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The action of force measurement for the three-point hitch of a tractor

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Abstract. The object of the executed measurements which were carried out was to obtain time courses for the forces and pressures inherent in a hydraulic system for the three-point hitch of a tractor during the process of ploughing with a carrier-mounted plough and also with a semi-mounted plough. It was necessary to obtain experimental data on the basis of which it was then possible to consider and analyse the issue of dynamic loading for the three-point hitch of a tractor during basic agricultural operations. The selected operation was ploughing in random working conditions using, in turn, a carrier-mounted plough and a semi-mounted plough. The aim was to use the results obtained to simulate the loading and full usage of the three-point hitch (TPH) under laboratory condition by means of hydrostatic simulator.

Key words: tractor, three-point hitch, hydraulic system.

INTRODUCTION

At present, agricultural tractors as manufactured are characterised by high rates of standardisation and feature a range of additional attachments which allow the wider use of each tractor and greatly facilitate its operation (Kosiba et al., 2012). The need for tractors and agricultural machinery to be tested from the point of view of their suitability to agricultural use will grow continuously because these machines directly affect agricultural production. This is within the context of rising demands on new tractors in terms of their performance and work productivity rates, while it also relates to increasing requirements for technical lifetimes, and the reliability of individual functions and assembly parts (Majdan et al., 2011; Porteš et al., 2013; Zastempowski, 2013 and Tulík et al., 2014). Last but not least, the introduction of elements which are of brand new designs requires the possibility of their parameters being testing during operation, within reason, due to the need for operational reliability. So the need for the technical parameters and individual properties of newly-designed parts and systems increases (Kučera & Rousek, 2008; Zastempowski & Zastempowski, 2012).

The analysis of forces which serve to influence the three-point hitch of a ploughing tractor was carried out because, when compared with tractor tractive tests, the loading for a ploughing tractor shows characteristic differences. Whilst ploughing, the tractor wheels slide into a furrow on one side of the tractor so that the vehicle becomes inclined to that one side (Čupera & Šmerda, 2010; Hoffmann et al., 2013; Simikić et al., 2014). In combination with the power effects of the plough itself, this inclination results in a different loading for individual wheels and also in changes in the loading for both axles. This results in significant changes not only in the grip of the driving wheels but also in an increased compaction of the soil (Čupera et al., 2011; Manes et al., 2012). This measuring was carried out and completed for the tractor factory, Zetor Tractor a.s. as requested by the factory's owners. As may be known, no such similar measurements have been carried out anywhere in the world up to this date.

MATERIALS AND METHODS

The tractor being tested has to fulfil the specified data requirements in the testing report, has to be used in accordance with manufacturer recommendations which concern standard operations and, before testing, it has to be fully run-in. Hydraulic fluid has to be recommended by the manufacturer and determined by type and viscosity according to the ISO 3448 standard. In order to achieve the goals which have been determined for this issue, the following procedures were selected:

- experiments with a ploughing kit (tractor and PH1-435 plough (four furrows));
- experiments with a ploughing kit (tractor and PH1-422 plough (four furrows));
- processing for measurement results by PC.

In order to be able to obtain the characteristics of TPH operational loading, The mechanical and physical state of the soil was detected by penetrometer and also by an analysis of soil samples. The samples for humidity determination, bulk density, and specific weight were collected during the process of taking measurements and also following the completion of measurements. The physical-chemical properties from the collected samples were as follows:

- weight humidity: 14.3%;
- bulk density of wet soil: 1.45g cm^{-3};
- specific weight of the soil grain: 2.5g cm^{-3};
- porosity: 37%.

On the basic of penetrometer measurements, an average value was determined for soil resistance of about 110 kPa. The soil samples were collected from each 10 m^2 area of soil. The soil type was clay loam. Soil moisture content was at 18%, with no stones. Soil texture was not determined. During the process of taking measurements, a tractor's ploughing tools were used, consisting of the tractor itself and two types of plough, and the technical parameters were as shown below in Table 1. In order to be able to carry out the measurement process, the following parameter ranges were selected:

- ploughing depth: 25 cm and 27 cm;
- tractor speed – engaged speed when in gear: I/2, I/3;
- tractor regulation control: position control (P), draught control (D), and mixed control (M).

The length of each measured section for all measurements was 100 m. Sections were prepared at a length of 25 m. The measurements for a three-point hitch were realised for the purpose of obtaining of the following experimental data:

- time courses for forces in the left-hand lower drawbar (LBD) TPH;
- time courses for forces in the right-hand lower drawbar (RBD) TPH;
- time courses for forces in the left-hand upper drawbar (LTD) TPH;
- time courses for forces in the right-hand upper drawbar (RTD) TPH.

Table 1. Technical parameters of ploughs

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^{-1}	7.5 km h^{-1}
Transport speed	10 km h^{-1}	10 km h^{-1}
Maximum working depth	24 cm	27 cm
Maximum rated soil resistivity	120 kPa	130 kPa
Engagement width (adjustable)	35 cm	from 30 to 42 cm
Weight	665 kg	2.850 kg

Essential criterion for the selection of measurement results was the maximum loading of the three point hitch. This refers to the maximum loading for the bottom drawbars (horizontal forces) and connecting bars (vertical forces). In order to determine the forces in specific components for the tractor's three-point hitch during ploughing, the three-point hitch was offset by a tensiometer. During the process of conducting the measurements, telemetry apparatus were used and the time courses for the forces employed were analysed using a spectrum analyser. Thanks to this, frequency spectrum and histograms were obtained. From the measurements obtained and following their processing, results were selected for presentation which were important in terms of the designed simulation device for the loading of a three-point hitch.

RESULTS AND DISCUSSION

The prevailing conditions during the ploughing process are shown in Table 2. The main experimental values covering the forces used at the individual drawbars, TPH, as obtained during the measurements process are shown in Table 3.

Table 2. Conditions of ploughing

Number of measurements	Depth of plough, m			Position of gear shift	Control	Working speed		Note
	Required	Real	Standard deviation			m s^{-1}	km h^{-1}	
	h_p	h_r	δ_h			v_p	V_p	
1	0.27	0.283	0.158	I/3/Z	P	1.15	4.14	Plough PH1 – 422
2	0.27	0.305	0.146	I/2/Z	M	1.05	3.79	
3	0.27	0.276	0.285	I/2/Z	D	1.04	3.74	
4	0.25	0.273	0.164	I/3/Z	P	2.08	7.50	Plough PH1 – 435
5	0.25	0.276	0.144	I/3/Z	M	2.10	7.56	
6	0.25	0.296	0.419	I/3/Z	D	2.08	7.50	

Legend: h_s – arithmetic mean of measured ploughing depth, δ_h – standard deviation of ploughing depth, P – position control, D – draught control, M – mixed control.

Table 3. Forces in TPH during ploughing

Number of measurements	Drawbar	Left bottom drawbar Force F_{dl} (F_{sl}), kN min.	median	max.	$\sigma_{\Phi\delta\lambda(\sigma\lambda)}$ kN	$\lambda_{\Phi\delta\pi(\sigma\pi)}$ -	Right bottom drawbar Force F_{dp} (F_{sp}), kN min.	median	max.	$\sigma_{\Phi\delta\pi(\sigma\pi)}$ kN	$\lambda_{\Phi\delta\pi(\sigma\pi)}$ -
1		15.04	23.35	33.12	3.74	0.32	0.72	4.14	10.72	2.98	0.56
2		9.33	18.16	28.43	3.21	0.35	1.45	11.01	20.93	2.14	0.39
3		9.33	20.75	35.33	3.56	0.34	0	8.73	22.4	3.22	0.73
4		7.78	18.16	25.9	3.88	0.42	0	9.01	22.4	2.45	0.54
5		9.33	20.75	33.67	3.44	0.33	6.32	14.45	25.79	3.08	0.43
6	top	10.38	19.21	32.02	2.89	0.3	5.85	15.02	23.79	2.99	0.4
1		15.97	26.34	36.57	4.42	0.34	12.08	19.52	26.6	2.76	0.28
2		6.21	13.59	22.25	3.32	0.49	9.64	15.85	21.72	2.08	0.26
3		2.87	13.49	23.,4	3.97	0.59	8.48	15.36	22.94	3.18	0.41
4		5.84	10.28	23.37	3.71	0.49	4.15	10.28	17.64	2.36	0.46
5	bottom	3.89	11.93	22.88	3.51	0.59	2.59	9.88	19.2	3.15	0.64
6		6.68	14.14	21.42	2.71	0.38	2.59	11.25	20.24	3.43	0.61

The formulas used for arithmetic mean and standard deviations are as follows:

$$\bar{\bar{x}} = \frac{1}{n}\sum x_i \quad (1)$$

$$\delta = \sqrt{\frac{1}{n-1}(x_i - \bar{x})^2} \quad (2)$$

Figs 1–5 show the values which were obtained from Measurement No 6 in order to demonstrate the measurements as a whole. Figs 1 and 2 show the measured time courses for forces in the left-hand lower drawbar, F_{dl}, and in the right-hand lower drawbar, F_{dp}, of the three-point hitch. Fig. 3 illustrates the probable action of forces (F_{dp}), (F_{dl}). Figs 4 and 5 show the normalised power spectral density of these forces during ploughing with an operational speed: $v_p = 7.20$ km h^{-1}, with force regulation and depth of ploughing included. A tractor was used with a five-carrier-mounted plough, model PH1-435.

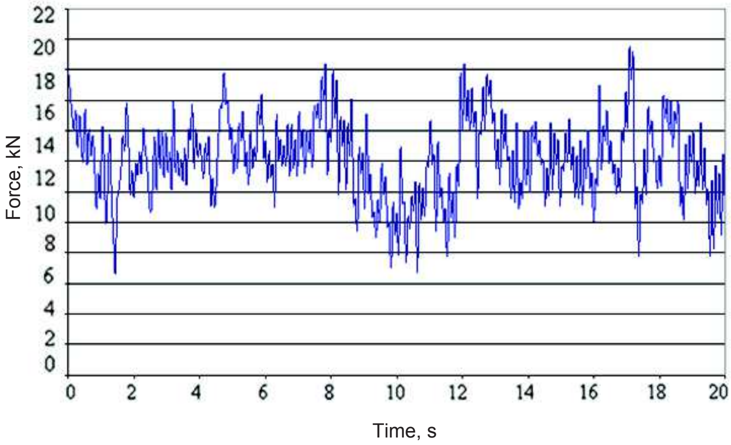

Figure 1. Times courses of forces on the left down drawbar F_{dl}.

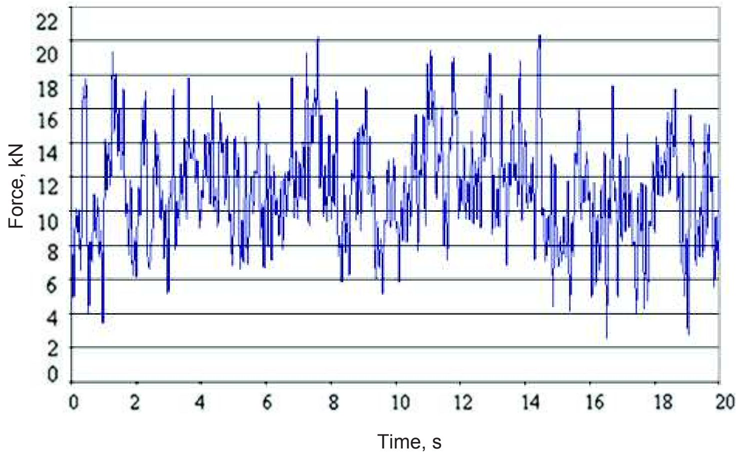

Figure 2. Times courses of forces on the right down drawbar F_{dp}.

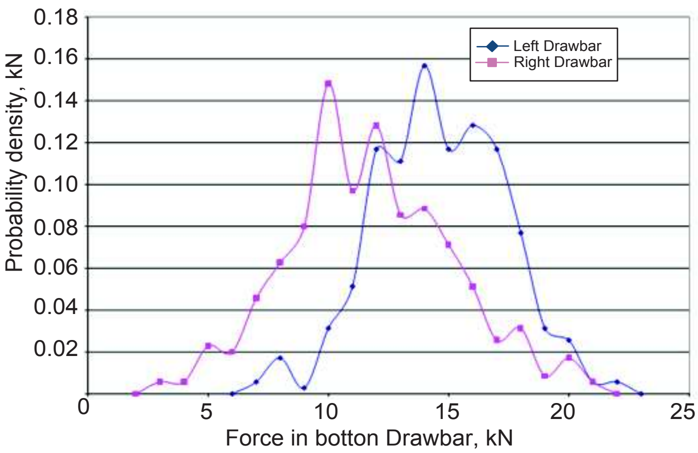

Figure 3. Probable densities of forces in right down and left down drawbars $p(F_{dp})$, $p(F_{dl})$.

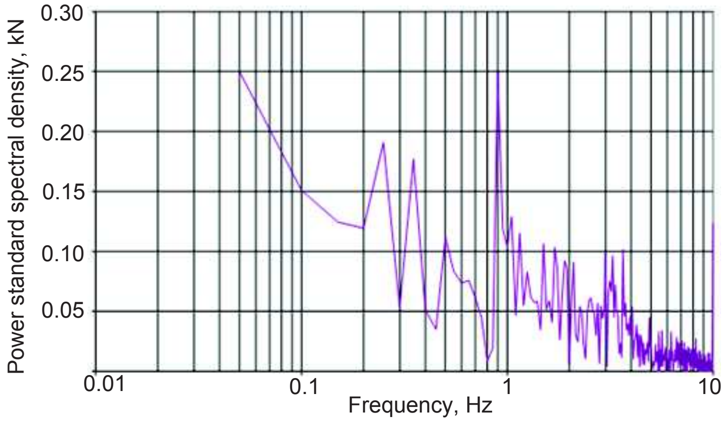

Figure 4. Normalized power spectral density – G_{Fdl}.

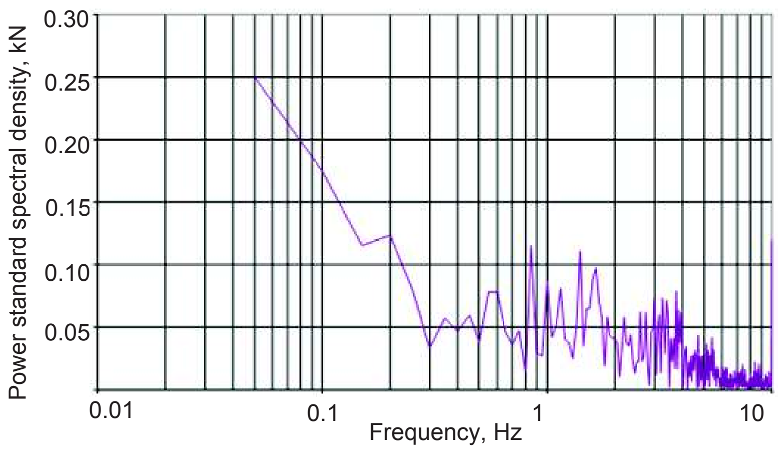

Figure 5. Normalized power spectral density – G_{Fdlp}.

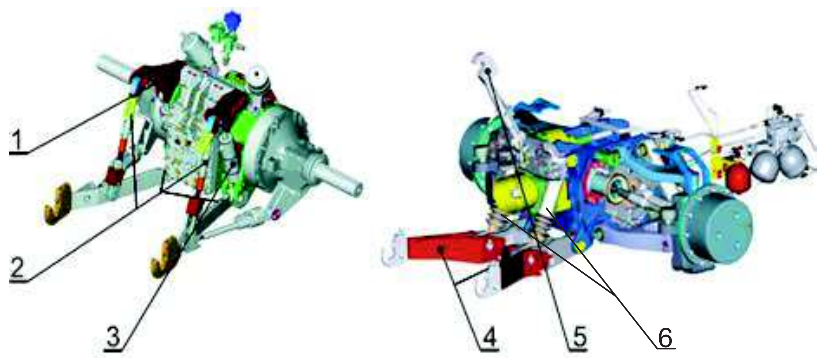

Figure 6. Three point-hitch: 1 – lifting arm, 2 – position of tensiometer, 3 – rectilinear hydraulic motor, 4 – left and right bottom drawbars, 5 – upper drawbar, 6 – connecting drawbars.

CONCLUSION

The results obtained showed the following:

- forces in the lower drawbars (LBD, RBD) were within the phase of the monitored frequency range;
- for LBD, generally higher amplitude of forces were registered;
- significant components in the Fast Fourier Transform spectrum (FFT spectrum) for measured signals, RBD and LBD, did not exceed a value of 5 Hz;
- the maximum values for forces on the RBD and LBD did not reach values of 37 kN;
- forces for the connecting drawbars (LTD, RTD) in the monitored frequency range were practically in antiphase, which means that they were phase-shifted from 160° to 200°;
- on the LTD, the amplitude of forces was higher;
- significant FFT spectrum components for the measured forces, RTD and LTD, did not exceed a value of 5 Hz;

- the maximum value of forces on the LTD and RTD did not reach a value of 36 kN.

The results of experimental measurements for forces and pressures on the three-point hitch of the tractor's ploughing assembly allows the design type and operational loading simulation conditions on a dynamic system to be realised under laboratory conditions. By using only a traditional process of mobile device testing in operational conditions, an excessive increase would be created in demands on the range and the number of repetitions for the verification of constructive modifications. As part of the process of carrying out experimental measurements for a tractor plough assembly, excepting the measurement of forces in the three-point hitch, also measured were the pressures involved in the tractor's hydraulic circuit. These values were compared with obtained values for pressures in the hydraulic circuit of the testing device under laboratory conditions (Majdan et al., 2011; Tulík et al., 2013). By carrying out individual experimental measurements for the tractor ploughing assembly, the necessary data to determine the requirements for the development of a functional design in the hydrostatic simulator of tractor and its control circuits were obtained under laboratory conditions.

On the basis of the results obtained, it can be claimed that the unsteadiness coefficients in terms of operational loading which are expressed in maximum, minimum, and mean values, as specified by most authors, are unstable and are also highly variable (Bentaher et al., 2008, Seyedabadi, 2015). On the other hand, when it comes to the unsteadiness coefficients for the operational loading of a tractor which are specified on the basis of mean square deviation and mean values $\lambda_x = \frac{2.\sigma_x}{\bar{x}}$, these are constant, and accurately express the unsteadiness of the given quantity for courses, as seen in Table 4.

Table 4. Significant values of forces coursed in TPH

Number of measurements	Significant values of spectrum, Hz			
	Bottom 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

*This status was caused by error during the processing of the measured results.

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