NOISE CONTROL OF VACUUM CLEANERS

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ABSTRACT

This is a whitepaper on how to control the noise emitted by vacuum cleaners - particularly airborne noise. The objective of this paper is to provide readers with a background to help them assess noise problems with respect to vacuum cleaners, and provide insights on appropriate solution techniques for reducing airborne noise levels. The blowers used in vacuums are the main source of airborne noise and blade wakes are unavoidable in turbo machines. Turbulence due to wake formation contributes significantly to blower noise. This noise is further carried along the flow path to the exhaust ports. The study here, involves the design of a spiral enclosure for the blower in the vacuum cleaner. The enclosure was designed to provide better acoustic covering to the blower and motor assembly so as to reduce the velocity of the exhaust air of the vacuum; thus, reducing the sound being expelled from the exhaust ports.

ABBREVIATIONS

Sl. No.	Acronyms	Full form
1.	dB	decibel
2.	dBA or dB(A), dB(B) or dB(C)	decibel with A/B/C-weighting filter
3	P_1 & P_0	Sound power and reference power value
4	I & I0	Sound intensity and reference intensity value
5	p & p0	Sound pressure and reference pressure value

MARKET TRENDS AND CHALLENGES

One of the major problems associated with a vacuum cleaner is its noise.

Common noise levels and their effects are as follows:
Usually the noise level of typical conversation is 60-68 dB. Sound levels over the range of 70dB to 80dB are considered to be loud, and a person continuously exposed to a sound level of over 85dB will gradually suffer hearing losses. The maximum time one can safely be exposed to 100dB is for 15 minutes only. This means it is best to choose a vacuum cleaner with a noise output that is less than 70 dB.

However, the noise levels of vacuum cleaners fall between 75dB to 85dB. Thus, continuous exposure to such noise levels affect a user's health while also being a sign and source of inefficiencies in the equipment. It is therefore important to diagnose noise problems in order to reduce sound levels and improve the efficiency and life of the vacuum cleaner.

SOUND AND NOISE

A sound wave is an infinitesimal pressure wave that propagates longitudinally with a repeating pattern of high-pressure and low-pressure regions through a medium.

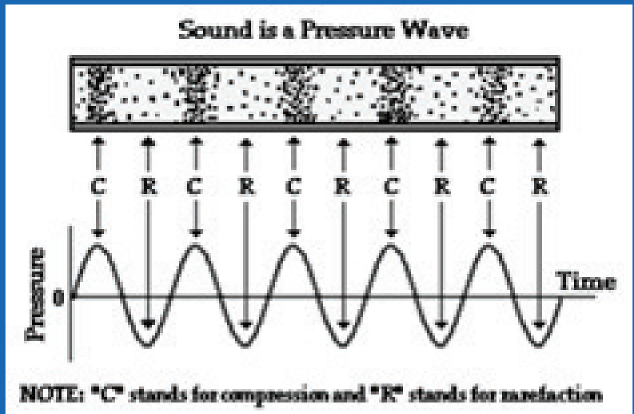

Fig. 1 Sound wave

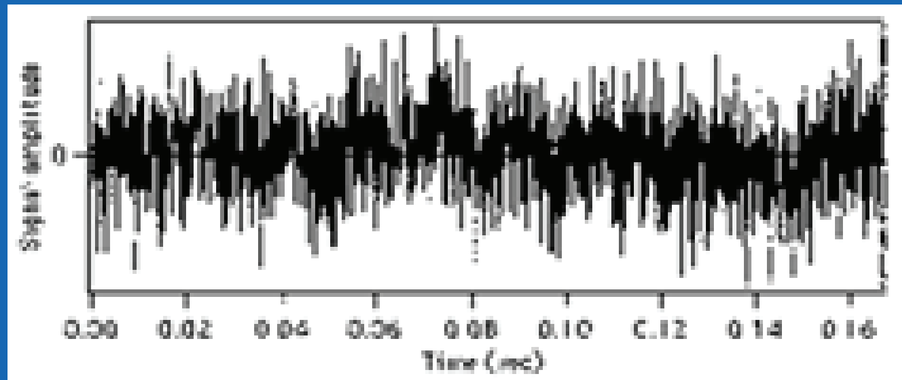

Fig. 2 Spectrum of Noise

We hear different sounds from different vibrating objects because of variations in sound wave frequency and amplitude. The sensation of a frequency is commonly referred to as the pitch of a sound. The level of air pressure in each fluctuation - the wave's amplitude, determines how loud the sound is.

So what is noise?

Noise means any unwanted sound. All sounds are not considered noise, but the sound emitted by a vacuum cleaner is definitely considered one. Usually the characteristic of noise is its complex and random wave pattern; however, noise is not necessarily random.

Any noise problem may be described in terms of:
A source
A transmission path, and
A receiver (ears)

Noise control may be achieved by altering any one, or all of these.

MEASUREMENT OF SOUND AND ITS CHARACTERISTICS

Sound Intensity
The amount of sound energy that is transported past a given area of the medium per unit of time is known as the intensity of the sound wave. (Power/area - Watts/meter2)

Since energy is conserved, and the area through which this energy is transported is increasing, the power (being a quantity that is measured on a per area basis) must decrease.

Inverse square relationship. The intensity varies inversely with the square of the distance from the source.

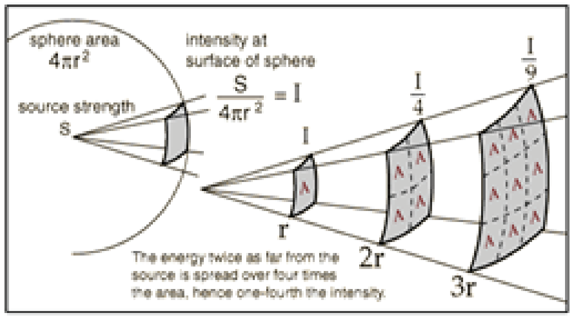

Fig. 3 Inverse square relationship

Decibel Scale (dB)
As explained in the introduction, sound is an infinitesimal pressure wave. Pressure fluctuations in the sound waves are very small changes (of the order of a billionth of atmospheric pressure), and the range of sound intensities that the human ear can detect is so large and varied (diverse), so the scale that physicists use to measure the intensity of sound is a logarithmic scale called the decibel scale.
Mathematically, it is defined as the ratio (Ldb) of a power value (P1) to a reference power value (P0) on a logarithmic scale as presented in Table 1.

Decibel measurement based on	Reference value	dB level correlation
Sound Power level - dB(SWL)	10^{-12} W	$L_{dB} = 10log_{10}(\frac{P_1}{P_0})$
Sound Intensity Level - dB(SIL)	10^{-12} W/m^2	$L_I = 10\ \log_{10}\left(\frac{I}{I_0}\right)\ \mathrm{dB}$
Sound Pressure Level - dB(SPL)	2×10^{-5} Pa	$L_p = 20\ \log_{10}\left(\frac{\tilde{p}}{p_0}\right)\ \mathrm{dB}$

All measurement methods will result in same dB level

Table. 1 Decibel reference

Difference between the two levels [dBA]	Addition to higher level [dBA]
0	3
1	3
2	2
3	2
4	1
5	1
6	1
7	1
8	1
9	1
10 and over	0

Table. 2 Addition of Noise level

The doubling of power is represented approximately by 3dB, and a doubling of amplitude by 6dB.
In Table 2 - referring to noise level addition, during a test measurement, the background noise level should always be kept 10 dB below the noise level to be measured.

How hearing works with human ears

Human hearing does not respond equally to all frequencies (it is more sensitive to sounds in the frequency range from 1 kHz to 4 kHz than it is to low or high frequency sounds). For this reason, sound measurements often have a weighting filter applied to them whose frequency response approximates that of the human ear (A-weighting). A number of filters exist for different measurements and applications and these are given the names A, B, C and D weighting. The resultant measurements are expressed, for example, as dBA or dB(A) to indicate that they have been weighted.

Standard filter contours are used to make the instrument more nearly approximate the normal human ear. The different contours were intended to match the ear at different sound intensities

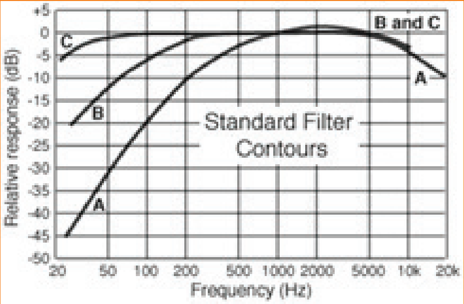

Fig. 4 Nature of A, B, C filters

A 3 dB increase/decrease in the level of noise is a doubling/halving of the sound pressure level (or in the energy contained), but we would only just notice this increase; whereas if we actually perceived a doubling or halving, the noise level would have changed by 10dB.

NOISE AUDITING AND CONTROL

Keeping in mind all the things discussed so far, let's proceed to the noise control methodologies.

Noise Auditing:

The first step in noise control is to perform noise auditing of the unit and to identify noise sources and their transmission paths. This needs a standard test set up for performing the sound measurements. While building the test setup, it is very important that we consider the points discussed in the previous section - inverse square law, background noise level, and decibel scale and its filters.

The sound is either absorbed or reflected or transmitted further. The sound pressure that we hear or measure with a micro-phone is dependent on the distance from the source and the acoustic environment (sound field) in which sound waves are present. It also depends on the size & nature of the room and sound absorption of the surfaces. Sound measurements are done in either fully anechoic, semi-anechoic, or reverberation rooms but these need huge investments for their construction. In the absence of such facilities we can perform the measurement exercise in an open ground late night which will also give good results.

All noise measurements should be made from a standard test setup, at a constant distance from the noise source. There should be sufficient distance between the micrometer and the test equipment as even a slight variation in the testing distance will lead to higher variations in the readings of sound pressure levels.

After establishing the test set up to adequately define the noise problem and to set a good basis for the control strategy, the following factors must be considered:

- The type of noise
- Noise levels and temporal patterns
- Frequency distribution
- Noise sources (location, power, directivity)
- Noise propagation pathways, through air or through structure
- Noise rank order - in terms of contributions to excessive noise

After identifying and ranking the key noise sources, one should solve the highest sources first as the lower ones will be obscured by the higher ones.

When control takes the form of understanding the noise-producing mechanism and changing it to produce a quieter process, as opposed to the use of a barrier for control of the transmission path, the unit cost per decibel reduction is of the order of one tenth of the latter cost. So it needs an in-depth study of the physical process associated with key noise sources and the experience to decide upon the behavior of the noise source and its control. A study of the failure history, technical issues list, technical brainstorming, knowledge of vibration and resonance, aerodynamics, and patent searches will be best to understand noise sources and their control.

CONTROL OF VACUUM CLEANER NOISE

We used the standard test setup as shown in figure 5 below and the Type 2 sound level meter. Measurement tests were carried out with various configurations i.e. by rotating the vacuum cleaner unit in four directions and also measuring the sound levels by eliminating the subsystems (foot assembly, connecting hoses, filter cartridges, and filter foams/HEPA filters) of the vacuum cleaners, one by one.

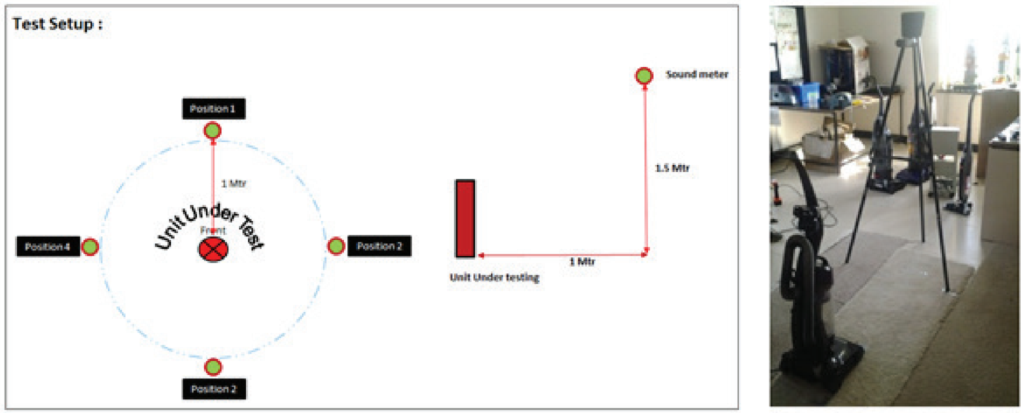

Fig. 5 Test setup for measurement of Sound level

After ranking the measured values of the sound levels, two primary sources of noise were identified. The first primary source of noise is due to the mechanical vibration of the motor blower assembly, and the second is noise generated by the air blower and air exiting out of it.

If the whole vacuum cleaner unit measures a sound level of 78 dBA, the uncovered blower motor measures around 85 to 86 dBA. Noise so generated is mainly carried forwarded by the air stream, in its flow direction.
Some of the interesting things observed during the testing of sound levels, are:

- Porous filter foams and HEPA filters used near the motor, helped in reducing the noise level
- The crevice tool recorded higher than the wand, due to its smaller inlet cross-section area
- The placement, orientation, and distribution of the exhaust port openings also had appreciable effects on the noise levels recorded
- Slight misalignments and gaps near the blower inlet would lead to an abrupt increase in noise levels

Centrifugal blowers used in vacuum cleaners work with adverse pressure gradients along their flow path. An adverse pressure gradient occurs when the static pressure increases in the direction of the flow. This is important for boundary layer flows where increasing fluid pressure is akin to increasing the potential energy of the fluid, thereby leading to a reduced kinetic energy and a deceleration of the fluid. Since the fluid in the boundary layer is relatively slower, it is more greatly affected by an increasing pressure gradient. For a large enough pressure increase, this fluid may slow to zero velocity or even become reversed. When flow reversal occurs, the flow is said to be separated from the surface. This has very significant consequences in aerodynamics. The flow reversal near the surface is the cause of vortex formation, creating oscillatory flows and a region of chaos. Thus, adverse pressure gradient and flow separation take a greater role in airborne noise generation.

On the other hand, there is one more phenomenon, which affects the sound level of noise carried by air - the Doppler Effect, related to the velocity of the air flow. As the flow velocity increases, the ability of air to carry sound waves forward increases. Imagine when you stand in the direction of the wind flow, you can hear sound for a longer distance in contrast to the direction opposite to the wind flow. But when you reduce the velocity of flow, it gives rise to an adverse pressure gradient which is also not desirable. So, there should be a breakeven point for the velocity, where the reduction of velocity should not create boundary layer separation.

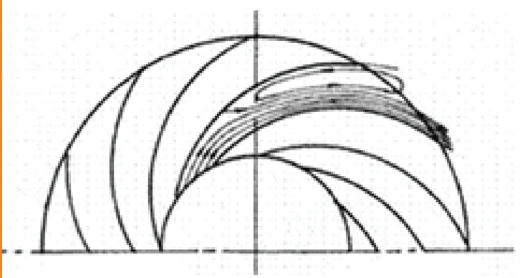

Fig. 6 Sector of the centrifugal blower, with flow separation.

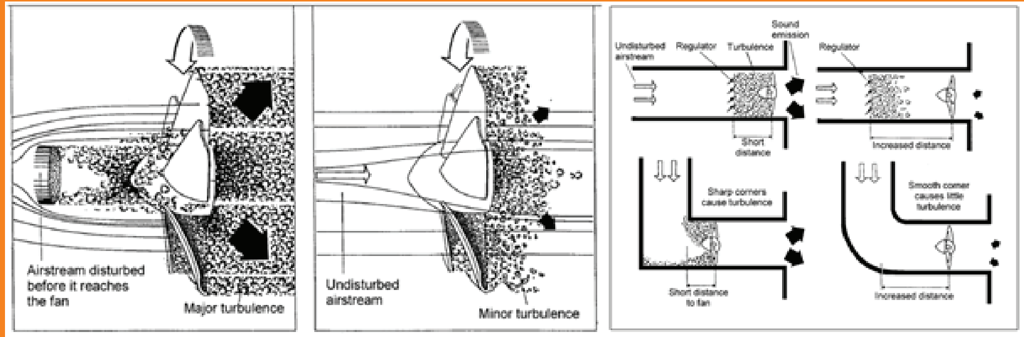

Fig. 7 Effect of initial flow condition on impeller turbulence

Any disturbance in the upstream of the flow has a fast exponential growth as they travel downstream, as shown in figure 7. So any small fluctuations present at the orifice, may have a large positive growth rate and quickly become very big; this was the reason that a small sealing gap near the blower orifice created a huge noise.
Air filtering foams made of PU or plastics fiber mesh are also good air diffusers as they are flexible and have the ability to observe pressure waves and damp down the sound level.

SOLUTION

Usually, in vacuum cleaners, due to design constraints and other reasons, the flow path after the blower is not well designed from the point of aerodynamics and NVH. The challenge here is to reduce the noise level without affecting the suction power of the vacuum.

Noticing this, we decided to modify the design of the blower casing. Our main intention was to consider all the above requisitions and come up with a feasible design, before preparing for the NVH test. The idea was to use a spiral casing, thus, slowing down the velocity of the outgoing exhaust air and guiding it smoothly to avoid vortex and turbulence zones while diffusing the air over a greater area around the vacuum cleaner.

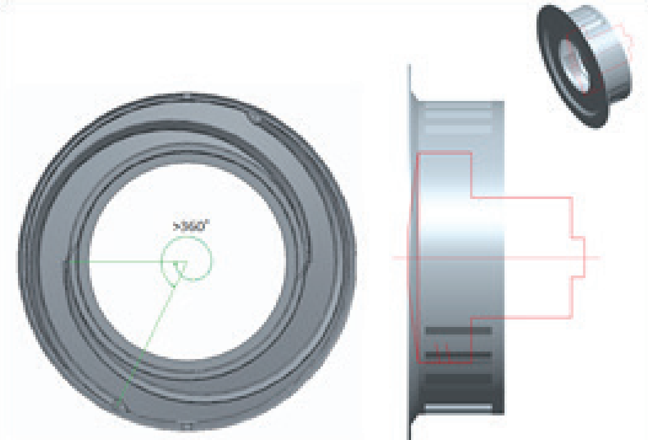

Fig. 8 Enclosure design for blower

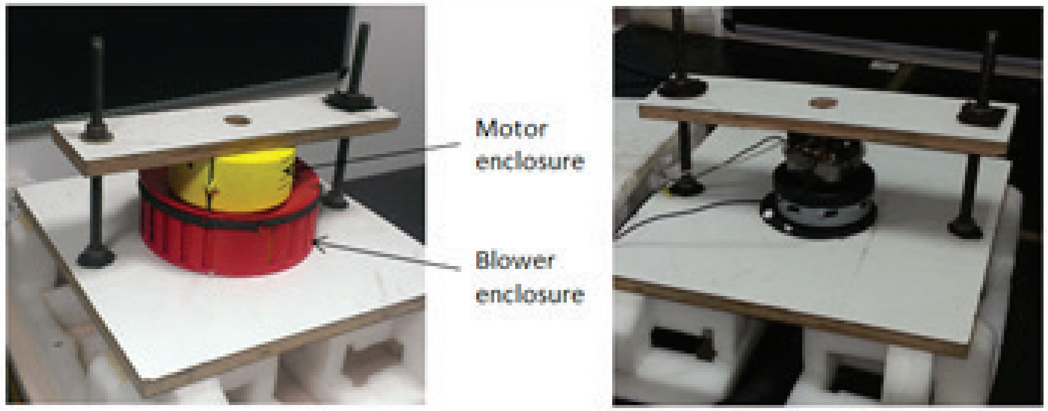

Fig. 9 Testing fixture for proto design of enclosure

The vortex casing concept that was built is shown in figure 8. The spiral was extended more than 360 degrees to provide better enclosure muffling for the blower, and the spirals were split in to two halves so as to distribute the flow all around the vacuum cleaner, avoiding noise gradients in any single direction. The spiral enclosure concept was prototyped and a test fixture was built to test the spiral enclosure with a selected diffuser pump. The arrangement was tested fornumber-of-iterations by varying the number of exhaust port openings to determine the optimum exhaust port opening areas and their placement locations that would help in reducing noise levels.

The results of the tests were recorded in a workbook and then compared with the existing enclosure designs by conducting similar sound level tests for both. Existing enclosures designs measured the sound levels of 84 to 85 dBA, whereas the iterations of the spiral enclosure prototype measured 82 to 85 dBA. One thing to consider is that the existing enclosure design had good sealing through properly designed gaskets and seals but the proto model sealing was not effective, in spite of which, the spiral enclose measured 2 dBA less than the existing designs in some testing iterations.

CONCLUSION

Understanding and controlling noise is a complex subject. It is even more difficult with vacuum cleaners as it involves both structural and airborne noise sources and maintaining suction pressure. The use of good acoustic dampers for the blower motor, and the designing of a smooth flow path for a stable flow without flow separation and vortex zones will help in reducing the noise levels. The reduction in flow velocity of the exhaust will definitely help in reducing the sound level, but at the same time, the design should be evaluated to understand its effect on suction power, and care should be taken to avoid any separation along the flow paths. The diffusion effect of exhaust ports should also be given greater importance, which in turn depends on the proper sizing and location of the exhaust ports.

Further study and research can be carried out on the design and implementation of Helmholtz resonators to the exhaust.

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AUTHOR INFO

Anand Jittanakatti
HCL Engineering and R&D Services

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