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REDUCING THE EXHAUST AND VENTING NOISE OF A VACUUM MOTOR WITH MINIMUM USE OF SOUND ABSORBING FOAM

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1. INTRODUCTION

The major noise sources of a central vacuum cleaning system were identified as noise from the motor exiting through the exhaust and through the ventilation of the motor enclosure. A noise control design was developed through an iterative approach driven by experimental rather than theoretical results. For the exhaust noise, a muffler was designed using a duct lined with sound absorbing foam. The next most prominent noise source, the motor cooling port in the lid of the unit, was also reduced with a foam lined duct lined. For each lined duct, the optimum amount of foam was determined. Optimum was defined as the limit where more foam did not significantly increase the noise reduction. The results clearly show how iterative design methods with testing can develop effective designs which conserve material use. The results also indicate some important guidelines for reducing noise in a highly turbulent moderate temperature flow.

2. EXPERIMENTAL METHODS

Two experimental methods were used in this research: (1) Acoustic intensity measurements and (2) the sound pressure measured in the reverberant field of a room. The acoustic intensity measurements provided the means to perform a very careful characterization of the sources radiating sound from the vacuum. The sound pressure measurements in the room provided a means to quickly measure changes in the radiated sound power of the vacuum as modifications to the unit were made. This single step determination of changes in the radiated sound power provided an efficient means to perform an iterative design process

The procedures for the sound intensity measurements [1] and the results will not be presented here. The conclusion of the measurements was that the resonant shell vibration was isolated to low frequencies and that the major noise path of the motor cooling air was through the lid.

The room measurements were performed with the sound source placed in the room and the sound pressure measured at one location. The source and microphone were always placed at consistent locations so that the microphone was in the reverberant field of the source. Although not an exact measure of the sound power radiated by the unit the measured sound pressure indicated the change in the radiated sound power as the design iterations were performed. Several measurements indicated that the results were repeatable to within ±0.5 dB.

The sound radiated by the exhaust was measured with a vacuum unit placed in an anechoic room with the exhaust piped out into the measurement room, thus isolating the exhaust noise from the unit noise. The muffler was placed on the exhaust outlet and the sound pressure was measured as described above. The sound levels measured with and without a muffler attached to the exhaust were subtracted to determine the insertion loss of the muffler in dB.

In all measurements the microphone signal from a one inch diameter B&K 4145 microphone was amplified using a B&K 2807 microphone power supply then input to an Ithaco model 453 amplifier and a Krohn-Hite model 3905A multi-channel filter which served as an anti aliasing filter.

3. MUFFLER DESIGN OPTIMIZATION

The development of an improved muffler design required several iterations. The original muffler supplied by the company consisted of two end caps, a section of 0.076 m diameter PVC piping 0.216 m in length, and a contoured open cell foam, approximately 10 mm thick, lining the inside of the muffler. The exhaust from the unit and outlet from the muffler flows through 0.051 m diameter PVC pipe which is attached to the muffler with end caps.

Initial experimentation centered around gaining an understanding of the parameters that influence the effectiveness of the muffler. Because of the high flow rate of the exhaust air, it was suspected that the uneven surface of the interior of the current muffler was inhibiting the effectiveness of the design. Figure 1 shows that the effectiveness of the muffler can be enhanced by reversing the orientation of the foam so that the smooth surface rather than the contoured surface is exposed to the air flow.

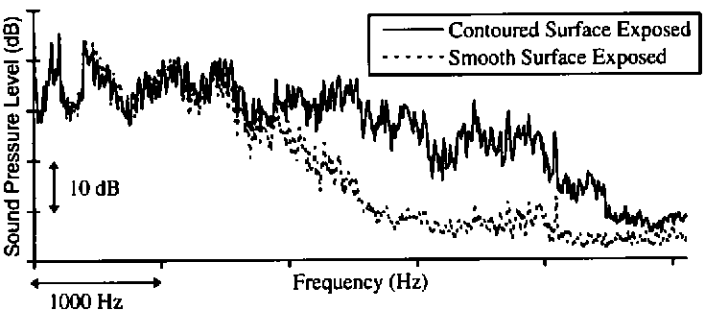

Figure 1. Muffler performance with the smooth and contoured foam surface exposed to the flow

Thus the contoured surface created additional flow noise. In addition, these experiments showed that, at these high flow rates, the expansion chamber behavior expected for the muffler was not significant. It was therefore decided to pursue a design that used smooth foam as the means of noise reduction, with the foam surface flush with the interior of the incoming and outgoing exhaust piping so that the largest amount of foam could be used in the muffler.

Based on these design parameters, the investigation then centered on finding an optimum length for the muffler while using an appropriate foam. Using the same diameter as the initial muffler an optimum insertion loss of 11.6 dB was found. It was decided that even more reduction could be achieved by using a larger, 0.102 m diameter, muffler with 0.0254 m thick foam.

The optimum length was determined by constructing various lengths of the muffler and determining the shortest length beyond which minimal reduction is obtained. The overall sound pressure levels for four lengths of the 0.102 m diameter mufflers, Table 1, shows no significant difference between the 0.508 m and 0.445 m lengths, and only a slight difference between the 0.445 m and the 0.381 m lengths. There is, however a 1.5 dB difference between the 0.381 m length and the 0.318 m length. Comparing the frequency spectra revealed no significant difference between the 0.508 m and 0.381 m length mufflers. There is, however, a significant difference between the 0.381 m and 0.318 m lengths, Figure 2, especially in a high frequency, 1000 Hz wide band circled on the figure. Based on these results, the 0.381 m length was determined to be the optimal muffler, because it has the best performance with the least material.

Table 2: Insertion loss for the 0.102 m diameter muffler.

Length (m)	0.508	0.445	0.381	0.318	0.254
Insertion Loss (dB)	17.5	17.7	17.0	15.5	14.1

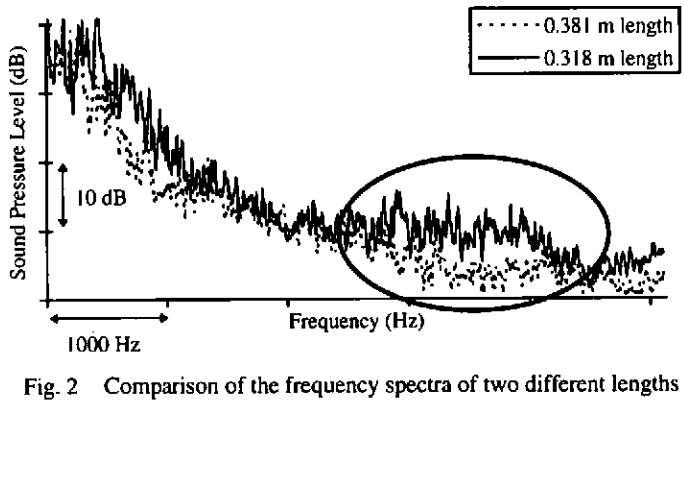

Fig. 2 Comparison of the frequency spectra of two different lengths mufflers.

4. REDUCING DIRECT MOTOR NOISE

Since a significant amount of noise was determined to be coming from the motor cooling air vents in the vacuum case, design modifications centered on the lid of the unit which was the greatest sources of noise after the muffler was added. The intake of the motor cooling air is located in the center of the top of the unit while the exhaust leaves the motor housing through the louvers on the side of the unit. The basic design concept was to force the air to travel along a duct lined with foam. Once the shape of the new lid was designed based on aesthetic, cost, and manufacturing constraints, an iterative technique was again used to determine the appropriate amount of sound absorbing foam for the lid.

Table 2 summarizes the A-Weighted sound level reductions due to the new lid with two foam configurations. Other cases were tested, but not presented here. The bottom foam refers to the case where only a single surface was covered with foam. This bottom foam surface was easy to install during manufacturing and was necessary to seal the new lid. The full foam case added foam to all the surfaces along the interior of the new lid.

The results clearly indicate that there is nothing to gain by using the full foam case which adds to production cost, so the bottom foam case was chosen. In addition the lid had little effect on the overall level, but produced a significant reduction, 5 dBA, in the 4000 Hz octave band, which represents a significant reduction in the annoyance of the noise. Thus the lid does represent a significant improvement.

Table 2: Sound pressure level reductions with the new lid design, dBA.

Octave Band	31.5	63	125	250	500	1000	2000	4000	Overall
bottom foam	2.4	0.4	0.0	0.7	-1.0	0.0	0.6	5.1	0.5
full foam	2.4	-0.1	0.6	1.0	-0.9	0.2	1.1	5.0	0.7

4. CONCLUSIONS

An iterative design technique based on experimental data rather than theoretical models has been shown to yield good results when searching for a design which makes minimum use of damping material while maintaining an acceptable level of effectiveness. The combined reduction of all the design changes was 10.1 dBA. While the iterative technique described is very effective in determining an optimum solution under present operating conditions, the present solution may not continue to be optimum as other modifications are made to the product which reduce other significant noise sources. Thus, continued review of previous optimization results is necessary as a product continues to be improved.

The research results also showed that a smooth foam surface in a dissipative muffler design performs better in moderate temperature turbulent flow than a reactive muffler design such as an expansion chamber.

5. REFERENCES

[1] Rittmueller, S.R., "Reducing Noise of a Central Vacuum System", MS Thesis, Iowa State University, 1995