The Noise Emitted by a Vacuum Cleaner Treated as a Device with Extensive Sound Sources

Wojciech RUKAT
Poznan University of Technology,
Faculty of Mechanical Engineering and Management,
Piotrowo 3 St, 60-965 Poznan; wojciech.rukat@put.poznan.pl

Bartosz JAKUBEK
Poznan University of Technology,
Faculty of Mechanical Engineering and Management,
Piotrowo 3 St, 60-965 Poznan; bartosz.jakubek@put.poznan.pl

Adam MADEJ
Poznan University of Technology,
Faculty of Mechanical Engineering and Management,
Piotrowo 3 St, 60-965 Poznan; adam.madej@student.put.poznan.pl

Abstract

Vacuum cleaners can be found in almost every household. They are one of the most intense noise sources there. Noise generated by vacuum cleaners is partially of mechanical, electrical and aerodynamic origin. A suction unit is the source of mechanical and electromagnetic noise. A suction nozzle or a cleaning head as well as a flexible hose that connects the components are sources of aerodynamic noise. The noise of the suction unit depends on the load and the technical condition of the motor. The noise of the nozzle and the hose depend on the flow capacity, presence of solid particles and the type of cleaned surface. The article presents a comparison of acoustic parameters of a vacuum cleaner working on various surfaces. In addition, the noise generated by the vacuum cleaner was compared according to the standard noise testing procedure and according to the definition of devices with extensive sound sources.

Keywords: devices with extensive sound sources (DESS), sound power level, vacuum cleaner, noise

1. Introduction

Vacuum cleaners belong to the group of small household appliances and they can be found nearly in every household (approx. 95% [1]). In addition to their primary function they are often used to remove solid contaminants (granular particles) such as concrete and brick particles, sawdust, ash from fireplaces, etc. Noise emitted by vacuum cleaners due to its origin can be divided into mechanical and electromagnetic – related to engine operation and aerodynamic – related to the air flow through the device [2-6]. The noise level generated by vacuum cleaners is among others influenced by the type of equipment used: different suction tips or a cleaning head [7].

According to the regulations in force, producers of machinery and devices are required to provide information on the value of the intensity of harmful factors emitted by the product [8]. The test code for determining the noise parameters of vacuum cleaners is described in the IEC 60704-2-1:2014 standard [9]. The conditions prevailing in the course of standard measurements deviate from conditions usually prevailing during the operation of the device at home. These differences result mainly from:

- the use of a standardized testing carpet during measurements[3],
- the spatial orientation – the way the suction unit is positioned relative to the tip,
- the type of the nozzle used (cleaning head) and its own drive,
- the load of the device by the vacuumed material, the level of the container filling and the condition of filters.

The spatial arrangement of components of the vacuum cleaner during measurements is shown in Figure 1.

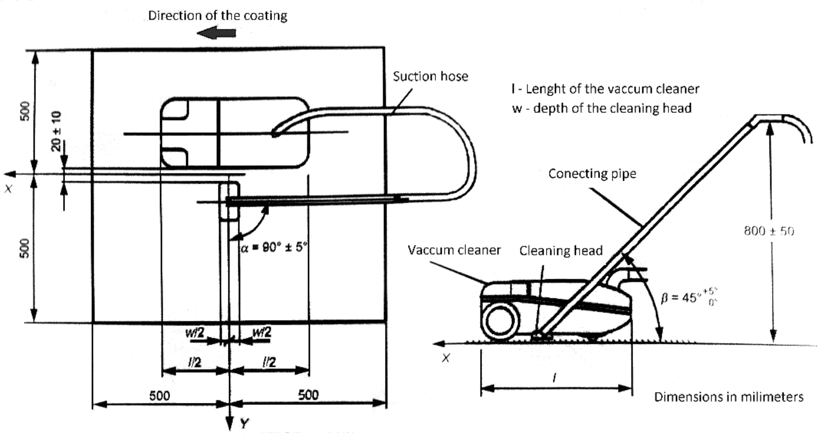

Figure 1. Spatial orientation of the device's components during measurements according with IEC 60704-2-1:2014 (compact arrangement) [9]

Basing on the analysis of 150 vacuum cleaners offers available on the market, it was found that there is no information on noise hazard for 20% of offered devices. Secondly, only in the case of one device, the noise level exceeded the threshold of 85 dB [8] and according to the datasheet it is equal to 87 dB, which obliges the manufacturer to carry out the procedure of determining the level of harmful factor which is the noise. In order to meet the market requirements and customers' expectations manufacturers provide information on the level of noise emitted, which is in the range from 58 to 85 dB and is equal on average to 77 dB. It can be assumed that the manufacturer under the noise level means the A-weighted sound pressure level averaged over the measurement surface $\overline{L_{pfA}}$, 1 m away from the device.

A questionnaire conducted by authors among a group of 80 people showed that on average only 25% of the usable floor area of residential buildings is covered with a soft, sound-absorbing material. The remaining part is covered with smooth, reflecting surfaces

[3] The following features of standardized testing carpet are defined in the standard: geometrical dimensions, type of material, weave density and the length of fibers forming the cover

like floor panels or terracotta. Due to the significant difference in acoustic properties (absorption coefficient, reflection coefficient) [11, 12], it is expected that the noise generated by vacuum cleaners will depend on the type of cleaned surface.

Moreover, vacuum cleaners meet the criteria that allow them to be classified as a device with extensive sound sources (DESS) [13]. They consist of a central unit – a suction pump (usually in the form of an axial turbine mounted on the motor shaft) equipped with filtration and dirt separation systems, a flexible hose, a telescopic tube and a suction nozzle or a cleaning head. While the device is being used, the operator's ears are away from both the suction unit and the tip. The ratio of these distances varies and depends, on the type of cleaning equipment used as well as the length of the hose and the tube. It is possible that the nozzle will be much closer than the suction unit. This leads to the conclusion that it is necessary for acoustic properties of vacuum cleaners to be described with at least two parameters. Figure 2 shows the typical operator's position during vacuuming and the distance ranges from the his ears to the components. The market offers various types of accessories for vacuum cleaners including suction hoses up to 5m long that allow to increase the range of work.

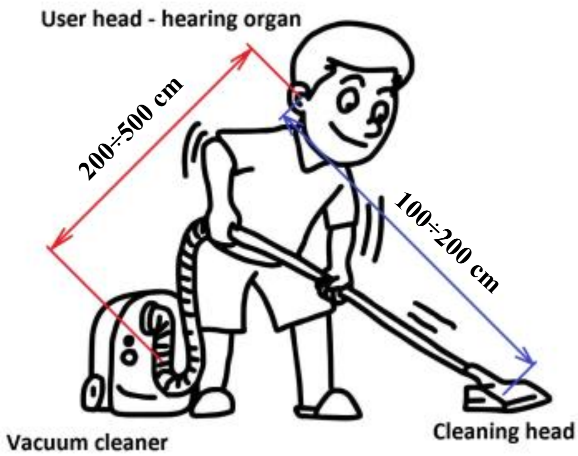

Figure 2. Typical position of the body and distance between cleaning head, vacuum cleaner and user head [14]

This paper presents the results of acoustic measurements of the vacuum cleaner of a popular on the market brand, for which the manufacturer declared the noise level equal to 81 dB. The vacuum cleaner has a mower of 2100 W. The authors have focused on two aspects:

- the work of the vacuum cleaner with different types of surfaces (carpet and terracotta) with a constant load,
- the noise generated by individual components of the vacuum cleaner treated like DESS, and in accordance with the standardized noise testing procedures [9, 10].

2. Research methodology

The sound pressure measurements were made in accordance with IEC 60704-2-1 [9], while the sound power level was determined by survey method in accordance with ISO 3746:2011 [10]. In each case, the workload was simulated by the container's filling. When the suction unit was measured the hose, the tube and the nozzle were detached. When the suction nozzle was measured, the suction unit was separated by a sound absorbing barrier ensuring the required 10 dB difference from the background noise.

The measurements were made in a room that met the requirements specified for the survey method. The room volume was equal to 260 m^3. The acoustic absorption of the room was tested experimentally by measuring the reverberation time. The K_2 correction was less than 2.5 dB each time. Most of the measurements were made at a distance of d_1 equal to 600 mm. In order to ensure an adequate distance from the background noise, the sound pressure measurements for the suction nozzle were made at a distance d_2 = 300 mm.

For the measurements of acoustic pressure the following equipment was used: free-field microphone Roga RG-50 ICP® S/N064 (sensitivity 50 mV/Pa), data acquisition module Vib DAQ 4+, PC with Dasy Lab software in which digital signal processing application was elaborated. During the acquisition of the acoustic signal, the following settings were used: sampling frequency f_s = 48.83 kHz, measurement block size - 8192 samples, frequency band from 20 Hz to 20 kHz. Calibration of the measurement system was carried out before and after measurements using the acoustic calibrator type KA-10 No. 363, L_p = 94 dB for 1000 Hz. Measurements were done in five points on the measurement surface in accordance with the standard guidelines. Each acquisition lasted 30 seconds.

3. Research results

This chapter presents the results of measurements and analyses of acoustic pressure including: average sound pressure levels $\overline{L_p}$, sound power levels L_{WA} and narrowband pressure spectra. Figure 3 shows the octave spectra of $\overline{L_p}$ obtained from measurements made in accordance with the standard guidelines [9]. The spectra show the results of measurements made while the nozzle was on the carpet and on terracotta. The device emits high-frequency band noise. In each octave band, higher $\overline{L_p}$ were observed in the case of terracotta in comparison to the carpet. The differences are up to 8.8 dB for octave with a centre frequency of 8 kHz. The linear $\overline{L_p}$ in cases of carpet and terracotta surfaces differ by 6.5 dB while $\overline{L_{pA}}$ differ by 6.6 dB. The differences between these levels for the same cleaned surface are small.

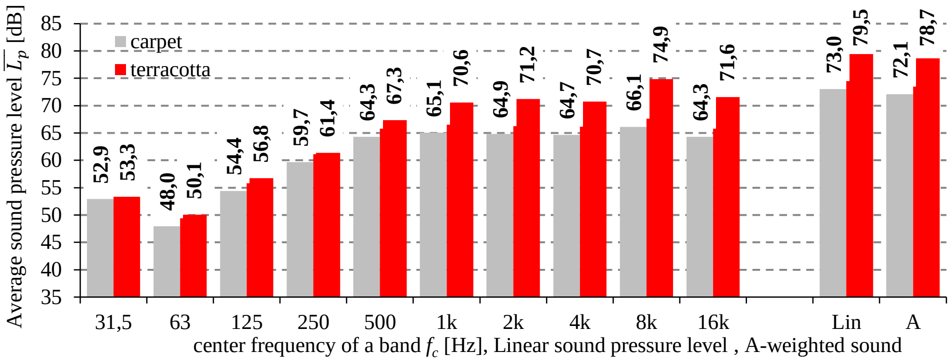

Figure 3. Noise emitted by tested device spatially oriented in compact arrangement

Figure 4 shows the octave spectra of $\overline{L_p}$ of the tested vacuum cleaner treated as DESS. Similarly as before, noise measurements of the nozzle were made on the carpet and on terracotta. In the figure one can see that the dominating source of the noise when working on terracotta is the suction nozzle, the dominant octave is 8 kHz, the noise is of broadband high frequency nature [2, 15]. The linear $\overline{L_p}$ of the suction unit is more than 10 dB lower than $\overline{L_p}$ of the suction nozzle while on terracotta and it is almost 3 dB higher than $\overline{L_p}$ for the carpet surface. Therefore, the determination of L_{WA} according to the normalized procedure [9] (see Fig. 1) is justified as long as we consider the noise generated by the device working on the carpet surface. Taking into account the results of the survey, the equivalent noise level L_{pA_eq} to which the user is exposed when vacuuming a typical flat (exposure time equal to the percentage share of the cover area) will be 77.8 dB.

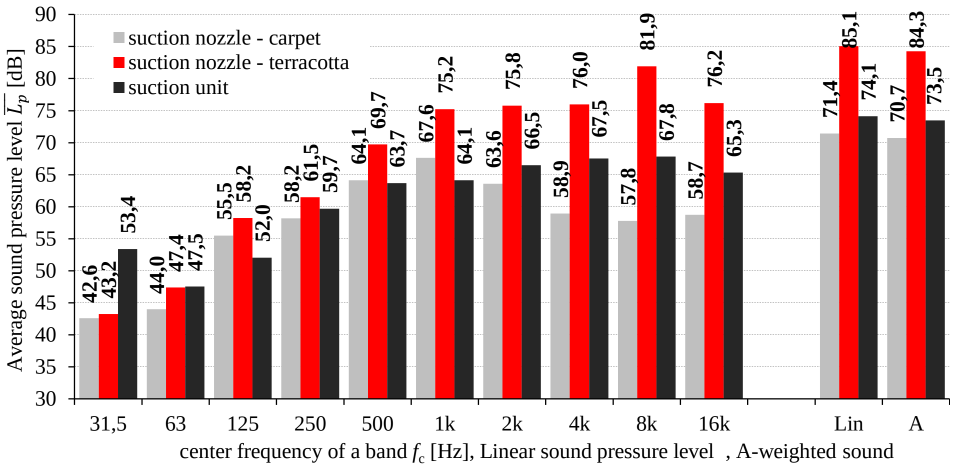

Figure 4. Noise emitted by tested device treated as DESS

Figure 5 presents a narrowband sound pressure spectrum in the range from 20 Hz to 10 kHz. The dominant component in the spectrum is the vane-pass frequency f_{vp} [3, 5] of the suction unit approximately equal to 597 Hz (rotating frequency f = 23.84 Hz, number of blades 25). It has been highlighted in the picture.

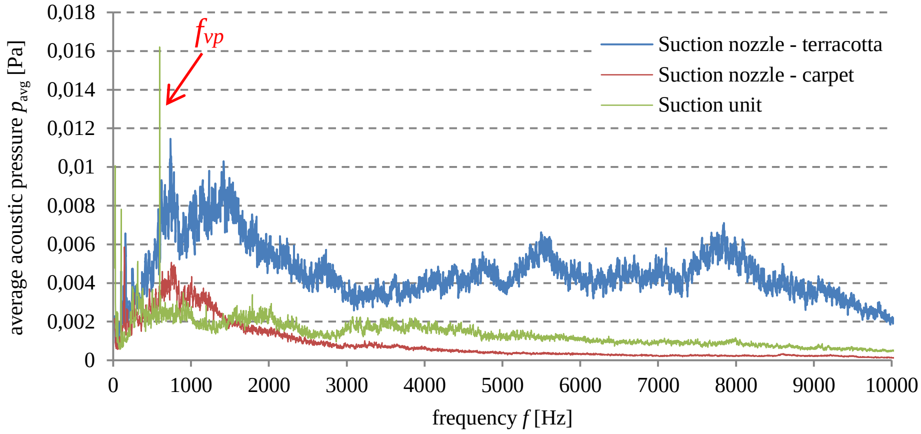

Figure 5. Narrowband spectra of acoustic pressure averaged over the measurement surface

Figure 6 shows L_{WA} of the vacuum cleaner determined by the survey method [10] in a compact arrangement (see Figure 1) and separately for the components of the vacuum cleaner.

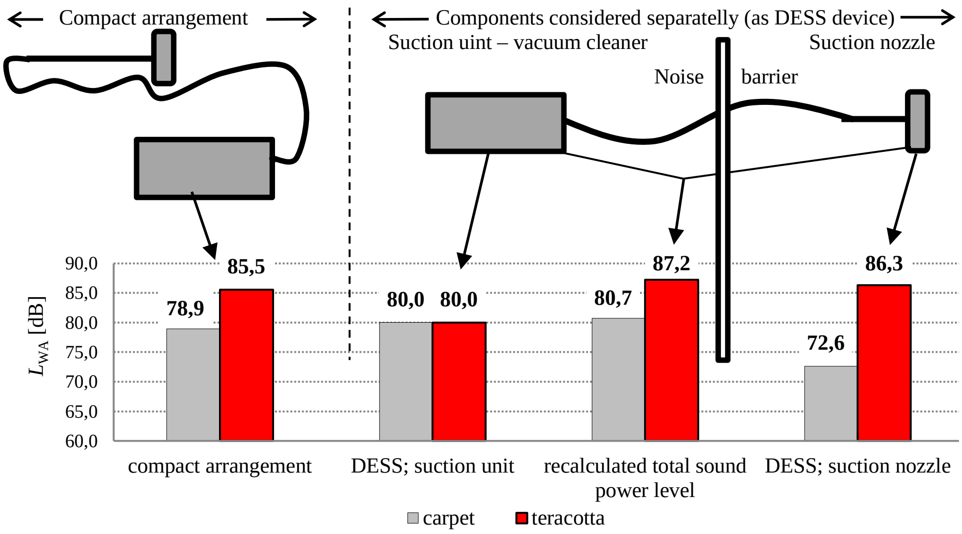

Figure 6. Spatial arrangement of components during testing and theirs L_{WA}

As with pressure levels, the type of vacuumed surface has significant influence on L_{WA} which is 6.6 dB higher for measurements on terracotta than measurements on carpet. Recalculated total sound power level is 1.8 dB higher than L_{WA} level of the whole device together. This is probably a consequence of the standard procedure for determining the noise level where the reference box does not accurately reflect the dimensions of the object and the location of the local sound sources [9].

4. Conclusions

The noise emitted by the vacuum cleaner depends on the type of cleaned surface. The noise emitted on a flat surface (terracotta) is much higher than the noise in the case of carpet. Determining the acoustic parameters of the vacuum cleaner as DESS results in slightly higher results than those obtained in accordance with the procedure from IEC 60704-2-1: 2012. Since there are no information on L_{WA} of the tested vacuum cleaner provided by the manufacturer the comparison can only be made between the A-sound levels. It should be emphasized that the sound pressure level is strongly determined by the environment, none the less the measured A-weighted sound levels $\overline{L_{pA}}$ are lower than the manufacturer's declaration.

The noise emitted by the components of the vacuum cleaner is broadband. It is sufficient to parameterize device's noise by providing only one value. However, for the wellbeing of the user, it is recommendable to declare the noise level in the most unfavourable working conditions not only due to the load but also due to the type of the cleaned surface. An alternative would be to determine the equivalent sound level based on the time share of work on different surfaces. As in the case of the procedure for determining the equivalent vibration level of chainsaws [16].

Acknowledgement

The results presented are results of the research that was funded with grant 02/21/DSPB/3515 for education allocated by the Ministry of Science and Higher Education of the Republic of Poland.

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