USE OF SOUND QUALITY METRICS FOR THE ANALYSIS OF AUTOMOTIVE INTAKE NOISE

Colin Novak, Helen Ule and Robert Gaspar
Dept. of Mechanical, Automotive and Materials Engineering, University of Windsor
401Sunset Ave., Windsor, Ontario, Canada, N9B 3P4, novak1@uwindsor.ca

1. INTRODUCTION

Due to consumer demands, the need to attenuate the various sources associated with the operation of today's automobiles has become paramount. One such source of noise often overlooked from a consumer's perspective, is engine induction noise. This intake noise is the audible result of pressure fluctuations propagating through the intake system ducting as a result from the valve action of the engine.

Automotive intake noise is most often attenuated through the application of passive control techniques. These techniques are the simplest and least expensive form of attenuation but do not always yield the best results. A common example of a passive noise control technique used in automotive applications is the Helmholtz resonator. Experimentation with active noise control techniques has thus far also shown promise. This method, however, has not yet realized full commercial viability.

Independent of which method of attenuation is used to control intake noise, quantification of its success is paramount. However, from a consumer's point of view, the perceived quality of noise emissions takes precedence over what traditional acoustical analysis techniques may imply. Given this, sound quality metrics can be an important analysis tool for the evaluation of the various noise control techniques. The present study investigates the validity of using several psychoacoustic metrics for the analysis of automotive intake noise.

2. PSYCHOACOUSTICS

In the evaluation of the acoustic comfort of a sound, fundamental quantities such as the acoustic sound pressure level are not adequate to truly represent the actual hearing sensations. The science of psychoacoustics involves the quantitative evaluation of these subjective sensations using sound quality metrics. Application of sound quality metrics allow for the visualization of the complicated relationship that exists between the physical and perceptual acoustic quantities.

For this investigation, several sound quality metrics were used to evaluate automotive induction noise. These metrics included loudness, sharpness, roughness, fluctuation strength and articulation index. Before a discussion of any results using these metrics can be presented, a description of each is warranted.

Loudness is a standardized metric that describes the human perception of how loud a source is perceived as opposed to a simply reported sound pressure level. Loudness, using the units of sones, takes into account the temporal processing and audiological masking effects of sounds across the frequency range.

Sharpness, which has units of acum, describes the high frequency annoyance of noise by applying a weighting factor on sounds above 2 kHz. This overall measurement is most often applied to broadband sources such as rushing air noise, gear meshing noise and grinding sounds.

Roughness and fluctuation strength are two metrics used to describe the annoyance of modulating sounds. Fluctuation strength, with units of vacil, focuses on sounds which modulate at frequencies between 0.5 Hz and 20 Hz, with a 4 Hz fluctuation being the most annoying. Roughness, using units of asper, focuses on modulating noise at frequencies between 20 Hz and 300 Hz. The most annoying modulation occurs at 70 Hz. A siren is an example of a modulating sound.

Articulation index is a calculated measure of the intelligibility of speech in the presence of a sound. This is accomplished through consideration of the levels of the masking signal in the frequency bands most critical to the understanding of speech. A calculated AI of 0.1 indicates poor speech intelligibility whereas an AI greater than 0.6 is considered good with a value of 1.0, or 100%, being the best.

3. PROCEDURE

Induction noise was measured from a 16 valve 4 cylinder Toyota 4A-GE engine. The engine, which was located in a semi-anechoic room, was motored on a DC dynamometer at engine speeds from 1000 to 6500 rpm in increments of 500 rpm. The microphone was located at a distance of 100 mm in front of the intake orifice and was connected to a 01dB Orchestra data acquisition system which allowed recording to a PC hard disk. This data was later post-processed to determine, among other parameters, the psychoacoustic metric results.

4. RESULTS

Figure 1 shows the measured results for A-weighted pressure level and loudness. These two metrics are expected to show similar data trending since they are both designed to compensate for the human perception of sound amplitude at various frequencies. The difference is that loudness also compensates for other effects such as temporal processing. Given these similarities, it can be surmised that loudness is just as useful, if not better, a tool for induction noise analysis.

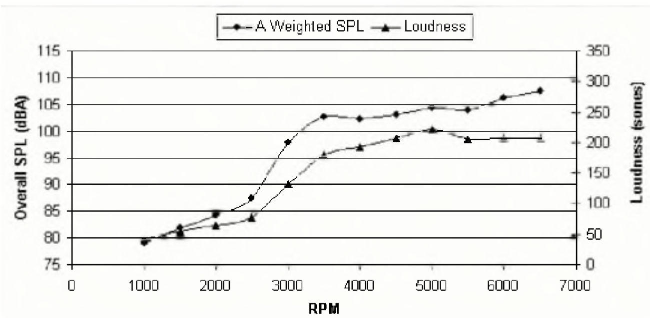

Fig. 1. Results of A-Weighted Sound Pressure Level and Loudness with respect to Engine Speed illustrate good correlation.

It was assumed that sharpness might be an appropriate metric for the evaluation of intake noise given that a high frequency component of intake noise is created by the intake air traveling across the intake valve seat at a high velocity. Examination of figure 2, however, shows that very little sharpness is realized. This is most likely due to a reduction of high frequency content in the noise resulting from influences of the manifold ducting and air cleaner.

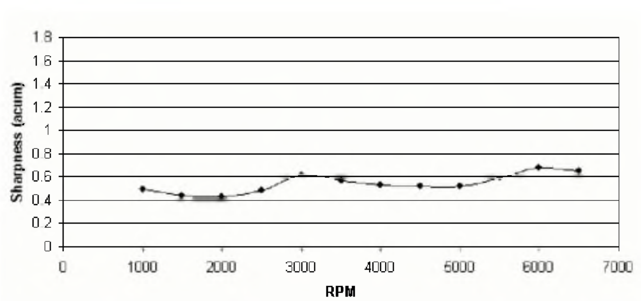

Fig. 2. Results of Sharpness versus Engine Speed show very little high frequency content in the induction noise signal.

Figure 3 illustrates the calculated roughness and fluctuation strength values across the reported engines speed range. Values for roughness are relatively low indicating that for this type of noise source, very little low frequency modulation exists. The reported values for fluctuation strength are similarly low with a couple of peaks occurring at specific engine rpm's which are the result of harmonics occurring at these engine speeds. This can be controlled through appropriate tuning of the intake ducting. These observations have been reinforced by a parallel study that used various frequency analysis tools.

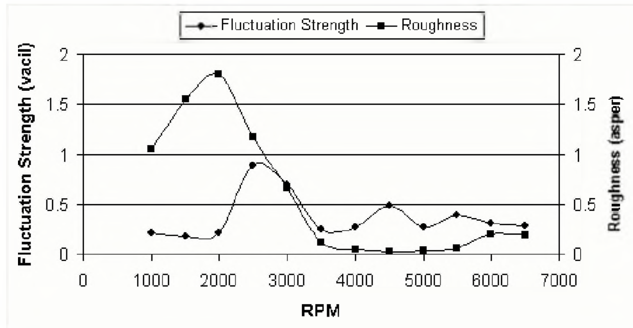

Fig. 3. Results of Fluctuation Strength and Roughness with respect to Engine Speed show very little low frequency and moderate mid frequency modulation of the induction noise data.

Figure 4 shows the results of an articulation index analysis. It should be noted that the location of these measurements was not the most appropriate. It would have been better to conduct these measurements inside the passenger cabin of the vehicle. This would have not only resulted in higher values for speech intelligibility but would have also been more representative of true human exposure. The merits of this metric, however, are still apparent.

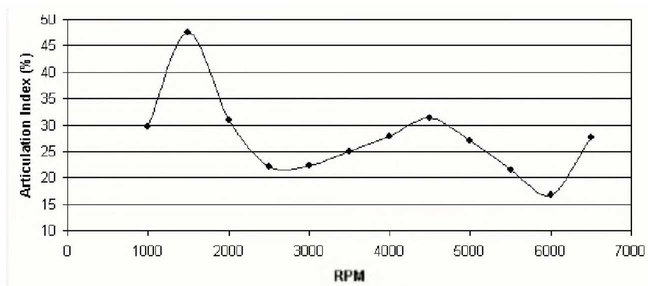

Fig. 4. Results of Articulation Index with respect to Engine Speed.

5. CONCLUSION

The focus of this investigation was to investigate the applicability of using several sound quality metrics for the analysis of automotive induction noise. It was seen that loudness correlated well with an A-weighted SPL analysis, thus demonstrating it usefulness. Sharpness, however, was not shown to be an appropriate metric in this case due to the lack of high frequency content in the acquired noise. The roughness analysis was able to demonstrate a lack of low frequency modulation while a more apparent fluctuation strength illustrated the presence of harmonics. This information could prove useful in a tuning exercise of these ducts. While the articulation index analysis provided good results, the noise data for this analysis should not have been collected in the under hood environment. Instead, this noise data needs to be collected at a more representative location such as the passenger compartment of the vehicle.

While some of the metrics employed in this study proved more applicable than others, the overall merit of using psychoacoustic tools for intake noise was demonstrated.