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WHEEL SLIP DURING WOOD EXTRACTION

Klizanje kotača prilikom privlačenja drva

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Abstract

In the paper is conducted comparison of the wheel slip of the two different skidders in the equal conditions of extraction (equal loads and slopes of the tractor road and skid trail). The first skidder in the research is ECOTRAC 120 V of the Croatian manufacturer Hittner d.o.o. with the mechanical transmission and the other skidder is of the Slovenian manufacture WOODY 110 with the hydrostatic transmission.
Wheel slip of the skidder during the research is determined on the basis of the number of wheel rotations. Distance travelled is calculated from the multiplied number of rotations of the fifth wheel and its circumference.
During the extraction downhill, the wheel slip is negative. Generally, it could be said that, in the same conditions during the extraction uphill, wheel slip is increased with the increase of load weight and during the extraction downhill are less negative values of slip with the increase of the load weight.
By comparing the wheel slip at the researched skidders are established the advantages of the hydrostatic mechanic transmission during the wood extraction uphill. But, during the extraction downhill, with the mechanic transmission are achieved less wheel slips.

Key words: *Skidder, wheel slip, wood extraction, mechanic transmission, hydrostatic transmission*

INTRODUCTION - *Uvod*

Research goal is the comparison of wheel slip of the two different skidders in the equal conditions of extraction (equal loads and slopes of the tractor road and skid trail). The comparison of wheel slip will be implemented on the skidders of the different system of the power transfer. The first skidder in the research is ECOTRAC 120 V, of the Croatian manufacturer Hittner d.o.o. with the mechanical transmission and the other skidder is of the Slovenian manufacture WOODY 110 with the hydrostatic transmission. Both researched skidders belong in the same group of medium skidders, more exactly are of the equal mass, which is approximately 7.2 tons. The basis for the comparison of wheel slip of the mentioned skidder are the

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previous implemented studies of the tractive characteristics of the skidder ECOTRAC 120 V ŠUŠNJAR, (2005) and skidder WOODY 110 MARENČE, (2005).

MATERIAL AND METHODS – *Materijal i metode*

Wheel slip is impossible to avoid because the traction of the wheel is conducted based on the basis of the shear stress in the ground. Wheel slip during the wood extraction with skidder is a limiting factor for realizing of the necessary tractive force. SEVER (1980) states the conclusions on the ratio of the slip and tractive force: there is no slip without the existence of the tractive force, or the tractive force without the slip. Even with the smallest thrust force on the wheel appears the slip. At some percentage of the slip appears the threshold size of the tractive force. The same author establishes limit slip percentage of 40% where it is recorded the net tractive factor of 0.3. SAARILAHTI (2002) also mentions the limit percentage of the slip of 40% while in the bigger percentages of slip determines the sudden decline of the effective energy on the wheel and bigger damages of the ground.

The slip itself as an phenomenon does not limit the necessary thrust force or tractive force, but it represents the energy loss that reduces the speed of movement of the vehicle HORVAT (1993a) and thereby the effectiveness of the working machine. Wheels slip effect on the creation of the rut and soil compaction. ARNUP (1998) mentions that at the wheels slip the contact pressure on the ground is up to five times higher than the nominal pressure. Greater compaction of the ground at the appearance of the wheel slip may be explained with the long term effect of the wheel pressure at the same ground surface. The reduction of the wheel slip can be achieved by the use of the chains on the wheels, by the differential lock control, wheel slip control systems MEEK (1996) or by hydrostatic or mechanical and hydrostatic transmission RIEPPO et al (2002) in order to harmonize torque and necessary tractive force.

Measurement of the wheel slip of the skidder ECOTRAC 120 V and WOODY 110 during wood extraction on the different slopes of the tractor road or trail were performed within the complex research of the tractive characteristics of the mentioned skidders. The research of the tractive characteristics of the skidder includes the surveying of several technical characteristics, for which it was necessary to set more different measurement transducers on the forest vehicle.

For the determination of the tractive characteristics of the skidder, several measurement devices were designed or purchased and applied for the simultaneous measurement of the following values:

1. Torques on each wheel, M (Nm),
2. Loads on each wheel, G_{ak} (kN),
3. Number of the rotations of each wheel, n,
4. Number of the rotations of the fifth wheel, $n_{5K,}$
5. Horizontal component of the force in a rope, H (kN),
6. Vertical component of the force in a rope, V (kN),
7. Time, t (s).

Calculation of the following technical characteristics of the skidders during wood extraction can be performed on the basis of the surveying data of the mentioned values: adhesive weight of the skidder, tractive and thrust forces, skidding factors, gross and net traction and rolling coefficients, dynamic radius of the wheel, forces in the rope and the rope inclination angles, load weight distribution coefficient, speed of wheel movement, wheel slip, thrust and tractive power and the force of rolling resistance and usefulness of the wheels.

Basic method of measurement of the mechanical values is tensometry. 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 length (the so-called "strain gauge").
The application of the tensometry method enables the measurement without affecting adversely the vehicle structure, but it requires the transformation of vehicle elements into measurement parameters. For expressing of the values of the measured values in its basic measure unit, it is necessary the scale calibration elements.

Tensometric method was used by SEVER (1987), MARKLUND (1987), HORVAT (1987), MARENČE (2005) and ŠUŠNJAR and HORVAT (2006), and TOMAŠIĆ et al (2009) for measuring wheel torques and wheel load of skidders and forwarders.

Measurement of the dynamic wheel loadss and torques at the skidders ECOTRAC 120 V is performed with the application of the strain gauges positioned on the construction of the skidder, that is, on the upper side of the shaft's housing and on the circumference of the housing of the final planetary gears. (ŠUŠNJAR, 2005).
In the measurement of the skidder WOODY 110 wheel doses/dynamometers with the build in strain gauges for each were constructed for measuring of the dynamic wheel loads and torques (Figure 1). MARENČE (2005)

Figure 1. Dynamometer with the build in strain gauges for measurement of the torques and wheel loads of the skidder Woody 110 (MARENČE 2005)
Slika 1. Dinamometar sa ugrađenim mjernim trakama za mjerenje zakretnih momenata i opterećenja na kotačima skidera Woody 110 (MARENČE (2005)

Determining of the horizontal and vertical component of the force in a rope during the wood extraction at the both researched skidder has been performed with the application of the two dynamometers. Dynamometers are interconnected under the angle of 90º degrees and positioned on the carrier which is fixed in an articulated manner on the place of the vertical rollers of the winch (Figure 2 and 3).

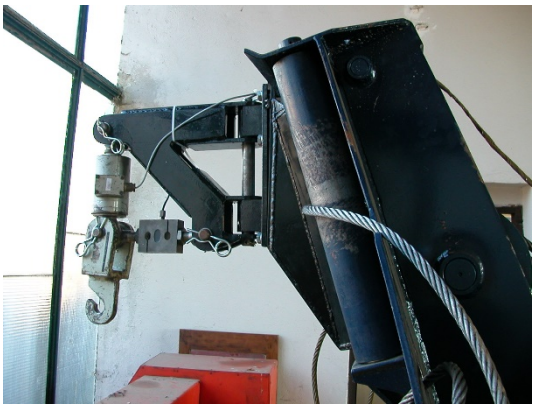

Figure 2. Dynamometers on the skidder Ecotrac 120 V (ŠUŠNJAR 2005)
Slika 2. Dinamometri na skideru Ecotrac 120 V (ŠUŠNJAR 2005)

Figure 3. Dynamometers on the skidder Woody 110 (MARENČE 2005)
Slika 3. Dinamometri na skideru Woody 110 (MARENČE 2005)

For determining of the number of rotations of the wheel ECOTRAC 120V on each wheel are positioned slip converters with the ring and graphite brushes, which were used as the encoders.

On the wheel axis of the skidder WOODY is positioned rotary optical encoder for measuring the distance travelled of the drive wheel, including the slip.

Actual distance travelled is measured with the mounting of the free rolling fifth wheel and its application is necessary for determining of the speed of movement of the skidder and wheel slip by the comparison of its number of the rotations and number of rotations of the driven wheels.

The fifth wheel is positioned in the articulated manner on the front board of the skidder (Figure 4 and 5) and the length of the distance travelled is determined on the basis of its number of rotations and measured circumference of the wheel.

Wheel slip of the skidder during the research is determined on the basis of the number of rotations of the wheels on the road.

With the assistance of the measurement transducers (encoders)
Readings of the rotations' impulses of the driven wheels of the skidder and the fifth wheel are performed with encoders. By processing of the impulse data is determined the number of rotations of each individual wheel and the fifth wheel in the tractive tests.

Figure 4. Fifth wheel on the skidder Ecotrac 120 V (ŠUŠNJAR 2005)
Slika 4. Peti kotač na skideru Ecotrac 120 V (ŠUŠNJAR 2005)

Figure 5. Fifth wheel on the skidder Woody 110 (MARENČE 2005)
Slika 5. Peti kotač na skideru Woody 110 (MARENČE 2005)

All measuring transducers and strain gauges are connected to measuring amplifiers HBM Spider 8 installed on the skidders. Measurement amplifiers are positioned on the stand fixed behind the cabin of the skidders and protected from moisture and mechanical damages.

Likewise, the masses of all wood assortments are measured, which are used in the tractive tests.

RESULTS AND DISCUSSION – *Rezultati i diskusija*

For the purpose of determination the technical and exploitation characteristics of the skidder in wood extraction, it is necessary to know the features of the load which will be used in the tractive tests. In wood extraction with the skidder, one end of the load is dragged on the ground while the other end is lifted from the ground and is tied with the rope where there occurs a higher wheel loads of the rear axle.
Features of the load which will be used in the tractive tests are determined on the basis of the measured masses and calculated volumes of the wood assortments.

In the total of 19 tractive tests with the skidder Ecotrac 120V, a total of 8 different loads of which 3 loads with the short wood assortments and 5 loads with the long wood assortments. (ŠUŠNJAR 2005).

In the total of 22 tractive tests with the skidder Woody 110, it is used a total of 10 different loads. (MARENČE 2005).

For the comparison of the wheel slip of the skidder in wood extraction, it is necessary to select approximately equal loads. There are a very small number of the equal loads by the volume and therefore for the comparison are selected only tractive tests with the loads equal by the mass. There it is necessary to emphasise that the loads at the research of ECOTRAC 120 V are consisted of the oak wood assortments and with the research of WOODY 110 of the fir wood assortments. Therefore, great differences are observed in the ratio of the volume and the mass of the load in the research. At the end it is selected 5 pairs of loads equal by the mass that is the difference between the loads is not higher than 110 kg.

Table 1. Selected loads for the comparison
Tabela 1. Odabrani tovari za usporedbu

Loads ECOTRAC 120 V		Loads WOODY 110		Difference
Volume	Mass	Volume	Mass	
m^3	kg	m^3	kg	kg
2.16	**2 273**	2.89	**2 383**	110
2.37	**2 519**	3.11	**2 430**	89
3.61	**3 868**	5.12	**3 958**	90
4.50	**4 797**	6.14	**4 729**	68

As in the mentioned research are used the same loads several times, for example the same load is performed the tractive test uphill and downhill and on the different longitudinal slopes of the trail, the comparison of the wheel slip of the skidder in total can be performed on the 9 pairs of the similar tractive tests.

Table 2 Selected tractive tests for the comparison
Tabela 2. Odabrani vučni pokusi za usporedbu

Direction of the extraction	Slope		Load			
	WOODY 110	ECOTRAC 120 V	WOODY 110		ECOTRAC 120 V	
			m^3	kg	m^3	kg
uphill	Up to 20 %	15 %	3.11	2430	2.37	2519
uphill	Up to 20 %	15 %	5.12	3958	3.61	3868
uphill	Up to 20 %	15 %	5.12	3958	3.61	3868
uphill	Over 30 %	30 %	2.89	2383	2.16	2272
uphill	Up to 20 %	15 %	3.11	2430	2.37	2519
uphill	Up to 20 %	15 %	5.12	3959	3.61	3868
uphill	Over 30 %	30 %	3.11	2430	2.37	2519
uphill	Over 30 %	30 %	5.12	3958	3.61	3868
uphill	Over 30 %	30 %	6.14	4729	4.5	4797

In the table 3 are displayed the results of measurement of the wheel slip in wood extraction with the skidder ECOTRAC 120 V with the selected loads for the comparison on the different slopes of trail. At the same time, for each tractive test are displayed the results of the measurement of the horizontal and vertical component of the force in the rope, torques by the axles and the distribution of the adhesive weight on the wheels.

In wood extraction downhill, the vertical component of the force in the rope always has higher values of the horizontal component of the force.

In wood extraction downhill of 30% , the vertical and horizontal component of the force in the rope are increased with the increase of the load weight, except in the case of extraction of the biggest load of the mass 4797 kg. In that case, the horizontal component of the force has a negative value what indicates that the load was leaned with the front end on the rear protective blade of the skidder and pushed the vehicle in the direction of the movement. The assumption is that this phenomenon occurs in the certain negative slopes and the limit weights of the load. Heavy weight of the load in the higher negative slopes with the activity of the gravitation force moves by itself in the direction of extraction what is considered positive from the point of exploitation, because it is not needed the tractive force of the skidder. On the other hand, there is a negative approach which is manifested in the heavier steering of the skidder during the braking and consequently the reduced stability of the skidder in the work on the slope and the safety of the workers in the cabin. There should also be taken into consideration the service life of the vehicle of the skidder exposed with the additional strains by blows load impacts.

In the extraction downhill, the torques on the wheels are negative and the distribution of the torques by the axes is in accordance with the wheel load distribution

by the axles. The values of the torques on the axle are higher where the wheel loads are higher.

With the extraction downhill , the torques on the wheels of the skidder are negative because they do not serve for achieving of the tractive force on the wheels but with the torque transfer through the transmission system is conducted the braking of the skidder. The need for braking the skidder is manifested in the impact of the horizontal component of the skidder's weight (G sin α) that operates in the direction of the skidder's movement and during its operation occurs the overcoming of the tractive resistances. From the above, it derives that in the case of extraction downhill it can not be the realization of the real traction because the skidder pulls the loads by its weight and the transfer of the power from the drive motor on the wheels is not used for realizing of the tractive force.

Table 3. Tractive tests with the skidder Ecotrac 120 V (ŠUŠNJAR 2005)
Tabela 3. Vučni pokusi sa skiderom Ecotrac 120 V (ŠUŠNJAR 2005)

Direction of extraction	Slope	Load		Wheel load		Torque		Force in the rope		Wheel slip
				Front axle	Rear axle	Front axle	Rear axle	horizontal	vertical	
		V	m	G_k		M		H	V	δ
		m^3	kg	%		kNm		kN	kN	%
downhill	15 %	2.37	2519	43	57	-4.619	-6.008	3.44	13.738	-1.8
downhill	15 %	3.61	3868	33	67	-3.392	-7.821	4.136	21.598	-0.6
downhill	30 %	2.37	2519	57	43	-10.739	-7.935	1.118	9.421	-5.1
downhill	30 %	3.61	3868	53	47	-10.14	-8.249	2.379	13.49	-3.1
downhill	30 %	4.5	4797	52	48	-11.235	-8.726	-0.247	14.176	-2.7
uphill	15 %	2.37	2519	19	81	3.87	14.793	8.602	13.063	46.3
uphill	15 %	3.61	3868	13	87	3.593	18.094	13.238	19.684	47.9
uphill	15 %	3.61	3868	17	83	4.831	17.821	15.243	17.586	11.7
uphill	30 %	2.16	2272	19	81	4.781	23.044	11.079	13.364	60.9

Wheel slip in the wood extraction downhill is also negative. Lower negative values of the wheel slip occur during extraction downhill of 15%. At the higher slope of the trail, the negative values of the wheel slip are higher.

During the extraction downhill of 15% values of the slip were -1.8% for the load of the mass 2519 kg, that is, -0,6 for the load mass of 3868 kg.

During the extraction uphill of 15%, the slip was 46.3% and 47.9% for the same two tested loads.

On the third day of measurement, the state of the ground of the skid trail changed due to the very low air and ground temperature during the weekend when the measurements are not performed. The ground of the trail was frozen and very solid so the measurements of the shear solidness of the ground were not performed due to inability of impact of wing probe into the ground. On that day, the measured wheel slip was significantly lower. From the previous tractive tests with the load of the mass of 3868 kg, when the slip was 47.9 %, in the repeated tractive test with the same load was recorded the slip of only 11.7%.

During the extraction on the skid trail of the slope of 30% the temperatures of the air and ground did not change. During the tractive tests downhill, the wheel slip is from -8.0% with the smallest load to -2.7% at the highest load.

With extraction uphill of 30% is measured the highest wheel slip of even 60.9% although the mass of the load was 2272 kg.

In the table 4 on the same manner are displayed the results of the measurement of the wheel slip, torque and component of the tractive force during the wood extraction with the skidder WOODY 110.

Torques are measured on each wheel and in the table are displayed the aggregated values of the wheels of the same axles. Likewise, the wheel slip is measured on each wheel but are displayed the values of the arithmetic mean of the slips of all wheels.

During the wood extraction of the skidder WOODY 110 downhill up to 20 %, the torque on the front wheels has a positive value, while on the rear wheels has a negative value. By the increase of the mass of the load is increased the value of the torque on all wheels of the skidder.

During the wood extraction with the skidder downhill of 30%, torques have a negative value on all the wheels. By the increase of the mass of the load comes to the reductions of the values of the torque on the front wheels while the values of the torque on the front wheels are increasing.

As with Ecotrac 120V during the movement downhill, the torque is not used for achieving of the tractive force but for the achieving brakeage.

During the wood extraction uphill, the values of the torque are positive because the torque is used for achieving the tractive force. By the increase of the mass of the load are increased the values of the torque.

Wheel slip, as with Ecotrac 120 V, during the wood extraction downhill is negative. Less negative values of the wheel slip occur during extraction downhill up to 20%. On the higher slope of the trail the negative values of the wheel slip are

higher. By the increase of the mass of the load the negative values of the wheel slip have reduced during the wood extraction downhill. During the wood extraction uphill, the wheel slip has increased with the increase of the slope, likewise, with the increase of the mass of the load have increased the values of the wheel slip.

Table 4. Tractive tests with the skidder WOODY 110 (MARENČE 2005)
Tabela 4. Vučni pokusi sa skiderom WOODY 110 (MARENČE 2005)

Direction of extraction	Slope	Load		Wheel encumbrance		Torque		Force in the rope		Wheel slip
				Front axle	Rear axle	Front axle	Rear axle	horizontal	vertical	
		V	m	G_k		M		H	V	δ
		m^3	kg	%		KNm		kN	kN	%
downhill	Up to 20 %	3.11	2430	40	60	1.326	-1.100	5.417	9.874	-4
downhill	Up to 20 %	5.12	3959	29	71	2.504	-1.827	5.839	17.580	0
downhill	Over 30 %	3.11	2430	49	51	-8.794	-8.059	2.787	7.643	-14
downhill	Over 30 %	5.12	3958	39	61	-8.101	-10,200	2.719	15.003	-11
downhill	Over 30 %	6.14	4729	47	53	-6.388	-8.311	6.987	10.192	-9
uphill	Up to 20 %	3.11	2430	34	66	7.243	12.781	10.609	11.200	7.75
uphill	Up to 20 %	5.12	3958	25	75	5.978	18.091	13.137	19.093	10
uphill	Over 30 %	2.89	2383	27	73	7.202	26.260	15.056	7.992	19.25

In the table 5 was displayed the comparison of the results of measurement of the wheel slip at the both researched skidders. In wood extraction uphill are recorded a much less values of the wheel slip at the skidder WOODY 110 with the hydrostatic transmission. That leads us to the conclusion that the hydrostatic-mechanical transmission more effectively transfers the torque on the wheels during the extraction uphill, although we have to take into consideration that the skidder WOODY has moved along the built tractor road and the skidder Ecotrac on the newly formed tractor trail. Also, skidder WOODY during the research was equipped with the chains on all wheels with the aim of the increase of the traction of the wheel and the decrease of the slip. Proper comparison with the purpose of determining of the advantages of the hydrostatic-mechanical transmission at the skidders would be with the simultaneous research of both skidders in the same working conditions (the same skid road, the use of chains and the same loads).

During wood extraction downhill less negative values of the wheel slip are measured at the skidder Ecotrac 120 V with the mechanical transmission. What is primarily manifested with the movement of the skidder downhill of 30%. According to the mentioned, it may be concluded that with the mechanical transmission is a better braking system, that is, in the same conditions with the hydrostatic transmission occurs the pressure drop in the hydraulic system.

Table 5. Comparison of the wheel slip in the tractive tests
Tabela 5. Usporedba klizanja kotača u vučnim pokusima

Direction of extraction	Slope		Loads		Wheel slip	
	WOODY 110	ECOTRAC 120 V	WOODY 110	ECOTRAC 120 V	WOODY 110	ECOTRAC 120 V
			kg	Kg	%	%
uphill	Up to 20 %	15 %	2430	2519	7.75	46.3
uphill	Up to 20 %	15 %	3958	3868	10	47.9
uphill	Up to 20 %	15 %	3958	3868	10	11.7
uphill	Over 30 %	30 %	2383	2272	19.25	60.9
downhill	Up to 20 %	15 %	2430	2519	-4	-1.8
downhill	Up to 20 %	15 %	3959	3868	0	-0.6
downhill	Over 30 %	30 %	2430	2519	-14	-5.1
downhill	Over 30 %	30 %	3958	3868	-11	-3.1
downhill	Over 30 %	30 %	4729	4797	-9	-2.7

CONCLUSIONS - *Zaključci*

During extraction downhill, the wheel slip is negative. Generally, it can be said that in the same conditions during the extraction uphill, the wheel slip is increased with the increase of the load weight and during the extraction downhill are less negative values of the slip with the increase of the load weight. Wheel slip depends on the load weight and the state of the ground. At the frozen ground is a less wheel slip.

By the comparison of the wheel slip at the researched skidders are determined the advantages of the hydrostatic-mechanical transmission during the wood extraction uphill. However, during the extraction downhill with the mechanical transmission are achieved lower wheel slips.

Mentioned conclusions can be explained with the higher rigidity of the mechanical transmission, that is, higher internal frictions of the mechanical transmission that enable holding of the skidders during the movement uphill.
On the other hand, it may be concluded the insufficiency of the hydrostatic-mechanical transmission during the movement downhill because it most likely occurs a pressure drop in the hydraulic system.

At wood extraction uphill is manifested the advantage of the hydraulic-mechanical transmission due to more effective transfer of the torques on the wheels.
Mentioned assumptions are necessary to substantiate with the further studies of the skidders of the different systems of transmission during the same working conditions (the same skid road, the use of chains and the same loads).

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SAŽETAK

U radu je izvršena usporedba klizanja kotača dva različita skidera pri jednakim uvjetima privlačenja (jednaki tovari i nagibi traktorskog puta i šumske vlake). Prvi skider u istraživanju je ECOTRAC 120 V, hrvatskog proizvođača Hittner d.o.o. sa mehaničkom transmisijom, a drugi skider je slovenske proizvodnje WOODY 110 s hidrostatskom transmisijom.

Klizanje kotača skidera tijekom istraživanja utvrđivano je na osnovu broja okretaja kotača po putu. Prijeđeni je put izračunat iz umnoška broja okretaja petoga kotača i njegovog opsega.

Pri privlačenju niz nagib klizanje kotača je negativno. Općenito se može reći da se, pri istim uvjetima pri privlačenju uz nagib, klizanje kotača povećava s povećanjem težine tovara, a pri privlačenju niz nagib su manje negativne vrijednosti klizanja s povećanjem težine tovara. Klizanje kotača ovisi o težini tovara i stanju tla. Kod smrznutog tla manje je klizanje kotača.

Usporedbom klizanja kotača kod istraživanih skidera ustanovljene su prednosti hidrostatsko-mehaničke transmisije pri privlačenju drva uz nagib. No, pri privlačenju niz nagib mehaničkom transmisijom su se ostvarila manja klizanja kotača.

Navedeni zaključci se mogu objasniti većom krutošću mehaničke transmisije odnosno, većim unutarnjim trenjima mehaničke transmisije koji omogućavaju zadržavanje skidera pri kretanju niz nagib.

S druge strane može se zaključiti o nedostatku hidrostatsko-mehaničke transmisije pri kretanju niz nagib jer vjerojatno dolazi do pada tlaka u hidrauličkom sustavu.

Kod privlačenja drva uz nagib očituje se prednost hidrauličko-mehaničke transmisije uslijed učinkovitijeg prijenosa zakretnih momenata na kotače.

Navedene pretpostavke potrebno je potkrijepiti daljnjim istraživanjima skidera različitih sustava transmisije pri jednakim radnim uvjetima (isto stanje podloge, uporaba lanaca i isti tovari).

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