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Improving the acoustic evaluation of motor cars

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ABSTRACT

In recent years sound quality has become a key issue for the Automotive Industry. As a consequence better testing procedures associated with improved analysis tools have been in constant development to enable car manufacturers to adequate their products to the customers needs. The present study represents an initiative under current development by the Federal University of Minas Gerais in cooperation with FIAT Automoveis do Brasil. The approach makes use both of the so-called engineering parameters and classical psychoacoustics parameters. Traditional psychoacoustic metrics have been associated with subjective evaluation obtained from the database of the car manufacturer. The idea is to try to establish a predictable pattern where the metrics try to predict the resulting quality to be later defined by the car owner. Some of the initial results, composed of a combination of objective and subjective assessments are presented and organised in what is hoped to be a potential improvement and contribution for the acoustic evaluation of motor cars.

INTRODUCTION

In recent years the acoustic behaviour of road vehicles has become a vital issue for the Automotive Industry [1]. As a consequence. The acoustic quality of road vehicles has remarkably improved as a result of applied research. On the other hand, car users have become more demanding, providing strong stimulation for this applied research.

At the beginning car costumers were only concerned about noise reduction both inside and outside their vehicles. Gradually, the sound quality issue has begun to appear. Nowadays cars have not only to be as quiet as possible, but also they have to produce the right kind of sound, and they have to be the comfortable environment where one is able to talk comfortably of listen to music.

The previously mentioned analysis requires a new kind of approach, as it involves not only conventional engineering measurements and physical parameter assessment but also has to take into account the subjective interpretation of the human brain. This is not an easy task but it is crucial issue in a competitive market where even smaller gains are able to define the buyer option.

At the same time, new products are coming into the market at speed which requires an improvement of the ability to quickly predict the car behaviour by means of fast tools. This coupled with the increasing demand for the use of new materials, new engines and new technologies has stressed the need for the production of more adequate In other words, this means that more adequate testing procedures associated with improved analysis tools have been in constant development to enable car manufacturers to adequate their products to the costumers needs.

These new needs have gradually introduced a new perspective into the car manufacturer paradigm, namely: the Psychoacoustics issue. In fact this are of knowledge has been in development for a while.

However there still plenty of ground to be covered as very specific demands from the car industry exist now as a result of tougher competition. The following text describes an initiative where this new challenge is being considered.

PSYCHOACOUSTICS OVERVIEW

Overview

Psychoacoustics can be described in a general way as the study of how humans perceive sound. It describes the characteristics of the human auditory system, and how sound pressure is converted by the ear to enable the brain to process and interpret this information. As such Psychoacoustics is the field of study where standard and generally exact sound wave parameters are associated with more difficult to quantify, hence subjective, parameters.

Despite the obvious difficulty in describing human perception with exact mathematical figures, very interesting and useful results have arised from the research dedicated to the study of Psychoacoustics. A generally accepted set of descriptors has been in current use for some time, and it has been increasingly more used to establish the Sound Quality for a given object of study.

Essential Metrics

The more often used descriptors which have been in use for some time, are briefly described in the following text. Additional information may be found for example in [6]. These metrics correspond exactly to what has been analysed in the present work in the objective parameter evaluation phase.

Probably, the more often used of these metrics is the *Loudness* (L), since it is together with the Sound Pressure Level (SPL) a parameter used in all the applied areas of Acoustics. The former represents a better indication of sound perception than the latter.

For some applications it can be more useful to define a *Specific Loudness Parameter (N´)* [2] which corresponds to the perception for each critical bandwidth. The specific loudness *(N´)* in *sones* can be conveniently described by Equation 1.

$$N' = 0{,}08\left(\frac{E_{TQ}}{E_0}\right)^{0{,}23}\left[\left(0{,}5 + 0{,}5\frac{E}{E_{TQ}}\right)^{0{,}23} - 1\right] \quad [1]$$

Where:
E_{TQ} is the acoustic excitation at the threshold of silence, and,
E_0 is the excitation intensity corresponding to the reference sound,
E is the excitation noise that falls within the critical band being analysed

A very useful parameter in automotive applications is the sense of *Roughness (R)*, which is closely associated to the *Fluctuation Strength (F)*. They are associated with the modulation of a sound on a very low frequency signal. The fluctuation strength is used for lower modulation frequencies and roughness is used for higher modulation frequencies. Equation 2 expresses the fluctuation strength in vacil, and,

$$F = \frac{0{,}008\int_0^{24}\Delta L(z)\,dz}{\left(\frac{f_{\text{mod}}}{4}\right) + \left(\frac{4}{f_{\text{mod}}}\right)} \quad [2]$$

Equation 3 expresses roughness in asper.

$$R = \frac{0{,}3 f_{\text{mod}}}{1000}\int_0^{24}\Delta L(z)\,dz \quad [3]$$

Where:
f_{mod}: is the modulation frequency in Hz, and,
$\Delta L(z)$ is the depth masking.

Another useful parameter is known as the *Sharpness (S)*. This metric is associated with balance between lower and higher frequencies, and it is sometimes translated as a weighed expression for loudness.

The global sharpness expressed in *acum* can be conveniently expressed by Equation 4.

$$S = c\,\frac{\int_{z=0}^{24} N'(z)\,g'(z)\,dz}{\ln\left(\frac{N + 20}{20}\right)} \quad [4]$$

And the weighing function is expressed in equation 5.

$$g'(z) = 0{,}0165\exp(0{,}171 z) \quad [5]$$

Where:
z is the critical band in Barks,
N and N' are the specific loudness and loudness in sones,
c is constant that is associate with the reference signal

Another important parameter, particularly for motor cars, is the *Articulation Index (AI)*. It provides an indication about the audibility and efficiency of speech communication. It gives an indication about how vehicle noise is able to mask the communication inside the car, for a given condition. Equation 6 provides an useful form to express this quantity.

$$AI = \sum\left[\left(N_s(f) - L(f)\right)^{P(f)}\!\big/_{30}\right] \quad [6]$$

Where:
f is the frequency in 1/3 octave bands, from 200 to 6300 Hz,
$N_s(f)$ is value of sound pressure, in dB, for each 1/3 octave band, the upper limit of the region of idealised speech,
$L(f)$ is the value of sound pressure level, in dB, of the internal noise of the vehicle, for each 1/3 octave band,
$P(f)$: is the weight corresponding to the maximum contribution to the IA, for each 1/3

These parameters have been used in the present evaluation for a given set of cars.

PSYCHOACOUSTICS IN VEHICLES

At its start Psychoacoustics in vehicles has made strong use of other general studies. As preciously mentioned, competition has meant that more specific analyses and targets have become necessary as a consequence of narrow margins of gains resulting from tougher competition.

As in any Psycoacoustics analysis, vehicle evaluation comprises a set of experiments where *objective* parameters are determined in order to produce the previously discussed metrics. At the same time, the opinion of car users has to be obtained in order to associate their feelings (the *subjective* evaluation) with the previously mentioned objective parameters [3], [4]. The customers care and support of vehicle manufactures are daily engaged in obtaining the opinion of car users. Some of this opinion is obtained by direct answer questionnaires. Also, a staff of highly trained "subjective observers" provide their evaluation during testing procedure inside the factory. Additional supporting information can be found in [5].

The initiative now being carried at Fiat in Brazil in cooperation with the Federal University of Minas Gerais is discussed in the following text.

THE PROPOSED METHODOLOGY

The basis of the procedure here proposed has a background on the standard testing being carried out daily at Fiat Automoveis S.A. In this initial phase only part of this procedure has been used to provide results which are simpler but without compromising the generality of the results.

This shortened procedure comprised essentially three testing conditions, here indicated by the symbols AV3, AL5 and CD, respectively:

1) Fast acceleration in third gear (1000 to 6000 RPM)
2) Slow acceleration in fifth gear (1000 to 6000 RPM)
3) Fast deceleration with the engine turned off (120 km/h to 40 km/h

The objective metrics which are being initially used in this initial phase of the research are still the classic psychoacoustics parameters, namely: loudness (together with sound pressure level values), roughness and fluctuation strength, sharpness and index of articulation.

The environment of the car cockpit has been monitored with the use of two microphones positioned typically: one close to drivers head, the other close to where the head of front passenger would be. The data gathering has been associate with the operational condition of the specific car, comprising forward speed, selected gear and engine rpm. Road conditions are also included as part of the observation. The results were saved and automatically recorded in a notebook to be later analysed either directly using the equations shown previously shown in this text, or employing the software ARTEMIS® .

The obtained results have been compared with subjective evaluations obtained from FIAT database. These evaluations contains a set of statistically organised data, which provide a subjective car evaluation, classifying the vehicle as being: not so good, fair and good.

During the course of a typical subjective evaluation a car driver is asked to provide his/her opinion about the vehicle which has been used under normal conditions, ranging from stand still to highway driving. A questionnaire is used for all cases, limiting the universe of answers which can be given.

For this initial set of experiments seven different cars, with different engines, and different capacity have been chosen. They are indicated in the following text by capital letters from (car) A to G.

MAIN RESULTS

The previously mentioned objective evaluation has also been organised in graphs which help to provide an insight into the observed car behaviour. Figures 1, 2, and 3 are representative of the results obtained for the changes in loudness, roughness, and sharpness for different cars.

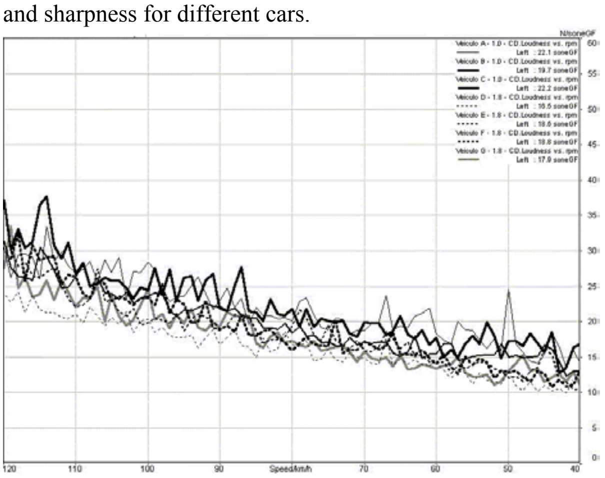

Figure 1. Loudness for condition CD

In Figure 1 loudness is shown in engine sones as a fimction of car speed. This corresponds to test procedure CD, where there is a fast deceleration, and the speed decreases from 120 km/h to 40 km/h with the engine turned off.

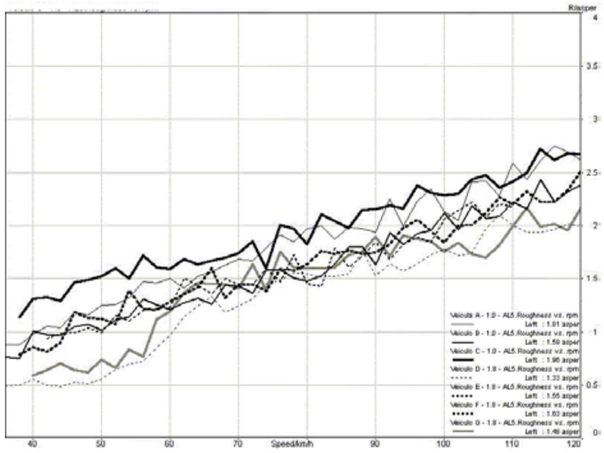

Figure 2. Sharpness for condition AL5

In Figure 2 sharpness is shown is asper as the car speed increases, from 40 km/h o 120 km/h as the engine speed varies from 1000 RPM to 6000 RPM, corresponding to condition AL5.

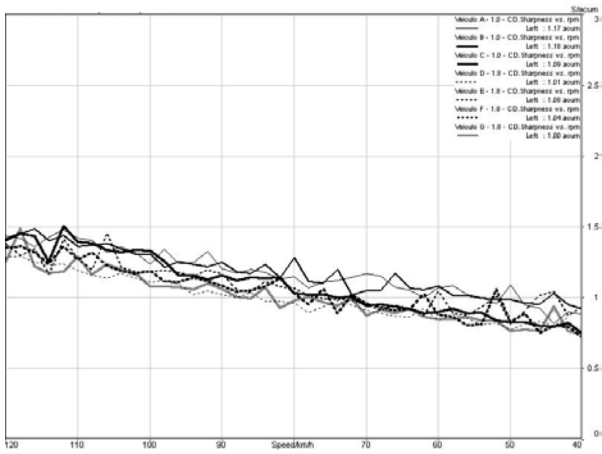

Figure 3. Sharpness for condition CD

In Figure 3 sharpness is shown in acum as a fimction of car speed. This corresponds to test procedure CD, where there is a fast deceleration, and the speed decreases from 120 km/h to 40 km/h with the engine turned off.

Combination of the complete set of results with Fiat subjective evaluation data can be conveniently represented in Figure 4.

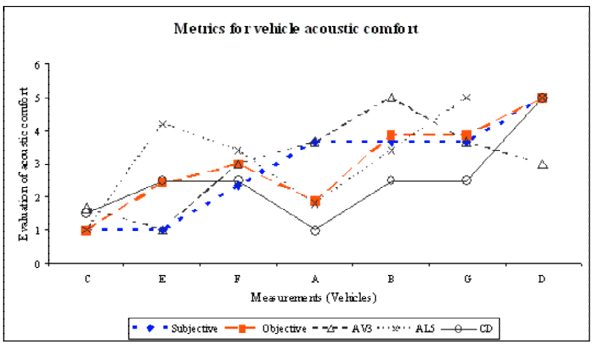

Figure 3. Combined results for all conditions

In Figure 3 the final results obtained for all the vehicles which have been analysed can be observed. Although the present research is in its initial phase a general trend may be already observed. It is possible to perceive that the results obtained from the subjective evaluation data show a pattern similar to that obtained from the normalised grading originated from the objective standard testing procedures.

CONCLUSIONS

A procedure combining phsychoacoustic and subjective evaluation of motor cars in a manufacturing environment has been presented. Even though the presented development is at its initial phase there a general trend has already emerged. The phsychoacoustic evaluation follows a trend which compares fairly well with the hierarchic rating provided by subjective evaluation.

It also seems that part of the testing procedure the so called combination of the slow acceleration with the fast deceleration provide a better description of the daily conditions for motor car use, as far as acoustic performance is considered.

The present research continues to improve the analysis and predictably of car acoustic behaviour.

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