



Exhaust System Cooldown Noise Assessment - Objective 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. This test is used to record exhaust system cooldown noise associated with thermal expansion/contraction for the purpose of assessing the performance of GM and competitive exhaust systems for component development and benchmarking purposes.

1.2 Applicability. This test procedure is appropriate for use with all cars and trucks.

1.3 Remarks. This is a vehicle level objective sound measurement procedure to allow an evaluator to record the level of cooldown noise of an exhaust system in a controlled manner. Vehicle exterior measurements are recorded at the global vehicle exterior observer locations and also in close proximity to the exhaust components. For the purposes of establishing the relationship between subjective impressions and objective measures, this procedure may be used in conjunction with GMW15878. For exhaust subsystem validation purposes, cooldown mechanical noise may be evaluated according to GMW15880. This procedure is based on the results of the Design for Six Sigma (DFSS) Project Number 1368.

2 References

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

2.1 External Standards/Specifications.

ANSI S1.4	IEC 651	IEC 61672-1
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2.2 GM Standards/Specifications.

GMW14555	GMW15878	GMW15880	GMW16178
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2.3 Additional References.

- Bosch Automotive Handbook, 4th Edition
- Design for Six Sigma (DFSS) Project: Number 1368: Epsilon Exhaust Cooldown Tick/Ping Noise Elimination
- HEAD Acoustics ArtemiS Suite, available at www.head-acoustics.de/eng/nvh_artemis_suite.htm
- Siemens LMS Test.Lab, available at www.plm.automation.siemens.com/en_us/products/lms/testing/test-lab/desktop
- Subsystem Technical Specification (STS)

3 Resources

3.1 Facilities. The test facility should be a hemi-anechoic chassis dynamometer capable of fixed speed control and load control up to 110 km/h and 6600 N tractive effort respectively. Data acquisition is to be conducted in an environment where the ambient background noise level shall be at least 10 dB below the lowest sound levels of interest. Additionally, it is recommended that the ambient noise levels be no greater than 40 dB(A). The ambient air temperature shall be within the range of 18 °C and 30 °C.

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

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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 Microphones. Microphones with appropriate signal conditioning and cables with a flat response between 22 Hz and 17.2 kHz, meeting Class 1 requirements corresponding to IEC 61672-1, or equivalent, for the application shall be used. Ensure that the maximum usable temperature of the microphone is not exceeded.

3.2.1.1 Microphones used near exhaust components shall be free-field or pressure type.

3.2.1.2 Microphones used at the global exterior microphone locations shall be free-field type or equivalent.

3.2.2 Data Acquisition Devices. Multi-channel data acquisition hardware devices shall be capable of recording data for 5 minutes at a sampling rate of 44 kHz and have a minimum dynamic range of 80 dB. This hardware shall meet Class 1 accuracy corresponding to IEC 651 or be equivalent for the application with precision of ± 0.7 dB or $\pm 8\%$. The measuring instruments used shall conform to the significant characteristics of the standards. The conformity to the tolerances is limited to the frequency range 22 Hz to 17.2 kHz.

3.2.3 Thermocouples.

3.2.3.1 Gas Stream Thermocouples. Type K sheathed probe, 3.2 mm diameter with 100 °C to 1250 °C temperature range capability.

3.2.3.2 Surface Thermocouples. Type K thermocouple wire, 24 gauge type 508 special grade with 0.4% accuracy > 260 °C and temperature capability to 870 °C.

3.3 Test Vehicle/Test Piece. The tests shall be performed on a vehicle that represents the current production or current part release status. For GM vehicles, the exhaust system used for testing shall be a “new” production tooled exhaust system that has been preconditioned according to 4.1.1. Any additional preconditioning or “aging” of the exhaust system must be documented according to 4.1.1.2. Verify and record the status of all hardware relative to the current release status. Record the exhaust system part numbers. Record the testing date, time, ambient temperature and test location. Deviations (e.g., obvious faults) shall be eliminated or recorded.

3.4 Test Time.

Calendar time: 1 day

Test time: 6 hours

Coordination time: 0 hours

3.5 Test Required Information. Not applicable.

3.6 Personnel/Skills. One (1) qualified engineer or technician trained in the use of data acquisition and recording equipment and having basic knowledge of acoustic and vibration signal processing. One (1) qualified chassis dynamometer operator. Test personnel shall have a working knowledge of HEAD Acoustics ArtemiS Analyzer and Recorder or equivalent analyzer/recorder.

4 Procedure

4.1 Preparation.

4.1.1 Exhaust Preparation.

4.1.1.1 Exhaust System Preconditioning. All new, “out-of-the-box” exhaust systems shall be preconditioned by operating the engine to achieve a steady temperature in the gas stream at the inlet of at least 500 °C for a minimum of 30 minutes.

4.1.1.2 Exhaust System Aging (Optional). In certain instances it is desirable to test aged exhaust components. The aging process shall be established independent of this procedure by the appropriate GM program engineer. The aging process shall be documented with the data in terms of duration; kilometers and/or time, exhaust gas temperatures and vehicle operating schedule.

4.1.2 Thermocouple Installation. Thermocouples shall be installed in accordance with Appendix C, Figures C1 and C2. For this procedure, an alternative junction method such as twisted solid wire may be used for measuring surface temperatures. A band clamp must be placed securely over the location where the wires contact one another and the exhaust surface. The thermocouple locations are described as follows:

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4.1.2.1 Required Thermocouple Location. The exhaust surface temperature shall be measured on the inlet pipe, 50 mm upstream of the first tuning element that is downstream of the converter, see Appendix C, Figure C2.

4.1.2.2 Optional Thermocouple Locations. For exhaust cooldown noise development purposes, it is recommended that a thermocouple be placed in the gas stream, see Appendix C, Figure C1. If it is not possible to locate thermocouples in the exhaust gas stream due to the resulting damage of the exhaust system, it is permissible to use only the location described in 4.1.2.1 for the purposes of this test. The recommended gas stream locations are:

- Exhaust Gas Stream Temperature, Manifold Outlet
- Exhaust Gas Stream Temperature, Converter Outlet

4.1.3 Microphone Placement: Exhaust Components. Microphones shall be placed near an exhaust component at a distance of 100 mm as shown in Appendix B, Figures B1, B2 and B3. A microphone shall be placed at the center of each component that could exhibit cooldown noise. This includes, but is not limited to: emissions components, converters, mufflers, resonators and any heat shields attached to the exhaust system.

4.1.4 Microphone Placement: Global Exterior Microphone Locations. A subset of the global exterior microphone locations as described in Appendix A shall be used. The microphones shall be positioned 1.0 m from the vehicle and 1.6 m from the ground per Appendix A. For benchmarking purposes, microphones shall be placed at MG4, MG5 and MG10 per Appendix A and additional locations as necessary. For product development purposes, the test engineer is responsible for identifying the locations which demonstrate the majority of the objectionable noise. This can be determined during a trial run as described in 4.3.6.

4.2 Conditions.

4.2.1 Environmental Conditions. Confirm that the environmental conditions meet the requirements defined in 3.1. If conditions are outside of the specified range, make a note in the test log.

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.

4.2.3 Test Piece Conditions. Confirm that each test sample meets the exhaust system conditioning requirements defined in 3.3, 4.1.1.1 and 4.1.1.2. If there are any pertinent issues, make a note in the test log.

4.3 Instructions.

4.3.1 Operating Exhaust Temperature. The intent of this procedure is to achieve temperatures in a repeatable manner, in a controlled environment, and at a representative operating condition. Due to differences in the airflow in the chassis dynamometer as compared with on road, the temperatures may be more similar to those achieved during the GMW14555 Rural Highway/City Traffic Schedule than to those achieved at cruising speeds of 100 km/h on a flat smooth road. The operating temperatures are the stabilized temperatures attained according to 4.3.6.1. Additionally, for the purpose of program development and root cause assessment, it is recommended the engineer obtain the temperatures specified for the exhaust cooldown noise requirement from the program specific Exhaust Subsystem Technical Specification (SSTS) for reference.

4.3.2 Dynamometer Load Calculations. Determine chassis dynamometer loads as described in Appendix F. Dynamometer loads are generally between 650 N and 850 N.

4.3.3 Vehicle Chassis Dynamometer Setup.

4.3.3.1 Allow the vehicle to adjust to the test laboratory ambient temperature. Attach vehicle to chassis dynamometer rolls. If lateral body tie downs are used, they must isolate the body. Ensure that wheel chocks do not contact the body.

4.3.3.2 Set the exhaust collector and ventilation system to properly remove exhaust gases without affecting engine performance. The exhaust removal system should be placed in line with the exhaust exit at a minimum of 0.3 m away from the tailpipe(s).

4.3.3.3 Install a thermocouple in the engine cooling system at engine block coolant outlet point or use an alternate method to monitor coolant temperatures.

4.3.3.4 Install emergency engine shutoff lead. Check for proper operation. Close hood.

4.3.3.5 Set up external cooling fan directed toward the engine cooling system. Raise all chassis dynamometer floors.

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4.3.3.6 Install throttle controller. Turn off vehicle radio and HVAC system. Check that parking brake is released and vehicle traction control is disabled.

4.3.4 Data Acquisition Setup. See Appendix G for Siemens LMS Test.Lab setup and Appendix H, Figure H1 for HEAD Acoustics ArtemiS Suite setup. It is necessary to record the time data and then post process afterward when using LMS.

4.3.4.1 Microphone Channels.

- A-weighted
- Sampling frequency: 44 kHz
- Bandwidth: 22 Hz to 17.2 kHz
- The microphone channel dynamic range shall be set as to maximize the signal amplitude without overloading it during the course of the test. Make a pretest if necessary to establish settings
- Microphone channel identification labels shall indicate the exhaust component or the global exterior measurement location Identification (ID)

4.3.4.2 Thermocouple Channels.

- Static channel in LMS Test.Lab (or 5 Hz sampling rate)
- No filtering
- Units set to degrees Celsius
- The thermocouple channel dynamic range shall be set as to maximize the signal amplitude without overloading it during the course of the test. Make a pretest if necessary to establish settings. Temperatures typically range from 200 °C to 800 °C depending on the thermocouple location
- Thermocouple channel identification labels shall indicate whether the thermocouple is on surface or in gas stream and its location (e.g., surface_muffler_in)

4.3.4.3 Data Processing. The acquisition system may be set up to record time data or to process the event real time according to 5.1.1 and 5.1.2.

4.3.5 Calibration Verification.

4.3.5.1 Microphones. Verify calibration of the transducers as specified in GMW16178. Record calibration tone prior to and immediately after the test measurement sequence. Record calibration values and gain settings.

4.3.6 Measurement.

4.3.6.1 Warmup. Select highest available gear. Set chassis dynamometer to “V over F” mode and enter the dynamometer load as calculated in 4.3.2. The external front cooling fan should remain on. Operate the vehicle so as to maintain a constant speed of 100 km/h until the exhaust gas and surface temperatures being recorded stabilize. After the temperatures stabilize, operate the vehicle for a minimum of 5 minutes. Record stabilized temperatures of exhaust components in test documentation.

4.3.6.2 Data Acquisition During Cooldown. Turn off all external cooling. Remove dynamometer load and return to idle. Quickly, shut off the vehicle and brake to stop the chassis dynamometer rolls. Begin data acquisition and record for a minimum of 5 minutes.

Make a practice run, as necessary, to set signal gains, check vehicle operation, and check ambient noise levels.

4.3.6.3 Repeat the measurement sequence three (3) times allowing the exhaust system to reach room temperature in between runs.

5 Data

5.1 Calculations.

5.1.1 Acoustic Data Post-Processing Setup. See Appendix G for LMS Test.Lab setup and Appendix H, Figure H1 for ArtemiS setup.

Filter:

- High pass filter set at 1 kHz
- 4th order Butterworth filter for 1 kHz to 17.2 kHz

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- Frequency Weighting: No Change (Data was recorded as A-weighted)
- Level vs. Time setup as User Defined with a time constant integration time of 0.01 s

Note: Root Mean Square (RMS) level in the time domain over the filtered measurement bandwidth of 1 kHz to 17.2 kHz, compliant to the IEC 61672-1/ANSI S1.4 standard. Exponential averaging shall be used with a time constant, integration time, of 0.01 s.

Note: Do not use the time constant associated with Fast Averaging, typically 0.125 s; or Impulse Averaging, typically 0.035 s. The resulting Sound Pressure Level (SPL) maxima associated with the tick/ping event will not be consistent with those processed with the time constant specified for this procedure, 0.01 s. Fast, Slow, or Impulse averaging will result in sound pressure level maxima lower than that calculated with a 0.01 s time constant.

5.1.2 The maximum SPL shall be reported for each 1 minute time segment and for the total 5 minute time segment.

5.1.3 Statistical Calculations for Acoustic Data. A histogram normalized to the number of data points and multiplied by 100 to obtain a percentage shall be calculated for each 1 minute time segment and for the total 5 minute time segment. All values shall be reported to two (2) decimal places (e.g., 3.01%).

5.1.3.1 For the SPL data acquired at the exhaust component microphones, the reported histogram intervals shall be defined as follows:

For non-luxury vehicles as specified in SSTs:

- 65 dB(A) to 70 dB(A)
- 70 dB(A) and greater

For luxury vehicles as specified in SSTs:

- 60 dB(A) to 65 dB(A)
- 65 dB(A) and greater

5.1.3.2 For the SPL data acquired at the global exterior microphones, the recommended histogram intervals are defined as:

- 40 dB(A) to 45 dB(A)
- 45 dB(A) and greater

5.1.3.3 When measuring multiple test iterations, the average over the total number of iterations shall be calculated for each time interval for the histogram intervals defined in the sample Test Log Form and the sample Test Summary Form in Appendix D, Data Sheet D1.

5.1.4 Thermal Data Calculations. The thermal data is recorded at a 5 Hz sampling rate with no filtering. All of the temperature data for the components of interest are plotted in degrees Celsius on the same graph, for the entire duration of the test. Time is plotted on the x-axis, with temperature data plotted on the y-axis.

5.1.5 Cooldown Noise Event Counting (Optional). The number of cooldown events may be manually counted. In some circumstances is more meaningful to indicate the number of events with local maxima in the defined intervals described in 5.1.3. It is practical to do this when the sample size and number of test iterations is small.

5.1.6 Bubble Charts. The data collected from the evaluation can be compiled and plotted on a bubble chart with time intervals on the x-axis and A-weighted overall sound pressure level on the y-axis. The maximum SPL in a particular time interval is plotted as the y-value. The bubble sizes will represent either the normalized histogram value for the interval in which the maxima falls or the number of cooldown events with maxima in the intervals described in 5.1.3.1 or 5.1.3.2 (see Appendix E, E1 and Figures E5 and E6).

5.2 Interpretation of Results.

5.2.1 Correlation with Subjective Measures. The histograms, acoustic data plots, maximum levels and bubble charts for the cooldown noise observed at the global exterior microphone locations may be used with subjective data acquired according to GMW15878 to develop targeted levels.

5.2.2 Relationship Between Levels at the Component Microphones and Global Exterior Microphone. The relationship between the levels measured at the global exterior microphone locations and the component microphone locations may be used to develop proposals for revisions to targeted levels for the components. Correlation with subjective data acquired according to GMW15878 is highly recommended.

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5.2.3 Levels at the Component Microphone Locations. Refer to the program specific exhaust SSTs for specific program values. Unless otherwise stated in the SSTs:

- a. For non-luxury vehicles, there shall be no component noise events > 70 dB(A) for any test sample or test run;
- b. For luxury vehicles, there shall be no component noise event > 65 dB(A) for any test sample or test run.

5.2.4 Thermal Data. The thermal plots can be used to establish a relationship between temperature and cooldown noise, and also they are useful when comparing two (2) or more vehicles.

5.3 Test Documentation.

5.3.1 Conditions. Documentation shall include a list of all exhaust part numbers, the test date, time and location, the ambient temperature and a description of the heat source used. The actual stabilized temperature at the start of the test run shall be recorded. Use sample template in Appendix D, Data Sheet D1.

5.3.2 Data Summary and Test Log Form. The sample forms in Appendix D, Data Sheets D2 and D3 may be used as appropriate.

5.3.3 Data Plots. The following conventions should be used when plotting data:

5.3.3.1 The acoustic data is plotted with time on the x-axis and the A-weighted SPL on the y-axis. Time data is shown in 5 minute intervals with major axis at every 60 s. The typical range for the y-axis is 40 dB(A) to 100 dB(A), but may vary to fit the data. The requirement values from the exhaust SSTs shall be included on the plots. See example in Appendix E, Figure E2.

5.3.3.2 The acoustic data statistical data shall be plotted as shown in Appendix E, Figure E1. The numerical values as calculated in 5.1.3 shall be displayed to two (2) decimal places.

5.3.3.3 Bubble charts shall be plotted as described in Appendix E, E1 and Figures E5 and E6.

5.3.3.4 Thermal Data. All exhaust gas temperatures and surface temperatures shall be plotted in degrees Celsius on the y-axis with time plotted on the x-axis for the duration of the test. See example in Appendix E, Figure E1.

Note: For examples of Cooldown Noise Statistical Data and an Unacceptable Repeating Cooldown Event, see Appendix E, Figures E3 and E4.

6 Safety

This Engineering Standard may involve safety requirements for hazardous materials, the method of operations and equipment. This standard does not propose to address all the safety issues associated with its use. It is the responsibility of the user of this standard to ensure compliance with all appropriate safety and health practices. This would include any specific training that may be required. The safety and health standards include site specific rules and procedures, company rules and procedures, and Government Standards. Contact shall be made with the appropriate site Safety and Health personnel for further direction and guidance in these matters.

7 Notes

7.1 Glossary.

Aged Exhaust System: An exhaust system that has been used more than a specified number of hours or miles according to a specified operating schedule.

Cooldown Noise: Any mechanical sound caused from the thermal contraction of an exhaust system, and/or its components, while the exhaust system decreases in temperature, because the vehicle's engine has stopped running. The vehicle's engine may have stopped running either because the vehicle had been keyed off or because of the functionality of a hybrid powertrain system.

Crinkle/Crackle: A continuous, audible, low amplitude level ticking noise, with a metallic characteristic.

New Exhaust System: An "out-of-the-box" exhaust system which has been preconditioned according to 4.1.1.

Ping: A cooldown noise event subjectively described as a high amplitude, solid tap type noise event followed by a metallic ringing undertone.

Tick: A cooldown noise event subjectively described as a solid metallic tap type noise without the ringing undertone. In most cases this is a repeating event that is lower in amplitude than a ping.

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7.2 Acronyms, Abbreviations, and Symbols.

DFSS	Design for Six Sigma
ID	Identification
N&V	Noise and Vibration
RMS	Root Mean Square
SPL	Sound Pressure Level
VPO	Vehicle Performance Owner

8 Coding System

This standard shall be referenced in other documents, drawings, etc., as follows:

Test to GMW15879

9 Release and Revisions

This standard was originated in April 2008. It was first approved by the Noise and Vibration Global Passby, Induction and Exhaust Harmonization Team in June 2009. It was first published in June 2009.

Issue	Publication Date	Description (Organization)
1	JUN 2009	Initial publication.
2	DEC 2010	Replaced references to obsolete GMW procedures. Included reference to GMW15878 Subjective Evaluation of Exhaust Cooldown noise. (Global Powertrain Induced N&V VPO Team)
3	FEB 2016	Revised to current template. (Global N&V VPO Team – Powertrain Induced)

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