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ANALYSIS OF MEASURED AND COMPUTED FORCE EFFECTS IN TRACTOR'S THREE-POINT LINKAGE DURING TILLAGE

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Abstract: *The aim of the paper is an analysis of the measured and calculated force effects which act on tractor during tillage. Effects of the forces on individual driving wheels are analysed too. A mathematical model describing the transformation of force effect acting in the three-point linkage to loads in individual tractor wheels is developed. It is shown that the results of performed computations and theoretical analysis are in a good agreement. Based on the model, it is possible to use the measured force effects for precise determination of forces acting on the wheels. The influence of the length of the upper link on the loading of individual wheels and consequently on the traction performance of the tractor is determined.*

Keywords: ***three-point hitch, tillage, force effects, mathematical model.***

1. Introduction

The attached or trailed attachments are connected to tractor through three-point linkage, thus force effects acting on tractor are usually significantly different from effects of simple tractive forces, which typically exist in tractive tests. The adhesive loading of driving wheels is generally desirable, since it leads to maximal tractive efficiency. But this action is unfortunately connected with undesirable soil compaction, especially in case of ploughing systems moving in furrow. Soil compaction can cause serious problems and proper design of working system is thus critical. Adhesive loading of driving wheels is determining factor for achieving the maximal tractive efficiency of tractors. This efficiency consequently highly influences general efficiency of working system. The tractor's tractive properties are thus affected (decreased), especially in the cases when differential lock is not used.

Using the computing software SAMS, the force effects measured in three-point linkage are converted into vertical reaction forces in individual wheels, side force on front and rear axle, and force acting in the longitudinal direction. The ploughing system was drawn by other tractor in order to determine the tractive force FxM. The measured force was, after deduction of tire rolling resistance and transmission mechanism resistance, compared with computed force FxBODY.

The field experiments were performed in the area located close to Slavkov u Brna (Czech Republic) on the black soil type, loess soil matrix. The soil was treated by disc harrows after the harvest of wheat. The average soil moisture by weight during the experiments was determined as 19.7 %. The ploughing was performed using the tractor Zetor 11741. The plough Kverneland EM 85 was used to perform the ploughing operation.

The forces acting in the three-point hitch were monitored using attached strain gauges. The force sensors located on the lift rods. The sensors in lower links are during normal operation loaded also in bending, except tension and pressure. Their design eliminates these extra loads and solely axial tension loads are sensed. The ploughing system was drawn by other tractor and the tractive force FxM in the tow rope was measured by strain gauge. The forces in the individual links and rods as well as force FxM in the tow rope were recorded in the whole length of testing plot.

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The determined force effects in the three-point hitch and developed algorithm were used for calculation of force FxBODY. The force FxM represents the overall ploughing resistance, which includes plough resistance, rolling resistance and transmission mechanism resistance. The rolling resistance and resistance of rotating parts of transmission mechanism (FxD) were determined experimentally. Determined plough resistance FxP was consequently compared with calculated plough resistance, defined using forces measured at three-point hitch and corresponding to theoretical driving force FxBODY. Received value of FxP force was compared with calculated force FxBODY with use of developed algorithm. Listed calculated values represent the force effects acting on the tractor during ploughing. Calculated forces acting on front axle FzCTFL and FzCTFR exhibit negative values, which means that front axle is lightened during working procedure. The front axle is loaded by 2920 kg, which is the weight sufficient for transmission of driving force from the wheels to the ground. It is evident from calculated values of FzCTRL and FzCTRR forces, that ploughing operation increase the load of both rear wheels. The calculated forces acting in the transverse direction in the y axis reach relatively low values with reference to adhesive forces (forces in z axis) and thus can not produce instability of the working system in transverse direction.

Ideally, the courses of FxBODY and FxP should overlap each other. The variations and differences are probably caused by inexact determination of rolling resistance and resistance of rotating parts in the transmission mechanism. The resistance forces were determined for ploughing system with plough in the transport position. The tractor's tires were loaded solely by weight of the machine (tractor) and the plough. But it is important to note, that forces acting on ploughing tractor are given by sum of plough weight and resistance forces acting on ploughing elements. The vertical components of ploughing elements resistance forces produce more intensive loads on tractor tires and thus increase the overall rolling resistance. This explanation is supported by the fact that experimentally determined plough resistance is bigger than calculated one. The verification of the mathematical model was performed by use of regression test, which involved dependence of theoretically determined plough resistance FxBODY on experimentally determined plough resistance FxP.

As it is obvious from regression analysis, the measuring sets I and II are characterized by larger variation of calculated and measured values in comparison with sets III and IV, which exhibit smaller level of data scatter. This result can be explained as a consequence of a fact that measuring sets I and II were connected with 17 cm working depth of ploughing, while sets III and IV with 27 cm depth. The forces in case of sets I and II were thus lower indeed.

Performed statistical analysis proven that calculated value of theoretical plough resistance FxBODY and experimentally determined value of plough resistance FxP clearly exhibit the linear dependence. The high value of determination coefficient approves the high dependence tightness. It can be concluded from the determination coefficient value $I^2 = 0.962$ that 96.2 % of calculated values variability is defined by proposed regression function. The regression function was tested by F-test. It is obvious that tested regression function very well describes the measured values. The performed t-test revealed that coefficient significance, where the coefficient represents the slope of the line) is very high.

2. Conclusion

The presented results and performed analysis approve that theoretically calculated plough resistance correspond to experimentally determined values. Thus it is possible to conclude that mathematical model is functional with satisfying level of accuracy and measured force values in the three-point hitch can be used for calculation of force effects arising during ploughing operation on individual tractor wheels. If the force effects on individual wheels (with attachment connected to the three-point hitch) are known, it is possible to formulate and determine the traction characteristics. It is e.g. possible to evaluate, how different types of attachment connection influence the load of individual wheels. The change and alternation of the force effecting in the upper link of the three-point hitch, which can be influenced and determined by adjustable length, highly influences the final load of tractor's axes. It was experimentally determined and confirmed by consequent calculation with use of proposed algorithm, how exactly the length of the upper link influences the loading of individual wheels and thus traction performance of the tractor.