Forces Affecting Timber Skidding

Željko Tomašić, Marijan Šušnjar, Dubravko Horvat, Zdravko Pandur

Abstract – Nacrtak

The research was carried out on the strip road where longitudinal slopes were determined by the leveling method as well as individual distances of the strip road of uniform slope. Skidders were used for carrying out traction tests in downhill and uphill skidding of 9 different loads. Measurement of wheel loads, wheel torques and components of rope force was performed by tensiometric method and remote transferring of measurement signal.

According to the results of research, by the increase of longitudinal slope, more tractive force is used for overcoming the terrain slope than for overcoming the traction resistance. In downhill skidding, the horizontal component of the skidder weight (G sinα) acts in the skidder travel direction and hence its value is higher than the traction resistance.

Torque distribution depends on the skidder wheel vertical load. In uphill skidding, torques increase proportionally to the vertical component of rope forces and adhesive weight of the skidder. In downhill skidding, the skidder wheel torques are negative, because they are not used for achieving wheel tractive force and instead, the transmission of torque through the transmission system causes skidder's braking performance. The skidder's need for braking arises under influence of the horizontal component of the skidder weight (G sinα) that acts in the direction of the skidder travel and under its effect the traction resistances are overcome. It can be concluded that in case of downhill skidding we cannot speak of achieving real tractive force because the skidder pulls the load only by its weight, and the transmittion from engine to wheels is not used for achieving the tractive force.

Key words: skidder, wheel load, wheel torque, pulling force, adhesive weight, slope

1. Introduction – *Uvod*

Skidders, as forest vehicles for timber skidding, are exclusively designed for achieving tractive force through wheel circumference. By the skidder transmission system, torque is transmitted and changed from the drive engine to the wheels. Under the effect of torque, thrust force is generated on the wheel. Horizontal component of the thrust force is partly used for overcoming the rolling resistance of the vehicle (F_f), and the remaining force (F_v) is used for pulling the load, for overcoming the slope and surface obstacles or for vehicle acceleration (Wong 2001, Stoilov 2007).

When using skidders equipped with forest winch, timber is extracted with one end of the load lifted off the ground and through the winch rope leaned on the rear part of the vehicle, while the other part of the load is dragged on the soil. The force generated in the rope is used for pulling the part of the load lifted off the ground (vertical component – *V*) and for overcoming the traction resistance of the part of load weight dragged on the soil (horizontal component – *H*).

Skidder's traction characteristic affects the ratio between forces applied on the wheel and forces resisting their action, where the adhesive weight of the vehicle (Šušnjar and Horvat 2006) plays an extremely important role. Adhesive weight (G_a) is the sum of vertical loads on skidder driving wheels under conditions of timber harvesting (Tomašić et al. 2007). Adhesive weight depends on the skidder mass, terrain slope and value of vertical component of rope force, which is primarily affected by the value and orientation of pieces of timber in the load:

$$G_a = G \cdot cos\alpha + V$$

Consequently, adhesive weight differs from the weight of the unloaded skidder (*G*) because the rear axle is additionally loaded by full vertical component of rope force, which is distributed on rear wheels

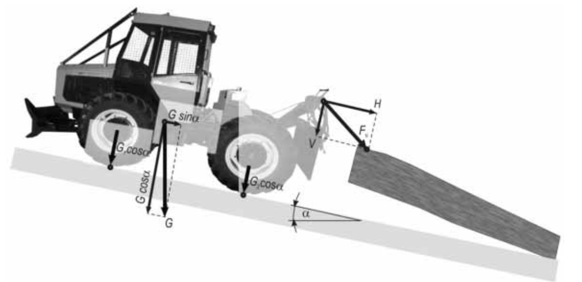

Fig. 1 Distribution of forces during uphill timber skidding

Slika 1. *Raspodjela sila pri privlačenju skiderom uz nagib*

through horizontal winch rollers (Hassan and Gustafson 1983). The value of tractive force depends on the adhesive weight of the skidder and hence for obtaining higher tractive force higher adhesive weight is necessary (Sever 1984). Therefore, in timber skidding, the heavier end of timber assortments in the load should be lifted off the ground so as to increase the adhesive weight by higher value of vertical component of rope force.

The distribution of loads by skidder axles changes with respect to the load volume and weight, orientation of assortments in the load, travel direction and terrain slope. During travel on longitudinal slope, the rear axle is additionally loaded as the load of the skidder weight is transferred from the front axle due to the effect of the parallel weight component of the skidder (G sinα). During uphill timber skidding, the tractive force must overcome the traction resistance of the part of load dragged on the soil (H), as well as the resistance of the horizontal weight component of the skidder (G sinα) that pulls the vehicle downhill (Fig. 1).

During downhill travel, under the effect of the horizontal weight component of the skidder (G sinα), the load of the skidder weight is transferred to the front axle (Fig. 2). In the same way, the horizontal weight component of the skidder acts in the skidder's travel direction and hence it is only necessary to overcome the traction resistance of the part of load dragged on the soil (H).

Based on the above considerations, the highest load is expected at the skidder's rear axle during uphill skidding. Due to different wheel loads, transmission must enable the distribution of the torque with respect to the wheel load. Consequently with the mechanical transmission system, the distribution of the torque to the wheels should be in accordance with the wheel load distribution. The research of torque on skidder's wheel shafts (Horvat 1987, Šušnjar and Horvat 2006, Marenče 2005) confirmed the hypothesis that higher torque is applied on the wheel under higher load, where torques at the wheels of the same shaft are balanced.

The aim of this paper is to determine the dependence of components of rope force, wheel load distribution and torque on load weight and terrain slope, which represents a significant correlation for the assessment of tractive (exploitation) characteristics of skidders in timber skidding.

2. Materials and methods – *Materijali i metode*

In this research, the skidder ECOTRAC 55 V equipped with forest winch Hittner 2 × 35 kN (Fig. 3) was used. The skidder mass is 3483 kg (62% at the front axle and 38% at the rear axle). The skidder's driving engine is a 3-cylinder DEUTZ diesel engine, air cooled, displacement 3236 cm^3, compression ratio 20:1, power output 40 kW at 2300 min^{-1} and highest torque of 207 Nm at 1600 min^{-1}. The transfer of power is carried out by mechanical transmission: drive engine → clutch → gear box → drive distribution → front and rear differentials with individual blockade → final (planetary) drive in tractor wheels.

For measuring the dynamic load of the skidder, measuring parameters were designed or applied for simultaneous determination of components of rope force, load and torque on all driving wheels.

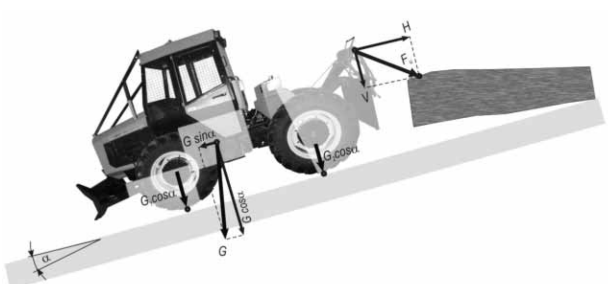

Fig. 2 Distribution of forces during downhill timber skidding

Slika 2. *Raspodjela sila pri privlačenju skiderom niz nagib*

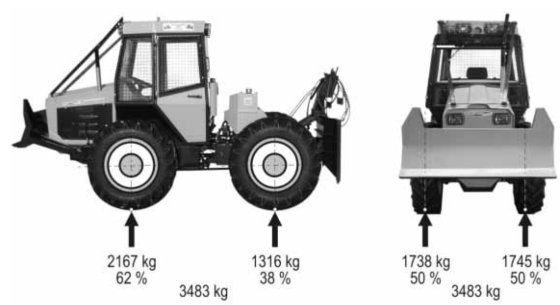

Fig. 3 Mass distribution of skidder Ecotrac 55 V

Slika 3. *Raspored mase skidera Ecotrac 55 V*

Tensometry is the basic method for measuring mechanical values. Heidl and Husnjak (1992) describe tensometry as a mechanical method for determining length deformation of a structure or model in order to determine the strain on the structure surface. In doing so, measurement transducers are used based on changeable electrical resistance caused by the change of its legth (the so-called »strain gauge«). This method provides the possibility to measure electrically non-electric values. The application of tensometric method enables the measurement without affecting adversely the vehicle structure, but it requires the conversion of vehicle elements into measurement parameters. Tensometric method was used by Sever (1987), Marklund (1987), Horvat (1998), Marenče (2005) and Šušnjar and Horvat (2006), Tomašić et al. (2008) for measuring wheel torques and wheel load of skidders and forwarders.

Horizontal and vertical component of rope force in timber skidding was determined with two transducers HBM 50 kN and HBM 20 kN. Transducers were connected under the angle of 90 degrees and installed on the support structure articulately mounted on vertical rollers of the winch (Fig. 4). Transducers were placed horizontally and vertically with respect to the basis at fully lifted skidder's rear protective and anchoring blade, corresponding to its position in timber skidding.

The measurement of torques was carried out by strain gauges placed opposite the housing of the final planetary drives. For measuring dynamic wheel load, the strain gauges were placed right behind the wheels on the upper part of the shaft housing leading from the differential to the wheel. Strain gauges were connected by conductors to the juncture. Due to wheel rotation it was necessary to install a sliding

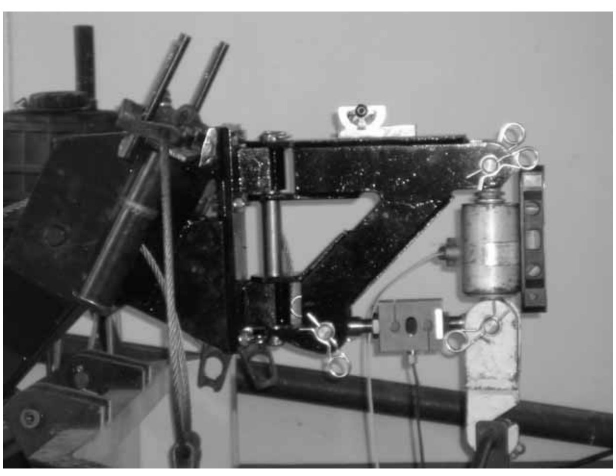

Fig. 4 Carrier with traction and tension transducers

Slika 4. *Nosač s vlačno-tlačnim dinamometrima*

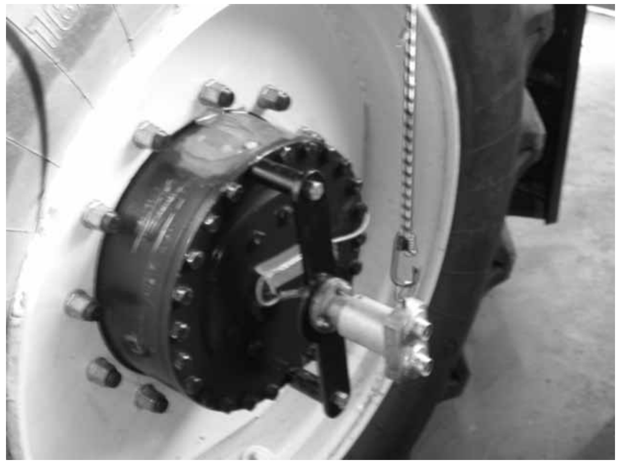

Fig. 5 Preparation of final (planetary) drive

Slika 5. *Prepariranje planetarnoga reduktora*

transducer on each wheel. The carriers of the sliding transducers were installed on the housing of the final drive (Fig. 5). The signal of the strain gauge resistance change is transmitted through the sliding transducer by cables to the amplifier. All measuring transducers and strain gauges are connected to measuring amplifiers HBM Spider 8 installed on the skidder.

The use of the radio modem ELPRO 805 U (ELPRO Technologies Pty Ltd.) enabled remote transmission of data. The radio modem was installed on the skidder and connected to the measuring amplifier HBM Spider 8. It received analogically amplified measurement signals and transmitted them through the antenna installed on the roof of the skidder cabin. Another radio modem received the measurement signals and transmitted them into the field computer. The software programme Catman 4.0 (Hottinger Baldwin Messtechnik GmbH) was used for making records of the measurement data at the frequency of 50 Hz. Measurement tranducers were recorded into the software programme by channels and measuring constants obtained by calibration of measurement transducers were then entered. Further data processing of the measuring results was carried out by the software programme Microsoft Excell.

During traction tests, changes were measured of wheel load of unloaded skidder on plane ground. In case of reduction of wheel load, the result of measurement will be deducted from the wheel load of the unloaded skidder, i.e. it will be added in case of increase of wheel load. Due to the described way of measurement, it was necessary to establish the mass and wheel load of the unloaded skidder. Although these data are provided by the manufacturer, by installing the measuring equipment, carriers and auxiliary structures and devices, the basic skidder mass and wheel load increased. The mass and wheel load of an unloaded skidder were determined by four scales by a Sweden manufactured TELUB connected to a measuring amplifier HBM Spider 8, which is directly connected to a laptop so that the measuring results were read by a computer programme Catman 4.0.

The measurement showed that the mass of the equipped skidder was 3647 kg, i.e. that the mass was increased by 164 kg compared to the basic mass. The front wheels were additionally loaded, 36 kg by each wheel. Rear wheels have a slightly higher load (45 kg and 47 kg), which is caused by installation of traction and tension transducers for measuring the vertical and horizontal rope force at the rear end. Traction and tension transducers are installed on the carrier connected to the carrier connected to roller bases of the winch on the skidder rear protective and anchoring blade, and since higher loads are possible, the structure of the transducer carrier is massive.

Load distribution to wheels remained almost unchanged compared to the distribution of values measured by manufacturers. The skidder front axle, equipped with the measuring devices, is loaded with 61% of the total skidder weight, and the rear axle with 39%, while the load ratio of the front/rear axle of the skidder as delivered by the manufacturer is 62%:38%. The load distribution to wheels with respect to the left and right side of the skidder is 50%:50%.

3. Research results – *Rezultati istraživanja*

The research was carried out on the strip road where longitudinal slopes were determined by the leveling method as well as individual distances of the strip road of uniform slope. Longitudinal slopes increase with the distance from the beginning of the strip road. The lowest route slope was recorded at the beginning of the strip road (2.3%), and then followed the road sections with higher longitudinal slope: 15%, 18.3%, 27.0% and 35.5%. The highest slope of the strip road was selected based on the investigation of limit slopes for skidder movement. MacDonald (1999) recorded the highest limit slope for skidders of 35% downhill, and Inoue and Tsuji (2003) the slope of 45% downhill and 30% uphill.

8 beech logs with the mean diameters ranging between 27 cm and 39 cm were used for the research. Based on the measured dimensions, log volumes were calculated. Log volumes ranged between 0.32 m^3 and 0.50 m^3. The mass of individual logs was weighed by two scales TELUB connected to the measuring amplifier HBM Spider 8 and laptop.

Based on the known volume and mass of logs, the characteristics were determined of the load to be used in traction tests. 9 types of load were selected, with 1 to 4 pieces in a load, of the size between 0.27 and 1.8 m^3 and weight ranging between 2.49 kN and 17.38 kN.

Skidders were used for carrying out traction tests in downhill and uphill skidding of different loads. The traction test consisted of skidding of a certain load from the starting point at the beginning of the strip road through parts of the strip road with increasing longitudinal slopes until the end of the strip road. If not all terrain slopes could be overcome due to too large load, the traction test would be interrupted at the slope level that could be overcome. Downhill skidding started from the highest slope.

Out of 9 uphill traction tests, i.e. skidding of 9 types of load, the skidder reached the top of the slope in six tests. In skidding the three largest loads, successful traction tests were made on the first two uphill slopes. The same occurred with downhill tractive tests: the skidding of three largest loads was only recorded for the two lowest slopes. At the final tractive tests, the wheel load was measured in uphill and downhill unloaded skidder travel.

All measuring results were expressed as mean values per traction test with individual load and the determined longitudinal slope of strip road.

Table 1 shows the measuring results of the vertical and horizontal components of rope force in timber skidding by the skidder Ecotrac 55V according to strip road slope, skidding direction and load size.

In uphill skidding, the values of the vertical component of rope forces are higher than the horizontal component on all longitudinal slopes up to 18.3% for all skidded loads. On longitudinal slopes ranging between 27.0% and 35.5% the horizontal component is higher than the vertical for load weights of 7.83 kN and 9.55 kN. With smaller loads, the vertical component of rope forces remained higher than the horizontal one. These results show that the increase of slope results in decrease of part of load pulled by the rope, i.e. the part of load dragged on the soil is increased. Therefore, higher horizontal force component is required for overcoming the traction resistance of the part of load dragged on the soil.

In downhill skidding, the vertical component of rope forces in each traction test is higher than the horizontal component. The increase of downhill slope results in the decrease of values of both components of rope forces, and the described phenomenon is more conspicuous with the horizontal component.

Table 1 Components of rope force and tractive forces
Tablica 1. *Sastavnice sile u užetu i vučne sile*

Slope *Nagib*	Load weight *Težina tovara*	Horizontal component of skidder weight *Usporedna sastavnica težine skidera*	Uphill skiding – *Privlačenje uz nagib*			Downhill skiding – *Privlačenje niz nagib*		
			Component of rope force *Sastavnica sile u užetu*		Tractive force *Vučna sila*	Component of rope force *Sastavnica sile u užetu*		Tractive force *Vučna sila*
			Vertical *Okomita*	Horizontal *Usporedna*	*Fv*	Vertical *Okomita*	Horizontal *Usporedna*	*Fv*
	Q	*G*sin	*V*	*H*	*H* + *G*sin	*V*	*H*	*H* – *G*sin
	kN	kN	kN			kN		
2.3%	2.49	0.84	1.494	0.613	1.45	1.468	0.357	–0.48
	3.11		1.646	1.020	1.86	1.576	0.589	–0.25
	3.69		2.125	0.732	1.57	2.010	0.703	–0.14
	6.72		3.813	1.796	2.64	3.689	0.973	0.13
	7.83		4.055	2.024	2.87	3.777	1.706	0.86
	9.55		4.471	3.140	3.98	4.126	1.944	1.10
	12.03		6.621	3.407	4.25	6.265	2.418	1.58
	14.91		7.018	4.133	4.97	7.239	3.345	2.50
	17.38		9.472	5.593	6.43	7.815	5.656	4.81
15.0%	2.49	5.39	1.496	0.769	6.16	1.450	0.147	–5.24
	3.11		1.674	1.278	6.67	1.564	0.303	–5.09
	3.69		2.264	1.302	6.69	1.984	0.499	–4.89
	6.72		3.858	2.082	7.47	3.502	0.450	–4.94
	7.83		4.520	2.814	8.20	3.584	1.295	–4.10
	9.55		4.686	3.397	8.79	3.824	1.091	–4.30
	12.03		7.027	4.142	9.53	6.234	1.643	–3.75
	14.91		7.714	5.434	10.82	7.055	2.329	–3.06
	17.38		10.444	6.461	11.85	7.647	4.217	–1.17
18.3%	2.49	6.59	1.502	0.942	7.53	1.496	0.215	–6.37
	3.11		1.651	1.285	7.87	1.681	0.421	–6.16
	3.69		2.235	1.319	7.90	1.971	0.473	–6.11
	6.72		3.618	2.432	9.02	3.369	0.343	–6.24
	7.83		4.070	3.775	10.36	3.881	1.084	–5.50
	9.55		4.240	3.960	10.55	3.326	0.640	–5.94
27.0%	2.49	9.54	1.485	1.125	10.66	1.426	0.029	–9.51
	3.11		1.583	1.420	10.96	1.487	0.259	–9.28
	3.69		2.202	1.503	11.04	1.828	0.182	–9.35
	6.72		3.664	3.083	12.62	3.350	0.118	–9.42
	7.83		3.917	4.190	13.73	3.523	0.803	–8.73
	9.55		4.285	4.816	14.35	3.498	0.454	–9.08
35.5%	2.49	12.24	1.503	1.384	13.62	1.151	0.030	–12.21
	3.11		1.618	1.732	13.97	1.234	0.187	–12.05
	3.69		2.229	1.730	13.97	1.424	0.312	–11.93
	6.72		3.734	3.857	16.10	3.134	0.103	–12.14
	7.83		3.978	4.647	16.89	3.480	0.258	–11.98
	9.55		4.545	5.926	18.16	3.164	0.930	–11.31

The lowest value of the horizontal component of rope forces (0.03 kN) was recorded in downhill skidding with the slope of 27% and 35% of the smallest load of 2.49 kN. In downhill skidding on higher longitudinal slopes, the front end of the load gets closer to the rear end of the skidder, which causes the increase of the vertical component of rope forces that holds the load eleveted off the soil. In doing so, lower horizontal component of forces is required because lower weight of the load is dragged on the soil.

It was not possible to tie the loads made of three or four timber assortments to the carrier of the rope tied to transducers exclusively with the heavier end eleveted off the ground. With respect to the position of timber assortments in the load, and the position of the load with resprect to the rear end of the skidder, irregular sequence of values of horizontal component of forces was observed in downhill skidding on the two highest longitudinal slopes.

In uphill skidding, the tractive force is used for overcoming the traction resistance of the part of load dragged on the soil (*H*) and the opposite effect of resistance of horizontal component of skidder weight ($G \sin\alpha$) that pulls the skidder downhill, due to the effect of gravitation, in the opposite direction of traction. Table 1 shows the values of this calculation of tractive force. It can be seen from the presented data that the values of horizontal component of skidder weight increase with the increase of the slope of the test skid trail. On lower slopes, the effect of horizontal component of rope forces, used for overcoming the traction resistance, increases, because the horizontal component of the skidder weight has lower values due to small angles. From the slope of 18.3%, the effect of horizontal component of skidder weight on the value of the tractive force is considerably higher than the traction resistance, regardless of the size of the skidded load.

In downhill slope, the horizontal component of skidder weight ($G \sin\alpha$) acts in the direction of skidder travel, by which traction resistances are overcome more easily. Only on the lowest slope, positive values were recorded of the tractive force, due to low inclination of the skid trail (the value $G \sin\alpha$ that is deducted from the the horizontal component of the traction resistance is only 0.84 kN). On other skid trail slopes the calculated values of tractive forces were mostly negative. It can be clearly seen from the above data that due to the increase of the load weight (*Q*), and hence also of the horizontal component of rope forces (*H*), the negative values of tractive forces are usually decreased, and however compared to the effect of the skidder weight in the traction direction, this effect on the value of the tractive force is incomparably lower.

The dependence of the tractive force on the load weight, skidding direction and strip road slope is shown in Fig. 6 and 7. In uphill skidding, the tractive force increases with the increase of the longitudinal slope and load weight. With the increase of the slo-

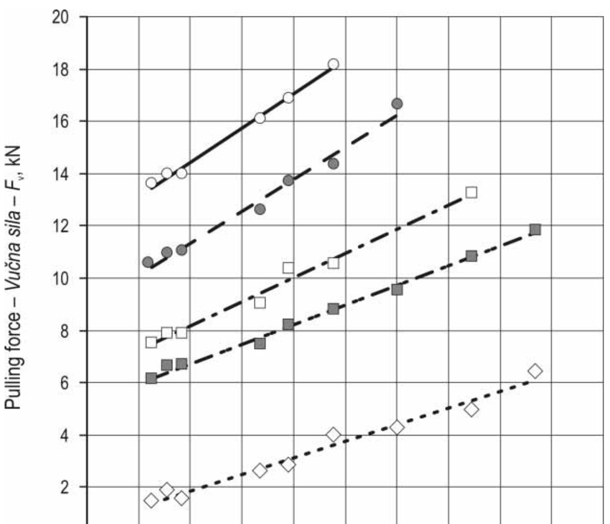

Fig. 6 Dependance of tractive force on load weight in uphill skidding

Slika 6. *Ovisnost vučne sile o težini tereta pri vuči uz nagib*

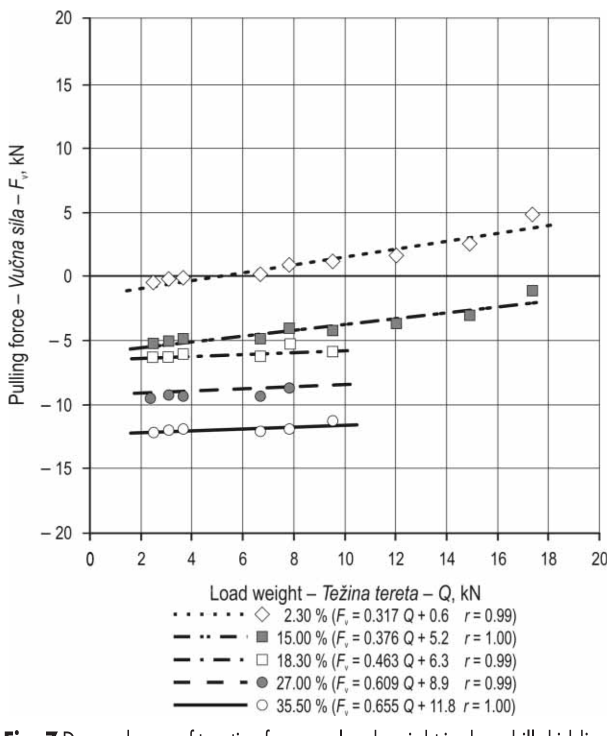

Fig. 7 Dependance of tractive force on load weight in downhill skidding

Slika 7. *Ovisnost vučne sile o težini tereta pri vuči niz nagib* pe, resistances increase caused by the impact of the part of skidder weight, acting contrary to the traction direction, and the increase of load weight increases the values of the horizontal component of rope forces (traction resistance). The skidder's tractive force must overcome the values of both resistances in uphill skidding. In downhill skidding, based on low inclination of regression lines, it can be established that horizontal component of the skidder weight has a lower impact on the values of tractive forces, than the impact of traction resistance.

In this research, the wheel load was determined from the data of dynamic measurement of changes of wheel loads in traction tests from the previoiusly determined values of statistical weight distribution of unloaded skidder.

Tables 2 and 3 show the measured skidder's adhesive weights and axle load distribution in traction tests. The results of measurement of unloaded skidder travel are presented for the purpose of analysing the impact of load weight and strip road slope on axle load distribution.

During uphill travel of unloaded skidder, the front axle load decreases with the increase of longitudinal slope. On the highest slope of 35.5%, the rear axle load of the unloaded skidder is higher due to the effect of horizontal component of skidder weight $G{\cdot}\sin\alpha$, which contributes to the transfer of load weight from the front axle to the rear axle.

In traction tests, the rear axle load increases with the increase of load weight and slope. The increase of load weight increases the vertical component of rope forces that carries the part of load eleveted off the ground and additionally increases the load on the rear axle. On the lowest slope, the front axle is under higher load with the 4 smallest loads, on the following slope of 15% with the three smallest loads, on slopes of 18.3% and 27% only with the smallest load. On the highest slope, higher load was recorded on the rear axle in all tracton tests.

Sever (1984) states that the longitudinal stability of the skidder is questionable when the load ratio of the front and rear axle reaches the value of 1:3.5 or 22%:78%. According to Weise and Nick (2003) at least 10% of the total dynamic load should remain on the front axle so as to enable steering.

The highest load of the rear axle was recorded in skidding the largest load of 17.38 kN on the slope of 15% and it was 76% of the total adhesive weight. Under such conditions, 24% of the total adhesive weight remains on the front axle, which is very close to the limit value when the skidder's longitudinal stability is compromised. This is why the skidder could not pull the three largest loads on the following slope of the strip road of 18.3%. Higher values of the vertical force component with these loads along with the effect of the horizontal component of the skidder weight $G \sin\alpha$ on such longitudinal slope would result in the decrease of the front axle load under the limit value of 22% of the total adhesive weight and in the disruption of the skidder's longitudinal stability.

The analysis of the measuring results of downhill traction tests shows higher load of the front axle with the increase of the slope in skidding the same load, but also higher load of the front axle with the decrease of load weight on the same slope.

In all traction tests, including the unloaded skidder, on slopes higher than 18.3% in download skidding, higher load of the skidder's front axle was recorded. It should be noted that in downhill skidding of the largest loads on lower slopes, the load of the skidder's rear axle is higher than the load of its front axle, i.e. the load of the front axle decreases with respect to the rear axle. It can be concluded that the horizontal component of the skidder weight ($G \sin\alpha$) contributses to the load transfer from the rear axle to the front axle, but overcoms the effect of the vertical component of rope force (V) so that higher load is applied on the rear axle.

As already explained, the essence of the effect of the skidder transmission system is the transmission of torque from the engine to the wheel. In doing so, the value of torque changes, starting with the gear box, through drive distributio to the final (planetary) drives in skidder wheels. As the transmission system with skidders is mechanical, the torque is tramsmitted mechanically and during this transmission its value changes with respect to wheel load.

Along with wheel load distribution Tables 2 and 3 also show the measured mean values of the skidder axle torque distribution.

In uphill skidding, uniform increase can be observed of the total values of torques with the increase of load and slope. When analisying the torques of the front and rear axle, it can be clearly seen that the increase of the load results in considerable increase of rear wheel torques, and in the decrease of front wheel torques, which is in accordance with the above considerations on loads. The skidder could not reach the top of the 3 highest slopes with the largest load, but on the last slope of 18.3% that was overcome, the mean torque of 7.0 kNm was achieved at the rear wheels, which is the highest value achieved up to that slope in all uphill traction tests. After that, the highest value of the skidder's rear axle torque is achieved in traction tests on higher slopes with the heaviest loads with which the said slopes were overcome.

In downhill skidding on testing skid trails, a very interesting situation appears in the analysis of the skidder's wheel torques in timber skidding. On the

Table 2 Axle load and torque distribution in uphill skidding

***Tablica 2.** Raspodjela opterećenja i momenata po osovinama pri privlačenju uz nagib*

Slope *Nagib*	Load weight *Težina tovara*	Uphill skiding – *Privlačenje uz nagib*					
		Adhesive weight *Adhezijska težina*	Axle load distribution *Raspodjela opterećenja*		Torgue *Moment*	Torgue distribution *Raspodjela momenata*	
			Front axle *Prednji most*	Rear axle *Stražnji most*		Front axle *Prednji most*	Rear axle *Stražnji most*
	Q, kN	G_a, kN	G_{aF}, %	G_{aR}, %	M, kNm	M_F, %	M_R, %
2.3%	0	35.479	60	40	2.401	62	38
	2.49	37.556	58	42	3.000	60	40
	3.11	37.433	57	43	3.324	57	43
	3.69	38.032	57	43	3.141	57	43
	6.72	39.220	52	48	3.730	52	48
	7.83	42.444	46	54	4.059	45	55
	9.55	40.835	47	53	4.419	45	55
	12.03	44.871	43	57	5.074	40	60
	14.91	43.971	40	60	5.453	41	59
	17.38	46.439	34	66	6.298	34	66
15.0%	0	35.142	57	43	5.016	56	44
	2.49	37.125	55	45	5.466	54	46
	3.11	37.754	53	47	5.958	51	49
	3.69	39.080	52	48	6.185	50	50
	6.72	40.498	46	54	6.459	46	54
	7.83	41.974	42	58	7.143	44	56
	9.55	42.512	41	59	7.341	42	58
	12.03	43.686	37	63	8.014	36	64
	14.91	44.714	31	69	8.559	31	69
	17.38	45.613	24	76	9.093	23	77
18.3%	0	34.661	56	44	5.837	56	44
	2.49	37.398	53	47	6.246	53	47
	3.11	38.189	50	50	6.508	50	50
	3.69	39.395	50	50	6.729	51	49
	6.72	39.643	47	53	7.439	47	53
	7.83	41.547	39	61	8.217	38	62
	9.55	40.201	37	63	7.955	37	63
27.0%	0	36.695	53	47	7.025	52	48
	2.49	37.838	50	50	8.053	49	51
	3.11	37.617	46	54	8.209	46	54
	3.69	39.188	48	52	8.422	50	50
	6.72	38.497	42	58	9.228	42	58
	7.83	40.161	34	66	9.511	34	66
	9.55	37.736	33	67	9.846	34	66
35.5%	0	36.306	48	52	8.543	46	54
	2.49	37.588	46	54	9.547	47	53
	3.11	37.088	43	57	9.956	44	56
	3.69	36.612	44	56	9.771	45	55
	6.72	39.444	37	63	11.128	37	63
	7.83	39.863	30	70	11.250	28	72
	9.55	38.228	31	69	12.294	31	69

Table 3 Axle load and torque distribution in downhill skidding

Tablica 3. *Raspodjela opterećanja i momenata po osovinama pri privlačenju niz nagib*

Slope *Nagib*	Load weight *Težina tovara*	Downhill skiding – *Privlačenje niz nagib*					
		Adhesive weight *Adhezijska težina*	Axle load distribution *Raspodjela opterećenja*		Torgue *Moment*	Torgue distribution *Raspodjela momenata*	
			Front axle *Prednji most*	Rear axle *Stražnji most*		Front axle *Prednji most*	Rear axle *Stražnji most*
	Q, kN	G_a, kN	G_{aF}, %	G_{aR}, %	M, kNm	M_F, %	M_R, %
2.3%	0	38.040	66	34	1.967	65	35
	2.49	36.369	59	41	1.806	59	41
	3.11	36.460	58	42	1.973	55	45
	3.69	36.616	60	40	2.140	63	37
	6.72	39.311	54	46	2.427	52	48
	7.83	39.509	49	51	2.900	47	53
	9.55	39.294	49	51	2.608	49	51
	12.03	41.394	44	56	3.450	45	55
	14.91	44.872	42	58	4.058	41	59
	17.38	45.100	37	63	4.963	38	62
15.0%	0	34.593	68	32	–0.893	66	34
	2.49	37.719	68	32	–0.604	68	32
	3.11	37.537	67	33	–0.518	69	31
	3.69	37.188	65	35	–0.429	67	33
	6.72	37.342	58	42	–0.442	59	41
	7.83	39.287	54	46	0.240	50	50
	9.55	38.699	57	43	–0.022	50	50
	12.03	42.862	50	50	0.504	49	51
	14.91	42.463	48	52	0.959	46	54
	17.38	45.291	43	57	2.070	42	58
18.3%	0	35.271	67	33	–1.433	65	35
	2.49	37.314	69	31	–1.167	69	31
	3.11	36.743	66	34	–1.069	64	36
	3.69	37.366	63	37	–1.011	63	37
	6.72	37.318	59	41	–1.203	59	41
	7.83	37.606	57	43	–0.725	54	46
	9.55	37.337	59	41	–1.067	56	44
27.0%	0	34.989	69	31	–3.350	69	31
	2.49	35.729	73	27	–3.176	73	27
	3.11	35.062	71	29	–2.911	72	28
	3.69	36.694	64	36	–2.911	64	36
	6.72	36.659	66	34	–3.059	68	32
	7.83	37.172	59	41	–2.621	59	41
	9.55	38.068	65	35	–2.832	65	35
35.5%	0	33.742	73	27	–4.579	76	24
	2.49	35.388	76	24	–4.149	77	23
	3.11	36.698	71	29	–4.307	73	27
	3.69	35.846	67	33	–4.693	67	33
	6.72	36.295	69	31	–4.332	70	30
	7.83	37.343	66	34	–4.170	65	35
	9.55	36.187	67	33	–4.251	68	32

lowest negative slope, the wheel torque is positive. On the following longitudinal slope of 14.9% in skidding smaller loads, negative torque appeared at the skidder shafts, in very low negative amounts that ranged between –0.2 kNm and –0.9 kNm in unloaded skidder travel. In skidding larger loads, the skidder had to achieve the required combination of tractive forces by positive amounts of total wheel torques of 0.2 kNm and up to 2.1 kNm.

On the following slope of 18.3%, in skidding of all types and sizes of loads in unloaded skidder travel, all values of torques were recorded in negative amounts. The negative values of total torques are relatively low and they range between –0.7 kNm in skidding the heaviest load, tested on this slope, and –1.4 kNm achieved durting unloaded skidder travel.

We have a similar situation with the last two highest slopes, with the difference that the amounts of the achieved negative wheel torques are considerably higher and they range between –2.6 kNm and –4.7 kNm, which implies that the increase of negative slope results in the increase of the achieved negative amounts of torques.

This phenomenon of negative skidder wheel torques in downhill skidding was also recorded by Marenče (2005) and Šušnjar and Horvat (2006). In this case, torques are not used for generating wheel tractive forces, and instead, the transmission of torque through the transmission system causes skidder's braking performance. The skidder's need for braking arises under the influence of the horizontal component of the skidder weight ($G \sin\alpha$) that pushes the skidder downhill.

Torque distribution to skidder axles shows the same ratios as wheel load distribution. Considering the impact of the vertical component of rope forces (V) on the value of the skidder adhesive weight, the analysis was made of torque dependence right on this value (force). Figures 8 and 9 show the data with regression lines. Points on the ordinate axis represent wheel torques during unloaded skidder travel on testing skid trails. At such values, torques enable overcoming of terrain slope and rolling resistance of an unloaded skidder.

In uphill skidding (Fig. 8) it can be observed that the increase of the vertical component of rope forces results in the increase of skidder wheel torque. This can be understood because the vertical component of rope forces directly causes the increase of the skidder adhesive weight, and hence also the rolling resistance, which is consequentially related to the increase of torques that must enable the generation of the circumferential force required for overcoming this increased resistance and other traction resis-

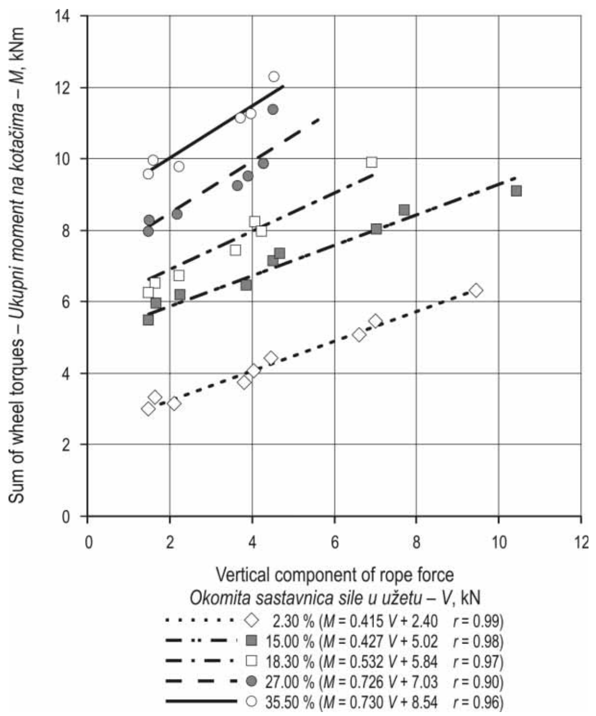

Fig. 8 Dependance of wheel torque on vertical component of rope force and uphill slope

Slika 8. *Ovisnost zakretnoga momenta na kotačima o vertikalnoj sastavnici sile u užetu i nagibu u usponu*

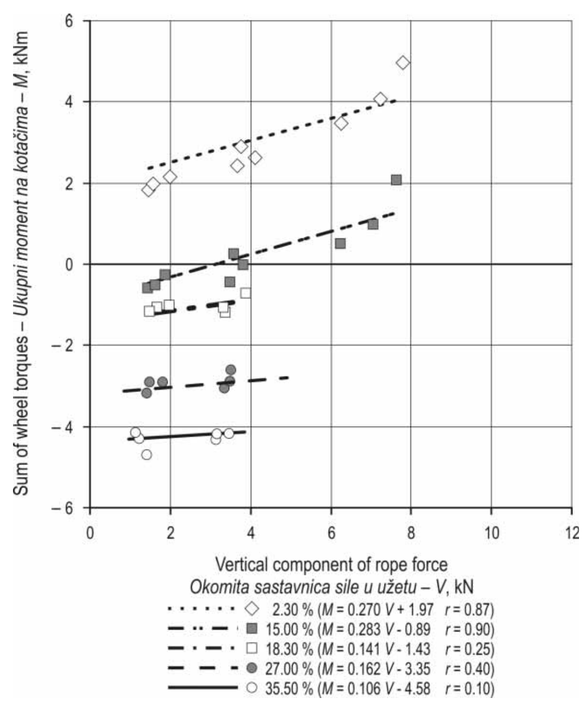

Fig. 9 Dependance of wheel torque on vertical component of rope force and downhill slope

Slika 9. *Ovisnost zakretnoga momenta na kotačima o vertikalnoj sastavnici sile u užetu i nagibu u padu* tances. According to the position and equations of regression lines it can also be read from Fig. 8 that the value of slope and load (load size) undoubtedly affect the value of wheel torque. On lower slopes, the lines are more horizontal (direction coefficients of 0.42 and 0.43), which means that the increase of the vertical component of rope forces result in slower increase of torque. On higher slopes this impact is definitey more significant (0.73). It can be concluded from this analysis that the value of wheel load that represent the pulled load affects considerably the increase of the values of required wheel torque.

In downhill skidding, it can be observed in Fig. 9 according to the heights of regression lines that here the values of parallel skidder weight forces have a prevailing impact on the value of the skidder wheel torques. This is confirmed by low values of the correlation coefficient of regression lines. However, the impact of the vertical component of rope forces can be seen in the increase of the rolling resistance, by which the skidder's downhill travel is slowed, and hence less braking is necessary as well as lower torque. Thus, it can be concluded from the survey of achieved torques in downhill travel that the negative values of wheel torques were decreased in skidding larger loads at the highest slopes.

4. Conclusions – *Zaključci*

The determination of dependence of components of rope forces, skidder load and wheel torques on load weight and terrain slope represents a significant relationship for the possibility of assessing skidder traction characteristics in timber skidding.

Torque distribution depends on the skidder wheel vertical load. In uphill skidding, torques increase proportionally to the vertical component of rope forces and adhesive weight of the skidder.

According to the results of research, the following conclusions can be made related to the effect of forces with respect to the required tractive force in uphill skidding: by the increase of longitudinal slope, more tractive force is used for overcoming the terrain slope than for overcoming the traction resistance. In downhill skidding, the horizontal component of the skidder weight (G sinα) acts in the skidder travel direction and hence its value is higher than the traction resistance.

In the same way, with downhill skidding, the skidder wheel torques are negative, because they are not used for achieving wheel tractive force and instead, the transmission of torque through the transmission system causes skidder's braking performance. The skidder's need for braking arises under influence of the horizontal component of the skidder weight (G sinα) that acts in the direction of the skidder travel and under its effect the traction resistances are overcome. Further to the above said, it can be concluded that in case of downhill skidding we cannot speak of achieving real tractive force because the skidder pulls the load only by its weight, and the transmittion from engine to wheels is not used for achieving the tractive force.

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Sažetak

Utjecajne sile pri privlačenju drva

Cilj je rada utvrđivanje ovisnosti sastavnica sila u užetu, raspodjele opterećenja kotača i zakretnih momenata o težini tovara i nagibu terena. Ti su odnosi važni za mogućnost procjene vučnih (eksploatacijskih) svojstava skidera pri privlačenju drva.

Skideri, kao šumska vozila za privlačenje drva, isključivo su namijenjeni postizavanju vučne sile koja se ostvaruje preko oboda kotača. Sustavom transmisije skidera prenosi se i mijenja zakretni moment od pogonskoga motora na kotače. Zbog djelovanja zakretnoga momenta na kotaču se javlja obodna sila. Horizontalna se sastavnica obodne sile dijelom troši za svladavanje otpora kotrljanja vozila (F_f), a ostali dio sile (F_v) služi za vuču tereta, svladavanje nagiba i površinskih prepreka terena ili ubrzavanje vozila (Wong 2001, Stoilov 2007).

U primjeni skidera opremljenih šumskim vitlom drvo se privlači s jednim krajem tovara odignutim od tla i preko užeta vitla oslonjenim na zadnji kraj vozila, dok se drugi kraj tovara vuče po tlu. Sila koja se javlja u užetu služi za nošenje težine dijela tovara odignuta od tla (vertikalna sastavnica – V) te za svladavanje otpora vuče dijela težine tovara oslonjena na tlo (horizontalna sastavnica – H).

Pod adhezijskom se težinom (G_a) razumijeva zbroj okomitih opterećenja na pogonskim kotačima skidera u uvjetima pridobivanja drva (Tomašić i dr. 2007). Prema tomu je adhezijska težina različita od težine praznoga skidera (G) jer se stražnji most dodatno opterećuje punim iznosom vertikalne sastavnice sile u užetu, koja se raspoređuje na stražnje kotače preko horizontalnih valjaka vitla (Hassan i Gustafson 1983).

Raspodjela se opterećenja po mostovima skidera mijenja s obzirom na obujam i težinu tovara, orijentaciju sortimenata u tovaru, smjer kretanja i veličinu nagiba terena. Kretanjem po uzdužnom nagibu dodatno se opterećuje stražnji most jer dolazi do prijenosa opterećenja težine skidera s prednjega mosta zbog djelovanja usporedne sastavnice težine skidera (G sinα). Pri privlačenju uz nagib vučna sila treba svladati vučne otpore dijela tovara oslonjenoga na tlo (H), ali i otpor horizontalne sastavnice težine skidera (G sinα) koja povlači vozilo prema dolje (slika 1).

Pri kretanju niz nagib zbog djelovanja horizontalne sastavnice težine skidera (G sinα) opterećenje se težine skidera prenosi na prednji most (slika 2). Također će horizonatalna sastavnica težine skidera djelovati u smjeru kretanja skidera te je potrebno svladati jedino vučne otpore dijela tovara oslonjena na tlo (H).

Zbog različitih opterećenja na kotačima transmisija mora omogućiti i raspodjelu zakretnoga momenta s obzirom na opterećenje kotača. Prema tomu kod mehaničkoga sustava transmisije raspodjela momenata po kotačima treba biti u skladu s raspodjelom opterećenja po kotačima.

U istraživanju je korišten skider ECOTRAC 55 V opremljen šumskim vitlom Hittner 2 × 35 kN (slika 3). Za mjerenje dinamičkoga opterećenja skidera konstruirana su ili primijenjena mjerila za istodobno određivanje sastavnica sile u užetu, zakretnih momenata i opterećenja na svim pogonskim kotačima.

Istraživanja su provedena na traktorskom putu gdje su metodom niveliranja utvrđeni uzdužni nagibi te pojedine udaljenosti traktorskoga puta jednolika nagiba. Početni dio traktorskoga puta ima najmanji nagib trase (2,3 %), a zatim uzastopno slijede dijelovi puta sa sve većim uzdužnim nagibom: 15 %, 18,3 %, 27,0 % i 35,5 %. Odabrano je 9 vrsta tovara, s 1 do 4 komada u tovaru, veličinom od 0,27 do 1,8 m^3 te težinom od 2,49 kN do 17,38 kN. Skiderom su se izvodili vučni pokusi privlačenja različitih tovara uzbrdo i nizbrdo. Svi su rezultati mjerenja izraženi u srednjim vrijednostima mjerenja po vučnom pokusu s pojedinim tovarom i određenim uzdužnim nagibom traktorskoga puta.

Rezultati mjerenja okomite i usporedne sastavnice sile u užetu pri privlačenju drva skiderom Ecotrac 55V prikazani su prema uzdužnomu nagibu traktorskoga puta, smjeru privlačenja i veličini tovara u tablici 1. Pri privlačenju uz nagib rezultati pokazuju da se s povećanjem nagiba smanjuje težina dijela tovara koji je nošen na užetu, tj. povećava se dio težine tovara koji se oslanja na tlo. Stoga je potrebna veća usporedna sastavnica sile za svladavanje otpora vuče dijela tovara po tlu. Pri privlačenju niz nagib prednji se kraj tereta približava stražnjemu kraju skidera čime raste okomita sastavnica sile u užetu koja tovar drži odignutim od tla. Pri tome je potrebna manja usporedna sastavnica sila jer je manja težina tovara oslonjena na tlo.

U tablici 1 prikazani su iznosi izračuna vučne sile. Pri privlačenju uz nagib porastom uzdužnoga nagiba veći se dio vučne sile troši za svladavanje nagiba terena nego za svladavanje vučnih otpora. Pri privlačenju niz nagib usporedna sastavnica težine skidera (G sinα) djeluje u smjeru kretanja skidera, čime se olakšava svladavanje vučnih otpora. Samo na najmanjem nagibu utvrđene su pozitivne vrijednosti vučne sile. Na ostalim nagibima vlake izračunate su vrijednosti vučnih sila, uglavnom negativne. Ovdje se dakle ne radi o ostvarivanju vuče u pravom smislu jer prevladavaju gravitacijski utjecaji djelovanja sila na nagibu, već se vuča drva ostvaruje djelovanjem težine skidera u smjeru vuče.

Ovisnost vučne sile o težini tovara, smjeru privlačenja i nagibu traktorskoga puta prikazana je na slikama 6 i 7. Pri privlačenju uz nagib vučna sila raste s povećanjem uzdužnoga nagiba i težine tereta. Pri privlačenju niz nagib može se utvrditi veći utjecaj usporedne sastavnice težine skidera na vrijednosti vučnih sila od utjecaja sila vučnih otpora.

U provedenom je istraživanju opterećenje na kotačima određeno iz podataka dinamičkih mjerenja odstupanja opterećenja na kotačima u vučnim pokusima od prije utvrđenih vrijednosti statičke raspodjele težine neopterećenoga skidera. U tablicama 2 i 3 prikazane su izmjerene adhezijske težine skidera i raspodjela opterećenja po mostovima u vučnim pokusima. Radi analize utjecaja težine tovara i nagiba traktorskoga puta na raspodjelu opterećenja po mostovima prikazani su rezultati mjerenja pri kretanju neopterećenoga skidera.

U vučnim se pokusima uz nagib opterećenje stražnjega mosta povećava s povećanjem težine tovara i nagiba. U raščlambi mjernih rezultata vučnih pokusa niz nagib uočava se jače opterećivanje prednjega mosta s povećanjem nagiba pri privlačenju istoga tovara, ali se također povećava opterećenje prednjega mosta sa smanjenjem težine tovara na istom nagibu.

U svim vučnim pokusima niz nagib veći od 18,3 % zabilježeno je veće opterećivanje prednjega mosta skidera. Zanimljivo je primijetiti da pri vuči najvećih tovara niz manje nagibe opterećenje stražnjega mosta premašuje ono na prednjoj osovini skidera, odnosno prednja se osovina rasterećuje više od stražnje. Zaključak je da horizontalna sastavnica težine skidera (G sinα) pridonosi prijenosu opterećenja sa stražnjega mosta na prednji, ali prevladava djelovanje vertikalne sastavnice sile iz užeta (V) tako da je veće opterećenje na stražnjem mostu.

U tablicama 2 i 3 usporedno s raspodjelom opterećenja po kotačima prikazane su mjerene srednje vrijednosti zakretnih momenata raspodjela momenata po mostovima skidera.

Raspodjela zakretnih momenata u ovisnosti je o vertikalnom opterećenju na kotačima skidera. Pri privlačenju uz nagib zakretni momenti proporcionalno rastu s vertikalnom sastavnicom sile u užetu i adhezijskom težinom skidera. Pri privlačenju niz nagib zakretni su momenti na kotačima skidera negativni jer ne služe za ostvarivanje vučne sile na kotačima, već se prijenosom zakretnoga momenta kroz sustav transmisije skider koči. Potreba za kočenjem skidera očituje se u utjecaju horizontalne sastavnice težine skidera (G sinα) koja djeluje u smjeru kretanja skidera i zbog njezina djelovanja dolazi do svladavanja vučnih otpora. Iz navedenoga izlazi da se u slučaju privlačenja niz nagib ne može govoriti o ostvarivanju prave vuče jer skider vuče tovare svojom težinom, a prijenos snage s pogonskoga motora na kotače ne koristi se za ostvarivanje vučne sile.

Ključne riječi: skider, opterećenje kotača, zakretni momenti, vučna sila, adhezijska težina, nagib

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