Original scientific paper

Resistance coefficients on ground-based winching of timber

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Abstract

This paper deals with the research of resistance differences in winching of logs with their thicker or thinner end turned forward. Winching represents traction of wood assortments on the ground from the felling site to the forest vehicle equipped with a forest winch. The winching coefficient is determined by the horizontal tractive force and weight of the traction load. The research of resistance in winching wood assortments was carried out for the purpose of determining the size of the forest winch designed for equipping the prototype of the thinning tractor assembly (adapted farming tractor, forest semi-trailer and hydraulic crane) and developing an environmentally and economically viable technology for timber production.

The research was carried out on flat forestland in a pedunculate oak stand by winching three logs of different weight.

The research results have shown that the winching coefficients depend on the weight of logs, shape of log and their direction. Higher weight causes higher traction resistance. In all cases, the winching coefficients were higher in winching of logs with their thicker end turned forward. In order to achieve lower ground-based traction resistance and, at the same time, cause less damage to forest soil, winching of logs should be carried out with their thinner end turned forward.

Keywords: *winching coefficient, traction, tractor assembly, thinnings, weight of log*

1. Introduction – *Uvod*

Naturally regenerated forests of pedunculate oak in the east part of Croatia are considered the most valuable forests in the country, but also ecologically the most sensitive. These forests developed on deep pseudoglay type of soils characterised by poor load--carrying capacity and high water content. These forests are operated and maintained on the principle of sustainable management, and hence problems arise in carrying out wood production operations. Due to the above mentioned characteristics of forest soil, timber is mostly forwarded so as to minimise the damages to soil. During winter, the extraction of timber from the main felling is carried out by forwarders. However, forwarders are not suitable for extracting timber from thinning operations during vegetation periods. Due to their large mass (also including load mass), they exert large contact pressure on the soil, which is of poor load-carrying capacity in that period, so that serious damage is caused. Furthermore, forwarders have to get close to the processed assortments so as to load them by hydraulic crane, which is very often impossible with thinnings, due to high density of the stand and large dimensions of forwarders. On the other side, wood assortments from thinning operations are smaller and of lower quality, and they make approximately 50 % of the whole annual cut, which reduces considerably the economical efficiency of forwarders. Therefore, the issue of extracting wood from thinning is not only an ecological but also an economic issue, because the use of expensive machines (forwarders) also increases the cost of wood extraction.

The application of forest machines in thinning operations in Croatia started in early 70s of the last century with tractor assemblies: adapted farming tractor and forest semi-trailer equipped with mechanical crane and forest winch. The first tractor assembly of that kind was the so-called »Pionir«, (Fig. 1) which was equipped with mechanical crane and forest winch. Ecological issues demanded winching of processed assortments (logs) from the stand (felling site) to one of the parallel strip roads (laid out at a 75 m distance between them). However, tractor assemblies moved through the stand causing damage to forest soil and disturbing ecological features of the stand as well as its economic aspects. Further improvements were made by providing better forest opening with a 37.5 m distance between parallel strip roads. It should be noted that the operations carried out with »Pionir« assembly were ergonomically disputable and provided inadequate safety.

In time, tractor assemblies were developed and upgraded with hydraulic cranes and forest winches. In early 90s of the last century, serious efforts were made for developing an optimum tractor assembly. At that time, the solution was in parallel work of a »Pionir« and an adapted farming tractor equipped with crane and grapple, which collected timber assortments in the stand and skidded them to the strip road. From ecological and primarily from the economic point of view (two machines for one work and large time consumption for loading and unloading with unsuitable mechanical crane), such organization of work could not last for long (Horvat et al. 2004).

Figure 1 Tractor assembly »Pionir«

Slika 1. *Traktorska ekipaža »Pionir«*

After that, the following tractor assemblies were used:

1. Croatian farming tractor Torpedo 55A, semi-trailer Moheda 6t and hydraulic crane FMV 230 with hydraulic winch on the crane (1993)
2. Croatian thinning skidder with semi-trailer and hydraulic crane instead of forest winch (1996)
3. Farming tractor Steyr 860, semi-trailer Kronos 6t and hydraulic crane Kronos 250 with hydraulic winch on the crane (1997)
4. Farming tractor Steyr 8090 with narrow track, semi-trailer Igland Swingtrac 480 and hydraulic crane Igland 43–65 without winch (2003)

In 2004 a new tractor assembly (named Formet) was produced. It consisted of: silvicultural tractor Steyr 8090 with narrow track, double-drum winch Igland 6002 Pronto TL, hydraulic crane Igland 43–65, semitrailer Metalac S-6 (Croatia) with loading capacity of 6 t (Figure 2).

Figure 2 Tractor assembly »Formet«

Slika 2. *Traktorska ekipaža »Formet«*

The research of resistance in winching timber assortments was carried out for the purpose of establishing the dimensions of the forest winch for equipping the prototype of the thinning tractor assembly Formet for an environmentally and economically acceptable technology for the transport of timber from thinning operations in low-lying stands of pedunculate oak in the east part of Croatia.

2. Main issues – *Problematika istraživanja*

Winching represents traction of wood assortments on the ground from the felling site to the forest vehicle equipped with a forest winch. The traction resistance appears in ground-based winching of wood assortments, and for defining such resistance, non-dimensional values are used such as winching coefficient. The winching coefficient is determined by the coefficient of horizontal tractive force -F_H, and mass of the traction load – Q (Hasan & Gustafson 1986):

$$\mu = \frac{F_H}{Q} \tag{1}$$

Ground-based winching of logs of a certain weight is realised by the action of the horizontal force component of the cable. The horizontal force overcomes the resistance of the whole load lying on the soil and resisting the movement (Sever & Horvat 1983). Therefore, unlike skidding where one end of the log is elevated from the ground, the winching coefficient is higher then the skidding coefficient. Sever (1980) set forth the results of investigation showing that ground-based winching of logs required twice the horizontal force necessary for skidding of logs with one end elevated from the ground. With skidding of logs, Sever (1990) established the highest skidding coefficient of 0.32 on a flat skid trail. Still higher coefficients have been recorded with skidding whole trees.

By the forest vehicle transmission system, the torque is brought from the engine to the winch drum. When maximum torque is brought to the winch drum, the highest (nominal) tractive force can be achieved in the cable, with the empty winch drum, i.e. when the cable is completely pulled out. Ground-based winching of logs is performed by horizontal component of the tractive force. The value of the horizontal force depends on the weight of logs and winching coefficient.

Figure 3 and expression 4 show that in winching the angle of the cable inclination (β) increases as the log gets closer to the forest machine, meaning that for maintaining a constant horizontal component, an increasingly higher tractive force is required.

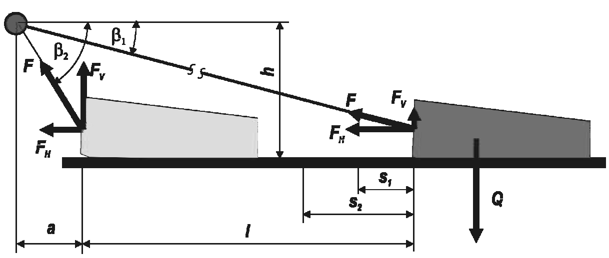

Figure 3 Ground-based winching
Slika 3. *Vuča po tlu*

$$F_H = F \cos \beta \qquad (2)$$

$$s_i = v\, t_i \qquad (3)$$

$$\beta_i = arcctg \frac{(l+a)-s_i}{h} \qquad (4)$$

$$F_{Hi} = F_i \cos \beta_i \qquad (5)$$

$$\mu_i = \frac{F_{Hi}}{Q} \qquad (6)$$

On the other hand, as the log gets closer to the winch, the cable is more and more wound up on the drum, and in this way the tractive force that the winch can achieve gets increasingly lower. With forest winches the nominal tractive force is defined as the force achieved by bringing the necessary torque when the drum is empty, i.e. when the cable is completely pulled out. It should, therefore, be taken into account that the tractive force must get higher as the log gets closer to the tractor assembly, and that at the same time, due to cable winding, the winch can achieve increasingly lower tractive force.

When working with the tractor assembly equipped with a forest winch and a hydraulic crane, it is necessary to winch the log on the ground from the felling site to the area within reach of the hydraulic crane. The installed forest winch should have such nominal tractive force to ensure sufficient horizontal component of tractive force also at high inclination angle of the cable, when the cable is almost completely wound on the drum, for winching even the largest wood assortments.

The resistance coefficient in winching of logs depends on their weight, shape and winching direction. The objective of this paper is to investigate the resistance differences in winching of logs with their thicker end turned forward or otherwise with their thinner end turned forward. According to Megille (1975) the tree species has practically no effect on the winching coefficient. The condition of the soil is essential, particularly the soil moisture content, and also the tree diameter as the element having impact on the size of the contact surface between wood and soil. In winching, the front part of the log removes the humus layer of soil and then pushes it in front of itself, increasing considerably the resistance force. The extent of damage to soil, as well as the value of the traction resistance, depends on the type and condition of soil (soil moisture).

The surface of the forest soil is not homogenous so that in ground-based winching different obstacles are met (stumps, branches, bushes, roots) and they can cause the occurance of much more serious resistance. This has also to be taken into consideration in selecting the forest winch based on the required tractive force.

3. Research methods – *Metode istraživanja*

The research was carried out on flat forestland in winching of logs of different size and with different winching direction (with the thicker end or thinner end turned forward). The tractor assembly was positioned on the skid trail, and the distances between the front part of the log and the winch pulley were recorded by use of a measuring tape at the beginning and at the end of winching, when the log was dragged into the area within reach of the hydraulic crane.

A double-drum winch – Igland 6002 Pronto TL, of the nominal tractive force of 60 kN was installed on the tractor assembly. The winching cable was of 10 mm in diameter and 40 m long.

The research was carried out with the use of the measuring equipment of the Mechanical Testing Laboratory of the Faculty of Forestry in Zagreb. The weights of the selected logs were determined by their weighing at the landing before the field research (Figure 4). For this purpose, special measuring devices (compression transducers) were used, produced by the Swedish manufacturer TELUB, and then adapted in our Laboratory.

The equipment of the company Hottinger Baldwin Meestechnik GmbH was used for measuring tractive forces. The traction-compression (push-pull) transducers HBM U1 (100 kN), F. Nr. 73771 was installed at the end of the winch cable gauged with weights whose mass was calibrated by the State Office for Standardisation and Metrology of the Republic of Croatia.

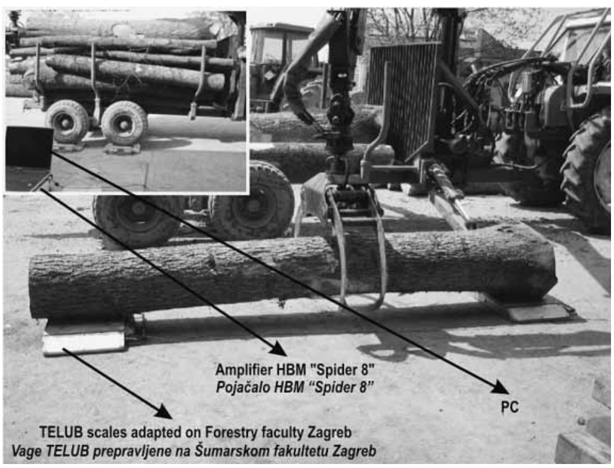

Figure 4 Weighing of logs

Slika 4. *Vaganje trupaca*

The transfer of data related to the tractive force was realised through the measurement amplifier HBM Spider 8 and the software program Catman 4.0 of the same manufacturer. The sample rate of the measuring data was 50 Hz. Along with reading the tractive force achieved in the transducers, the software program also makes records of the time elapsed at the same rate.

Based on total time required for winching of logs (t) and measured winching distance (l) the mean winching speed (v) was determined.

As in winching of logs, the inclination angle of the cable gets higher, as well as the value of the tractive force, the distance passed by the log in a unit of time was calculated based on the mean winching speed. According to the expression (4) and Figure 3, the inclination angle of the cable was calculated as well as the actual horizontal force and winching coefficient.

In further processing of data, the average and maximum values of horizontal force and winching coefficient were expressed for each case of winching.

4. Research results – *Rezultati istraživanja*

The research was carried out with the use of three logs of different weight, determined by weighing (Table 2). It should be noted that the heaviest log was a butt-log of irregular shape with large differences in

Table 1 Example of calculation of the cable inclination angle, horizontal force and winching coefficient of logs weighing 7.475 kN

Tablica 1. *Primjer proračuna kuta nagiba užeta, horizontalne sile i koeficijenta otpora vuče za trupac težine 7,475 kN*

Measuring data – *Mjerni podaci*		Calculation – *Proračun*			
Time	Tractive force	Winching distance	Cable inclination angle	Horizontal force	Winching coefficient
Vrijeme	*Vučna sila*	*Prijeđeni put*	*Kut nagiba užeta*	*Horizontana sila*	*Faktor vitlanja*
t	F	s	β	F_H	μ
s	kN	m	°	kN	
0	6.198	0	3.134	6.189	0.828
0.02	6.327	0.005	3.135	6.318	0.845
0.04	6.445	0.009	3.136	6.436	0.861
0.06	6.545	0.014	3.137	6.535	0.874
0.08	6.634	0.018	3.137	6.624	0.886
0.1	6.710	0.023	3.138	6.700	0.896
...	...	...	...	...	...
79.88	2.731	18	20.973	2.550	0.241

Table 2 Weights, masses and volumes of logs

Tablica 2. *Težina, masa i drvni obujam trupaca*

No. of log *Broj trupca*	Weight *Težina*	Mass *Masa*	Volume *Obujam*
	Q	m	V
	kN	kg	m^3
1	7.475	762	0.66
2	4.405	449	0.35
3	1.413	144	0.14

size between its thicker and thinner end. The other two logs were of a more or less regular cylindrical shape. The volume of logs was determined by measuring the mean diameter and length in accordance with the standard HRN EN 1309-2 »Round and sawn timber – Method of measurement of dimensions – Part 2: Round timber«.

In the first test, ground-based winching of logs was carried out with their thicker end turned forward, and then the test was repeated with their thinner end turned forward. The measurement results of the tractive force achieved for logs of different weight in both tests are shown in Figure 5 and 6. Contrary to theoretical assumptions, during winching decreasing trend has been recorded of the tractive force, particularly for two heavier logs. The explanation lies in the field conditions of testing. At the beginning of measurement, the logs were dragged on forest ground, and then by winching to the tractor assembly they were brought to a flat clean area between the border of the forest stand and the skid trail, where lower tractive resistance was met and hence lower tractive force was required. Peak forces occurred at the very beginning of winching, which is in accordance with the investigations carried out by Lünzmann (1968), who concluded that maximum tractive resistance occurred at the moment of starting off.

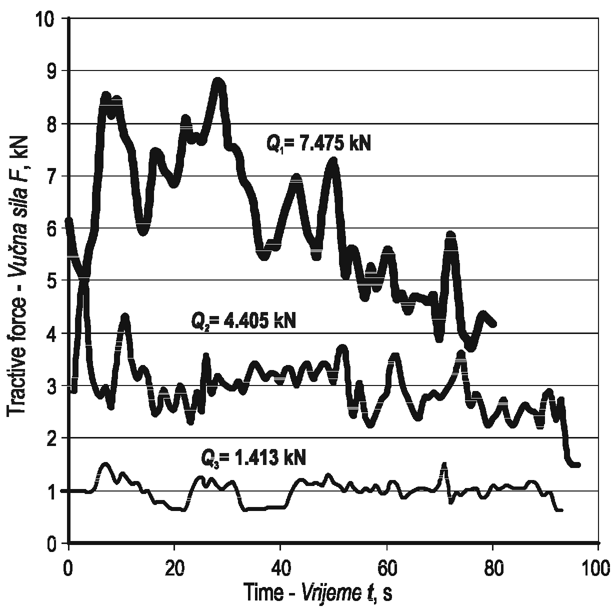

Figure 5 Tractive force in winching of logs with their thicker end turned forward

Slika 5. *Vučna sila pri privitlavanju trupaca s debljim krajem naprijed*

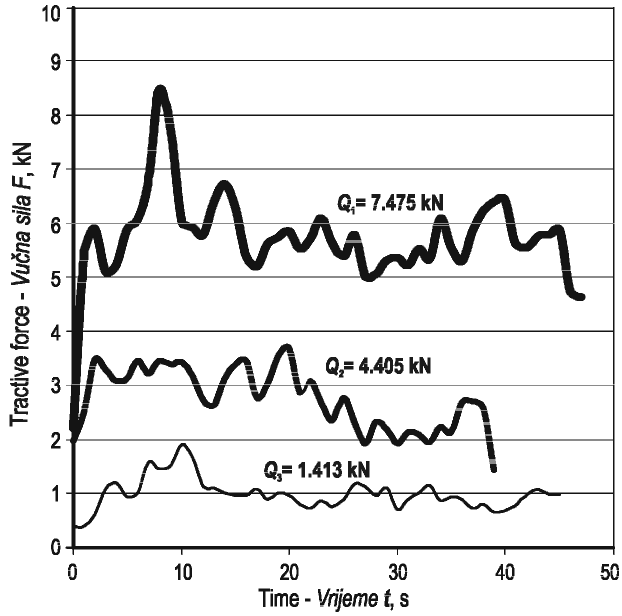

Figure 6 Tractive force in winching of logs with their thinner end turned forward

Slika 6. *Vučna sila pri privitlavanju trupaca s tanjim krajem naprijed*

In the first test, winching of logs was carried out with their thicker end turned forward. The logs were at a distance of 21 m from the winch pulley at the beginning of winching. The winch pulley was positioned 1,150 mm above the ground. Winching was carried out until the front part of the log reached the mark denoting a distance of 3 m from the winch pulley. Based on the measured distances and height of the winch pulley, it can be seen that the inclination angle of the cable changes from 3.13° at the beginning of winching to 21° at the end of winching (Figure 7).

Based on calculations shown in the previous chapter, the results were obtained as shown in Table 3.

If the mean values of the winching coefficient μ are considered, the highest value of 0.81 can be seen with winching of the heaviest log. The resistance coefficient μ for the other two logs is 0.7 and 0.66, respectively.

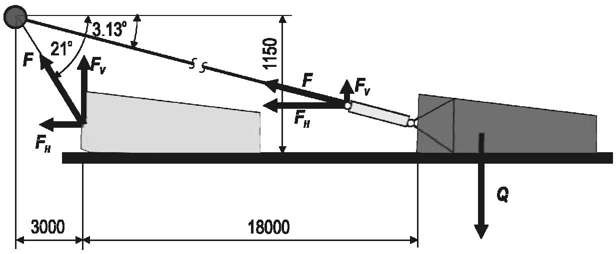

Figure 7 Ground-based winching of logs with their thicker end turned forward

Slika 7. *Privitlavanje trupaca po tlu s debljim krajem prema naprijed*

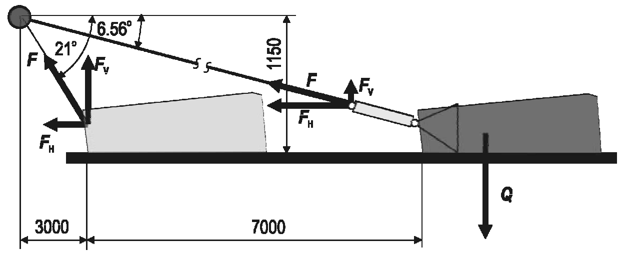

Figure 8 Ground-based winching of logs with their thinner end turned forward

Slika 8. *Privitlavanje trupaca po tlu s tanjim krajem prema naprijed*

Maximum values of the resistance coefficients depend on the surface obstacles on forest ground that logs have to overcome. Thus, in one instance, a log weighing 4.405 kN required the horizontal force of 7.428 kN to overcome a minor stump, which caused an instantaneous resistance coefficient of 1.69.

In the second test, for winching of logs with their thinner end turned forward, the starting distance between the log and the winch pulley was 10 m. Winching was carried out up to the same mark denoting the distance of 3 m from the winch pulley. Based on the measured distances and height of the winch pulley, the change was calculated of the inclination angle of the cable from 6.56° at the beginning of winching to 21° at the end of winching (Figure 8).

Winching was slower than the one in the first test – the mean winching speeds ranged between 0.15 and 0.18 m/s (Table 4).

The mean values of resistance coefficients were lower than in winching of logs with their thicker end turned forward and hence lower horizontal forces were required. The highest drop of resistance coefficient was recorded in winching of the heaviest butt-log with its thinner end turned forward. Due to its large size differences between its thicker and thinner end, in the first test the front thicker end of the log covered a larger ground surface and during winching it removed and pushed a layer of soil in front of itself, which resulted in a higher resistance coefficient (Figure 9). The lowest differences were recorded with the lightest log of regular shape (resis-

Table 3 Results of research in ground-based winching of logs with their thicker end turned forward

Tablica 3. *Rezultati istraživanja pri privitlavanju trupaca po tlu s debljim krajem prema naprijed*

Weight of log *Težina trupca*	Number of data *Broj podataka*	Winching time *Vrijeme vitlavanja*	Speed *Brzina*	Horizontal force *Horizontalna sila*		Winching coefficient *Faktor vitlanja*	
Q	*n*	*t*	*v*	F_H	F_{hmax}	μ	μ_{max}
kN		s	m/s	kN	kN		
1.413	4651	93.00	0.19	0.992	2.180	0.70	1.54
4.405	4785	95.68	0.19	2.923	7.428	0.66	1.69
7.475	3995	79.88	0.23	6.085	9.518	0.81	1.27

Table 4 Results of research in ground-based winching of logs with their thinner end turned forward

Tablica 4. *Rezulati istraživanja pri privitlavanju trupaca po tlu s tanjim krajem prema naprijed*

Weight of log *Težina trupca*	Number of data *Broj podataka*	Winching time *Vrijeme vitlavanja*	Speed *Brzina*	Horizontal force *Horizontalna sila*	Winching coefficient *Faktor vitlanja*		
Q	*n*	*t*	*v*	F_H	F_{hmax}	μ	μ_{max}
kN		s	m/s	kN	kN		
1.413	2258	45.14	0.16	0.976	2.216	0.69	1.57
4.405	1964	39.26	0.18	2.721	4.829	0.62	1.10
7.475	2375	47.48	0.15	5.631	8.931	0.75	1.19

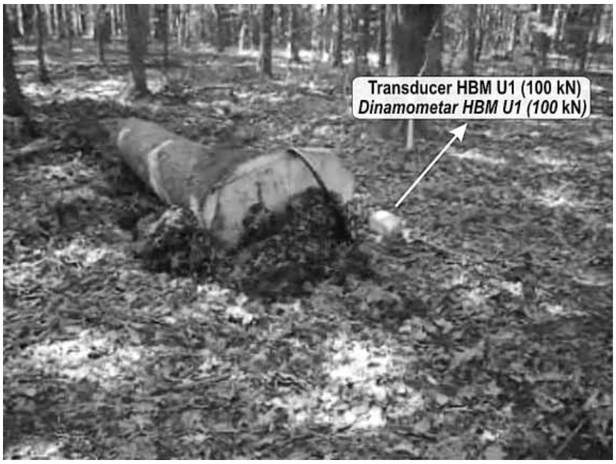

Figure 9 Winching of logs
Slika 9. *Privitlavanje trupca*

tance coefficient of 0.7 in winching of logs with the thicker end turned forward and 0.69 in winching with the thinner end turned forward). However, in both cases, the maximum coefficient was high, which implies that it came across serious surface obstacles, so that due to low mass inertia of the log, higher force was required for overcoming these obstacles.

Based on technical characteristics and dimensions of the winch, a conclusion may be reached of the suitability of the installed forest winch Igland 6002 Pronto TL on the tractor assembly FORMET. Along with the described work technology with parallel skid trails laid out at a distance of 37.5 m between them, the cable length does not have to exceed 40 m, although a longer cable can be wound in the winch drum. When the cable of 10 mm in diameter and 40 m long is completely wound, the highest tractive force is 46.67 kN (Horvat & Šušnjar 2004). For further estimate of the possibilities of the installed winch, the highest cable inclination angle of 45° will be assumed. With the height of the point of force on the winch pulley of 1 m, the angle of 45° is achieved at 1 m distance of the log from the tractor assembly. For determining the weight of the log that can be dragged, the highest winching coefficient was inserted, recorded when the log had to overcome a stump.

The calculated limit value of the weight of the log that can be dragged on the ground is equal to the mass of 2 tons or approximately 1.65 m^3 of oak wood. As the tractor assembly is primarily intended for the operations of wood production from thinning stands, wood assortments in felling and processing trees cannot be expected to be larger than the calculated limit weight or limit wood volume. By the installed forest winch it will also be possible to perform winching of several logs tied together into a load. In this way the share of winching time will also be reduced in the total time of the working process and consequently the productivity of the tractor assembly will be increased. The selection of the forest winch of the nominal force of 60 kN is a correct technical solution, although its nominal tractive force is higher than required for thinning operations, because its installation provides higher work safety in winching operations as well as the possibility of work on steep terrain.

5. Conclusions – *Zaključci*

The results of research have shown that the resistance coefficients in ground-based winching of logs or the so-called ground-based winching coefficients are much higher than the resistance coefficients in skidding when one end of the log is elevated from the ground. The winching coefficients depend on the weight of logs, shape of logs and their direction. Higher weight of logs causes higher tractive resistance. The logs of irregular shape (butt-logs) have a higher winching coefficient.

In selecting the forest winch for equipping a tractor assembly, interest should be focused on the highest ground-based winching resistances that can occur when wood assortments have to overcome some surface obstacles.

The winching coefficients were higher in all cases of winching of logs with their thicker end turned forward. In order to achieve lower tractive resistance on the ground, and at the same time cause less damage to forest soil, winching of logs should be carried out with their thinner end turned forward. When the tractor assembly is engaged in thinning stands, lower ground tractive resistance of wood assortments from the felling site to the skid trail can be achieved by directional felling. In this way, the assortments would be directed with their thinner end toward the skid trail already in the phase of felling and the winching distance would also be reduced. Directional felling of trees has also some ecological advantages, because it causes less damage to forest soil, and economic advantages as higher productivity is achieved by the tractor assembly due to lower winching distances.

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Sažetak

Faktori otpora pri vuči drva po tlu

U radu se istražuju razlike u otporima pri privitlavanju trupca s debljim i tanjim krajem prema naprijed. Istraživanjem otpora pri privitlavanju drvnih sortimenta nastojalo se odgovoriti na pitanja o potrebnoj vučnoj sili šumskoga vitla za opremanje traktorskih ekipaža te ustanoviti ekološko i gospodarski prihvatljivu tehnologiju pridobivanja drva. Istraživanje je provedeno na traktorskoj ekipaži FORMET koja se sastoji od traktora Steyr 8090, dvobubanjskoga vitla Igland 6002 Pronto TL nazivne vučne sile od 60 kN, hidraulične dizalice Igland 43–65 i poluprikolice Metalac S-6 nosivosti 6 t (slika 2). Vučno uže vitla bilo je promjera 10 mm i duljine 40 m.

Privitlavanje je vuča drvnih sortimenta po tlu od mjesta izrade u sječini do šumskoga vozila za privlačenje drva opremljenoga šumskim vitlom. Pri vuči se drvnih sortimenta po tlu pojavljuju otpori vuče, a za njihovo se definiranje koriste bezdimenzijske veličine, kao što je faktor otpora ili faktor privitlavanja. Faktor privitlavanja je određen odnosom horizontalne sile vuče i težine vučenoga tereta (izraz 1). Vuča po tlu trupca određene težine ostvaruje se djelovanjem horizontalne komponente sile u užetu. Stoga je za razliku od privlačenja drva kada je jedan kraj trupca odignut od tla faktor privitlavanja veći od faktora privlačenja. Sever (1980) navodi rezultate istraživanja gdje je za vuču trupca po tlu potrebna dvostruko veća vodoravna sila nego pri privlačenju s podignutim jednim krajem trupca.

Nazivna se vučna sila vitla postiže kod praznoga bubnja (uže potpuno izvučeno) pri određenom zakretnom momentu dovedenom na bubanj vitla. Za potrebe privitlavanja trupca po tlu koristi se određena vodoravna sila manja od nazivne vučne sile. Pri privitlavanju se kut nagiba užeta povećava približavanjem trupca šumskomu stroju, a član $\cos\beta$ *se smanjuje (izraz 2) te je za približnu jednaku horizontalnu silu za vuču trupca po tlu potrebna sve veća vučna sila. Također se nazivna vučna sila ne može ostvariti tijekom cijeloga vremena privitlavanja te se uz maksimalni zakretni moment doveden sustavom transmisije na bubanj vitla namatanjem užeta povećava krak djelovanja sile i smanjuje veličina ostvarive vučna sile. Pri radu s traktorskom ekipažom opremljenom šumskim vitlom i hidrauličnom dizalicom potrebno je trupac privitlati po tlu iz sječine do područja dosega hidraulične dizalice. Za privitlavanje najvećih drvnih sortimenta ugrađeno šumsko vitlo treba biti nazivne vučne sile koja omogućuje dovoljnu vodoravnu komponentu sile pri velikom kutu nagiba užeta i pri gotovo potpuno namotanom užetu na bubnju.*

Ovisno o vrsti tla i stanju tla (vlažnosti tla), razlikovat će se veličine oštećivanja tla, ali i veličina vučnih otpora. Površina je šumskoga tla nehomogena te pri vuči po tlu trupac nailazi na površinske prepreke (panjevi, grane, grmlje) koje mogu utjecati na pojavu mnogo većega otpora.

Istraživanje je provedeno na ravnom šumskom tlu pri privlačenju triju trupaca različitih težina (tablica 2) i dimenzija. Traktorska se ekipaža nalazila na šumskoj vlaci, a mjernom su vrpcom zabilježene udaljenosti prednjega kraja trupca od koloture vitla na početku i na kraju privitlavanja. Za mjerenje vučnih sila korišten je vlačno-tlačni dinamometar HBM U1 (100 kN). Prijenos podataka ostvaren je preko mjernoga pojačala HBM Spider 8 te *računalnoga programa Catman 4.0. Frekvencija je očitanja mjernih podataka bila 50 Hz, a računalni program bilježi i protok vremena u istoj frekvenciji.*

Na temelju ukupnoga vremena privitlavanja trupca i izmjerene udaljenosti privitlavanja odredila se srednja brzina privitlavanja. Na osnovi srednje brzine privitlavanja određen je put koji trupac prijeđe u jedinici vremena te prema izrazu (4) i slici 3 izračunan kut nagiba užeta te trenutna horizontalna sila i faktor otpora vuče. Rezultati su mjerenja ostvarene vučne sile za trupce različitih težina u oba pokusa prikazani na slikama 5 i 6. U prvom su pokusu trupci privitlavani s debljim krajem prema naprijed. Kut se nagiba užeta mijenjao od 3,13° na početku do 21° na kraju privitlavanja (slika 7). Maksimalne vrijednosti faktora otpora ovise o nailasku trupca na površinske prepreke na šumskom tlu. U drugom pokusu pri privitlavanju trupaca po tlu s tanjim krajem prema naprijed kut se nagiba užeta mijenjao od 6,56° na do 21° (slika 8). Srednje su vrijednosti faktora otpora manje nego pri privitlavanju s debljim krajem naprijed i potrebne su manje horizontalne sile (tablica 4). Najveća razlika faktora privitlavanja je pri privlačenju najtežega trupca. Zbog velikih dimenzijskih razlika između debljega i tanjega kraja trupca u prvom pokusu prednji deblji kraj trupca je zahvaćao veću površinu tla i pri vuči skidao te gurao sloj zemlje (slika 9).

Na osnovi tehničkih značajki i dimenzija vitla možemo dati sud o povoljnosti ugrađenoga šumskoga vitla. Uz tehnologiju rada s paralelnim traktorskim vlakama na međusobnoj udaljenosti od 37,5 m, duljina užeta veća od 40 m nije potrebna, iako se s obzirom na dimenzije bubnja vitla može namotati dulje uže. Najveća vučna sila kada je potpuno namotano uže iznosi 46,67 kN (Horvat i Šušnjar 2004). Za daljnji proračun pretpostavljen je najveći kut nagiba užeta od 45° (visina hvatišta sile na koloturama vitla od 1 m, udaljenost trupca od traktorske ekipaže 1 m). Za utvrđivanje težine trupca koji se može vući uvršten je najveći izmjereni faktor privitlavanja koji je utvrđen pri nailasku trupca na panj (1,7). Proračunana granična težina trupca koji se može vući po tlu odgovara masi trupca od 2 tone ili otprilike 1,65 m^3 hrastova drva. Kako je traktorska ekipaža ponajprije namijenjena za radove pridobivanja drva iz prorednih sastojina, ne mogu se očekivati drvni sortimenti veći od izračunane granične težine ili graničnoga drvnoga obujma. Ugrađenim šumskim vitlom moći će se privitlati i više trupaca vezanih u jedan tovar. Time će se ujedno smanjiti vrijeme privitlavanja u ukupnom vremenu radnoga procesa te povećati proizvodnost traktorske ekipaže. Pri odabiru šumskoga vitla za opremanje traktorske ekipaže treba obratiti pozornost na najveće otpore vuče po tlu koji se mogu pojaviti zbog nailaska drvnih sortimenata na površinske prepreke. Odabir šumskoga vitla nazivne sile od 60 kN ispravno je tehničko rješenje jer, iako je nazivne vučne sile veće od potrebne za rad u proredama, njegova ugradnja povećava sigurnost rada pri privitlavanju i mogućnost rada na nagnutom terenu.

Rezultati su istraživanja pokazali da faktor privitlavanja ovisi o težini trupca, obliku trupca i njegovoj usmjerenosti. Veća će težina trupca uzrokovati veći otpor vuče. Faktori privitlavanja su u svim slučajevima bili veći pri privitlavanju trupaca debljim krajem prema naprijed. Radi postizanja manjih otpora vuče po tlu, a ujedno i s manjim oštećivanjima šumskoga tla, privitlavati treba s tanjim krajem prema naprijed, a utovar/istovar se i tako obavlja hidrauličnom dizalizom. U radu traktorske ekipaže u prorednim sastojinama manji otpori vuče po tlu drvnih sortimenta od mjesta sječe i izrade do šumske vlake može se postići usmjerenim obaranjem. Na taj bi način drvni sortimenti već pri izradi bili usmjereni tanjim krajem prema šumskoj vlaci, a i smanjio bi se put privitlavanja. Usmjereno obaranje stabala ima prednost u ekološkom smislu zbog manjega oštećivanja šumskoga tla, kao i u gospodarskom smislu zbog veće proizvodnosti traktorske ekipaže na manjim udaljenostima privitlavanja.

***Ključne riječi**: faktor privitlavanja, trenje, traktorska ekipaža, prorede, težina trupaca*

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