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AN EXPERIMENTAL STUDY ON VIBRO-ACOUSTIC CHARACTERISTICS OF A WET AND DRY TYPE VACUUM CLEANER

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Abstract.
Vacuum cleaners are widely used household appliances and they usually generate quite unpleasant sound. The four most common sources of vacuum cleaner noise are the motor, the fan, the airflow and the surface vibrations. Connections between the motor and such vibrating surfaces of a vacuum cleaner allow very efficient transmission of the force and the motion, which are then transformed to sound. The surface velocity, the sound pressure and the acoustic power of the vibrating surfaces are very important parameters in the noise control and source location problems. The purpose of this study is to asses the vibro-acoustical characteristics of a sample wet and dry type vacuum cleaner and to determine the acoustic power radiated from this type of vacuum cleaner. For this purpose, the near-field sound pressure, the surface velocity and the sound intensity levels are measured. By using these measurements, the sound intensity, the near-field sound pressure and the surface velocity mappings are generated and using these measurements, the sound intensity compares the results compared to find the effects of the vibrating surfaces on the total vacuum cleaner sound power level.

INTRODUCTION

Household appliances which play an important role in our daily life should be functional and quite with an acceptable sound quality. Vacuum cleaners are among the noisiest household appliances and at the present time the correct identification and reduction of noise generated by the vacuum cleaner is very important stage of the design cycle. In addition reduction of the vacuum cleaner noise has become a main concern of manufacturers in order to comply with EU directives [1]. For that purpose the sound intensity measurements are carried out to estimate the sound power level and to identify the noise sources. Different researchers in the past [2] have studied identification and reduction of the vacuum cleaner noise.

In this work a wet and dry type vacuum cleaner is investigated. The vacuum cleaner is driven by a 1600 W electric motor that includes the cooling fan with twelve blades. Speed of the motor is about 19.000 rpm (~315 Hz). The locations of the electric motor, the cooling fan, and the parts of the air flow intake and the operating air exhaust in the wet and dry type vacuum cleaner are shown schematically in Fig. 1. The operating air flow intake is front of the vacuum cleaner drum and the air exhaust has opposite position on the drum, according to the operating air flow intake. The electric motor is placed in the central left part of the vacuum cleaner body. The material of the vacuum cleaner drum is the moulded plastic.

The four most common sources of vacuum cleaner noise are the electric motor, the fan, the airflow and the surface vibrations. The noise generated by the electric motor consists of three main categories, magnetic forces (tangential and radial), mechanical forces (friction of rotor bearings and brushes) and aerodynamic forces (airflow). Although there is some windage noise due to the rotation of the rotor, most airflow noise comes from the cooling fan. Furthermore the hose of the vacuum cleaner is the other source of airflow noise.

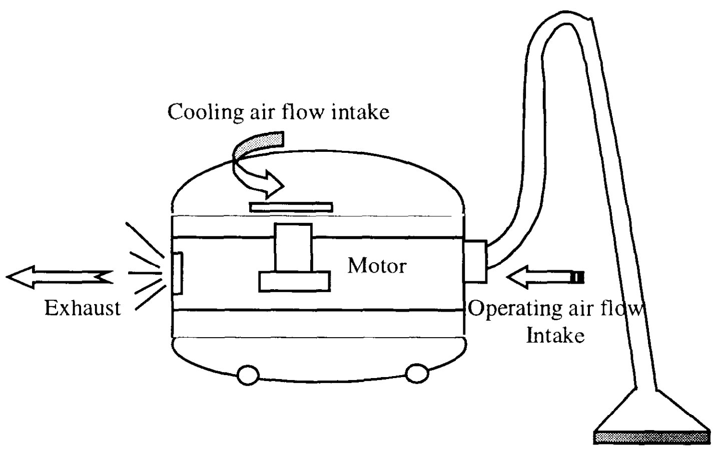

Fig. 1. A schematic representation of a wet and dry type vacuum cleaner.

In the present work, vibro-acoustical properties of a sample wet and dry type vacuum cleaner were experimentally determined using the sound intensity, the near field sound pressure, and the surface velocity measurements. The objective of this paper is to find the effects of the vibrating surfaces on the total vacuum cleaner sound power.

EXPERIMENTAL SET-UP

Measurements are made on the compressor itself in a semi-anechoic room. Acoustic intensity methods offered a number of advantages over traditional measurement methods, and therefore acoustic intensity method is opted for measurements. Sound intensity is a measure of the magnitude and direction of the flow of the sound energy [3]. The major point in the noise source location problems is an analysis of the product sound field that includes both the position and frequency content of each sound source. This analysis can be made with sound intensity measurements. To identify and evaluate the noise sources of the vacuum cleaner, the sound intensity measurements were made in a semi-anechoic room with a volume of 144 m^3 in accordance with IEC 704-2-1: 1984 [4].

The vacuum cleaner was set on the floor, and placed in a 0.6mx0.8mx1m cubic grid equipped with hose and water tank, and set to operate under normal working conditions. The measurement surface on which the measuring points are located is the cubic grid enveloping the vacuum cleaner in order to measure sound power according to ISO 9614-1 standard [5]. Sound intensity measurements were made with a Brüel&Kjær type 3548 intensity probe with a 12 mm spacer and a real-time dual-channel frequency analyzer Brüel&Kjær type 2144. A sound intensity calibrator Brüel&Kjær type 3541 calibrates the microphones. The measuring grid has

79 measuring points and linear averaging time for each measuring point was 16 sec. A GPIB Board then transferred the sound intensity measurements to a PC and the sound intensity mappings of vacuum cleaner were determined by using Brüel&Kjær Noise Source Location Software type 7681.

Both the measurements of the near field sound pressure and the surface velocity were carried out at the normal working conditions of the vacuum cleaner in a semi-anechoic room. It was set on the floor and equipped with all accessories. 120 measurement points were defined on the surface of the vacuum cleaner drum, uniformly distributed. The near field sound pressure measurements were made very close (approximately 20 mm) to the vacuum cleaner surface with a Brüel&Kjær type 4192 microphone. The surface velocity measurements were made with an accelerometer Brüel&Kjær type 4371.

RESUTS AND DISCUSSION

Preliminary measurements revealed the acoustic behaviour of the vacuum cleaner. Fig.2 shows the results of the near-field sound pressure measurements as mapping on each side of the vacuum cleaner. One of the near-field sound pressure measurements on the vacuum cleaner is shown in Fig.3. as a sound pressure level spectrum. Fig.3. presents the near-field sound pressure spectrum of the vacuum cleaner with respect to the centre frequencies of the one-third octave bands. The frequency range of the sound pressure measurements is between 200 Hz and 8 kHz.

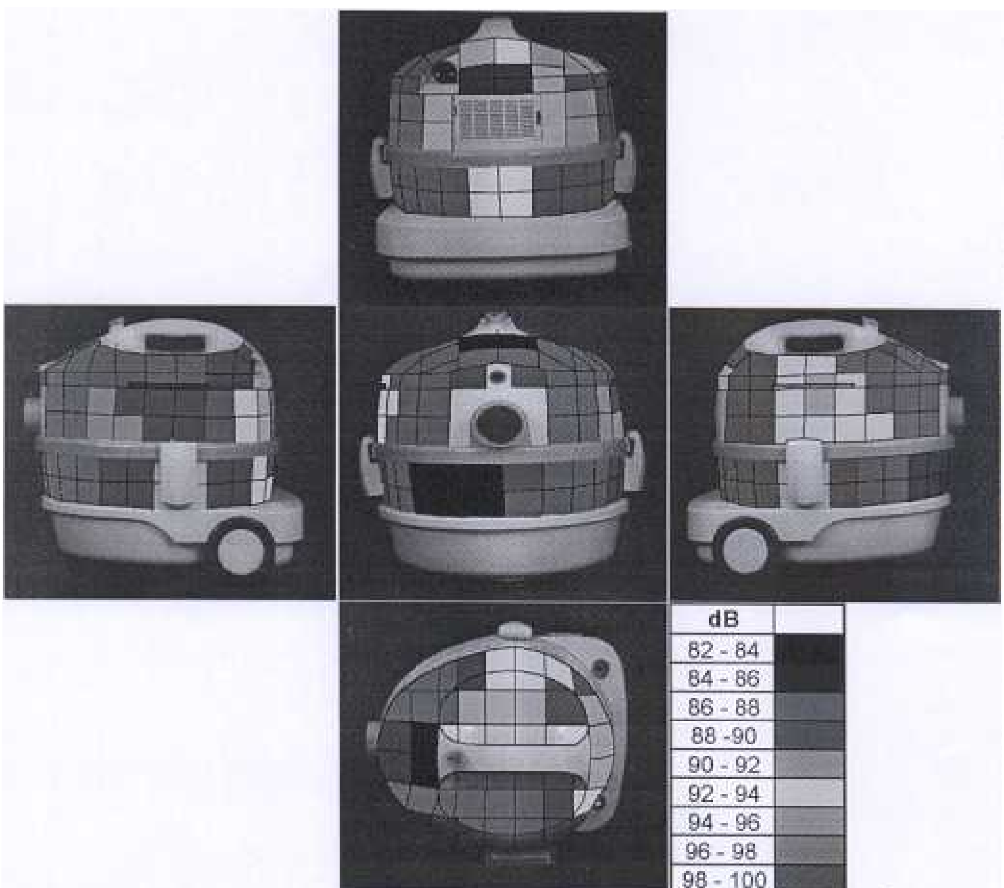

Fig.2. Overall sound pressure levels. (reference pressure: 2×10^{-5} Pa)

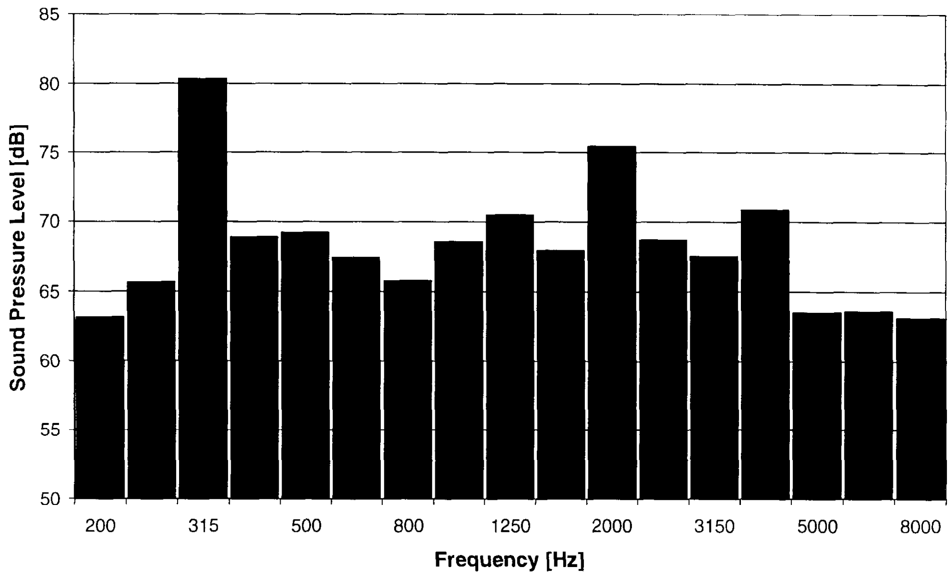

Fig.3. One of the near-field sound pressure measurements on the vacuum cleaner. (reference pressure: 2×10^{-5} Pa)

The measurements presented in Fig.2 and Fig.3 established the main components of the near-field sound pressure level at three frequencies. 315 Hz is the fundamental frequency related to the unbalance of the rotor at the rotational speed. 2 kHz and 4 kHz could be related to the blade passing frequencies such that the six blades of the electric motor cooling fan and the twelve blades of the electrical motor fan respectively. These peaks represent the unpleasant noise perceived as pure tones especially at 315 Hz by the customer.

Fig.2. demonstrated that the sound pressure levels are higher at the locations of the motor side of the vacuum cleaner, the operating air exhaust behind the top cover and the cooling air intake side of the top cover.

The sound intensity mapping on each side of the vacuum cleaner is shown in Fig.4. The orders of mappings individually in Fig.4 are the same as in Fig.2. The mappings indicated that the main noise propagation is from behind the top cover and left hand side of the enclosure of the wet and dry type vacuum cleaner where the electric motor, the operating air exhaust and the cooling air intake are located.

Fig.5. shows the sound power spectrum measured on the vacuum cleaner with respect to the centre frequencies of the one-third octave bands. The frequency range of the sound power measurements is between 200 Hz and 8 kHz. The vacuum cleaner is operating under the normal working condition during the sound power measurements.

The measurements as shown in Fig.5 demonstrated that the main component of the sound power spectrum is at 315 Hz. This is the frequency related to the unbalance of the rotor at the rotational speed.

The overall sound power levels are compared for each side of the vacuum cleaner as shown in Fig.6. This gives an idea on the radiated sound from the excited shell of the vacuum cleaner.

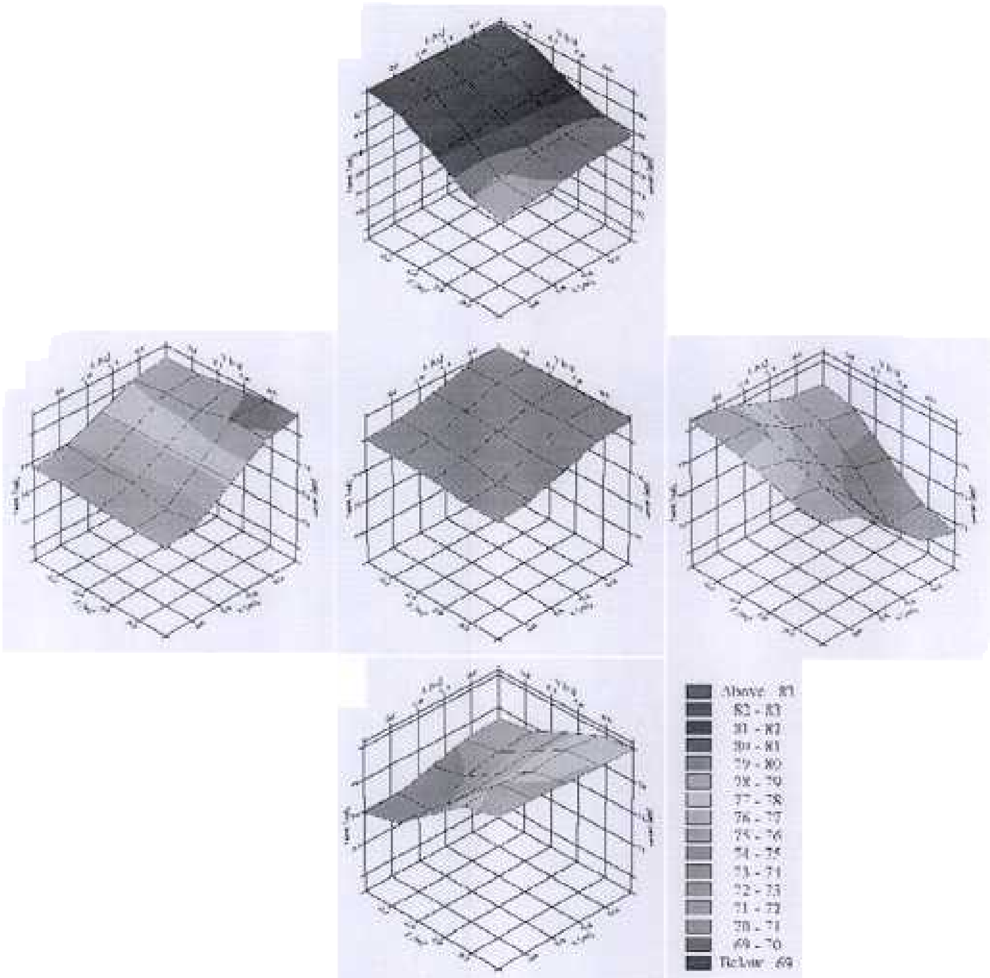

Fig. 4. The sound intensity mappings.
(The order of the figures is the same as in Fig.2.)

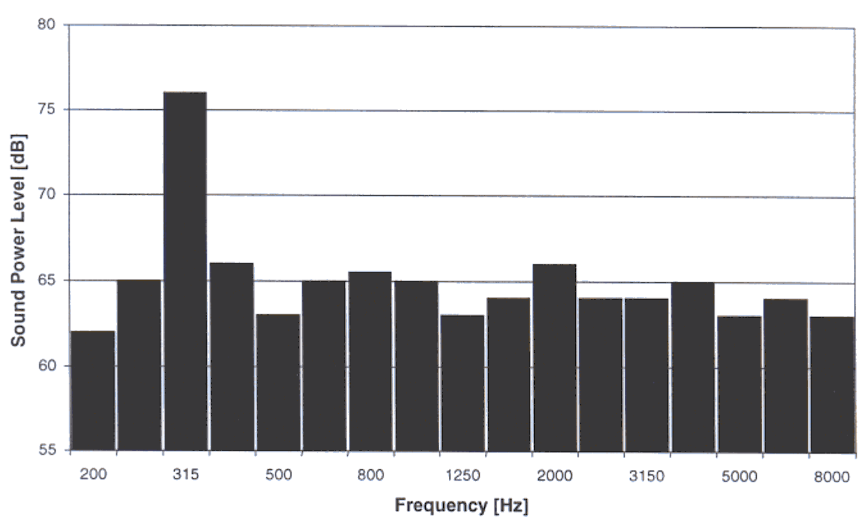

Fig. 5. The sound power spectrum of the vacuum cleaner.

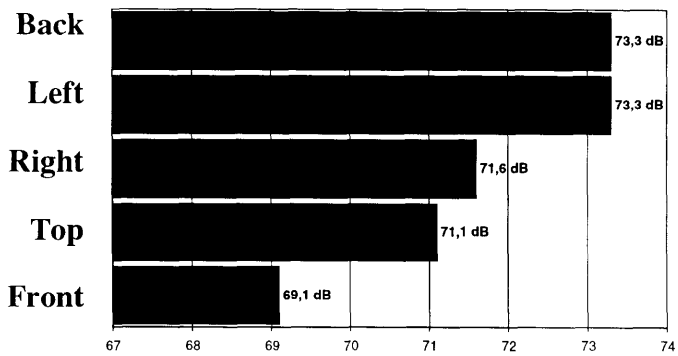

Fig. 6. Contributions to the sound power level on each side of the vacuum cleaner.

One of the surface velocity measurements on the vacuum cleaner is shown in Fig.7. as a vibration level spectrum. Fig.8. presents the surface velocity spectrum of the vacuum cleaner with respect to the centre frequencies of the one-third octave bands. The frequency range of the surface velocity measurements is between 200 Hz and 8 kHz.

The measurements presented in Fig.7 and Fig.8 established the main components of the surface vibration levels at two frequencies. 315 Hz is the fundamental frequency related to the unbalance of the rotor at the rotational speed. 2 kHz could be related to the blade passing frequency.

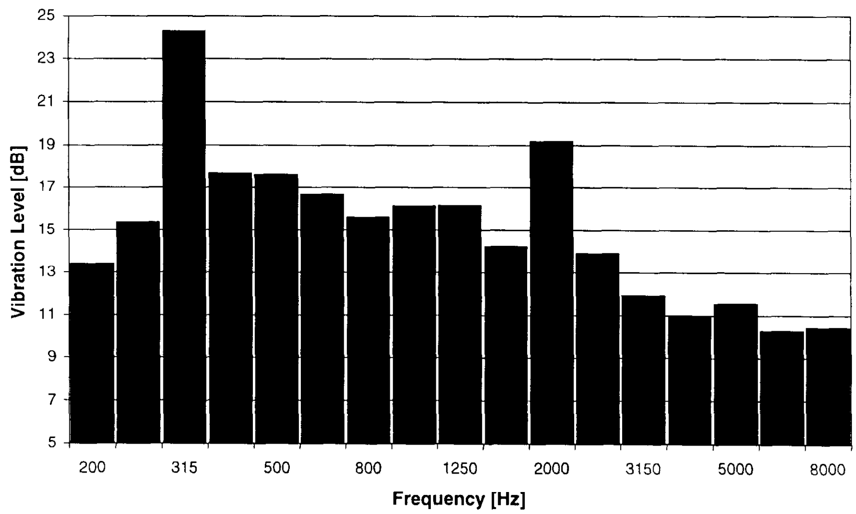

Fig. 7. One of the surface velocity measurements on the vacuum cleaner. (reference acceleration: 1.0 x 10^{-6} m/s^2)

Fig.8. demonstrated that the surface vibration levels are higher at the locations of the motor side of the vacuum cleaner, the operating air exhaust behind the top cover and the cooling air intake side of the top cover.

From the previous measurements, the main sound sources are the electric motor, vibrating surfaces, the fan and the airflow. Connections between the electric motor and the vacuum cleaner drum allow very efficient transmission of the force and the motion. Due to these transmissions, the vacuum cleaner drum surfaces are mechanically excited by the electric motor and the vibrating surfaces produce sound. In order to achieve a noise reduction both on sources and on transmission paths are investigated. The following design improvements to reduce the sound power level radiated by vacuum cleaner should be analyzed.

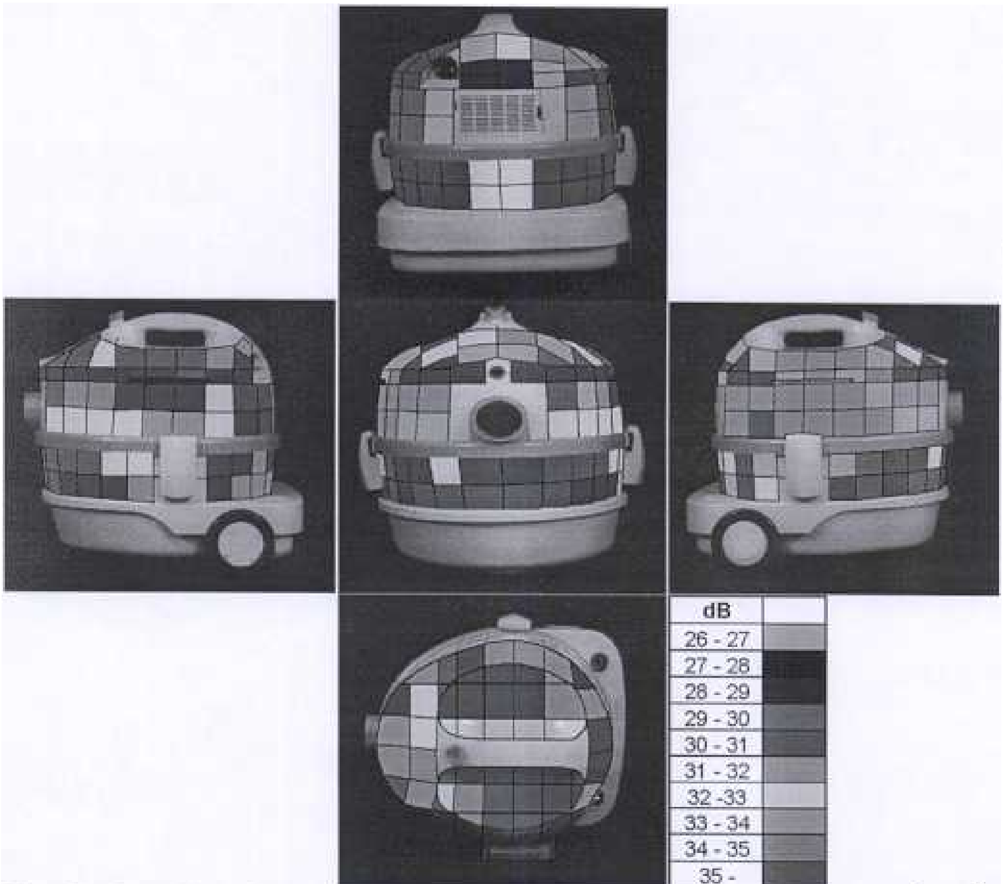

Fig. 8. Overall surface velocity levels. (reference acceleration: 1.0 x 10^{-6} m/s^2)

The first design modifications should be concentrated on the reduction of the side flat surfaces, the back and the top of the shell are also involved in the design variations to eliminate the abrupt changes at the bending points. The overall stiffness of the shell could be increased to raise the resonant frequencies and reduce the vibration amplitudes. It has to be avoided abrupt changes in shell curvature that act as semi-rigid boundary conditions. The basic strategy is the elimination, as much as possible, of the flat surfaces in terms of the sound and the vibration transmitted. Finally, the balance quality of the rotor as the main source could be upgraded in order to achieve a vibration reduction.

CONCLUSIONS

In this study, vibro-acoustical properties of a sample wet and dry type vacuum cleaner were experimentally determined using the sound intensity, the near-field sound pressure, and the surface velocity measurements. The objective of this paper is to find the effects of the vibrating surfaces on the total sound power level of the vacuum cleaner.

Results obtained in this study will be usefull data for the design of the noise and the vibration reduced vacuum cleaners.

References

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