INTERACTION BETWEEN DRIVING WHEEL AND ROAD SURFACE OF ALL WHEELED DRIVEN TRACTOR

Vaclovas Kurkauskas, Algirdas Janulevicius, Gediminas Pupinis, Vidas Damanauskas
Aleksandras Stulginskis University, Lithuania
vaclovas.kurkauskas@gmail.com, algirdas.janulevicius@asu.lt,
gediminas.pupinis@asu.lt, damvid@gmail.com

Abstract. Interaction between the tires of a 4x4 wheeled driven tractor and the road surface, the influence on the slippage of the vertical load of the wheels and air pressure of the tires, the theoretical speed of the front and rear wheels and their influence on interaction between the surface of the road are analyzed in this article. The driving torque of the 4x4 wheeled drive tractor has been distributed in proportion to the friction coefficient between the wheel-road surface and the distribution of the vertical load and dynamic radius of the wheel. The results of the experimental investigation on the interaction between the road surface, vertical load and the air pressure in the tires of the 4x4 wheeled drive tractor which is operating with the front loader are presented. The optional air pressures are found in the front and rear tires of the 4x4 wheeled driven tractor, which is operating with the front loader.

Keywords: tractor, driving wheels, slippage, slid, air pressure in the tires, the vertical load of the wheel, front loader.

Introduction

There are all driving wheels in the tractor (4x4). Tractors with all driving wheels are more advantaged in the work on the fields, damp and light soils, because they are more terraining. However, in dry and hard road surfaces a lot of energy is wasting in the front driving axle [1; 2].

Wheeled tractors are used for a whole year in agriculture. There are three groups of operation modes of the tractor by specification of work: work on the fields, when tractor is loaded by a big tractive force (plugging cultivation, sowing etc.); work at a big friction efficiency in high speed (work of transport); work with the tractor when the driving wheels are loaded unproportionally on the driving axles (work with front loader etc.) [3; 4].

Most of the tractors with 4x4 driving wheels are made that they would have 55-60 % of the total tractor weight on the rear axle in the static state. To keep these proportions in the exploitation period is recommended. To keep the vertical loads of the driving axles should not deviate more than 10 % if it impossible. The main condition is that the load of the front driving axle is not less than 20 % of the total weight of the tractor to keep good handling and safety during exploitation [5; 6].

The driving wheels of the tractor in all cases slip, when the tractor is loaded on tractive force. In this case, the factual speed v_f is less than the theoretical speed v_t of the tractor. These loses are evaluated by slippage δ, % [7; 8].

The ways to reduce slippage are: usage wider or dual wheels, to force the driving wheels to the road surface. The contact area of the wheel–road surface and the tractive force increases by 20 % by decreasing air pressure in the tires [9]. The tractive force of the tractor increases by increasing the air pressure in the tires only in damp and light soils, because the wheels sink less into the soil. When the air pressure in the tires is enough high, the wheel in the soil sinks more [1; 2; 10]. 10 cm depth of the rut is according to 10 % hillside [10].

The exploitation period of the tire, economical effect, and tractive force of the tractor depend on the air pressure in the tires. The air pressure in the tires must be increased on the road. The air pressure in the tires must be about 1.4-1.6 bar on the road in higher speed [11].

It was found that correct air pressure in the tires reduces the power loses in association with the tire and road surface contact area. In this case the controlled air pressure in the tires is increasing the friction between the tire road surface. As a result of it – increased driving force of the wheel of the vehicle [1; 2]. The contact area of the front and rear wheels can be increased or decreased twice by varying the air pressure in the tires [11]. However, the driving radius of the wheel and theoretical speed of the axis change by changing the air pressure in the tire. Although, the factual speed of the driving axles is equal to the tractor speed, because the driving axles of the tractor are connected with the tractor steadily. In this case the driving wheels of the tractor during exploitation with 4x4 driving wheels slip differently [7; 12]. This problem is actually for tractors, which work with the front loader wit 4x4 driving wheels.

The driving axis is called rushing, the theoretical speed of which is higher and lagging, if the speed is lower. The driving wheels of the rushing driving axle slip more than the wheels of the lagging driving axle. Also the wheels can slid of the lagging axle. The worst situation is when the wheels slid of the lagging driving axle, because this axle has not driving force and also resists to the motion of the tractor [7; 12; 13].

The aim of the research: to investigate the dependences between the interaction of the driving wheels with the road surface, air pressure in the tires and vertical load of the tractor.

Theoretical analyses

Mostly, the vertical loads of the driving axles of the tractor are different. In this case the driving moments of these axles are dissipated unproportionally. For example, the tractor with the front loader works in the horizontal area in stable speed (Fig. 1).

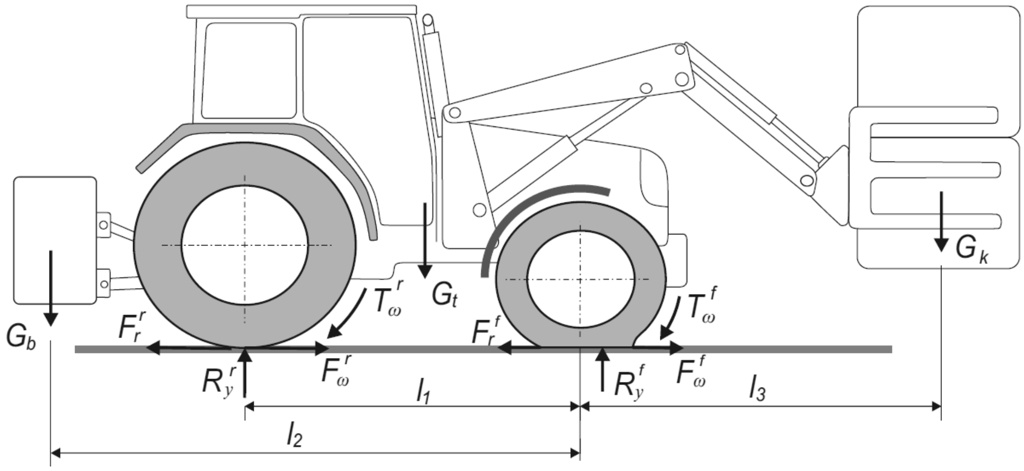

Fig. 1. **Free body diagram of tractor with 4x4 driving wheels with front loader:** G_t – gravitation force of the tractor; G_b – gravitation force of the ballast; G_k – gravitation force of the cargo; T_ω^f and T_ω^r – driving torque of the front and rear driving wheels, R_y^f and R_y^r – vertical loads of the front and rear driving wheels, F_f^f and F_f^r – rolling resistance force of the front and rear driving wheels; F_ω^f and F_ω^r – driving force of the front and rear driving wheels; l_1 – wheelbase of the tractor, l_2 – distance between the center of the ballast and rear axle; l_3 – distance between the center of cargo and rear axle

The gearbox transfers the torque to the driveline system. The driving torques of the front and rear wheels are T_ω^f and T_ω^r, which generates the driving forces F_ω^f and F_ω^r. These driving forces are equal to the rolling resistance forces of the wheels F_f^f and F_f^r [2; 4]. The balance of the forces is:

$$F_\omega^f + F_\omega^r = F_r^f + F_r^r \tag{1}$$

The driving force can be calculated by equation: $F_\omega = M_e i_{tr} \eta_{tr} / r_d$. In this case, the balance of the forces is:

$$T_e \left(\frac{i_{tr}^f \eta_{tr}^f}{r_d^f} + \frac{i_{tr}^r \eta_{tr}^r}{r_d^r} \right) = F_r^f + F_r^r \tag{2}$$

where T_e – torque of the engine;
i_{tr}^f and i_{tr}^r – gear ratios of the front and rear driving wheels
η_{tr}^f and i_{tr}^r – efficiency of transmission of the front and rear wheels;
r_d^f and r_d^r – dynamic radius of the front and rear wheels.

Maximal driving forces of the front and rear driveline systems depend on the friction between the tire and the road surface. The friction between the tire and the road surface depends on the vertical reactions of the front and rear driving axles R_y^f and R_y^r [7; 8; 12; 13]. Maximal torque of the front and rear driving axles is calculated considering the maximal driving forces of the wheels by these equations:

$$T_{\omega}^{f} = F_{\omega}^{f} r_{d}^{f} = \varphi^{f} R_{y}^{f} r_{d}^{f} \tag{3}$$

$$T_{\omega}^{r} = F_{\omega}^{r} r_{d}^{r} = \varphi^{r} R_{y}^{r} r_{d}^{r} \tag{4}$$

where φ^f and φ^r – friction coefficient between the tire and the road surface.

The proportion of driving moments:

$$\frac{T_{\omega}^{f}}{T_{\omega}^{r}} = \frac{\varphi^{f} R_{y}^{f} r_{d}^{f}}{\varphi^{r} R_{y}^{r} r_{d}^{r}} \tag{5}$$

Equation 5 shows, that the driving torque must be dissipated to the front and rear driving axles in proportion to the friction coefficient between the tires and the road surface, vertical reactions of the front and rear driving axles and the driving radius of the front and rear wheels of the tractor. In this case the slippage of the driving wheels will be equal and the whole total weight of the tractor to the friction between the tire and the road surface will be used, too. However, the driving torque is dissipated to the driving axles considering the rolling resistance of the driving wheels [7; 14].

The vertical load of the driving axles distributes unproportionally of the tractor with the front loader and the tires of the front and rear axle deform differently. As a result of it, there are different theoretical speeds of the front and rear driving axles. When the theoretical speeds of the driving axles are different and the factual speeds of the driving axles are equal, if the slippage of the front and rear wheels are different:

$$v_{f} = v_{t}^{f}\left(1 - \delta^{f}\right) = v_{t}^{r}\left(1 - \delta^{r}\right) \tag{6}$$

where v_f – factual speed of the driving axle;
$v_t^{\,f}$ and $v_t^{\,r}$ – theoretical speeds of the front and rear axles;
δ^f and δ^r – slippage of the front and rear wheels.

It is known that the theoretical speed of the driving axle is equal: $v_t = r_d^f \omega^f$ or $v_t = r_d^f \omega^f$. Equation 6 can be written:

$$v_{f} = r_{d}^{f} \omega^{f}\left(1 - \delta^{f}\right) = r_{d}^{r} \omega^{r}\left(1 - \delta^{r}\right) \tag{7}$$

where ω^f and ω^r – angular velocity of the front and rear wheels.

Equation 7 shows that driving with the tractor with “4x4“ driving wheels, the wheels do not slip/slid, when the ratio between the driving radius of the front and rear driving wheels would be equal to the gear ratio between the front and rear driving wheels ($r_d^f / r_d^r = i_{tr}^{f \to r}$).

Object and methods

The investigations were performed with the tractor “New Holland T 5060” with the front loader “MX 10”. The main technical data are shown in Table 1.

The tests were performed on a horizontal, hard road. The bales of the silage were used as a cargo on the front loader; the total weight of the bale of silage was 500 ± 10 kg. The tests were performed by following the values of air pressure in the front and rear tires: 0,8; 1,2; 1,6; 2,0; 2,5 bar; and driving without cargo, 500 kg and 1000 kg cargo on the front loader. The position of cargo in the point of the tractor varied within +/-10 cm.

All investigations were performed on the same road and direction with turned on and turned off the front driving wheel. The distance at 10 rates of the front and rear driving wheels was measured. The digital laser rangefinder Bosch PLR 50 was used to measure the distances in 2mm error. The vertical load of the tractor was measured by the electronic portable axle weigher WPD-2, error 1 kg.

The slippage (slide) of the driving wheels of the tractor was calculated by the following equation:

$$\delta = \frac{s_{4x2} - s_{4x4}}{s_{4x2}} \cdot 100\% , \% \tag{8}$$

where s_{4x2} and s_{4x4} – distance, which drives the front and rear wheels of the tractor at 10 rates.

Table 1

The main technical data of the tractor "New Holland T5060" with front loader "MX 10"

Weight of tractor	5770 kg
Wheelbase l_1	235 cm
Front tires	"Contract AC" 70 T / 380/70R24 /125 A8
Rear tires	"Contract AC" 70 T / 480/70R34 /143 A8
Vertical load to the front axle with cargo:	
0	3600 kg
500 kg	3848 kg
1000 kg	4873 kg
Vertical load to the rear axle with cargo:	
0	2695 kg
500 kg	2403 kg
1000 kg	1876 kg
Weight of the front loader with bale grab	685 kg
Distance between the center of the ballast and rear axle l_2	1.0 m
Distance between the center of cargo and rear axle l_3	5.41 m

Results and discussion

The dependence of the slippage (slid) between the front and rear driving wheels of the tractor and the air pressure in the front and rear tires, working without cargo are shown in Fig. 2. The air pressure in the rear tires was: 2.5; 2.0; 1.6; 1.2; 0.8 bar.

Fig. 2 shows, that working with or without cargo on the front loader and tractive force, in the majority of cases the front wheels slipped and the rear wheels slid. For example: the front wheels slipped about 1.4 % and the rear wheels slipped about 0.3 %, when the air pressure in the front and rear wheels was 2.5 and 0.8 bar. There were no slippage and slid when the air pressure in the rear and front tires was: 2.5 and 1.8; 2.0 and 1.65; 1.60 and 1.45 bars.

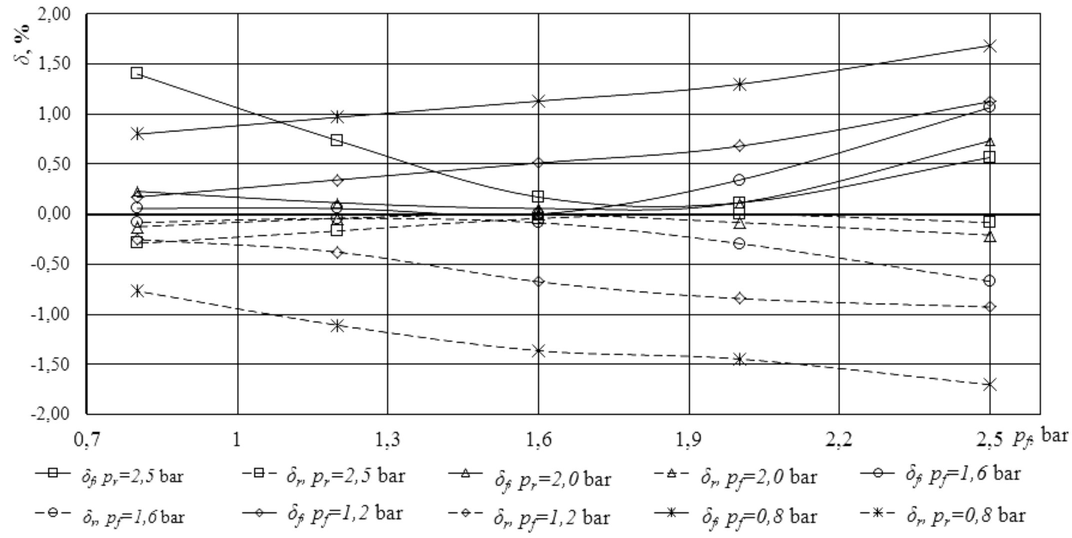

Fig. 2. **Dependence of slippage of front δ_f and rear δ_r wheels of the tractor and different air pressure in the front tires pf driving without cargo and changing air pressure in the rear tires p_r 0.8; 1.2; 1.6; 2.0; 2.5 bar**

The dependence of slippage (slid) between the front and rear driving wheels of the tractor and the air pressure in the front and rear tires, transporting 500 kg cargo on the front loader are shown in the Fig. 3. The air pressure in the rear tires were: 2.5; 2.0; 1.6; 1.2; 0.8 bar.

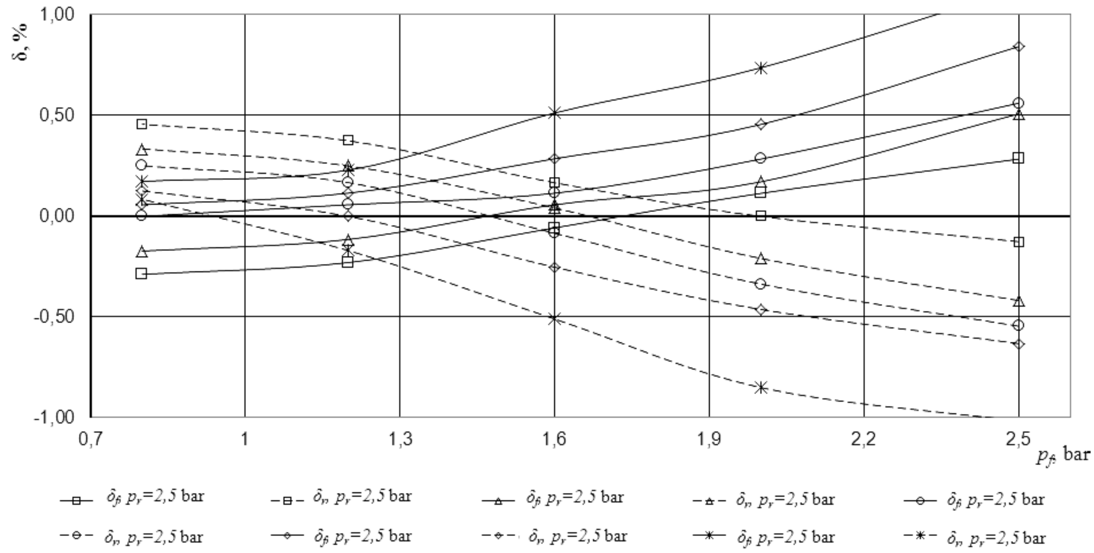

Fig. 3. **Dependence of slippage of front δ_f and rear δ_r wheels of the tractor and air pressure in the front tires p_f driving with 500 kg cargo and changing air pressure in the rear tires p_r – 0.8; 1.2; 1.6; 2.0; 2.5 bar**

Fig. 3 shows that transporting 500 kg cargo on the front loader and tractive force the front and rear driving wheels slid and slipped. For example, the rear driving wheels slipped, when the air pressure in the rear tires was 2.0 bar and higher than 1.7 bar in the front tires. The rear driving wheels slid when the air pressure in the rear tires was 2.0 bar ant lower than 1.6 bar in the front tires. The front and rear wheels did not slid and slipped when the air pressure in the front and rear tires was: 2.5 and 1.9; 2.0 and 1.85; 1.6 and 1.35; 1.2 and 1.0 bars.

The dependence of the slippage (slid) between the front and rear driving wheels of the tractor and the air pressure in the front and rear tires, transporting 1000 kg cargo on the front loader are shown in the Fig. 4.

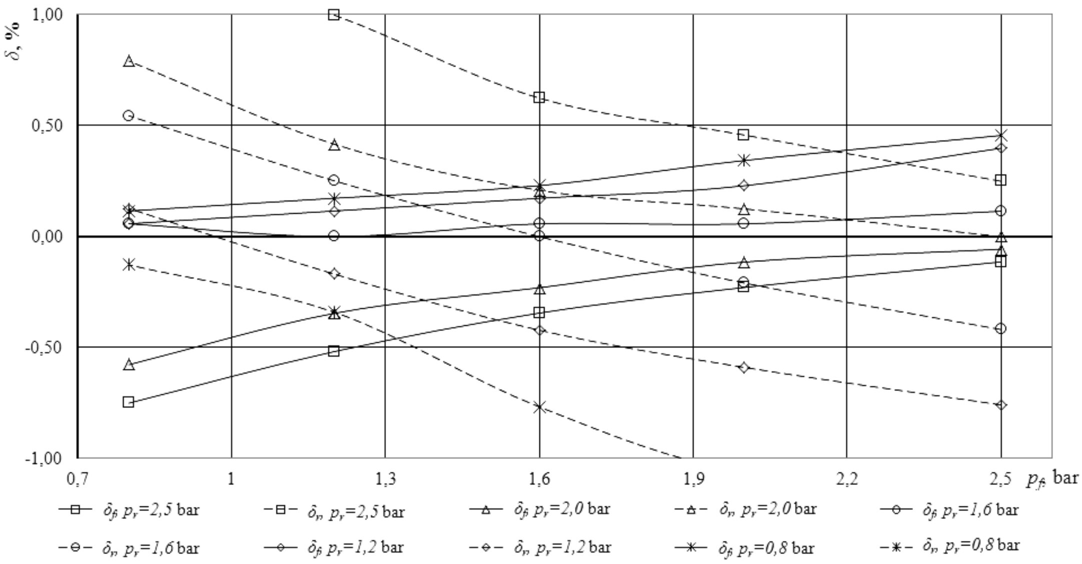

Fig. 4. **Dependence of slippage of front δ_f and rear δ_r wheels of the tractor and air pressure in the front tires p_f driving with 1000 kg cargo and changing air pressure in the rear tires p_r – 0.8; 1.2; 1.6; 2.0; 2.5 bar**

Fig. 4 shows that transporting 1000 kg cargo on the front loader the front and rear driving wheels do not slip (slid), when the air pressure in the front and rear driving wheels was: 2.5 and 2.0; 1.6 and 1.5; 1.2 and 0.95 bars.

Fig. 2-4 show that working with the tractor with the front loader without cargo and transporting 500 and 1000 kg cargo on the front loader the slippage (slid) was minimal when the air pressure in the front and rear wheels was 1.35-1.5 and 1.6 bars.

The dependence of the slippage (slid) between the front and rear driving wheels of the tractor and the air pressure in the front tires, driving without cargo and transporting 500 and 1000 kg cargo on the front loader are shown in the Fig. 5. The air pressure in the rear tires was 1.6 bar.

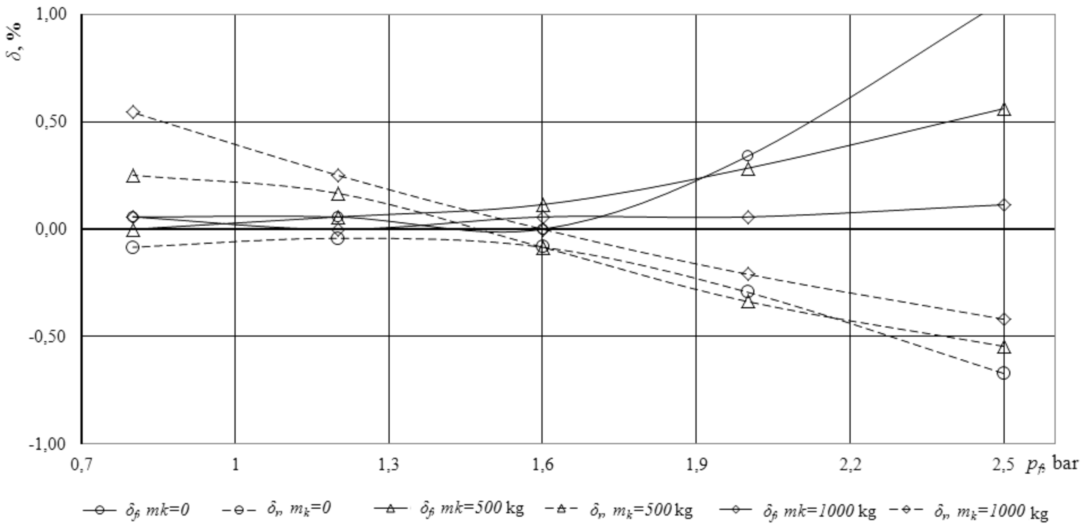

Fig. 5. **Dependence of slippage of front δ_p and rear δ_g wheels of the tractor and air pressure in the front tires p_p driving with 500 kg, 1000 kg , without cargo and changing air pressure in the rear tires p_g 1.6 bar**

Fig. 5 shows that the front and rear wheels slipped and slid. When the air pressure in the rear tires was 1.6 bar and 1.6-1.35 bar in the front tires, slippage and slid of the front wheel was minimal. The rear wheels of the tractor slipped, when the air pressure in the front tires was lower than 1.35 bar. The rear wheels of the tractor slid, when the air pressure in the front tires was higher than 1.5 bar.

Conclusions

When the air pressure in the tires is chosen improperly, some of the driving wheels slip and other wheels slide of the tractor with 4x4 driving wheels.

1. The front and rear wheels can slip or slide, it depends on the air pressure in the tires and the mass of cargo.
2. The driving wheels of the tractor "New Holland T 5060" (front tires – Contract AC 70 T / 380/70R24 / 125 A8; rear tires – Contract AC 70 T / 480/70R34 / 143 A8.) with the front loader MX 10 rolling have minimal slippage and no slide, when the air pressure in the rear tires – 1.6 bar, front tires – 1.4 ± 0.1 bar.

References

1. Kiss P. Rolling Radii of a Pneumatic Tire on Deformable Soil, Biosystems Engineering (2003) 85 (2), pp. 153-161.
2. Jun H., Kishimoto T., Way T. R., Tauinguhi T. Three direction contact stress distributions for a pneumatic tractor tire in soft soil, Transaction of the ASAE, Vol 41, No 5, 1998, pp. 1237-1242.
3. Janulevičius A., Giedra K. Vertikalios apkrovos ir oro slėgio padangoje įtakos rato sukibimui su dirva tyrimai, Žemės ūkio inžinerija, 2008, 40(1), pp. 42-53.
4. Szente M. Slip calculation and analysis for four-wheel drive tractors, Járművek és Mobilgépek, II.évf. 2009, No.V, pp. 404-424.

5. Damanauskas V., Janulevičius A., Pupinis G. Effect of tires' pressure on the kinematic mismatch of a four-wheel-drive tractor, MECHANIKA. Volume 19(1) 2013, pp. 73-80.
6. Janulevičius A., Giedra, K. Tractor ballasting in field work, Mechanika, 2008, 5(73), pp. 27-34.
7. Коваль А. А., Самородов В. Б. Пространственно–топологический подход при определении основных технико-экономических показателей колесных тракторов. Тракторы и сельскохозяйственные машины, 2008, 3, сс. 20-23.
8. Stoilov S., Kostadinov G. Effect of weight distribution on the slip efficiency of a four-wheel-drive skidder, Biosystems engineering, 2009, 104, pp. 486-492.
9. Senetore C., Sandu C., Torque distribution influence on tractive efficiency and mobility of off-road wheeled vehicles, Journal of Terramechanics 48, 2011 pp. 372-383.
10. Janulevičius A., Giedra K. The slippage of the driving wheels of a tractor in a cultivated soil and stubble.– Transport. Vilnius : Technika. 2009, T. 24, Nr. 1, pp. 14-20.
11. Самородов, В. Б., Лебедев А. Т., Митропан Д. М., Сергиенко Н. Е. Рациональное агрегатирование тракторов на вспашке, Тракторы и сельскохозяйственные машины, 2004, 11, сс. 19-22.
12. Махмудов М. М., Хафизов К. А. Оптимизация параметров колесного движителя, Тракторы и сельскохозяйственные машины, 2004, 2, сс. 20-21.
13. Vantsevich, V. V. Power losses and energy efficiency of multi-wheel driver vehicles: A method for evaluation, Journal of Terramechanics, 2008, 45(3), pp. 89-101.
14. Senetore C., Sandu C., Torque distribution influence on tractive efficiency and mobility of off-road wheeled vehicles, Journal of Terramechanics 48, 2011 pp. 372-383.
15. Pranav P. K., Pandey K. P. Computer simulation of ballast management for agricultural tractors, Journal of Terramechanics, 2008, 45(6), pp. 193-200.