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Noise reduction of handheld vacuum cleaners according to geometric optimization of air passages

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Abstract

This project has been done with joint cooperation of Pars Khazar industrial group – Nur Toushe home appliances company and NVA research center of the university of Tehran on the HVC412 commercial product. Each part of the vacuum cleaner assembly is geometrically optimized according to fluent streamlines in order to minimize the noise level. In this procedure it is attempted to avoid most important aero-noise generating mechanisms such as : turbulence , rapid air passage changes , impact , sudden exhausting traps , cavity noise and etc.

In addition to noise reduction of the product the main purpose was to increase the vacuum pressure of the device. In each segment prototypes of concerned parts have been made and tested in various conditions. Tests results include noise level reduction and vacuum pressure increase.

1 Introduction

Nowadays according to extended researches regarding the negative effects of noise on mental and psychological health of human kinds, noise reduction has been considered seriously in various trades specially in the home appliances industry. Vacuum cleaners have always been one of the most important noise sources in residential places and always have been following with consumer's complaints. Inasmuch as the noise generated in vacuum cleaners has an aerodynamic source , it seems necessary to study the regime of air flow through the passage. To eliminate each aero-noise ,the source and the generating mechanism should be known firstly . The second step is to change the geometric parameters of the air passage in order to avoid the concerned mechanism. The most important noise portion is generated in the suction fan which will be decreased via turbo machinery design considerations.

In the following there is a brief review on aero-noise generating mechanisms:

A) Ideal acoustic source models:

1- Mono pole : It is a result of volumetric unsteady flow which is seen in exhausted flow. The intensity of noise in mono poles is related to the velocity of flow by the fourth power.

2- Dipole : Which is the result of the interaction between unsteady flow and rigid surfaces. Vortexes cause fluctuating forces on these surfaces and the following vibration generates the noise. The noise intensity is related to sixth power of the velocity .

3- Quad pole : As two separate flow incident each other result in internal stresses which lead to noise generation.

It should be mentioned that monopoles are more powerful than dipoles and dipoles than quad poles.

B) Physical noise models :

1-Leak noise : Leak noise is produced as air flows through a leak , hole or slot as a result of pressure difference. Leak noise contains both monopole and dipole sources.

2- Cavity noise : Standing waves produces in a standing cavity of the air and generate a broad band noise containing disturbing bass frequencies.

3- Rush noise : Turbulent flow makes fluctuating forces on rigid bodies. Providing the flow separates , vortexes come bigger and the mentioned forces will be equal to ten times in comparison with the boundary layer .

2 Noise sources detection in HVC412

2-1 : Front Body :

Inlet profile of the air is very critical. However as it is evident in the figure 1 the inlet flow is pulled into the front body without any guidance and with an extremely sudden angle change, which leads to turbulence and will be followed with noise.

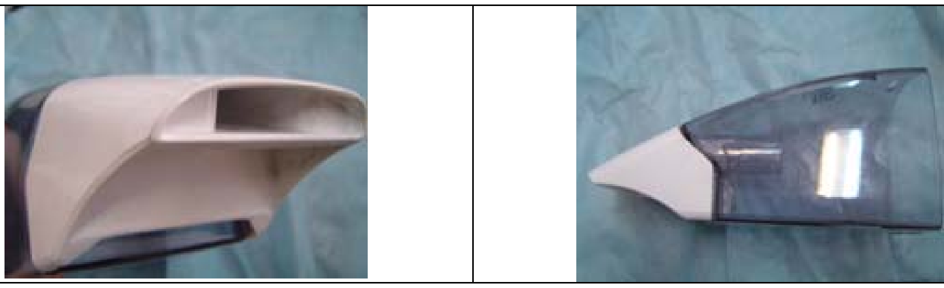

Figure 1:Front body

2-2: Filter Body:

After entering the front body , the air should pass through the filter to get rid of any kind of dust. Yet before entering the filter zone any possible companion liquids should be divorced from the air. Hence the filter body was designed to …. The air as it impact the bottom part of it. In this process we face with two main source of noise . First and former the cross impact of entering air to the surface of the filter cause noise . Secondly 90 degree sudden change in direction of the flow in order to enter the filter through top holes , cause vortexes which lead to broad band noise . Moreover these non-smooth path results in pressure drop and vacuum decrease. After all as the air pass through filter slots leak noise will be produced . Figure 2 shows the filter body in which the air path is obvious .


Figure 2 Filter Body

2-3:Main body :

main body is considered in two distinct sections . first body air inlet and second
Body air outlet.

A) Body inlet : As it is shown in figure 3 the air entering the body is not directed properly yet pulled into the body suddenly which leads to streamlines disturbance and eventually aero-noise generation.

B) Body outlet: Figure 4 represents the exhaust trap through which the air passes after leaving the fan and finally meet the atmosphere. Indeed this part produce a noticeable amount of device noise .

- Sudden incidence of the air with interior surface of the trap cause an impact noise.
- Leak noise produced as high velocity air passes through slots of the trap.
- Rush noise is result from exhausting high pressure air without velocity reduction.

In addition to noise generation this form of exhaust trap causes high pressure drop which equals to vacuum reduction . Moreover according to these air resistances the fan will work far away from its design point which means working in low efficiency area.

Note : Turbo machinery noise produced by the fan will be mentioned in next section.


Figure 3 Main body inlet

Figure 4 Main body outlet

3 Geometric optimization of the vacuum cleaner's parts:

According to previous section considerations a new design has been done to omit the noise source mechanisms via geometric modifications.

3-1 : Front Body :
In order to avoid streamline disturbances the inlet profile of the front body is designed to provide laminar directing the air in . This profile eliminates previous sudden streamline breaks. (Figure 5)

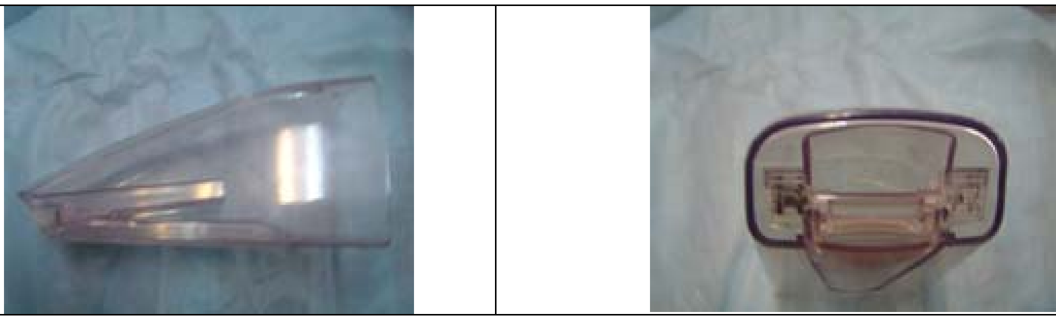

Figure 5 : Front Body

3-2 : Filter Body :

The filter body's geometric form was changed fundamentally . The air flow slides smoothly on the bottom surface of the filter instead of impacting to any rigid body and continues its way to the entering trap gently. Moreover the cavity at the bottom part of the filter was eliminated. The entering filter trap has been modified this way : the trap area was increased and the its surface was accompanied with the filter body's surface in order to minimize turbulences. (Figure 6)

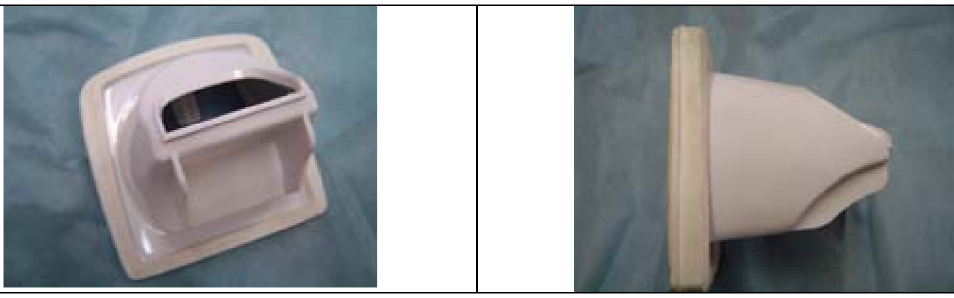

Figure 6

3-3 : Main Body :

A) Inlet : The air inlet to the main body has been converted to a converging nozzle in which flow streamlines continue without any interrupt , sudden break or impact to the front of main body. (Figure 7)
B) Outlet : The outlet trap has been modified fundamentally .As the air leaves the fan enters the exhaust duct the width of which grows gradually to provide laminar exit with velocity reduction for the flow. In addition to designing exhaust duct , the outlet taper was extended to eliminate the leak noise and to reduce the air resistance which leads to increase vacuum of the device. (Figure 8)

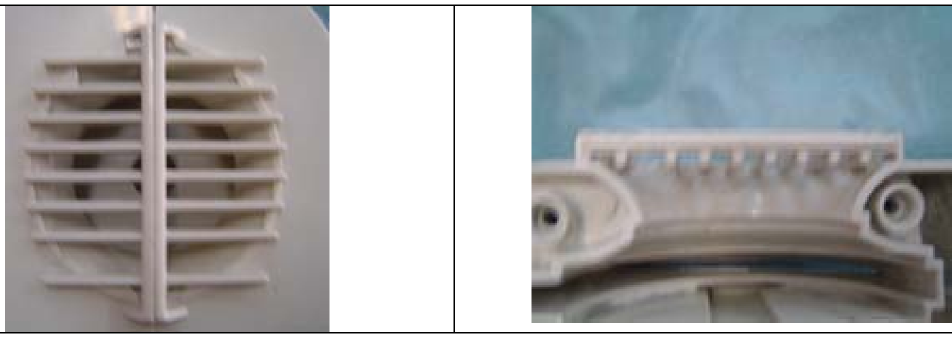

Figure 7 : Body Inlet

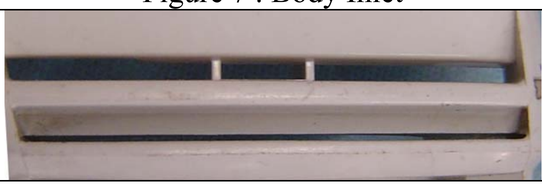

Figure 8 : Body Outlet

The air should not be exhausted directly to the atmosphere to reduce the noise generated by turbulences . consequently the exhaust duct was designed diagonally which has two advantageous : firstly the turbulence noise reduced through the duct as a result of the velocity reduction and flow lamination, secondly the fan does not have direct access to the atmosphere and its rotating noise will not transmit completely to the out of the device. In the following there is a relation between noise level reduction and the angle of diagonal exhaust duct (figure 9):

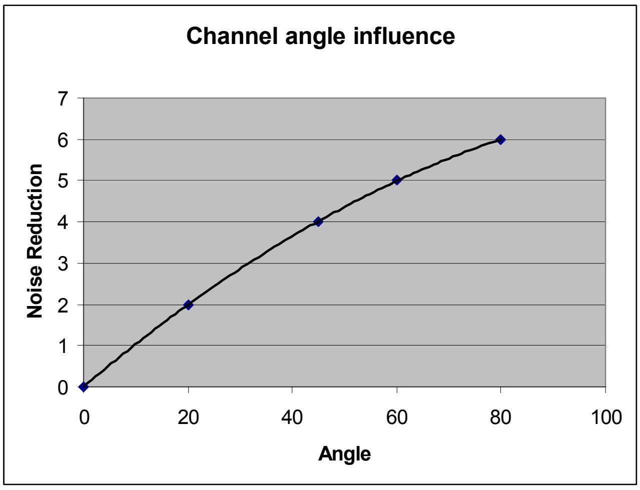

Figure 9

Although the more the angle of the duct the more noise reduction will be achieved , the diagonal duct causes a pressure drop in the passage which leads to vacuum decrease. Hence in order to make an equilibrium between these two poles the duct angle has been selected to 45 degree.

3-4 : Fan :

Turbo machinery noise has been investigated in last few decades and various solutions have been presented for the noise reduction. Generally centrifugal fan noises divide to broad band noise and a pure tone noise . The broad band noise is a generated as a result of turbulence while the pure tone noise is produced by fan blades interaction with the surrounding air and its frequency is as follows :

$$f = n \times \omega \qquad (1)$$

n: number of blades

ω : rotational speed of the fan

The noise level of centrifugal fans could be estimated from the following equation:

$$Lw = 10 \log \omega^5 R_2{}^6 b_2 - 36 \qquad (2)$$

R_2 : Outlet radius of the fan

b_2 : blade height at the outlet

Lw: Sound power level

There is also another practical equation from ASHRAE handbook for the noise power estimation of backward centrifugal fans :

$$L_w = K_w + 10 \log Q + 20 \log P + BFI + C_N \qquad (3)$$

L= Noise power level Q= Flow rate P=Fan produced pressure
K=

63 Hz	125 Hz	250Hz	500Hz	1000Hz	2000Hz	4000Hz	8000 Hz
35	35	34	32	31	26	18	10

Table 1

BFI= 3 which will be added to the blade frequency as described in equation (1).
C: is a result of the fan deviation from its maximum efficiency point which leads to noise production.

Efficiency	C
%90	0
%75	5.2
%40	12.2

Table 2

As the reduction in fan rotational speed or the external radius will lead to vacuum drop of the device , these changes are not applicable . However other modifications has been done to reduce the fan noise level . As it is shown in equation (3) noise level of the fan is related to the pressure difference produced by the fan . Changes in the blade angle at the outlet of the fan has been done to reduce the extra exhaust pressure which leads to noise generation. Furthermore air resistance decrease in the passage helped the fan to work near its design point that reduce C parameter in equation (3).
Following researches show that some other parameters involve in fan noise generation in addition to those mentioned above. The most important parameters are : the blade profile , inlet and outlet profiles.
Therefore following modifications have been done to reach the maximum noise reduction :
- Directing edge was provided at the inlet of the fan.
- In the center of the fan there is a curved surface which directs the flow to the entrance of the blades .
- Entering form of the blades has been converted from 2D profile to 3D profile- in other words there are chamfers in tow directions - in which the flow involves with blades gradually and smoothly .
Figure 10 , 11
- Blade tips at the outlet are also chamfered to reduce the air interaction with blades.


Figure 10 – old Fan


Figure 11 – New Fan

4 Experiments and test results

A) Noise level test :

The noise level was tested in free field with 2260 B&K portable device . In order to investigate the effect of each section the noise level of each part was recorded separately and then in the assembly. In parts such as front body or filter body the noise was recorded according to an air-jet provided through the passage.

B) Vacuum pressure test:

Vacuum pressure is tested via three different methods :

1- Test vacuum chamber: in which orifices simulate various working conditions for the vacuum cleaner and the head – flow curve will be achieved.

2- Air tunnel : the flow rate is measured with anemometer and desired head is applied at the inlet of the vacuum cleaner.

3- Pipe line : in which the flow rate is calculated via the Bernouly equation and a pressure gage.

On account of the fact that the purpose of current paper is to investigate the noise reduction , the vacuum pressure test results is mentioned briefly in the following in companion with noise level measurements .

Part Optimization	Sound level reduction (dB)	Vacuum Increase (%)
Front Body	2	6%
Filter Body	1	15%
Main Body (Input)	3	7%
Main Body (output)	5	12%
Ventilator	9	18%
Assembled Product	12	58

Table 3

5 Discussion and Conclusion

According to applied modifications the effect of geometrical parameters is obvious on the aero-noise production of the air-flow devices. This has been considered in aero industries and automotive industry. Furthermore in another section the effect of geometric parameters in the turbo machinery noise was considered in spite of their simplicity. In further investigation the CFD simulations seems useful as it reduce the iteration in the product design.

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