



Electric Power Steering - Zipper Noise Evaluation Procedure for Steering Wheel Inputs in Vehicle

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. Acquire and evaluate Electric Power Steering (EPS) zipper noise present during various velocity steering wheel inputs at zero (0) vehicle speed. Test procedure is designed to reproduce consistently the worst case operating condition for zipper noise hence the reason for evaluation at zero (0) vehicle speed. Dynamic parking lot maneuvers may be performed, but this procedure does not correct for changing back ground noises like road noise.

1.2 Applicability. All vehicles with full electric power steering systems (non-hydraulic). Component bench test data obtained per GMW17112.

1.3 Remarks. This procedure describes test setup, data acquisition and analysis of EPS zipper noise. Zipper Noise is typically caused by the electric motor rotor poles and stator teeth causing multiple orders. Zipper noise can also result from gear meshing frequencies or ball screw running noises. See Appendix B for more information on Zipper Noise. Appendix B, Figure B1 shows an acoustic noise color map example.

2 References

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

2.1 External Standards/Specifications.

None

2.2 GM Standards/Specifications.

GMW15927 GMW17112

2.3 Additional References.

- ArtemiS suite - HEAD acoustics, available from www.head-acoustics.de/eng/nvh_artemis_suite.htm.
- The 3M Company, 3M Corporate Headquarters, Maplewood, Minnesota, USA.
- Vehicle Technical Specification (VTS), Electric Power Steering, paragraph 3.2.1.3.8.5.7.e.

3 Resources

3.1 Facilities. Dry, clean, smooth, level asphalt or concrete surface typical of a paved parking lot or use 3M "safety-walk" Series 600 anti-slip material (or equivalent), size: 50 cm × 50 cm (2 in × 2 in) per front wheel, positioned under the front wheels. The test surface may be located inside a hemi-anechoic measurement facility, or outside (e.g., an actual parking lot).

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. Data acquisition system (DAS) consists of a Sound Pressure Recording system with a valid, current calibration label or certificate. Also, reference GMW15927 for Binaural Data Acquisition Master Test Procedure. A quiet spinner knob must be attached to the top center of the steering wheel to assist in reaching

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January 2016

Page 1 of 12

the maximum steering wheel velocity during the test and to avoid hand slip noises on wheel while turning. Either Vehicle Controller Area Network (CAN) or a zebra wheel with optical tachometer can be used to track steering wheel speeds during data acquisition. See Appendix D, Figure D1 for an example of a zebra wheel.

3.3 Test Vehicle/Test Piece. Test is performed on a production vehicle or development vehicle as required. Care must be taken to eliminate any binding, clicking, scuffing or other anomalous steering column or dash panel noises unrelated to the EPS actuation. Verify and note the status of all hardware and software relative to the current release status. Adjust tire pressures to nominal values as stated by the vehicle manufacturer (cold). Ensure radio/entertainment system and Heating Ventilation and Air Conditioning (HVAC) is turned off.

3.4 Test Time.

Calendar time:	1 days
Test time:	2 hours
Coordination time:	1 hours
Data Analysis time:	2 hours

3.5 Test Required Information. Certain data should be recorded with every test such as: evaluator, date, test location (asphalt, concrete, 3M pads), vehicle model year make and model, tire pressure, gear supplier, gear technology type (column, rack belt, rack dual pinion), is cradle isolated, is gear isolated, and front or rear steer. Other information helpful for determining orders includes: ball nut lead, small pulley teeth count, large pulley teeth count, c-factor, gear ratio, motor rotor pole count and motor stator teeth count.

3.6 Personnel/Skills. Test requires an engineer or technician with basic knowledge of acoustics. Data analysis requires an engineer or technician with moderate knowledge of acoustic data processing.

4 Procedure

4.1 Preparation. Place recording device in unoccupied passenger seat (driver seat is allowed if using binaural headset). Be sure recording device is not resting in contact with seat or headrest. Position seat halfway between fore and aft positions, and halfway between lowest and highest position. See Appendix A for more information on placing seat in mid-point positions. If a binaural head or other microphone recording device is used, position recording device so that microphones are at passenger left and right ear locations of the unoccupied seat. If a single microphone is used, position using the unoccupied seat position as per Appendix A, Figures A1 and A2. Attach spinner knob to steering wheel securely using two (2) or more heavy tie wraps. Switch off HVAC, Radio and all other accessories. Close all doors and windows. Move vehicle to a facility as described in 3.1. Test technician should be wearing soft, loose clothing that does not make excessive brushing sounds during steering wheel maneuvers.

4.2 Conditions.

4.2.1 Environmental Conditions. Outside test site must be level. Wind must be less than 10 km/h (6 mph) with no significant gusts. Test should be performed at an ambient temperature of $+23^{\circ}\text{C} \pm 5^{\circ}\text{C}$ ($73^{\circ}\text{F} \pm 41^{\circ}\text{F}$) unless otherwise specified. Vehicle traffic and miscellaneous outside noise must be sufficiently low as to be imperceptible to the test technician in the vehicle. A short drive of about 8 km (5 mi) before testing will help ensure vehicle is warmed up so engine idle is consistent and tires are not cold.

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 Calibration Verification. Verify the calibration of the measuring instruments according to the operating instructions. Note the expiration date on the calibration label. Record calibration tone if applicable. The sound pressure level should be measured in dB(A) referenced to 20 μPa .

4.3.2 Measurement Pre-Test. Make a pre-test if necessary to optimize input gains on the recording device.

4.3.3 Measurement of Idle Noise. Operate the vehicle in Park at idle. Position the steering wheel at the neutral or 12 o'clock position. Acquire and record the sound pressure time history for 30 s.

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January 2016

Page 2 of 12

4.3.4 Measurement of Engine-Off Background Noise (when applicable). If vehicle has EPS that remains active during Idle-Engine-Off (IEO) conditions, position the steering wheel at the neutral or 12 o'clock position. Acquire and record the sound pressure time history at IEO for 30 s.

4.3.5 Measurement of EPS Noise at 30 Revolutions per Minute (RPM). Position vehicle so front wheels are on a dry asphalt surface or 3M paper as described in 3.1. Operate the vehicle in Park with foot off the brake pedal (to not couple in corner mass to steering system at ends of rack travel) and the engine at idle (or IEO when applicable). The key when determining which background condition to use is to make sure the EPS noise stands above background noise enough so only EPS noise is portrayed in frequency plots. Typically, 75 RPM of the steering wheel has enough EPS noise to stand at least 5 dB(A) above the background noise even with engine on at idle, but background noise comparisons should always be made against EPS noise. Position the steering wheel at the left stop position, usually about 1½ turns off center. Name the file name with steering wheel RPM. Begin the data acquisition. Turn steering wheel at 30 RPM (180 degrees/s) from left-stop to right-stop (be careful not to hit the end stop), pause approximately 1 s, then turn the steering wheel from the right-stop to the left-stop (be careful not to hit the end stop) thus completing one (1) Left-Right and Right-Left stop-to-stop (StS) sequence. Repeat this Left-Right and Right-Left StS sequence ten (10) times while recording the sound pressure time history and steering wheel speed. After ten (10) sequences are recorded, tester must pause the recording, move the vehicle to a fresh patch of asphalt, or fresh 3M paper section to avoid creating bald spots on the tire.

4.3.6 Measurement of EPS Noise at 45, 60, and 75 RPM. Repeat 4.3.5 at 45 RPM (270 degrees/s), 60 RPM (360 degrees/s), and 75 RPM (450 degrees/s). When a minimum of ten (10) Left-Right and Right-Left StS sequences are recorded for 30, 45, 60, and 75 RPM, data collection is complete. More than ten (10) Left-Right and Right-Left StS sequences may be recorded (especially at higher steering wheel speeds) to allow for more samples to choose from later during processing.

5 Data

5.1 Calculations. Several steps are performed on the sound pressure time histories to calculate the steering Zipper Noise. Low pass and high-pass filtering of the raw sound pressure data (for listening only), followed by listening based trimming of the sound pressure time history samples, then final selection of three (3) representative samples all precede the final calculation of the sound metric(s). For recording binaural head or other two (2) microphone recording devices, the left and right channel results are averaged for all calculations.

5.1.1 Low-Pass and High-Pass Filter Sound Pressure Data. All of the sound pressure time data is passed through a 3300 Hz low-pass filter (Butterworth 4th order or equivalent) and 100 Hz high-pass filter (Butterworth 4th order or equivalent) to remove the majority of unwanted sound caused by the tester actuating the steering wheel or clothing noises and engine noises.

5.1.2 Listening Based Trimming of Samples. Test engineer listens to entire sound pressure time history of the ten (10) (or more) Left-Right and Right-Left StS sequences recorded in 4.3.5 and 4.3.6. After listening to all of the steering sequences, identify the Left Right (steering wheel Clockwise (CW)) and Right-Left (steering wheel Counter Clockwise (CCW)) events that subjectively contain the highest tonal (or zipper) noise content and have most flat steering wheel speed. From these events, trim exactly 1 s of the sound, preferably where the sound is most stable, and free of anomalous sound not associated with EPS actuation (scuffing, squeaking, clicking, brushing, etc.) During this process, it helps the engineer if the time history is displayed in a level vs. time (or loudness vs. time) format and RPM vs time format to see steering wheel speed. Trim (or create marks for) three (3) of these representative 1 s events for each direction (meaning three (3) from Left to Right and three (3) from Right to Left). Reference examples in Appendix C, Figures C1 thru C7 for more detail regarding processing.

5.1.3 Final Calculation of ⅓ Octave metric. Using the three (3) selected samples, calculate the average A-weighted (dB(A)) ⅓ Octave (8192 sample rate, 50% overlap, Hanning window) Sound Pressure Level (SPL). A ⅓ Octave plot for each speed and direction in dB(A) is required (eight (8) ⅓ Octave plots will result from 30 CW, 30 CCW, 45 CW, 45 CCW, 60 CW, 60 CCW, 75 CW, and 75 CCW).

5.2 Interpretation of Results. The two (2) different types of interpretation are subjective (suggested) and objective (required for comparison to Electric Power Steering Vehicle Technical Specification (VTS) paragraph 3.2.1.3.8.5.7.e).

5.2.1 Subjective Interpretation (Suggested). In addition to the ⅓ Octave analysis, it is strongly recommended that a thorough, subjective, listening based evaluation of the zipper noise be done. Anomalous sounds related to EPS, but not necessarily related to zipper type tonality may still be present at an undesirable level. Subjective

GM Confidential

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January 2016

Page 3 of 12

listening should be done by subject matter experts on EPS so that informed, engineering judgments can be made.

5.2.2 Objective Interpretation (Required). For comparison to Electric Power Steering VTS, two (2) ranges of the $\frac{1}{3}$ Octave plot are summed together. The low frequency range sums $\frac{1}{3}$ Octave center frequencies of 160 Hz to 400 Hz and the high frequency range sums $\frac{1}{3}$ Octave center frequencies of 500 Hz to 2000 Hz. This ensures the entire frequency range from lower limit of 160 Hz $\frac{1}{3}$ Octave center frequency to upper limit of 2000 Hz $\frac{1}{3}$ Octave center frequency is plotted against VTS. Only the maximum dB(A) sum of CW or CCW for both frequency ranges is plotted against the VTS. This maximum dB(A) sum typically comes from 75 RPM, but all speeds should be processed since a system resonance could occur at a lower speed.

5.3 Test Documentation. Documentation depends on specific objective of the test.

6 Safety

This standard may involve hazardous materials, operations, and equipment. This standard does not propose to address all the safety problems associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.

7 Notes

7.1 Glossary.

Stop-to-Stop (StS) Sequence: Full rotation of steering wheel from left-stop to right-stop and right-stop to left-stop without hitting the stops at each end.

Zipper Noise: High tonal content noise from EPS system caused by steering wheel maneuvers, typically with vehicle at a speed of 10 km/h and below.

7.2 Acronyms, Abbreviations, and Symbols.

Avg	Average
CAN	Controller Area Network
CCW	Counter Clockwise
CW	Clockwise
DAS	Data Acquisition System
EPS	Electric Power Steering
FFT	Fast Fourier Transform
HAN	Hanning window
HVAC	Heating Ventilation and Air Conditioning
IDSR	Integration Driven Subsystem Requirements
IEO	Idle-Engine-Off
LFRE	Left Front Right Ear
N&V	Noise and Vibration
RFLE	Right Front Left Ear
RPM	Revolutions per Minute
SAS	System Actuated Sound
SPL	Sound Pressure Level
StS	stop-to-stop
TU	Tonality Units
VPO	Vehicle Performance Owner

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January 2016

Page 4 of 12