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# MODELLING AND SIMULATION TESTS OF SWITCHING ON FRONT DRIVE AXLE AT FARM TRACTOR

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**Summary**. In this paper the problem of switching on power transmission from engine to front wheels in farm tractor is considered. Criteria of switching on/off the front axle drive are given. A functional model of a system tractor-tools-soil is presented, which was the basis for creation of the computer model later used to simulation tests. The schema of this model and examples of simulation results are presented. The paper is ended with conclusion considering the main criteria of switching the front axle drive.

**Key words:** farm tractor, wheel spin, front axle drive, control, automatic control switching on front axle drive.

## INTRODUCTION

Thousands of farm tractors work for hundreds of hours per year in fields all over the Earth. Their inefficient work causes excessive money loss and undesired environmental pollution. Those losses can be reduced by proper use of front axle drive. The power transmission to front wheels enables the use of the whole tractor's wheels load on the soil to reach the propelling force. The coupling of front wheels with engine done in a proper state results in a lower wheel slip for the same traction force and when it is needed it gives bigger maximum traction force in comparison to the case when only rear wheels are propelled [Prospect and catalog Case IH; Prospect and catalog John Deere].

The power transmission to the front wheels should be switched on when after their coupling the propelling force of front wheels would have the same value as propelling force of rear wheels. It means a positive value during propelling and a negative one during braking. It increases the potential traction force in the first case and reduces the braking distance in the second case. Steering and regulation of this coupling is achieved by means of mechatronic devices [Auernhammer 1991; Żebrowski J., Żebrowski Z. 2002].

## FUNCTIONAL MODEL

To achieve a significant improvement of tractor work efficiency, at first the functional model of the tractor-tools-soil system was built. And after its successful tests the simulation computer model of the system was created. The aims of building this model were:

– to define the tractor load and its distribution to particular axles,
– to define the state when the propulsion of front axle should be switched on /off [Renius 1987],
– to define the state when the interlock of differential of driving axles should be interlocked,
– to fit the ratio of the driving system.

The functional model is shown in Fig. 1 [Prospect and catalog Fendt]

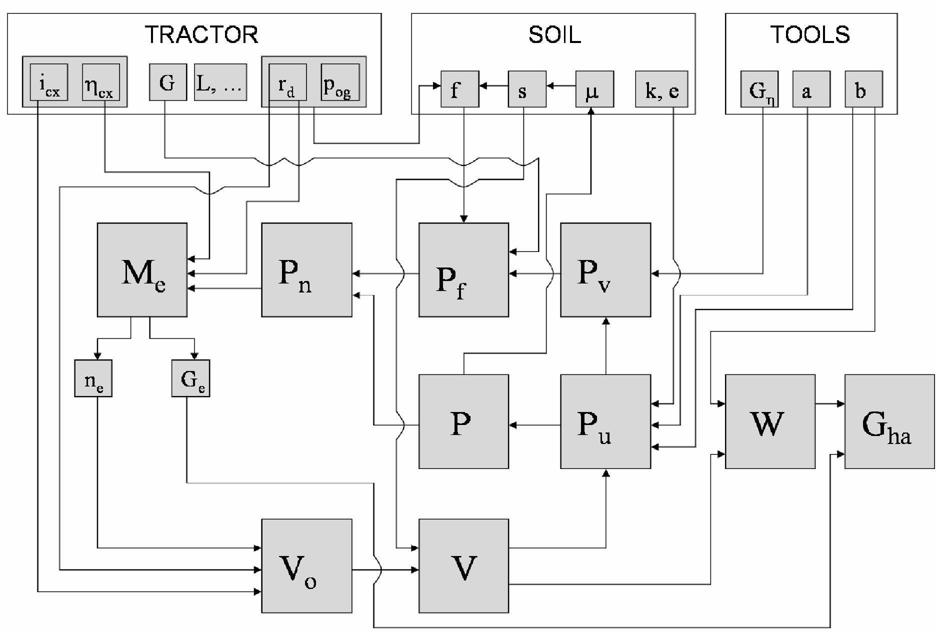


Fig.1. Functional model of tractor-tools-soil system

## CRITERIA OF COUPLING AND DECOUPLING POWER TRANSMISSION TO FRONT WHEELS

The unit of front wheel propulsion is the one of the tractor's systems which demands the automatic control. Today, in tractors with propelled front wheels, the coupling and decoupling of front axle is done manually or automatically under the condition of reaching a defined value of threshold parameter.

The front wheels drive should be switched on in the situation, when it would wield an effect of their propelling force of the same value as the propelling force of rare wheels. It means a positive value during propelling and a negative value during braking, which would increase the potential traction force or reduce the braking distance.

Many firms use automatic steering of the front axle coupling, considering the work safety and overload of tractor driving system only.

In this case, the front axle coupler control system should have a possibility of choosing one of the three duty options.

1) the front axle is uncoupled with the tractor engine,
2) the front axle is constantly coupled with the engine,
3) the coupling is controlled automatically.

In the first case the front axle is constantly uncoupled with the engine. Because braking distance decreases, the road adhesion of front wheels should be used as well. It is more significant at a faster running speed. So above a certain earlier settled speed, e.g. V>19 km/h, and pushing down both brake pedals simultaneously, the drive of front axle should be switched on.

In the second case the drive of the front axle is switched on all the time. Because of wearing of tyres this drive should be switched off above the speed of a certain earlier settled value e.g. V>24 km/h, which can be realized mostly on a hardened road, during transport. This option is used as a protection against the possibility of a driving system failure.

In the third case the automatic controller should:

I Switch on the front axle drive when:

1) in result of slowing down the running speed is below a settled value, e.g. v <15 km/h,
2) both brake pedals are pushed down simultaneously,
3) one brake pedal has been pushed down and released at that moment,
4) the rear wheels slip passed over the settled value, e.g. $s_t$ > 15%,
5) the differential gear is blocked,
6) the hydraulic lift is above 75% of its maximum lifting range,
7) the front wheels angle is smaller than the settle value, e.g. 25%.

II Switch off the front axle drive when:

1) the running speed exceeds the settled value, e.g. v <15km/h,
2) only one brake pedal is pushed down,
3) the rear wheels slip is bellow the settled value e.g. $s_t$ > 15%,
4) the differential gear is unblocked,
5) the hydraulic lift is below 75% of its maximum lifting range,
6) the front wheels angle is bigger than the settled value ( e.g. 25%) – to reduce the tires wearing.

In order to the fulfil the above control criteria of coupling and decoupling, the power transmission to the front axle of the tractor should be equipped with sensors to enable the measurement of the following variables:

1) real running speed,
2) position of brake pedals,
3) average speed of two rare wheels,
4) average speed of two front wheels,
5) position of the hydraulic lift arm

6) the front wheels angle during tractor turning.

The above analyses reveal that in the control criteria of switching on/off the front wheels drive, the direct mechanics of the wheels-soil interaction was neglected.

Regarding the wheel interaction mechanics, the switching on front wheels drive, (when the tractor works with a certain traction force) should cause an appearance of the additional propelling force of front wheels [Niziński *et al.* 1996, Dudziński and Mendelowski 2000].

During switching on the front wheels drive the problem of different peripheral speed on dynamic radius of particular wheels arises, due to the kinetic incompatibility ($k \neq 1$).

The kinetic incompatibility between front and rear wheels is defined as a relation of peripheral speed of the dynamic radius of front wheels ($V_{op}$) to rear wheels ($V_{ot}$) [Mirosław and Żebrowski 2001].

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

where: $s_t$ – rare wheel slip, $S_p$ – front wheel slip.

When there is the dynamic compatibility (k = 1), during a straight line running, all tractor wheels work with the same slip ($s_p = s_t$).

Sometimes, because of measurement reasons, as a criterion of front wheel drive switching on, the comparison of rotary speeds $\omega_s$ of front axle drive coupler output shaft (front wheel drive trough front axle and wheel reduction gear) with rotary speeds $\omega_{ws}$ of the input shaft is used. Example diagram with speed courses for value $k$<1 for a uniform tractor motion with coupled and uncoupled front axle drive is shown in Fig. 2.

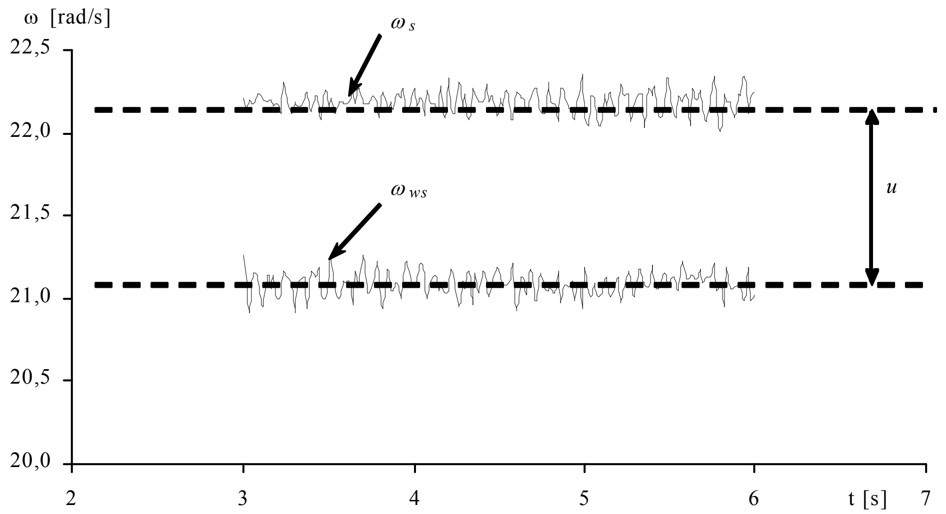


Fig. 2. The courses of rotary speed of front axle drive shafts, with $k$<1 for uniform tractor running with an uncoupled front axle drive: $\omega_s$ – rotary speed of shaft propelling the front axle, $\omega_{ws}$ – rotary speed of input shaft to coupler of the front axle drive, $u$ – the difference rotary speed as result of kinetic incompatibility

## COMPUTER MODEL FOR SIMULATION OF TRACTOR WORK

To reach the significant improvement of tractor work efficiency, after creation of the functional model of the tractor-tools-soil system, and after its successful tests, the simulation computer model of a system was built. This computer model gives, among others, the possibility of defining when the front axle drive should be switched on or off.

The computer model was built in the Matlab program environment with the use of the Simulink interface. This program allows for an easy input of necessary data and relations such as engine characteristic, relation concerning factors characterizing interaction of wheels and the ground ($\mu$ = f($s$), $f$ = f($s$)), traction force in function of the real tractor speed ($P_u$ = f($V$)) and many other relations.

In the simulation, changes of the value of the required parameters can be made in the time function and the received results have a convenient form to further analyse (diagrams, number compositions etc.). The graphical presentation of the program is presented below, shows directly the computer model of the tractor-tools-soil system.

At the present work state, a simplified computer model of 2D (two dimension) was built. It means that the same speed, slips, and torques were taken for both wheels (right and left) of each axle.

General schema of the model is shown in Fig. 3. It consists of a series of blocks. The block of engine ia characterized by ($n_e$ = f($M_e$), $G_e$ = f($M_e$) and soil-wheel interaction parameters for each tractor axle. Other input data defining the rest of the tractor parameters are in the workspace of the Matlab program, where they were introduced according to the tractor data and tractor's work condition.

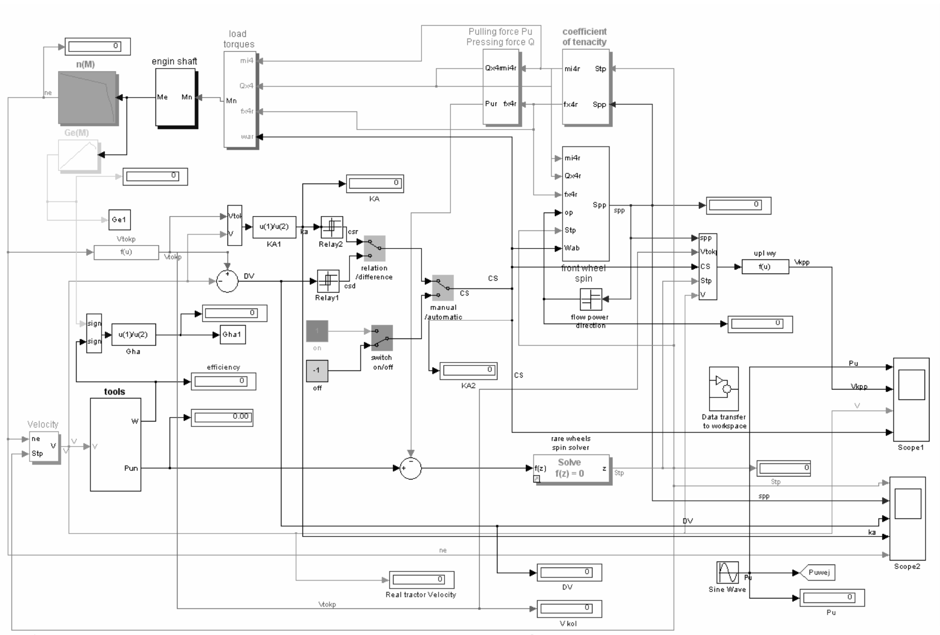


Fig. 3. Computer model of the Tractor-Tools-Soil system

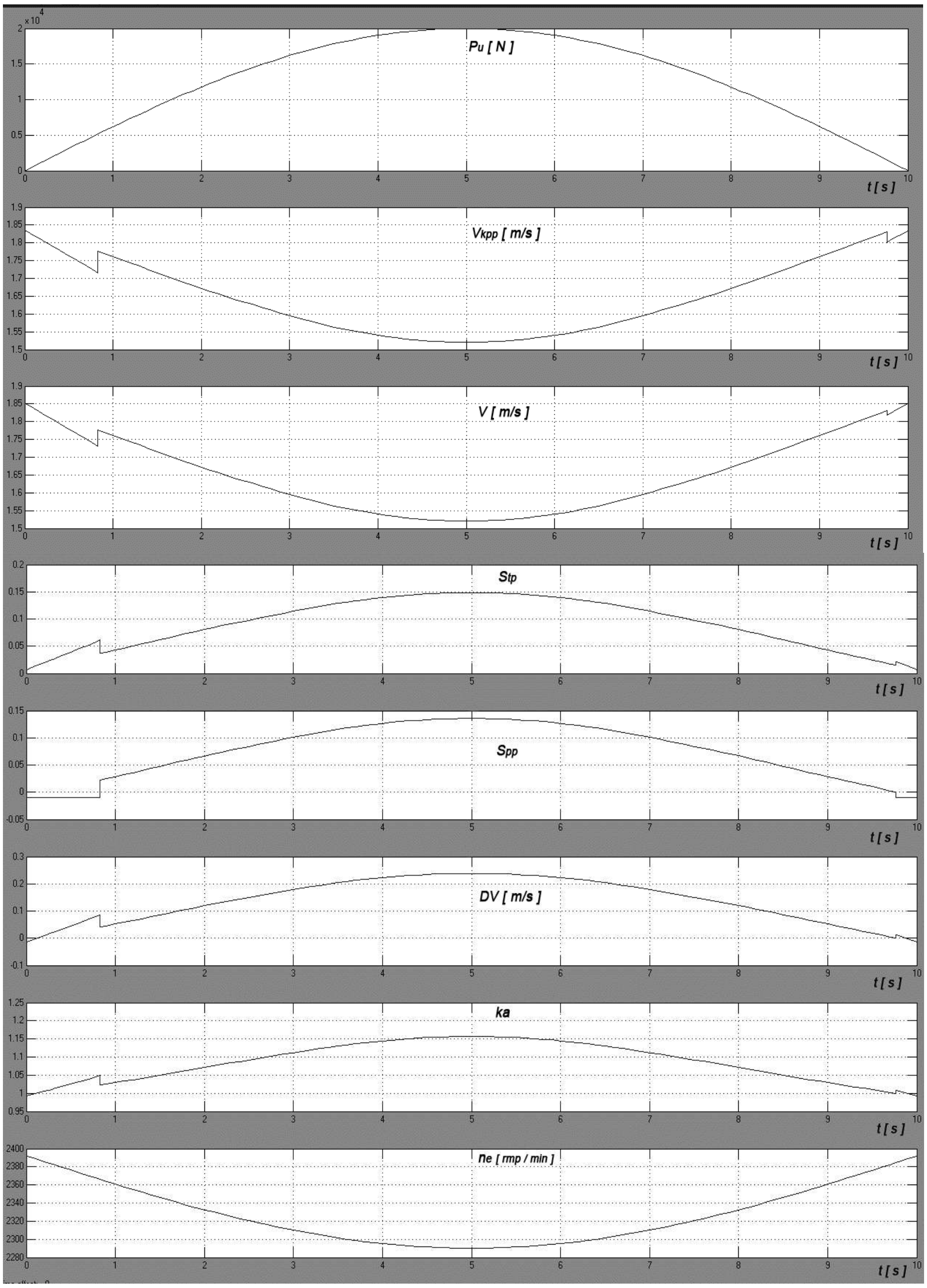


Fig. 4. An example of the obtained diagrams of the selected variables runs

One of the most important blocks is called „load torque". In this block the engine load torque is calculated, based on traction forces, wheel torques, payload, and gears ratio in the power transmission system with regard to the power flow direction between engine and wheels.

## SIMULATION RESULTS

As a result of computer simulation provided by the presented model, the time diagrams of the variables given below were obtained:

– traction force ($P_{u,}$ N) – given value
– speed of front wheels ($v_{kp,}$ m/s);
– real speed of tractor ($v$, m/s);
– rear wheels slip ($s_t$);
– front wheels slip ($s_p$);
– difference between theoretical and real speed of front wheels ($DV$ m/s);
– difference of theoretical and real speed of front wheels ($k_a$)
– rotary speed of engine shaft ($n_{e,}$ rpm).

The examples of the obtained diagrams are presented in Fig. 4.

## CONCLUSION

The criteria of the front axle drive switch on/off can be worked out by matching the theoretical peripheral on the dynamic radius front wheel speed (expected after switching on front wheel drive) with the real tractor speed. The result can be reached under one main condition: the peripheral speed of wheels is higher than the real tractor speed.

The control criteria presented in this paper enable the automatic control of switching on/off the front axle drive, independently on the tiers size and pressure. It gives an improvement of the tractor traction parameters by a proper use of the front axle drive. It results in an increase of the tractor's speed and the decrease of the rear wheels' slip.

Based on the simulation results and their analyses, the assertion can be settled that the front axle drive should be switched on when the propelling force of front wheels has the same sense as the propelling force of rear wheels, which means a positive value during propelling and a negative value during braking

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