



Exhaust System Cooldown Noise Assessment - Objective Component 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 due to thermal expansion/contraction for the purpose of validating the exhaust system cooldown noise performance requirements. This test is also used to assess the performance of GM and competitive exhaust systems during cooldown 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 subsystem level, objective sound measurement procedure that allows an evaluator to record the level of cooldown noise of an exhaust system in a controlled manner without any influence from the vehicle. The subsystem is tested using a test rig that includes a heat source; no vehicle is used. For issue identification purposes, cooldown mechanical noise may be evaluated according to GMW15879 Exhaust Cooldown Noise - Objective Vehicle Level Test and/or GMW15878 Exhaust Cooldown Noise - Subjective Vehicle Level Test. 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

2.2 GM Standards/Specifications.

GMW14555 GMW15878 GMW15879 GMW16178

2.3 Additional References.

- Design for Six Sigma (DFSS) Project Number 1368: Epsilon Exhaust Cooldown Tick/Ping Noise Elimination
- Subsystem Technical Specification (SSTS)

3 Resources

3.1 Facilities. Data acquisition is to be conducted in an environment where the ambient background noise level is at least 10 dB below the lowest sound levels of interest. Additionally, it is recommended that the ambient noise levels be greater than 40 dB(A). A hemi-anechoic chamber is recommended, but not required. 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.

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. Free-field or pressure microphones with appropriate signal conditioning and cables and with a flat response between 22 Hz and 17.2 kHz, that also meet Class 1 requirements corresponding to

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IEC 61672-1, or equivalent for the application shall be used. Confirm that the maximum usable temperature of the microphone is not exceeded.

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 (0.125 in) diameter with 100 °C to 1250 °C temperature range capability (see Appendix E, Figure E1).

3.2.3.2 Surface Thermocouples. Type K thermocouple wire, 24 gauge type 508 special grade with 0.4% accuracy above 260 °C and temperature capability to 870 °C (see Appendix E, Figure E2).

3.2.4 Heat Source. An engine running on an engine dynamometer is the preferred heat source. A hot gas generator may be used, but correlation with data acquired on an engine may be required.

3.3 Test Vehicle/Test Piece. A complete exhaust system from the manifold flange to the tailpipe shall be the standard test piece unless otherwise agreed upon by the appropriate GM engineer. The option exists to test only the rear exhaust or front exhaust when agreed upon by the appropriate GM engineer. The test shall be performed on six (6) "new" production tooled exhaust systems that have been preconditioned according to 4.1.1. Additional preconditioning or "aging" may be required as described in the program specific exhaust Subsystem Technical Specification (SSTS). 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, heat source used and test location.

3.4 Test Time.

3.4.1 Single Sample.

Calendar time: 1 day
Test time: 4 hours
Coordination time: 1 hour

3.4.2 Six (6) Samples.

Calendar time: 4 days
Test time: 32 hours
Coordination time: 4 hours

3.5 Test Required Information. Not applicable.

3.6 Personnel/Skills. One (1) qualified engineer and/or technician trained in the use of the heat source device and in the use of data acquisition and recording equipment and having basic knowledge of acoustic and vibration signal processing.

4 Procedure

4.1 Preparation.

4.1.1 Exhaust System Preconditioning. All new exhaust systems shall be preconditioned by operating the heat source to achieve a steady temperature in the gas stream at the inlet of 500 °C for 30 minutes.

4.1.2 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.

4.1.3 Determination of Thermocouple Locations and Stabilized Temperatures. The thermocouple locations and stabilized temperatures shall be obtained from the program specific exhaust SSTS. Deviations from the temperatures and locations in the program specific SSTS shall be agreed upon with the appropriate GM personnel prior to testing. Unless otherwise specified in the program specific exhaust SSTS, the locations and

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temperatures specified in 4.1.3.1 thru 4.1.3.3 can be used and are based on a survey of validation data obtained via the City Traffic/Rural Highway schedule according to GMW14555.

4.1.3.1 Complete Exhaust System.

4.1.3.1.1 A thermocouple shall be located in the gas stream immediately upstream of the manifold flange. The stabilized gas stream temperature shall be 800 °C. The thermocouple may be located in an adapter that couples the exhaust system to the heat source.

4.1.3.1.2 A second thermocouple shall be located on the surface of the exhaust pipe 50 mm upstream of the first tuning element. The temperature at this location is a function of the exhaust system inlet gas stream temperature and the thermal characteristics of the specific exhaust system being tested. Record the resulting temperature in the test report. As a reference only, the temperatures at this location should stabilize near 300 °C ± 50 °C.

4.1.3.1.3 (Optional). An additional thermocouple may be attached in the exhaust system tailpipe to read the exiting gas flow temperature for reference.

4.1.3.2 Rear Exhaust System (Cold End).

4.1.3.2.1 A thermocouple shall be located in the gas stream immediately upstream of the coupling flange that is located downstream of the converter. The stabilized gas stream temperature shall be 700 °C. The thermocouple may be located in an adapter that couples the rear exhaust system to the heat source.

4.1.3.2.2 A second thermocouple shall be located on the surface of the exhaust pipe 50 mm upstream of the first tuning element. The temperature at this location is a function of the exhaust system inlet gas stream temperature and the thermal characteristics of the specific exhaust system being tested. Record the resulting temperature in the test report. As a reference, the temperatures at this location should stabilize near 300 °C ± 50 °C.

4.1.3.2.3 (Optional). An additional thermocouple may be located in the exhaust system tailpipe to read the exiting gas flow temperature for reference.

4.1.3.3 Front Exhaust System (Hot End).

4.1.3.3.1 A thermocouple shall be located in the gas stream immediately upstream of the manifold flange. The stabilized gas stream temperature shall be 800 °C. The thermocouple may be located in an adapter that couples the exhaust system to the heat source.

4.1.3.3.2 (Optional). An additional thermocouple may be used to read the exiting gas flow temperature for reference.

4.1.4 Exhaust System Setup. Use stands to support the exhaust system and connect it to an engine or hot gas generator. The stand should not interfere with thermal expansion and/or contraction of the exhaust system (see Appendix A, Figures A1 and A2).

4.1.5 Microphone Installation. Microphones shall be placed near a component at a distance of 100 mm as shown in Appendix D, Figures D1, D2, and D3. A microphone shall be placed at the center of all components that could exhibit cooldown noise. This includes but is not limited to:

- Emissions components
- Converters
- Mufflers
- Resonators
- Heat shields attached to the exhaust system

4.1.6 Thermocouple Installation. Refer to 4.1.3 for thermocouple locations. Thermocouples shall be installed in accordance with Appendix E, Figures E1 and E2.

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.

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4.3 Instructions.

4.3.1 Test Setup.

4.3.1.1 Install and attach exhaust system to heat source making sure no unwanted noise emanates from the heat source or connecting joints.

4.3.1.2 Instrument the exhaust system with thermocouples and microphones as described in 4.1.

4.3.1.3 Record all pertinent information about the exhaust system (see sample Vehicle/Exhaust Information Sheet shown in Appendix B.).

4.3.2 Data Acquisition Setup.

4.3.2.1 Microphone Channels.

- Linear (option to record A-weighted)
- Sampling Frequency: 44 kHz
- Bandwidth: 22 Hz to 17.2 kHz

4.3.2.2 Thermocouple Channels.

- Sampling Rate: 5 Hz
- No filtering
- Units set to degrees Celsius

4.3.3 Calibration Verification.

4.3.3.1 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.

4.3.3.2 Thermocouples. Verify that the thermocouples are functioning properly.

4.3.4 Measurement.

4.3.4.1 The microphone instrumentation shall be set up as to maximize the signal amplitude entering the recording device without overloading it during the course of the test. Make a pre-test if necessary to establish settings.

4.3.4.2 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 pre-test, if necessary, to establish settings. Temperatures typically range from 200 °C to 800 °C depending on the thermocouple location.

4.3.4.3 Record event numbers, gain, and range settings as applicable. Check ambient noise levels at the same setting used for the test to ensure that the requirements specified in 3.1 are met.

4.3.5 Cooldown Evaluation Procedure. Test each sample according to the following sequence.

Note: Make a practice run, as necessary, to set signal gains, check heat source operation, and check ambient noise levels.

4.3.5.1 Start the engine dynamometer or hot gas generator and warm up the exhaust system using an appropriate engine load to obtain the temperatures described in 4.1.3. Use a fan to generate airflow over the system as necessary. The exhaust system temperatures should reach the steady state gas stream temperatures at a minimum of one location, preferably at the thermocouple placed in the gas stream nearest the converter. See 4.1.3 for a description of thermocouple locations.

4.3.5.2 Once the desired temperature is reached, hold and stabilize the temperatures for 5 minutes.

4.3.5.3 Shut down the heat source and any other noise sources.

4.3.5.4 Immediately start the data acquisition and record for 5 minutes. Make sure there is only limited downtime between the end of the warmup cycle and the start of the data acquisition.

4.3.5.5 Allow the exhaust system to reach ambient temperatures before repeating the test sequence. The test sample may be removed from the heat source to cooldown while the next sample is installed and tested.

4.3.5.6 Repeat the test sequence for five iterations or the number of iterations defined in the program specific exhaust SSTs.

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5 Data

5.1 Calculations.

5.1.1 Acoustic Data Processing Setup.

Filter:

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

Final Weighting:

- A-weighted

Level versus Time Parameters:

- 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 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 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 decimal places (e.g., 3.01%).

5.1.2.1 For the sound pressure level 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

5.1.2.2 When measuring five (5) iterations of six (6) samples, the average over the total number of samples and iterations shall be calculated for each time interval for the histogram intervals defined in Appendices B and C.

5.1.2.3 The maximum sound pressure level over the 5 minute time segment shall be reported.

5.1.3 Thermal Data Calculations. The thermal data is recorded at a 5 Hz sampling rate with no filtering.

5.2 Interpretation of Results. Refer to the program specific exhaust SSTs for specific program values. Unless otherwise stated in the SSTs:

- For non-luxury vehicles, there shall be no noise events above 70 dB(A) for any test sample or test run
- For luxury vehicles, there shall be no noise event above 65 dB(A) for any test sample or test run

The sample Vehicle/Exhaust Information Sheet in Appendix B and the sample Test Log Form in Appendix C shall be populated for each component and supplied to the appropriate GM engineer.

5.3 Test Documentation. 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. See the sample Vehicle/Exhaust Information Sheet in Appendix B.

5.3.1 Vehicle/Exhaust Information Sheet and Test Log Form. The sample Vehicle/Exhaust Information Sheet in Appendix B and the sample Test Log Form in Appendix C shall be populated for each component and supplied to the appropriate GM engineer.

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

5.3.2.1 The acoustic data is plotted with time on the x-axis and the A-weighted sound pressure level 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

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