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ACOUSTIC INVESTIGATION OF VACUUM CLEANERS

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Abstract: The noises evolving from our environment can be defined as pollutants, as they can lead to the impairment of different environmental factors (e.g: air, soil, waters). Within environmental noise sources we differentiate between noises caused by industry or traffic. Noises emitted during flow and the noise of machinery is considered industrial noise, which are mainly emitted during the flow of fluid for gasses. The aerodinamical noise effects (e.g.: safety valves, compressors, ventillation systems, pneumatic machinery, vacuum cleaners) which were widespread with the development of different technologies are considered to be the highest intensity noise sources [1]. In this article we focus on the investigation of the noises emitted by household machinery, specifically vacuum cleaners.

Keywords: *vacuum cleaner, noise pressure levels, Brüel & Kjær, 3rd octave band analysis*

1. INTRODUCTION

The noises emitted by using vacuum cleaners are caused by the engine itself but mainly by the flow of the medium forming in the tube. For many people vacuum cleaning can cause a headache. This can be traced back to the noise emitted by the machine. The noise reduction of vacuum cleaners was investigated by Electrolux Ltd. among others. The Ultra Silencer type vacuum manufactured by them is considered to be really quiet as the 68 dB noise emission is even less then the noise produced by watching TV [3]. However this isn't negligible either because almost all laws define the noise emission limit at 65 dB, above this level noise can harmfully effect living organisms.

2. EXECUTION OF MEASUREMENTS

Our tests were conducted on 3 different vacuum heads provided to us by Electrolux Ltd which were operated with the Ultra Silencer vacuum cleaner. The vacuum cleaner we used was the Electrolux Vol. 1 Type, serial number: 34200852, it's maximum performance is 2200 W. The acoustical test was performed in the semi-anechoic chamber of the University of Miskolc Institute of Machine and Product Design equipped for this purpose. Our goal was to determine the vacuum heads' noise output levels on 3 different suction levels. For this – according to the "surface sheathing" method – we measured the noise pressure levels in 9 monitoring points in 1 m distance.

The vacuum cleaner itself was placed outside the chamber in order to filter out the mechanical noise emitted by the engine. Only the vacuum tube and the 3 vacuum heads were placed inside the chamber. The tube was sealed with acoustic insulation material to filter out the noise emitted by the tube.

The heads were connected to the vacuum by a 40 mm diameter PVC tube which we connected to a Prandtl-tube. We needed the Prandtl-tube to register the pressure differences inside the plastic tube with the help of a pressure metering device; from these values we can calculate the flow velocity. The suction levels used by us are the equivalents of 2,7 m/s; 4,7 m/s; 6,1 m/s; flow velocities. The noise pressure levels were measured by the Brüel & Kjær Observer 2260 type integrating noise meter and third band octave analyser. From the measured values we calculated the special averages and noise output levels according to the EN 60704 standard. The test sequence was performed on the carpet that was defined for this purpose by the standard.

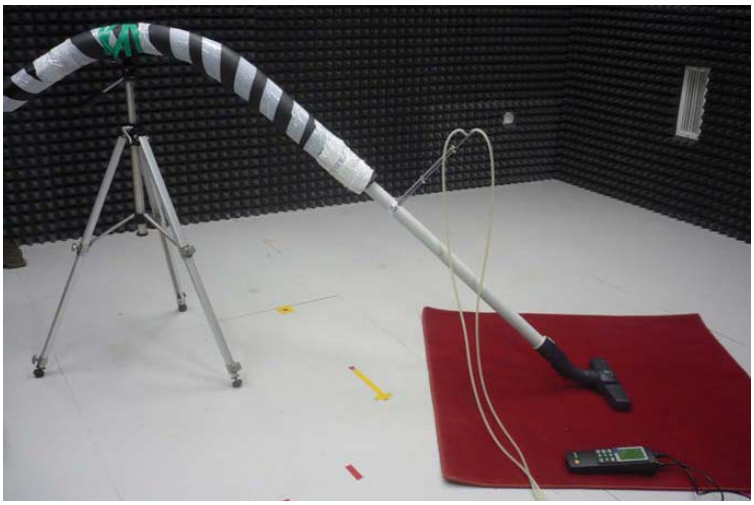


Figure 1. Placement of the equipment according to standard

Before starting the tests we calibrated the equipment and registered the meteorological conditions. The temperature was 23,9 C°; pressure was 1051,6 MPa; the relative humidity of the air was 61%. These results were provided by the equipment measuring meteorological data that were installed in the laboratory. Following the arrangement and calibration of the equipment, we measured the environmental background noise which was 17,7 dB. Because the difference of the measured value, and the background noise is more than 10 dB in every measured point we overlooked its effect during the evaluation of the tests. Following the measurement of background noise we metered the A-sound pressure levels in 15-15 second time intervals in 9 different monitoring points with the vacuum cleaner on operating warmth.

3. EVALUATION OF TEST RESULTS, CONCLUSIONS

The noise output levels calculated from the test results can be observed in the *Table 1* and *Figure 2*. both show well, that according to expectations all 3rd vacuum head's noise output levels increased with the increase of the flow velocity. In the case of the 1st vacuum head the noise output was raised with 8 dB and another 5 dB, with vacuum head 2nd the noise output level increased with 13 dB and another 4 dB, with the 3rd vacuum head the noise output increased with 12 dB, then 3 dB with the increase of the revolution number.

Table 1
Comparison of noise-output levels

Vacuum Cleaners		v [m/s]	L_W [dB]
The first cleaner head		2,7	60
		4,7	68
		6,1	73
The second cleaner head		2,7	55
		4,7	68
		6,1	72
The third cleaner head		2,7	54
		4,7	66
		6,1	69

As the figure shows the 1st vacuum head caused the highest noise-output level, while the 3rd vacuum head with the most complex geometry strains the environment the least.

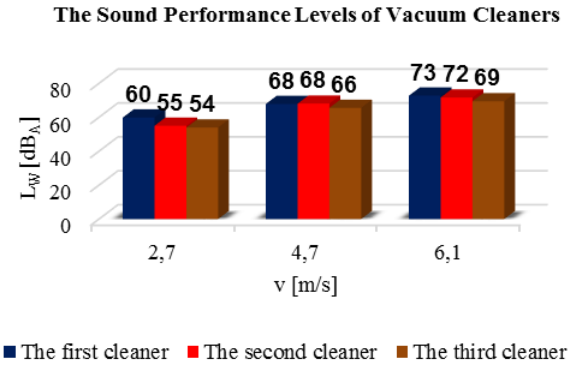


Figure 2. Noise-output levels of the vacuum heads on the carpet

From the values in *Table 1* we can see that on the lowest suction level the 1st vacuum head produced a noise-output level of 60 dB while on the highest we measured 73 dB. Therefore while we set the rev count on the vacuum cleaner from the smallest to the maximum value, the noise level increased with $\Delta L = 13$ dB in the case of the 1st vacuum head. According to the rules of the qualification of levels we relate back to the $P_0 = 10^{-12}$ W referential value, we calculate the noise-output levels:

$$P_{min} = 10^{-12} \cdot 10^{6,0} = 10^{-6}\ W, \tag{1}$$

$$P_{max} = 10^{-12} \cdot 10^{7,3} = 2 \cdot 10^{-5}\ W. \tag{2}$$

Relation of noise-outputs according to (1) and (2):

$$\frac{P_{max}}{P_{min}} = \frac{2 \cdot 10^{-5}}{10^{-6}} = 20. \tag{3}$$

We can conclude that with the 1st vacuum head the acoustical output was raised to an estimate 20-fold value, which is not an inconsiderable multiplier while the flow velocity "only" increased to its 2,3 times value. In case of the 2nd head the noise-output level is increased with a value of $\Delta L = 17$ dB which is a considerate, estimated 63,5 times increased value (With the 3rd head $\Delta L = 15$ dB equals to around a 32 times increased value).

4. 3RD OCTAVE BAND ANALYSIS OF THE MARK1 VACUUM HEAD

Beside focusing on the determination of the noise-output levels we executed a different test as well, its purpose was the determination of the noise-output levels per third octave band. In this case for the sake of simplicity we only had a single monitoring point on which we measured the 3 vacuum heads from a 1 m distance, and registered the noise pressure levels belonging to the 3rd octave band mid-frequencies. We operated the vacuum cleaner on maximum suction capacity on operating warmth. For this we had the machine run in idle for 15 minutes.

Before conducting the test we measured the background noise with 3rd octave band analysis. As a result we observed that the difference of the measured value, and the background noise is more than 10 dB, therefore we disregarded it. In the 3rd octave bands under 125 Hz the noise level was insignificant.

The instrument and its microphone was placed on suitable stand while securing equal measuring conditions for each vacuum head. During the course of the test we used the A-filter specified for human-centric measurements in all 3 cases.

The measured A-sound pressure levels per 1 m 3rd octave band are shown in the *Table 2. Figure 3* shows these values in diagram form, from which it can be clearly seen that the vacuum head marked 1st strains the environment with the most amount of noise. The difference is not significant, but from the perspective of the full sound frequency interval, the rundown of the components per 3rd octave band is

much more even in the case of the 3rd vacuum head. This is unmistakably the result of better engineering creating a better flow environment.

Table 2

Sound pressure levels of vacuum-heads by 3rd octave band metering

	Lp [dB$_A$]		
fm [Hz]	**The first cleaner**	**The second cleaner**	**The third cleaner**
125	19,7	20,1	19,4
160	23,3	23,8	22,6
200	35,2	35,0	35,3
250	35,6	34,8	34,9
315	38,8	39,0	38,9
400	47,0	46,9	43,8
500	44,9	45,7	40,1
630	50,6	54,7	47,1
800	51,0	56,7	51,5
1000	52,0	53,4	51,3
1250	60,2	52,7	52,3
1600	56,2	54,7	51,0
2000	47,9	52,3	49,0
2500	46,5	45,1	41,7
3150	47,1	44,1	39,4
4000	43,8	37,7	35,2
5000	42,3	39,3	35,8
6300	47,6	45,7	40,5
8000	41,9	39,6	35,0
10000	33,2	27,8	28,4
12500	25,2	23,3	22,8
16000	24,1	19,2	17,5
20000	27,5	17,5	15,5
Overall	63,5	62,7	59,0

The raised section f_m = 400 Hz mid-frequency 3rd octave band was caused by the rotating frequency of the vacuum's rotating component. We experience the highest sound pressure level in the case of the 1st vacuum head, in the 125 Hz mid-frequency 3rd octave band (60,2 dB). In the case of the f_m = 6300 Hz mid-frequency 3rd octave band a significant peak can be observed. Supposedly this is caused by

the drive unit of the vacuum cleaner, namely the blade frequency of the turbine. This supposition could be cleared up with an FFT test.

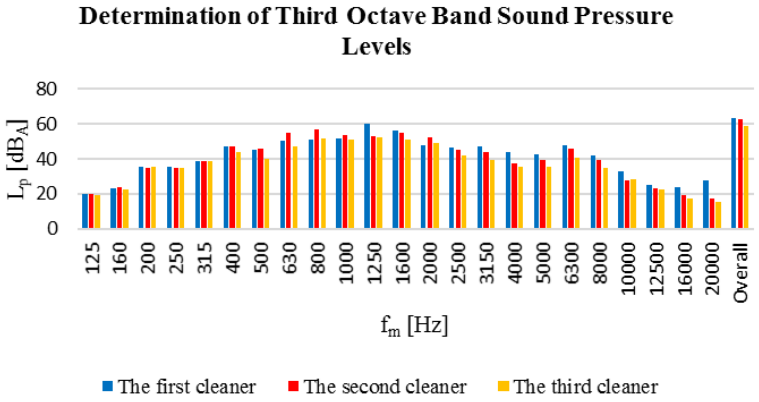


Figure 3. A-sound pressure levels per 3rd octave band of the vacuum heads (on the carpet)

Evaluating the different tests conducted on the vacuum heads we can establish a definite order considering noise emission and we can conclude that the vacuum head marked 3 with the most complex geometry strains the environment with the least amount of noise.

5. Opportunities for further investigation

So far we can only conclude these observations from the tests, however there is room to conduct further investigations. The flow simulation software called AnsyFluent has a noise module with which our further goal is to detect the flow emitted noise of the arbitrarily selected vacuum heads through simulation tests. We expect to get similar dB values to our test results.

6. Acknowledgements

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