Load characteristic of tractor three-point hitch for their simulation in laboratory condition

Š. Drabant, Z. Tkáč, M. Mojžiš

Faculty of Agricultural Engineering, Slovak University of Agriculture, Nitra, Slovak Republic

Abstract: Presented paper is dealing with operation load of three-point hitch (TPH) of agriculture tractor in randomly changeable working conditions and their simulation in laboratory. The basic goal was to obtain experimental data, after which we can judge and analyze problematic of dynamic load of wheel tractor at plowing with orientation on TPH. Another goal was using obtained result from operating measures on their simulation in laboratory conditions by hydrostatic simulator. In presented paper is solved power analysis in each elements TPH of agricultural tractor ZTS 160 45 UR II A. The tractor during exploiting was in set with four-ploughshare carried and five-ploughshare semi-mounted plough. The measuring was realized for 3 varieties of set speed (gear ratio I/2, I/3, I/1), 3 depths of plowing (20, 25 and 27 cm) and 3 varieties of TPH – positional, mixed and draught control.

Keywords: load characteristic; three-point hitch of tractor; plow set

The tractor development comes out from quality analysis of effort to maximize the efficiency of energy use in agricultural production and also from requirement to manufacture mobile energetic devices with parameters enabling to reduce the specific consumption on unit of final product of agricultural production. It is necessary to co-ordinate the components of mobile energetic devices so as to create conditions for their optimum work. One of these that have significant influence on transmission and use of the tractor output is the exploitation equipment of tractor – the three-point (two-point) hitch (TPH).

The optimum use of output, characterized by highest effectiveness at their transmission, can – among others – be secured by appropriate control of tools. This problem is currently ensured by control system of tractors three-point hitch. The problems which try to solve the control system in mobile energetic device at transmission of energy are given by operating technology in the first place.

At work of tractor set, in which is the tool hitched by TPH, are power effects of tool transferred on the tractor by drawbars of TPH. Important quantities, characterizing operating load of tractor, are powers in single drawbars of TPH. At regular motion of tractor this power is all the time changing due to the variations of pull resistance power. Variability of pull resistance is caused mainly by non-homogeneous structure and changing mechanical quality of soil, ground profile of field and irregularity of the tractor driving wheels movement (Drabant 1978).

The biggest change of pull resistance characterized by amplitude and period exists at plowing. The amplitude of agriculture tools pull resistance is increasing with escalating of tractors operating speeds. At other types of agricultural work (harrowing, smoothing, sowing etc.) the value of pull resistance varies too, reaching however low values.

At research and development of new tractors for agriculture the needs of testing in field and also in laboratory conditions (Petranský 1989) still more come into focus. From point of view of relatively quickly changing operating conditions in agriculture simulating of these operating conditions in surroundings with minimal dependence on external meteorological conditions gains still higher importance (Tkáč & Škulec 2000).

The R and D work hence requires such testing methods that would enable to verify the descired attributes any time independent of agrotechnical terms nature of soil and weather conditions. Wherefore are developed such methods of experiments, which can replace operating conditions thus allowing their simulations in laboratory conditions (Tkáč *et al.* 2001).

On dynamic load of tractor and groups (clutch, transmission etc.) are used devices, which use mechanical brakes operated by hydrostatic circuit

(Tkáč *et al.* 2000), hydrodynamic brakes, hydrostatic brakes, electrical brakes (turbulent brakes in limited frequency range of load conditions) and combination brakes of different determination and different characteristics. Most of all it is a combination of hydrodynamic and mechanic brakes, possibly electric brake.

The paper was worked out under the terms of solution research project VEGA 1/3483/06 The research into developing more effective and ecological operation of mobile and stationary technique in agriculture.

MATERIAL AND METHODS

The basic goal of discussed problems was to obtain experimental data, on the base of which it will be possible to judge and analyse problems of dynamic load of tractor TPH at basic agricultural work – plowing in randomly changing operating conditions in set with mounted or semi- mounted tools and to use the obtained results from operating measuring simulation of exploitation load of tractor TPH in laboratory conditions by hydrostatic simulator.

To achieve the research aim we choose following method:
– experiments with plowing set – tractor ZTS 16045 and plough PH1-435 (with supported wheel and without supported wheel);
– experiments with plowing set – tractor ZTS 16045 and plough PH1-422;
– processing of measured results by PC;
– working out of functional proposal of control of the hydrostatic simulator of TPH load in laboratory conditions.

To ascertain the forces in single components of TPH during plowing there were adjusted the TPH arms for measuring of force by strain gauge. There were used foil strain gauges M-M Vishay, type CEA-06-250 UW- 120. The whole strain gauge bridges there were positioned on the following parts of TPH:
– left lower drawbar (LLD),
– right lower drawbar (RLD),
– drawbar of left stabilizer (LS),
– drawbar of right stabilizer (RS),
– upper medium drawbar (UMD),
– left connecting drawbar (LCD),
– right connecting drawbar (RCD).

At measuring we used a working set composed of tractor ZTS 16045 and two types of plough, with technical parameters summarized in Table 1.

For measuring we choose following range of parameters:
(1) depth of ploughing: 20, 25, 27 cm
(2) speed of set – transmission gear I/2, I/3, II/1
(3) the control: positional, draught and mixed I (near to positional)

At using semi-mounted plough we used floating control. With reciprocal combination of points (1) to (3) we performed 45 measurements (including repeated measuring). The length of measured section was 100 m at all measurings, but especifically were marked sections in length of 25 m.

The mechanical-physical properties of soil were found out by penetrometer PT 211. At measuring there were simultaneously taken samples of soil. The samples of soil for establishing the granulometry were taken before main measuring, samples for establishing the moisture content, voluminous and specific mass of soil were taken during the measuring and after its finishing. Physical-mechanical properties established from samples taken were as follows: moisture content 14.3%, volume mass of dry earth 1.16 g/cm^3, volume mass of wet earth 1.45 g/cm^3, specific weight of earth grain 2.5 g/cm^3 and spore volume 37%.

Table 1. Technical parameters of used ploughs

Parameter	Mounted four-share plough	Semi mounted five-share plough
Mark – type	PH1-435	PH1-422
Working speed (km/h)	7	7.5
Transportation speed (km/h)	10	10
Maximum working depth (cm)	24	27
Maximum measuring resistance of soil (kPa)	120	130
Working width (adjustable) (cm)	35	30–42
Mass (kg)	665	2 850
Serial number	10 160	61 045

Respective measurements were done mainly in purpose to obtain following experimental data:

– time runs of forces in the left lower drawbar (LLD),
– time runs of forces in the right lower drawbar (RLD),
– time runs of forces in the left connecting drawbar (LCD),
– time runs of forces in the right connecting drawbar (RCD).

At measurements recording the time run of chosen data we used the measuring device MC-23 S of the firm BMC, Germany. The time runs of forces were analyzer by PC and on spectral analyzer model TR 9405 of the firm TEKADA RIKEN, Japan. This way was obtained the densities of probability and spectral frequency histograms of the forces.

By the experiments we obtained needed data for establishing of requirements on working up of the functional proposal of hydrostatic simulator of the operating load control in laboratory conditions and its control circuit.

RESULTS

From realized measurement and their treating we present selected results, which are most interesting from point of view of projecting of the simulation device for loading of TPH. The conditions at measuring are presented in Table 2 and obtained basic experimental data of forces in single drawbars of TPH are presented in Table 3.

In Figure 1 and 2 are presented measured time run of force in right F_{dp} and left lower drawbar F_{dl} TPH, in Figure 3 their density of probability $p(F_{dp})$, $p(F_{dl})$ and in Figures 4 and 5 normative spectrum output density G_{Fdp}, G_{Fdl} of these forces at plowing with operating speed v_p = 1.15 m/s, position control, depth of plowing 28.25 cm for tractor ZTS 16045 with semi-mounted five-ploughshare plough PH1-422 (measuring No. 1).

In Figures 6 and 7 are presented measured forces time runs in right F_{dp} and left lower drawbar F_{dl} TPH, in Figure 8 their density of probability $p(F_{dp})$, $p(F_{dl})$ and in Figures 9 and 10 normative spectrum output density G_{Fdp}, G_{Fdl} of these forces at plowing

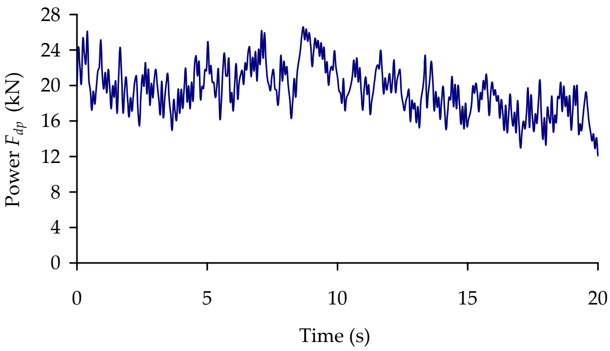

Figure 1. Time run of forces in right lower drawbar F_{dp} tractor ZTS 16045 at plowing with semi-mounted five-share plough PH1-422

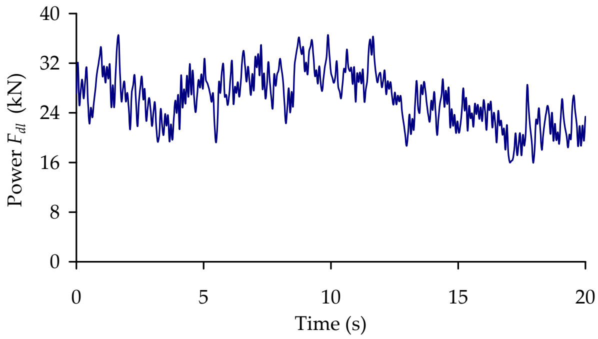

Figure 2. Time run of forces in left lower drawbar F_{dl} tractor ZTS 16045 at plowing with semi-mounted five-share plough PH1-422

Table 2. The conditions of measuring at plowing

Number of measuring	Depth of plowing (cm)			Position of gear shift	Control	Speed of operation (m/s) v_p	Note
	h_p	h_s	σ_h				
1	27	28.25	1.58	I/3/K	P	1.15	
2	27	30.50	1.41	I/2/Z	ZI	1.05	Plough PH1-422
3	27	27.58	2.81	I/2/Z	S	1.06	
4	25	27.29	1.60	I/3/Z	P	2.08	
5	25	27.56	1.42	I/3/Z	ZI	2.08	Plough PH1-435 without support wheel
6	25	29.58	4.17	I/3/Z	S	2.00	

h_s – arithmetical average from measured depth of plowing; σ_h – standard deviation of plowing depth; P – position control; S – draught control; ZI –mixed control I

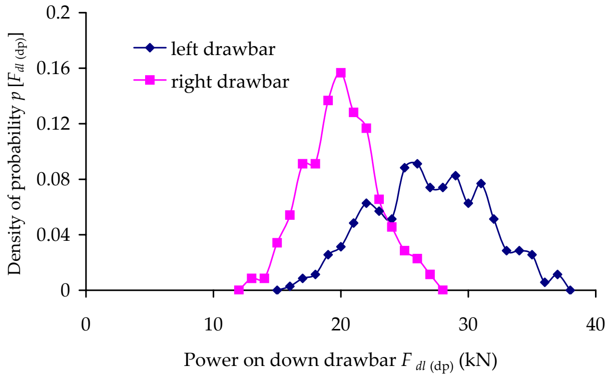

Figure 3. Density of probability forces in right and left lower drawbars $p(F_{dp})$, $p(F_{dl})$

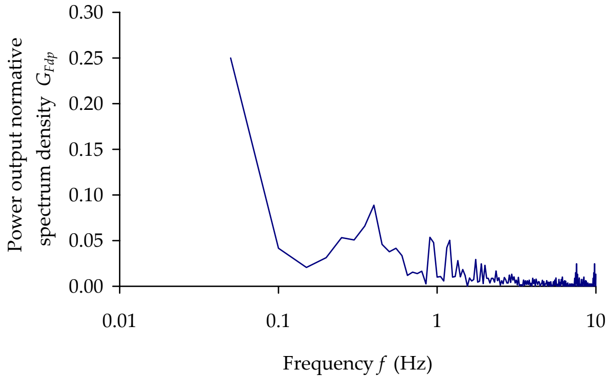

Figure 4. Power output normative spectrum density G_{Fdp}

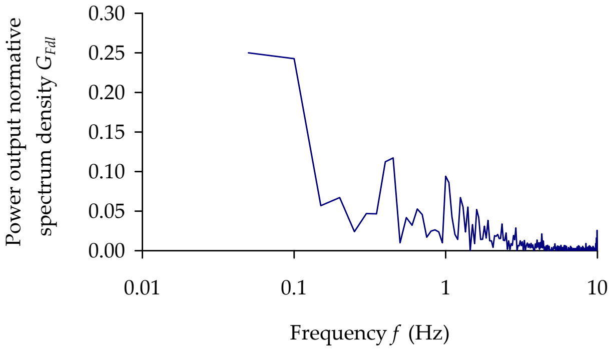

Figure 5. Power output normative spectrum density G_{Fdl}

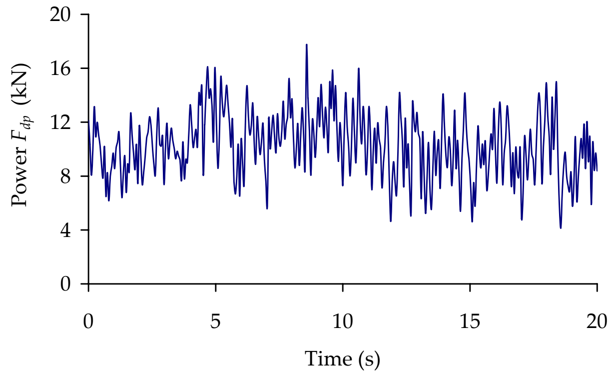

Figure 6. Time run of forces in the left lower drawbar F_{dl} tractor ZTS 16045 at plowing with semi-mounted four-share plough PH1-435

Table 3. The basic experimental number force data in TPH at plowing

Number of measuring	Drawbar	Right					Left				
		force F_{dp} (F_{sp}) (kN)			$\sigma_{Fdl(sl)}$ (kN)	$\lambda_{Fdp(sp)}$ (–)	force F_{dl} (F_{sl}) (kN)			$\sigma_{Fdl(sl)}$ (kN)	$\lambda_{Fdp(sp)}$ (–)
		min	str.	max.			min.	str.	max.		
1	lower	12.08	19.52	26.60	2.76	0.28	15.97	26.34	36.57	4.42	0.34
2		9.64	15.85	21.72	2.08	0.26	6.21	13.59	22.25	3.32	0.49
3		8.48	15.36	22.94	3.18	0.41	2.87	13.49	23.4	3.97	0.59
4		4.15	10.28	17.64	2.36	0.46	5.84	10.28	23.37	3.71	0.49
5		2.59	9.88	19.20	3.15	0.64	3.89	11.93	22.88	3.51	0.59
6		2.59	11.25	20.24	3.43	0.61	6.68	14.14	21.42	2.71	0.38
1	connecting	0.72	4.14	10.72	2.98	0.56	15.04	23.35	33.12	3.74	0.32
2		1.45	11.01	20.93	2.14	0.39	9.33	18.16	28.43	3.21	0.35
3		0.00	8.73	22.40	3.22	0.73	9.33	20.75	35.33	3.56	0.34
4		0.00	9.01	22.40	2.45	0.54	7.78	18.16	25.90	3.88	0.42
5		6.32	14.45	25.79	3.08	0.43	9.33	20.75	33.67	3.44	0.33
6		5.85	15.02	23.79	2.99	0.40	10.38	19.21	32.02	2.89	0.30

Table 4. Pronounced components of force spectrum in TPH

Number of measuring	Pronounced components of spectrum (Hz)			
	lower drawbar		connecting drawbar	
	right	left	right	left
1	0.4	0.45; 1.0	0.4	0.4
2	0.15; 0.4	0.15	–	–
3	0.3	0.3	–	0.4
4	0.3	0.2	0.6	0.6
5	0.45; 1.05	0.35; 1.05	0.8	0.3
6	0.85; 1.5	0.25; 0.9	0.25	0.25

with operating speed v_p = 2.08 m/s, position control, depth of plowing 27.29 cm for tractor ZTS 16045 with semi-mounted five-ploughshare plough PH1-435 (measurement No. 4).

On the base of obtained results we can maintain, that the irregularity coefficients of operating load λ represented by maximum, minimum and middle values, how it is presented by the main part of authors, are instable and less exact. On the contrary, the coefficients of the non-uniformity of the operation load of the tractor established on the base of middle quadratic deviations and of the middle value $\lambda = 2\sigma_x/\overline{x}$, which are presented in Table 3 expressing more precisely the non-uniformity of the given quantity.

The coefficients of non-uniformity of forces F_{dp} and F_{dl} at plowing with plough PH1-422 are in the range of values from 0.26 to 0.59 and at plowing with plough PH1-435 in range from 0.38 to 0.64. In the connecting drawbar the coefficients of force non-uniformity F_{sp} and F_{sl} at plowing with plough PH1-422 are in range of values from 0.32 to 0.73 and at plowing with plough PH1-435 in range from 0.30 to 0.54. These are values higher in comparison with known values of non-uniformity coefficients of pulling, or driving forces presented in bibliography. This reality needs to be regarded at simulation of TPH load in laboratory.

From obtained results of experimental measurements at plowing it results that macro-relief of ground has no significant influence on middle quadratic deviation size. This fact we can use with advantage at simulation of operating load in the sense that we can also use the results of measurings on runs of operating load on flatland we can apply at simulation of operating load at driving down the descent as well as at crossing a wavy terrain.

It results from runs of density probability of forces in right and left drawbars $p(F_{dp})$, $p(F_{dl})$ (Figures 3 and 8), that their character of spread out is similar at both types of tested ploughs. The margin of forces in lower drawbars is usually bigger in the left drawbar. The spectrum frequency of oscillations loading forces in lower drawbars is spread out maximally to

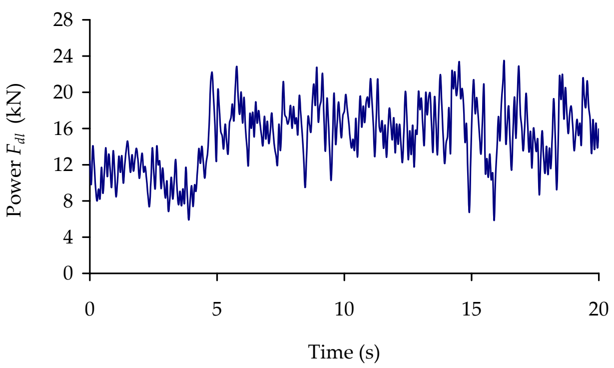

Figure 7. Time run of forces in the left lower drawbar F_{dl} tractor ZTS 16045 at plowing with semi-mounted four-share plough PH1-435

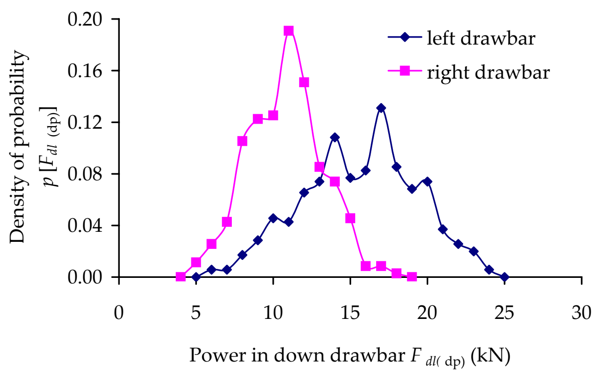

Figure 8. Density of probability forces in right and left lower drawbars $p(F_{dp})$, $p(F_{dl})$

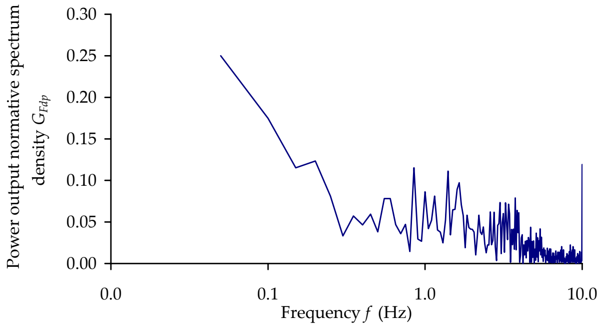

Figure 9. Power output normative spectrum densities G_{Fdp}

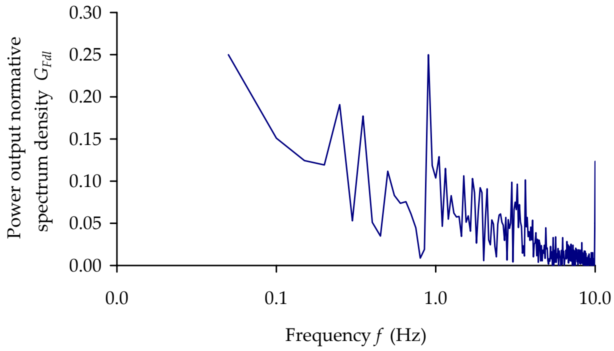

Figure 10. Power output normative spectrum densities G_{Fdl}

5 Hz at all variants of measures. The maximum values of spectrum density are obtained at 0.05 Hz.

From the measured values there resulted following conclusions:

– the forces in lower drawbars (RLD, LLD) are in monitored frequency extent in phase,
– the amplitude of forces is usually bigger in LLD,
– important elements of spectrum FFT of measured signals RLD and LLD do not surpass the value of 5 Hz (Table 4),
– maximal forces in RLD and LLD do not reach the value of 56 kN,
– forces in connecting drawbars (RCD, LCD) are in the recorded frequency zone practically in opposite-phase, i.e. fase shifted by 160° and 200°,
– the amplitude is bigger in LCD,
– important elements of spectrum FFT of measured forces RCD and LCD do not-exceed the value of 5 Hz (Table 4),
– the maximum size of forces in LCD and RCD does not reach the value of 60 kN.

The normative output spectrum densities of operation load obtained on the base of the cognition of inner structure of the observed operating loads by frequency spectrum give us the keystone for the determination of the requirements on simulator from presented point of view. On the base of technical conditions resulting from realized experiments and technical solution of simulator we shall work out functional scheme of simulator control. After this we determine basic parameters of control system of simulator and we design needed circuits and equipment with connecting to the complete system. In such a way the obtained results present new knowledge about operating load of TPH of the wheeled agricultural tractor.

The designed system of simulator control will secure load operating conditions at energetically demanding types of agriculture works – at plowing (it hasto fulfill the task of the amplitude and frequency indicator) of operating load, allow arbitrary reproduction of load, it will be characterized by austere change of load conditions and at simulation it will use the records of time run obtained by measurements.

CONCLUSION

The results of experimental measurement make possible to realize projected method of simulation of operating loads of dynamic system of tractor three-point hitch in laboratory conditions. Projected method of simulator control gives extensively opportunities for complex technical-economical evaluations of operative comparison of mobile agricultural sets, for evaluate their theoretical output and for optimization of measured consumption of fuel on unit of treated area, or of matter produced. It for the facilitates tests of TPH lifetime at loading TPH by common run of forces in horizontal and vertical orientations, so as to answer conditions of the practical loading process. From point of view of methodical considering we can suppose, that at comparison of different types of control systems the presented type of simulation will be at each repeating of load cycles the same, without influence of random factors existing in operating conditions.

The possibility of repeating of operating load creates appropriate conditions for judging the influence of single technical parameters on output parameters of monitored TPH set, on project of model and on establishing of optimum parameters.

In the further project part the designed control system of hydrostatic TPH simulator will be realized. After experimental verifying the load runs of forces will be evaluated and compared with results of input runs. The fulfillment of stipulated requirements by the simulator will also be evaluated. Increasing technical and exploiting qualities of tractors is focused on asserting electro-hydraulic control systems. In this orientation the results can serve as basis material for research teams working at solution of the presented problem.

List of symbols

F_{dp} – force in right lower drawbar (N)
F_{dl} – force in left lower drawbar (N)
F_{sp} – force in right connecting drawbar (N)
F_{sl} – force in left connecting drawbar (N)
v_p – working speed of set (m/s)
h_p – working depth of plowing (cm)
h_s – real plowing depth (cm)
σ_h – standard deviation of plowing depth (cm)
λ_{Fdp} – non-uniformity coefficient of force in right lower drawbar
λ_{Fdl} – non-uniformity coefficient of force in left lower drawbar
λ_{Fsp} – non-uniformity coefficient of force in right connecting drawbar
λ_{Fsl} – non-uniformity coefficient of force in left connecting drawbar
t – time (s)
$p(F_{dp})$ – density of probability of force in right lower drawbar
$p(F_{dl})$ – density of probability of force in left lower drawbar
G_{Fdp} – power output normative spectrum density of force in right lower drawbar
G_{Fdl} – power output normative spectrum density of force in left lower drawbar
P – position control
S – draught control
Z – mixed control
LLD – left lower drawbar
RLD – right lower drawbar
LCT – left connecting drawbar
RCD – right connecting drawbar

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Received for publication April 10, 2006
Accepted after corrections October 3, 2006

Abstrakt

Drabant Š., Tkáč Z., Mojžiš M. (2006): **Zaťažovacie charakteristiky trojbodového závesu traktora pre ich simuláciu v laboratórnych podmienkach.** Res. Agr. Eng., **52**: 129–135.

Príspevok sa zaoberá prevádzkovým zaťažením trojbodového závesu (TBZ) poľnohospodárskeho traktora v náhodne premenlivých pracovných podmienkach a jeho simulovaním v laboratóriu. Základným cieľom bolo získať experimentálne údaje, podľa ktorých možno posúdiť aj analyzovať problematiku dynamického zaťaženia kolesového traktora pri orbe so zameraním na TBZ. Ďalším cieľom bolo využiť získané výsledky z prevádzkových meraní na ich simulovanie v laboratórnych podmienkach hydrostatickým simulátorom. V príspevku je riešený silový rozbor v jednotlivých prvkoch trojbodového závesu poľnohospodárskeho traktora ZTS 160 45 UR II A. Traktor počas exploatácie bol v súprave s 4-radličným neseným a 5-radličným návesným pluhom. Merania boli uskutočnené pre 3 druhy rýchlosti súpravy (prevodový stupeň I/2, I/3, II/1), 3 hĺbky orby (20, 25 a 27 cm) a 3 typy regulácie trojbodového závesu (TBZ) – polohovú, zmiešanú a silovú.

Kľúčové slová: zaťažovacia charakteristika; trojbodový záves traktora; orbová súprava

Corresponding author:

Doc. Ing. Štefan Drabant, CSc., Slovenská poľnohospodárska univerzita, Mechanizačná fakulta, Katedra vozidiel a tepelných zariadení, Trieda A. Hlinku 2, 949 76 Nitra, Slovenská republika
tel.: + 421 376 414 531, fax: + 421 377 417 003, e-mail: stefan.drabant@uniag.sk