MECHATRONICS, AND EFFICIENCY OF TRACTORS IN OPERATION

Jerzy Żebrowski*, Zbigniew Żebrowski**

*Technical University of Warmia and Mazury in Olsztyn, Poland
** The Warsaw University of Technology, Poland

INTRODUCTION

An achievement of a significant tractor operation efficiency improvement is possible by bringing in the automation into its working processes [8] In order to achieve that, a system tractor-implement-ground should be modelled at first, and then a control and adjusting of the tractor – machine combination should be elaborated and implemented according to appropriate criteria [2, 7, and 9].

The control and adjustment is carried out by mechatronic devices [1].

Appropriate data about the tractor, its implement, and ground, as well as the ones received from the input signals of appropriate sensors during the tractor operation, are necessary for an automatic control.

Current measurements of the tractor operational parameters, and the previously developed optimising algorithms allow to control in an automatic way the tractor operation.

One of the tractor assemblies which require an automatic control of the front wheels is the driving assembly. At present, a four-wheel drive tractor has this assembly switched on and off in a manual or automatic way according to the constant limiting parameters.

SWITCHING ON AND OFF CRITERIA OF THE FRONT WHEEL DRIVE

In order to achieve a significant improvement of the tractor operation efficiency, at first the functional model of the tractor – implement – ground system has been developed and then after its successful testing a simulation computer model of the tractor – implement – ground system has been elaborated [9]. The computer model aims to allow:

– to determine the tractor weight and its distribution among the tractor axles;

– to determine a situation, when the front wheel drive ought to be switched on or off;

– to determine, when the interlocking of differential mechanisms and driving axles [5] ought to be switched on or off;

– to select an appropriate transmission ratio.

One of the above mentioned factors is the problem of automation of switching on and off the front wheel drive of a wheeled agricultural tractor.

The front wheel drive enables to utilise a total load of the tractor wheel on the ground for obtaining an adequate propeller force. The switched on wheel drive in this case causes, that at a given pulling force the tractor operates with a smaller wheel slip and, when necessary, it achieves a bigger maximum pulling force than while driving the rear wheels only.

The front-wheel drive should be switched on just in the situation when, after switching on their drive, the propeller forces will act on the front wheels with the same senses, as on the rear wheels, i.e. positive at driving, negative at braking. Then in the first case it will increase potential pulling force, and in the second, it will decrease the braking distance.

Many producers use an automatic control of a front-wheel drive taking into account only occupational safety and an eventual overloading of the power transmission system of the tractor. The currently used exemplary conditions of the front drive switch on are as follows:

– both the braking pedals have been pressed simultaneously;

– when the front-wheel drive was earlier switched on and one of the brake pedals, which had been earlier depressed, was released;

– when the slip of the rear wheels has surpassed a certain value (e.g. $s_t > 15\%$);

– the interlock of rear differential mechanism is switched on;

– at the decreasing driving speed of the tractor, and when it decreases below the limiting value (applied by different firms the limiting value is contained in the range of 13-19 km/h);

– a turning angle during cornering is smaller than a given limiting value (e.g. 25^o);

– the hydraulic jack of the implement linkage is in a position below 75% of the maximum raising range and with the automatic control of this unit is switched on.

Whereas a disconnection of the front drive occurs when the following conditions are fulfilled:

– when the front drive was earlier switched off and both of the break pedals, which had been earlier depressed, have been released;

– the only one of the braking pedals has been pressed;

– when the slip of the rear wheels has decreased below a given value ($s_t < 10\%$),

– when the driving speed increases above a given value (15-19 km/h) and both the brake pedals are released;

– the interlock of the rear differential mechanism is switched off;
– a turning angle during the tractor cornering is bigger than a given value (25°),
– the hydraulic jack of the implement linkage is in a position above 75% of the range of the maximum raising and when the automatic control of this unit is switched on.

The above data analysis shows that in the applied algorithm of the switch on and off control of the front-wheel drive, the mechanics of the co-operation of the wheel and the ground have not been taken into direct consideration.

Taking into account the wheel mechanics, the switch on of the front-wheel drive (when the tractor operates with a pulling force) should cause an occurrence of the positive propelling force of the front wheels [6].

THE OBJECT AND RESULTS OF THE EXPERIMENT

In order to take into account the wheel mechanics when switching on the front wheel drive basing on the previous considerations [2, 6, 7], the control unit for the front wheel drive operation has been developed, executed and mounted on the tractor.

For the experiments a tractor with four wheel drive and with the control of the front-wheel by a multi-disk brake actuated by a hydraulic distributing valve controlled electrically was used. The research object was equipped with the following sensors (allowing to obtain the input values for the control unit resulting from the previously developed algorithms of its operation [7]):
– angular velocities of the tractor wheels,
– driving speed of the tractor.

Before starting the experiments, the calibration of the control unit was carried out. It consists in a test run with disconnected front-wheel drive. As a result of that the wheel dynamic radiuses were determined as well as the kinematic inconsistency between the rear and front-wheel axles [4, 6].

The kinematic inconsistency between the rear and front-wheel axles is defined as a ratio of circumferential speeds at the dynamic radius of the front wheels (V_{op}) to the rear wheels (V_{ot}) [6].

$$k = \frac{V_{op}}{V_{ot}} = \frac{1 - s_t}{1 - s_p} \tag{1}$$

where:
s_t – slip of the rear wheels,
s_p– slip of the front wheels.

Therefore at switching the front wheel drive on, the problem of different circumferential speeds at dynamic radius of the particulars wheels occurs, resulting from the kinematic inconsistency ($k \neq 1$). When the kinematic inconsistency occurs, all the wheels of the tractor running straight ahead operate with the same slips ($s_p = s_t$).

Utilising the values of appropriate transmission ratio of the tractor power transmission system, and basing on the recorded speeds of wheels, the angular velocities of both the shafts of the front-wheel drive clutch have been determined.

Fig. 1 shows the courses of the angular velocities, when the tractor is running at steady motion and with the front wheel drive switched off. In the case presented in Fig. 1, the kinematic inconsistency is $k < 1$.

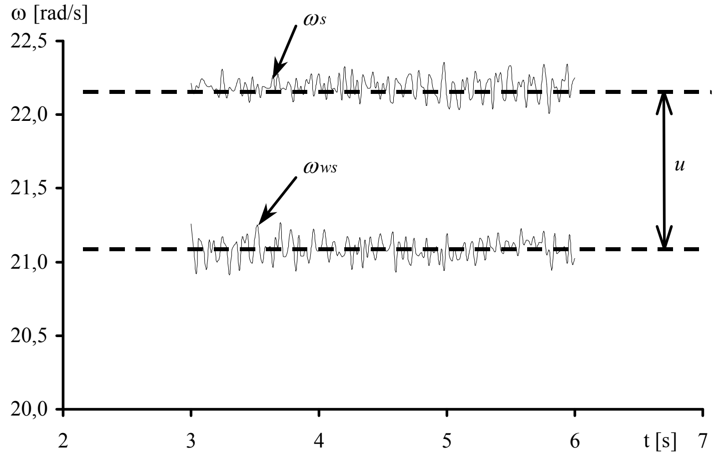

Fig. 1. Time courses of the angular velocities of the shafts of the front-wheel drive clutch: ω_s – angular velocities of the front axle driving shaft, ω_{ws} – angular velocities of the input shaft of the clutch switching on the front drive, *u* – angular velocity difference resulting from kinematic inconsistency

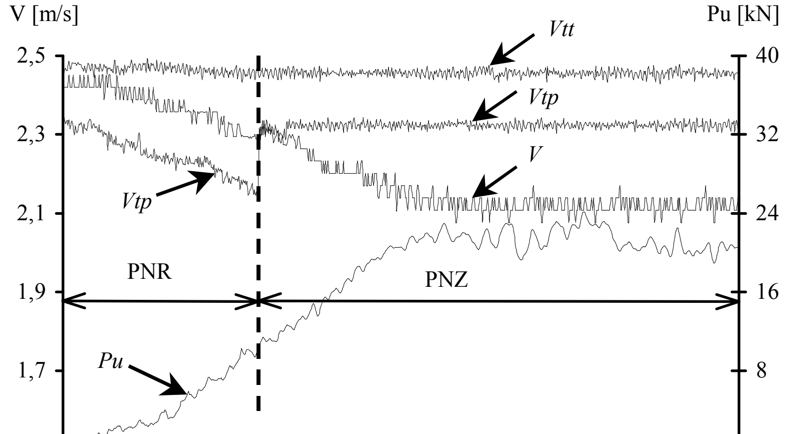

Fig. 2. The courses of the recorded values during the test run: *Pu* – pulling force, *V* – travelling speed, *Vtt* – theoretical speed of the rear wheels, *Vtp* – theoretical speed of the front wheels PNR – the front-wheel drive disconnected, PNZ – the front-wheel drive connected

After the calibration of the control unit has been done, the measurement run was carried out, which started at the disconnected clutch of the front-wheel drive and at the pulling force equal to zero. During the passage, the pulling force was increasing progressively up to moment when the switching on the front wheel drive occurred (Fig. 2). After switching on the front wheel drive, the theoretical speeds of the tractor V_{tt}, V_{tp} are interdependent and result from the following factors:

- rotational speed of the engine;
- transmission ratio in the power transmission system;
- dynamic radius of the wheels.

FINAL CONCLUSIONS

The appropriate sense of power flow that should be flown from the engine to the ground and not contrary is the basic requirements of driving the tractor by its front wheels.

Criteria of the switching on of the front-wheel drive can be expressed as a condition to equalise the expected circumferential speed of the driven front wheel with real speed of the tractor. This effect is achieved only in the case, when the circumferential speed of the front wheels driven by the engine is greater than the real speed of the tractor.

The applied system enables to control the front drive automatically, independently from the size of the tractor wheel or the pneumatic and applied pressures. It works in such a way, that the front wheel drive is switched on, when the propelling forces act on the front wheels with this same sense as on the rear ones.

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SUMMARY

An increase of operational efficiency of a tractor machine combine is possible by using mechatronic devices for its control.

This paper presents an operation of that system with automatic controls of the front wheel drive in such a way, that the front wheel drive is switched on when the propelling forces act with the same sense on the front as on the rear wheels, i.e. positively at propelling, and negatively at braking.

The applied system enables to control automatically the front wheel drive, independently from the sizes of the tyres mounted on tractor wheels or from the pressure inside the tyres.