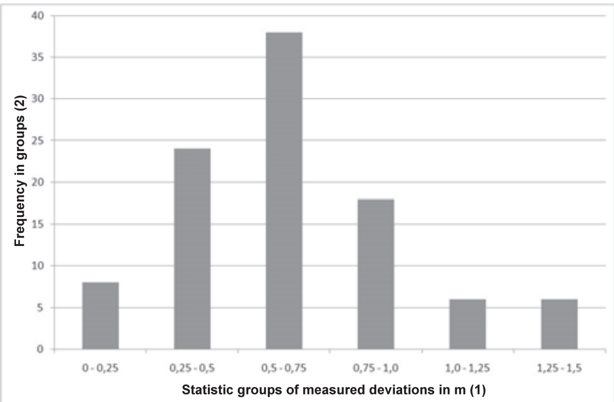

Figure 3 Frequency's distribution bar chart of measured deviations of machine trajectory without satellite guidance system
Obrázok 3 Histogram rozdelenia nameraných odchýlok bez satelitnej navigácie
(1) štatistické triedy nameraných odchýlok, (2) početnosť výskytu v jednotlivých triedach

Economic benefits

In order to determine the economic benefits from the use of automated satellite navigation, we must accept the fact that not all the benefits of using this system are numerically quantifiable, and therefore we are not able to quantify them and the monetised.

When using the mathematical model to calculate the return on the investment related to implementation of the automated satellite guidance system, we proceeded exactly according to methodology described in chapter Material and methods.

Table 1 shows the results of a comprehensive evaluation of economic efficiency and returns from the implementation introduction of automated satellite guidance system for steering of tractor-machine set into the cropping system on the farm.

In calculations we have considered the basic structure of cereal cropping system. The number of field operation can vary in relation to the soil and production condition on the farm.

In Table 1 there are presented indicators, which express the level of cost for individual field operations. The costs related to the pest control have usually large share due to high prices of pesticides (herbicides, insecticides, fungicides, acaricides, etc.). And then there are the costs of fertilizers, the price of which are rising from year to year, and last but not least are the cost of seeds. Each one of these three input costs we can significantly reduce by using of more accurate application on the field. The value of the cost items (see Table 1) give us an overview of the significant savings opportunities in this part of the costs related to the material inputs. Most we can save on costs associated with application of fertilizers. On the area of 600 ha the more accurate application of fertilizer can bring the savings 4 038 €.

On the Fig. 4 we can see the level of costs of seeds, chemicals for pest control and fertilizers for two variants of application (application with satellite guidance and application without satellite guidance).

Using of satellite guidance system allow to achieve also the savings of labour connected with the work of operator when steering the machine. The correct setting of working width overlaps for particular field operation saves the order of several tens of hours of work. From the results obtained from the calculation model it is evident that the largest labour savings bring the operation of soil loosening.

Using of automated satellite guidance system for navigation of the tractor-machine set allows to increasing the machine capacity and subsequently the shortening of the time for field operation. It means the saving of costs, which are connected with the payment of the staff salaries. The wearing of machine parts is also reduced. Both items with the above mentioned savings of labour.

Cost savings of diesel fuel can be considered as a very significant factor affecting the decision to purchase an automated satellite guidance system. In our case, on the 600 ha we have achieved savings of up to 1 086 litres.

The price of diesel fuel as an input item in calculation algorithm, changes very often. It is very difficult to foresee the development of oil prices on the world market. But in the long term development of oil prices has prolonged upward trend in all countries. Fuel costs are an essential part of production costs and why it is very important in agriculture to reduce these costs by using of modern satellite – based navigation systems.

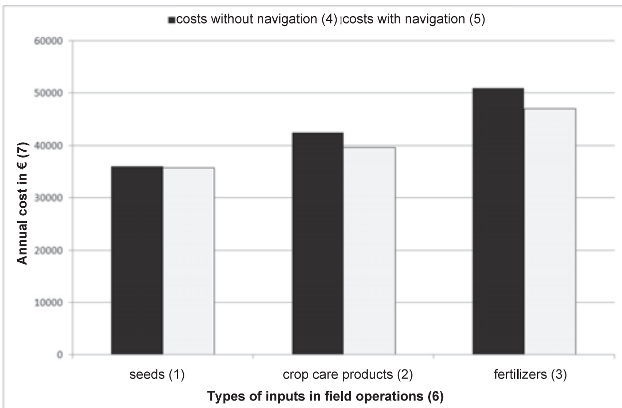

Figure 4 Effect of satellite guidance on the annual costs of inputs within cropping system (600 hectares farmed)
Obrázok 4 Rozdiel ročných nákladov na vstupy pri jednotlivých pracovných operáciách (rozloha plodiny 600 ha)
(1) osivo, (2) chemické ochranné prostriedky, (3) priemyselné hnojivá, (4) náklady bez navigácie, (5) náklady s navigáciou, (6) vstupy pri jednotlivých pracovných operáciách, (7) ročné náklady

Table 1 Results of the economic evaluation of the automated satellite guidance system

Operation detail (1)	Unit (2)	Operations in cereal cropping system (3)					
		stubble loosening (4)	seedbed preparation (5)	spraying (6)	fertilizing (7)	sowing (8)	harvest (9)
Farmed area (10)	ha	600					
Working width (11)	m	6	6	24	24	6	9.15
Overlap without sat. guidance (12)	cm	50	50	150	200	15	50
Overlap with sat. guidance (13)	cm	10	10	10	10	10	10
% overlap reduction (14)	%	6.7%	6.7%	5.8%	7.9%	0.8%	4.4%
Machine operation speed (15)	km/h	12	10	8	12	12	6
Labour productivity without guidance (16)	ha/h	5.28	4.40	12.6	18.48	4.91	3.63
Labour productivity with guidance (17)	ha/h	5.66	4.72	13.38	20.08	4.96	3.80
Labour cost (18)	€/h	5					
Machinery cost rate (without fuel) (19)	€/h	14	14	5	5	20	40
Crop care products cost (20)	€/h	–	–	70	–	–	–
Seed cost (21)	€/h	–	–	–	–	60	–
Fertilizer cost (22)	€/h	–	–	–	85	–	–
Fuel consumption (23)	l/ha	8	6	1	1	10	15
Fuel price (24)	€/l	1.250					
Fuel consumption (without guidance) (25)	l/j	42.2	26.4	12.6	18.5	49.1	54.5
Machinery costs (without guidance) (26)	€/h	74	62	63	92	98	145
Passes per year (27)	–	1	1	3	2	1	1
Without guidance (28)							
Labour hours (29)	h	114	136	143	65	122	165
Labour costs (30)	€	568	682	714	325	611	826
Equipment cost without fuel (31)	€	8 400	8 400	9 000	6 000	12 000	24 000
Total crop care product cost (32)	€	–	–	42 000	–	–	–
Total seed cost (33)	€	–	–	–	–	36 000	–
Total fertilizer cost (34)	€	–	–	–	51 000	–	–
Total fuel used (35)	l	4 800	3 600	600	600	6 000	9 000
Total fuel cost (36)	€	6 000	4 500	750	750	7 500	11 250
Total costs without guidance (37)	**€**	**13 768**	**12 682**	**52 314**	**57 925**	**54 611**	**33 826**
Total unit cost without guidance (38)	**€/ha**	**23**	**21**	**87**	**97**	**91**	**56**
Annual savings with guidance (39)							
Total time savings (40)	h	8	9	8	5	1	7
Labour cost saving (41)	€	38	45	42	26	5	36
Equipment cost saving (42)	€	560	560	525	475	100	1 049
Crop care product cost saving (43)	€	–	–	2 450	–	–	–
Seed cost saving (44)	€	–	–	–	–	300	–
Fertilizer cost saving (45)	€	–	–	–	4 038	–	–
Fuel cost saving (46)	€	400	300	44	59	63	492
Total savings (47)	**€**	**998**	**905**	**3 060**	**4 598**	**468**	**1 577**
Summary (48)							
Total annual cost saving (49)	€	**11 606**					
Total annual labour saving (50)	hours	**38**					
Annual cost of guid. system operation (51)	€	**1 400**					
Total guidance investment (52)	€	**25 000**					
Guidance system payback period (53)	years	**2.395**					
Economic benefit after 3 years (54)	€	**5 618**					

Tabuľka 1 Výsledky ekonomického hodnotenia satelitnej navigácie
(1) vstupné údaje, (2) jednotka, (3) pracovná operácia v technologickom postupe pestovania hustosiatych obilnín, (4) podmietka, (5) predsejbová príprava, (6) ochrana, (7) hnojenie, (8) sejba, (9) zber, (10) výmera pestovanej plodiny, (11) šírka náradia, (12) prekrývanie bez sat. navádzania, (13) prekrývanie so sat. navádzaním, (14) percentuálna redukcia prekrývania, (15) pracovná rýchlosť, (16) produktivita práce bez navigácie, (17) produktivita práce s navigáciou, (18) cena práce obsluhy, (19) cena práce stroja bez PHM, (20) náklady na chémiu, (21) cena osiva, (22) cena hnojiva, (23) spotreba paliva, (24) cena paliva, (25) spotreba (bez navigácie), (26) náklady na stroj (bez navigácie), (27) počet operácií za rok, (28) výsledky bez navigácie, (29) potreba hodín na prácu, (30) cena za prácu, (31) cena za náradie bez PHM, (32) celkové náklady na chémiu, (33) celkové náklady na osivá, (34) celkové náklady na hnojivá, (35) spotrebované palivo, (36) celkové náklady na palivo, (37) celkové náklady bez navigácie, (38) celkové náklady na ha bez navigácie, (39) [spora s navigáciou, (40) úspora práce, (41) úspora nákladov na prácu, (42) úspora nákladov na náradie, (43) úspora nákladov na chémiu, (44) úspora nákladov na osivá, (45) úspora nákladov na hnojivá, (46) úspora nákladov na PHM, (47) celková úspora, (48) sumarizácia, (49) celková ročná úspora nákladov, (50) celková ročná úspora času, (51) ročné náklady na prevádzku navigácie, (52) obstarávacie náklady na navigáciu, (53) doba návratnosti systému, (54) ekonomický efekt po 3 rokoch prevádzky

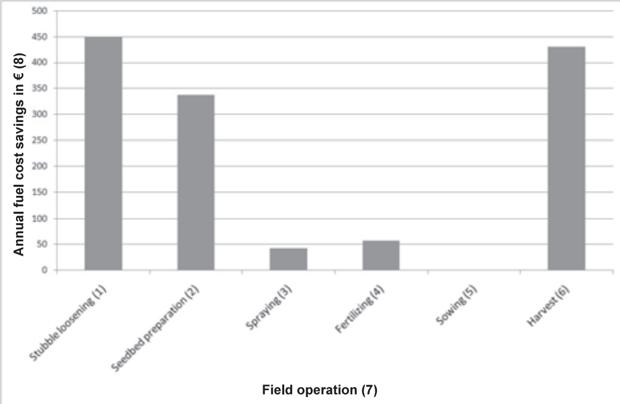

Figure 5 Fuel cost savings for field operations (600 hectares farmed)
Obrázok 5 Ročná úspora nákladov na palivo pri výmere 600 ha pri jednotlivých pracovných operáciách
(1) podmietka, (2) kyprenie, (3) postrekovanie, (4) hnojenie, (5) sejba, (6) zber, (7) pracovná operácia, (8) ročná úspora nákladov na palivo

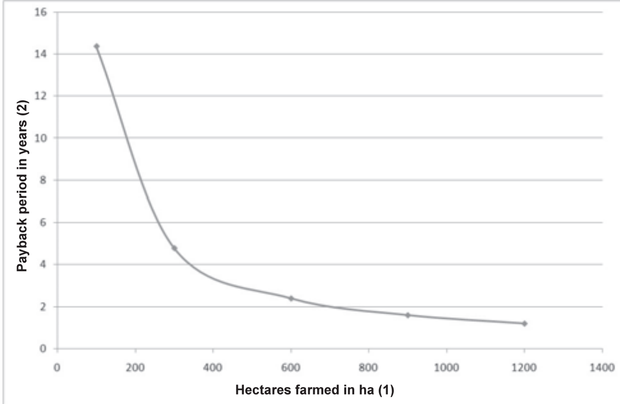

Figure 7 Effect of the hectares farmed on the payback period of the automated satellite guidance system
Obrázok 7 Závislosť doby návratnosti vynaložených finančných prostriedkov (na navigačný systém) na rozlohe pestovanej plodiny
(1) rozloha pestovanej plodiny, (2) ekonomická návratnosť

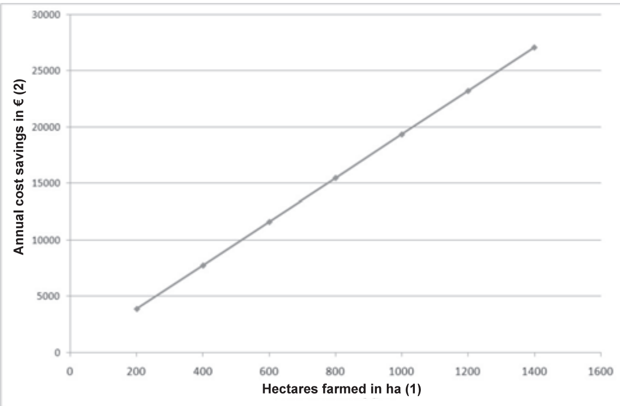

Figure 6 Effect of the hectares farmed on the guidance system payback period
Obrázok 6 Závislosť úspory nákladov na výmere pestovanej plodiny pri zavádzaní satelitného navigačného systému
(1) výmera plodiny, (2) ročná úspora nákladov

Fuel cost savings for particular field operations are presented on the Figure 5.

Each farmer interested to purchase the automated satellite – based navigation system wants to know the minimum extent of use of the system (the break – even point), which ensures a return on capital as well as the cost of its operation. In our calculation model the purchase price of the navigation system was 25 000 € and the annual costs associated with the operation of this system represents a value of 1 400 €. Under the annual operation cost is basically included payment for receiving of the correction signal allowing to use a higher level of guidance accuracy.

From the results presented in Fig. 6 it can be seen that in case of using of the automated satellite – based navigation system the annual cost savings increases proportionally with increasing the acreage of cultivated crops. It is possible to conclude that the payback period of the guidance system with the total investment 25 000 € (acquisition price) and the farmed area of 600 ha will be at around 2 years and 5 months.

From the Table 1 and Fig. 7 it can be seen that for the 600 hectares farmed the payback period of the automated satellite guidance system is 2.395 years (2 years and 5 months). For the 1 200 hectares farmed the payback period can be reduced to 14 months.

Conclusion

Using of automated satellite guidance systems for navigation of machines during field operation allows to increasing the accuracy of the machine passes and efficiency of the field operations. In order to quantify the economic benefits the mathematical model was developed. In real field conditions the accuracy of the automated satellite guidance systems was measured. The results obtained have been compared with those obtained with manual steering of tractor-machine set. The data characterizing the accuracy of the two guidance variants (with/without guidance) have been used to calculate the economic benefits. The model has been verified for six field operations of the cereal cropping system with the acreage of 600 ha (stubble loosening, seedbed preparation, spraying, fertilizing, harvest).

Results obtained as a outputs from the model have confirmed that for the 600 hectares farmed the payback period of the automated satellite guidance system is 2 years and 5 months, while the total guidance investment were 25 000 € and annual cost on guidance system operation were 1 400 €. The payback period was calculated for the model conditions and it is possible to state that the payback period can be reduced due to increasing of the hectares farmed or increasing of the price of material inputs (fuel, crop care products, fertilizers, etc.). Return of investments of the guidance system and the benefits depend upon the specific production conditions, extent of field operations as well as the credibility and objectivity of the input data.

Súhrn

Práca sa zaoberá využitím riadenia a navigácie strojových súprav pri poľných pracovných operáciách v rastlinnej výrobe s využitím satelitného navigačného systému s autopilotom. Výhodnosť a efektívnosť použitia tohto systému je konfrontovaná výpočtom ekonomickej návratnosti pri jeho zavádzaní do podniku. Celkové riešenie práce sa orientuje na všetky výhody (napr. úspora paliva, priemyselných hnojív, postrekov, osiva, zvýšenie časového fondu pracovníka, ...) súvisiace so zavádzaním a využívaním tejto technológie pri rastlinnej prvovýrobe. Pri realizácií plošného spracovania pôdy sú vyzdvihnuté mož-

nosti zvyšovania výkonnosti pracovnej súpravy a možnosti znižovania spotreby paliva v prepočte na jednotku spracovanej plochy pri presnej a kvalitne pracujúcej satelitnej navigácii v porovnaní s manuálnym riadením súpravy.

Kľúčové slová: satelitná navigácia, presnosť navigácie, ekonomické úspory, výkonnosť

Predložený príspevok vznikol v rámci riešenia projektu „Aplikácia informačných technológií na zvýšenie environmentálnej a ekonomickej udržateľnosti produkčného agrosystému“, aktivita 1.1 Výskum agrotechnológie s priestorovo diferencovanými vstupmi, aktivita 3.1 Vytvorenie útvaru transferu inovatívnych technológií do praxe, projekt ITMS 26220220014, EU Operačný program výskum a vývoj.

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OPERATING MODES OF HYDRAULIC CIRCUIT OF TRACTOR ZETOR FORTERRA 114 41

PREVÁDZKOVÉ REŽIMY HYDRAULICKÉHO OBVODU TRAKTORA ZETOR FORTERRA 114 41

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In this paper an analysis of the operating load of hydrostatic pump of the tractor Zetor Forterra 114 41 is presented. Operational measurement with a tractor set with disc harrow LBD 4.5 was carried. During the operational measurements temperature and pressure regimes were recorded into output hydrostatic pump. At the same time surface temperature of the output pipe was measured by using the thermal imager output MobIR M3. The aims of the measurement is to verify the possibility of using biodegradable plant-based oil in gear and hydraulic system of the tractor Zetor Forterra 114 41 and also to determine the values of operating parameters in the hydraulic system of the tractor.

Key words: biodegradable oil, output temperature and pressure of oil, hydrostatic pump

At the present time, hydrostatic systems are widely dispersed in the industry. It provides the various types of motions. The power transmission is realized by hydraulic fluid. Hydraulic fluid needs service and observation of operating parameters (Majdan et al., 2007). For proper function of hydrostatic transmission and also of hydraulic circuit the temperature and pressure of the hydraulic system is very important. Measurement of operation regimes was carried out during the autumn of work in the village Marcelová.

Temperature and pressure of the oil are important from the point of view of performance parameters of the hydraulic system. Tractor Zetor Forterra 114 41 has a common oil reservoir for gearbox and hydraulic system. The temperature in the hydraulic and gear system is very important parameters for determination of the possibility of using the biodegradable oil in tractors. Value of pressure in the hydraulic circuit is important for the verified of proper function of the hydraulic circuit and also for proper function of the safety valve (Drabant et al., 2005, Jablonický et al., 2007).

During the experimental test of the hydraulic and the gear system of tractor synthetic oil MOL Farm UTTO Synt from the company Slovnaft Plc was used.

Electro-hydraulic circuit diagram of the tractor Zetor Forterra 114 41

Electro-hydraulic circuit diagram of the tractor Zetor Forterra 114 41 is shown in Figure 1. The source of pressure oil is the hydrostatic pump (1), which supplies by oil auxiliary hydraulic divider (2). From the divider hydraulic oil input to the control divider (3), this controls lifting and dropping the three point arms. Lifting arms are connected with lower arms of the three – point hitch to connect of agricultural implements. Electronic Control Unit (6) receives electrical signals from the measuring pins (7) and from position transducer (8). Electrical signals are compared with set values on the control panel (9). Deviation between desired and actual values of the resulting control deviation occurs, which is transmitted to the control divider (3). Control divider consist of with two proportional electromagnets (www.zetor.cz)

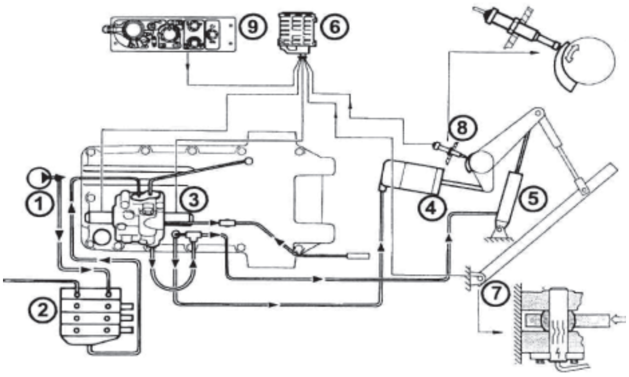

Figure 1 Electro-hydraulic system ZMS 23 LS
Obrázok 1 Elektro-hydraulický systém ZMS 23 LS

Material and methods

In the Figure 2 block diagram is of the measurement modes of tractor Zetor Forterra 114 41 is presented. This tractor is equipped with hydrostatic pump UD 25 made by the company Jihostroj Aero Technology and Hydraulics. For the pressure measurement pressure sensor HDA-3444-A-250-000 was used. For the temperature measurement temperature of oil in the output of the hydrostatic pump UD 25 sensor Pt 100 was used. Digital recording unit HMG 2020 was used to record electrical signals. Recorder was designed for record measurement values in real time and also to record this value in memory and also for transmition of information to computer.

For measurement of the temperature in the output pipe hydrostatic pump UD 25 during the operational measurement

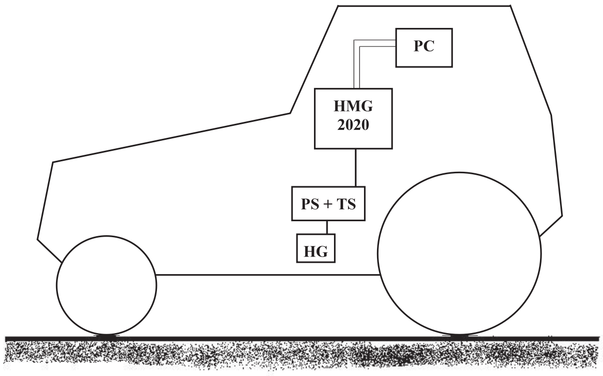

Figure 2 Block diagram of measurement modes of operation hydraulic tractor Zetor Forterra 114 41
HG – hydrostatic pump, PS – pressure sensor, TS – temperature sensor, HMG 2020 – digital recording unit, PC
Obrázok 2 Bloková schéma merania prevádzkových režimov hydrauliky traktora Zetor Forterra 114 41
HG – hydrogenerátor, PS – tlakový senzor, TS – teplotný senzor, HMG 2020 – digitálna záznamová jednotka, PC

Figure 3 Zetor Forterra 114 41 with disc harrow LBD 4.5
Obrázok 3 Zetor Forterra 114 41 a diskový podmietač LBD 4.5

thermal imager MobIR M3 was used. Technical parameters of thermal imaging camera are shown in Table 1.

Table 1 Technical parameters of the thermal imaging camera MobIR M3

Detector type (1)	Uncooled FPA microbolometer, 160 × 120 focal plane array (2)
Spectral range (3)	8 – 14 µm
Field of view (4)	25° × 19°
Thermal sensitivity (5)	< 0.12 °C by 30 °C
Electronic zoom (6)	× 2
Display (7)	2.2“ TFT a 1.2“ CSTN color LCD
Color pallets (8)	5 Pallets (12)
Temperature range (9)	-20 °C to 250 °C
Accuracy (10)	± 2 % or ± 2 °C
Other options (11)	Remote measurement of temperature and relative humidity (13)

Tabulka 1 Technické parametre termovíznej kamery MobIR M3
(1) typ snímača, (2) FPA nechladený ohniskový rovinný zväzok, 160 × 120 pixelov, (3) spektrálny rozsah, (4) zorné pole, (5) teplotná citlivosť, (6) elektronický zoom, (7) displej, (8) farby, (9) rozsahy meraní, (10) presnosť, (11) ďalšie možnosti, (12) palety, (13) meranie vzdialenej teploty a relatívnej vlhkosti)

Tractor set consist of the tractor Zetor Forterra 41 114 and disc harrow LBD 4.5 is shown in Figure 3. Working width of tractor set was 4.5 meters. The tractor during the measurement works with first gear without reduction. Working speed was 10.2 $km.h^{-1}$ and temperature was 26.2 °C.

For operation measurements of the pressure and temperature regimes two section was determinated against on opposites side with length 100 m. The measuring sections were divided into equal parts with 10 sections. During measurement speed and working width was recorded.

Results and discussion

Operational measurement lasted 3 000 seconds seconds (50 minutes). During experimental measurement in the output of hydrostatic pump the connecting flange was placed for temperature and pressure sensor. Location of digital recording unit HMG 2020 during an operation measurement is shown in Figure 4.

Figure 4 Location of digital recording unit HMG 2020 on the tractor
1 – digital recording unit HMG 2020, 2 – hydrostatic pump, 3 – pressure and temperature sensor, 4 – generator

Obrázok 4 Umiestnenie digitálnej záznamovej jednotky HMG 2020 na traktore
1 – digitálna záznamová jednotka HMG 2020, 2 – hydrogenerátor, 3 – teplotný a tlakový senzor, 4 – zdroj

Figure 5 shows pressure at the output hydrostatic pump UD 25. Operation pressure varies about value of 1 MPa. Pressure peaks at the operational measurements reached values above 9 MPa. Pressure peaks were by variable soil resistance. Safety valve in the hydraulic circuit was adjusted at 20 MPa. During pressure measurement in the output of hydrostatic pump UD 25 the safety valve was not activated.

During experimental measurement of tractor set consisted of tractor Zetor Forterra 114 41 and plough 5 PHN 30 working pressure oscillated from 1.2 MPa to 4 MPa. In the hydraulic and gear system was applied mineral oil PP 80. Pressure peaks due to the increased of soil resistance reached values above 8 MPa (Cvíčela et al., 2008).

Figure 6 shows output temperature of the hydrostatic pump UD 25. The initial temperature of oil in the gear and hydraulic circuits was 51.3 °C. Temperature of oil in hydraulic and gear system was stabilized after approximately 1 200 seconds (20 minutes). Oil temperature varies with minimum deviations after stabilization of temperature values around 62 °C.

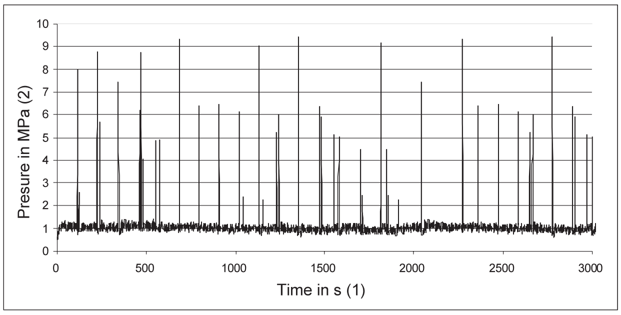

Figure 5 Pressure in the output of hydrostatic pump UD 25
Obrázok 5 Tlak na výstupe hydrogenerátora UD 25
(1) čas, (2) tlak

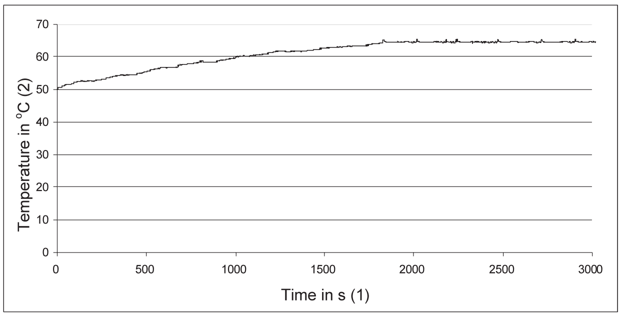

Figure 6 Temperature in the output of hydrostatic pump UD 25
Obrázok 6 Teplota na výstupe hydrogenerátora UD 25
(1) čas, (2) teplota

Measured temperature in the output of hydraulic pump is suitable for risk using of the biodegradable plant oils in hydraulic and gear system of Zetor Forterra 114 41.

During application of mineral oil PP 80 in gear and hydraulic system of the tractor Zetor Forterra 114 41 output oil temperature of hydrostatic pump was stabilized after approximately 2 500 seconds. Tractor set consisted of tractor Zetor Forterra 114 41 and combined cultivators 231 B. The initial oil temperature in output hydraulic pump was 50 °C, oil temperature varies with minimum deviations after temperature stabilization around a value of 66 °C (Kosiba et al., 2010).

Thermograph shows the surface temperature of mechanical parts of the tractor, which are influenced by function of the gear a hydraulic system. On the based of measured results there is possibility to determinate wear or

Figure 7 Temperature in the output line hydrostatic pump
Obrázok 7 Teplota na výstupnom vedení hydrogenerátora

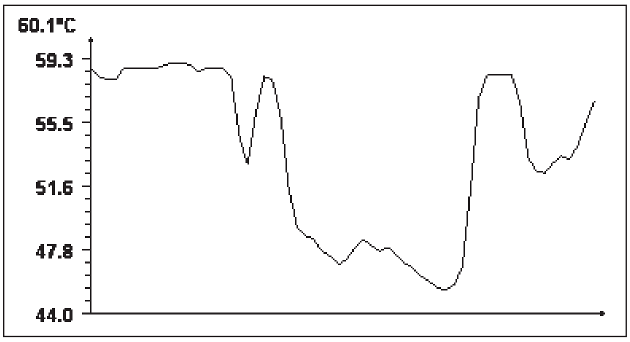

Figure 7 Temperature at the output lines hydrostatic pump along the chosen line
Obrázok 7 Teplota na výstupnom vedení hydrogenerátora pozdĺž zvolenej úsečky

failure certain parts of the mechanical and hydraulic system of tractor (Tkáč et al., 2010).

Figure 7 shows a photograph of the thermal imager MobIR M3. The photograph shows the output pipe of hydrostatic pump UD 25. Figure 8 show the temperature of the output pipe of hydrostatic pump along the line L1. The temperature in the output pipe does not exceed 60 °C.

Conclusion

By operational measurement the time courses of operating modes in output hydrostatic pump UD 25 of tractor Zetor Forterra 114 41 set with disc harrow LBD 4.5 was found. As the working fluid in the hydraulic circuit and gear of tractor synthetic biodegradable oil MOL Farm UTTO Synt was used.

Maximum temperature in the output hydrostatic pump UD 25 was 62.4 °C. The maximum value of pressure measured in the output hydrostatic pump UD 25 was 9.4 MPa. Measured temperatures and pressures confirmed that used synthetic oil is suitable for gear and hydraulic system of the tractor Zetor Forterra 114 41.

Súhrn

Príspevok sa zaoberá analyzovaním prevádzkového zaťaženia traktorového hydrogenerátora traktora Zetor Forterra 114 41. Prevádzkové meranie bolo uskutočnené pri práci traktora s diskovým podmietačom LBD 4,5. Počas prevádzkového merania boli zaznamenávané teplotné a tlakové režimy na výstupe hydrogenerátora. Zároveň bola meraná teplota povrchu výstupu pomocou termovíznej kamery MobIR M3. Cieľom príspevku je overenie možnosti použitia biologicky odbúrateľných olejov na rastlinnej báze v hydraulickom a prevodovom systéme traktora Zetor Forterra 114 41 a zároveň zistenie hodnoty tlaku v hydraulickom systéme ohľadne funkcie poistného ventilu.

Kľúčové slová: biologicky odbúrateľný olej, výstupná teplota a tlak oleja, hydrogenerátor

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EFFECT OF TEMPERATURE ON PHYSICAL PROPERTIES OF SELECTED CHEESES

VPLYV TEPLOTY NA FYZIKÁLNE VLASTNOSTI VYBRANÝCH SYROV

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The article presents selected physical parameters of cheeses. Theoretical part contains description of different cheeses, their classifications and properties. Theory of plane source method which was used for the experiments is described. The main part of the article is the presentation of experimental results which were obtained for samples of selected cheeses. Presented results are relations of thermophysical parameters as: thermal conductivity, thermal diffusivity and volume specific heat to the temperature. All measured relations have mainly linear decreasing progress.

Key words: cheese, temperature, thermal conductivity, thermal diffusivity, volume specific heat

Cheese is a diary product which belongs between milk-based food products. Styles, textures and flavours depend on the origin of the milk. Flavours, textures, and forms of cheeses are different throughout the world. Cheeses are made from milk, usually the milk of cows, buffalos, goats, or sheeps. According to origin of milk, cheeses have different content of proteins and different fat content. Many different types of cheeses are produced. In generally cheese during processing and storage goes through the thermal or mechanical manipulation. So it is convenient to know its physical properties, especially thermophysical and rheologic. Rheologic behaviour of dairy products were examined by Patočka et al. (2006). Choosen types of cheeses rheologic properties were measured by Buchar (1996). Kfoury et al. (1989), Robert and Sherman (1988) pointed that rheologic properties of cheeses are twinned with their quality.

This article deals with physical properties which are very complicated characteristics of food materials. Knowledge of physical properties of food materials has a decisive importance for the realization of many technological processes, especially for monitoring of their quality.

Materials and methods

The word cheese written in Latin is *caseus*. Cheese is a generic term for a diverse group of milk-based food products. Cheese is produced throughout the world in wide-ranging flavours, textures, and forms. Cheese consists of proteins and fat from milk, usually the milk of cows, buffalos, goats, or sheeps. It is produced by coagulation of the milk protein casein. Typically, the milk is acidified and addition of the enzyme rennet causes coagulation. The solids are separated and pressed into final form. Some cheeses have molds on the rind. Most cheeses melt at cooking temperature. Hundreds of types of cheese are produced. Their styles, textures and flavours depend on the origin of the milk (including the animal's diet), whether they have been pasteurized, the butterfat content, the bacteria and mold, the processing, and ageing. Herbs, spices, or wood smoke may be used as flavouring agents. The yellow to red colour of many cheeses is from adding annatto. For a few cheeses, the milk is curdled by adding acids such as vinegar or lemon juice. Most cheeses are acidified to a lesser degree by bacteria, which turn milk sugars into lactic acid, than the addition of rennet completes the curdling. Vegetarian alternatives to rennet are available; most are produced by fermentation of the fungus *Mucor miehei*, but others have been extracted from various species of the *Cynara* thistle family. Cheese is valued for its portability, long life, and high content of fat, protein, calcium, and phosphorus. Cheese is more compact and has a longer shelf life than milk (Fankhauser-Simpson, 1979).

There are many different kinds of cheeses that can be found, each with its own colour, texture, flavour and rind. Cheese can usually be classified in four ways: by texture, by covering, by ripening or by cooking types. Classifications of cheeses with some examples are shown below. When looking at a cheese by texture, you can find a variety of flavours and rinds. Under the covering classification, you can get an idea of the cheese inside by looking at the outside. Cheese can be easily chosen for a cheeseboard or platter when looking at the ripening. There are many ways to classify cheeses. Some classify cheeses by its texture, whether it's hard or soft, or by its ripening, etc. Here are the four main types of classification groups of cheeses and also their descriptions.

Classifications of Cheeses by Texture:

- Hard Grating Cheeses (Parmesan, Sbrinz).
- Firm/Hard (Emmental, Cheddar, Provolone).
- Semisoft (Brick, Muenster, Roquefort, Talleggio).
- Soft (Camembert, Brie, Hermelín, Plesnivec).
- Fresh (Ricotta, cottage).
- Processed (smooth cheeses made from mixing several cheeses or adding other ingredients: American, cheese spreads, Lunex, Karička).

Classifications of Cheeses by Covering:

- Hard/Leather/Waxed Rind (larger cheeses, longer maturity, pressed to remove moisture: Raclette, Gruyčre, Gouda).
- Bloomy/Downy Rind (soft rinds, often 'fuzzy', usually softens with ages: Brie).
- Natural Rind (interior is soft to firm with a natural rind that has a soft grey/blue colour or that often changes colour with age: Sainte Maure, Pouligny St. Pierre).

- Saltwater Washed Rind (saltwater-bath as it ripens: Muenster, Feta).
- Blue Cheeses (blue/green veined, cheese is cultured with bacteria to give it its colours: Stilton, Roquefort, Gorgonzola).
- Fresh Cheese (no rind, high water content, unripened: fromage frais, Demi-sel, Ricotta, fresh goat cheese, mascarpone).

Classifications of Cheeses by Ripening:

- Bacteria ripened from outside (Cheddar, Parmesan).
- Bacteria ripened from inside (Limburger, Liederkranz).
- Mold ripened from outside (Stilton, Saga Bleu).
- Mold ripened from inside (St. André, Explorateur).
- Unripened (Cottage).

Plane source method

Transient methods represent a large group of techniques where measuring probes, i.e. the heat source and the thermometer, are placed inside the specimen. This experimental arrangement suppresses the sample surface influence on the measuring process which can be described as follows. The temperature of the specimen is stabilized and made uniform. Then the dynamic heat flow in the form of a pulse or stepwise function is generated inside the specimen. From the temperature response to this small disturbance, the thermophysical parameters of the specimen can be calculated.

Plane source method is based on using an ideal plane sensor (PS). The PS acts both as heat source and temperature detector. The plane source method is arranged for a one dimensional heat flow into a finite sample. The theory considers ideal experimental conditions – ideal heater (negligible thickness and mass), perfect thermal contact between PS sensor and the sample, zero thermal resistance between the sample and the material surrounding sample, zero heat losses from the lateral surfaces of the sample (Karawacki et al., 1992). If q is the total output of power per unit area dissipated by the heater, then the temperature increase as a function of time is given by (1) (Beck and Arnold, 2003):

$$\Delta T(x,t) = 2\frac{q\sqrt{at}}{\lambda}\, ierf\left(\frac{x}{2\sqrt{at}}\right) \qquad (1)$$

where:

a – is thermal diffusivity

λ – is thermal conductivity of the sample

ierf – is the error function (Carslaw and Jeager, 1959)

We consider the sensor, which is placed between two identical samples having the same cross section as the sensor in the plane $x = 0$. The temperature increase in the sample as a function of time (2):

$$T(0,t) = \frac{q\sqrt{a}}{\lambda\sqrt{\pi}}\sqrt{t} \qquad (2)$$

which correspond to the linear heat flow into an infinite medium (Karawacki and Suleiman, 2001). The sensor is made of a Ni-foil, 23 μm thick protected from both sides by an insulating layer made of kapton of 25 μm thick made on SAS. Several corrections have been introduced to account for the heat capacity of the wire, the thermal contact resistance between the wire and the test material, the finite dimension of the sample and the finite dimension of the wire embedded in the sample (Assael and Wakeham, 1992; Liang, 1995)

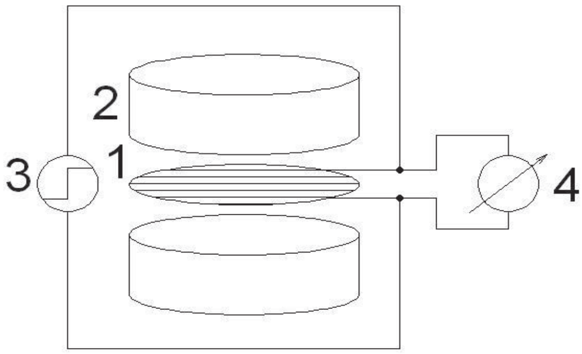

Figure 1 Plane source method
1 – plane sensor, 2 – samples, 3 – current source, 4 – milivoltmeter

Obrázok 1 Metóda plošného zdroja
1 – plošný senzor, 2 – vzorky, 3 – zdroj prúdu, 4 – milivoltmeter

Results and discussion

There are made various types of processed cheese with different fat content in Slovakia. The most famous types of processed cheeses are Lunex®, Syrokrém® and Karička® (www.mlieko.sk, 2010).

Measurements were performed on samples of processed cheese Lunex and Tekovský – Unsmoked Hard Cheese. At first were measured samples of Lunex. Relations of thermal conductivity, thermal diffusivity and volume specific heat to the temperature during the temperature stabilisation in temperature range from 13 °C to 24 °C were analysed. For thermophysical parameters measurements was used instrument Isomet 2104 with plane sensor and measured material (processed cheese Lunex) was inserted into plane sensor. Thickness of all samples was 10 mm according to advices in users manual.

The values of thermophysical parameters as thermal conductivity, thermal diffusivity and volume specific heat are

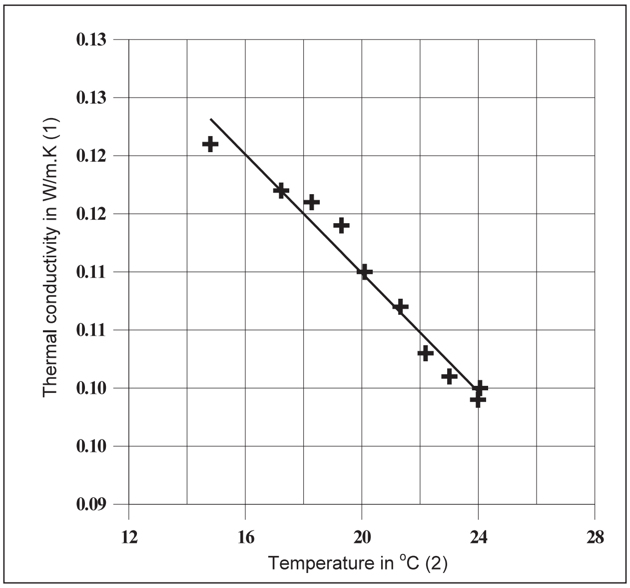

Figure 2 Temperature relation of thermal conductivity for sample Lunex Classic

Obrázok 2 Teplotná závislosť tepelnej vodivosti pre vzorku Lunex Classic
(1) tepelná vodivosť v W/m.K, (2) teplota v °C

presented on Figures (2 – 7). All measured relations have linear decreasing progress. Graphic relations have very similar coefficient of determination approximately from 0.95 to 0.96. These coefficients are near the lower limit value of determination coefficient which is acceptable. When the coefficient of determination is smaller than 0.95, it is better to choose other mathematical function for graphic representation. The highest coefficients of determination was found for linear decreasing progress in our case. Our results for all thermophysical parameters are concident with values known from literature, for example Ginzburg (1985).

Tekov cheese is natural half hard, maturing, full cream cheese, smoked or unsmoked. Producer prefers hand manipulation because they want to protect the quality of cheese and the form of cheese. Tekov cheese includes: (53.5 – 58.5) % of dry mass, (43.0 – 47.5) % of fat content in dry mass and maximum 2.5 % of salt. Tekov cheese is made from pasteurized milk with admixture of acid milk cultures *Lactococcus* or *Streptococcus*. Measurement conditions were the same like in the first series of measurements for Lunex.

Results of thermophysical parameters measurements for samples: Low – fat leaf processed cheese, Low – fat leaf processed cheese – Sandwich, Processed cheese – Karička, Sheep cheese – natural, Slovak sheep cheese Bryndza,

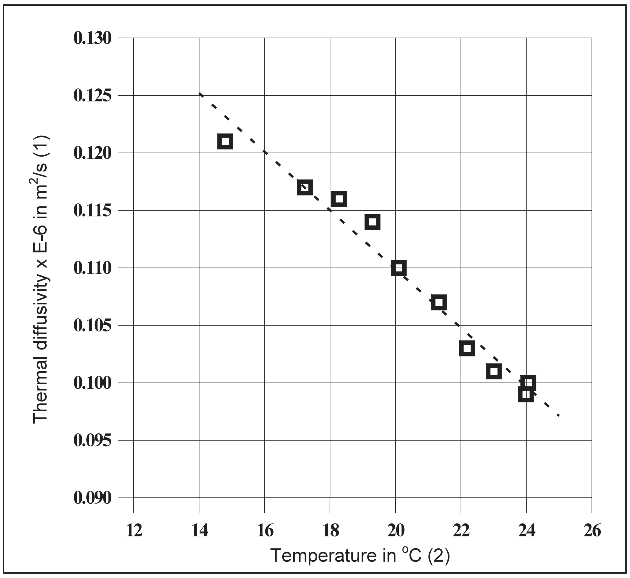

Figure 3 Temperature relation of thermal diffusivity for sample Lunex Classic
Obrázok 3 Teplotná závislosť teplotnej vodivosti pre vzorku Lunex Classic
(1) teplotná vodivosť x E-6 in m²/s, (2) teplota v °C

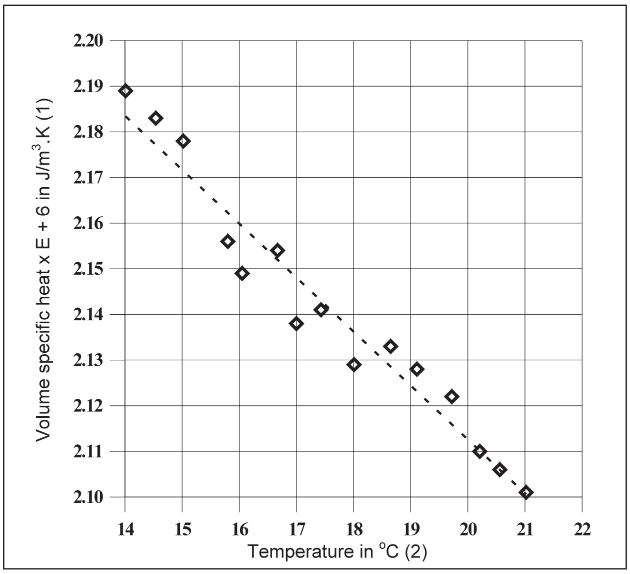

Figure 4 Temperature relation of volume specific heat for sample Lunex Classic
Obrázok 4 Teplotná závislosť mernej objemovej tepelnej kapacity pre vzorku Lunex Classic
(1) objemová tepelná kapacita x E + 6 v J.m³.K, (2) teplota v °C

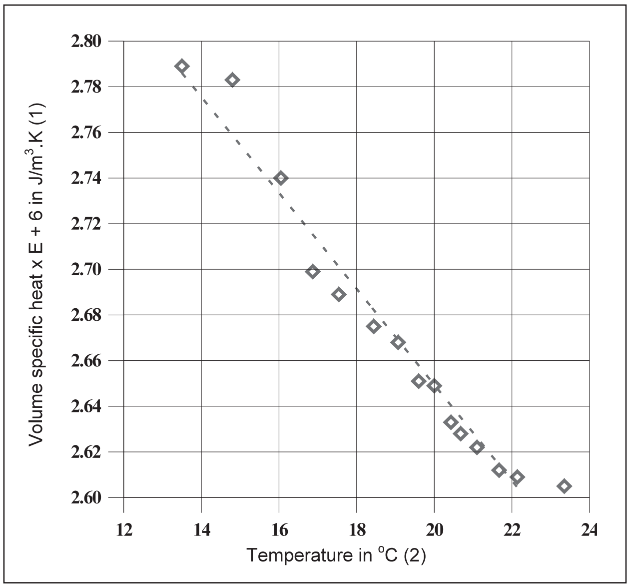

Figure 5 Temperature relation of volume specific heat for sample Unsmoked Hard Cheese – Tekovský
Obrázok 5 Teplotná závislosť mernej objemovej tepelnej kapacity pre Tekovský – tvrdý neúdený syr
(1) objemová tepelná kapacita x E + 6 v J.m³.K, (2) teplota v °C

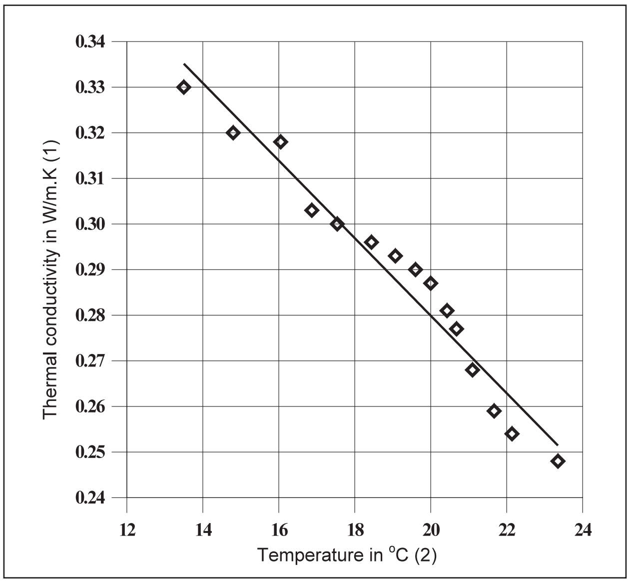

Figure 6 Temperature relation of thermal conductivity for Unsmoked Hard Cheese – Tekov
Obrázok 6 Teplotná závislosť tepelnej vodivosti pre vzorku Tekovský – tvrdý neúdený syr
(1) tepelná vodivosť v W/m.K, (2) teplota v °C

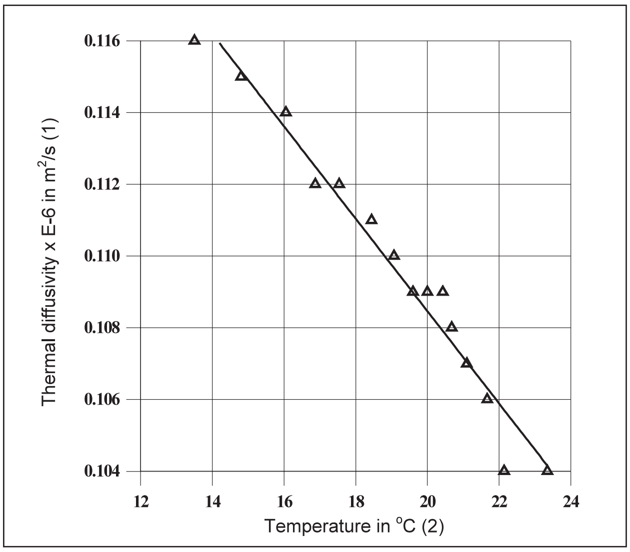

Figure 7 Temperature relation of thermal diffusivity for Unsmoked Hard Cheese – Tekov

Obrázok 7 Teplotná závislosť teplotnej vodivosti pre vzorku Tekovský – tvrdý neúdený syr
(1) teplotná vodivosť x E-6 in m^2/s, (2) teplota v °C

Slovak organic sheep cheese Bryndza are presented in the Tables 2, 3. Presented values are averages from one hundred values for every measured sample. Averages were valued by probable measurement error of arithmetic average and probable error in %. Maximum value of thermal conductivity has Processed cheese – Karička 0.700 W.m^{-1}.K^{-1}. Very similar value of thermal conductivity had Low – fat leaf processed cheese 0.510 W.m^{-1}.K^{-1} and Low – fat leaf processed cheese – Sandwich 0.505 W.m^{-1}.K^{-1}. There were big differences between Slovak sheep cheese Bryndza made by using commercial high technology and Slovak organic sheep cheese Bryndza made from organic milk by using traditional hand made technology. Hand made cheese Bryndza had lower thermal conductivity 0.460 W.m^{-1}.K^{-1} than commercial made Slovak cheese Bryndza 0.580 W.m^{-1}.K^{-1} because of higher content of organic ingredients and because of higher fat content. Very similar value of thermal conductivity had Sheep cheese – natural and Slovak sheep cheese Bryndza, both made by standard production technology.

Thermal diffusivity had very similar values for Low – fat leaf processed cheese and Low – fat leaf processed cheese – Sandwich, Processed cheese – Karička and Sheep cheese – Natural from interval (0.107 – 0.118) × 10^{-6} m^2.s^{-1}. The highest thermal diffusivity had hand made Slovak organic sheep cheese – Bryndza 0.131 × 10^{-6} m^2.s^{-1}. Volume specific heat is calculated from other thermophysical parameters of cheese and density of cheese, so values of specific heat was highest for Slovak organic cheese – Bryndza 2.6811 × 106 J.m-3.K^{-1}. In generally the temperature changes effects physical properties of cheeses. Modification of physical properties can be caused

Table 1 Regression equations, average values and coefficients of determination

Sample (1)	Relations of thermophysical parameters to temperature in temperature range (13.5 – 23.35) in °C		
	regression equations (2)	average values (3)	R^2 (4)
Lunex Classic	λ = -0.00695 t + 0.475	0.334 W.m^{-1}.K^{-1}	0.955669
	a = -0.00255 t + 0.1610	0.109 × 10^{-6} m^2.s^{-1}	0.969536
	$c\rho$ = -0.0118 t + 2.3490	2.14 × 10^6 J.m^{-3}.K^{-1}	0.952612
Unsmoked Hard Cheese Tekov (5)	a = -0.00129 t + 0.134	0.288 W.m^{-1}.K^{-1}	0.956638
	λ = -0.00850 t + 0.1610	0.110 × 10^{-6} m^2.s^{-1}	0.966221
	$c\rho$ = -0.0118 t + 2.3490	2.67 × 10^6 J.m^{-3}.K^{-1}	0.960669

Next were measured samples: Low – fat leaf processed cheese, Low – fat leaf processed cheese – Sandwich, Processed cheese – Karička, Sheep cheese – natural, Slovak sheep cheese – Bryndza, Slovak organic sheep cheese – Bryndza. Same relations were examined. Results are shown in the Table 2, Table 3
R^2 – coefficient of determination

Tabuľka 1 Regresné rovnice, priemerné hodnoty, koeficienty determinácie
(1) vzorka, (2) regresné rovnice, (3) priemerné hodnoty, (4) koeficient determinácie, (5) tvrdý neúdený Tekovský syr

Table 2 Measurement results of thermal conductivity and thermal diffusivity for cheese samples

Sample (1)	λ in W.m^{-1}.K^{-1}	$\overline{\vartheta}$ (λ) in W.m^{-1}.K^{-1}	$\overline{\vartheta}_{r\%}$ (λ) in %	a in m^2.s^{-1}	$\overline{\vartheta}$ (a) in ×10^{-6} m^2.s^{-1}	$\overline{\vartheta}_{r\%}$ (a) in %
Low – fat leaf processed cheese (2)	0.510	±0.0014	±0.28	0.107 × 10^{-6}	±0.0001	±0.093
Low – fat leaf processed cheese Sandwich (3)	0.505	±0.0015	±0.30	0.112 × 10^{-6}	±0.0009	±0.804
Processed cheese Karička (4)	0.700	±0.0070	±1.00	0.118 × 10^{-6}	±0.0007	±0.59
Sheep cheese Natural (5)	0.540	±0.0058	±1.02	0.109 × 10^{-6}	±0.0002	±0.18
Slovak sheep cheese Bryndza (6)	0.580	±0.0028	±0.48	0.122 × 10^{-6}	±0.0004	±0.33
Slovak organic sheep cheese Bryndza (7)	0.460	±0.0014	±0.30	0.131 × 10^{-6}	±0.0005	±0.38

$\overline{\vartheta}$ – probable error of the measurement, $\overline{\vartheta}_{r\%}$ – relative probable measurement error
$\overline{\vartheta}$ – pravdepodobná chyba aritmetického priemeru, $\overline{\vartheta}_{r\%}$ – pravdepodobná relatívna chyba

Tabuľka 2 Výsledky meraní tepelnej a teplotnej vodivosti pre vzorky syrov
(1) vzorka, (2) nízkotučný tavený syr, (3) nízkotučný tavený syr Sandwich, (4) tavený syr Karička, (5) ovčí syr Natural, (6) bryndza, (7) organická bryndza

Table 3 Measurement results of volume specific heat for cheese samples

Variety (1)	$c\rho$ in ×10^6 J.m^{-3}.K^{-1}	$\overline{\vartheta}(c\rho)$ in ×10^6 J.m^{-3}.K^{-1}	$\overline{\vartheta}_{r\%}(c\rho)$ in %
Low – fat leaf processed cheese (2)	2.5841	± 0.0010	± 0.039
Low – fat leaf processed cheese Sandwich (3)	2.5917	± 0.0012	± 0.046
Processed cheese Karička (4)	2.6101	± 0.0017	± 0.150
Sheep cheese Natural (5)	2.5811	± 0.0019	± 0.074
Slovak sheep cheese Bryndza (6)	2.2622	± 0.0043	± 0.190
Slovak organic sheep cheese Bryndza (7)	2.6811	± 0.0034	± 0.130

$\overline{\vartheta}$ – probable error of the measurement, $\overline{\vartheta}_{r\%}$ – relative probable measurement error
$\overline{\vartheta}$ – pravdepodobná chyba aritmetického priemeru, $\overline{\vartheta}_{r\%}$ – pravdepodobná relatívna chyba

Tabuľka 3 Výsledky meraní mernej objemovej tepelnej kapacity pre vzorky syra
(1) vzorka, (2) nízkotučný tavený syr, (3) nízkotučný tavený syr Sandwich, (4) tavený syr Karička, (5) ovčí syr Natural, (6) bryndza, (7) organická bryndza

by changes of water content and proteins content during the temperature stabilisation.

Conclusion

In generally the structure, ingredients used for making cheese and technological process has important influence on physical parameters of cheeses. The most important physical properties are: thermal, rheologic and textural. Patočka et al. (2006) had examined rheologic behaviour of dairy products. Buchar (1996) examined rheologic properties for chosen types of cheeses (Edam, Moravian block, smoked cheese, Gouda). Kfoury et al. (1989), Robert and Sherman (1988) pointed that rheologic properties of cheeses are twinned with their quality. Our results showed that thermophysical parameters are in significant connection with duality of cheeses. Detailed knowledge about thermophysical characteristics of cheeses during thermal manipulation can improve technological and storage processes. Information about physical characteristics can be used for quality protection of food materials.

Súhrn

Článok prezentuje vybrané fyzikálne parametre syrov. Teoretická časť obsahuje popis rôznych typov syrov, ich klasifikáciu a vlastnosti. V článku je popísaná teória metódy plošného zdroja, ktorá bola použitá pri realizácii experimentov. Nosná časť článku je venovaná experimentálnym výsledkom, ktoré boli získané pre vzorky vybraných druhov syra. Získané výsledky sú teplotnými závislosťami termofyzikálnych parametrov ako napríklad: tepelná vodivosť, teplotná vodivosť a objemová tepelná kapacita. Sledované závislosti mali prevažne lineárne klesajúci charakter.

Kľúčové slová: syr, teplota, tepelná vodivosť, teplotná vodivosť, objemová tepelná kapacita

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CALIBRATION OF SENSORS FOR HYDRAULICAL VERTICAL PENETROMETER

KALIBRÁCIA SNÍMAČOV PRE HYDRAULICKÝ VERTIKÁLNY PENETROMETER

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The contribution deals with the design of penetration device, hydraulically operated and carried by the three point hitch of tractor. This system uses several force sensor associated with control unit. Measuring equipment has got attached a GPS system for measuring the position of the measuring probes and for defining the position of measurement in field. Before the experiments, it is necessary to calibrate the sensors after their inclusion in the measurement chain. This achieve the elimination of systemic errors and setting errors of measuring system, an overview of the measurement accuracy, which affects the sensor measurement error at different values of load forces, or amplifying member in the measuring apparatus. Involvement of the whole measurement chain, in our case the system: measuring probe – sensor – control unit – computer, may cause differences in measurements. Calibration of the sensors carry out for us the functional tests of equipment designed for field experiments.

Key words: soil compaction, penetration resistance, cone penetrometer, measuring system, calibration

One of the main reasons for changes in soil properties by the action of human activity is excessive mechanical loading. Mechanical loads acting on the surface in a vertical or horizontal plane done by the movement or by the action of penetrating of agricultural instruments into the soil change its volume status. Consequence of an inappropriate load on the land or the use of inappropriate techniques is an excessive compaction of soil in the surface soil layers – soil compaction. Soil compaction result is a reduction of the root system, deterioration of infiltration, reduced ability to retain soil moisture and reduced aeration, which in consequences affects crop growth and reduce yields (Raper, 2006). To find appropriate solutions to these problems is possible only on the basis of sufficiently accurate information on state of land, and changes to its spatial arrangement. Monitoring of soil compaction is usually performed by penetrating devices which one enables immediate identification of soil. Used hand-held devices are not sufficiently productive in mapping large areas of compaction and therefore appear more and more technical solutions based on mechanical operation with constant speed of penetrometer cone insertion in the soil, which increases the correctness and reproducibility of the measurements. At The Department of Machine Design at the Technical Faculty of SAU was designed a prototype of horizontal penetrometer, operated by a hydraulic system. To measure penetration resistance, standard mass produced force sensors have been chosen, the measurement system was prepared by an order and the whole measuring chain was accompanied by a depth measurement and GPS system. To verify the accuracy of measurement functions of measurement chain before field tests it is necessary to calibrate the device to determine an appropriate range of measurement values, assigning values to electrical signals from force sensor, and its correctness, which is needed in order for precise evaluating of the measurements. Functions of measurement system are necessary to examine in the lab and prepare all the equipment for carrying out of experimental measurements in field conditions. Laboratory calibration tests of measurement system have been performed and the results are presented in this paper.

Materials and methods

Hydraulically controlled vertical penetrometer, shown in Figure 1 was designed for use in field conditions to increase the efficiency of soil measurement in the fields. In combination with

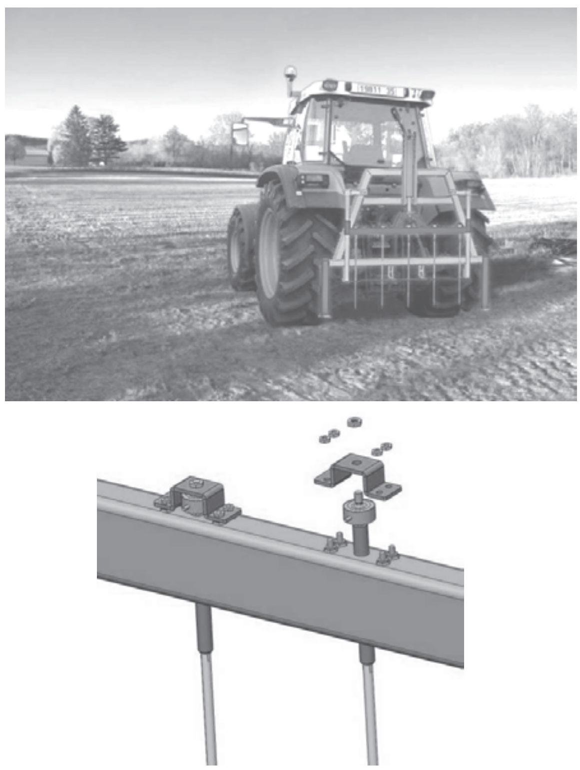

Figure 1 A hydraulically controlled, vertical penetrometer and the mounting detail of EMS sensors 20 on the support frame
Obrázok 1 Hydraulicky ovládaný, vertikálny penetrometer a detail uchytenia snímačov EMS 20 na nosnom ráme

– Measuring range: to 5 kN
– Sensitivity (mV/V+/- 2%): 1,5
– Accuracy: 2% from the steady value
– Voltage drop error: 0.1 % for 30 min
– Max. static load: 150 % from end value

Figure 2 Technical parameters of the sensor EMS 20
Obrázok 2 Technické parametre snímaču EMS 20

the GPS system and evaluating penetration resistance at specified locations it gives us the possibility of creating soil maps. Designed penetration device to determine soil compaction, was designed so, that the dimensions of cones are selected in accordance with ASAE standard S 313.3 for cone penetrometer.

The penetration device was designed to allow the measurement of penetration resistance of soil simultaneously in several places and record the resistance values at depths up to 50 cm. In the device are used force sensors from EMSYST manufacturer, type EMS 20 with a measuring range of forces up to 5 kN, showed at Figure 2.

Sensor calibration was performed by the use of calibration station which one was adjusted for mounting of force transducer EMS 20 and the control force transducer Ahlborn K 25 showed in Figure 3. The calibration station allows by the use

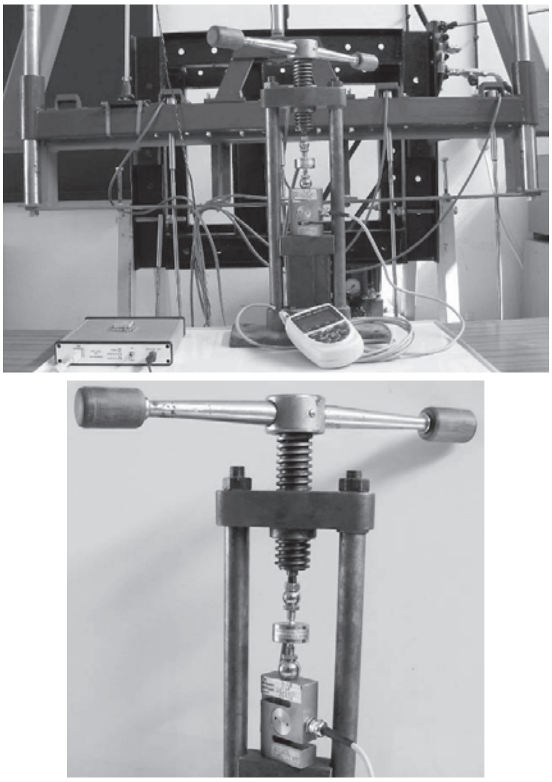

Figure 3 Calibration chain and the detail of calibration station
Obrázok 3 Kalibračný reťazec a detail meracieho prípravku pre kalibráciu

Sensor Ahlborn Typ K25:
– measuring range: 0.02 to 50 kN
– nominal measuring distance < 0.15 mm
– accuracy: 0.5% from the steady value
– voltage drop error: 0.07% for 30 min
– max. static load: 150% from end value
– max. Dynamic load: 70% from end value

ALMEMO 2490:
– volts DC -2.0 to +2.6 V
– milliampere DC -26 to +26 mA
– delta-sigma A / D converter with high resolution, 16 bit, 10 measuring operations per second

Figure 4 Control elements used for calibration of force sensors
Obrázok 4 Použité kontrolné prvky pre kalibráciu snímačov sily

Figure 5 Controller of the measuring penetrometer
Obrázok 5 Riadiaca jednotka celého meracieho systému penetrometra

of the motion screw to model a force on the tested sensor. With the use of the device ALMEMO 2490 with attached force transducer Ahlborn K25 in Figure 4 was gradually adjusted the range of forces for all sensors where by the measuring system of penetration device recorded the calibration data. Reference data obtained from calibrated sensor were used for comparison of the force, indicated by the calibration plots. These data were registered by the control unit of penetrometer system and processed through a service program on a portable computer as shown in Figure 5.

At the calibration station were for each of tested sensors gradually adjusted values of the load by the motion screw. Each sensor was loaded to a peak force of 2.5 kN, in which we assume as the maximum value achievable in field experiments. The selected force is 2.5 times higher than the load that can be achieved with manual insertion of penetration cone. This assumption should provide adequate security system for its overload. Simultaneously, this method allows settings to increase the sensitivity of measuring system and its accuracy due the fact that the force sensor has a maximum measuring range up to 5 000 N. For the calibration purpose it has been adjusted 40 values of load at the calibration station. Measured and recorded values were processed by standard statistical procedures in Microsoft Excel.

Results and discussion

Figure 6 illustrative shows calibration graph of the first sensor, which shows the dependence of force imposed on the value