AN ANALYSIS OF POWER FLOWING THROUGH THE WHEEL OF A RUNNING VEHICLE

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INTRODUCTION

The most frequently used tractors in agriculture are wheeled tractors. At present the majority of wheeled tractors are manufactured with a four-wheel drive.

Wheels in agricultural tractors constitute the bearing elements and in many cases the only springing elements. They also serve to maintain and change a driving direction. The function of the wheels, besides the above mentioned one, are delivering the power from the power transmission system to the ground during the driving of the vehicle and receiving the power from the ground and transferring it to the brakes or to the power transmission system [6] during braking. During this process the power losses occur [2, 3], that arise from the overcoming of the rolling resistance, and slipping of the operating wheels [1]. Moreover, during the transient rotational movement of the wheel, the same part of the power delivered to it can be lost or recovered. In order to optimally utilise the propelling force of the wheel, a power balance should be made and analysed for a wheel in different movement cases occurring during the tractor operation.

BALANCE OF THE WHEEL POWER

In Fig. 1. the force and moment systems acting on the wheel which drive the vehicle in its rectilinear movement are shown.

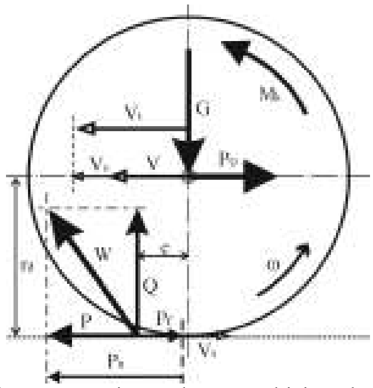

Fig. 1. Arrangement of forces and moments acting on the tractor driving wheel: G – a normal component of the force acting on the wheel axis, P_0 – a horizontal component of the force acting on the wheel axis, Q – a normal component of the ground reaction on the wheel axis, P – a driving force (a horizontal component of the ground reaction on the wheel axis, P_n – a driving force, P_f – the resistance force of the wheel rolling, M_k – the moment applied to the wheel, ω – the angular velocity the of wheel, V_t – the theoretical speed of the wheel, V – the real speed of the wheel, V_s – the slip velocity of the wheel, r_d – the dynamic radius of the wheel, e – the shift of the normal component of the ground reaction on the wheel

The values presented in Fig. 1 are defined by the following relationships:

$$P_n = \frac{M_k}{r_d} - J_k \frac{d\omega}{dt} \tag{1}$$

$$P = m \cdot \frac{dV}{dt} + P_u \tag{2}$$

$$V_t = r_d\,\omega = V + V_s \tag{3}$$

$$s = 1 - \frac{V}{V_t} \tag{4}$$

where:

P_u – pull force of the wheel,
J_k – mass moment of the wheel inertia relative to its rotation axis,
m – wheel mass,
s – wheel slipping.

Power balance for the wheel can be made by the multiplication of the equilibrium equation of acting forces in the direction parallel to the ground, on which the wheel is moving, with a theoretical speed. The balance is represented as follows:

$$M_k\omega - J_k \frac{d}{dt}\left(\frac{V_t^2}{2}\right) - P_f V_t - P V_s - m\frac{d}{dt}\left(\frac{V^2}{2}\right) - P_u V = 0 \tag{5}$$

or:

$$N_k + N_j + N_f + N_s + N_b + N_u = 0 \tag{6}$$

where:

N_k – power delivered from the power transmission system to the wheel,
N_j – power used on acceleration or delay of the wheel in its rotational movemen,
N_f – power wasted on the overcoming of the wheel rolling resistance,
N_s – power wasted as a result of the wheel slipping,
N_b – power as a result of the transient movement of the wheel in a translatory motion,
N_u – drawbar horse power,

where:

$$N_n = P_n V_t \tag{7}$$

$$N_{p^{\cdot}} = PV \tag{8}$$

N_n – driving power of the wheel,
$N_{p^{\cdot}}$ – propelling power of the wheel.

During the vehicle movement, its wheels – dependent on the values and senses of the applied turning moments as well as the values and senses of forces – can move with the slipping within the limits $-\infty \leq s \leq 1$.

TRACTION RESEARCHES

In order to determine the particular power components values and their senses of flowing through the wheel depending on the wheel's slipping value, the traction research in natural conditions using an adequately equipped tractor was carried out. For the determination of the particular power components during the test passages the following measurements were made:

- driving moment applied to the wheel M_{kp},
- pull force of the tractor P_u,
- angular velocity of wheel ω,
- real speed of the wheel V.

The turning moment M_{kp} was measured by strain gauges located on the semi-axes of the driving wheels in such a way that, independently of the load of the wheels, the stain gauges responded to the torsional moment only.

Pull force P_u was measured directly with an HMB type U9B force transducer. It was mounted on the tractor in such a way that the value of the force P_u did not influence the normal components of the ground reactions on the tractor wheels.

Angular velocities of the wheels ω were determined by induction gauges. For this purpose special toothed disks were mounted on the wheel hubs. The real speed of the wheel V was measured with a DICKEY-JOHN Doppler radar.

All these gauges were connected to HMB transducers type Spider 8, and the measured values were registered in the real time by a Panasonic portable computer type J27.

The values of effective rolling perimeters of the wheels and rolling resistance forces of the rear wheels [4] P_{ft} and the front wheels P_{fp} were determined basing on the preliminary tests.

In order to obtain the changes of the propelling force from a negative to positive value, the tractor under study at first braked a pulling vehicle with a progressively decreasing brake force up to the zero value ($P_u \leq 0$), then it made the driving wheels work at negative slipping. In the final phase of the passing the braking force value was zero and the driving wheels of the tractor overcame the resistance force of its own movements only, working with a positive slipping.

In order to increase further a driving wheel slipping the next passage was made with an increased load of the tested tractor by the force $P_u \geq 0$, beginning from a value $P_u = 0$. Exemplary courses of measured values during the passages are shown in Fig. 2-5.

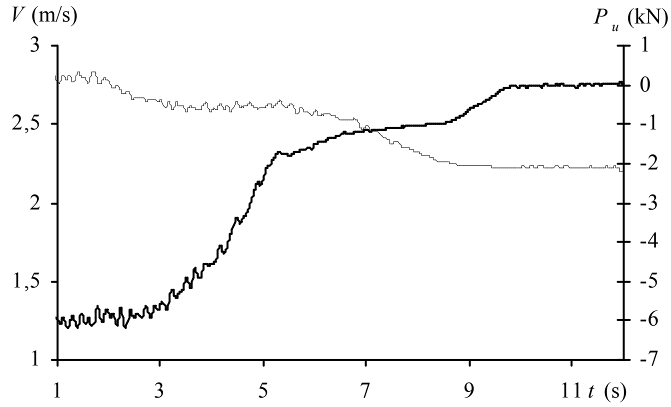

Fig. 2. The course of force P_u and real speed V during the force P_u increase from negative to zero value

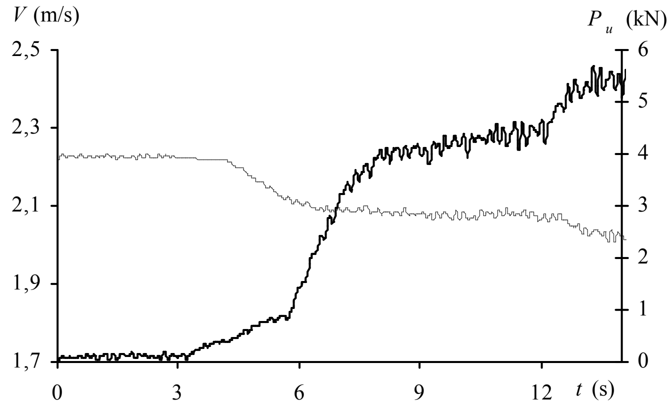

Fig. 3. The changes of force P_u and real speed V during the force P_u increase above zero value

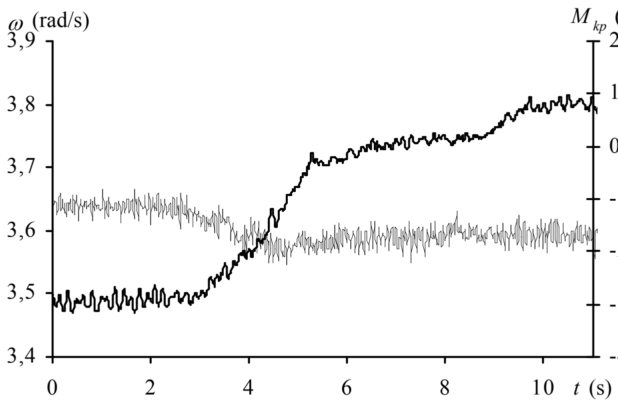

Fig. 4. The course of moment M_{kp} and angular velocity of the wheel ω during the force P_u increase from negative to zero value

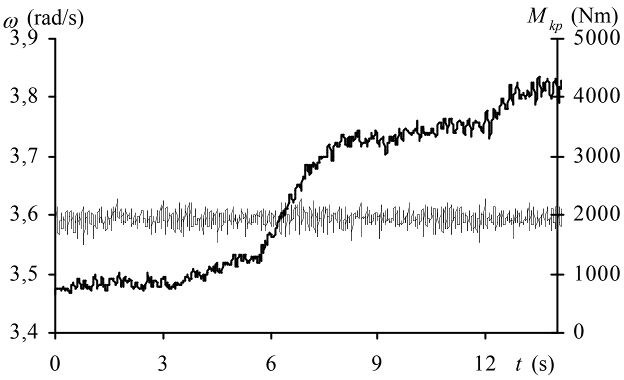

Fig. 5. The course of moment M_{kp} and angular velocity of the wheel ω during the force P_u increase above zero value

The presented courses showed that the tractor's speed changed slowly, and the angular velocity of the wheels had an almost constant value. Therefore these forces and moments of inertia were so small that they could be neglected in the further analysis.

EXPERIMENT RESULTS

Basing on the registered values, the courses of the force P_u, moment M_k, real speed V, and angular velocity of the wheel ω, the following courses of the driving wheel power have been determined:

- N_n – driving power of the wheel
- N_p – propeller power of the wheel,
- N_s – power lost as a result of the wheel slip.

The value of the lost power as a result of rolling resistance of the wheels was practically a constant value, because passages were carried out on homogeneous ground and the wheel loads (thrusts) did not change.

The powers determined during braking and driving of the tractor wheels were compiled in separated courses for particular powers (Fig. 6 and 7).

During the braking of the wheel, the propelling power N_{p}. is delivered from the ground to that wheel. Part of that power N_s is lost as a result of wheel slip and part N_f is used for overcoming the rolling resistance of the wheel. The rest of the power N_n is received from the wheel either by the brake or by the power transmission system. During the force increase P_u from a negative value to zero, the propelling force increase occurred P (in Fig. 6 and 7, courses on left side of the vertical marker). When the force P_u overcomes the rolling resistance force of the tractor wheel, the driving force $P_n = 0$, driving moment $M_n = 0$, the driving power $N_n = 0$.

The N_s power is smaller than zero. If the force P achieved the value of zero, the force P_u would overcome the rolling resistance force of the front wheels only. In this situation the power: N_{p}. = 0 and $N_s = 0$, also the power $N_n > 0$ respectively. Towards that, at further increasing the force P_u (it approaches the zero value), the tractor will able to move, the force P must change its character and take positive values.

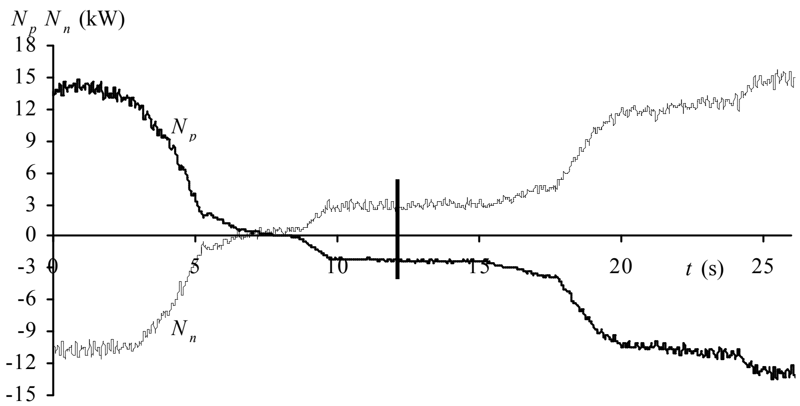

Fig. 6. The course of powers N_p and N_n during the increase of the force P from negative to positive values

When the force $P_u = 0$, the propelling force P overcomes the rolling resistance force of the front wheels, the wheel receives the driving power: N_n from the power transmission system and transmits it at losses resulting from the rolling resistance of the wheel N_f and the wheel slip N_s to the ground as the power N_p. A further increase of the pulling force P_u is possible because of the increase of the propelling force P as a result of the driving force P_n, and is connected with the increase of the driving moment acting on the wheel.

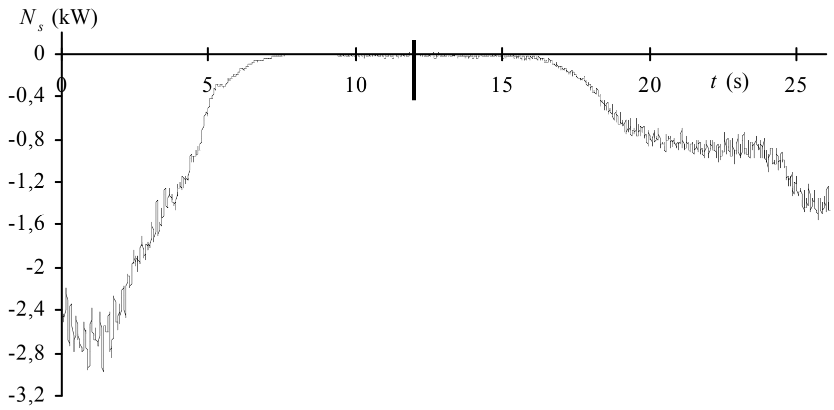

Fig. 7. The course of lost power as a result of wheel slip N_s during the increase of the force P from negative to positive values

During a tractor's running its driving wheel may work in the considered range of the loads. Therefore the carried out analysis of the power flows is significant considering the traction problems of a tractor [5, 7, 8].

SUMMARY

Considering the carried out researches and the analysis of the obtained results the following conclusions have been drawn:

1. The research procedure allows to determinate in a continuously way the changes of particular power streams and the senses of its flow in the range of driving moment changes from negative to positive values.

2. The courses obtained during the study for particular power streams confirm the theoretical considerations on the courses of power values of the wheel at its different loads.

3. The determination of the power flow through the wheel is particularly useful for an analysis of traction problems of the vehicles with four-wheel drive as well as automatic control problem of switching on and off the drive of the four wheels and interlocking of differential mechanisms.

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SUMMARY

Determination of the optimal traction performance of a tractor is possible basing on the analysis of the wheel power balance for different cases of the tractor’s movements during its operation.

In order to determine the values of particular power components and senses of its flow through the wheel, the traction research in natural conditions was carried out on the appropriately equipped tractor, which was being loaded by the pulling force changing from the negative to positives values. During the runs the courses of the appropriate values of speeds, forces and torques have been registered.

The determination of the power flows through the wheel is particularly useful for traction problem analyses considering vehicles with a four-wheel drive and the problem of automatic control of the switching on all the wheels as well as the interlocking of differential mechanisms.

The problem presented above is a fragment of a bigger complex topic in the scope of KBN (State Committee for Scientific Research, in Poland) research project no. 7T07C 02514 being just in elaboration, entitled: “Modelling and Automation of the Working Processes of Computer Controlled Tractor/Implement Systems”.