Determination of the vibration emission level for a chipper with combustion engine

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Abstract. Presently, we observe an increase in automation and mechanization of many areas of life and industry, which allow to increase work efficiency and reduce costs. However, many circumstances such as terrain shape, forestation or urban planning can prevent the deliver and operation of various types of machinery. Consequently, an important area of development for the basics of machine construction is non-road machinery. The high mobility and relatively low own weight allow operation in the most adverse conditions. One of such machines are chippers for wood branches. They are usually driven by combustion engines, which means they emit pollutants in the fuel combustion process together with noise and vibrations. All the above factors can negatively affect both the machine operator and the environment. It is therefore justified to examine the possibility to reduce the emission level of harmful media. This paper presents the results of study involving the measurement of vibration and noise generated during operation of a chipper with combustion engine under various operating conditions. The presented results will allow to identify the scale and place of origin of vibrations. They can act as a source of practical guidelines for the design of machines of this type.

1. Introduction

The works entail the study of an actual device, i.e. the mobile wood chipper. The device is shown on figure 2. The mechanism is driven by a spark-ignition combustion engine which underwent prior modernization of its injection and ignition system. The base construction is based on the cylindrical wood chipper Red Dragon RS-100 Standard by Remet CNC Technology. The chipper allows fragmenting waste timber and branches with diameter not exceeding 80 mm. The blades of the cutting mechanism (figure 1b) were made of Hardox with hardness 500 HB, which is a type of abrasion-resisting steel. Machine modernization entailed replacing the drive unit. The new drive system is an overhead valve four-stroke engine with spark ignition system by German (figure 1a), featuring 13 KM power rating and 390 cm³ piston displacement. Fuel consumption is between 2.1 to 3.3 l h⁻¹, depending on machine load [1]. The technical parameters of the machine are given in table 1.

A major advantage of the engine in comparison to the LIFAN 188FD 13HP OHV preferred by the manufacturer is the built-in electrical starter, which is an important function after the modernization of the ignition-injection unit as it facilitates the synchronization of the system during engine startup. The factory model uses carburetor-based fuel supply system as well as a contact-free ignition system without adjustment of ignition lead angle. The system was examined and described earlier at [2, 3]. Other characteristics of this drive are provided in table 2 [3]. The drive unit GX 390 is coupled with the S-100
cutting mechanism by means of a flexible connection drive with two V-belts. The rotation speed is controlled manually with a lever, allowing operation with maximum torque [4].

Table 1. Technical parameters of the chipper construction and timber cutting mechanism [5].

| Parameter                                                                 | Value             |
|---------------------------------------------------------------------------|-------------------|
| Total chipper weight with engine                                          | 225 kg            |
| Cutting mechanism weight                                                  | 75 kg             |
| Internal width of cutting mechanism (fresh, soft timber)                   | 180 mm            |
| Maximum branch cutting diameter (fresh, soft timber)                       | 80 mm             |
| Maximum branch cutting diameter (fresh hard timber)                       | 70 mm             |
| Maximum branch cutting diameter (dry hard timber)                         | 60 mm             |
| Inter-shaft span                                                          | 100 mm            |
| Blade thickness                                                           | 10 mm             |
| Gear wheel diameter                                                       | 180 mm            |
| Feed hopper                                                               | 620/380 mm        |
| Chipper dimensions with collapsed feed hopper (length/width/height)      | 1300 × 800 × 1600 mm |
| Length of cut branches (4 blades)                                         | 90 ÷ 180 mm       |
| Cutting mechanism dimensions (length/width/height)                        | 220 × 480 × 500 mm |
| Minimum (recommended) power of cutting mechanism                          | 15/25 kM          |
| Recommended rpm of the cutting mechanism shaft                            | 540 rpm (clockwise) |
| Recommended parameters of overload clutch                                 | 900 Nm            |

Figure 1. Chipper working system components; a) German GX 390 engine [1], b) Cutting mechanism S-100 by Remet CNC Technology [5].

Table 2. Characteristics of the GX 390 drive used for the chipper [1].

| Parameter                                | Value             |
|------------------------------------------|-------------------|
| Cooling medium                           | air               |
| Horizontal drive shaft (length and diameter) | 90 × 25 mm       |
| Engine displacement capacity             | 389 cm³           |
| Maximum power                            | 9.6 kW/13KM       |
| Maximum torque                           | 26.5 Nm           |
| Weight                                   | 31 kg             |

2. Study methodology
The registration of vibration acceleration utilized two tri-axial piezoelectric converters 3023M2 by DYTRAN. The measurement of vibration acceleration was performed for low engine rotation speed (idle – A), maximum rpm without load (B) as well as when operating under load (C), which entailed the fragmentation particle boards with dimensions 200 × 15 × 1.8 cm. Vibration accelerometers were distributed in sequence in 4 different locations: on engine cover (sensor no. 1), on the cutting mechanism transmission (sensor no. 2), at the frame between the engine vibration dampers (sensor no. 3) as well as on the device frame near the flexible connection drive (sensor no. 4). Whereas the measurement of acoustic pressure was carried out using ROGA RG-50 (ICP) free-field microphone, placed at the position corresponding to the operator’s head. The exact placement of the sensors is provided on figure 4. The calibration procedure was carried out before and after taking measurements. The calibration of registration paths and vibration measurements utilized a standard vibration source – K10 type RPT97-146 (α_{cal} = 10 m s⁻²), and a standard acoustic source KA-10 (L_{cal} = 94 dB at 1000 Hz frequency).

Signals from accelerometers and the microphone were registered synchronically using and eight-channel recorder TEAC LX-10. The recorder operated as a front-end device and was connected to the workstation via LAN. The analog-to-digital conversion was performed at sampling frequency
\( f_s = 48 \text{ kHz} \). The block diagram of the measuring system is provided on figure 3. This guarantees the measurement and analysis of noise at the full audible spectrum (from 20 Hz to 20 kHz). Signal activation, processing and post-processing was handled by a dedicated application developed by the authors in the DASYLab environment [6].

The final type of measurement performed was to determine the noise level value at the entire audible acoustic range. The processing of results was based on frequency ranges at 31, 125, 500, 2000 and 8000 Hz together with the acoustic level for sound A, sampled every 0.05 s.

For the purpose of preliminary evaluation of the vibration values, the average values of obtained signals together with the average value of the ten largest vibration acceleration values were determined.

![Figure 2](image2.png)

**Figure 2.** The placement of sensors in relation to the object of examination; all dimensions are given in mm.

![Figure 3](image3.png)

**Figure 3.** Measuring system diagram; for clarity, two out of four vibration sensor locations are indicated on the illustration.

3. Results of experimental study

3.1. Vibration acceleration

Figures 4 and 5 present the selected effective values (RMS) of the vector sum of vibration accelerations measured at 20 Hz sampling rate.
Figure 4. Measured effective values of vibration accelerations for sensor no. 1 installed on engine enclosure; A – measurement for low engine rpm value, B – measurement for high engine rpm value, C – measurement for engine under load.

Figure 5. Measured effective values of vibration accelerations for sensor no. 2 installed on the enclosure of the cutting mechanism transmission; A – measurement for low engine rpm value, B – measurement for high engine rpm value, C – measurement for engine under load.

3.2. Noise

Figures 6 to 8 show the graph of sound intensity level (SIL) distribution measured as a result of performed experiments. Figure 9 shows the distribution of sound intensity as a function of frequency on a logarithmic scale. The distribution of sound intensity level was compared to Fletcher-Munson isophonic curves [7], according to which 1 dB is equal to 1 phone at frequency equal to 1 kHz.

Figure 6. Sound intensity level at low engine rpm values.
Figure 7. Sound intensity level for engine operation under load.

Figure 8. Sound pressure level dB(A) for 3 modes of device operation; A – measurement for low engine rpm value, B – measurement for max. engine rpm value, C – measurement for engine under load.

Figure 9. Distribution of isophonic curves; A – measurement for low engine rpm value, B – measurement for max. engine rpm value, C – measurement for engine under load, D – low audibility threshold, E – pain threshold.

3.3. Characteristic values
Figure 10 presents average vibration acceleration (VA) values for every examined variant for each sensor. Figure 11 shows an average value of ten largest vibration values (LVV) for all the outlined examination conditions.
4. Study results analysis

Based on the performed calculations, it was determined that the largest effective average values of vibration RMS were registered at the engine enclosure (sensor 1) during high rpm operation, without load (B) and were equal to approximately 80 ± 23 m s⁻² (figure 10). Furthermore, it is prominent that the average of top vibration values for operation cases (B) and (C) are very high and originate close to this measuring location. These characteristics of the results obtained diverges from the others – the difference in measured values are significant for sensors from 2 to 4 (figure 11). This allows to determine that the vibrations generated by the drive unit depend significantly on its rotation speed [8, 9]. This is clearly visible on figure 4. In the initial 5 seconds, the combustion engine accelerates up to speed which is reflected in the increase in vibration acceleration value within this time interval. It is worth noting that two largest average vibration values (for operating modes B and C) are recorded for sensors placed on the engine cover and on the device frame where the engine is mounted.

A significant increase in the ten maximum vibration values is observed for sensors 2 and 4 during measurements under load (C). This is due to the actual fragmentation process of the device which is discrete in nature, and its frequency is dependent on the rotation speed of the working element as well as the number of blades. One needs to point out that the initialization of the fragmentation process increases the LVV value for sensor 1 to a minor degree (whereas the average vibration acceleration...
value decreases). Such result indicates that the vibrations originating from the working element are not transferred to the drive engine. This may be a result of the chipper’s construction. For drive transmission, flexible connection drive with V-belts is used. One of its advantages includes, among others, the ability to attenuate sudden changes on load and vibration damping.

Another issue raised in this work was the analysis of noise if the full audible acoustic spectrum from 20 Hz to 20 kHz. Based on the measurements, it was determined that the maximum level of acoustic pressure of 119.83 dB was for the engine operation under load. Whereas the mean acoustic pressure of sound A at frequency 440 Hz for operation under load was 109.25 dB with standard deviation 8.49.

Based on the acoustic pressure diagrams for all 3 operating modes (figure 8), one can determine that similarly to vibration, the main source of noise was the operation of the combustion engine, and the increase of its rotation speed directly effects the increase in sound intensity. The increase in rotation speed caused an average increase in acoustic pressure by approximately 10.2 dB (operating mode A in comparison to operating mode B). Whereas during normal operation of the chipper (working mode B in comparison to working mode C) the recorded momentary increase in acoustic pressure (only during fragmentation) was by approx. 7.2 dB.

Comparing the logarithmic distribution of the mean acoustic pressure as a function to Fletcher-Munson isophonic curves (figure 9) it was determined that the noise level engine operation under load was lower than the pain threshold by 7 dB at frequency 4 kHz.

5. Conclusion
Based on the performed study, the vibration emission level of the wood chipper with combustion engine was determined in four selected structural points for three different modes of operation. The largest individual recorded RMS value of vibration acceleration is: 172.5 m s⁻² (the sensor located on the enclosure of the cutting unit, operation under load). The highest average RMS value of vibration acceleration is: 80 m s⁻² (the sensor placed on the engine enclosure, operation at maximum rpm, unloaded). The average value from ten largest vibration values (LVV) was 139 m s⁻² and was recorded also at the engine enclosure during work under load. Based on the performed analyses, it was determined that the main source of vibration and noise is the combustion engine powering the device as well as the fragmentation process itself.

Based on the analysis of available literature relating to the matter of noise [7, 10, 11], it is seen that the safe operating time for the examined wood chipper from the standpoint of operator’s health is only 15 min in relation to the 8-hour standard working day.

All the measured and calculated parameters achieve significant values. Such state of affairs is acceptable as mobile chippers are intended for short-term, discontinuous operation. Moreover, during use, the operators is obligated to utilize the necessary individual protection measures. Despite this, it is justified to undertake studies to improve the working safety and efficiency of human work by reducing the level of noise and vibration on this type of devices.

6. References
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