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How driving wheels of front-loaded tractor interact with the terrain depending on tire pressures

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Abstract

This paper analyzes peculiarities of wheel interaction with the terrain for 4WD tractors working with front-mounted loaders. When tractor wheels are loaded by a vertical forces that do not correspond to the specified proportions, deformations of front and rear tires also do not correspond to the specified proportions, and this leads to a kinematic discrepancy because of change in ratio between driving wheels' rolling radiuses. In case of kinematic discrepancy, wheel slip/skid is taking place. In the paper test results are presented, how driving wheels' slip/skid of 4WD tractors with front-mounted loaders depend on the vertical loads acting on the wheels and their tire inflation pressures. It was determined that there are dependences on relation between front and rear tire pressures, which allow avoiding wheel slip/skid for the 4WD tractor with front-mounted loader that runs without a load and transports loads. By preparing a tractor for work with front-mounted loader, it is advisable for operator to select a set of tires that would ensure the lead of front wheels lesser compared to the lead that is commonly used for traction works. In this case, the operator creates conditions for wheels' interaction with the terrain without slip/skid at higher inflation pressures in the front tires.

Keywords: Tractor; Front-mounted loader; Driving wheel; Slip/skid; Tire pressure; Wheel load

1. Introduction

The tractors are mainly designed to provide draft and PTO (power take off) power for the agriculture implements. Having in mind specifics of tractor work and nature of the load, the works can be divided into groups: works in the fields with the tractor loaded by heavy traction force (tilling, cultivation, seeding, etc.); works in the fields with the tractor loaded by light traction force from the pulled implements and PTO power for the rotary implements (harvesting, haymaking, pressing, etc.); works at higher speeds when conditions for the grip are sufficient (transport works) and works when the tractor is loaded by high vertical loads (e.g., works with front-mounted loader, etc.). Each of these applications can result in large, disproportionate axle/wheel loads when weight is transferred from mounted implements or unbalanced trailers [1–3]. Analysis results show that for a tractor, working with front-mounted loader, vertical loads of front and rear wheels can vary in a very large range. Disproportion between vertical loads of front and rear wheels is significantly higher, compared to a disproportion when the tractor is used for the other works; in addition to that, when a tractor is operating with front-mounted loader, disproportion between vertical loads of front and rear wheels varies in a wider range and changes occur in sudden steps [1,4]. Another major difference is that when a tractor works with a front-mounted loader, it is not affected by pulling forces.

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Nomenclature

4WD	four-wheel drive
PTO	power take off
β	longitudinal inclination angle of the tractor caused by tire deformation (disproportionate) (°)
δ	slip/skid coefficients
δ^f	slip/skid of front driving wheels (%)
δ^r	slip/skid of rear driving wheels (%)
G	weight forces of tractor with loader (N)
G_b	weight forces of the ballast (N)
G_l	weight forces of load (N)
m	mass (kg)
L	tractor wheelbase (m)
p_f	inflation pressure of front tires (kPa)
p_r	inflation pressure of rear tires (kPa)
r	radius (m)
r_d	dynamic radius of wheel (m)
r_d^f	dynamic radiuses of front wheel (m)
r_d^r	dynamic radiuses of rear wheel (m)
Δr_d^f	deformations of front wheel tires (m)
Δr_d^r	deformations of rear wheel tires (m)
s_{th}^f	theoretical distances of front wheels' travel during 10 revolutions (m)
s_{th}^r	theoretical distances of rear wheels' travel during 10 revolutions (m)
s_a^f	actual distances of front wheels' travel during 10 revolutions in 4WD condition (m)
s_a^r	actual distances of rear wheels' travel during 10 revolutions in 4WD condition (m)
v	actual speed (m s^{-1})
v_ω	wheel speed (m s^{-1})
v_t^f	theoretical speeds of front wheels (m s^{-1})
v_t^r	theoretical speeds of rear wheels (m s^{-1})
ω	angular velocity (s^{-1})
ω^f	angular velocity of the front wheels (s^{-1})
ω^r	angular velocity of the rear wheels (s^{-1})
z_p	lead ratio of front driving wheels
h, l; h_l, l_l; h_b, l_b	position coordinates of weight forces of tractor, loader with load and the ballast (m)

It is known that if the tractor is not loaded by a pulling force, the slip of the driving wheels is close to zero [1–3].

Four wheel drive tractors are characterized as tractors with both their axles driving. Tractors with all-wheel drive perform better in field work, especially when working in loose, wet, saturated soils, as they have better terrain crossing capacity; however, on the dry and hard terrain or a road, a lot of their energy is wasted to drive the second (front) axle [5–8]. Although in the tractor manuals it is specified to avoid usage of 4WD on the roads, specifics of works sometimes force to use 4WD even when conditions of wheels' grip with the terrain are good enough. Such situations often occur when the tractor is combined with the front-mounted loader and is carrying loads on it. When load is carried in such a way, the front wheels – that are loaded much more – are more resistive to movement, and the rear driving wheels – that are exposed to a small vertical load – slip considerably. In such cases, 4WD drive (a front wheel assist tractor) is very helpful [2,9,10].

Most multi-purpose 4WD tractors are manufactured in such a way that in static conditions rear wheels would be loaded by 55–65% of the total weight of the tractor [2,3,5,11]. Tractor researchers recommend maintaining this proportion of vertical wheel loads in working conditions as well [12,13]. If it is difficult to maintain this proportion between vertical loads of front and rear wheels exactly, it should not deviate from recommended proportion more than 10% [2,3,12,14]. When multi-purpose 4WD tractor is combined with front-mounted loader, it is often impossible to maintain such wheel loads during operation. When front-mounted loader lifts the load, it increases the vertical load of front wheels and reduces the load of rear wheels. Tires of more loaded (front) wheels become more deformed and more resistive to movement (or rolling) [15–17]. When carrying the load, especially under field conditions, it often results in the lack of grip of rear driving wheels with the ground. Their slip exceeds the allowable limit of 15% [9,18,19]. Slip is reduced and sufficient terrain crossing capacity is achieved by activating the second, i.e., the front driving axle. When driving without a load, vertical load of front wheels decreases, while the load of rear wheels increases. In this case, rear tires are subject to more deformation. Thus, when a tractor is working with a front-mounted loader, front and rear tires deform variably and disproportionately, because the wheels are loaded by variable, disproportionate vertical loads [4,20]. When tires are deformed, wheel radiuses and theoretical rolling speeds are changed [2,14,21,22].

Tire radiuses have to be matched so that the ratio of the front and rear axle speeds produces the correct ground speeds. Because the front wheels are smaller, they have to roll more quickly than the rear wheels to give approximately the same ground speed for both tires. This speed difference is even higher because of the fact that the front wheels usually turn slightly faster compared to the speed value that would give exactly the same ground speed as the rear tires. The transmission has a front axle lead ratio (z_p), defined by [3]: