

The comparison of vibro-acoustic impact of chainsaws with electric and combustion drives

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Abstract. Chainsaws generate high level vibrations and noise during work. No matter what type of the drive (electric, combustion) they exceed the permissible levels defined for a standard eight-hour working day. The intensity of a vibro-acoustic impact on chainsaw operators depends on many factors. One of them is the type of the drive. This is due to significant differences in saw design (inter alia characteristics of the drive, rotational speeds – quasi-constant for an electric drive and variable for a combustion one). For chainsaws of the same or similar power and different types of the drive the levels of vibrations and noise may vary. The paper compares the noise levels and frequency weighted vibration accelerations for different types of the drive. The tests were performed with the same interchangeable cutting set (guide bar, cutting chain). The repeatability of the cutting process was ensured. The test results may be helpful when choosing the tool.

1 Introduction

There exist various mechanized hand-held tools used for timber production and processing. Chainsaws fall within this product group. Most of tools of this type are driven by means of a combustion engine or an electric engine powered by a battery. This is because the work has to be performed under field conditions requiring mobility or at heights. The mains powered electric chainsaws constitute a separate group of tools. Such tools are mainly used for household and construction works. Because of the character of work a chainsaw operator is particularly exposed to various harmful factors, such as vibrations, noise, chemical substances, and dust. Moreover, moving parts of the cutting system [1-3] cause the risk of various limb and body injuries.

The petrol end electric chainsaws available on the market, and especially the models for non-professional use may be characterized by lower quality of used materials and workmanship. Designers of such models pay less attention to ergonomic features. As a result, this leads to an increase in operators' exposure to the above mentioned factors. An analysis of catalogue data for 57 tools of 10 brands has shown that hand-arm vibration (frequency weighted vector sums of r.m.s. values of vibration accelerations – a_{hv}) declared by manufacturers, recorded at the handles of electric chainsaws (determined according to the EN ISO 60745-2-13 standard [4]) do not exceed in any case the value of 11.2 m/s^2 . This is the maximum value of a_{hv} with exposure time of up to 30 minutes. However, the declared a_{hv} values of vibrations exceed the permissible value defined for an eight-hour working day. Their range is between 2.9 and 6 m/s^2 .

In case of chainsaws with combustion engines the catalogue data analyzed for 157 tools of 12 different brands show that the a_{hv} values determined according to ISO 7505:1986 [5] or ISO 22867:2011 [6] range between 4.4 and 7.1 m/s^2 . These values also do not exceed the maximum value for a short-time exposure (11.2 m/s^2), simultaneously exceeding the permissible values for an eight-hour working day. To minimize negative impacts of vibrations on

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operators it is justified for them to use personal protective equipment, such as anti-vibration gloves [7].

User's manuals contain also data concerning noise emission. The analysis these data shows that the A-weighted sound pressure level, measured according to [4] for electric chainsaws ranges between 83.7 and 96 dB. In case of petrol chainsaws the A-weighted sound pressure level, declared by manufacturers and determined according to ISO 22868:2011 [8] ranges between 100.1 and 105.3 dB. That is why it is necessary to protect operator's hearing by means of personal protective equipment, such as, for example, earmuffs [9].

Test results presented in some papers indicate, that the vibration level emitted by chainsaws depends on:

- the tool itself [10-15],
- processed material [16-18], and
- the operator [19, 20].

The vibration levels of chainsaws, declared by their manufacturers are purely indicative. This stems from the simplifying assumption, where the same time shares are assumed for different load conditions of the drive in the overall working time of the device. For petrol chainsaws they equal to 1/3 for work at Idle Speed (ID), maximum speed without load (Racing – RA) and maximum load (Full Load – FL) each. Equation (1) allows to determine the value of vibration accelerations for a petrol chainsaw according to [5, 6].

$$a_{hv,eq} = \sqrt{\frac{1}{3}(a_{hv,ID}^2 + a_{hv,FL}^2 + a_{hv,RA}^2)} \quad (1)$$

In case of electric chainsaws the shares equal to 1/2 for work at maximum speed without load (Racing – RA) and at maximum load (Full Load – FL) each [4]. The design of an electric chainsaw makes it impossible to work at idle speed. The value of vibration accelerations is determined according to [4] by means of Equation (2).

$$a_{hv,eq} = \sqrt{\frac{1}{2}(a_{hv,FL}^2 + a_{hv,RA}^2)} \quad (2)$$

The figure below presents percentage time shares for the respective working conditions for petrol and electrical chainsaws according to the standard.

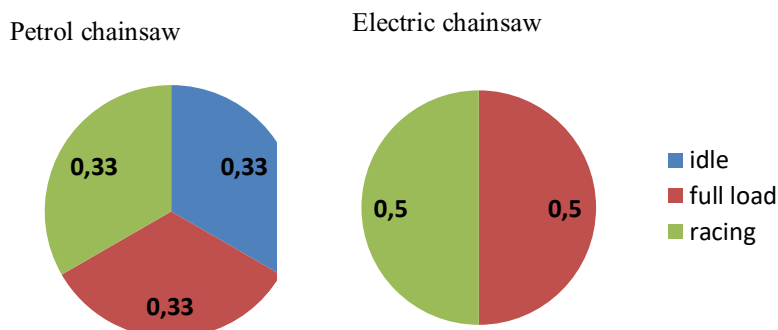


Fig. 1. Time shares of working conditions in the overall working time of a chainsaw depending on the type of its drive

Another important factor is the way vibrations are transmitted to the device handles. The petrol chainsaws are equipped with a vibro-isolation system separating their driving units from the handles. In the older models there were rubber shock absorbers mounted, which have currently been replaced by a system of coil springs or sometimes by combined elements. The electric chainsaws usually do not have any vibration reduction system, and their handles are permanently joined with the driving unit making a whole manufactured as a monolith.

As it was shown in the paper by K. Wójcik [21] a precise determination of time shares for the individual operating modes (ID, RA, FL) in the total operating time depending on the performed processing operation (felling, pruning, cross-cutting) is of key importance at the assessment of vibration and noise exposure.

Determination of a_{hv} according to Equations (1) and (2) is only justified in case of estimation of the impact of local vibrations on a chainsaw operator for a particular type of the device. A comparison of vibration impacts of electric and petrol chainsaws having similar parameters based on these equations would not be completely unbiased. This is due to the assumption of different time shares for the respective operating modes of the devices. Having this in mind the comparison of vibrations and noise was performed based only on measurement results obtained for the operation at full load (FL). The vibrations and noise were recorded during cross-cutting of pine beams with the same cross-sectional dimensions and parameters (grade, moisture content).

The authors of this paper focused on the comparison of vibro-acoustic impacts of chainsaws for non-professional use depending on the type of a driving unit – a combustion engine or an electric one.

2 Experimental

The methodology of chainsaw handle vibration acceleration measurement was based on the guidelines of the ISO 7505:1986 and ISO 33867:2011 standards [5, 6]. The A-weighted sound pressure level measurements were performed according to the z ISO 22868:2011 standard [8]. Two three-axial piezoelectric transducers DYTRAN 3023M2 were used to record the vibration accelerations. The sound pressure was recorded by means of a free field microphone ROGA RG-50 (ICP). Calibration of recording channels was performed using a reference source of vibrations – K10 type RPT97-146 ($a_{cal} = 10 \text{ m/s}^2$), and a reference sound source KA-10 ($L_{p,cal} = 94 \text{ dB}$ at a frequency of 1000Hz). The calibration procedure was performed both before and after the measurements.

The signals from the vibration transducers and the microphone were recorded synchronously using an eight-channel recording unit TEAC LX-10. The recording unit was used as a front-end and it was connected by LAN with a workstation. The A/D conversion was performed at a sampling frequency $f_s = 48 \text{ kHz}$. This ensured the noise measurement and analyses to be performed in the whole audible range (from 20 Hz to 20 kHz). The spectral analyses and the determination of measures parametrizing noise - L_A , L_{Lin} and vibrations a_{WX} , a_{WY} , a_{WZ} , a_{hv} were done by means of digital signal processing in the DasyLAB* environment.

The way and place of fixing the transducers to the chainsaw handles are shown in Fig. 2a. Fig. 2b shows the position of the microphone toward the operator's head. The vibration acceleration transducers were connected to the chainsaw handles by means of a SA 50** adapter. To obtain a durable and repeatable coupling between the SA 50 adapters and the handles screw-type band clips were used additionally.

To obtain repeatable parameters of a cutting technique and constancy of ontogenetic traits, all of the tests were performed by one operator (a man; weight 85 kg, height 175 cm). The way the tool was held during the tests and the measurement stand is shown in Fig. 3. Fig. 3a show additionally the directions of reference axes of the coordinate system - its orientation conforms to the device and standards [5, 6].

The cutting was performed on pine beams with a cross-section of 70×90 mm, being in the air-dried state. The wood moisture content was measured by means of POWERFIX Profi + Moisture Meter HG03064C. The moisture content of the wood was equal to 11±2 %. The tests involved an uninterrupted sequence of eight cuttings of a beam across fibers in a material

* Data Acquisition System Laboratory®

** dedicated adapter for accelerometer fixing

without defects. The test conditions were selected in a way that full load of the driving unit was obtained.

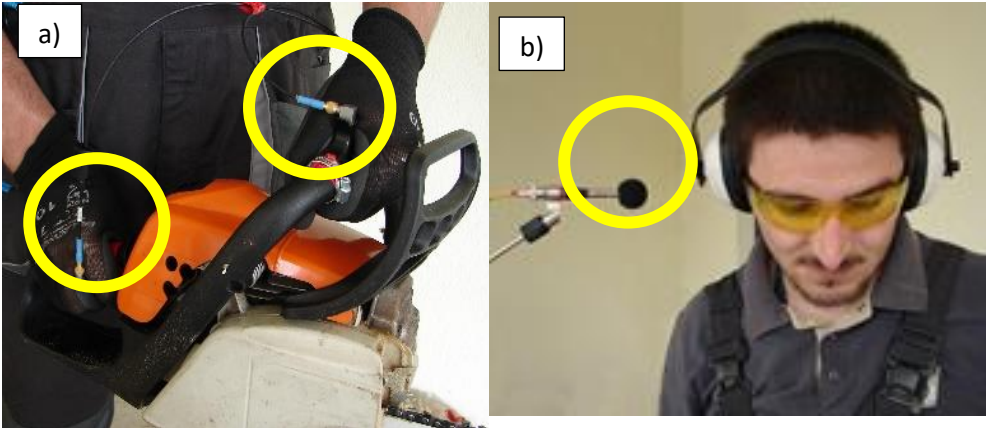


Fig. 2. Location of vibration transducers on the chainsaw handles - a), and the microphone - b)

Electric and petrol chainsaws of a leading brand on the market were subjected to the tests – models for non-professional use. The tests on chainsaws were carried out with the same cutting set (cutting chain, guide bar). This was possible due to the standardization of cutting sets by the chainsaw manufacturer. After installation of the cutting set the same tension of the chain was fixed. Such an approach enables to reduce to a large extent the influence of the cutting set and its settings on measurement results. Technical parameters of the tested chainsaws are shown in Table 1.

Table 1. Technical parameters of the chainsaws being tested

Type of drive		Combustion	Electric
Power [kW]		1.5 (at 10000 RPM)	1.4 (at 7900 RPM)
Maximum linear speed of cutting chain [m/s]		24.8	14.6
Cutting chain	pitch [in]	3/8 P	
	manufacturer’s designation	61 PMM3	
	drive link gauge [mm]	1,1	
	type of chain	semi-chisel	
Guide bar length [mm]		350	

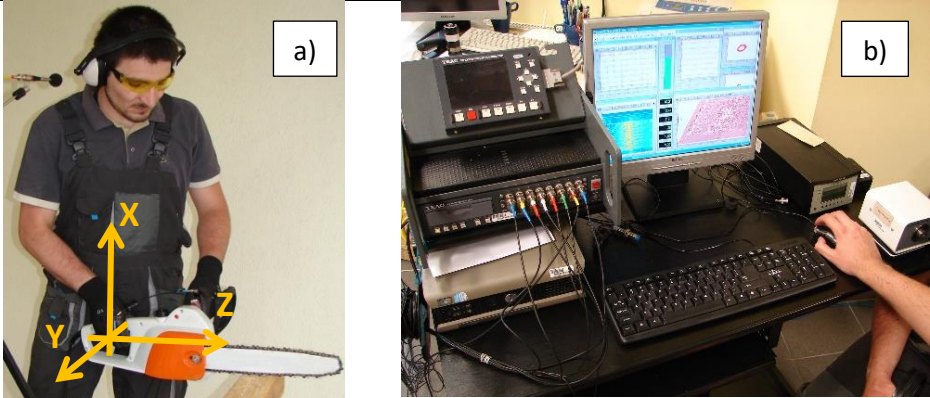


Fig. 3. Operator’s body position – a) and the measurement equipment – b).

3 Results

Fig. 4 shows the results of measurement of vibrations of chainsaw handles (taking frequency weighting W_h into account). The averaged values of vector sums a_{hv} (singled out in the figure) and values measured in X, Y and Z directions – a_{hwi} are presented in the form of a bar chart. To determine the average values three signal sequences (lasting approximately 20 seconds each) involving eight cuttings of beam were used. It should be emphasized that the sequences involved only the process of wood cutting – i.e. the FL mode. If parametrization of all operating modes of the driving unit (ID, RA, FL) are taken into account, the determined values of a_{hv} will be slightly lower than those presented in the figure.

In case of the petrol chainsaw the highest values of a_{hwi} were obtained for the X direction, for the rear handle. The highest value of a_{hwi} at the front handle was recorded for the Z direction. The lowest values at the front and rear handles were recorded in the X and Z directions respectively. In this way the earlier test results obtained by the authors [22] have been confirmed. Generally, the values of a_{hwi} measured for the electric chainsaw are higher than those obtained for the petrol one. The only exception is the Y direction at the rear handle. For both electric chainsaw handles the values of vector sums a_{hv} are higher than those for the petrol chainsaw ones. The differences equal 1.81 m/s^2 for the front handle and 1.51 m/s^2 for the rear handle.

Fig. 5 presents a comparison of octave spectra of noise for the tested chainsaw and the A-weighted sound pressure level. The nature of generated noise is similar for both devices. The differences in sound pressure levels for individual octave bands of the tested chainsaws range between 1.9 and 19.8 dB. The biggest difference was noted for the octave band with the center frequency of 125 Hz. High values of the sound pressure levels were recorded in the octave bands with center frequencies of 1 kHz, 2 kHz and 4 kHz. This corresponds to the range of the highest sensitivity of human hearing. That is why the noise generated by petrol chainsaws is particularly burdensome for their operators. A higher sound pressure level for the petrol chainsaw in the octave band with the center frequency of 125 Hz may stem from the phenomena accompanying the driving unit operation at the maximum speed and full load. The highest values of the sound pressure level were recorded in the octave band with the center frequency of 2 kHz. They equal to 95.3 dB and 99.6 dB for the electric and petrol chainsaw respectively. The spectral composition of the noise emitted by the chainsaws with the dominance of components in frequency bands between 500 Hz and 8 kHz causes that the total linear sound pressure level and the A-weighted sound pressure level differ only slightly. The values of the A-weighted sound pressure level equal to 100.3 dB and 105 dB for the electric and petrol chainsaws respectively.

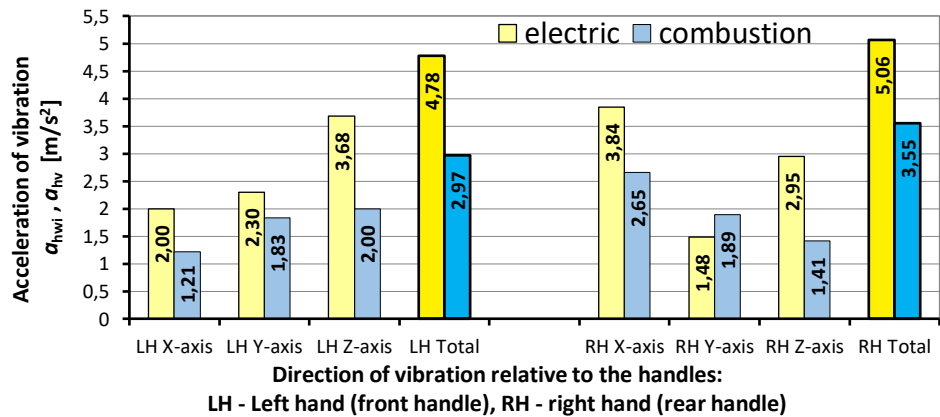


Fig. 4. Frequency weighted chainsaw handle vibration accelerations for the process of cutting.

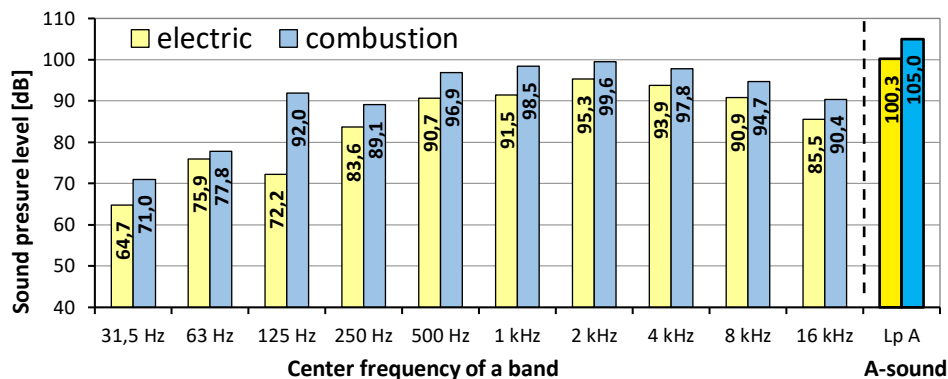


Fig. 5. Comparison of the octave spectra of the noise emitted by the electric and petrol chainsaws during cutting and L_{pA} .

4 Summary

The measures parametrizing the handle vibration accelerations (a_{hwi} , a_{hv}) are higher for the electric chainsaw than those for the petrol one (about 60% for front handle and 42% for rear handle). For both types of drives higher vibration acceleration values are recorded at the rear handle (right hand). Generally, electric chainsaw vibrations for the individual directions are higher than those for the chainsaw with a combustion engine. The only exception is direction Y for the rear handle. The dominant direction of front handle vibrations is the Z direction, and for the rear handle vibrations – the X direction. Based on the obtained results it can be said that it is necessary for an operator to use individual protective equipment, such as anti-vibration gloves. This is particularly important for work with an electric chainsaw.

Higher values (about 5 dB) of the sound pressure level accompany the petrol chainsaw operation. For the tested tools the highest values of the sound pressure level were obtained for the octave band with the center frequency of 2 kHz. Taking the A-weighting into account causes that the dominant components of noise emitted by the chainsaws correspond to the bands of the highest sensitivity of human hearing. Hence, noise will be particularly burdensome for users. The nature of the noise emitted by both types of devices is similar, excluding the octave band with the center frequency of 125 Hz, where the sound pressure level is by 19.8 dB higher for the chainsaw with a combustion engine. The A-weighted sound pressure level is higher in case of work with the petrol chainsaw and it equals to 105 dB, and differs from the value obtained for the electric chainsaw by 4.7 dB. This indicates the necessity of use of personal protective equipment, such as, for example, earmuffs.

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