COMPARISON OF EXPERIMENTAL AND MODELED INSERTION LOSS OF A COMPLEX MULTI-CHAMBER MUFFLER

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1. INTRODUCTION

Given the greater legislative emphasis on the reduction of automotive noise emissions, the design of attenuators has become a paramount issue in the area of car development. Engine developers have been able to improve engine performance through lowering inlet and outlet valve resistance but at the cost of greater amplitudes of noise propagation downstream of the exhaust valves. As a result, exhaust system manufactures must design their products to achieve greater attenuation levels while not increasing flow resistance which would impinge on engine performance.

The complex multi-chamber muffler is the most common noise control filter used in automotive exhaust applications. Historically, the acoustical design of these mufflers has involved the construction of a prototype based on the initial application of the fundamental equations which would then be experimentally evaluated for performance. This trail and error process is a very costly and time consuming exercise which does not meet the development goals of today's highly competitive automotive market. As a result, the development of powerful computer based design systems for acoustical modeling have given way to the prototyping method of design primarily due to their ability to reliably predict automotive noise. Care, however, must be taken in the utilization of these sophisticated software packages to ensure that any input criteria is applied correctly to ensure meaningful results.

This study investigates the effect of using Ricardo WAVE, a computational simulation using a one-dimensional finite-difference formulation, to determine the realized insertion loss for an 'off the shelf' muffler. The theoretical results are compared to experimental measurements of the same muffler design. The purpose of this study is to investigate the effectiveness of using the theoretical model as a design tool for automotive muffler applications.

2. THEORY

Beranek [1] defined the muffler as any section of pipe that has been shaped in order to reduce the transmission of sound, while at the same time allowing the free flow of gas. The actual muffler used in the experimental portion of this investigation is a commercial reactive muffler. Figure 1 is a cutaway of the muffler showing the multiple chambers. In a reactive muffler, the multiple pipes and chambers provide an impedance mismatch for the acoustic energy traveling through it. "This impedance mismatch results in a reflection of part of the acoustic energy back toward the source of the sound" which prevents some of the energy from transmitting past the muffler.

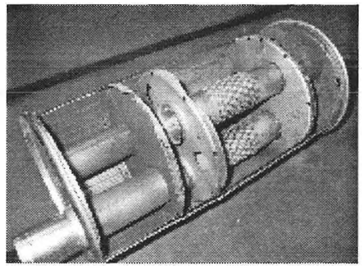

Figure 1: Cutaway of Experimental Muffler

The muffler used in the theoretical portion of this study is a complex multi-chamber muffler. The schematics of this muffler are as shown in figure 2. Time and resources available when the study was conducted did not permit an exact modeling of the muffler used in the experiments, however, the model used is similar in design and still reflects the purport of the study.

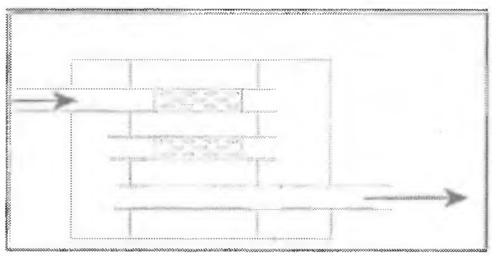

Figure 2: Schematic of Theoretical Muffler

Insertion Loss was used to compare the experimental results to the theoretical model. Insertion loss is the difference, in decibels (dB), between two sound pressure levels measured at the same location before and after the muffler is inserted between the measurement location and the source.

3. PROCEDURE

To experimentally determine the insertion loss of the muffler, a speaker was espoused to one end of a 10 foot exhaust pipe which was inserted through the wall of a semi-anechoic chamber. The other end of the pipe was attached to the muffler inside the anechoic environment which had a 2 foot pipe attached to its output. The speaker played a white noise signal into the system and a microphone located 0.1 metres from the outlet measured and recorded spectral results. Figure 3 shows the muffler in the anechoic room. The procedure was again repeated only with a straight pipe of the same length of the muffler, in its place.

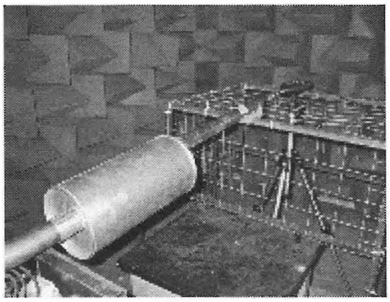

Figure 3: Experimental Muffler in Semi-Anechoic Room

To model the insertion loss, a computer model of the exhaust system complete with white noise source, was created
with WAVE which outputted spectral results, also downstream of the muffler location. The model was run with both the muffler in place as well as the case with it replaced with a straight pipe.

4. DISCUSSION OF RESULTS

Examination of figure 4 shows the spectral results of experimental exhaust system with both the muffler inserted and without. It is clearly shown that the sound pressure level (SPL) without the muffler is greater than the SPL with the muffler. Addition of the spectral information gives a total SPL of 97.4 dB without the muffler and 82.2 dB with the muffler. This gives an insertion loss of about 15 dB.

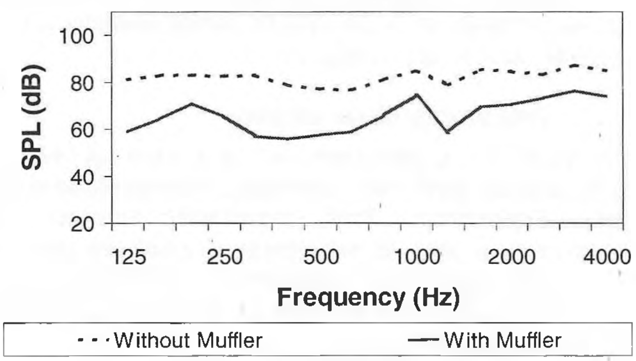

Figure 4: Experimental Spectral Analysis of Multi-Chambered Muffler

Figure 5 shows the results of the theoretical model. Again, it is clear that the muffler improved the acoustical performance of the system. Here, the overall SPL of the exhaust system without the muffler is 97.4 dB which is the same value determined in the experimental exercise. The SPL with the muffler in place is 79.1 dB giving the muffler a realized insertion loss of about 18 dB.

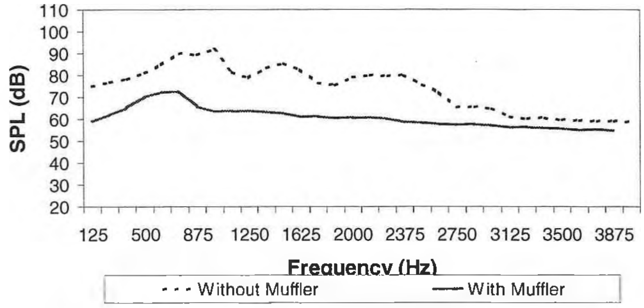

Figure 5: Theoretical Spectral Analysis of Multi-Chambered Muffler

The two studies show similar results with a difference of insertion loss of about 3 dB. A point of validation that can be made is that both studies resulted in identical overall SPL's without the muffler inserted. One should be aware that the modeled muffler was not a perfect match to the actual muffler, but none the less, the similarities still exist giving warrant to pursue the investigation further.

5. CONCLUSIONS

The purpose of this study was to investigate the effectiveness of using a theoretical model as a design tool for automotive muffler applications. Theoretical insertion loss of the computer model compared favorably to those determined from the experimental exercise. While good agreement was obtained in this investigation, some fundamental simplifying assumptions were made which incontrovertibly influenced the theoretical results thus encouraging further investigation.

6. REFERENCES

1. Beranek, L., "Noise and Vibration Control", McGraw-Hill, Cambridge, MA, 1988.

2. Novak, C., Ule, H., Gaspar, R., "Comparative Investigation of Muffler Models", Journal of the Canadian Acoustical Association, vol. 29 No. 4, 2001.

3. "Ricardo WAVE Tutorial", Burr Ridge, IL, 2001.