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ORIGINAL ARTICLE

Coupling forces resulting from the type of chain saw used

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Abstract

Introduction. Woodcutters' working conditions are difficult due to the presence of numerous occupational hazards. Petrol –fuelled chain saws commonly used in forestry produce vibration, which may lead to the development of non-specific disorders in the upper extremities of the chain saw operator, referred to as hand-arm vibration syndrome (HAVS). The magnitude of coupling forces exerted on a vibrating tool handle may affect the severity of HAVS and hand-wrist cumulative trauma disorders. The aim of the presented study was to measure coupling forces exerted by fellers on various chain saws and to find correlation between force magnitude and type of tool used.
Material and methods. Coupling forces applied by workers on different types of chain saws were measured by means of a hydro-electronic force meter. All measurements were carried out during the harvesting of wood in real work conditions.
Results. Mean force applied by forestry workers on their tools was 44.2 N. Coupling forces registered during cutting wood with small universal chain saws were larger than forces exerted on models characterized by higher power profile. Forces applied on comparable tools produced by various manufacturers also differed.
Conclusions. The relationship between coupling forces and power of the chain saw should lead to ergonomic improvements of the tool and vibration-reducing devices. These results can also be used as a recommendation for fellers in a range of using proper machines for different types of cut or types of wood. They may also be applicable to develop more effective methods for assessing vibration exposure risks among woodcutters.

Key words

Coupling forces, woodcutters, chain saw, force measurement

INTRODUCTION

Woodcutters' working conditions are difficult due to the presence of numerous occupational hazards. Petrol-fuelled chain saws commonly used by lumberjacks in the process of harvesting wood, purposely produce vibration. Prolonged, intensive exposure to vibration may lead to the development of sensorineural, vascular and musculoskeletal disorders in the upper extremities of the chain saw operator, referred to as hand-arm vibration syndrome (HAVS) [1]. The risk assessment of HAVS is currently realized according to International Standard ISO 5349-1: 2001 [2].

The international safety standard ISO 5349-1 is based on measurements of the acceleration of mechanical vibrations emitted by a tool according to its frequency components and time of exposure, while the contribution due to the hand force is ignored. Other factors which can modify the intensity of mechanical vibration transmitted throughout the body, i.e. position of the body, hand size, condition of the machines, are also not determined in the risk and health assessment. Hence, in epidemiological studies, there is often no correlation between vibration exposure assessed according to ISO-5349 model and health effects observed in workers exposed to vibration [3, 4, 5].

The hand-arm vibration damage depends not only on parameters determined by accelerometers positioned over the handles, such as intensity of vibration, and direction of propagation. It has been suggested in many studies that the magnitude of coupling forces exerted on a vibrating tool handle affects the severity of HAVS and hand-wrist cumulative trauma disorders [6, 7, 8]. Different couplings of the hand to a vibrating tool can affect the human body in two different ways. Firstly, a tight hand-tool coupling increases the transmissibility of vibration to the hand and arm [9, 10, 11]. Secondly the coupling can result in a synergistic effect with vibration exposure which affects the vascular system, nerves, joints and tendons of the worker's body [12, 13].

A simultaneous measurement of the vibration produced by vibrating tools, and forces applied to the tools by their operators, is significant from the health point of view. Coupling forces involved in the operation of a vibrating machine generally consist of two different components. The first component is the force applied by the hand-arm system, which is used to provide necessary control and guidance of the machine and to achieve the desired productivity. The second component is the biodynamic force which results from the biodynamic response of the hand-arm system to a vibration [14, 15]. International standard ISO 15230:2007 concerning the measurement of forces exerted on vibrating tools by their operators provides the definition of coupling forces in a simplified manner as a sum of the gripping force and the push or pull force [14].

Coupling forces are still not considered in the risk assessment of forestry workers exposed to HAVS because the methodology for measurements of those forces has not been evaluated yet. There is a lack of measuring devices which would allow for such a measurement. One possible method for the measurement of forces exerted on vibrating tools, included in an annex to the ISO 15230 standard, is based on

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the hydro-electronic force meter [14, 16].

There are many variables involved in magnitude of coupling forces applied on chain saws. Different chain saws have various characteristics due to differences between models, maintenance history, sharpness of chains, age and different component configurations. The operator, type of wood and cutting technique also influence coupling forces [17].

OBJECTIVE

The aim of the presented study was to discover how the type of chain saw influences coupling forces. A detailed investigation of each of the variables involved was not intended. Understanding how the type of a chain saw affects the magnitude of coupling forces should lead to improvements in the ergonomic design of the tool and the workplace. A more detailed relationship between coupling forces and the power of various chain saws is also desirable for the development of safer and more efficient hand tools.

MATERIAL AND METHODS

Methods, subjects and design. Measurements of coupling forces were carried out for left-hand holding the front handle of the chain saw, as well as for the right-hand placed on the rear handle, by means of a hydro-electronic force meter (Fig. 1). An active liquid pad of the force meter was placed between the woodcutter's palm and the handle of the tool.

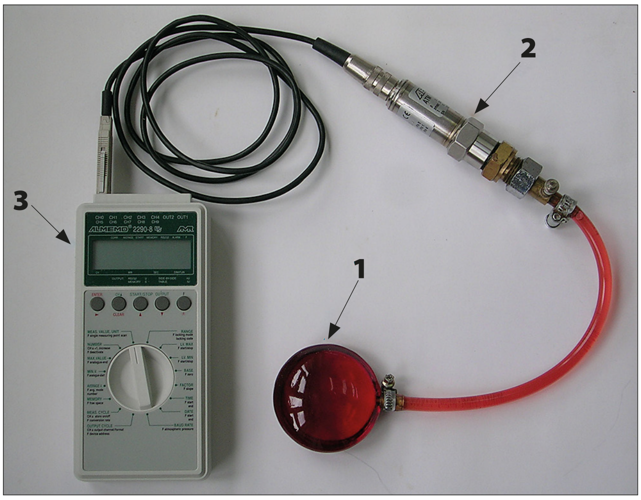

Figure 1. Hydro-electronic force meter and its components: 1 – Active Liquid Pad (ALP); 2 – pressure transducer; 3 – electronic manometer

Calibration of hydro-electronic force meter was performed in loading and unloading with a specially designed calibration system. A calibration was used to convert the force data into Newtons. Pressure values, displayed on a digital manometer of the force meter, was compared to load values measured by the tensometric load cell, displayed on a digital weight indicator (Fig. 2).

The loading and unloading of the device followed similar paths (Fig. 3). Measurement error in the range of 55 – 300 N did not exceed 2% (0 – 1.29%). For forces less than 55 N, measurement error was 2.7% – 29%. The correlation coefficient R > 0.99 showed that the device had good linearity.

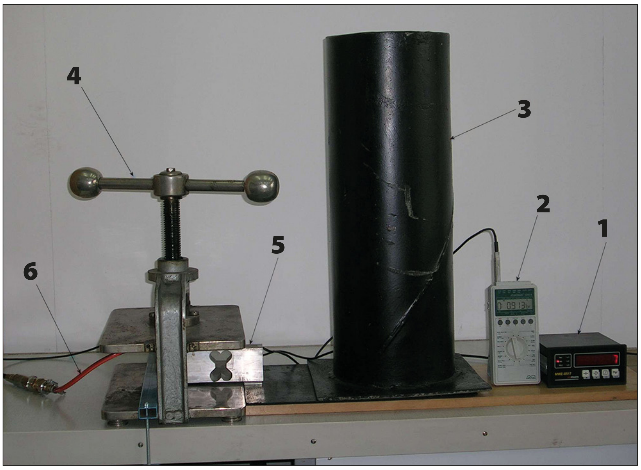

Figure 2. Calibration system with its components: 1 – digital weight indicator; 3 – source of load; 4 – counterweight; 5 – tensometric load cell; 2,6 – hydro-electronic force meter

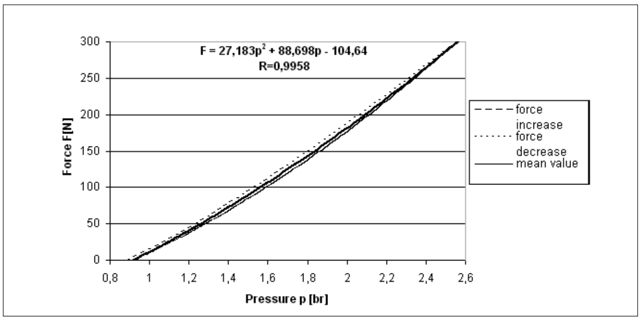

Figure 3. Calibration curves for the hydro-electronic force meter

The source population for the presented study was a group of 33 professional lumberjacks who had worked under normal logging conditions in Silesian forests. Workers had a mean age of 43 years (SD= 9.3) and mean seniority 13 years (SD= 9.0). Coupling forces were measured during three different kind of cuts, i.e. felling, cross-cutting and limbing. Felling is the action of cutting down a tree. The cross-cutting technique is used to cut trunk lying on the ground into logs. Limbing means removing branches from the trunk with the use of a chain saw. The type of cut was sequential. The tree was firstly felled (felling), the branches were then cut off (limbing), and finally it was cut into logs (cross-cutting).

The measurement cycle for all types of cuts lasted 21 seconds because this is the length of time required to complete cross-cutting, the shortest forest operation. Coupling forces were measured once per second. The data recorded for one measurement cycle were summarized with the mean as a measure of central tendency and standard deviation as a measure of dispersion. Woodcutters used the same own tool for all three logging operations. Routine maintenance, such as cleaning and sharpening of cutting teeth of chain saws, were carried out the day before the measurements in the same authorized servicing dealer. During logging, chain saw operators decided when the measurements should be stopped because of blunting of the saws. All measurements were undertaken during the process of harvesting wood in forestry districts localized in the Silesian Province of Poland.

Machines characteristic. In this work, the most common chain saws used by fellers were: Husqvarna model 353,

Table 1. Comparison of all types of chain saws used by 33 woodcutters

Manufacturer	Husqvarna			Stihl			Husqvarna			Stihl		Dolmar
Model	345	346 XP	353	MS 260	MS 250	MS 280	372	357 XP	365	MS 361	MS 440	115i
Type	HM	HM	HM	SM	SM	SM	HL	HL	HL	SL	SL	D
Cylinder displacement (cm^3)	45	45.0	51.7	48.7	45.4	54.7	70	56.5	65.1	59	71	52
Power output (kW)	2.2	2.5	2.4	2.6	2.3	2.8	3.9	3.2	3.4	3.4	4	2.7
Fuel tank volume (cm^3)	500	500	500	460	470	520	770	680	770	685	500	560
Oil tank volume (cm^3)	250	280	280	290	280	280	400	380	400	325	260	280
Weight (kg)	4.8	4.8	5.0	4.7	4.6	5.3	6.1	5.5	5.9	5.6	6.3	4.6
Weight to Power ratio (kg/kW)	2.2	1.9	2.1	1.8	2	1.9	1.6	1.7	1.7	1.6	1.6	1.7

Husqvarna model 357XP, Husqvarna model 346XP and Stihl model MS260. The lumberjacks also cut wood with the use of other models of tools produced by Stihl and Husqvarna. Comparison of all types of chain saws used by woodcutters in this study is presented in Table 1.

In the presented study, all chain saws used by forestry workers were divided into 5 groups according to the manufacturer and mass and power of the machine. In a group labeled 'HM' there were small and medium tools produced by Husqvarna (models: 345, 346 XP, 353). Models 357 XP, 365 and 372 had a power output bigger than 3 kW and were categorised as large, powerful chain saws (HL). Models MS 250, MS 260 and MS 280 by Stihl were in another group labeled 'SM'. Chain saws produced by Stihl and characterized by a higher power profile (MS 361 and MS 440) were in a group labeled 'SL'. The last type of chain saws used by lumberjacks, Dolmar 115i, was in the final group labeled 'D'.

Statistical analysis. Data analysis was performed with statistical software Statistica version 9 (Statsoft Poland, 2009). Data were summarized using the mean as a measure of central tendency and the standard deviation as a measure of dispersion. The χ^2 statistic was applied to independent data (tabulated in 2x2 contingency tables). A single factor analysis of variance (ANOVA) was used to study the influence of different types of chain saws on the magnitude of coupling forces. Differences were considered significant at the $p<0.05$ level.

Analysis of the relationship between the examined variables was carried out with the use of the backward elimination regression method. The model included all the available variables, namely the age, work experience, the hand for which the measurement of the forces was carried out, type of the cut, hardness of the wood and type of chain saw, after which the variables were removed one by one, checking how the removal of each variable influences the fitting of the regression model to the experimental data.

RESULTS

The most popular chain saws used in measurements were chain saws of premium range produced by Husqvarna (HM). These chain saws were the most often used and over 60% of measurements were carried out during logging with these tools (Fig. 4). Almost 8% of coupling force measurements were carried out during logging trees with powerful Husqvarna chain saws (HL). Tools produced by Stihl were used in 28% of measurements. Dolmar chain saws were very rarely used.

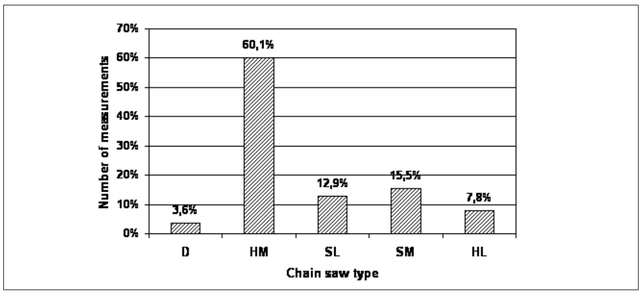

Figure 4. Frequency of coupling force measurements due to chain saw type

Frequency of coupling force measurements on different types of chain saws during felling, cross-cutting and limbing is presented in Table 2. No statistically significant difference was found between frequency of measurements during the three different techniques of cut and the chain saws used (p=0.12).

Table 2. Frequency of coupling force measurements during felling, cross-cutting and limbing according to tool type

Type of cut	Frequency of coupling force measurements (%)				
	D	HM	SL	SM	HL
Felling	14.3	11.7	20.0	20.0	22.00
Cross-cutting	85.7	72.7	64.0	46.7	65.8
Limbing	0.0	15.6	16.0	33.3	12.2

Multiple regression analysis showed that the type of cut, wood hardness and chain saw type have an impact on the range of applied forces. Five of the variables, i.e. limbing, soft wood, hard wood, small all-round chain saw and large professional chain saw, included in the model of regression, had a significant influence on the average value of the force (Fig. 5).

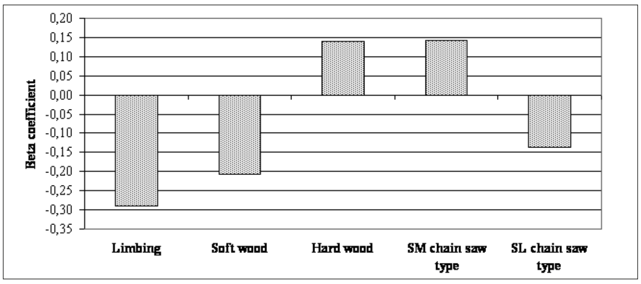

Figure 5. Results of backward elimination regression. Beta coefficient is the standardized coefficient representing the independent contributions of each variable to the prediction of the dependent variable

There was a negative relationship between coupling forces and limbing (Beta < 0). More specifically, limbing required less force than cutting a tree into blocks, which constituted the reference point. Soft deciduous trees required using less force in comparison with coniferous trees, which were classified as wood of moderate hardness. Felling hard wood, i.e. birch, oak and beech, required bigger forces than felling coniferous trees. The type of the chain saw also had an influence on the force value. Larger forces were measured during cutting with small tools (Beta > 0). Woodcutters using powerful chain saws applied smaller coupling forces. Mean coupling forces registered for five different types of chain saws are included in Table 3.

Table 3. Mean values of forces exerted by woodcutters on different chain saw types (n=193)

Chain saw type	No. of mean forces registered	Mean force ± SD (N)
SM	30	53.6 ± 35.9
D	7	48.3 ± 16.3
HM	116	44.2 ± 28.7
HL	15	41.3 ± 2.6
SL	25	33.8 ± 21.4
Total	193	44.2 ± 28.7

The largest mean forces which exceeded 50 N, were exerted on chain saws of the SM type. More powerful chain saws produced by Stihl needed smaller forces of about 33.8 N. Forces exerted by lumberjacks on models MS 361 and MS 440 by Stihl were the smallest forces measured. Chain saws produced by Husqvarna, characterized by higher power, also needed smaller forces than universal models manufactured by this company. Although chain saws of the SM and HM type had comparable weight and power, the forces measured on these tools differed. There was also a difference between coupling forces measured on tools type HL and SL, characterized by similar parameters but produced by different manufacturers. The mean value of coupling forces registered during cutting with Dolmar was 48.3 N. The type of tool did not significantly influence the average value of force exerted on the chain saw by professional fellers ($F_{4.188}$=1.78). A detailed analysis only suggests that larger forces are used during cutting trees with tool categorized as SM. Powerful chain saws required the application of smaller forces than other tools (Tab. 3).

DISCUSSION

The coupling forces applied on different types of chain saws while being operated by professional fellers have been presented. Although many factors could affect the coupling forces exerted by woodcutters on chain saws, the presented study considered only the impact of power and size of chain saws on the magnitude of the coupling forces. No other scientific reports concerning the measurement of forces exerted on chain saws by forestry workers in real field conditions have been found.

The average value of the force measured as part of the presented study can be compared with the results obtained by Scalise et al., who used pressure sensors wrapped around the handle to measure grip forces [20]. The measurements were carried out in the laboratory with the participation of six individuals, including three chain saw operators. The manufacturer of the chain saw, however, was not stated, but taking into account the mass and power (5.4 kg / 2.3 kW) of the tool, it seems that the chain saw used was small and universal. The mean push force was 31.5 N and mean grip force applied by woodcutters to working at maximal speed but not cutting tool was 46.7 N. During cross-cutting, lumberjacks used a lower value of grip forces, amounting 23 N. Coupling force as a sum of the gripping force and the push or pull force was about 45 N. Nonetheless, the order of magnitude of the force corresponds quite well with the results obtained in the presented study.

Laboratory measurements of coupling forces applied on chain saws by their operators were also carried out by the Institute for Occupational Health and Safety of German Statutory Accident Insurance (BGIA) at the Stihl facility in July 2008. The tool used in this study was a chain saw manufactured by Stihl, model MS 361. Stihl MS 361 was characterised by a power of 4.6 kW and weight of 5.6 kg. This was also the tool used by the lumberjacks participating in the presented study (SL). The forces exerted by six subjects during a felling operation were measured by sensors produced by Novel GmbH in Munich, Germany. The mean value of the force – 75 N – was much higher than in the presented study [21].

Forces exerted on chain saws were also studied by Wójcik and Skarżyński [22]. Measurements were carried out in a laboratory with the use of a tensometric measuring set manufactured by SENSOR-AT. Husqvarna model 254 XP, characterized by a cylinder displacement of 54 cm^3 and power output of 3 kW, was used in that study. Parameters were similar to those found in HM tools. The number of subjects was not given in the study. Mean force measured on the rear handle was about 65 N. The range of forces (46 – 82 N) corresponds quite well to the results obtained in the presented study. However, in a study by Wójcik and Skarżyński, the mean force exerted on the front handle of a chain saw was bigger and amounted about 90 N (range: 64 – 120 N). In the presented study, no statistical difference was found between mean values of coupling forces exerted by the right and left hand.

In the presented study, smaller coupling forces were used during cutting with large powerful chain saws. On the other hand, with the increase in weight of the chain saw, the cardiovascular strain also increases. The heavier chain saw has greater power and imposes a significantly greater cardiovascular strain than a lighter chain saw [23]. The coupling forces exerted on powerful tools are smaller than the forces exerted on universal chain saws. It seems that from the ergonomic point of view the most desirable chainsaw should be very light and very powerful. However, mass and power are not the only parameters which influence coupling forces. Although chain saws of the SM and HM type have comparable weight and power, the mean forces measured on these tools differed. There was also a difference between coupling forces measured on small machines produced by two different manufacturers. The forces exerted by skilled forestry workers on SM chain saws were about 10 N larger than the forces exerted on comparable chain saws produced by Husqvarna.

According to the findings presented in this paper, measurements of coupling forces exerted by forestry workers should not be estimated or carried out only in a laboratory. There are too many variables involved in the magnitude of coupling forces applied on chain saws, e.g. different characteristics of chain saws, maintenance history, sharpness of chains, age, design and component configurations. A standardized coupling force meter and method of measurements is needed to measure coupling forces in vibration risk assessment.

CONCLUSIONS

The relationship between coupling forces and power of a chain saw should lead to improvements of the tool itself and vibration-reducing devices. These results can also be used as a recommendation for fellers in a range of using proper machines for different types of cut or types of wood. Finally, they may also be applicable to assist in developing more effective methods for assessing vibration exposure risks.

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