PREDICTION OF PSYCHOACOUSTIC METRICS FROM SUSPENSION INDUCED VIBRATION AND ROAD INDUCED NOISE USING TRANSFER PATH AND PSYCHOACOUSTIC ANALYSIS TECHNIQUES

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1. INTRODUCTION

In terms of noise generation, the automobile is simply a set of different systems that when excited at specific frequencies will eventually lead to the creation of noise. This statement was of course also true in the early days of automobiles, however, it was always taken to be a secondary issue that was simply accepted since more important factors had to be addressed. Both technology improvements and legislative advancements have since led to the evolution of the modern automobiles and the development of new performance targets, including noise.

Today, automakers invest significant time and money in research and development associated with the reduction of vehicle noise pollution. Since automakers are also more aware of the importance of the perception of noise, vibration and harshness (NVH) emissions, there is also an increased focus on the sound quality of vehicle cabin noise. Consumers now also demand safer and more comfortable vehicles, especially given the significant increased use of cellular phones, entertainment and interactive voice controls in vehicles. As part of this, it is recognized that the investigation and performing of psychoacoustics analysis of vehicle cabin acoustics is essential in the improvement of today's vehicles.

A significant source of unwanted cabin noise is the result of road-induced excitation of the vehicle suspension which propagates into the vehicle cabin. Keeping this in mind, the main objective of this study was to evaluate the transmission paths of the excitation energy into the vehicle cabin from road induced noise and vibration using frequency response functions. Finally, the objective was to establish a correlation between the noise and vibration measurements taken outside of the vehicle to noise and psychoacoustic observations inside the vehicle. These included Loudness, Roughness and Fluctuation Strength as well as the A-weighted sound pressure level.

2. EXPERIMENTAL DETAILS

For this investigation, acoustic pressure measurements were taken inside a 2004 Chevrolet Epica cabin at the driver's left ear location using conventional microphones as well as at the passenger's ears position with a binaural head for the evaluation of the resulting sound quality. A microphone was also located outside the car near the front wheel. Acquisition recording time was 15 seconds per run. The testing was done at the Brüel & Kjær Application Research Center (ARC) in Canton, Michigan, USA within a semi-anechoic room equipped with a 4WD dynamometer.

For vibration acquisition, one accelerometer positioned on the wheel hub and was stationary for the entire experiment. A second accelerometer was moved between tests, initially located on the lower A-arm and later moved to the top of the McPherson strut. Six Brüel & Kjær Type 2635 and Type 2626 amplifiers were used to condition the two 3-axis accelerometers.

Data acquisition was performed during motored and driven conditions. For both cases, the following operation conditions were considered:

- Idling/Ambient
- Steady speeds (20, 40, 50, 60 & 80 km/hr)
- Acceleration run-up from 0 to 80 km/hr

3. Data Analysis

The ten acquired time signals were used for the determination of the frequency response functions (FRF) and coherence between the pressure and acceleration excitations from outside of the vehicle and the sound pressure obtained inside the cabin with the intent to predict several psychoacoustic metrics. Estimation of the relationship between the input and the output of the system was performed using Matlab. For this process, each of the ten input signals needed to be correlated to each of the three output signals. Two different trials were also considered at six different steady speeds. Additionally, two different driving conditions were considered which gave frequency response functions and coherence functions for correlation between the sound pressure from outside and sound pressure inside the vehicle cabin.

For the first case, in order to generate the frequency response and coherence functions between any input and output signal, several steps were required. First, the two signals of interest were selected and the auto-spectrum and cross-spectrum of each of them are found using narrow band spectrum analysis. The FFT window type was then selected as well as the window overlap and the number of FFT lines. To reduce computational time, the frequency band was specified in this case to be limited to 1000 Hz. The cross-spectrums were calculated in the similar matter making sure that all of the selected parameters match the ones used for auto-spectrum calculations to be able to compute the Transfer Functions, FRFs and Coherence values. A Matlab function was also used to estimate the transfer function of the system with input A and output B using Welch's averaged periodogram method. Coherence was also estimated this way.

4. RESULTS

Testing was done at six different steady speeds. These were all performed with the conditions of the vehicle being driven and motored. As this provided hundreds of different FRFs and coherence functions, discussions are limited to a few examples to illustrate the main points.

From the results of the FRF calculation procedure, it was found that both the microphone and accelerometer stimuli can be used to obtain pressure inside the car. Using this information, the psychoacoustic metrics of interest were then predicted. The following Figures 1 through 4 show the agreement between the original and calculated levels at the passenger's right ear for all metrics for the motored car. The condition of the 60 km/hr motored vehicle is taken arbitrary simply to illustrate the point of the typical results. For this speed, the predicted mean levels of A-weighted sound level are within 2 dB with respect to the original data. This represents a variation that cannot be distinguished by human perception. Roughness and fluctuation strength showed excellent agreement as well as shown in the figures.

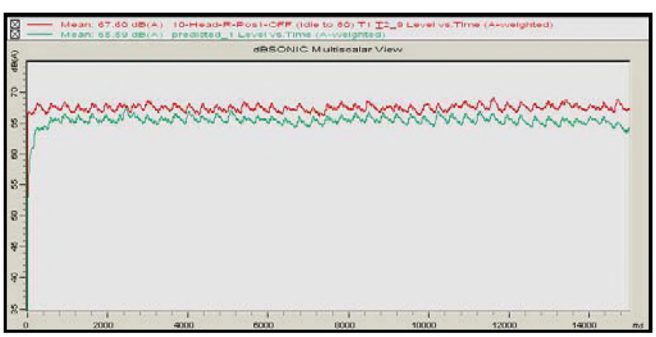

Figure 19: *Original (Red) and Predicted (Green) A-weighted SPL for Motored Car at 60 km/hr.*

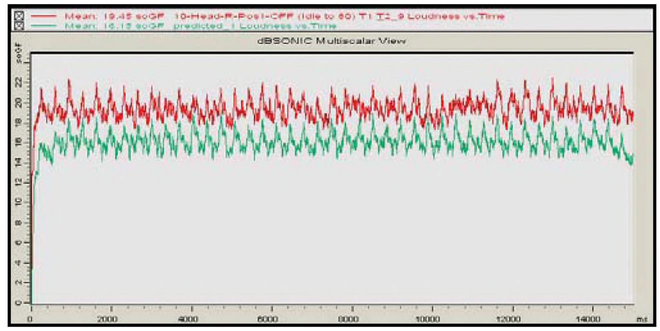

Figure 20: *Original (Red) and Predicted (Green) Loudness for Motored Car at 60 km/hr.*

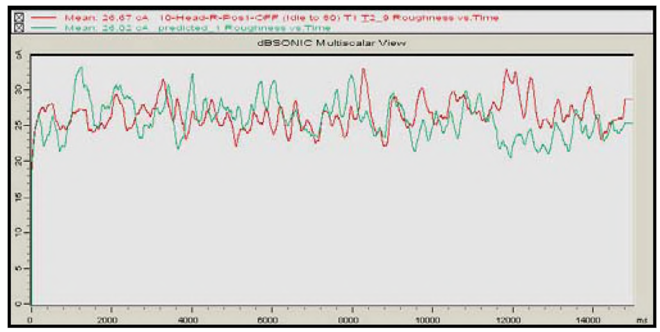

Figure 21: *Illustration of Original (Red) and Predicted (Green) Roughness for Motored Car at 60 km/hr.*

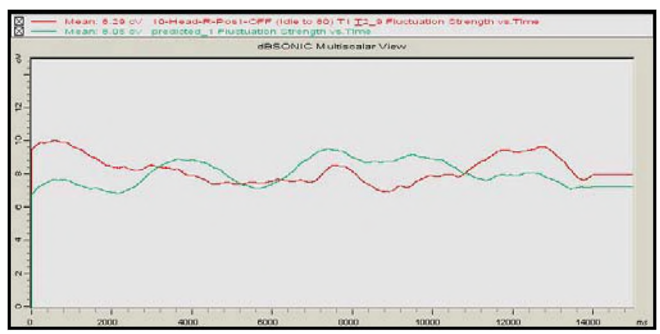

Figure 22: *Original (Red) and Predicted (Green) Fluctuation Strength for Motored Car at 60 km/hr.*

5. CONCLUSIONS

An attempt was made to establish a correlation between the noise and vibration measurements from the outside of the vehicle to the noise and psychoacoustic observations inside the vehicle. This was proven to be possible with some inherent limitations. Direct prediction of the sound quality metrics inside the vehicle from both acceleration and sound pressure observed only outside of the vehicle cabin did not show compatible results to the measured data. However, it was proven possible to predict the sound pressure for which the psychoacoustic metrics could be calculated indirectly.