LOUDNESS PREDICTION MODEL COMPARISON USING THE EQUAL LOUDNESS CONTOURS

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1. INTRODUCTION

With the increase in demand for customer satisfaction, psychoacoustic metrics are playing a larger role in product development. For instance, the loudness level of a particular device could greatly influence a potential buyer's decision. Loudness can be described as the perceived intensity level of a noise source as compared to a reference level. Once calculated, the application of loudness can be broadened to calculate a variety of other perception models including roughness, annoyance and modulation. By understanding how these different characteristics of sound effect human perception, it is possible to apply the findings to a variety of related fields such as product health and safety.

When describing loudness levels, the ISO 226 standard for equal loudness contours is one of the most descriptive and well documented resources available. Updated in 2003, this standardized document represents a collaborative study describing the strong and weak points of loudness recognition in human hearing.[1] A plot of frequency versus sound pressure level indicates pure tones varying in amplitude and frequency as being equally loud across the hearing spectrum. Since the initial ISO 226 document produced in 1961 several loudness models have appeared to predict the loudness level of stationary noise sources.

This paper focuses on two of the few standardized methods for calculating steady-state loudness that are available. The first is a German standard, DIN 45631, based on an approach developed by Zwicker. The second metric studied is the American ANSI S3.4:2005 standard based on the work of Glasberg and Moore.[2-3] The ISO 532B method for predicting loudness was also included in the initial investigation. However, due to the poor performance of the model it was neglected from this paper due to space restrictions.

The German organization Deutsches Institut für Normung (DIN) adopted a stationary loudness metric commonly referred to as the Modified Zwicker Method. Originally based on the 1975 ISO 532B document, the DIN 45631 approach calculates the loudness levels in a similar manner with minor modifications to the procedure. As an English version of this German document was not available at the time of the study, specific differences were not able to be identified by the authors of this study. It is known, however, that this modified version does improve upon the loudness level calculations for the lower frequency ranges; a problematic area in the original ISO 532B document.

The second commonly used loudness metric is an American standard which has origins to work produced by S.S. Stevens. The ANSI S3.4:2007 standard was recently updated to better approximate human perception and is the only known model to match and account for the latest updates made to the ISO equal loudness contour document.

2. PROCEDURE

To compare the models under investigation, the ISO 226:2003 equal loudness curves were selected as reference values. This set of contours was selected due to their distinctive shapes across the frequency spectrum and general acceptance within the scientific community. As the equations contained within the ISO 226 document allow a high resolution plot to be generated, a comparison set of data was produced with each 3rd octave from 20 Hz to 12.5 kHz in the frequency spectrum. Equal loudness contour lines were then located from 20 to 90 phons representing the applicable range of the standard. To locate the respective curves of equal loudness pure tones could now be recorded and analyzed for each prediction model.

Loudness levels using the German standard DIN 45631 were determined directly using the commercially available Brüel & Kjær PULSE LabShop software. To control the signal quality, pure tones were generated using a B&K 3560 B-Frame and fed back directly into an input channel on the acquisition system. The raw data was recorded this way in order to minimize any external influences which might affect the quality of the signal and results. Pure tones were then generated by varying the voltage output at each center frequency until the target loudness level could be located, recorded and saved.

A standalone executable file from the University of Cambridge Auditory Perception website was used to derive the ANSI S3.4:2007 contours.[4] The program named LOUD2006a accompanies the standard and was updated to correspond to the 2003 revisions to the ISO 226 contours. Within the program itself, pure binaural tones can be specified at any sound pressure level within the range of human perception. The program then takes into account the recording method specified (free field, binaural, ect.), and reports back the corresponding loudness level. For the application used in this study, data was collected for in-harmonic tones recorded binaurally over the frequency spectrum using a free field application. Using this procedure the corresponding equal loudness contours were located and plotted as the DIN standard.

3. ANALYSIS

Once the equal loudness contours were located for each of the loudness models under study, a thorough comparison of the models could be completed between them with reference to the ISO 226 contours. As the ISO standard only applies between 20 phons and 90 phons, other contours were extrapolated using the given equations to help with the comparisons (dotted lines). In order to graphically show the differences, each model will be compared separately as follows.

As shown in **Figure 1**, the DIN 45631 tends to follow the reference curves quite well, particularly in the mid frequency ranges. However, both the lower end and higher end frequencies drop off when compared to the current ISO 226 standard. This result was expected as when this model was accepted, the current equal loudness contours were developed in 1987, having a much shallower slope. At the time, the DIN 45631 standard performed exceptionally, matching the equal loudness contours almost entirely. Due to space restrictions this plot was not included.

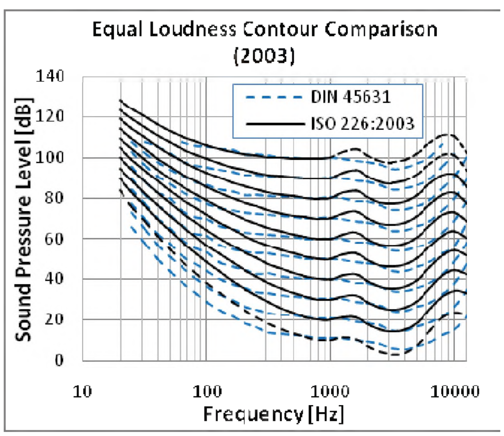

Figure 1: DIN 45631 Equal Loudness Contours compared to ISO 226:2003

As the ANSI S3.4:2007 model was updated to the recent changes of the ISO document, the contours tend to follow the reference curves more consistently. As seen in **Figure 2**, the ANSI S3.4:2007 was able to follow the trends of the present standard with minimal drop-offs. Above 1 kHz, the contours drop slightly but still reasonably follow the characteristics of the ISO 226:2003 standardized curves. As with the DIN standard, this model is unable to completely describe the hump in the curves between 1000 Hz and 2000 Hz. A reason for this may be that this particular characteristic was not as exaggerated in the 1987 version of the contours. Like the DIN method, this standard was initially fit to the equal loudness contours of ISO 226:1987. When compared to the older contours, the upper frequencies for the ANSI standard match well to the standardized curves, particularly below 80 phons. Although the higher frequencies are slightly shifted from the ISO 226:2003 curves, the ANSI derived equal loudness contours overall perform the best out of the two calculation procedures.

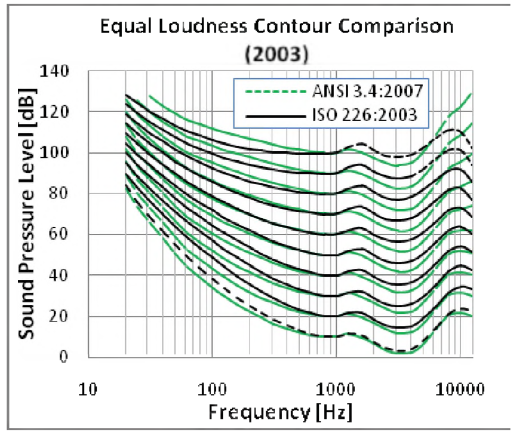

Figure 2: ANSI S3.4:2007 equal loudness contours compared against ISO 226:2003

4. CONCLUSION

For each of the stationary loudness metrics under study, equal loudness contours were produced and compared thoroughly. Each model was compared against the set of reference contours as described in the ISO 226:2003 document. From this comparison, it was apparent that the ANSI S3.4:2007 stationary loudness prediction model correlated the best with the updated ISO experimental data, outperforming the other models in all areas across the applicable frequency spectrum. As the ANSI best approximates the reference contours, it would therefore be recommended for use when determining the loudness of stationary noise sources. The DIN 45631 model for predicting loudness does an accurate job of estimating the older, obsolete equal loudness contours of ISO 226:1987. However, based on the updated data this model should not be used for very high frequency tones.

5. REFERENCES

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