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High intensity and low frequency tube sound transmission loss measurements for automotive intake components

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As the requirements for realistic analytical modeling become greater, the need to test automotive intake components under realistic conditions for correlation purposes increases accordingly. Sound pressure levels in automotive intake systems reach levels as high as 170 dB at the throttle body and firing frequencies can be as low as 20 Hz. At these high sound levels, nonlinear effects are observed due to drain holes and flexure of non-circular cross-sections. Testing at low frequencies is challenging because transitions used to match the area of the test components to the area of the tube produce significant low frequency errors for which corrections need to be made. A test system and data processing procedures to address these issues are presented.

1 INTRODUCTION

Even though analytical noise predictions for automotive intake systems have progressed significantly, there still exists a need for component testing. Usually testing needs fall into two categories: (1) testing for analytical model validation, and (2) testing to support the final development stage of the project where unexpected problems are addressed or sound quality tuning is performed to match vehicle performance to customer expectations under realistic operating conditions.

Testing at high intensity and low frequency presents a number of practical challenges, and the methods of dealing with these challenges are addressed in this paper. Issues include: (1) hardware requirements for constructing powerful sound sources and for microphones capable of measuring sound levels up to 170 dB; (2) correcting for the significant low frequency effect of area change adapters; and (3) measuring nonlinear effects due to drain holes and flexure of non-circular cross-sections. Nonlinear effects due to shock wave formation are not addressed in this paper.

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2 HARDWARE REQUIREMENTS

Sound pressure levels measured at the throttle body of a typical four cylinder SUV engine during a wide open throttle sweep are shown in Figures 1 and 2. Figure 1 shows the overall level and order contributions versus engine speed, and Figure 2 shows the second order level versus frequency. The levels are very high with a maximum second order amplitude of 171.5 dB (sound pressure level of 7535 Pa, rms). Reproducing these high sound levels using a loudspeaker was challenging.

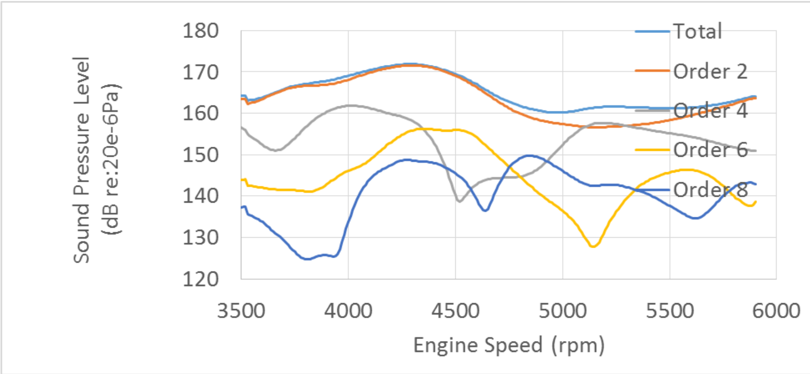

Fig. 1 – Overall sound pressure level and order contributions versus engine speed for a typical four cylinder SUV engine.

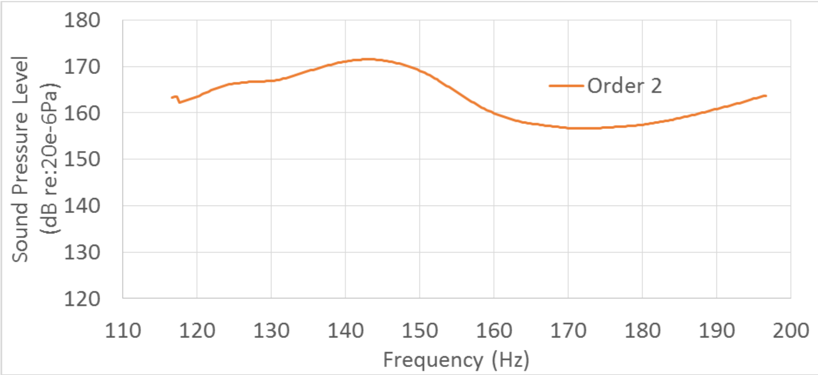

Fig. 2 – Second order contribution versus frequency for a typical four cylinder SUV engine.

The very low frequency source (VLFS) constructed to simulate engine intake sound levels is shown in Figure 3. The source consists of a cone loudspeaker (222 mm diameter, 8 ohm impedance, 500 W power) housed in a 254 mm outside diameter aluminum tube. There is a step transition from the large tube to the small tube which matches the 100 mm inner diameter of the B&K Type 4206T Transmission Loss Tube. The VLFS can be used for testing from 20 Hz to 1600 Hz eliminating the need for separate low and high frequency tests for most applications.

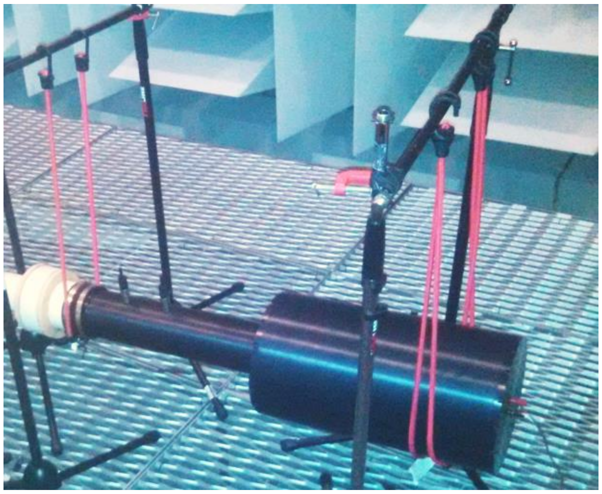

Fig. 3 – Very low frequency sound source.

The VLFS shown in Figure 3 is suspended by elastic cords. It was found that when the VLFS was placed on a table top, low frequency modes of the table were excited adding artifacts to the response data. The elastic cords reduced the modes of the VLFS suspension to frequencies far below the excitation frequency (e.g. 1 Hz suspension and 20 Hz excitation) which improved response data quality. Intake systems can have unusual shapes (inlet and outlet are different angles and elevations), so they were also suspended by elastic cords to make the experiment setup more convenient.

A commercially available audio amplifier rated at 750 W was used to amplify the input signal.

Due to the high sound levels, a low sensitivity B&K Type 4944-B (0.9 mV/Pa) microphone was used for the throttle body sound pressure measurements (with a UA-0385 bullet tip adapter to minimize flow noise during vehicle operating measurements).

3 CORRECTING FOR AREA CHANGE ADAPTERS

The material in this section is considered in more detail by the author in another article [1], but it is repeated here in a more condensed form in the broader context of this paper as compared to the previous article. Other authors have also addressed the subject of this section [2, 3].

Consider the case of a simple expansion muffler (representing a simple model of an air filter box) with cones to transition from a standard tube (inner) diameter of 100 mm to a diameter of 57 mm as shown in Figure 4. The muffler has an area ratio of 10 and is 300 mm long.

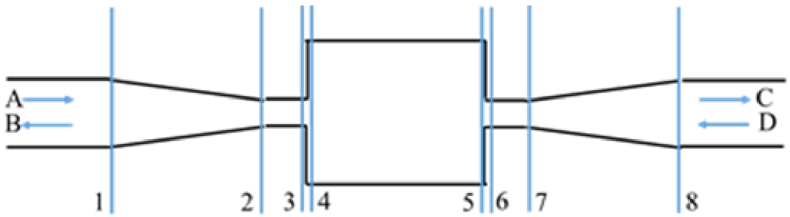

Fig. 4 – Model of an automotive intake system air filter box.

If the test article was removed leaving just the area adapter cones, the calculated transmission loss [1] for a pair of 600 mm cones (1200 mm total) and a pair of 150 mm cones is shown in Figure 5. From these plots it would be expected that the effect of the cones on the transmission loss measurement would be primarily at lower frequency (in inverse proportion to the length of the cones). Also it would be expected that the effect of the cones would be significant (more than a couple of decibels).

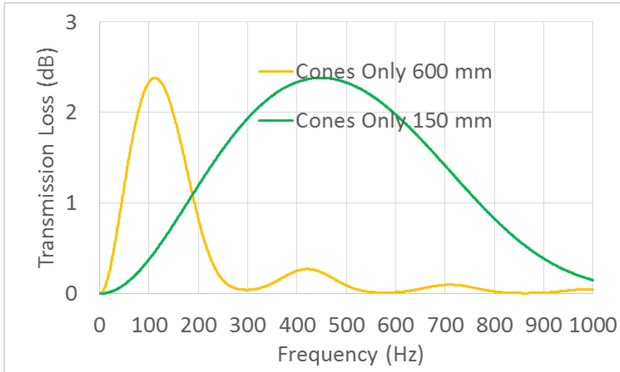

Fig. 5 – Transmission loss of just the area adapter cones.

Figure 6 shows the calculated transmission loss for the muffler (the desired quantity) and the muffler with cones. For the shorter cones, the effect of the cones is significant over most of the plotted frequency range. For the longer cones, the effect of the cones is significant below 120 Hz. For the cones to have no significant effect down to 20 Hz, prohibitively long cones are required.

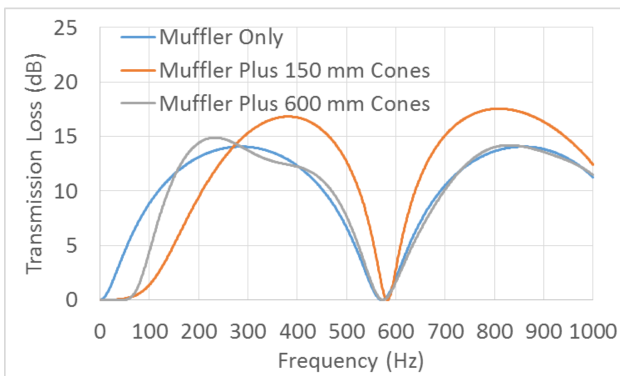

Fig. 6 – Effect of area cones on muffler transmission loss.

This example shows that if it is desired to make accurate measurements down to a frequency of 20 Hz, it is necessary to make some correction to the measurements if area adapters are used to match the test article to the test apparatus. A procedure for correcting measured data using the transfer matrix technique is shown in [1].

3 MEASURING BREAKOUT NOISE

The breakout noise of intake clean air tubes was measured using a bench test with the throttle body sound level matched to that of the engine during wide open throttle operation (as discussed in section 1 above). The setup is shown in Figure 7, and a diagram of the setup is shown in Figure 8.

The measurement setup had the following features:

- The VLFS was used as the sound source for the bench test with a swept sine as the input signal. The input signal amplitude matched the second order contribution as shown in Figure 2.

- A low sensitivity microphone was used to measure the sound level at the throttle body location during the bench test. Note that a different approach could have been taken here. Instead of matching the SPL at the throttle body, source power measurements could have been made on the engine [4], and those source power measurements could have been reproduced in the bench test.
- A tube was added to the inlet of the clean air tube to simulate the throttle body and the tube from the throttle body that extends into the engine intake manifold (sometimes called the zip tube). Area expansions were added to the inlet and outlet to simulate the boundary conditions at the intake manifold and air filter box so that the sound pressure distribution along the tube would approximate that of the clean air duct mounted to the engine.
- The breakout noise (sound power radiated from the clean air tube surface) was measured using a two microphone intensity probe.
- The measurement was performed in a fully anechoic chamber.

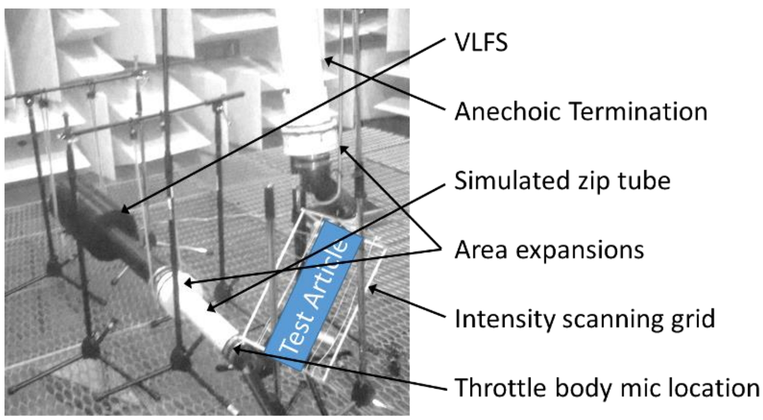

Fig. 7 – Clean air tube breakout noise measurement setup.

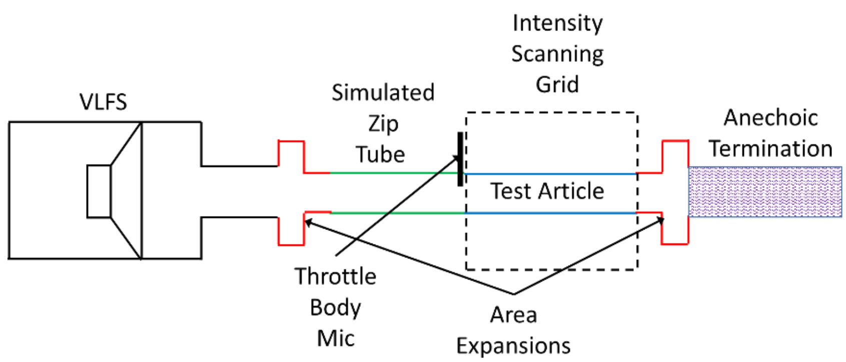

Fig. 8 – Diagram of clean air tube breakout noise measurement setup.

As noted above, area expansions were used at both ends of the tube to simulate the area expansions at the intake manifold and the air filter box. Figure 9 is a diagram of the actual tube boundary conditions versus the test setup with short expansion chambers (50 mm length). Relative sound pressure amplitude inside the tube for the two cases at 145 Hz is shown in Figure 10. The agreement in the shape is reasonably good, so this is a good method for simulating the boundary conditions to produce an approximation of the proper pressure amplitude distribution inside the tube.

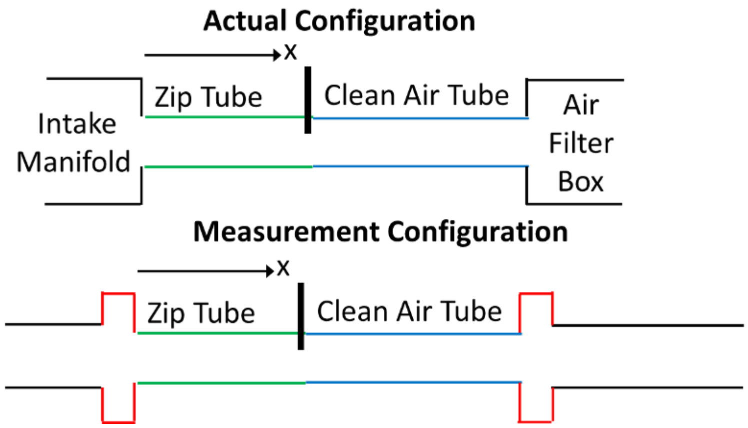

Fig. 9 – Diagrams of the actual engine configuration versus the measurement configuration.

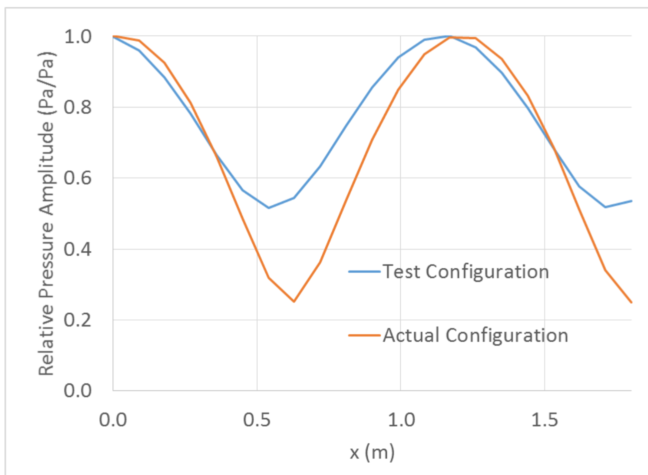

Fig. 10 – Relative sound pressure amplitude in the tube for the engine (actual) and test configurations.

An example of the total sound power radiated by the test article (clean air tube) as a function of engine speed (corresponding to second engine order) is shown in Figure 11.

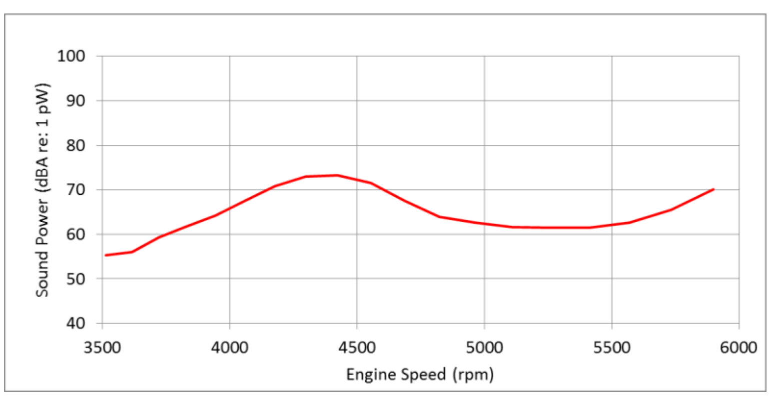

Fig. 11 – Total sound power for an example clean air tube versus order engine speed corresponding to the second order contribution to the throttle body SPL shown in Figure 1.

4 OBSERVED NONLINEARITIES

There were two motivations to build the VLFS. The primary motivation was to be able to test down to 20 Hz, but it was also desired to perform testing at high sound levels to see if significant nonlinear behaviors exist. In other words, do response levels go up in proportion to excitation levels, and is wave distortion noted (producing harmonics and sub-harmonics).

In testing to date (VLFS has been used for two years), few significant nonlinear behaviors have been observed. The noted nonlinear behavior are shown here.

Figure 12 shows the breakout noise measured from a clean air tube measured with full amplitude excitation (matching vehicle measurements) and with quarter amplitude (-12 dB, output scaled for direct comparison with full amplitude results). The results show that at full input amplitude the scaled response was less than at quarter input amplitude. This particular clean air tube had a non-circular cross-section, and it was made of a relatively soft plastic. It is assumed that the stiffness of the tube cross-section increased with increasing displacement. Note that the nonlinear effect was relatively small (2 dB). This behavior was not observed with tubes with circular cross-sections.

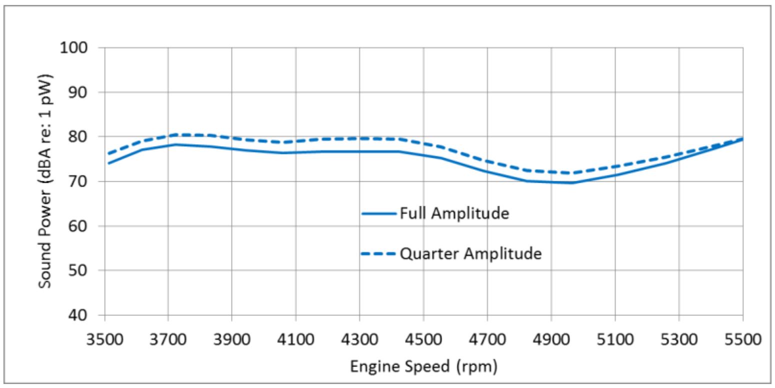

Fig. 12 – Total sound power for an example clean air tube versus order engine speed comparing acoustic levels at full amplitude (matching wide open throttle running engine) and quarter level.

Figure 13 shows the transmission loss of an automotive muffler (Helmholtz resonator type) where nonlinearity was observed. In this case, a small change in the peak amplitude (1.5 dB) at 75 Hz. It is assumed that this nonlinear effect was due to the drain hole. While not desirable, drain holes are sometimes present in Helmholtz resonators of intake systems, so the linearity of the measurement should be checked by making measurements at different excitation levels. Nonlinear effects have not been observed while testing expansion mufflers with drain holes.

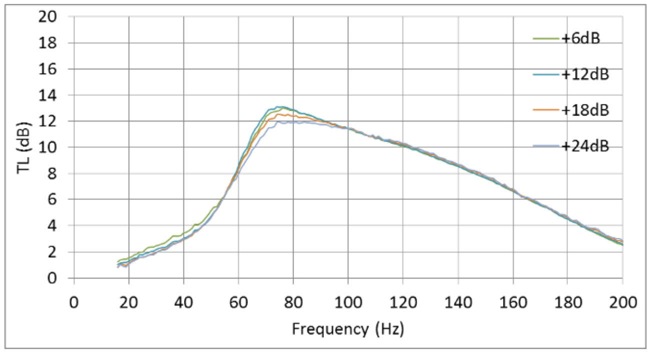

Fig. 13 – Measured sound transmission loss of an automotive exhaust resonator with drain hole at different relative excitation levels.

5 DISCUSSION AND CONCLUSIONS

Methods of dealing with the challenges of testing at high intensity and low frequency are described in this paper including:

- Hardware requirements for constructing powerful sound sources.
- Microphones capable of measuring sound levels up to 170 dB.
- Correcting for the significant low frequency effect of area change adapters.
- Nonlinear effects due to drain holes in Helmholtz resonators and flexure of non-circular cross-sections.

The Very Low Frequency Source has demonstrated its value in producing good signal to noise ratios for testing at very low frequencies. The value of testing at higher intensities (beyond those required for good signal to noise ratios) representative of measured levels in engine intake systems at higher frequencies is questionable. Nonlinearities have been observed, but their observed effect on measurements has been small.

5 ACKNOWLEDGEMENTS

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6 REFERENCES

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