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Research paper

Observation of load transfer from fully mounted plough to tractor wheels by analysis of three point hitch forces during ploughing

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ABSTRACT

During in-furrow ploughing the wheel running in the furrow exposes the soil to greater risk of undesired compaction of the subsoil. This fact is due to a different load placed on the rear axle wheels of the tractor. The wheel moving in the furrow is loaded more than the wheel moving on the land. This fact is also reflected in fuel consumption and performance.

The aim of this paper was to analyse the possibility of eliminating the problem with different loads of the rear wheels by changing the length of the upper link of the three-point hitch. We also studied the impact of adjustments made on the economics of ploughing. During the experimental ploughing carried out for three lengths of the upper link, we have indirectly evaluated the load on the wheels. In the course of ploughing the exerted forces were measured by the strain gauge sensors attached to each link of the three-point hitch. These measured forces we used to calculate the load on individual tractor wheels using a verified algorithm that uses a multibody tractor model.

The results show that the large difference between the loads on the left and right rear wheels typical for in-furrow ploughing can be reduced by adjusting the length of the upper link of three-point hitch from the original 5 kN–1 kN. Changing the wheel load resulted in reduction of fuel consumption per ploughed area by 13.7% and increased performance, namely the area ploughed per unit time, by 6.45%.

1. Introduction

Ploughing is an energy-intensive agro-technical operation. Despite this the ploughing by a mouldboard plough plays an irreplaceable role in soil processing. The complex effects of quality ploughing on the soil cannot be replaced by any other action.

Ploughing can be analysed in relation to two main categories. The first category includes the criteria of fuel economy, which is consumption of fuel per ploughed area, and of performance, which is the area ploughed per unit time. The second category deals with the soil compaction risk. An important factor affecting the above mentioned categories and criteria is the load placed on individual tractor wheels during ploughing. Wheel load requirements are, however, contradictory. To overcome the ploughing resistance and to achieve good performance, a high traction force is needed which the tractor must produce and transfer through the wheels to the soil. The magnitude of the maximum traction force is proportional to the vertical load of a wheel. From this standpoint, high wheel loads are therefore desirable. Moreover, a high wheel load reduces the wheel slip and thus the fuel consumption (Moitzi et al., 2013; Oberhaus et al., 2005).

In contrast, a high wheel load increases the risk of soil compaction. According to Keller and Arvidsson (2004), soil stress and soil compaction are neither a function of axle load nor total tractor load, but the load of the wheel itself. From this perspective, a high wheel load in the furrow, characteristic of the conventional ploughing, is disadvantageous. The conventional ploughing causes significantly higher vertical soil stress (i.e. under the furrow wheels) than the on-land ploughing. This is caused by two factors. Firstly, the in-furrow wheels run 0.25 m deeper than the on-land wheels. Secondly, the in-furrow wheels carry a higher load *(*Keller et al., 2002*)*. In particular, the in-furrow subsoil compaction is regarded as a serious problem, since it persists for a very long time and may be a threat to the long-term soil productivity (Etana and Håkansson, 1994; Håkansson and Reeder, 1994).

Papers dealing with technical options for decreasing the wheel load deal mostly with axle load as a whole. The desired change is achieved for example by means of adding ballast (Stombaugh et al., 2008) or by using an electro-hydraulic pressure control system (Oberhaus et al., 2005). However, this does not fully exploit the conclusions by Keller and Arvidsson (2004) that not the load of the whole axle, but the load of wheels themselves is important. Moreover, in terms of soil compac-

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Fig. 1. Measurement of conventional right-handed ploughing with mechanically controlled, four furrow reversible mounted plough and the three-point hitch with strain gauge sensors.

tion risk, the load on rear wheels is critical. According to Weisskopf et al. (2000), the rear wheels of a tractor always produced the highest stress, whereas under the front wheels only small stresses occurred.

This paper intends to highlight the possibility of influencing the load of individual rear axle wheels as a means of reducing the soil compaction risk and increasing the economics of ploughing. The aim of this article is to demonstrate through the realised experiments (Fig. 1) and calculations that technical means of changing the load on left and right rear wheels may be the change in length of upper link (Fig. 2) of the three-point hitch (TPH) and to show that by adjusting the upper link length it is possible to increase the tractor performance and reduce the fuel consumption.

2. Materials and methods

The paper deals with the individual axle loads and especially with the difference in loads on the left and right wheels of the rear axle. In the following text, it is referred to as the rear wheel load difference –

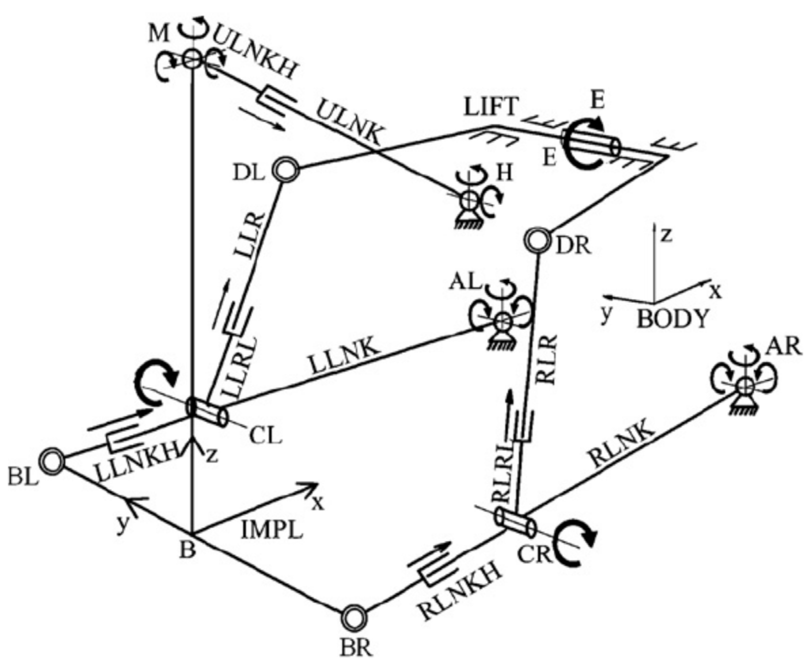

Fig. 2. Kinematic sub-model of the tractor's three-point hitch. The arrows indicate kinematic degrees of freedom.
Legend:
ULNK, ULNKH two parts of (cut) upper link.
LLNK, LLNKH two parts of (cut) left lower link.
RLNK, RLNKH two parts of (cut) right lower link.
LLR, LLRL two parts of (cut) left lift rod.
RLR, RLRL two parts of (cut) right lift rod.
LIFT hydraulic arms.
IMPL implementation (plough).