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THE INFLUENCE OF A FOUR WHEEL DRIVE OF A WORKING MACHINE ON SOME OF ITS TRACTION PROPERTIES

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1. SUMMARY

This paper presents the results of theoretical analysis of all-wheel drive kinematic discrepancy influence on drawbar pull for wheeled working machines. The research project was undertaken to verify and confirm theoretical solutions. Presented analysis shows possibilities for improvement of wheeled machines in dynamic and energetic as well as exploitational way (e.g. lowering of tires wearing).

2. INTRODUCTION

To obtain for the machine the maximum possible drawbar pull (or thrust force for bucket, as for loaders) a four-wheel drive systems are adopted. However, because of constructional solutions (like difference in wheel diameter for front and rear axle), exploitational factors (difference in tire wear, tire pressure) and load of the machine during operation, the dynamic radius can vary for each wheel. For a vehicle with full-time four-wheels drive system not equipped with centre differential between driving axles, each wheel has different peripheral speed on its dynamic radius and operate with different slippage.

To determine the influence of this effect on the vehicle drawbar force the theoretical analysis was performed [4, 6] and then preliminary field tests were carried out for the machine with different peripheral speeds on dynamic radii for front and rear axle wheels (vehicle with two driving axles).

3. AN INFLUENCE OF KINEMATIC DISCREPANCY OF FOUR-WHEEL DRIVE ON EFFECTIVE DRAWBAR PULL

Proportion of peripheral speed of front wheels V_{op} (measured on dynamic radius) to peripheral speed of rear wheels V_{ot} is called kinematic discrepancy k [2]:

$$k = \frac{V_{op}}{V_{ot}} = \frac{1 - s_t}{1 - s_p} \qquad (1)$$

where: s_p - rear wheels slippage
s_t - front wheels slippage

$$s_t = 1 - \frac{V}{V_{ot}} \tag{2}$$

$$s_p = 1 - \frac{V}{V_{op}} \tag{3}$$

where: V - actual vehicle speed

As it was already mentioned, operation with different speeds V_{op} and V_{ot} results in difference in wheel slippage for front and rear axle which in turn results in different utilisation of tractive adhesion coefficient μ

With respect to above, driving forces for front and rear axle wheels are as follows:

$$P_{np} = Q_p \mu_p \tag{4}$$

$$P_{nt} = Q_t \mu_t \tag{5}$$

where: Q_p, Q_t - normal reaction soil to front and rear wheel

μ_p, μ_t - coefficient of tractive adhesion for front and rear wheel, depending on velocities: V_{op}, V_{ot}, V.

Driving forces for front P_p and rear P_t wheel:

$$P_p = P_{np} - P_{fp} \tag{6}$$

$$P_t = P_{nt} - P_{ft} \tag{7}$$

where: P_{fp}, P_{ft} - rolling resistance for front, rear wheel

and:

$$P_{fp} = Q_p f_p \tag{8}$$

$$P_{ft} = Q_t f_t \tag{9}$$

where: f_p, f_t - coefficient of rolling resistance for front and rear wheel

When vehicle wheels are moving (within considered period of time) on a surface with unknown structure and all have identical tires, it can be assumed [1, 3, 5] that:

$$f_p \approx f_t = f \tag{10}$$

and $s_p = \varphi(\mu_p)$ and $s_t = \varphi(\mu_t)$ are equal.

Considering stationary movement on horizontal ground, disregarding air resistance (low vehicle speed), drawbar pull is as follows:

$$P_u = P_p + P_t = Q_p \mu_p + Q_t \mu_t - fQ \tag{11}$$

$$Q = Q_p + Q_t \tag{12}$$

Knowing vehicle wheel base, distance from centre of gravity to wheel axle in vehicle longitudinal plane, co-ordinates of external pulling force application point, dynamic radii of front and rear wheels, vehicle weight, drawbar pull (its components) and coefficient k, it is possible to calculate forces Q_p and Q_t, coefficients μ_p, μ_t, s_p, s_t and forces P_{np}, P_{nt}, P_p, P_t [4, 6].

For the machine with identical tires:

$$k = \frac{V_{op}}{V_{ot}} = \frac{r_{dp}\,\omega_{kp}}{r_{dt}\,\omega_{kt}} = \frac{r_{dp}}{r_{dt}} \tag{13}$$

because $\omega_{kp} = \omega_{kt}$;

where ω_{kp}, ω_{kt} - angular speeds of front, rear axle wheels

Fig. 1-3 presents results of theoretical analysis of variation of above described forces for coefficients: $k < 1$; $k = 1$; $k > 1$ versus force P_u, with assumption that ground surface normal component is zero and force $Q_t > Q_p$ with $P_u = 0$ [4].

The separate case when the only drive wheels are rear wheels (index "2") and front wheel driving is discontinued, was also taken into account.

Based on the respective forces variation courses it could be seen that if $P_u = 0$, then with $k<1$ front wheels and with $k>1$ rear wheels are braking vehicle. Only when force P_u has increased up to a certain level, wheels stop braking the machine and with further increase, start driving the vehicle.

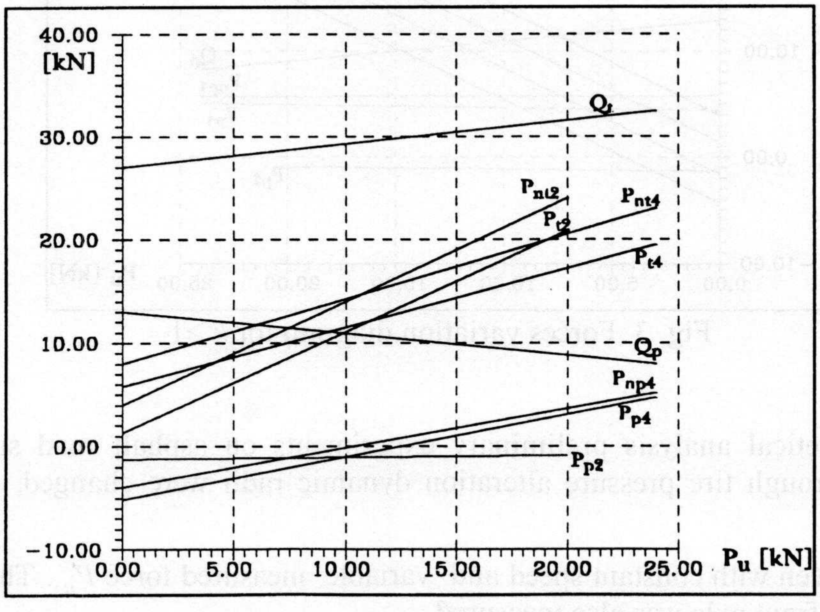

Fig. 1. Forces variation diagram for $k < 1$

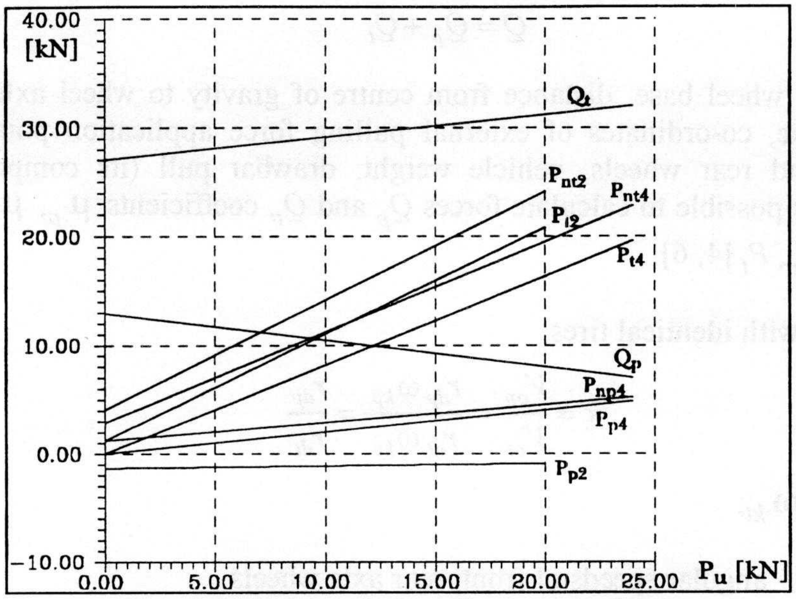

Fig. 2. Forces variation diagram for *k* =1

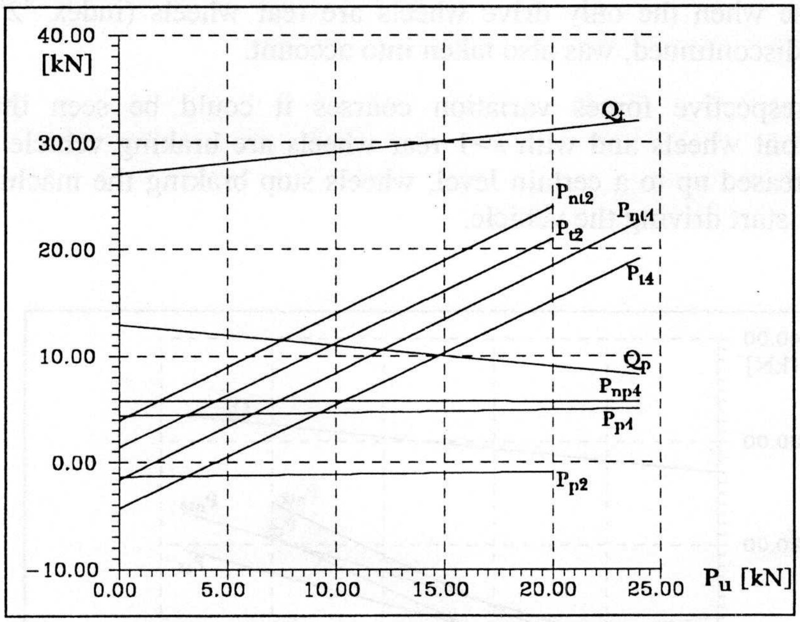

Fig. 3. Forces variation diagram for *k* >1

To verify theoretical analysis preliminary experiments on asphalt road surface were carried out. Through tire pressure alteration dynamic radii were changed, giving $k<1$ and $k>1$.

Vehicle was driven with constant speed and variable, measured force P_u . The torque on driving shaft of front axle was also measured.

The results obtained from field experiments confirmed previously performed theoretical analysis. Figures 4-10 present force P_u and torque M_p versus time for cases:

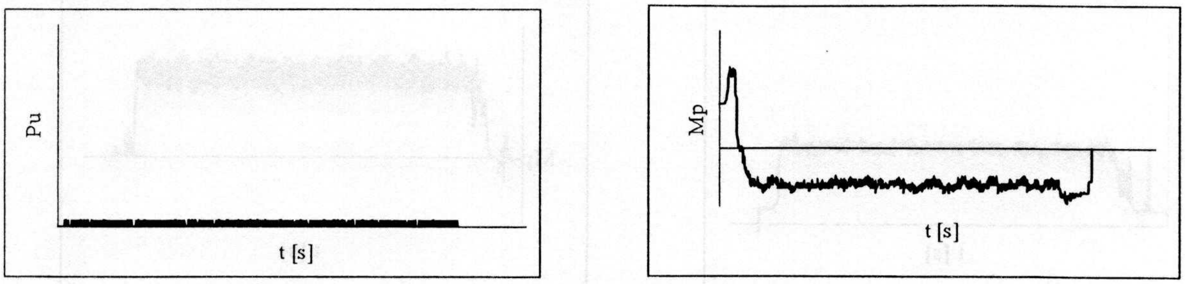

Fig. 4. $k < 1$; $P_{u4} = 0$; $M_p < 0$

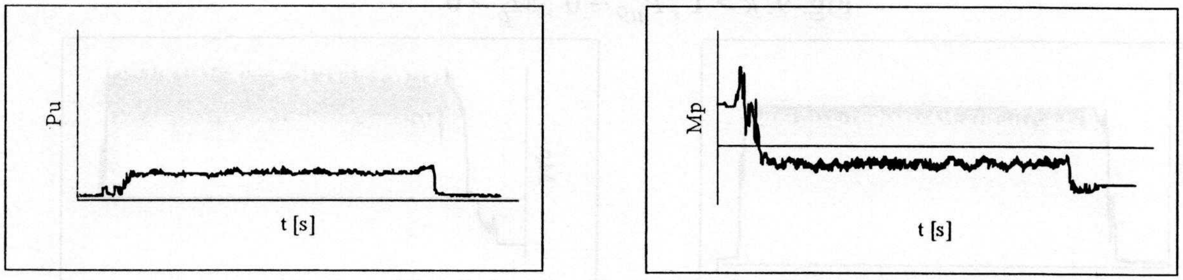

Fig. 5. $k < 1$; $P_{u5} > 0$; $M_p < 0$

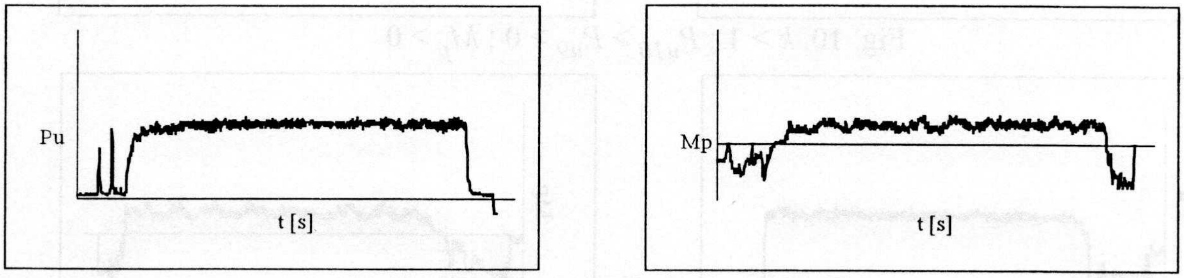

Fig. 6. $k < 1$; $P_{u6} > P_{u5} > 0$; $M_p > 0$

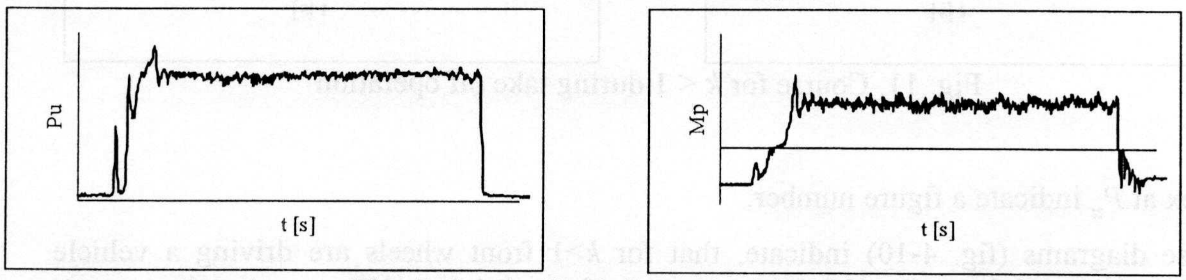

Fig. 7. $k < 1$; $P_{u7} > P_{u6} > 0$; $M_p > 0$

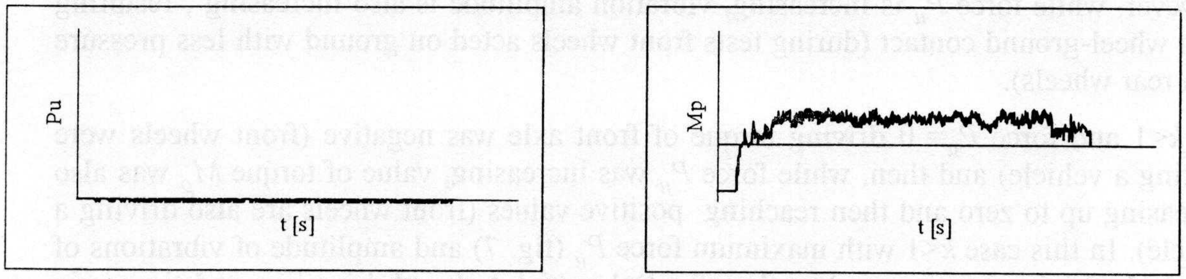

Fig. 8. $k > 1$; $P_{u8} = 0$; $M_p > 0$

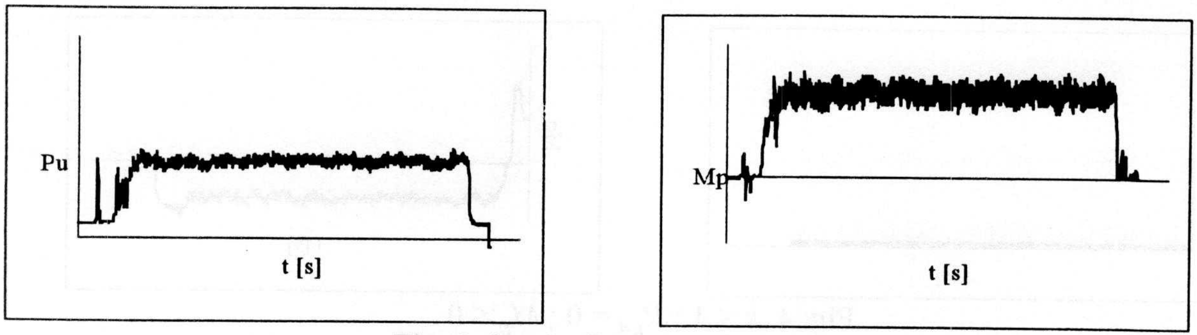

Fig. 9. $k > 1$; $P_{u9} = 0$; $M_p > 0$

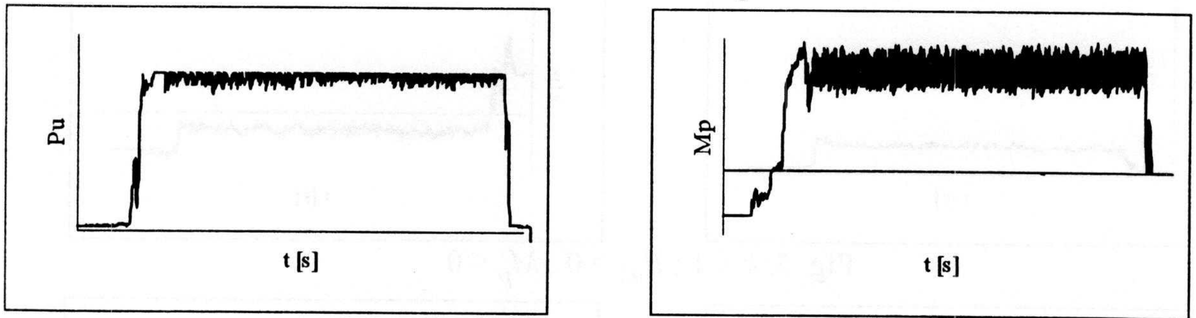

Fig. 10. $k > 1$; $P_{u10} > P_{u9} > 0$; $M_p > 0$

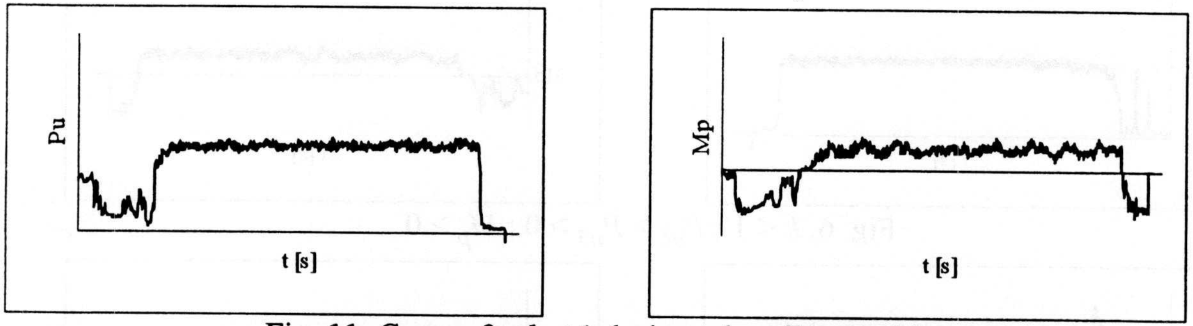

Fig. 11. Course for $k < 1$ during take off operation

Index at P_u indicate a figure number.

These diagrams (fig. 4-10) indicate, that for $k>1$ front wheels are driving a vehicle irrespectively of force P_u (driving torque on front axle is always grater than zero). However, while force P_u is increasing, vibration amplitude is also increasing , resulting from wheel-ground contact (during tests front wheels acted on ground with less pressure than rear wheels).

For $k<1$ and force $P_u = 0$ driving torque of front axle was negative (front wheels were braking a vehicle) and then, while force P_u was increasing, value of torque M_p was also increasing up to zero and then reaching positive values (front wheels are also driving a vehicle). In this case $k<1$ with maximum force P_u (fig. 7) and amplitude of vibrations of front axle driving torque was less than for $k>1$, which reduced drive line and tire wear. Fig. 11 presents courses during take-off for $k<1$.

For courses of P_u and M_p (fig. 11.) just as on figures 4-10 it could be seen that at very first moment, when value of drawbar pull P_u starts increasing, value of torque M_p is negative (front wheels are braking vehicle). Next, together with drawbar pull increase, it reaches zero and then becomes positive and stabilises together with force P_u (front wheels are also driving a vehicle).

Initial record shows the conversion of torque M_p value from negative to positive and is the result of initial back drive of vehicle with force $P_u = 0$ which in turn resulted in front to rear axle preload with positive torque.

After starting to drive forward value of M_p decreased to negative value and it then increased to positive values only because of drawbar pull increase.

Presented tests results show only characteristic rules of the matter and allow for determining an influence of four-wheel drive system on vehicle operation and determining ways of possible driving axles engaging control.

Presented results of theoretical analysis verified in experiments allows for formulating conclusions as follows:

3. CONCLUSIONS

1. For $k \neq 1$ engaging of front axle should takes place after achieving by vehicle appropriately high drawbar force P_u for which front wheels ($k<1$) or rear wheels ($k>1$) are not braking a vehicle.
2. While driving with $k \neq 1$ circulating power appears in drive line. Circulating power to input power ratio is highest for $P_u=0$.
3. Considering the drawbar pull force acting on a vehicle, the transmission ratio between driving axles should be matched to let the kinematic discrepancy coefficient reach the value close to 1 while machine reaches the rated drawbar force. This assures operation of wheels with equal slippage and tractive adhesion factor μ which assures full load utilisation for all vehicle wheels.
4. In consideration of driving torque vibration amplitude and consequently drive line and tire wear with front wheels acting on the ground with less pressure than rear wheels, coefficient k should be grater than 1, and when rear wheel load is grater - coefficient k should be less than 1.

4. REFERENCES

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