ACTA SCIENTIARUM POLONORUM
Acta Sci. Pol.
Silv. Colendar. Rat. Ind. Lignar. 5(1) 2006, 73-80

HUMAN ENERGY EXPENDITURE IN LATE THINNING PERFORMED IN MOUNTAIN SPRUCE STANDS*

Janusz M. Sowa, Krzysztof Leszczyński, Grzegorz Szewczyk
Agricultural University of Cracow

Abstract. Timber harvesting in Poland is performed with the use of manual and machine techniques with a large dynamic load. The aim of the present research was to analyse the level of energy expenditure in operators who harvest timber in a mountain spruce stand in the forest district of Nowy Targ. The technique under analysis included the performance of logging as part of late thinning with the use of a cable winch propelled by a chain saw engine. The research showed that, in the thinning technique under analysis, the elimination of manual unblocking of trees suspended during their felling increased work safety. The results also show a significant reduction of a chain saw operator's energy expenditure from 24 kJ·min^{-1} to about 17.6 kJ·min^{-1}. The energy expenditure reduction, which occurred in the thinning of coniferous species by means of a portable cable winch propelled by a chain saw engine, indicates a possibility to increase the humanization of the operators' work on the level of manual and mechanical techniques.

Key words: ergonomics, safety, timber harvesting, energy expenditure

INTRODUCTION

For a number of years, Polish forestry has been characterized by limited possibilities of sawmill timber harvesting and, simultaneously, by an increasing demand for middle-sized timber [Kubiak and Laurow 1994]. Forest maintenance often involves simple but labour-consuming techniques. A chain saw is a basic tool and horses are often used as tractive force. Due to a gradual reduction of the number of horses as well as a lack of investment possibilities for small forest enterprises, there is a need for suitable technological solutions. In 1973 Kubiak suggested the application of small cable winches in the logging of small-sized timber (poles). A KGR-I winch, designed by his team, had the performance of 1.47 m^3·h^{-1} during constant duty [Kubiak 1976].

Sowa and Stańczykiewicz [2003] presented a thinning technique which used a small cable winch propelled by a high-power chain saw engine. Such a technique seems to raise

* The research was part of the KBN 3 P06L 002 23 Grant.

Corresponding author – Adres do korespondencji: Prof. dr hab. Janusz M. Sowa, Department of Forest and Wood Utilization of Agricultural University of Cracow, al. 29 Listopada 46, 31-425 Cracow, Poland, e-mail: rlsowa@cyf-kr.edu.pl

the level of labour humanization and efficiency while the fund expenditure remains relatively low. Moreover, it causes less damage to forest environment [Sowa and Stańczykiewicz 2005]. This technology is characterized by constant cooperation between a chain saw operator who is cutting trees and a cable winch operator. A cable winch is used to immediately remove suspended trees and transport them to a trail where their timber is being manipulated. The tasks are ordered; the need to remove suspended trees manually, which is both dangerous and labour-consuming, is eliminated. This technique is therefore supposed to raise the labour safety standards and humanization thanks to the advantages of teamwork.

AIM AND SCOPE OF RESEARCH

The aim of the present research was to determine an individual energy expenditure of a worker during timber harvesting using the manual and mechanical technique. The scope of the research included maintenance connected with late thinning in the area of the forest district of Nowy Targ. Timber was harvested in a spruce stand in the Long Wood System, in the following techniques:

1. The traditional technique – by one person using a chain saw; the operator performs felling, delimbing and preliminary manipulation of timber.
2. The thinning technique – constant cooperation of two persons: a chain saw operator and an operator of a small Multi FKS cable winch propelled by a high-power Stihl 064 chain saw engine. In this technique, the chain saw operator performed felling, delimbing and preliminary manipulation of timber, while the cable winch operator performed all logging operations and all tasks connected with the mechanical removal of suspended trees.

LABOUR METHODS

Energy expenditure was determined on the basis of lung ventilation. The measurement method is based on a linear dependence between the amount of oxygen that is breathed in and the amount of effort during work [Koradecka 1997]. Measurements of energy expenditure were taken by means of the WE-4 gross expenditure meter, made in Poland. The results were noted after a few minutes of work in a mask, when the values were already stable. The values were read every minute in a 25-minute measurement cycle, which included the effective worktime. The values received were reduced by the value of basic metabolism, calculated according to equation 1, elaborated by the Central Institute of Labour Protection in Warsaw [Koradecka and Bugajska 1998]. In this way, the net values of energy expenditure were obtained.

$$p_{mat} = \frac{a + 13.752m + 5.003h - 6.755w}{1440} \cdot 4.1855 \ [\mathrm{kJ \cdot min^{-1}}]$$

where: p_{mat} – basic metabolism,
a – constant dependent on gender; 66.473 for men,
m – body weight, kg,
h – height, cm,
w – age, years.

The research on energy expenditure in field was carried out at three work stands: of a Multi FKS cable winch operator, of a chain saw operator cooperating with the cable winch operator in the thinning technique, and of a chain saw oparator who worked alone in the traditional technique. The day shift structure and the measurement of the parameters of the harvested trees during the whole shift were described in the work stands under analysis. This allowed for the determination of the structure of the distinguished working times as well as the positional statistics of the size of the harvested timber.

RESULTS

Determination of the energy expenditure level was conducted on the basis of lung ventilation in workers aged 41-46 years old, who had several years' experience in timber harvesting. The results presented here include the measurements taken in effective worktime. The highest average energy expenditure, amounting to about 24 kJ·min^{-1}, was noted during timber harvesting in the traditional technique (only one person) and during the use of a Multi FKS cable winch (Table 1). At the work stand of a chain saw operator who cooperated with the cable winch operator (the thinning technique), individual energy expenditure was considerably lower, amounting to 17.6 kJ·min^{-1}. At the same time, the measurement values obtained for this work stand revealed the greatest differentiation. The variability coefficient amounted to 58% and was three times higher than for the other two work stands.

Table 1. Results of measurement of net energy expenditure
Tabela 1. Wyniki pomiaru wydatku energetycznego netto

Work stand Stanowisko pracy	Mean Średnia $x_{śr}$, kJ·min^{-1}	Standard deviation Odchylenie standardowe s, kJ·min^{-1}	Variability coefficient Współczynnik zmienności v, %
Multi FKS cable winch operator Operator wciągarki linowej Multi FKS	23.7	6.53	27.55
Chain saw operator – one person technique Pilarz – ścinka jednoosobowa	24.1	4.88	20.25
Chain saw operator cooperating with Multi FKS cable winch operator Pilarz – współpracujący z operatorem wciągarki Multi FKS	17.6	10.22	58.07

The results allow for a conclusion that the the 17 kJ·min^{-1} value of the average energy expenditure, considered to be the terminal value of the permanent organism efficiency [Löffler 1990], is exceeded. The presented confidence intervals (Fig. 1) show that for a single chain saw operator and a cable winch operator, there is little possibility that their energy expenditure should approach the terminal value. For a chain saw operator who cooperated with a cable winch operator, 95% confidence interval for the mean value was between 12.4 and 22.9 kJ·min^{-1}, which allows for a conclusion that the energy cost of this job is inconsistent with the common hygienic standards.

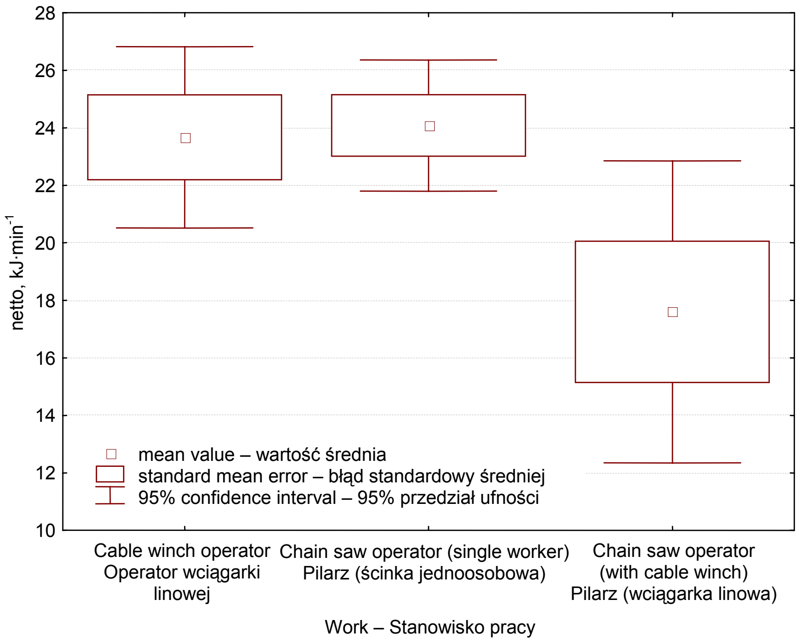

Fig. 1. Net energy expenditure at a work stand
Rys. 1. Wydatek energetyczny netto na stanowisku pracy

The differences between the confidence intervals (Fig. 1) also indicate the differences between energy expenditure of workers at the work stands under analysis. In order to verify the significance of these differences, the t-Student test was carried out with separate estimation of variance. The results (Table 2) allow for the following conclusions (on the level of significance $p = 0.05$):

1. The average individual energy expenditure at the work stand of a Multi FKS cable winch operator and a chain saw operator as a single worker does not differ in a statistically significant way.
2. The average individual energy expenditure at the work stand of a chain saw operator in the thinning technique, cooperating with a cable winch, reveals a statistically significant difference in comparison with a Multi FKS cable winch operator.
3. The statistically significant difference between the estimated variance of the individual energy expenditure of a chain saw operator in the thinning technique, using a cable winch, and a chain saw operator as a single worker indicates a different distribution of the feature under analysis.

Table 2. Results of the Snedecor test and the t-Student test for net energy expenditure
Tabela 2. Wyniki testu Snedecora i testu t-Studenta dla wydatku energetycznego netto

Variables Zmienne	F Snedecor test Test F Snedecora		t-Student test Test t-Studenta	
	F	p	t	p
Chain saw operator (single worker) Chain saw operator cooperating with Multi FKS cable winch operator Pilarz – ścinka jednoosobowa Pilarz – współpracujący z operatorem wciągarki Multi FKS	4.3881	0.0028*	2.5217	0.0164*
Chain saw operator (single worker) Multi FKS cable winch operator Pilarz – ścinka jednoosobowa Operator wciągarki Multi FKS	1.7931	0.2160	0.2232	0.8246
Multi FKS cable winch operator Chain saw operator cooperating with Multi FKS cable winch operator Operator wciągarki Multi FKS Pilarz – współpracujący z operatorem wciągarki Multi FKS	2.4473	0.0701	2.1461	0.0391*

*Test significant at the significance level $p = 0.05$.
*Test istotny na poziomie istotności $p = 0,05$.

In a shift during which a series of measurements of energy expenditure were taken, the chain saw operators harvested timber with average volume of 0.2310-0.2697 m^3 (Table 3). The significance of differences of the features of harvested timber was verified by means of the U Mann-Whitney test. The results (Table 4) revealed a lack of statistically significant differences at the significance level of $p = 0.05$ between:

– volume of single items of prepared timber,
– middle diameter of single items of timber.

Table 3. Positional parameters of harvested timber
Tabela 3. Parametry pozycyjne pozyskanego (zerwanego) drewna

Statistics Statystyka	Technique using Multi FKS cable winch Technologia z wciągarką Multi FKS		Chain saw operator – single worker Pilarz – ścinka jednoosobowa	
	middle diameter średnica środkowa $d_{1/2}$, cm	volume miąższość V, m^3	middle diameter średnica środkowa $d_{1/2}$, cm	volume miąższość V, m^3
Mean $x_{śr}$ Średnia $x_{śr}$	13.48	0.2310	13.63	0.2697
Lower quartile Q_{25} Dolny kwartyl Q_{25}	11.00	0.1209	12.00	0.1558
Mediana Q_{50} Mediana Q_{50}	13.00	0.2148	13.00	0.2415
Upper quartile Q_{75} Górny kwartyl Q_{75}	15.00	0.3091	15.00	0.3232

Table 4. Results of the difference U Mann-Whitney significance test for single items of timber harvested in the analysed techniques
Tabela 4. Wyniki testu istotności różnic U Manna-Whitneya dla pojedynczych sztuk pozyskanego (zerwanego) drewna w analizowanych technologiach

Feature of timber Cecha drewna	Sum of ranks of grouping variable Suma rang zmiennej grupującej		U Mann--Whitney statistics Statystyka U Manna--Whitneya	Test statistics Z Statystyka testowa Z	Significance level Poziom istotności p
	technique with Multi FKS cable winch technologia z wciągarką Multi FKS	chain saw operator – single worker pilarz – ścinka jednoosobowa			
Middle diameter $d_{1/2}$, cm Średnica środkowa $d_{1/2}$, cm	1 021.0	1 464.0	586.0	–0.10134	0.9193
Volume of an item of harvested timber V, m^3 Miąższość sztuki pozyskanego (zerwanego) drewna	929.0	1 556.0	494.0	–1.19822	0.2308

The test results indicate the uniformity of the selected features of harvested timber, which occurred during analyses of energy expenditure in both techniques.

In the course of research on energy expenditure, the time of individual tasks was measured too. The results presented in Table 5 show that the shortest operation time (T_1 + T_2) was noted for a chain saw operator which cooperated with a cable winch operator (76.9%). At the remaining work stands it amounted to about 95%. At the same time, the work of a chain saw operator in the thinning technique also included time T_4 for removing technical problems (unblocking of harvested logs) as well as over five times longer breaks T_5.

Table 5. Structure of worktimes of operators expressed in percentage of time of shift
Tabela 5. Struktura czasów pracy operatorów na powierzchni roboczej wyrażona w procentach czasu zmiany na powierzchni roboczej

Activity code Kod czynności	Chain saw operator cooperating with Multi FKS cable winch operator Pilarz współpracujący z operatorem	Multi FKS cable winch operator Operator wciągarki Multi FKS	Chain saw operator Pilarz (ścinka jednoosobowa)
Main (direct) worktime, T_1 Czas główny (bezpośredni), T_1	34.4	25.5	60.6
Subsidiary time, T_2 Czas pomocniczy, T_2	42.5	69.0	35.4
Time of technical service of the means of work, T_3 Czas obsługi technicznej środka, T_3	3.0	1.7	0.0
Time of removal of damage and blocked logs, T_4 Czas usuwania usterek, czas odblokowania zrywanej sztuki, T_4	3.6	0.6	0.0
Rest, long and short breaks, T_5 Czas odpoczynku, przerwy długie i krótkie, T_5	16.4	3.3	3.9

DISCUSSION AND SUMMING UP

The research results, presented here, allow for a conclusion that the energy expenditure of the workers exceeds the admissible value. Exceeding the value of 17 kJ·min^{-1} results in a negative energy balance of an operator and a lack of possibility of organism regeneration. The working process should therefore be organised so that there will not be any permanent need for a worker to regenerate his/her strength in their free time [Löffler 1990]. One of the solutions which lower the energy cost in thinning may be the introduction of a small cable winch. Working in a team, where the chain saw operator cooperates with a cable winch operator, allows for rotation at a work stand, and – what follows – reduction of its laboriousness.

The results indicate that the energy expenditure of a single chain saw operator is much lower. This is due to the fact that his work speed is related to simultaneous logging. It is confirmed by longer breaks, problem removal time (unblocking of suspended timber) and much shorter main time. The use of a cable winch eliminates the need to remove suspended logs manually. This reduces the workload of a chain saw operator, whose work (as shown during another research) is characterized by high energy expenditure, amounting to 37 kJ·min^{-1} [Józefaciuk and Nowacka 1993]. Moreover, the risk of undertaking dangerous tasks, due to the use of simplified, prohibited techniques, is reduced.

Some further advantages of the thinning technique with the use of a cable winch include rotation in work stands, which allows for reduction of daily energy expenditure and of monotony at work [Luczak 1993]. Moreover, concentration of timber makes it easier to manipulate it and eliminates the necessity of manual transport from the stand.

The disadvantage of this system is an increase in the acoustic threat to the operators [Sowa and Leszczyński 2005 a]. However, the problem of hearing damage will not occur if operators use special hearing protection. What is more, the occurrence of imposed breaks in the exposure of a worker to emission of chain saw fumes limits the negative influence of a chain saw as it results in a smaller concentration of fumes in the operators' breathing zone [Sowa and Leszczyński 2005 b]. For practical reasons, however, it must be added that the need to transport the 40-kg cable winch (with its carriage) may limit its use in some less accessible areas.

FINAL STATEMENTS AND CONCLUSIONS

The present research allows for the following statements and conclusions:

1. The energy expenditure of a Multi FKS cable winch operator and of a single chain saw operator amounted to about 24 kJ·min^{-1}.
2. Individual energy expenditure of a chain saw operator working in the thinning technique was much lower (17.6 kJ·min^{-1}), around the accepted limit of permanent organism efficiency.
3. A large variability of energy expenditure of a chain saw operator in the thinning technique indicates a different character of his work.
4. The use of a cable winch increases safety and humanization of harvesting labour at the manual and mechanical level.

REFERENCES

Józefaciuk J., Nowacka W., 1993. Ćwiczenia z ergonomii i ochrony pracy. SGGW Warszawa.
Koradecka D., 1997. Bezpieczeństwo pracy i ergonomia. CIOP Warszawa.
Koradecka D., Bugajska J., 1998. Ocena wielkości obciążenia pracą fizyczną na stanowiskach roboczych. CIOP Warszawa.
Kubiak M., 1976. Transport drewna w gospodarstwie leśnym. PWRiL Warszawa.
Kubiak M., Laurow Z., 1994. Surowiec drzewny. Fundacja Rozwój SGGW Warszawa.
Löffler H., 1990. Arbeitswissenschaft für studierende der Forstwissenschaft. Uniwersytet Monachium.
Luczak H., 1993. Arbeitswissenschaft. Lehrbuch. Springer Berlin.
Sowa J.M., Leszczyński K., 2005 a. Obciążenie akustyczne operatorów wybranych narzędzi przenośnych napędzanych silnikiem spalinowym. In: Ogólnopolska Konferencja Naukowa „Procesy produkcyjne w leśnictwie – technika, technologia, organizacja". Wyd. SGGW Warszawa.
Sowa J.M., Leszczyński K., 2005 b. Emission of carbon monoxide during work with a power chain saw and a cable winch propelled by a chain saw engine. In: International Scientific Conference "Ecological, Ergonomic and Ecological Optimization of Forest Utilization In Sustainable Forest Managment". Zesz. Nauk. AR Krak. 419, 91.
Sowa J.M., Stańczykiewicz A., 2003. Research on pre-ecological harvesting technology in thinning with the use of cable winch. In: Forest and Wood-Processing Technology and the Environment. Vol. 2. Mendel University of Agriculture and Forestry Brno.
Sowa J.M., Stańczykiewicz A., 2005. Determination of selected logging technologies impact, in thinned coniferous stands, on damage level of trees. In: International Scientific Conference "Ecological, Ergonomic and Ecological Optimization of Forest Utilization In Sustainable Forest Managment". Zesz. Nauk. AR Krak. 419, 91.

WYDATEK ENERGETYCZNY PRACOWNIKÓW TRZEBIEŻY PÓŹNEJ W GÓRSKICH DRZEWOSTANACH ŚWIERKOWYCH

Streszczenie. Pozyskiwanie drewna w Polsce odbywa się w sposób ręczno-maszynowy, co wiąże się z dużymi dynamicznymi obciążeniami przy pracy. Realizacja zabiegów pielęgnacyjnych w drzewostanach górskich, także w trzebieży, cechuje się zastosowaniem prostych
i jednocześnie pracochłonnych technologii, często ujemnie wpływających na środowisko leśne. Celem pracy jest analiza poziomu wydatku energetycznego operatorów realizujących zadania pozyskaniowe w górskim drzewostanie świerkowym na terenie nadleśnictwa Nowy Targ. Badana technologia obejmowała realizację zabiegów trzebieży późnej z wykorzystaniem do zrywki w drzewostanie wciągarki linowej napędzanej silnikiem pilarki. Prace trzebieżowe wykonywały dwie osoby współpracujące na powierzchni roboczej. Uzyskane wyniki świadczą o istotnym zmniejszeniu wydatku energetycznego operatora pilarki z 24 $kJ \cdot min^{-1}$ do około 17,6 $kJ \cdot min^{-1}$. Zmniejszenie wydatku energetycznego podczas realizacji trzebieży iglastych, z zastosowaniem przenośnej wciągarki linowej zagregowanej z pilarką spalinową, wskazuje możliwości zwiększenia humanizacji prac operatorów leśnych, na poziomie technologii ręczno-maszynowego wykonawstwa prac.

Słowa kluczowe: ergonomia, bezpieczeństwo, pozyskiwanie drewna, wydatek energetyczny

Accepted for print – Zaakceptowano do druku: 22.02.2006

For citation – Do cytowania: Sowa J.M., Leszczyński K., Szewczyk G., 2006. Human energy expenditure in late thinning performed in mountain spruce stands. Acta Sci. Pol., Silv. Colendar. Rat. Ind. Lignar. 5(1), 73-80.