Improvement of wheel skidder tractive performance by tire inflation pressure and tire chains

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Abstract – Nacrtak

The motion resistance ratio, gross traction ratio and net traction ratio of a wheel cable skidder were determined and mathematical models derived for three tire inflation pressure values with or without tire chains on forest road in mountainous conditions.

The motion resistance ratio increases with the increase of tire inflation pressure. On the contrary, the gross traction ratio increases with the decrease of tire inflation pressure. However, when the tires are equipped with tire chains the skidder motion resistance is higher. The motion resistance ratio with tire chains also increases with the decrease of tire inflation pressure due to windage between the tires and chains, which results in lower tractive performance of tire chains.

Therefore, by using tire chains, an increase of gross tractive ratio could be achieved, as well as the increase of motion resistance ratio compared to tires without chains.

The results of the study show that it is strongly recommended to use tire chains as tightly as possible.

***Keywords**: wheel skidder, tire inflation pressure, tire chains, tractive performance, motion resistance*

1. Introduction – *Uvod*

The wheel cable skidder is a self-propelled machine designed to transport trees or parts of trees by trailing or dragging them with one end on the ground. Cable skidders use a main winch cable and cable chokers to assemble and hold the load (Stokes et al. 1989).

Worldwide the wheel skidders are one of the basic machines in mountain logging on 10–20° steep slopes during thinnings, selection silvicultural systems and shelterwood regeneration.

The increasing demand for more efficient and productive logging technologies in mountain conditions requires improvement of mobility and tractive performance of forest machines. One of possible solutions is to equip skidders with special high-flotation tires with low inflation pressure controlled manually or by Central Tire Inflation System (CTIS), which allows the increase of tire contact area, thus preventing slip, soil compaction and sinkage, and improving traction. Tire chains are often in use to maximize traction, reduce slipping and fuel consumption, and providing minimal brake distance from the wheel skidder (Fig. 1). Sometimes the advantages of four-wheel or six-wheel drive skidder transmission cannot replace the need for tire chains during all seasons. In extreme muddy and deep snow conditions tire chains will enhance the mobility and improve tractive performance, as well as protect the tread and tire side wall from excessive damages. Greater tractive force along with minimum slip provided by tire chains means bigger tree load and higher speed, and therefore, greater productivity and efficiency of wheel skidder.

The tractive performance, as one of the main characteristics of wheel skidders, determines their mobility, productivity, and environmental damage under different terrain conditions of forest areas. Tractive performance is in close dependence on soil-

Fig. 1 Skidder wheel equipped with tire chains
Slika 1. *Skiderski kotač s postavljenim lancima*

wheel interaction. The milestones of terramechanics are the studies of M. G. Bekker (1956, 1969) and J. Y. Wong (1978, 1989). There are numerous papers that explored soil-wheel interaction, but investigations into use of tire chains have not been given sufficient attention.

The subject of this paper is the research of motion resistance ratio, gross traction ratio and net traction ratio of wheel skidder with or without tire chains.

2. Earlier research – *Prijašnja istraživanja*

The following five dimensionless ratios are used to describe tractive performance (Standards of ISTVS 1977):

⇒ travel reduction ratio, commonly called »slip«, is an indication of how the speed of the wheels differs from the forward speed of the vehicle;

⇒ tractive efficiency presents the ratio of tractive (drawbar) power divided by corresponding power at driven wheels (Wong 1998);

⇒ gross traction ratio μ_{gt} shows the torque delivered to the wheels divided by the rolling radius of the wheels and divided by the dynamic load of the skidder:

$$\mu_{gt} = T \; / \; (r \cdot W) = F_{per} \; / \; W \tag{1}$$

⇒ motion resistance ratio μ_r describes the resistance to movement of a vehicle provided by both the surface on which it moves and internal friction of its tires, and the energy losses in the wheels divided by the dynamic load of the skidder:

$$\mu_r = F_r / W \tag{2}$$

⇒ net traction ratio μ_{nt} demonstrates tractive force divided by the dynamic load of the skidder:

$$\mu_{nt} = F_t / W = \mu_{gt} - \mu_r \tag{3}$$

where:

W – dynamic load of the skidder
T – torque delivered to the wheels (input torque)
r – rolling radius

The force equilibrium for wheel skidder is as follows:

$$F_{per} = F_r \pm F_s \pm F_a + F_w + F_t \tag{4}$$

where:

F_{per} – peripheral force of skidder wheels
F_r – motion resistance force
F_s – slope resistance force
F_a – resistance of inertia
F_w – aerodynamic resistance force
F_t – tractive force (drawbar pull parallel to ground surface)

In mountainous logging the travel speed of loaded wheel cable skidder is not higher than 6–8 km/h. Therefore aerodynamic and inertial effect could be ignored due to low ground speed (i.e. $F_a = 0$ and $F_w = 0$). Thus tractive force equation (4) is simplified as follows:

$$F_t = W \cdot (\mu_{gt} - \mu_r) = W \cdot \mu_{nt} \tag{5}$$

For a four-wheel-drive skidder with rigidly coupled front and rear drive axles, the tractive performance under a hard surface condition can be achieved if theoretical speed of the front and rear wheels is equal. On forest terrain, where sinkage takes place, the theoretical speed of the front wheels should be faster (i.e. forerunning) than that of the rear because of different tire deflection, soil compaction and rut depth beneath front and rear wheels. To prevent transmission mechanical damage and to reduce tires wear, it is necessary to provide a kinematic discrepancy between the theoretical speeds of the front and rear wheels on deformable forest terrain to be used (Dimitrov and Stoilov 2005).

There are several studies of tractive performance of wheel skidders in field conditions (Hassan and Sirois 1984, Hassan and Sirois 1985, Sever 1989, Dimitrov and Stoilov 2005, Stoilov 2005) and laboratory conditions (Vechinski et al. 1998, Vechinski et al. 1999). However, only the last two investigations are focused on the effect of different tire inflation pressures and chains on motion resistance and traction of skidder tires in laboratory conditions.

The research of skidders equipped with tire chains operating in logging conditions will be of great importance and results will provide better understanding of vehicle-terrain interaction as well as ways to increase productivity and overall efficiency of wheeled machines during skidding. All this could be achieved by proper field testing and interpreting the experimental results.

The main objective of this paper is to present the effects of tire inflation pressure and use of tire chains on the motion resistance and tractive force of a four-wheel-drive cable skidder, respectively shown by motion resistance ratio, gross traction ratio and net traction ratio.

3. Materials and method – *Materijal i metode*

3.1 Technical data of the studied skidder – *Tehnički podaci o ispitivanom skideru*

The tests were conducted with two four-wheel-drive LKT–81T cable skidders, owned by the Petrohan Training and Experimental Forestry at University of Forestry. Skidder technical data are shown in Table 1.

3.2 Site and stand conditions – *Stanišni i sastojinski uvjeti*

The tests were conducted on a flat forest road in a 160-year beech stand, located in Petrohan Training

Table 1 Technical data of LKT–81T articulated four-wheel-drive cable skidder

Tablica 1. *Tehnički podaci zglobnoga skidera LKT–81T opremljenoga šumskim vitlom formule pogona 4 x 4*

Manufacturer – Proizvođač	Martimex–Alfa A. S. (Slovak Republic – *Slovačka*)
Diesel engine – *Dizelski motor*	4-stroke, direct injection, turbocharger – *4 cilindra, izravno ubrizgavanje, turbopunjač*
Manufacturer – *Proizvođač*	Martimex–Alfa A. S. (Slovak Republic – *Slovačka*)
Type – *Tip*	Martin Diesel (Zetor)-8022.138
Rated power – *Nazivna snaga*	72.25 + 3 % kW @ 2200 min^{-1}
Engine cooling – *Hlađenje motora*	water type – *hlađenje vodom*
Transmission – *Sustav prijenosa snage*	mechanical – *mehanički*
Gear box – *Mjenjač*	5-speed synchromesh – *5 brzina, sinkronizirani*
Transfer box – *Razdjelnik pogona*	2-speed – *2 brzine*
Axes – *Osovine*	rigid, mechanical differential lock with electropneumatic control, with final drive *kruta sa završnim reduktorima, mehanička blokada diferencijala s elektropneumatskim upravljanjem*
Tires – *Gume*	Barum Continental s.r.o.
Type – *Tip*	TL–1 Log Skidder PR 12
Tire size – *Veličina*	16.9–30''
Tire inflation pressure – *Tlak u gumama*	max. 240 kPa, min. 80 kPa
Skidder mass – *Masa skidera*	7145 kg
Weight distribution (unloaded skidder) *Raspored mase neopterećenoga skidera*	front axe – *prednja osovina* (61.5 %) rear axe – *stražnja osovina* (38.5 %)
Winch – *Vitlo*	double drum, free unwinded cable *dvobubanjsko, slobodno odmotavanje užeta*
Max. line pull – *Nazivna vučna sila*	70 kN (bare drum – *prazan bubanj*)
Max. cable length – *Najveća duljina užeta*	77 m (Ø14 mm)
Drive – *Pogon*	hydrostatic – *hidrostatski*
Control – *Upravljanje*	hydroelectric – *hidroelektrično*
Tire chains – *Lanci*	conventional type with lug rings *uobičajeni tip s oslanjajućim prstenovima*

and Experimental Forestry at University of Forestry, situated in Western Balkan Mountain.

Undisturbed soil properties of the site: brown forest soil, average moisture content: w = 20.3%, average cone index: 385 kPa. Atmosphere conditions: air temperature: 22°C, air moisture content: 61%, and air pressure: 940 hPa.

3.3 Measuring equipment – *Mjerna oprema*

The test skidder was instrumented with the following transducers for measuring tractive force (line pull) F_t (Fig. 2):

- ⇒ a 100 kN load cell for measuring tractive force (line pull) (Dept. of Strength of Materials at Technical University of Sofia);
- ⇒ a frequency amplifier with 3 ranges: 20, 40 and 100 kN (KWS-3073, Hottinger Baldwin Messetechnik GmbH);
- ⇒ a recorder (TSS-101, RFT Robotron).

The measuring equipment devices were powered by an autonomous source – two 12 V accumulator batteries.

3.4 Study layout – *Postavka istraživanja*

The two-way tests carried out to eliminate possible effects of test area grade (L_{ta}) 30 m in length of the road. Tire inflation pressure was set at different combinations and the above test sequence was repeated.

Equal tire inflation pressure was used in front and rear wheels so as to reduce the effects of kinematic discrepancy between the theoretical speeds of the front and rear wheels on deformable forest terrain.

3.5 Motion resistance measurements – *Mjerenje otpora kotrljanja*

The motion resistance force F_r was determined by the following method (Fig. 3). An auxiliary cable skidder towed the test skidder with a load cell (LC) connected between them. The gear box of the test skidder was placed in neutral position with tire inflation pressure set at one of the combinations shown in Table 2. At speed lower then 15–20 m/s the motion resistance ratio is assumed to be constant. The measured horizontal force is motion resistance force F_r.

Fig. 2 Measuring equipment
Slika 2. *Mjerna oprema*

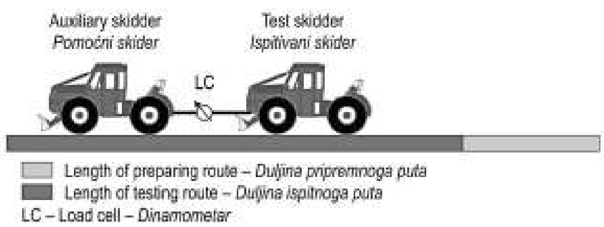

Fig. 3 Scheme of motion resistance test

Slika 3. *Shema ispitivanja otpora kotrljanja*

In this case the motion resistance ratio μ_r is the ratio of tractive force $F_t = F_r$ to the skidder weight W:

$$\mu_r = F_r \ / \ W = F_t \ / \ W \qquad (6)$$

3.6 Traction measurements – *Vučni pokusi*

The net traction force was determined by the following method (Fig. 4). The test skidder, operated with the throttle open wide, towed the auxiliary cable skidder with a load cell (LC) connected between them. The auxiliary skidder created increasing resistance force by transmission, breaks, and stacking blade until test skidder stopped due to 100% slip. The measured horizontal resistance force is maximum tractive force $F_{t(max)}$.

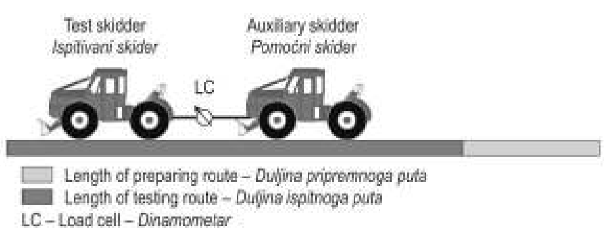

Fig. 4 Scheme of traction test

The gross traction ratio μ_{gt} is defined as the ratio of sum of the motion resistance force F_r and maximum tractive force $F_{t(max)}$ to the skidder weight W:

$$\mu_{gt} = (F_{t(max)} + F_r) \ / \ W \qquad (7)$$

4. Research results – *Rezultati istraživanja*

Motion resistance ratio μ_r, gross traction ratio μ_{gt} and net traction ratio μ_{nt} are calculated from experimental data using equations (6), (7) and (3), respectively. The average calculation results of the three tire inflation pressure combinations are shown in Table 2 and Figures 5, 6, 7.

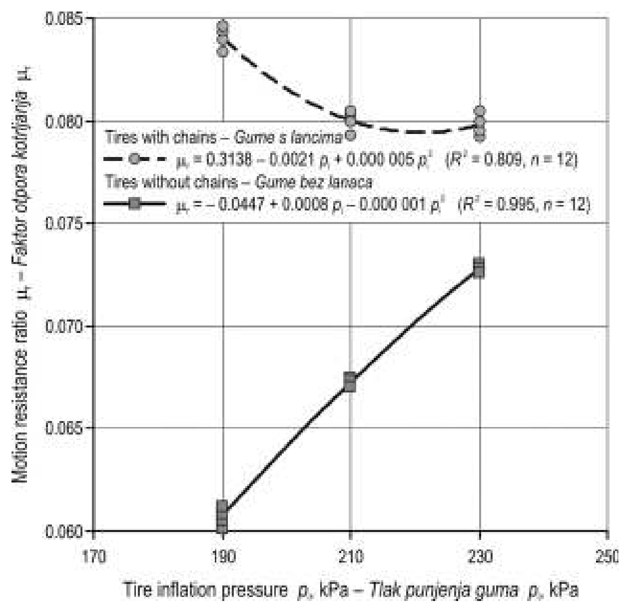

Fig. 5 Motion resistance ratio vs. tire inflation pressure

Slika 5. *Ovisnost faktora otpora kotrljanja o tlaku u gumama*

Table 2 Calculated results

Table 2. *Rezultati proračuna*

Tire inflation pressure *Tlak u gumama*		Motion resistance ratio *Faktor otpora kotrljanja*		Gross traction ratio *Faktor bruto vuče*		Net traction ratio *Faktor neto vuče*	
p_i, kPa		μ_r		μ_{gt}		μ_{nt}	
Front *Prednjim*	Rear *Stražnjim*	without chains *bez lanaca*	chains *s lancima*	without chains *bez lanaca*	chains *s lancima*	without chains *bez lanaca*	chains *s lancima*
230	230	0.0728	0.0798	0.4579	0.5048	0.3851	0.425
210	210	0.0672	0.0800	0.4628	0.5023	0.4021	0.4223
190	190	0.0607	0.0841	0.4695	0.5012	0.4113	0.4171

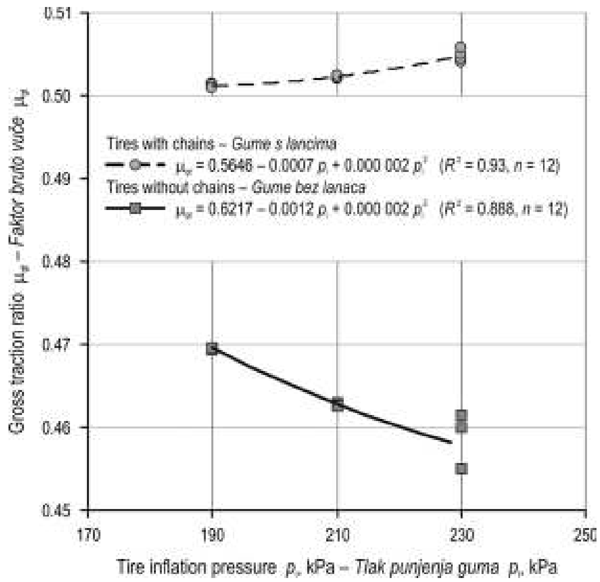

Fig. 6 Gross traction ratio vs. tire inflation pressure

Slika 6. *Ovisnost faktora bruto vuče o tlaku u gumama*

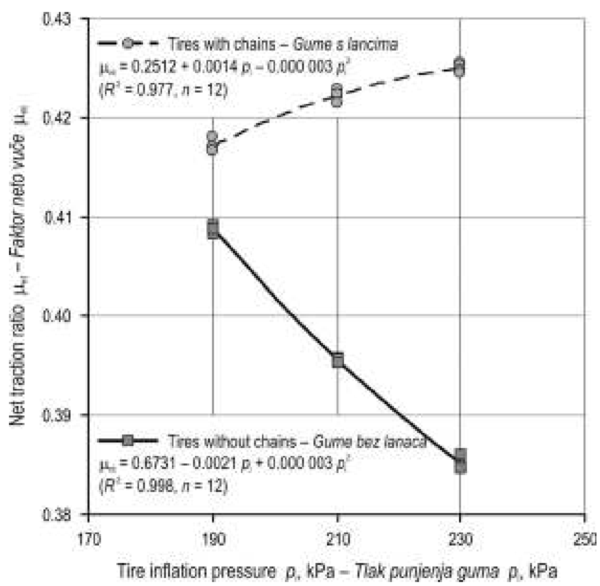

Fig. 7 Net traction ratio vs. tire inflation pressure

Slika 7. *Ovisnost faktora neto vuče o tlaku u gumama*

The rut depth after the passes was 50–80 mm. The rut depth difference after front and rear wheels was not significant due to macadam bottoming of the forest road.

After calculating these data, statistical processing of mathematical models was carried out. The linear, polynomial, logarithmic and exponential models were used for describing the relationship between tire inflation pressure and motion resistance ratio, and gross traction ratio and net traction ratio.

The best fitted models describing μ_r, μ_{gt} and μ_{nt} with or without chains are polynomial models shown in Figures 5, 6, 7.

5. Discussion – *Diskusija*

In case of skidder wheels without tire chains the motion resistance ratio decreases while tire inflation pressure is reduced (Fig. 5). Reduction of tire inflation pressure causes the decrease in motion resistance ratio (7.69%) and increase in gross tractive ratio (2.5%) (Fig. 6) and net tractive ratio (6.8%) (Fig. 7) without tire chains on deformable forest road at p_i = 190 kPa in comparison with p_i = 230 kPa. These improvements in tractive performance are on account of increased wheel contact area and lower sinkage depth. All these reduce the motion resistance component (»bulldozing resistance«, Wong 1989) of soil deformation resistance and improve traction forces.

For wheels equipped with tire chains the decrease of the tire inflation pressure leads to the increase of the motion resistance ratio (5.4%) at p_i = 190 kPa in comparison with p_i = 230 kPa (Fig. 5). The combination of tire chains and tire inflation pressure reduction caused the decrease of gross traction ratio (0,7%) (Fig. 6) and net tractive ratio (1.9%) (Fig. 7) at p_i = 190 kPa in comparison with p_i = 230 kPa.

Reduction of tire inflation pressure leads to the decrease of the rolling radii of the wheels and windage between tires and chains.

Generally, motion resistance ratio of the wheel skidder was higher with chains than without chains due to windage between tires and chains caused by the reduction of tire inflation pressure.

Use of tire chains improves the gross tractive ratio because of growth of the traction. Without tire chains, the decrease of tire inflation pressure gives rise to the gross tractive ratio due to the increase of the tire-soil contact area and adhesion forces, and lower sinkage.

Net traction ratio is the difference between gross tractive ratio and motion resistance ratio. Therefore, on deformable forest road the decrease of tire inflation pressure has a favorable impact on the increase of the net tractive ratio and tractive performance of the skidder with wheels without tire chains. Use of chains and reduction of tire inflation pressure cause a slight decrease of net tractive ratio due to higher motion resistance ratio and enlarged windage between the tires and chains.

6. Conclusions – *Zaključci*

Along with all-drive transmission of wheel skidder and operating factors, the reduction of tire inflation pressure has a noticeable effect on the increase of tire contact area and improvement of traction, and hence its mobility and productivity.

The results of field tests confirm theoretical findings that reduction of tire inflation pressure causes the decrease of motion resistance ratio and increase of gross tractive ratio and net tractive ratio without tire chains on deformable forest road.

The use of tire chains could cause an increase in gross tractive ratio, net tractive ratio, as well as motion resistance ratio in comparison with the case without tire chains. Experimental evidence shows that the use of tire chains leads to the decrease of gross tractive ratio and net tractive ratio at p_i = 190 kPa in comparison with p_i = 230 kPa, but also to the increase of motion resistance ratio due to the rise of windage between the wheels and tire chains.

The results of the study indicate that the use of tire chains applied as tightly as possible is strongly recommended, and that tire inflation pressure must be kept in appropriate range during operation to avoid the increase of windage and ensure the optimum performance of wheel skidder.

Improved mobility and tractive performance of wheel skidders equipped with tire chains could decrease the amount and costs of forest road maintenance.

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Sažetak

Poboljšanje vučne značajke skidera promjenom tlaka u gumama i primjenom lanaca na kotačima

Potreba za većom djelotvornošću privlačenja drva u planinskim područjima zahtijeva poboljšanje kretnosti i vučnih značajki šumskih vozila. Kotačni je skider najčešće šumsko vozilo koje se upotrebljava pri privlačenju drva u planinskim područjima. Opremanje skidera širim gumama te manjim tlakom u gumama omogućuje povećanje dodirne površine kotača i tla, smanjenje klizanja kotača, zbijanja tla, nastanka kolotraga te poboljšava vučnu značajku vozila. Opremanje kotača skidera lancima (slika 1) također povećava vučnu značajku skidera uz smanjenje klizanja kotača, potrošnje goriva i puta zaustavljanja. U uvjetima slabe nosivosti tla ili visokoga snježnoga pokrivača uporaba lanaca na kotačima omogućit će veću kretnost skidera i vučnu silu te manje klizanje kotača, što će se očitovati u većim obujmima tovara i brzinama kretanja zbog čega će se povećati proizvodnost skidera.

Cilj je rada istraživanje faktora otpora kotrljanja, bruto i neto vuče skidera ovisno o uporabi lanaca na gumama kotača i promjeni tlaka zraka u gumama.

Faktor se otpora kotrljanja opisuje kao otpor pokretanja vozila zbog stanja podloge, unutrašnjega trenja gume i energetskoga gubitka kotača u odnosu na dinamičko opterećenje kotača. Zbog djelovanja zakretnoga momenta na kotaču javlja se obodna sila (F_{per}) koja služi za svladavanje otpora kotrljanja vozila (F_r), a ostali dio sile (F_t) za vuču tereta, svladavanje nagiba (F_s), otpora inercije (F_a) i otpora zraka (F_w). Faktor bruto vuče opisuje se odnosom obodne sile i opterećenja kotača, a faktor neto vuče odnosom vučne sile i opterećenja kotača.

Istraživanje je provedeno na ravnom dijelu šumske ceste, pa nije bila potrebna sila za svladavanje nagiba, a zbog malih brzina kretanja opterećenoga skidera izostali su otpor inercije i otpor zraka.

U istraživanju se koristio skider LKT 81 T čiji su tehnički podaci prikazani u tablici 1. Tlak se zraka u gumama tijekom istraživanja postavljao na vrijednosti 190 kPa, 210 kPa i 230 kPa. U pojedinom je vučnom pokusu tlak bio jednak u prednjim i stražnjim gumama kotača.

Otpor se kotrljanja mjerio povlačenjem ispitivanoga skidera u praznom hodu ili neutralnim položajem transmisije te dinamometrom učvršćenim između skidera i vozila koje ga vuče (slika 3). Odnos zabilježene sile na dinamometru i težine vozila pokazuje vrijednost faktora kotrljanja.

Vučna se sila mjerila povlačenjem pomoćnoga vozila pomoću ispitivanoga skidera s učvršćenim dinamometrom na vučnom užetu vitla. Pomoćnim se vozilom povećavala sila otpora kočenjem, transmisijom i spuštanjem prednje odrivne daske sve do zaustavljanja ispitivanoga skidera zbog 100 % klizanja kotača. Odnos zabilježene sile na dinamometru i težine vozila pokazuje vrijednost faktora bruto vuče. Faktor neto vuče za svaki se vučni pokus odredio kao razlika između faktora neto vuče i faktora otpora kotrljanja.

Srednje vrijednosti faktora vuče pri različitim tlakovima u gumama kotača s lancima ili bez lanaca prikazani su u tablici 2. Ovisnosti pojednih faktora vuče o tlaku u gumama određene su regresijskom analizom podataka (slike 5, 6 i 7).

Manji tlak u gumama bez lanaca na kotačima uzrokuje smanjenje faktora otpora kotrljanja i povećanje faktora bruto i neto vuče zbog povećanja dodirne površine kotača i tla i manjega propadanja kotača u tlo. Kod kotača s postavljenim lancima smanjenje tlaka u gumama dovodi do povećanja faktora otpora kotrljanja i smanjenja faktora bruto i neto vuče zbog slabijega prijanjanja između guma i lanaca te smanjenja polumjera kotača.

Općenito skider s postavljenim lancima na kotačima ima veći otpor kotrljanja od skidera bez primjene lanaca. Veće vrijednosti faktora bruto i neto vuče u primjeni lanaca na kotačima posljedica su boljih vučnih mogućnosti skidera zbog smanjenja klizanja kotača.

Rezultati istraživanja pokazuju značajan utjecaj smanjenja tlaka u gumama na povećanje dodirne površine kotača i tla i poboljšanje vučne značajke skidera te time na povećanje proizvodnosti. Na osnovi rezultata preporučuje se postavljanje lanaca na kotačima što je moguće čvršće uz gumu uz održavanje tlaka u gumama u potrebnom rasponu kako bi se omogućilo bolje prijanjanje lanaca i kotača te osigurala optimalna vučna značajka skidera.

Rad pridonosi boljemu razumijevanju odnosa između značajki vozila i značajki tla te služi kao smjernica za povećanje proizvodnosti skidera pri privlačenju drva.

Ključne riječi: kotačni skider, tlak u gumama, lanci na kotačima, vučna značajka, otpor kotrljanja

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