



Calculating Vibration Isolation Characteristics of Isolation Element and Hard Tube Line Samples

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.

Note: GMW14172 and GMW14181 shall be referenced for more detailed information corresponding to the following procedure.

1.1 Purpose. The purpose of this procedure is to objectively determine the isolation capability of any metal or hard tube and isolator test samples from their objectively measured compliance values.

1.2 Applicability. The test is applicable to any test sample that can be accommodated by the test fixture.

1.3 Remarks. In some vehicles, an Electric Hydraulic Control Unit (EHC) is used as part of the brake system. The EHC is an electrically driven pump that accumulates pressure and stores it until needed. The EHC generates significant vibration when it operates. This vibration is a function of the electric motor speed and pump characteristics. If this vibration is allowed to be transmitted to the vehicle, then objectionable structure-borne interior noise may result. One such structure-borne noise path is through the brake lines to the brake master cylinder. This procedure was originally developed for just such a brake line system of tube running between the EHC and the Brake Master Cylinder, but has subsequently been expanded to cover the isolation element performance of any hard line system of tubing that has an isolation element. This procedure measures the impact Frequency Response Functions (FRF) of a test sample of a hard line and isolator assembly.

2 References

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

2.1 External Standards/Specifications.

IEC 61672-1:2003

2.2 GM Standards/Specifications.

GMW14172 GMW14181 GMW14229

2.3 Additional References.

- Component Technical Specification (CTS)
- Siemens Leuven Measurement System (LMS) Test.Lab software support at:
www.plm.automation.siemens.com/en_us/products/lms/testing/test-lab

3 Resources

3.1 Facilities. This testing shall be performed on a bedplate or equivalent. The bedplate shall be isolated from the local environment to prevent/minimize external vibration.

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.

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3.2.1 Accelerometers. Three triaxial low mass accelerometers with flat response from 2 Hz to 2000 Hz and an operating range of 10 °C to 50 °C.

3.2.2 Data Acquisition Equipment. Data acquisition hardware capable of calculating frequency domain results between 2 Hz and 1 kHz, with a minimum of 80 dB dynamic range. This hardware shall meet Class 1 accuracy corresponding to IEC 61672-1:2003 or be equivalent for the application (precision: ± 0.7 dB or $\pm 8\%$).

The preferred digital data acquisition system (DAS) is a personal computer running LMS Test.Lab software connected to an LMS Scadas III front end with impact testing module and PolyMax modal analysis module, or equivalent as approved by the Global Noise and Vibration Center (GNVC) Infrastructure Team.

3.3 Test Vehicle/Test Piece. Isolation element with hard line on both ends.

3.4 Test Time. Three samples minimum shall be tested.

Calendar time: 2 d

Hardware setup: 4 h

Test time: 4 h

Coordination time: 1 d

3.5 Test Required Information. No special information is required.

3.6 Personnel/Skills. One qualified engineer or technician trained in the use of data acquisition, with basic knowledge of digital signal processing of acoustic or vibration signals and modal analysis is required. Knowledge of LMS impact monitor, LMS data calculator, and LMS PolyMax modal analysis and Microsoft Excel is helpful.

4 Procedure

4.1 Preparation.

4.1.1 Hardware Requirements. This test requires a stanchion to be set up on a bedplate. Attached to the stanchion is a test fixture referred to as a hard line clamp, see Appendix A, Figure A1. Depending on the design of the stanchion and clamp, an adapter may be needed, see Appendix A, Figure A2. Refer to Appendix A, Figure A7 for a detailed photo of the entire setup.

4.1.2 Test Hardware and Setup. Set up the hardware in accordance with Appendix A, Figures A1 thru A7. Secure the stanchion to the bedplate using bedplate tie-down hardware. The stanchion shall be a minimum of 1.20 m high. The first mode of the stanchion, hard line clamp, and adapter shall have a minimum frequency of 85 Hz.

4.1.3 Test Sample and Preparation. The test sample consists of two lengths of metal or hard line connected by the isolation sample. One of the metal lines must be 10 cm longer than the design length between the vibration source and the isolation element. The other metal line length must be long enough so it can be trimmed to 5 cm. The isolation element length shall be design length, as specified for the appropriate vehicle application.

4.2 Conditions.

4.2.1 Environmental Conditions. The ambient air temperature should be between 15 °C and 25 °C.

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 Acquisition. For each test sample, a measurement will be taken with the sample clamped in two positions (refer to Appendix A, Figures A3 and A4). Data from one position will be used to determine the compliance of the isolation element. Data from the other test position will be used to determine the compliance of the metal line between the isolation element and the vibration source. Data will be acquired using the standard impact FRF measurement technique.

4.3.1.1 Acquisition Parameters. Set the measurement acquisition parameters for this test as follows:

- FRF measurement estimate Method H1 (based on software prompt)
- Set the frequency range to 512 Hz
- Set the frequency resolution to 0.125 Hz

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- If the impact response time signal decays to zero within the measurement time sample, use a uniform window
- If the impact response signal does not decay to zero in the time window, use a force window on the force channel and a matching exponential window on the response channel
- Window correction mode: amplitude
- Set the number of averages to 5
- Set the averaging method to linear

4.3.1.2 Naming Convention. If using LMS software, establish a consistent geometry format naming convention. The recommended coordinate system is illustrated in Appendix A, Figures A5, A6, and A7.

4.3.1.3 Measurement Point Locations. Place the accelerometer as illustrated in Appendix A, Figure A3 and Figure A4.

4.3.2 Measurement Acquisition.

4.3.2.1 Position 1. With the test sample in the first position (as shown in Appendix A, Figure A3) the driving point is at the bottom of the isolation element. Acquire trial impact FRF measurements in both the X direction and the Y direction. Inspect the coherence. Minimum acceptable coherence is 95% at the peaks of the FRF. Compare data from the trial measurements in two directions. If the test setup is correct and there is no influence from the microdot cable, the driving point FRF data from both directions should be the same.

4.3.2.1.1 Measure and Save Data. Make averaged measurements with impacts in both the X and Y directions and save the FRFs, Coherence, Response Autopowers, and Reference Autopowers.

4.3.2.2 Position 2. Adjust the test setup to position the sample as shown in Appendix A, Figure A4. The driving point is again at the bottom of the isolation element. Acquire trial impact FRF measurements in both the X direction and the Y direction. Inspect the coherence. Minimum acceptable coherence is 95% at the peaks of the FRF. Compare data from the trial measurements in two directions. If the test setup is correct and there is no influence from the microdot cable, the driving point FRF data from both directions should be the same.

4.3.2.2.1 Measure and Save Data. Make averaged measurements with impacts in both the X and Y directions and save the FRFs, Coherence, Response Autopowers, and Reference Autopowers.

4.3.2.3 Measure All Samples. Replace test sample and repeat measurements until all samples have been measured.

5 Data

5.1 Calculations.

5.1.1 Validating Test Assumptions. The person conducting this procedure must be aware that as the isolation element length increases, the test sample may violate the assumption that it is behaving as a beam with stiffness K and a portion of it may begin acting as a pendulum. For the test sample with the longest isolation element, the operator shall calculate the period of a simple pendulum of the same length. Compare the measured frequency of the first peak in the test sample FRF spectrum (from test Setup Position 1) to the calculated frequency of the simple pendulum. If the calculated frequency of the simple pendulum is > 60% of the frequency of the first mode (f_1) in the FRF, the assumption of a simple beam is violated. A non-negligible amount of the restoring force is gravitational (force of a simple pendulum: $F = \Theta mg$). The actual compliance is greater than what can be measured with this method and therefore, the isolation is greater. This also indicates that the isolation is or nearly is the maximum possible with this isolation element. See Appendix A, Figures A16 thru A19 for the graphical explanation. The equations to calculate the frequency of a simple pendulum are as follows:

$$P = 2\pi(L/G)^{0.5}$$

Where:

L = Length of the pendulum and G = Acceleration due to gravity

and

$$f = 1/P$$

Where:

f = Frequency and P = Period of the pendulum

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5.1.2 Selecting Measurements for Fitting. For both setup positions, the measurements from the accelerometer on the test fixture adjacent to the test sample should be used for reference only and should not be included to curve fit the data for isolation calculation.

For the isolation element only test (Setup Position 1; Appendix A, Figure A3), the measurements at the driving point are the only measurements that should be used for modal curve fitting.

For the test of the steel brake line and isolation element (Setup Position 2; Appendix A, Figure A4), the driving point and the point at the interface of the steel line and isolation element should both be used for modal curve fitting.

5.1.2.1 Fitting the FRF. Fit the FRFs as would be done for a modal analysis. Refer to GMW14229 for specific instructions. Most of the compliance for each test sample will be contributed by the first few modes; however, fitting the measurement set higher in frequency will improve the accuracy of the calculation. To ensure sufficient minimum accuracy, fit

- a. The first ten modes of the FRF, or
- b. All of the modes up to 10x the frequency of the first mode. Select whichever method results in the larger frequency range.

5.1.2.2 Synthesizing FRF. Use the results of the curve fit to synthesize acceleration FRF and compare synthesized results to the measured data. Refer to GMW14229 for specific instructions; however, a summary follows. In LMS synthesis module, select the "Upper Residual" and "Lower Residual" buttons. Set the rest of the parameters by selecting the "Parameters" button. Select "Compare with Original FRFs in Modal Data Selection" and "Zoom to Frequency Band of Mode Set". The measurements will now appear in a plot on the right side of the screen. If the comparison is not satisfactory, repeat the curve fit until satisfactory comparison is achieved. Although a definition of satisfaction for the fit of an entire measurement set can be found in GMW14229; a more stringent requirement is needed for the compliance calculation. For each measurement that is used in the compliance calculations, the correlation coefficient must be > 95% and the error coefficient must be < 5%.

5.1.2.3 Synthesizing Compliance FRF. After a satisfactory acceleration curve fit has been completed, reset the parameters of the synthesis module as follows:

- Select only the "Upper Residual" button
- In the parameters box, make the following selections:
 - "Use Specified Synthesis Parameters"
 - "Use Frequency Information of FRF in the Current Modal Processing Run"
- In the data format box, select "Displacement"

All other options should be deselected. These settings will produce compliance FRFs. The measurement that will be synthesized for the isolator element only test (Setup Position 1) is the driving point. For the isolator element and steel line test (Setup Position 2), two measurements will be synthesized: the driving point and the measurement for the point at the interface of the isolator element and the steel line in the same direction as the driving point. The 0 Hz value of these curves is the value that represents the static compliance.

5.1.2.4 Zero Hz Compliance from the FRF. The static compliance of the test sample measured in Setup Position 1 may be used directly for comparison between samples and confirmation of the calculated compliance in the following step.

5.1.2.5 Calculating Isolation. Appendix A, Figures A8 thru A15 show a detailed graphical explanation of the calculations. Measurements from Setup Position 2 are used to calculate the sample's actual compliance and isolation. Appendix A, Figure A8 shows where the two measurements come from: the synthesized compliance driving point FRF at the bottom of the test sample (X_2) and the synthesized compliance transfer function FRF from the driving point location to the steel line isolator interface location (X_1). From these curves, the amplitude at 0 Hz is taken for the following equations. Appendix A, Figure A15 shows how the 0 Hz values are obtained using a cursor. The following equation calculates the adjusted compliance for the isolation element of the test sample, and L is the length of the isolation element.

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$$X_{2Actual} = X_2 - [(9X_1/54) + X_1]$$

Once the actual compliance of the isolation element is calculated, the isolation performance can be computed in terms of decibel reduction. $X_{2Actual}$ is the result of the preceding equation and X_1 is the 0 Hz amplitude of synthesized compliance transfer function FRF.

$$\text{dB Reduction} = 20 \times \log_{10}(X_1/X_{2Actual})$$

5.2 Interpretation of Results. Not applicable.

5.3 Test Documentation. Compare calculated isolation from 5.1.2.5 to the requirement in the applicable CTS.

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. Not applicable.

7.2 Acronyms, Abbreviations, and Symbols.

DAS	Data Acquisition System
EHC	Electric Hydraulic Control Unit
FRF	Frequency Response Function
GNVC	Global Noise and Vibration Center
N&V	Noise and Vibration
VPO	Vehicle Performance Owner

8 Coding System

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

Test to GMW16947

9 Release and Revisions

This standard was originated in March 2013. It was first approved by the Global System Actuated Sound Vehicle Performance Owner (VPO) Team in August 2013. It was first published in September 2013.

Issue	Publication Date	Description (Organization)
1	SEP 2013	Initial publication.
2	JUN 2018	Revised to current template. (Global N&V VPO Team - Global Actuated Sounds)

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