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Monitoring of operation loading of three-point linkage during ploughing

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Abstract

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The research was focused on operational measurements of tractor plough tools and their subsequent utilisation and simulation under laboratory conditions by a hydrostatic simulator. In this field, theoretical and experimental works were focused on tractors, whereby the proposal of laboratory test arose out of the loading characteristics of the three-point linkage of the tractor. These characteristics were obtained from the agricultural tractor's operation in plough aggregation. Measurements were performed with the following tools: tractor with carrier-mounted four-mouldboard plough PH1-435 and tractor with Kuhn plough manufactured by. The subject of these measurements was to obtain the time courses of forces and pressures in the hydraulic system of the three-point linkage during ploughing with carrier-mounted and semi-mounted ploughs. For objective comparison of the obtained results during experimental measurements, we determined the characteristics of measurement conditions focused on physical and mechanical properties of the soil – bulk density, moisture, penetrometer resistance and slide strength of the soil.

Keywords: tractor; plough; soil properties

The development of agricultural tractors has a long tradition all over the world. Modern tractors have high universality and they feature with a range of additional attachment. Currently manufactured tractors are equipped with three-point hitch regulation (Žikla et al. 2005a,b, 2007; Turza, Kopiláková 2011; Porteš et al. 2013), and as the authors introduce in their papers (Žikla et al. 2006; Tkáč et al. 2007; Burg et al. 2012), tractor manufacturers use the electrohydraulic regulation of three-point linkage also in tractors of lower power classes. All the devices which these tractors are equipped with offer wider utilisation of the tractor and greatly facilitate its operation. Technical progress, featuring a high technical level of products, is reflected in the production of agricultural machinery (Kučera, Rousek 2003; Semetko, Janoško 2005; Cvičela et al. 2008; Brdarić et al. 2009). The need to test the tractors and agricultural machines from the point of view of their suitability for agriculture will be continuously growing because these machines directly affect the agricultural production. This article is focused on the design of a laboratory device which will analyse the tractor hydraulic circuits, monitor the durability of components and also verify the measuring system of the tractor TPH (Kosiba et al. 2008, 2013; Kročko et al. 2008; Majdan et al. 2012). By tractors testing, we obtain the data which can be used when comparing tractors from different manufacturers as well as types of tractor classes. These trials have to be carried out by an organisation independent of tractor manufacturers due to the ob-

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jectivity of independent assessment of a tested tractor. For this purpose, a specially designed laboratory device was used to observe the operational conditions of the machine (Brdarić et al. 2009; Turza, Kopiláková 2011; Burg et al. 2012; Máchal 2013, Porteš et al. 2013; Tkáč et al. 2014). The increase of technological parameters causes considerable wearing of components and also decrease of their durability (Kučera, Rousek 2003; Drabant et al. 2010; Turza, Kopiláková 2011; Majdan et al. 2012).

MATERIAL AND METHODS

The tested tractor has to fulfil the data specified in the report of testing, has to be used in accordance with manufacturer recommendations concerning normal operation and has to be run in before testing. Hydraulic fluid has to be recommended by the manufacturer and determined by the type and viscosity according to the standard ISO 3448:1992 (Industrial liquid viscosity – ISO viscosity classification). To determine the size of forces in specific components of the tractor three-point linkage while ploughing, the three-point linkage was offset by tensiometers. During the measurements, we used the telemetry apparatus H 1000 by Kayser (Hydac International, Martin, Slovak Republic). Time courses of forces were analysed on the spectrum analyser TR 9405 (Takeda Riken, Tokyo, Japan). Thus their frequency spectrum and histograms were obtained. During these measurements, very important is the requirement of registration of monitored values just for the inhomogeneity of the material used, instability of monitored actions and necessity to measure under adverse working conditions. Therefore, it is suitable to record the values and subsequently to evaluate the measured values under better conditions, respectively, to use them after processing during the simulation of characteristic loading for a concrete machine or its part under laboratory conditions. From the time-dependent courses of the measured values, it is necessary to determine by their evaluation the following relationships of individual monitored values, to determine mean values and effective values, the overall course of changes as well as other necessary values. Specific methods for monitoring, registration and processing of the measured values are shown in different parts resulting from the solved problems. In Fig. 1, the placement of the measuring device HMG 2020. A digital recording unit HMG 2020 (Hydac, GmbG, Germany) is used to record electrical signals from force sensors, which are placed on tractor drawbars.

Fig. 1. Measuring device HMG 2020 placement on the tractor

During measurements, tractors ploughing tools consisting from the tractor and two types of plough were used, with the technical parameters shown in

Table 1. Technical parameters of the ploughs used

Parameters	Carrier-mounted plough	Semi-mounted plough
Type	PH1-435 TP 536 111-198/84	PH1-422 TP 53 611.38.198/84
Working speed	7 km/h	7.5 km/h
Transport speed	10 km/h	10 km/h
Max. working depth	24 cm	27 cm
Max. rated soil resistivity	120 kPa	130 kPa
Engagement width (adjustable)	35 cm	30–42 cm
Weight	665 kg	2,850 kg
Serial No.	10 160	6 1045

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Table 1. For the measurement, the following ranges of parameters were chosen:
– ploughing depth: 20, 25, and 27 cm,
– speed of vehicle tool – engaged speed of the gear I/2, I/3, II/1,
– regulation: position, forced and combination I (close to position regulation).

If a semi-mounted plough is used, we insert a floating position. By combination of points 1–3 we performed 45 measurements (including repeated measurements). The length of the measuring section for all measurements was 100 m, whereby prepared sections with a length of 25 m were set. The mechanical and physical state of the soil was detected by the penetrometer, together with collecting soil samples during measurements. Soil samples for soil granularity determination were collected before the measurement. To determine soil moisture, bulk density and specific weight, samples were collected during measurements and after their finishing. The physical and mechanical properties determined from the collected samples were as follows: soil moisture 14.3% wt, bulk density of dry soil 1.16 g/cm^3, specific weight of the soil grain 2.5 g/cm^3 and porosity 37%. The measurements of the three-point linkage were performed primarily for the purpose of obtaining the following experimental data:
– time courses of forces in the left bottom drawbar (LDT),
– time courses of forces in the right bottom drawbar (PDT),
– time courses of forces in the left coupling drawbar (LST),
– time courses of forces in the right coupling drawbar (PST).

RESULTS AND DISCUSSION

By individual experiments, the data necessary for determination of requirements and for preparing the functional design of the control of hydrostatic simulator of operational loading under laboratory conditions and its control circuits were obtained. The presented results are interesting in terms of the design of simulator device for loading the tractor three-point linkage. Measuring conditions are shown in Table 2, and obtained basic experimental data of forces of individual drawbars are given in Table 3. The first three measurements in Table 2 (No. 1, 2, 3) are for plough PH1-422 and the measurements (No. 4, 5, 6) are for plough PH1- 435. It is possible to see the major differences of force loading on the right and left drawbars. The cause is an uneven power shot of the plough at work where there is oscillation as a natural response to the action taken by plough.

In Fig. 2 the measured time courses of forces are shown in the left bottom drawbar F_{dl} and in the right bottom drawbar F_{dp}. In Fig. 3, there is their probable density $p(F_{dp})$, $p(F_{dl})$, and Fig. 4 contains normalised power spectral densities G_{Fdl}, G_{Fdp} of these forces during ploughing at operational speed v_p = 4.14 km/h, with position regulation and the ploughing depth of 28.25 cm, using the tractor with carrier-mounted plough PH1 422 (Agrozet, Roudnice, Czech Republic) (measurement No. 1). On the basis of the obtained results, it can be claimed that the unsteadiness coefficients of operational loading, which are expressed from the maximum, minimum and mean value, as specified by most of the authors, are unstable and highly variable. On the other hand, the unsteadiness coefficients of opera-

Table 2. Requirements on measurements during ploughing

No.	Ploughing depth (cm)			Gear shift position	Control	Working speed		Note
	required (h_p)	real (h_s)	SD (δ_h)			v_p (m/s)	V_p (km/h)	
1.	27	28.25	1.58	I/3/K	P	1.15	4.14	plough PH1-422
2.	27	30.50	1.41	I/2/Z	ZI	1.05	3.79	
3.	27	27.58	2.81	I/2/Z	S	1.06	3.83	
4.	25	27.29	1.60	I/3/Z	P	2.08	7.50	plough PH1-435
5.	25	27.56	1.42	I/3/Z	ZI	2.08	7.50	
6.	25	29.58	4.17	I/3/Z	S	2.00	7.20	

No. – number of measurement; h_p – ploughing depth-required; h_s – arithmetic average of measured ploughing depth; δ_h – standard deviation of ploughing depth; SD – standard deviation; v_p – working speed (m/s); V_p – working speed (km/h); P – position control; S – power control; ZI – mixed control I; K – reduced transmission ratio (turtle); Z – standard transmission ratio (rabbit)

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Table 3. Basic experimental numerical data of forces in the three-point linkage during ploughing

No.	Right					Left				
	force $F_{dp}(F_{sp})$ (kN)			$\sigma_{Fdp(sp)}$ (kN)	$\lambda_{Fdp(sp)}$ (–)	force $F_{dl}(F_{sl})$ (kN)			$\sigma_{Fdl(sl)}$ (kN)	$\lambda_{Fdl(sl)}$ (–)
	min.	median	max.			min.	median	max.		
Drawbar – bottom										
1.	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
Drawbar – coupling										
1.	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

No. – number of measurement; $F_{dp}(F_{sp})$ – force on right bottom drawbar; $F_{dl}(F_{sl})$ – force on left; bottom drawbar; $\sigma_{Fdp(sp)}$ – sinusoidal course of load in right bottom drawbar; $\sigma_{Fdl(sl)}$ – sinusoidal course of operating load in left bottom drawbar; $\lambda_{Fdp(sp)}$ – uniformity coefficient of operating load in right bottom drawbar; $\lambda_{Fdl(sl)}$ – uniformity coefficient of operating load in left bottom drawbar

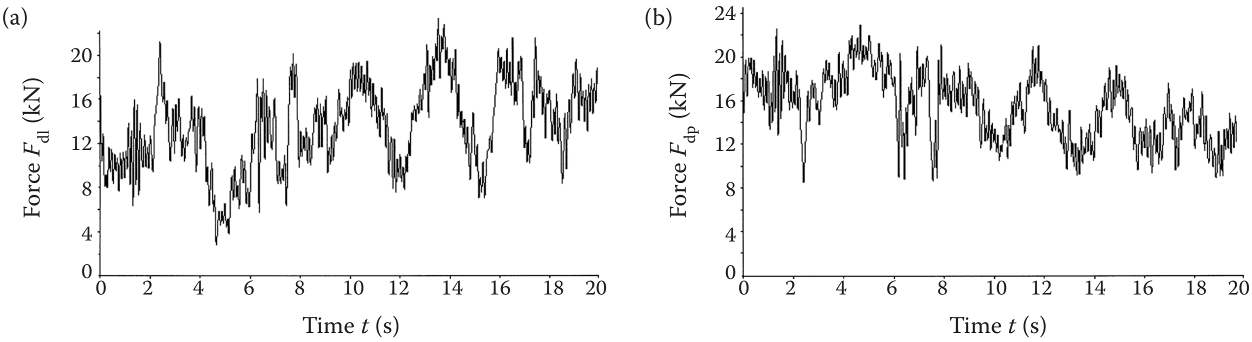

Fig. 2. Time courses of forces in (a) the left bottom drawbar (F_{dl}) and (b) the right bottom drawbar (F_{dp}) tractor ZTS 160 45 during ploughing with carrier-mounted plough PH1- 422

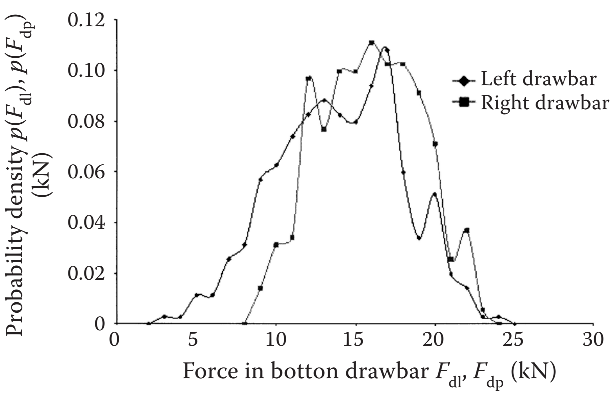

Fig. 3. Density probability of forces in the right bottom and left bottom drawbar $p(F_{dp})$, $p(F_{dl})$

tional loading of tractor which are specified on the basis of the mean square deviation and mean values (Table 4) are constant. It accurately expresses the unsteadiness courses of the given quantity.

The results of experimental measurements of forces and pressures in the three-point linkage of tractor ploughing assembly allow implementing the design and operational loading simulation of the dynamic system under laboratory conditions. Theoretical and experimental works were focused on tractors, and the design of the laboratory device is based on the loading characteristics obtained from the operation of the tractor aggregated with

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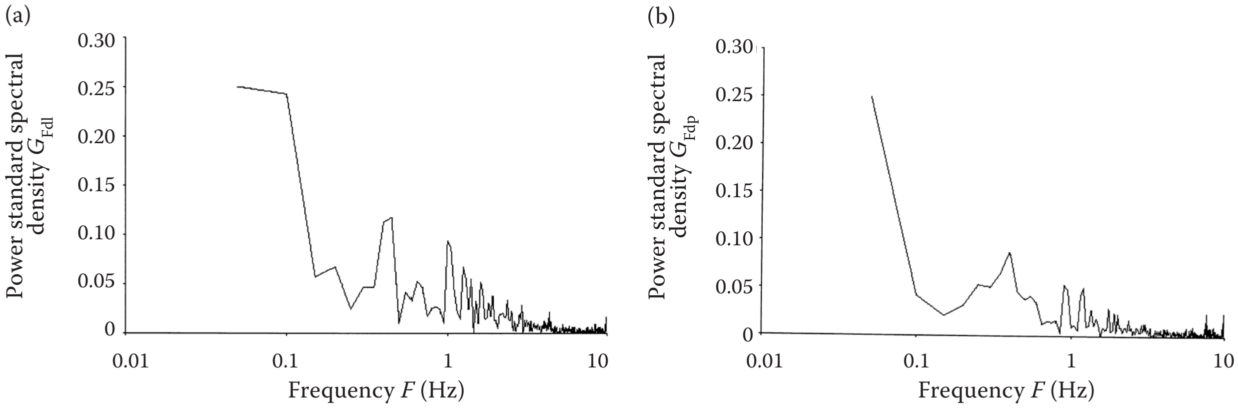

Fig. 4. Normalised power spectral density (a) left G_{Fdl} and (b) right bottom drawbar G_{Fdp}

Table 4. Significant values of forces in three-point linkage

No.	Significant values of spectrum (Hz)			
	bottom drawbar		coupling 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

No. – number of measurement

the plough. The subject of measurements was to obtain the time courses of forces and pressures in the hydraulic system of the three-point linkage during ploughing with carrier-mounted and semi-mounted ploughs.

CONCLUSION

In context of the rising demands on new mobile devices in terms of work productivity, performance and development of their function by introducing new design solutions using electronics, further requirements for technical lifetime, reliability and dynamic properties increase. In the traditional process of mobile devices testing only in operational conditions, the demands on the extent and number of repetitions for verification of structural modifications would excessively increase. In often a short period of possible employment of specific tractor sets at the time of soil cultivation, crop growing and harvesting of agricultural products, the result could be that the development of mobile devices used in agriculture would take a very long time, which would have a negative effect on the temporal and economical aspect of using specific devices. Therefore, it is necessary to pay attention to accelerated laboratory testing of mobile energy machines. In view of rapidly changing conditions in agriculture, the importance of simulation of operational conditions in the environment with a minimal dependence on external weather conditions in increasing. For research and development, this results in the requirement to use such testing methods that can verify the required properties at any time, regardless of agronomical dates, quality of natural surface and weather conditions.

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