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The Analysis of the New Conception Transportation Cableway System Based on the Tractor Equipment

The proportion of cableway skidding is still increasing compared to other technological and transportation ground-based ways of wood skidding which can dramatically change the quality of the environment. Wood skidding can be performed by an unconventional double-drum tractor winch powered by the wheels of the tractor rear axle. The principle of this unique tree transportation cable system with working attachment is protected by the patent. The article is focused on the description of working functions of this transportation system and the analysis of the dynamic strain of the forestry cableway system at different stages of its operating cycle. During the experiment the forces in the towing rope at different weights of tree logs and different speeds of their towing were measured and evaluated.

Keywords: *forest machinery; log skidding; pulling force; dynamic strain; cableway system; multi-factor analysis*

1. INTRODUCTION

Cableway skidding is one of the main ways of transporting trees in the forest during their logging [1]. This system has gone through its development since its beginning enthusiastic acceptance in the 1950's, stag–nation or decline in the middle of the 1960´s and the 1970´s when special forest tractors capable of operating in safe also on the slopes over 40% were wide-spread [2]. A rebirth of the forest cableways was seen in the mid-1980´s when a negative impact of building the heavy road system on the forest environment began to become evident. In mountainous regions, using of air haulage by cableways and helicopters is a condition of the ecological stability of most forest ecosystem types [3]. Other technological and transportation ground-based ways of skidding can dramatically change the quality of the environment. Recently, the proportion of cableway skidding has been increasing again. Pers–pectives of forest cableway skidding are also confirmed by establishing the specialized branch of forestry machinery. Substantial part of production costs of the tractor cableway system for skidding are costs of transmission apparatus between the output shaft of the tractor and the cable wheel or reel drums which provide the cable carriage with drive by means of the moving line [4-8].

In an effort to better understand the dynamic strain of the cableway system, we focused on the tractor cableway system where the forces in the towing rope at different weights of tree stems and different speeds of towing were measured and analysed during the expe–riment.

2. MATERIALS AND METHODS

The mentioned analysis has resulted in the design of a new conceptual solution of the forest cableway. The system uses wheels of the tractor driving axle with the direct drive of the main reels of the cableway. The concept of this system and the final 3D design has been created in the CAD system Creo Parametric from the PTC (Parametric Technology Corporation).

The first concept of this cableway system is shown in Figure 1. The FEM (Finite Element Method) calculations and optimization of the main frame of tree transportation cableway system have been carried out by the method of finite elements and by means of the ANSYS software (Figure 2) [9-12].

The analysis of the dynamic forces has been carried out by using multibody dynamics and motion analysis ADAMS CAE software which has shown how loads and forces are distributed throughout our mecha–nical systems (Figure 3). Using the results of this complex analysis, the unconventional cableway system has been redesigned and manufactured, as shown in Figure 3 [13-15].

The unconventional tree transportation cableway system cooperates with the working attachment driven by the rope of this system. The equipment allows turning on fast and turning off the towed tree log automatically.

The designed solution of the tree transportation cableway system in Figure 4 cooperating with the working attachment shown in Figure 5 is protected by the patents No. 280 350 and 285 564 at the Industrial Property Office of the Slovak Republic.

The unconventional winch system consists of two single-drum winches attached functionally to two

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wheels of the rear driving axle. Each winch is made up of the telescopic shaft fixed to the tractor wheel hub. The telescopic shaft is placed in the bearing house which is fixed to the pivoted arm. The rope of the winch is guided from the winch drum through the guide pulley. The wheels of the rear axle are lifted by the straight hydraulic engine over the terrain up to such a height that they can freely rotate. In this position, the tractor stands on two front wheels and on the rear shield. The rope is reeled to the drum with the locked claw clutch and shifted differential lock. After having skidded logs to the shield the claw clutch is turned off and at the same time the rope is closed by the lock. Thus, the rope is ensured against pulling out during dragging the logs by the tractor travel.

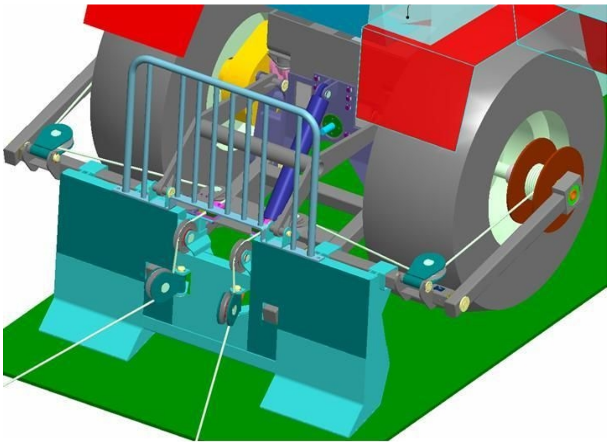

Figure 1. Concept of the transportation cableway system.

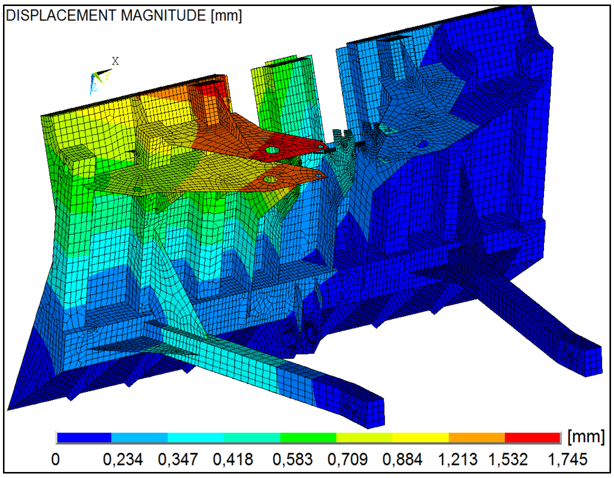

Figure 2. FEM calculations and optimisation of the main frame in ANSYS CAE system.

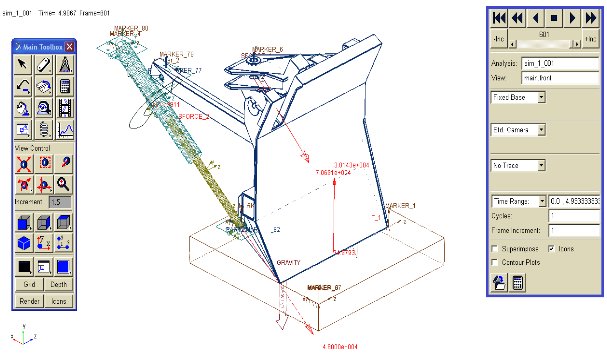

Figure. 3 Multibody dynamics and motion analysis in ADAMS CAE system.

Figure. 4 Final design of the tractor unconventional cableway system powered by the wheels of driving axle.

Figure. 5 Working attachment of the transportation cableway system.

The main advantage of the solution compared to those existing ones is the fact that transmissions of the base machine are used between the tractor engine and reel drums and thus corresponding to the results of the carried out value analysis the production costs of the most expensive constructional node of the given equipment will be significantly reduced.

The theoretical and practical bases for the results were the experimental tests carried out on a prototype of the unconventional tree transportation cableway system. The tests were performed in the Educational, training and research centre of the Technical University in Zvolen, which covers all forestry activities, assessing wood and the environment, processing wood in the enterprise's own facilities and others. During the tests the main loads of the equipment were measured. The main load force was measured by means of the tensometric dynamometer.

The operation principle of the cableway system during of the measurement is shown in Figure 6 and the scheme of all measured load forces is illustrated in Figure 7. Details are available in [16-20].

The aim of the paper was to experimentally test the functionality of the designed cableway system. The tests focused on experimental establishing the size of pulling forces in the pull and haul-back ropes using different weights of logs and different speed of their skidding in particular phases of the cableway operating cycle.

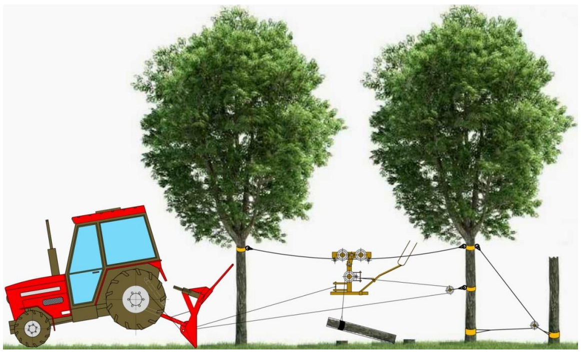

Figure. 6 Operation principle of the cableway system.

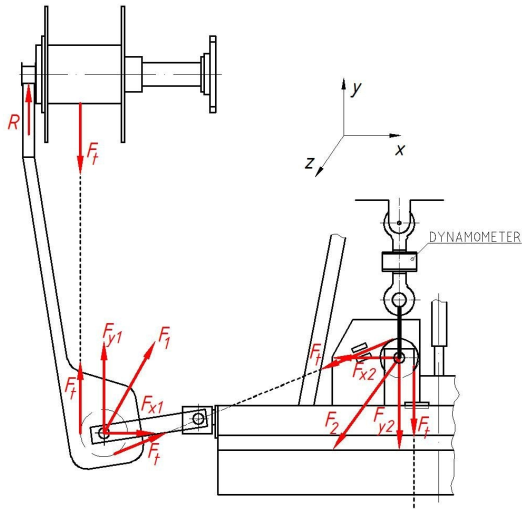

Figure. 7 The scheme of measuring the loading forces in the cableway system.

The experimental measurements were carried out on the logs towed on the slope inclined at ~ 30˚. We measured pulling force in the rope while skidding the logs up and down the slope and at the same time using different weights of logs and different skidding speed.

Table 1. Parameters of the experimental samples.

samples (beech)	length (m)	mean diameter (cm)	volume (m^3)	weight/gravity (kg/N)
1	6.14	18	0.156	184.08 / 1 840.8
2	6.11	20	0.191	225.38 / 2 253.8
3	6.10	19	0.172	202.96 / 2 029.6

The testing material for measuring the pulling forces was beech and completely parameters of the all three logs values used for experiment and calculations are presented in Table 1. The density of the used logs was found out by the indirect method on the basis of weighing the given stem volume where average density is 1180 $kg.m^{-3}$.

3. RESULTS

The aim of the work was observing and evaluating pulling force while skidding logs up and down the slope at a different speed and a different number of logs. The measured values were evaluated by means of the program STATISTICA.

The observed factors and resultant values are presented in Table 2 at the end of the paper. The factors observed include the woody species (beech), a number of logs (2 and 3 pieces) and skidding speed (speed gear: 2^{nd}, 3^{rd}, 4^{th}, and 5^{th}). Skidding was going on at the rated speed of engine $n=1800\ min^{-1}$.

Table 2 shows the results of the multi-factor analysis of dispersion for all numbers of logs, direction of skidding, and speed gear (speed of skidding). All of the given factors affecting the pulling force were statistically highly significant. Significance level p has to be lower than 0.05 in order that the results were statistically significant and thus, from the standpoint of evaluation, it would be possible to evaluate and take them into consideration.

The first line of Table 2 shows the likelihood that the total average value of pulling force is zero, i. e. it equals zero. The total average value of the pulling force for all skiddings and speed gear is zero H_1: $\bar{y} \neq 0$ is in force. The total average value of pulling force for a number of logs is not-zero, i. e. the hypothesis has not been confirmed. However, we can claim with 87% credibility that there are differences between numbers of skidded logs. Similarly, it can be stated with 100% credibility that a significant difference is also between the way of skidding and speed gear. Likewise, all two-factor as well as three-factor interactions are statistically significant.

From among three observed factors, the way of skidding has statistically the most significant effect and it is followed by speed gear and a number of logs.

The influence of a number of logs is included in random factors and therefore confidence intervals overlap (Figure 8), though it results from the table of the dispersion analysis (Table 2) that the influence of a number of logs is not statistically significant. However, we can claim with 87% confidence that there is a difference between numbers of skidded logs.

Table 2. Three-factor analysis of dispersion of pulling force (kN) including a number of logs, skidding and speed gear.

Source of variation	Total sum of squares	Degrees of freedom	Dispersion	F test	p significance level
Number of logs	6.59	1	6.59	2.38	0.126
Skidding	103.4	1	103.4	37.47	0.000
Speed gear	34.60	3	11.53	4.17	0.008
Number of logs*Skidding	31.9	1	31.99	11.59	0.001
Number of logs*Speed gear	50.63	3	16.87	6.11	0.000
Skidding *Speed gear	24.97	3	8.32	3.01	0.035
Number of logs*Skidding	34.05	3	11.35	4.11	0.009
Random factors	198.68	72	2.75		

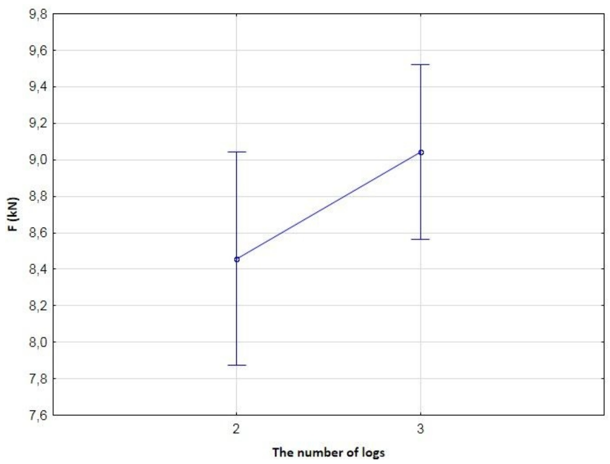

Figure. 8 Graph of 95% confidence inter□als for average values of pulling force depending on a number of logs.

From the graph of skidding – pulling force shown in Figure 9 it results that the pulling force in skidding upwards is statistically significantly higher than it is with two logs. That means that the total of all averages of pulling forces from measurements is higher when towing three logs as compared with towing two logs.

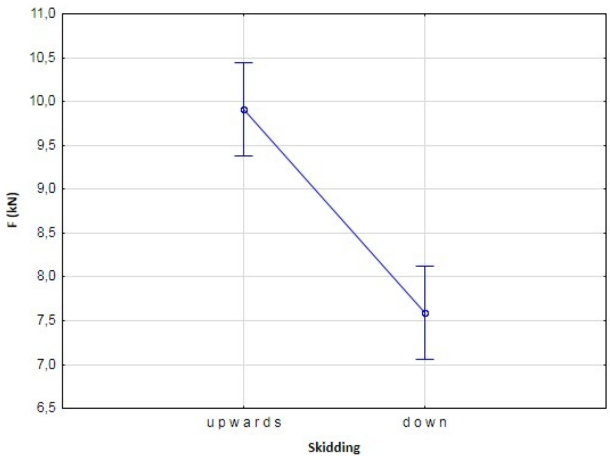

Figure. 9 Graph of 95% confidence inter□als for average values of pulling force depending on skidding.

In the graph of the single-factor analysis of speed gear – pulling force (Figure 10) it can be seen that at the highest speeds there was statistically significantly lower pulling force.

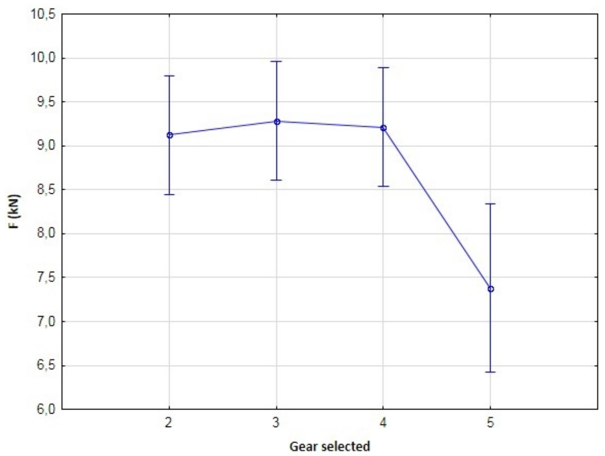

Figure. 10 Graph of 95% confidence inter□als for average values of pulling force depending on speed gear.

We can claim that the effect of dynamic impacts was not reflected on an amount of pulling force when skidding logs as it was at lower speed gears.

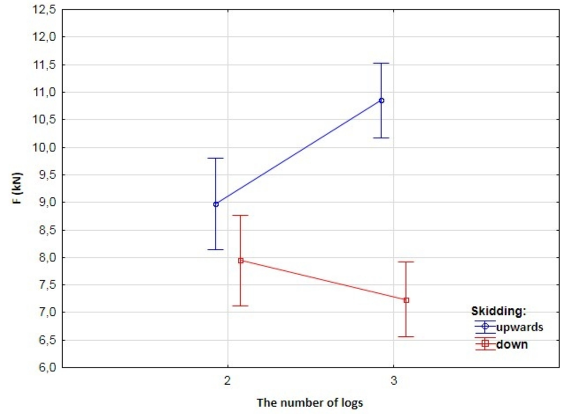

Figure. 11 Graph of 95% confidence inter□als for average values of pulling force depending on a number of logs and skidding.

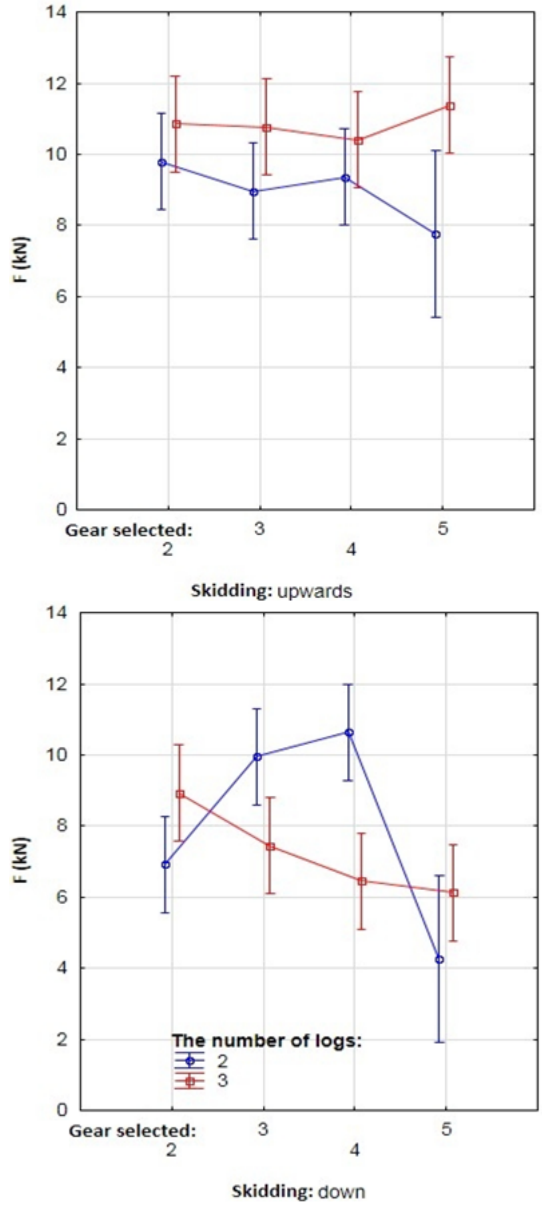

Figure. 12 Graph of 95% confidence inter□als for average values of pulling force depending on speed gear, skidding and a number of logs.

In the last graph (Figure 12) there is illustrated the influence of the interaction of all observed factors on pulling force. From the graph it is evident that the dispersion of measured data is even, except for the fifth gear where the dispersion is considerably higher.

From the observed interactions, the given interaction of a number of logs skidding has the greatest effect on the pulling force from the two-factor analysis. In the given graph (Figure 11) it can be seen that the load of skidded logs has markedly influenced the amount of pulling force when skidding downwards, where the pulling force decreased at a higher number of logs.

On this basis, the average value of pulling force was lower than at lower speed gears, which is confirmed also by the graph of pulling force and speed gear. This fact is caused by dynamic impacts of logs at a higher speed of skidding load which are transmitted onto the steel rope.

When skidding upwards there is a noticeable difference of pulling forces depending on a number of skidded loads. When skidding three logs downwards there is a linearly decreasing course of pulling force with increasing speed gear, where load weight was reflected positively in relation to the observed quantity. On the basis of the analysis we can claim that when skidding downwards a smaller number (weight) of logs there is greater pulling force in comparison with a greater number of skidded logs.

4. CONCLUSION

The designed equipment can be used as the tractor winch or the driving unit of the forest cableway which can be arranged in many constructional configurations. This is its biggest advantage over other types of cable systems usually designed as one-purpose cableway systems.

The pneumatic control of the cableway system sig–nificantly reduces the environmental impact on forest working environment. Many other types of cable systems are usually designed with hydraulics control system.

The designed tractor cableway system has a trans–port time to the workplace as compared with one-purpose cableway systems. Better mobility of the sys–tem can use the system more economically because downtime is minimized.

When skidding a smaller number (weight) of logs downwards, pulling force is greater compared to a gre–ater number of skidded logs. At a higher speed of skid–ding a load, an average pulling force is smaller than at a lower speed when the effect of dynamic impacts of skidded logs at a higher speed does not influence the amount of pulling force as it is at a lower speed of skidding.

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REFERENCES

[1] Saunders, C.J.: Cableway Extraction. Forest Rese–arch, The Research Agency of the Forestry Com–mission, 2006.

[2] Visser, R. and Stampfer, K.: Cable extraction of harvester felled thinnings: An Austrian case study. Journal of Forest Engineering, Vol. 9, No. 1, pp. 39–46, 1998.

[3] Safe Work Australia, Guide to managing risks in cable logging, Canberra, 2013.

[4] Li, D.: An integrated method for matching forest machinery and a weight-value adjustment, Journal of Forestry Research, Vol. 25, pp. 683-688, 2014.

[5] Tuhársky, J., Holý, T. and Remper, M.: Pomiar dynamicznego obciazenia kolejek linowych. Prace komisji nauk rolnicyzch, lesnych i weterynaryjnych PAU 14, pp. 177-186, 2010.

[6] Zhang, P.J. et al: Optimal Design of Small Winc–hing Drum Installed in Skidding Tractor Based on Computer Aided Design, Advanced Materials Research, Vol. 487, pp. 277-280, 2012.

[7] Fragassa, C., Pavlovic, A. and Massimo, S. Using a Total Quality Strategy in a new Practical Approach for Improving the Product Reliability in Automotive Industry In: International Journal for Quality Research, Vol. 8, No. 3, pp 297–310, 2014.

[8] Nedić, N. et al: Simulation of Hydraulic Check Valve for Forestry Equipment. International Journal of Heavy Vehicle Systems, Vol. 24, No. 3, p. 260-276, 2017. Doi: 10.1504/IJHVS.10001493

[9] Beňo, P., Kozak, D. and Konjatić P.: Optima–lization of thin-walled constructions in CAE system ANSYS. In Tehnički vjesnik: Technical Gazette, Vol. 21, No. 5, pp. 1051-1055, 2014.

[10] Megson, T.H.G.: *Structural and Stress Analysis*, Elsevier Butterworth-Heinemann, Oxford, 2005.

[11] Kastratović, G. et al: Some Aspects of 3D Finite Element Modeling of Independent Wire Rope Core, FME Transactions, Vol. 39 No. 1, 2011, pp. 37-40.

[12] Kastratović, G. et al: On finite element analysis of sling wire rope subjected to axial loading, Ocean Engineering, Volume 88, 2014, pp. 480–487

[13] Picchio, R. et al.: Improved winching technique to reduce logging damage, Ecological Engineering, Vol. 47, pp. 83-86, 2012.

[14] Samset, I.: *Winch and cable systems*, Dr. W Junk Publishers, Dordrecht, 1985.

[15] Kováč, J. et al.: Analysis of the frictional coef–ficient at the pulling load on the tilted, Acta facul–tatis technicae, Vol. 16, pp. 65-72, 2011.

[16] Biggs, D.: R & D Paper 94 Cableway design studies, Forestry Commission, Edinburgh, 1973.

[17] Bruno, D., Leonardi, A.: Nonlinear structural models in cableway transport systems, Simulation Practice and Theory Vol. 7, pp. 2007-2018, 1999.

[18] Boroška, J. et al: Mechanical Properties of Wires of Steel Ropes from Various producers, Metalurgija Vol. 35, pp. 261-266, 1996.

[19] Hoffmann, K.: *An Introduction to Measurements using Strain Gages*, Hottinger Baldwin Mess–technik GmbG, Marlborough, 1989.

[20] Olund, D.: The future of cable logging. In The International Mountain Logging and 11th Pacific Northwest Skyline Symposium, College of Forest Resources, University of Washington, Seattle, Washington, pp. 263–267, 2001.

АНАЛИЗА НОВОГ КОНЦЕПТНОГ ЖИЧАНОГ ТРАНСПОРТНОГ СИСТЕМА НА БАЗИ ОПРЕМЕ ТРАКТОРА

П. Бено, Ј. Крилек, Ј. Ковач, Д. Козак, К. Фрегаса

Удео жичаре се и даље повећава у поређењу са другим технолошким и саобраћајним основним начинима преноса дрвета који могу драматично променити квалитет животне средине. Заношење дрвета може се изводити неконвенционалним трак–тором са двоструким вретеном, погоњеним точко–вима задње осовине трактора. Принцип овог једин–ственог преносног кабловског система са радним прикључком заштићен је патентом. Рад је фокусиран на опису радних функција овог транспортног система и анализе динамичког напрезања шумског жичарног система у различитим фазама радног циклуса. Током експеримента су мерене и процењиване снаге у вучној ужади код различитих тежина дрвених трупаца и различитих брзина њиховог вучења.