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ESTIMATION METHOD OF VIBRATION EXPOSURE ASSESSMENT FOR MECHANIZED HANDHELD TOOLS OPERATORS BASING ON PRECISE DETECTION OF DEVICES OPERATING MODE

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Abstract

Currently, it is obligatory to assess the employees' exposure to harmful factors. An assessment of chainsaw operators' exposure to vibration and noise should be made at the workplace (in the field or forest). A precise determination of a chainsaw operator's exposure to vibration and noise during an 8-hour work day can be based on dosimetric measurements. However, this type of measurements are difficult to be performed in the field or forest conditions. The assessment of a chainsaw operator's exposure to vibration and noise can also be made by an indirect method, based on a determination of reference vibration and noise parameters related to operation of the chainsaw in particular modes (Idle, Racing or Full Load) and estimation of time shares of individual modes of the chainsaw's operation in its total operating time. This article presents an improved device dedicated for field measurements of rotational speed of a chain sprocket and a chainsaw's engine shaft. The article also presents the principles of identifying chainsaw operating modes based on these measurements. An analysis of the angular acceleration of the chain sprocket and engine shaft was also carried out. The presented approach, in addition to the basic operating modes, enables identification of transition states, such as acceleration, deceleration or jamming of the cutting set.

Keywords: chainsaw, operating modes, vibration exposure, rotational speed measurement

1. INTRODUCTION

Without a doubt, combustion powered chainsaws pose a significant threat to the health and life of their operators [1-5]. In addition to the risk of serious injuries, chainsaw operators are constantly exposed to harmful factors, including exhaust gases [6, 7], dust [8, 9], vibrations [10-12] and noise [13-14].

The assessment of operators' vibration exposure to this class of devices is made by determining the value of daily exposure to vibrations – A(8) and comparing it with the threshold limit values. Daily exposure to vibrations is determined in accordance with the procedure included in ISO 5349-1 standard [15] and is described by equation (1):

$$A(8)=\sqrt{\frac{1}{T_0}\sum_{i=1}^{n} a_{hv;i}{}^2\cdot t_i}\quad [m/s^2] \qquad (1)$$

where:
T_0 – reference time, T_0 = 8h = 480 min;
$a_{hv;i}$ – frequency weighted vector sum of RMS acceleration values (vibration total value) for i-th operation;
t_i – duration of the i-th operation;
n – the numer of individual vibration exposures.

While, the assessment of operators' acoustic exposure is made, in accordance with the guidelines contained in ISO 9612 standard [16] by determination of the A-weighted equivalent continuous sound pressure level – $L_{A;eq;8h}$, for the effective duration of the working day, as well as the daily A-weighted noise exposure level – $L_{EX;8h}$. $L_{A;eq,8h}$ is calculated from the following equation:

$$L_{A;eq;Te}=10\log_{10}\left(\frac{1}{T_e}\int_0^{T_e}10^{0,1L_{pA}(t)}dt\right)[dB] \qquad (2)$$

where:
T_e – the effective duration of the working day, T_e = 8 h,
$L_{pA}(t)$ – the A-weighted sound pressure level.

Precise determination of the daily level of exposure to noise and vibrations can be achieved in accordance with the ISO 5349-1 [15] and ISO 9612 [16] by means of dosimetric measurements. Such measurements are difficult to perform in field (forest) conditions and have some major hindrances and inconveniences, which include reducing the safety of the operator and research staff [17],

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especially when they are in the immediate danger zone, as well as the deterioration of comfort and work efficiency resulting from the installation of vibration transducers and signal cables on the chainsaw's handles and deviations from the typical workplace.

The authors are not aware of any publications describing day-long dosimetric measurements of vibration and noise to which a chainsaw operator is exposed in real working conditions. However, one can find articles dealing with chainsaw operator's daily exposure to vibrations involving vibration measurements in conditions simulating forest conditions.

Bacić et. al [18] determined indirectly the values of A(8). Vibration accelerations $a_{hv;i}$ were measured in simulated conditions – on a felled tree. The duration of the operation was estimated based on the analysis of video material (GoPro camera) recorded by professional forest workers during their own work. The same research team also presented the results of other studies [19], in which attention was drawn to the fact that all-day measurement of A(8) is very complex. In these studies, A(8) values were also determined indirectly. While determining A(8) one has to bear in mind that unwanted interruptions caused by the need to fix the accelerometer on the chainsaw handle, questionable battery life of the instrument, and harsh working conditions, may occur which would affect the accuracy of the results.

Mataché et. al [20] presented a similar approach. The chainsaw operator's exposure was estimated based on the results of measurements of vibration accelerations on chainsaw handles conducted in conditions simulating forestry work. The reported weighted vibration level were the mean value of 10 cutting experiments. The time used in estimation of A(8) was the real exposure time that was timed using a chronometer during a typical cutting tree cycle, multiplied by the number of cut trees during an 8-hour work day .

F. Neri et. al [21] determined the daily exposure to vibrations – A(8) and noise – $L_{\mathrm{EX,8h}}$, based on the results of measurements of the vibration accelerations of chainsaw handles, the results of acoustic pressure measurements and the assumed working time of 6 h. These measurements were carried out on previously intentionally prepared research material.

Rukat in his dissertation [22] proposed an alternative and more detailed indirect method for estimating a chainsaw's operator's exposure to vibration and noise based on the identification of the chainsaw's operating mode (OM). The method is based on the assumption that if the share of working time for individual OMs of the chainsaw's engine during T_e is known, it is possible to determine $a_{hv;eq}$ according to the equation:

$$a_{hv,eq} = \sqrt{ts_{ID}a^2_{\mathrm{hv,ID}} + ts_{FL}a^2_{\mathrm{hv,FL}} + ts_{RA}a^2_{\mathrm{hv,RA}} + ts_{UT}a^2_{\mathrm{hv,UT}}} \tag{3}$$

where:

$a_{hv,eq}$ – equivalent vibration level;

$a_{hv,ID}$ – vibration accelerations (weighted vector sum of RMS values) measured while Idling;

ts_{ID} – share in T_e corrspondiong to Idle speed;

$a_{hv,FL}$ – vibration accelerations measured under Full load;

ts_{FL} – share in T_e corrspondiong to Full load;

$a_{hv,RA}$ – vibration accelerations measured while Racing;

ts_{RA} – share in T_e corrspondiong to Racing;

$a_{hv,UT}$ – vibration accelerations measured while operating in Undeffined state or during Transients;

ts_{UT} – share in T_e corrspondiong to Undeffined and Transients.

The $a_{hv,i}$ values corresponding to OMs of the device are determined experimentally, under safe conditions. On the other hand, individual (from the point of view of the operator or working day) estimation of $a_{hv,eq}$ requires determination of the time shares of OMs of the device. In the dissertation, the author determined the time shares on the basis of time-lapse analysis of video footage. This approach guarantees high accuracy but is incredibly time-consuming. However, the time shares of the operating mode of a chainsaw can be determined in an alternative way.

Rukat et. al [23] described a methodology for identifying the mode of operation of a chainsaw based on the short-time parameterization of vibro-acoustic signals. They presented there an attempt to identify the OM of a chainsaw based on short-time analysis of:

- sound pressure level;
- sound pressure sonogram;
- sound pressure level in octave bands;
- RMS value of vibration acceleration;
- spectrogram of the RMS values of vibration acceleration.

The best results were obtained for the variant with octave analysis of the acoustic signal, but unfortunately in field conditions this approach does not guarantee high identification efficiency due to high sensitivity to noise disturbances. Analysis of the vibration acceleration spectrogram was similarly effective. In both cases, the effectiveness of the approach was related to tracking changes of the frequency of the rotational component and the fact that the dominant component of the sound emitted by the chainsaw changes octave during cutting. Consequently, tracking changes in the instantaneous values of rotational speed (frequency) appeared to be the most promising in terms of performing whole working day measurements, for the purpose of identifying the operating mode of the chainsaw's engine.

Wróbel et. al [24] presented a battery-powered device for measuring the speed of a chain sprocket. The paper shows that the recorded rotational speed signal of the chain sprocket allows us to identify all OMs except undefined and transient states that occur during operation of the device. The latter can cover up to 30 % of operating time. Which makes it impossible to accurately determine time shares of OMs solely on the basis of chain sprocket's rotational speed measurement when indirectly assessing operator's exposure to vibrations and noise.

The purpose of this research was to improve the method of identification of the OM of the engine of a petrol chainsaw by improving the existing measuring device, along with determining the effectiveness of its operation. The improved device had to allow us to more accurately determine the time shares of OMs of the chainsaw in operation time – T_e. With the values of $a_{hv;i}$ determined under safe conditions, the shares can be then applied to equation (3), and therefore they can be used in estimation of $a_{hv,eq}$. Alternatively, duration of each OM can be used to determine $A(8)$ in accordance with equation (1). In the aspect of determination of $a_{hv;i}$, the proposed method is in accordance to standard procedures.

2. MEASURING DEVICE REDEVELOPMENT

A prototype of the device for measuring the speed of the chain sprocket of the petrol chainsaw was previously developed by authors of this article [24]. The research carried out using a prototype device was used for formulate premises for further development of the method for identifying the OMs of the petrol chainsaw and modifications of the measuring device. Based on the measurement systems used in the prototype of the device and formulated recommendations, a new device for registrating the rotational speed of the chain sprocket and rotor of the petrol chainsaw's engine was developed and manufactured. A block diagram of developed device is presented in figure 1.

The device has been designed as an universal platform which gives a possibility of measuring and recording the following types of signals:

- analog voltage signal in the range of 0-12V (2 channels) and 0-3,3V (4 channels);
- analog current signal - measurement carried out using a shunt resistor (2 channels);
- digital signal (4 channels) determined on the basis of an external analog voltage signal in the range of 0-3,3V (possibility of adjusting the threshold value using a comparator).

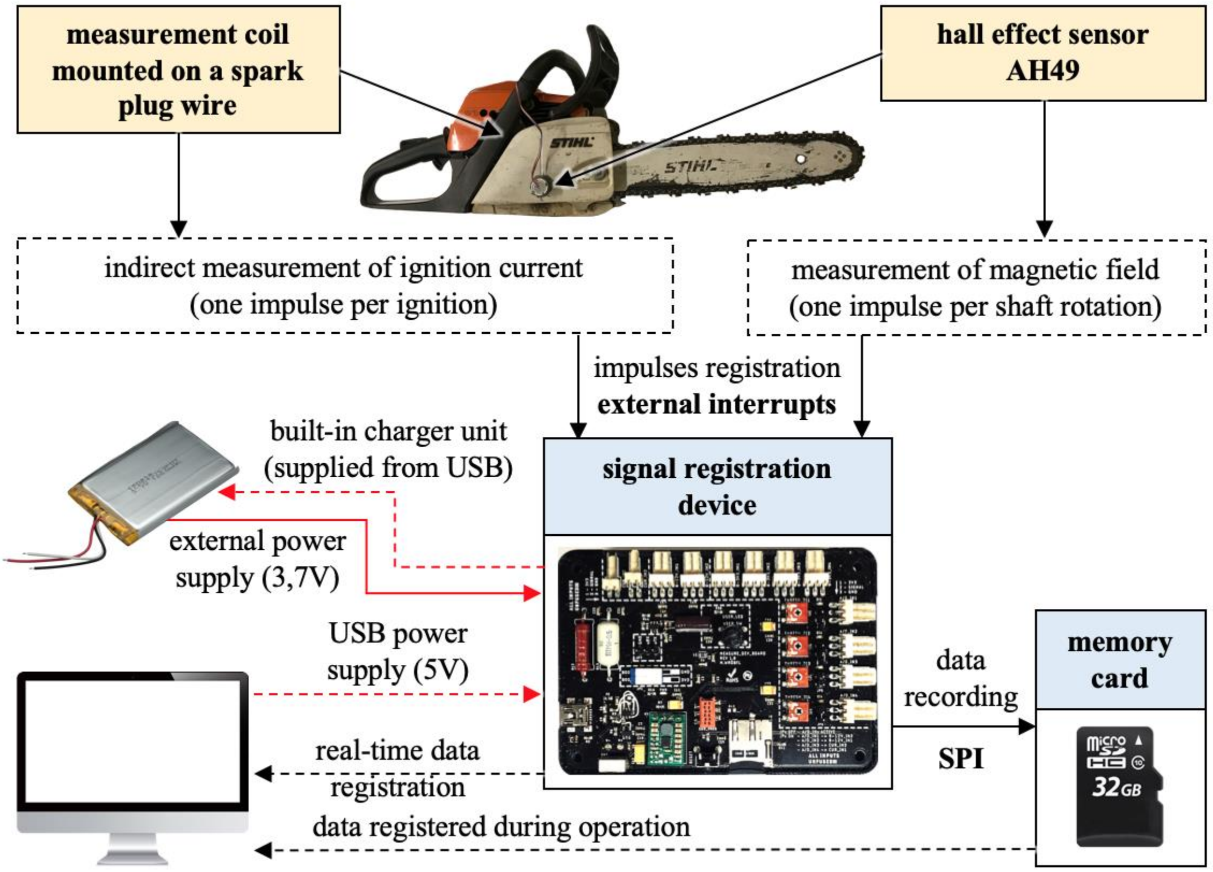

Fig. 1. A block diagram of the modified device for registration of the rotational speed of the chain sprocket and rotor of the petrol chainsaw's engine

Data recorded by digital inputs (GPIO - General Purpose Input/Output) and ADC (Analog - Digital Converter) converter inputs can be sent via the USB interface to an analysis application running on a PC. Optionally it is possible to operate the device as a mobile recorder, thanks to the use of a lithium-polymer battery with capacitance of 1800 mAh. The large capacity of the battery allows the device to operate continuously significantly longer than the standard working time of a chainsaw operator (8 hours). In this type of operation, the recorded data is saved on a micro SD card in the form of *.txt* text files, which can be imported on a PC for further analysis.

The rotational speed of the chain sprocket is measured using a neodymium magnet mounted in one of the teeth of the chain sprocket and the AH49E Hall sensor (Fig. 2). An analog signal is proportional to the magnetic field measured by the sensor is connected to one of the comparator inputs of the device and then converted into a digital signal. The measuring system provides one pulse per revolution of the chain sprocket. The measurement of the rotational speed of the chainsaw engine's rotor is performed using a measuring coil mounted on a spark plug cable (not visible on figure 2). The coil is connected to the input of the measuring device intended for current measurement, and then to the comparator. The measurement system prepared in this way enables obtaining two pulses per revolution of the rotor. Digital impulses of the rotation of the chain sprocket and the rotor are read by the microcontroller using external interrupts. The basis for further analysis is the number of pulses registered from both measurement channels (chain sprocket and engine's rotor) during 0,1 ms. Then, the instantaneous rotational speed of both considered elements can be determined during post-processing.

However, this method of recording and analyzing of data has the following disadvantages:

- low input levels of signals from the Hall sensor and the measuring coil may be problematic to read for the comparator system - therefore, an amplifier system should be introduced in the measurement chain;
- data transferred for further analysis are not intuitive - it is necessary to know the time interval for which the number of pulses was registered and to appropriately post-process this information to obtain the RPM value.

Despite the above-mentioned disadvantages, the acquired data enabled precise determination of the rotational speeds of the chain sprocket and engine's rotor of the petrol chainsaw.

Measurements were carried out using a STIHL chainsaw, model MS181. The saw is powered by a 1,5 kW two-stroke combustion engine and belongs to the group of devices intended for non-professional applications (home use). The cutting system consisted of the 7-pointed profile chain sprocket with a pitch of 3/8", a Rollomatic E guide with a length of 350 mm and a PM3 semi-chisel cutting chain with a pitch of 3/8" and the width of the guide link of 1,3 mm in brand new condition.

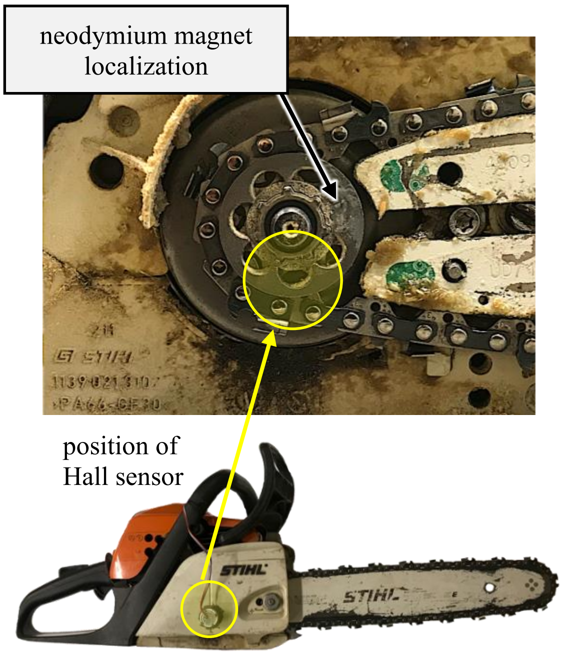

Fig. 2. View of localization of neodymium magnet mounted in chain sprocket and AH49E Hall sensor mounted in chainsaw's cover

3. RESULTS

The research involved a series of tests in which rotational speed of both the engine speed and the chain sprocket of the tested chainsaw were simultaneously recorded. These tests included:

- initial verification of the convergence of the signals from both channels,
- a simple test consisting of cutting a pine beam (180×220 mm) once,
- a test simulating real operation conditions, consisting of cutting the beam several times

3.1. Initial verification

One sequence was recorded in the first test. It consisted of: running the machine at idle speed, rapid acceleration followed by slow acceleration of the engine up to the maximum speed, maintaining maximum speed for a while, and then a free deceleration. The changes of the rotational frequency of the chain sprocket and the engine shaft during the initial convergence test is shown in figure 3.

As it can be seen in figure 3, to the end of the 3rd second of the test, the saw was idling - the signal was generated solely by the coil on the ignition cable. The chain sprocket (clutch drum) remained stationary. In the 4th second of the test, the engine speed was increased by pressing the lever controlling the opening of the carburettor throttle. The increase in engine shaft speed triggers the centrifugal friction clutch and starts the transmission to the clutch drum and in turn to the cutting chain – the transmission is then coupled. This situation occurs when the engine shaft frequency exceeds 70 Hz.

At the start of the transmission, a significant difference in the rotational frequencies of the engine shaft and chain sprocket can be noticed (up to 30 Hz). Above frequency of 90 Hz, this difference does not occur. This difference can also be seen when the rotational speed drops and the machine itself enters the idling phase (decoupling of the drive).

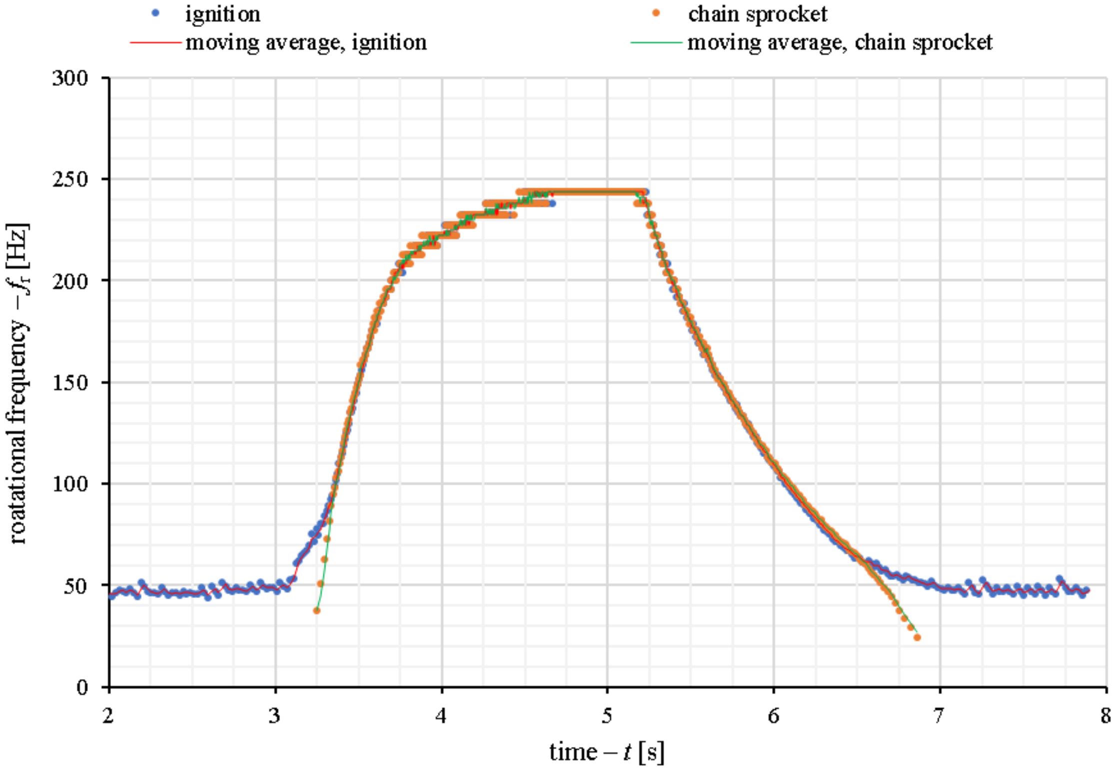

Fig. 3. Changes of rotational frequency of chainsaw drive train components during the convergence test

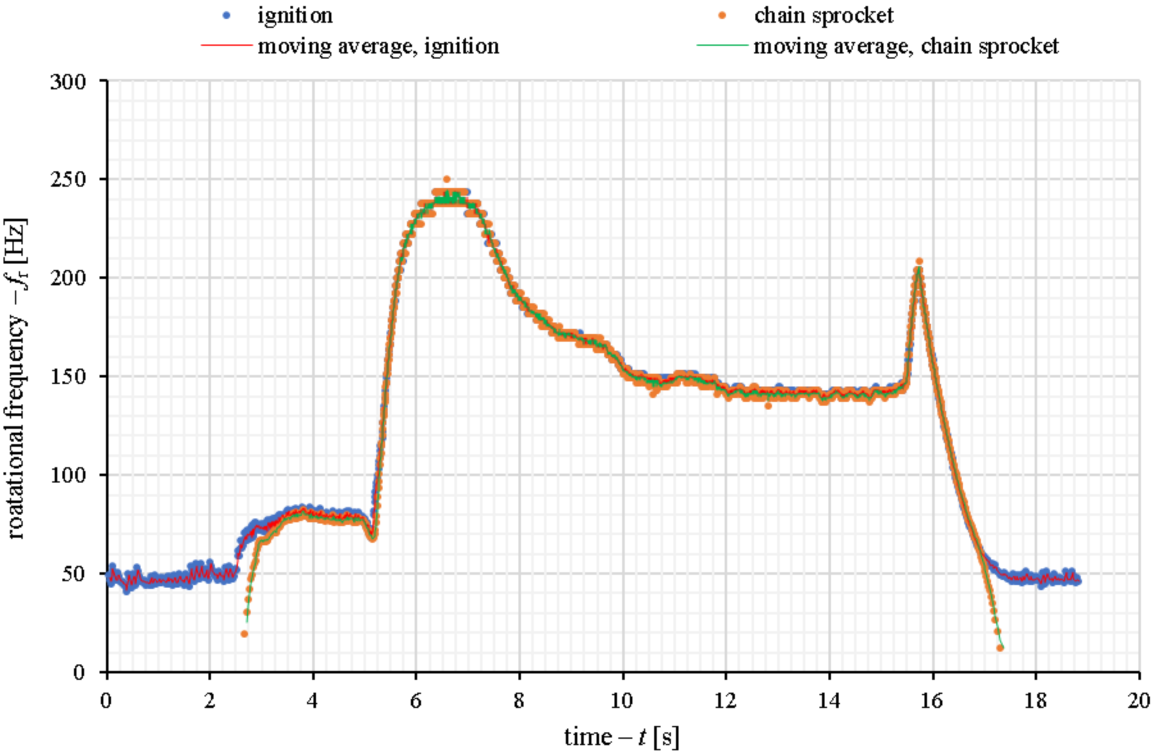

Fig. 4. Changes of rotational frequency of the chainsaw drive train components during the control test

In the 4th second of the test, there is a rapid increase in speed (up to approx. 200 Hz) followed by a slow increase in speed, which is related to the dynamic characteristics of the engine. Then stabilisation of the rotational speed associated with the carburettor reaching the optimum dosage level of the fuel-air mixture occurs. The engine reaches its maximum speed for which the rotational frequency is about 240 Hz (in the 5th second of the test). The maximum speed is maintained for a fraction of a second. Then, a linear/quasilinear drop in speed caused by the operator releasing the throttle takes place. Deceleration lasts for about 1.5 s.

Once the rotational frequency of the engine falls below 80 Hz. The frequency drop changes its character from linear/quasilinear to exponential - this is probably related to the loss of friction between the friction linings of the clutch jaws and the erroneous basket. Note the very high convergence of the signals in the frequency range higher than 90 Hz (4 800 RPM). The test proved that identification of racing mode of operation can be done basing on both recorded signals. Moreover, recording of the additional signal from the ignition coil eliminates the disadvantage of the previous approach [24] and makes it possible to distinguish between the idle mode of operation and the device switched off.

3.2. Control test – single cut

During the second test, a pine beam of 180×220 mm cross-section was cut. The recorded sequence consisted of: operating the device at idle speed, increasing and maintaining the speed above the speed for the centrifugal clutch response (intermediate speed, no load), followed by acceleration of the engine to maximum speed, followed by one cut of the beam (Full Load OM). After the cut was done, the device was put into the idle speed mode. The changes of the rotational frequency of the chain sprocket and the engine shaft during this test is shown in figure 4.

As can it be seen in figure 4, for the first 2,5 seconds of the test the chainsaw was idling – the engine shaft frequency was approximately 50 Hz, while at the same time the measuring system have not registered a signal coming from the Hall sensor (no rotations of the chain sprocket). The speed was then increased to reach the minimum possible engine speed at which the centrifugal clutch engages and the cutting chain starts to move along the guide bar. This also triggers the Hall sensor. The intermediate speed was maintained until the end of the 5th second of the test. After this, the engine was accelerated to maximum speed.

In the 8th second of the test, cutting began. The technique of guiding the saw and the shape of the cross-section of the beam being cut cause the length of the active cutting line to vary over time. In the beginning, it is short and then increases, which increases the cutting resistance and this in turn results in a decrease in rotational speed. For the maximum and, at the same time, optimum value of the cutting resistance force, which does not cause the cutting set to jam in the workpiece, the speed stabilises at approx. 7 200 RPM (rotational frequency approx. 140 Hz). The cutting process lasted from approx. 8th to approx. 15th second of the test. In the final cutting phase, an increase in RPM can be observed due to a decrease in the length of the active cutting line - a decrease in cutting resistance associated with the run-out and exit of the cutting set from the workpiece. The rest of the second test is identical to the end of the first test.

The figure allows us to conclude that beginning from 80 Hz and above, both analysed signals are equivalent regardless of OM of a chainsaw.

3.3. Simulation of real operation conditions

The simulation of real operating conditions involved three cuts of the beam, similarly to the cross-cutting operation that takes place e.g. in firewood preparation - cutting the log into assortments. During the test, the interval between cuts, during which the saw is idling, that typically occur in real operation, were ignored. This is because this OM is the easiest to identify (see figures 3 and 4). The changes of the rotational frequency of the chain sprocket and the engine shaft during this test is shown in figure 5.

The beginning of the test, up until the start of the cutting, does not differ from those described earlier. The completion of each cut also followed the same pattern. However, the cutting method differed from that used in the second test. The fluctuation in speed during cutting is due to the use of a technique of cutting in which the operator aims to minimise cutting resistance at all times through controlled swinging movements of the machine. This translates into a time-varying active length of the cutting line.

According to Rukat et al., identification of the operating mode of a chainsaw is possible based on the tracking of changes of the chain sprocket rotational speed [23]:

- Idle mode: frequency below 50 Hz,
- Full load: frequency from approx. 115 Hz to approx. 185 Hz,
- Racing: frequency above 210 Hz.

Between these ranges, undefined mode representing up to a third of the T_e occurs. Undefined mode can include acceleration time (without load), operation under minimal load and braking down.

For the tests described in this paper, the engine frequency ranges are similar:

- Idle mode: frequency below 60 Hz;
- Full load: frequency from approx. 100 Hz to approx. 180 Hz;
- Racing: frequency above 200 Hz.

However, as can be seen in figure 5, the use of the improved measuring system in this research study enables more accurate identification of the current OM of the chainsaw.

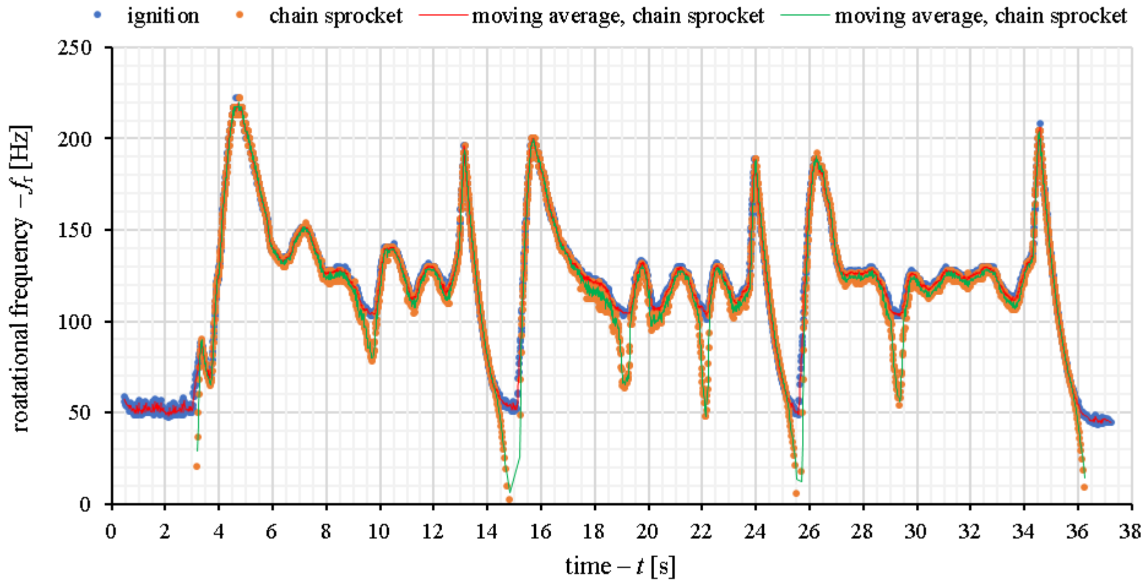

Fig. 5. Changes of rotational frequency of the chainsaw drive train components during the simulation of real operating conditions

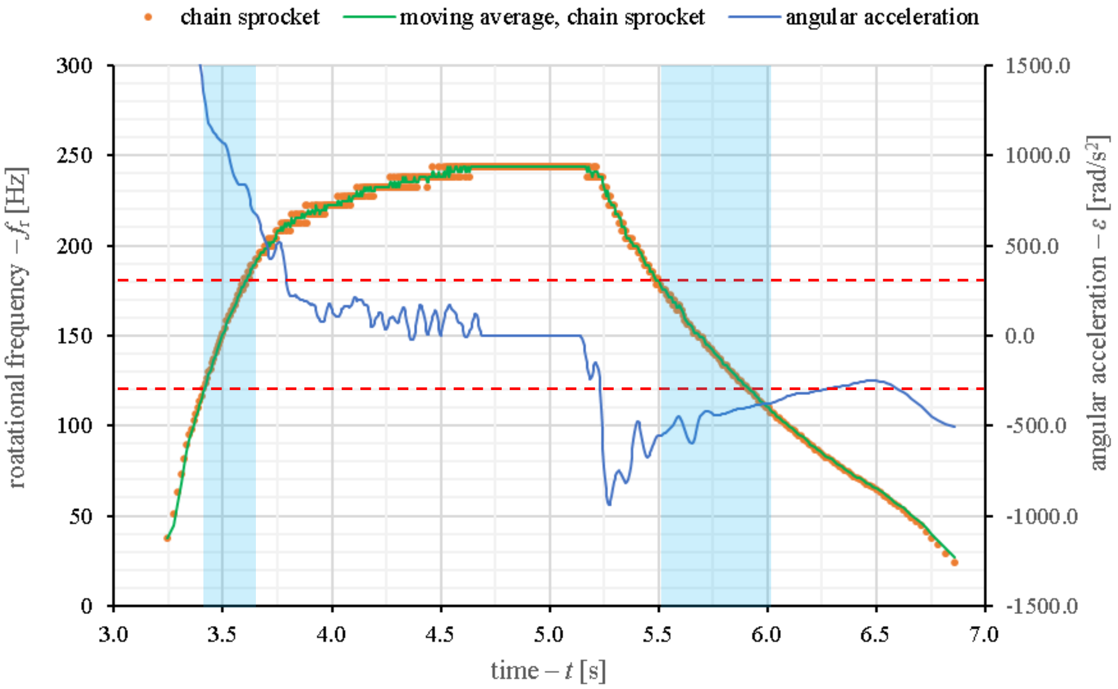

Fig. 6. Changes of angular accelerations of the chain sprocket during the convergence test

During the third test in the 10th, 20th, 23rd and 30th seconds of the test, differences in the rotational frequency of the engine and chain sprocket can be observed. This is related to the momentary jamming of the cutting set in the workpiece. The reason for this is that the resistance, which guarantees the sustained coupling of the drive system, is exceeded. When the cutting set is jammed, a drop in the chain sprocket frequency is observed while the engine frequency remains relatively constant – there is slippage between the clutch jaws and the drum of the clutch basket, which is also the chain drive wheel. Jamming of the chain sprocket should also be classified as an Undefined OM.

Basing on the aforementioned frequency ranges, time shares of OMs of the chainsaw in T_e have been determined. They are equal to: 14.06 % Idle, 66.00 % Full Load, 2.49 % Racing and 17.46 % Undefined and Transients.

4. ANGULAR ACCELERATIONS OF DRIVING SYSTEM

With the knowledge of the course of the tests presented in Chapter 3, it can be concluded that there is a situation in which the rotational frequency of the engine is in the range corresponding to Full Load, but the chainsaw is only accelerating (transition from Idle to Racing) or braking. Identification of such a situation based solely on the rotational frequency is impossible. However, since such transitions are short-lived, their identification is possible on the basis of analysis of changes in angular acceleration of the engine shaft or chain sprocket.

Changes in the rotational frequency of the chain sprocket and changes in the angular acceleration values of the chain sprocket (moving average of 10 data points) during the first of the control tests are shown in figure 6. In the figure, red dashed lines indicate the values of 300 rad/s^2 and -300 rad/s^2. While, the light blue color marks the test intervals in which the chain sprocket frequency is in the range of 100 Hz - 180 Hz but the device is not running under load.

During the operation of the chainsaw, the angular accelerations of the drive train components vary over a wide range. During the acceleration of the engine – the transition from the Idle OM to the Racing OM, the instantaneous acceleration values exceed 3000 rad/s2. As the rotational frequency of the chain sprocket increases, the angular acceleration decreases. When the saw reaches maximum speed and is in Racing OM range, the value of angular acceleration is close to 0. Closing the carburetor throttle results in a free fall of the rotational speed. Angular acceleration then takes on negative values. Free deceleration of a chainsaw is a less dynamic phenomenon than acceleration.

During acceleration and deceleration when the rotational frequency is in the range corresponding to Full Load OM (100 Hz – 180 Hz), angular accelerations greater than 300 rad/s2 are recorded. Another can be added to the conditions identifying OMs of the chainsaw: if the absolute value of the angular acceleration of the chain sprocket exceeds 300 rad/s2, then the chainsaw is accelerating or decelerating. The correctness of this condition can be verified by relying on the second test. Changes in the rotational frequency of the chain sprocket and changes of the angular acceleration of the chain sprocket during the single-cut test are shown in figure 7.

Colour marks has been added to the figure similarly to figure 6 (previous one). The acceleration of the chainsaw engine was recorded in the 6th second of the test and the deceleration of the engine in the 17th. In both of these cases, the absolute value of angular acceleration exceeded 300 rad/s^2. In addition, a short (about 0,15 s) segment of the signal corresponding to the end of the cut and the increase in the rotational frequency associated with the operator's reaction time was identified and marked in purple. In this interval, the angular acceleration also exceeds 300 rad/s^2. During undisturbed operation while ideling, under full load and while racing, the angular acceleration varies from -100 rad/s^2 to 100 rad/s^2.

Taking into account the condition: the absolute value of the angular acceleration of the chain sprocket is greater than 300 rad/s^2 and the rotational frequency of chain sprocket is in the range of 100 Hz – 180 Hz, the time shares of two OMs of the chainsaw in T_e (determined at the end of Chapter 3) were corrected: Full Load – 56,84% and Undefined and Transients – 26,64%.

The analysis of changes in the angular acceleration values of the chain sprocket (or engine shaft) is a good coaddition to measurements of engine shaft and chain sprocket rotational speeds. With angular acceleration, it is possible to detect transitions through the frequency zone corresponding to Full Load during acceleration and deceleration.

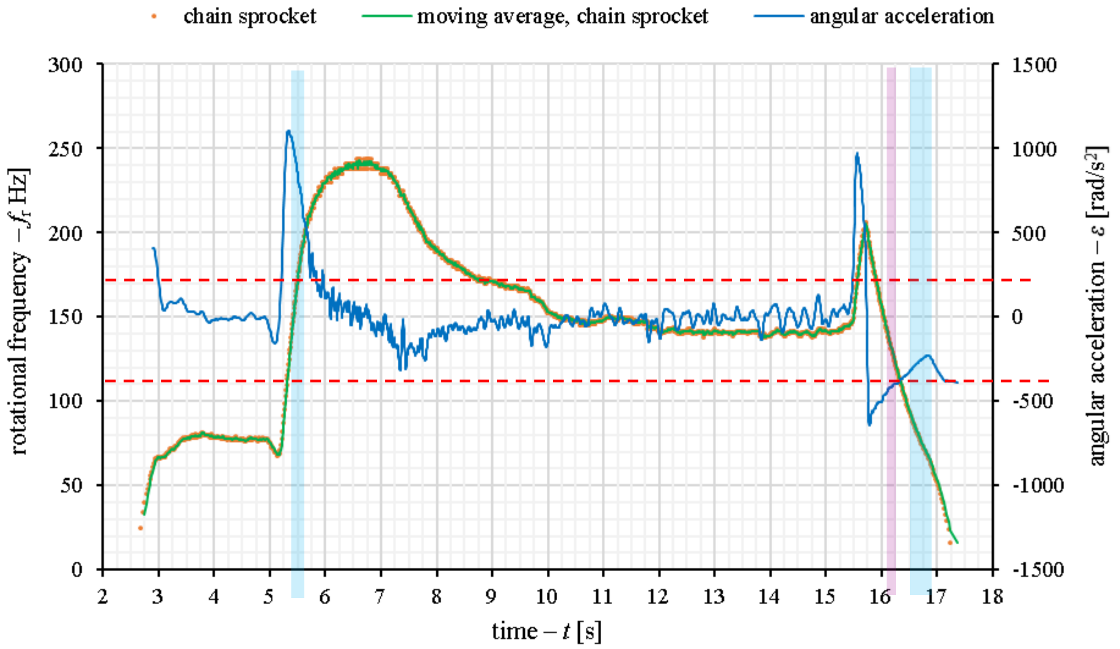

Fig. 7. Changes of angular accelerations of the chain sprocket during the single-cut test

5. VIBRATION EXPOSURE ESTIMATION

Time shares determined in previous chapters (the third test, simulation of real conditions):

- Idle – 14,05%;
- Full Load – 56,83%;
- Racing – 2,49%;
- Undefined and Transients – 26,63%,

after supplementing with the vibration acceleration values [22]:

- Idle – 5.10 m/s^2;
- Full Load – 4.92 m/s^2;
- Racing – 4.78 m/s^2;
- Undefined and Transients – 4.13 m/s^2;

can be used to determine $a_{hv,eq}$, the equivalent vibration level in accordance to equation (3). Which turned out to be equal to 4.83 m/s^2. The level of vibration exposure determined in this way is subject to similar uncertainties as other methods mentioned in the introduction. However, it carries an undeniable advantage compared to them, it does not require the analysis of video material to determine the time shares for individual operations or device's operation modes. The only aspect that cannot be unambiguously defined in the proposed method is the character of the UT operation mode. This means that the proposed method only enables an estimation of the vibration exposure level. However, considering the minimal chances of conducting dosimetric measurements among forest workers, such estimations still appear to be useful.

It should be added that in an analogous way, i.e. based on the determined time shares and averaged sound pressure levels, the operator's noise exposure level can be estimated.

6. CONCLUSIONS

The improvement of the device for measuring the rotational speed of the chain sprocket was successful. An additional channel for indirect measurement of the rotational speed of the engine's shaft allowed the authors, in comparison to the previously presented version of the device [24], to distinguish the idle speed from the switched-off device (engine rotation frequency 50-60 Hz, chain sprocket frequency 0 Hz) and to identify jamming of the cutting set in the material (engine rotation frequency 100-120 Hz, chain sprocket frequency less than 100 Hz).

Moreover, the analysis of changes in the value of the angular acceleration of the engine shaft or chain sprocket enables the identification of transitions from ideling to racing and vice versa (in the range of 100-180 Hz, the engine rotation frequency is equal to the chain sprocket frequency, while the angular acceleration is greater than 300 rad/s^2).

Finally, the chainsaw operating modes were precisely identified and the time shares of the chainsaw OM during its operation were determined. After determining the reference / calibration values of $a_{hv;i}$ i $L_{pA;i}$, it is possible to estimate the vibration and noise doses potentially received by the chainsaw operator based on the indirect method, without the need to conduct all-day, continuous vibration and noise measurements. This would increase the convenience of conducting measurements and the safety of both work and research personnel operating the measuring equipment.

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