



Customer Actuated Sound Vehicle Level Evaluation Procedure

1 Introduction

Note: Nothing in this standard supercedes applicable laws and regulations.

Note: In the event of conflict between the English and domestic language, the English language shall take precedence.

1.1 Purpose. To provide a common procedure for recording the sounds of subsystems (that can be directly actuated by the customer, i.e., Customer Actuated Sounds (CAS)) for analysis for sound quality evaluation using measuring microphones.

1.2 Applicability. Any subsystem or component that is installed on vehicles and can be directly actuated by the customer.

1.3 Remarks. The sounds of subsystems must be recorded to apply the objective methods for Sound Quality Metric evaluation. Many subsystems have multiple modes of operation. Each mode of operation must be recorded independently for evaluation and comparison. This procedure is intended to describe the operating conditions of the subsystems, the recording methods to be used and the various analysis methods that may be applied to the recordings for the objective Sound Quality Metric evaluations. Not all the analysis methods described in this procedure need to be applied to the sounds of every subsystem. The requirements for the individual subsystems will identify which methods are to be used.

2 References

Note: Only the latest approved standards are applicable unless otherwise specified.

2.1 External Standards/Specifications.

DIN 45631

2.2 GM Standards/Specifications.

None

2.3 Additional References.

2.3.1 Hardware and software operation manuals of analyzer/sound quality system and supporting equipment.

2.3.2 Percentile Frequency Method and Zwicker Loudness, R.J. Fridrich, Proceedings of the 2002 International Congress on Noise Control Engineering, August 2002.

2.3.3 Pitch Intervals: Linking Sound Quality Engineering and Musical Acoustics, R.J. Fridrich, Proceedings of the 2003 SAE Noise and Vibration Conference, May 2003.

2.3.4 Psychoacoustics, Facts and Models, Zwicker, E. and Fastl, H., Springer-Verlag, 1990.

2.3.5 Component Technical Specification (CTS).

2.3.6 Subsystem Technical Specification (SSTS).

2.3.7 Debron Industrial Electronics, Inc. products available at www.debron-electronics.com/products.html.

2.3.8 ArtemiS SUITE software solution available at www.head-acoustics.de/eng/nvh_artemis_suite.htm.

3 Resources

3.1 Facilities. Test Area: Hemi-anechoic room or outdoor test area free from interfering noises. Unless otherwise specified, the maximum Zwicker specific loudness of the background noise is not to exceed 0.2 sones/bark from 0 bark to 5 bark and 0.1 sones/bark at any frequency greater than 5 bark and the overall Zwicker loudness is

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August 2016

Page 1 of 28



Documents

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not to exceed 1.2 soneGF. Background noise is considered to include room or test cell ambient noise and room support equipment noise.

3.1.1 Calibration. The test facilities and equipment shall be in good working order and shall have a valid calibration label.

3.1.2 Alternatives. Alternative test facilities and equipment may also be used. However, all measuring variables as specified in this standard shall be determined correctly with respect to their physical definition.

3.2 Equipment.

3.2.1 Hardware.

3.2.1.1 Free field measurement microphone (12.7 mm diameter).

3.2.1.2 Microphone Preamplifier and connecting cables.

3.2.1.3 Microphone Power Supply (if the function is not already provided by the Digital Sound Recording System).

3.2.1.4 Microphone Stands (floor stand and seat stand or equivalent method for supporting the microphone).

3.2.1.5 Sound Level Calibrator.

3.2.1.6 Record with at least 16-bit quantization at a sample rate of 48 kHz.

3.2.1.7 Door Velocity Meter (as needed for closure systems).

3.2.1.8 Digital Voltmeter (as needed for electrically powered systems).

3.2.1.9 DC Power Supply (as needed for electrically powered systems).

3.2.1.10 PC Computer system (capable of running the sound quality analysis software).

3.2.2 Software.

3.2.2.1 Sound Recorder data acquisition program by Head Acoustics or an equivalent sound recording program.

3.2.2.2 ArtemiS sound quality analysis program by Head Acoustics or an equivalent analysis program.

3.3 Test Vehicle/Test Piece. A vehicle having the subsystem under test correctly installed.

3.4 Test Time.

Calendar time: 1 to 2 days

Test time: 8 to 16 hours

Coordination time: 4 to 8 hours

3.5 Test Required Information. Not applicable.

3.6 Personnel/Skills. One (1) technician or engineer with training in performing sound analysis, and with an understanding of the Zwicker Loudness Method and sound quality methods such as the Percentile Frequency method and the Relative Pitch evaluation method.

4 Procedure

4.1 Preparation.

4.1.1 Vehicle Setup.

4.1.1.1 Fill the fuel tank.

4.1.1.2 Allow the vehicle to acclimate to the environmental conditions in test cell or garage area for an appropriate time to allow the vehicle systems to reach test room temperature before the test.

4.1.1.3 Remove all loose items from the interior of the vehicle.

4.1.1.4 Eliminate or reduce sounds not associated with component or system being tested as feasible (i.e., exhaust heat shield rattle during door close). Note any modifications required.

4.1.2 Measurement Microphone Setup.

4.1.2.1 Microphone Positioning for Recording Sounds Inside the Vehicle.

4.1.2.1.1 Position the microphone horizontally and pointing toward the front of the vehicle for all interior measurements.

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August 2016

Page 2 of 28



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4.1.2.1.2 Position the microphone in the seat adjacent to the system being recorded except as follows:

4.1.2.1.2.1 For the glovebox door as well as all systems located on the centerline of vehicle (e.g., consoles and sunroofs), position the microphone in the driver seat.

4.1.2.1.2.2 See Appendix E, Figure E1 for microphone positioning coordinates and further information for the measurement microphone inside the vehicle.

4.1.2.2 Microphone Positioning for Recording Sounds Outside the Vehicle.

4.1.2.2.1 Position the microphone 1.6 m from the floor of the room for all exterior sound recordings.

4.1.2.2.2 Position the microphone so that it is pointing at the latch of the closure (in the closed position) being tested.

4.1.2.2.3 See Appendix F, Figure F1 for microphone positioning coordinates and further information for the measurement microphone outside the vehicle.

4.1.3 Position on Adjustable Seats (as needed). Refer to Appendix G for seat positioning information.

4.1.4 Position of Velocity Meter (as needed). Refer to Appendix H for velocity meter positioning information.

4.2 Conditions.

4.2.1 Environmental Conditions. Not applicable.

4.2.2 Test Conditions. Deviations from the requirements of this standard shall have been agreed upon. Such requirements shall be specified on component drawings, test certificates, reports, etc.

4.3 Instructions.

4.3.1 Sound Acquisition.

4.3.1.1 Verify calibration of the microphone, power supply and digital recording system using the Sound Level Calibrator and suitable initial equipment settings. Document the equipment settings and transducer sensitivities. For details concerning calibration, refer to the hardware and software operation manuals of the equipment being used.

4.3.1.2 Set the controls of the Digital Recording system to smallest range that allows all of the sounds for a particular operating condition to be recorded without overloading.

4.3.1.3 Perform the following tasks to record the sound of the subsystem under test while it is being operated according to the parameters outlined in the appropriate Appendix; (Appendix A for Exterior Swing Closures, Appendix B for Small Interior Closures, Appendix C for Power Operated Interior Components and Appendix D for Horizontal Exterior Sliding Closures).

4.3.1.3.1 Begin the data acquisition sequence by placing the digital recording system in its recording mode. Without pausing, record 2 s to 5 s of "quiet" before operating the subsystem. Record the sound of the subsystem in its mode of operation over its complete range. Monitor the recording system levels for overload conditions. The recording is invalid if an overload condition occurs while the subsystem is being operated. Without pausing, record 2 s to 5 s of "quiet" after operating the sound of the subsystem and then take the digital recording system out of its recording mode. For power-operated systems controlled using switches, wait at least 2 s before releasing the switch to allow the switch noise to be distinguishable from the operating sound of the system.

4.3.1.3.2 Repeat the preceding data acquisition sequence as needed for all other operating modes of the subsystem.

4.3.1.3.3 During the recording session, record an appropriate length of ambient background noise in the test facility to permit verification of the requirements of the test facility.

4.3.1.3.4 After the complete series of valid recordings have been made, check the calibration of the microphone, power supply and digital recording system using the Sound Level Calibrator and the initial calibration equipment settings. The calibrated level must not have changed more than ± 0.5 dB.

4.3.2 Sound Analysis.

4.3.2.1 Loudness Setup.

4.3.2.1.1 Follow the appropriate following section(s) to analyze the recorded sounds of the subsystem. When using any of the analyses based on Zwicker Loudness, the analysis parameters are to be set follows:

4.3.2.1.1.1 Calculation Method. Calculate loudness using DIN 45631.

4.3.2.1.1.2 Soundfield. Choose Free Field for all evaluations including the background noise in the facility.

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August 2016

Page 3 of 28



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4.3.2.1.1.3 Scale. Choose the sones scale.

4.3.2.1.1.4 Frequency Scaling. If it is selectable, choose the method that displays the frequency data in the Bark scale with a minimum resolution $\frac{1}{8}$ Bark. (The resolution in ArtemiS is fixed at $\frac{1}{10}$ Bark.)

4.3.2.1.1.5 Filter Order. If the system allows a choice, as in the case of ArtemiS, choose the 6th order filter method.

4.3.2.1.1.6 Sound files intended for analysis using Zwicker Loudness must allow a minimum of 0.2 s of quiet before the sound of the event being analyzed. If the sound event is an impulse the length of the sound file must be at least 1 s. The 0.2 s of quiet before the event will allow the Zwicker Loudness analysis to stabilize at the background noise level to ensure that the beginning of the sound event is properly analyzed. When the desired sound event has been selected using the mark editor in ArtemiS, it is recommended to save the selected sound event as a separate file before performing the analysis.

4.3.2.2 Steady State Loudness.

4.3.2.2.1 Recall the files containing the subsystem sound of the individual subsystem operations.

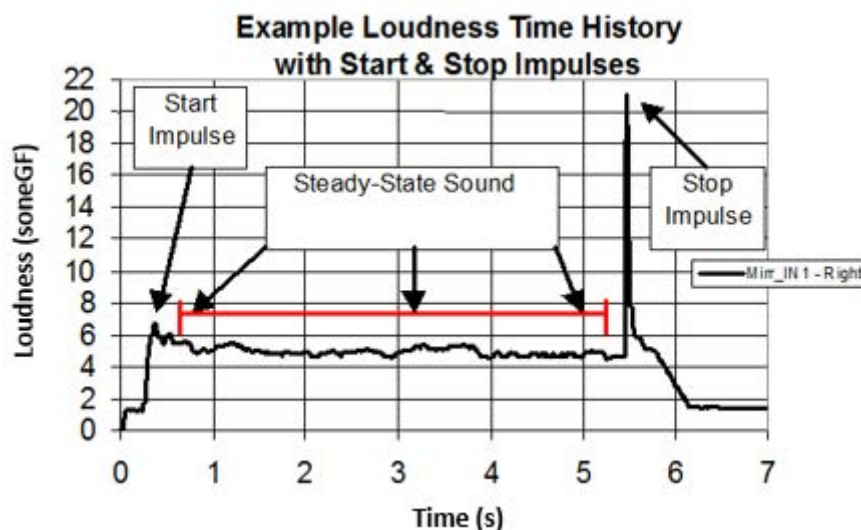
4.3.2.2.2 Display the Zwicker Loudness time history (Figure 1). Store the Zwicker Loudness time history data in a MS-Excel spreadsheet if the analysis program cannot determine the average Loudness in the method described in the following.

4.3.2.2.2.1 Identify on the Zwicker Loudness time history the beginning and end of the time interval containing the steady-state sound of the individual subsystem operation. Be sure to exclude any impulsive sounds that may have occurred at the start and stop of the subsystem operation.

4.3.2.2.2.2 Determine the average loudness that occurred during the steady-state sound by calculating the arithmetic average of the Zwicker Loudness time history data. If the analyzer or sound quality software cannot determine the arithmetic average, export the loudness time history to MS-Excel and perform the statistical calculations described in the following section(s).

Note: DO NOT determine an average spectrum and then from the average spectrum determine a Zwicker Loudness value. The result obtained from an average spectrum (i.e., energy averaging) often is not the same as the result from averaging arithmetically the individual loudness values of the time history.

Figure 1: Example of Loudness Time History with Start Impulse, Stop Impulse and Steady-State Travel Identified



4.3.2.2.2.3 Repeat the preceding analysis from the beginning of 4.3.2.1 for all the subsystem data files as needed to obtain the number of statistical samples required by the requirement.

4.3.2.3 Impulsive Loudness.

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August 2016

Page 4 of 28



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4.3.2.3.1 Recall the files containing the subsystem sound of the individual subsystem operations.

4.3.2.3.2 Impulsive Overall Loudness.

4.3.2.3.2.1 Display the Zwicker Loudness time history. Export the Zwicker Loudness time history data to MS-Excel.

4.3.2.3.2.2 If the sound from the subsystem contains impulsive start and stop sounds with a steady-state portion in between, identify on the Zwicker Loudness time history the beginning and end of the time intervals containing the start sound and the stop sound.

4.3.2.3.2.3 Exclude from any calculations, the steady-state sound that occurred during the subsystem operation (Figure 1).

4.3.2.3.2.4 Maximum Loudness Determination. Determine the maximum loudness of each impulse that occurred during the subsystem mode of operation. If the maximum loudness is not easily obtained using the analyzer or sound quality software, use the data exported to MS-Excel to determine the maximum loudness that occurred during the impulsive sound for each mode of operation. Record the values in a table of results (e.g., for a power window system, the values of maximum loudness of start and stop impulses are determined individually for both the up and down modes).

4.3.2.4 Steady-State Frequency Content (Specific Loudness).

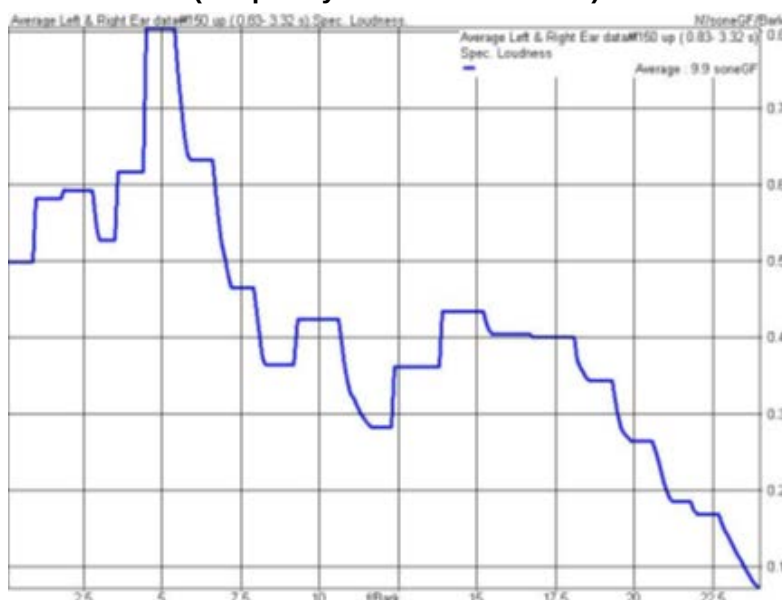
4.3.2.4.1 The purpose of the Zwicker Specific Loudness Spectrum Analysis (specific loudness) is to provide a spectral (frequency specific) view of the loudness of the event that is being evaluated.

4.3.2.4.2 Recall the files containing the subsystem sound of the individual subsystem operations.

4.3.2.4.3 Identify the beginning and end of the time interval containing the steady-state sound of the individual subsystem operation. Be sure to exclude any impulsive sounds that may have occurred at the start and stop of the subsystem operation. (Figure 1).

4.3.2.4.4 Determine the Zwicker Loudness spectrum (specific loudness) the steady-state sound. See Figure 2 for an example of the Zwicker Specific Loudness spectrum (averaged over time interval of the steady-state sound).

**Figure 2: Example of Zwicker Specific Loudness Spectrum
(Frequency Axis Scaled in Bark)**



4.3.2.4.5 In Figure 3, the same analysis is presented but instead, frequency in hertz (Hz) was selected as the x-axis. Caution: The main premise of Zwicker's method is that the area under the curve of a Specific Loudness Pattern as presented in Figure 2 is proportional to the overall loudness. This premise holds true as long as the

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August 2016

Page 5 of 28

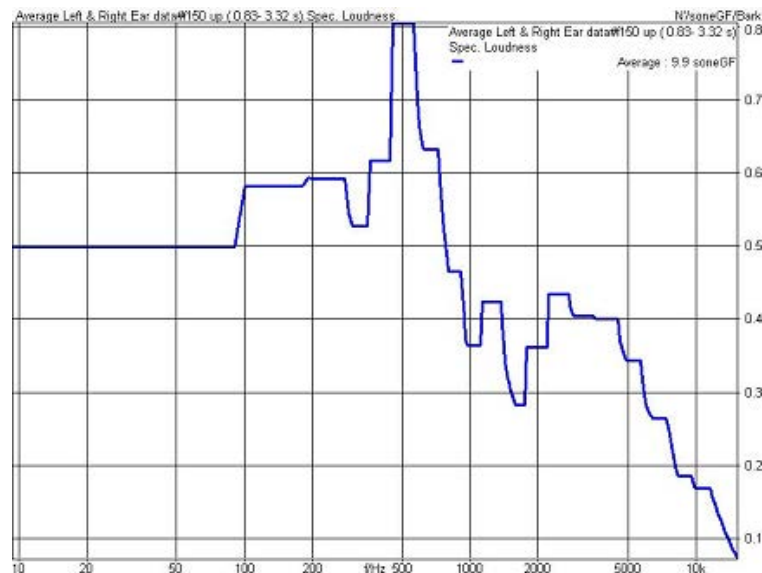


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Specific Loudness data are graphed linearly in critical bands (Bark) as in Figure 2. The premise is not true when the data are graphed logarithmically in frequency (Hz) as in Figure 3. Therefore, Figure 3 should only be used only as a means of referencing a feature in the data to frequency (Hz). Figure 3 must not be used to judge the relative contribution of the data to the overall loudness.

**Figure 3: Example Zwicker Specific Loudness Spectrum
(Caution: Frequency Axis Scaled in Hertz (Hz))**



4.3.2.4.6 Repeat the preceding analysis from the beginning of 4.3.2.4 for all the subsystem data files as needed to obtain the number of statistical samples required by the requirement.

4.3.2.5 Steady-State Relative Pitch.

4.3.2.5.1 This analysis is necessary when the pitch of the sound is changing as a function of time. The intent of the analysis is to extract information on the variation in time of a single tonal component that can be viewed in a color spectrogram (Figure 4). Two (2) possible methods for generating a color spectrogram are Power Spectral Density (PSD) vs. Time and the Hearing Model (a Head Acoustics proprietary method developed by Dr. Sottek).

4.3.2.5.2 Suggested starting parameters (in ArtemiS) for generating the color spectrogram using the PSD vs. time (Fast Fourier Transform (FFT) vs. Time) analysis are; 4096 points, Hanning window and 50% overlap to yield a frequency resolution of approximately 11 Hz per FFT line. For finer frequency resolution (at the expense of time resolution), increase the number of points (e.g., 8192 points yields a frequency resolution approximate 5.4 Hz but at half the time resolution). For finer time resolution, increase the overlap to 70%. An option when using ArtemiS is to use the Hearing Model, spectrum vs. time analysis, to generate the color spectrogram.

4.3.2.5.3 Users of this analysis method should listen to the sound while viewing the color spectrogram to decide if the selected analysis parameters are adequate for resolving the audible tones both in frequency and in time.

4.3.2.5.4 An example of a PSD vs. Time analysis is given in Figure 4 (spectrogram). The Hearing Model can also generate a spectrogram that looks similar to Figure 4. Note the curvature of the horizontal lines (tonal components) in the spectrogram. This results from the fact that this electric motor driven system slowed down in the middle of its travel. The horizontal axis is the time domain – time change is represented left to right, the vertical axis is the frequency domain; low frequencies lower on the axis and high frequencies higher on the axis, and color represents the level according to the scale provided.

4.3.2.5.5 Adjust the color scale of the spectrogram to highlight the tones in the sound.

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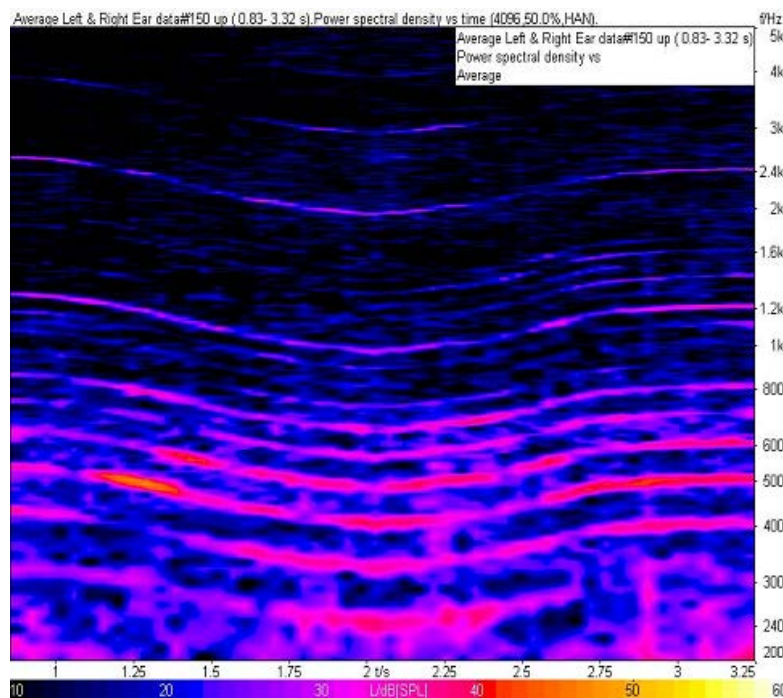
Page 6 of 28



Documents

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Figure 4: Example of PSD vs. Time Analysis (Color Spectrum)



4.3.2.5.6 Identify a dominant tone that exists for the entire duration of the event.

Note: Selecting a tone from the higher frequency region will produce better resolution in the Relative Pitch evaluation than selecting a tone at low frequencies.

4.3.2.5.7 Adjust the vertical frequency scale on the color spectrogram to narrow the displayed frequency range of the selected tone.

4.3.2.5.8 The frequency and time coordinates of the tonal component can be obtained by using a cursor on the color spectrogram to pick frequency and time coordinates that correspond with significant changes in frequency. If there are regions without significant changes in frequency, pick frequency and time coordinates at approximately the same sampling interval as used for regions with significant changes in frequency. Alternatively, the tonal component can be obtained from the PSD vs. time results by calculation methods after exporting to MS-Excel.

4.3.2.5.9 Repeat the preceding analysis from the beginning of 4.3.2.5 for all the subsystem data files as needed to obtain the number of statistical samples required by the requirement.

4.3.2.6 Impulsive Frequency Content.

4.3.2.6.1 This analysis is based on Zwicker Loudness (Specific Loudness vs. Time). Set the analysis parameters as defined in 4.3.2.1.

4.3.2.6.2 In addition to the parameters defined in 4.3.2.1, set (if the parameter is selectable) the Multispectrum (waterfall) parameter for the time-interval-between-spectra to a value between 0.001 s and 0.005 s. Due to the short duration of impulsive sounds, the smallest practical value for the time-interval-between-spectra is preferred. In ArtemiS because this parameter is not directly selectable, it is essential that the sound file be edited to a length of 1.0 s as described in 4.3.2.1.1.6 time so as to produce a time interval of about 0.003 s.

Note: The smallest time interval that ArtemiS seems to be able to produce is approximately 0.00260 s.

4.3.2.6.3 Recall the files containing the sound of the individual subsystem operations using the sound quality analysis program.

4.3.2.6.4 Perform the Specific Loudness vs. Time analysis and export the results to a MS-Excel file.

4.3.2.6.5 For each time data point calculate the value of 70% of the total loudness. Locate the frequency value closest to the 70% loudness value and note this value (70% Frequency Value). Continue finding the 70%

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August 2016

Page 7 of 28

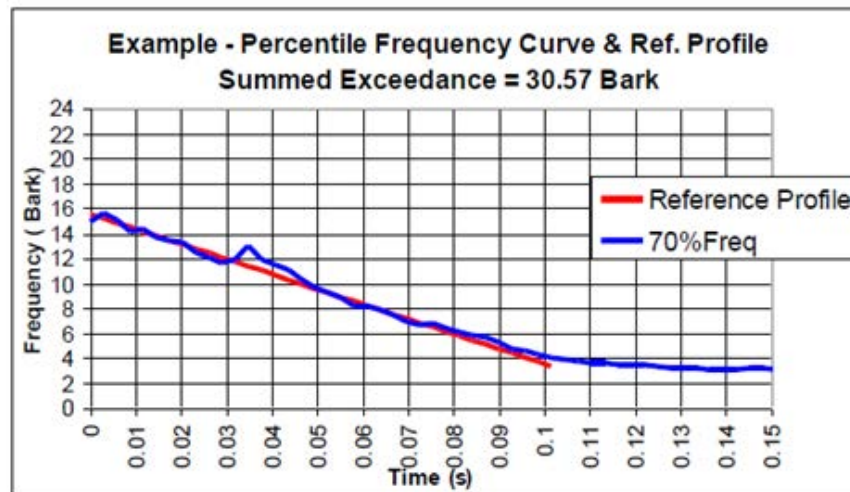


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Frequency Value for all time data up to 0.15 s. Evaluate each time data point 70% Frequency Value to the 70th Percentile Reference Line. If the 70% Frequency Value is greater than the 70th Percentile Reference Line value then subtract the 70th Percentile Reference Line value from the 70% Frequency Value. Sum all of these values together. Multiply this value by 10 to generate a larger value that aids in the interpretation of the data. This is called the 70th Percentile Summed Exceedance value. See Figure 5.

Figure 5: Example Graph of 70th Percentile Frequency Curve and Example Reference Profile Line



Note: Freq = Frequency, Ref. = Reference.

5 Data

5.1 Calculations.

5.1.1 Average Steady-State Loudness.

5.1.1.1 If the average loudness has not been obtained using the analyzer or sound quality software, use the data exported to MS-Excel to determine the arithmetic average loudness that occurred during the steady-state sound for each mode of operation. Also determine the slope and intercept of the Zwicker Loudness time history the steady-state sound using MS-Excel functions.

5.1.1.2 If the subsystem had multiple modes of operation, determine the Overall Average of the different modes of operation and the Spread between the loudest and the quietest mode of operation.

5.1.2 Warble (During Steady-State Sound).

5.1.2.1 If there appears in the display of the Zwicker Loudness time history a repetitive fluctuation similar to that shown in Figure 6 (e.g., between 1.5 s and 3.5 s) or Figure 7 (e.g., between 0.5 s and 3.5 s), there is most likely a warble in loudness at a rate between about 1 Hz and 10 Hz.

5.1.2.2 Estimate the frequency of the fluctuation by measuring the period of the fluctuation. (i.e., Frequency = 1/(Period)) (Acceptable resolution of the frequency estimation is approximately 0.5 Hz).

5.1.2.3 Determine the difference between consecutive maximum and minimum values for each period of fluctuation (Figure 6). Calculate the percentage difference compared to the minimum Zwicker Loudness value for each pair of values. Report the largest percentage difference measured.

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August 2016

Page 8 of 28



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Figure 6: Example Loudness Time History of a Power Subsystem with Warble (Approximately 2 Hz)

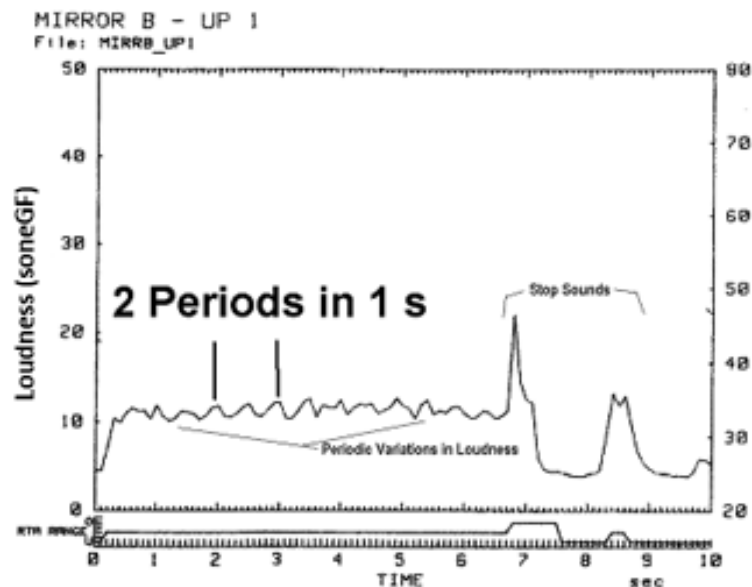
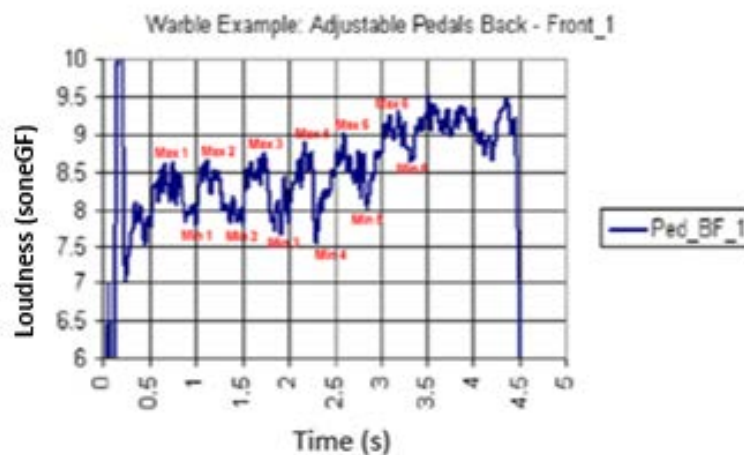


Figure 7: Example Loudness Time History of a Power Subsystem with Warble (Consecutive Maximums and Minimums Identified)



5.1.3 Impulsive Loudness. If the maximum loudness is not easily obtained using the analyzer or sound quality software, use the data exported to MS-Excel and the MAX function to determine the maximum loudness that occurred during the impulsive sound for each mode of operation.

5.1.4 Steady-State Frequency Content. The Zwicker Specific Loudness Spectrum is used to evaluate the average frequency content of the steady-state sound. Determine the summed exceedance of the specific loudness spectrum by calculating the area between the data and the requirement limit line where the data exceeds the requirement limit line. Multiply this value by 100 to get the “Specific Loudness Summed Exceedance” value. The multiplier is used to provide a larger value to aid in the interpretation of the data.

5.1.5 Relative Pitch Evaluation.

5.1.5.1 Identify the beginning and end of the subsystem “steady-state” operation by excluding any start and stop transients (Figure 8).

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