COMPARISON OF NON-STATIONARY LOUDNESS RESULTS TO EQUAL LOUDNESS CONTOURS

Colin Novak, Jeremy Charbonneau, Helen Ule
Dept. of Mechanical Engineering, University of Windsor, 401 Sunset, Ontario, Canada, N9B 3P4

1. INTRODUCTION

The increased interest and use of sound quality metrics has led to the refinement of existing calculation techniques as well as the development of new metrics. The most fundamental psychoacoustic metric is the loudness model for stationary sounds for which over the past 30 years several internationally accepted models have been introduced and standardized including ISO 532B and the similar German DIN 45631. Another is the ANSI 3.4:2005 Glasberg and Moore based loudness metric. For the most part, these approaches have demonstrated good correlation to human perception for steady sounds. However, many sounds of interest do not fall into the category of steady state which necessitates the development of loudness calculation methods that are capable of characterizing the loudness of unsteady sounds.

More recent studies have developed alternative loudness models for use with non-stationary sounds. Given the inherent complexity of evaluating the abilities of these models to correlate to human perception for unsteady sounds, a first comparison should be done using steady sounds as an unsteady model should work equally well with such sounds. This study used a methodical and scientific approach to evaluate the performance of two such models, the proposed German DIN 45631/A1 and the Glasberg and Moore unsteady model, to accurately predict reference steady loudness values and compare these to the ISO 226 equal-loudness contours. The goal of this study was to evaluate any differences between the DIN 45631/A1 and Glasberg and Moore approaches.

2. CALCULATING NON-STATIONARY LOUDNESS

For the calculation of unsteady loudness, two relatively common methods exist. The proposed German DIN 45631/A1 method is loosely based and an extension of what is commonly referred to as the Zwicker approach. The method for calculating stationary loudness developed by Eberhart Zwicker (1) provides the foundation for the standardized loudness calculation specified in ISO 532 (1975). This was procedure was later improved at the low frequency end of the spectrum in the DIN 45631 standard for stationary noise. Eventually this standard was expanded upon and now provides the basis for the draft DIN 45631/A1 for calculating unsteady loudness.

A second approach has been developed by Moore and Glasberg (2,3) which uses a method which they called long term integration. For this method a waveform is used as the input into the transfer function of the outer and middle ear followed by the calculation of the short term spectrum via six parallel FFTs. The excitation pattern is then calculated followed by its transformation to a specific loudness pattern. Finally the area under the specific loudness pattern is determined for the overall loudness.

3. APPROACH

Both of the above described methods are very different approach but purport to achieve the same end result of outputting a value for non-stationary loudness which correlates with human perception. For this to be an accurate statement, a first test used in this study was to evaluate the non-stationary approach using stationary sounds. For this, pure tone sinusoidal signals were used as the stationary input which served to further simplify things. From this, the resulting loudness values can be compared to the equal loudness curve specified by ISO 223:2003 (4).

The method used in this study was similar to that used in a previous investigation (5). The pure tones inputs which were used in the above referenced stationary study were inserted into each of the time varying loudness models. This also gave the advantage that the resulting loudness values could be directly compared to the results of the stationary loudness investigation.

The DIN model took in the signals directly as part of the commercially available Bruel & Kjaer Sound Quality software. For the Glasberg and Moore (G&M) model, a program available on their website was used. For this, 100 dB full scale sinusoids were recorded and scaled down to match the total sound pressure levels found in the stationary loudness test (ie 1000 Hz @ 80dB was derived by scaling down the 100 dB sinusoid by subtracting 20 dB). The lower levels used a 50 dB full scale sinusoid in order to prevent the loss of important information in the scaling process.

It was then assumed that any deviations between the models could be extended back to the equal loudness contours for comparisons.

4. RESULTS

Given in Figure 1 are the differences in loudness of the DIN unsteady results compared to the DIN steady calculation for the steady pure tone inputs across the frequency and level range. Also given is the same only for the G&M (indicated as the ANSI TVL Model) unsteady approach compared to the comparable ANSI S3.4:2007 steady method. For a perfect match, the resulting "difference" lines would be straight and horizontal.

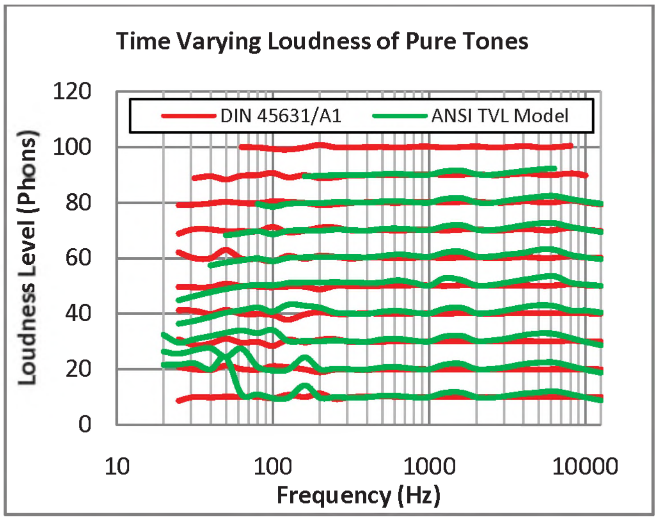

Figure 1: Loudness Difference between DIN (red) and G&M (green) Unsteady and Steady calculations for Pure Tone Input Signals.

Inspection of Figure 1 shows good correlation for both unsteady models when compared to their respective steady models at frequencies above 100 Hz with the DIN being moderately better.

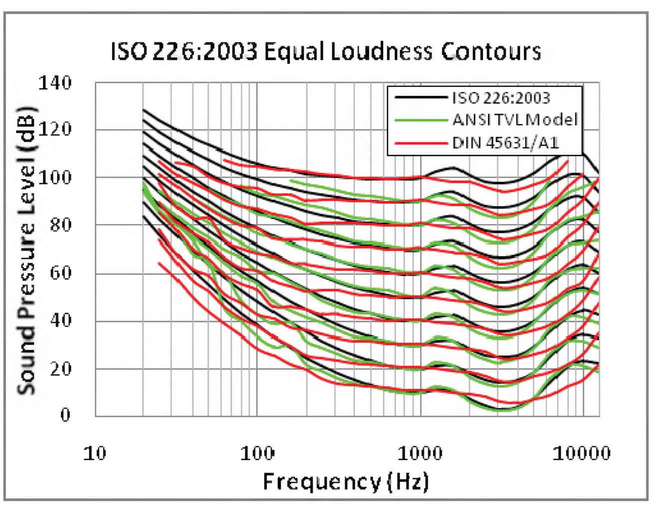

Figure 2: DIN and G&M unsteady Loudness plotted against the ISO 226:2003 Equal Loudness Curves.

Illustrated in Figure 2 are the calculated DIN 45631/A1 and Glasberg & Moore unsteady loudness results plotted against the ISO 332:2003 equal loudness curves. While the purpose of Figure 1 was to illustrate how well the unsteady calculations of steady tones correlated with the steady calculation methods, the results shown in Figure 2 provides insight on how well the unsteady results compare to standardized human perception.

Again, it can be seen in Figure 2 that good correlation between both methods and the equal loudness contours is realized. Both models performed less ideally below 100 Hz, particularly at lower levels. It should also be noted that the G&M model followed the equal loudness curves in the 1 kHz to 5 kHz range. This is particularly important as this is a very import frequency range for sound quality analysis. It is due to this that one may conclude that the G&M approach would be better for cases where human perception is important, as usually is the case for psychoacoustic studies.

5. CONCLUSSION

This study set out to evaluate the performance of two models for the calculation of loudness for non-stationary sounds. These models were the proposed German DIN 45631/A1 and the Glasberg and Moore unsteady model. The results of these models were compared to the results using the same input signals into the respective stationary calculation models as well as to the ISO 226:2003 equal-loudness contours. The goal was to quantitatively evaluate any differences between the two approaches. Using a signal generator, a full spectrum of pure tone input signals were fed into each of the loudness models over a large range of sound pressure levels. Using this input matrix, plots were presented to facilitate the comparison. On a common plot, minor discrepancies to the equal-loudness contours are identified with the Glasberg and Moore model showing slightly better performance in some frequency ranges. Both models did not perform well at frequencies below 100 Hz.

6. REFERENCES

1. Zwicker, E., Erratum: "Procedure for calculating loudness of temporally variable sounds". *Journal of the Acoustical Society of America*, 63(1), 283.
2. Moore, B. (2003). Temporal integration and context effects in hearing. *Journal of Phonetics*, 31, 563-574.
3. Glasberg, B., Moore, B., (2002). A model of loudness applicable to time-varying sounds. *Journal of the Audio Engineering Society*, 50(5), 331-342.
4. ISO226:2003. "Acoustics -- Normal equal-loudness-level contours," Stage: 90.93 (2008-12-22), *International Organization for Standardization*, Standard, Geneva, Switzerland. (2008).
5. Charbonneau, J., Novak, C., Ule, H., (2009). Comparison of Loudness Calculation Procedure Results to Equal Loudness Contours. Inter-Noise 2009.