



Trimmed Structure Modal Analysis

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. The purpose of this test procedure is to determine the natural frequencies and corresponding mode shapes of a trimmed structure in the 0 Hz to 50 Hz frequency range.

1.2 Applicability. This test procedure is appropriate for benchmarking competitive and GM passenger vehicles in the trimmed structure state. This procedure is valid for use with both Body-Frame Integral (BFI) and Body-on-Frame (BOF) trimmed structures.

The testing standards defined in this document are intended to pertain only to work being done for the corporate database and validation. Other testing methods and interpretations are useful and valid, and should continue to be used for normal trimmed structure development work where appropriate.

1.3 Remarks. Data from trimmed structure modal surveys is often used as a means of describing the structural performance of GM and competitive vehicles.

This test procedure shall be followed in its entirety with the exception of those deviations listed in the Regional Deviations.

2 References

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

2.1 External Standards/Specifications.

None

2.2 GM Standards/Specifications.

GMW14172 GMW14229

3 Resources

3.1 Facilities. The test facility may be any interior environment with a hard level surface to mount the trimmed structure and test equipment.

All facilities shall be free of extraneous noise and vibration sources example, electro-magnetic interference, 60 Hz in the U.S.

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 Processing Equipment. Personal Computer (PC) or Workstation based software capable of performing the modal parameter estimation process described in 5.1.3.

3.2.2 Test Equipment. Appendix A, Tables A1, A2 and A3 contain more detailed information regarding acquisition system, shaker and transducer requirements and examples.

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3.2.2.1 Data Acquisition System (DAS). An acquisition system featuring a minimum of 24 channels of acquisition.

3.2.2.2 Excitation Signal Generators. Appropriate source module(s) (contained in the DAS) or external dynamic signal generator(s) shall be used.

3.2.2.3 Exciters. Appropriate shaker(s) and attachments. These may be hydraulic or electro-dynamic actuated.

3.2.2.4 Input Transducers. Appropriate load cell(s) and/or impedance head(s).

3.2.2.5 Attachment Fixtures. Appropriate structure side excitation attachment fixtures including driving point blocks.

3.2.2.6 Accelerometers or Other Appropriate Transducers for Response Measurements.

3.2.2.7 Vehicle Isolators for Suspension of the Test Object. Four (4) pneumatic isolators (Appendix A, Figure A1).

3.2.2.8 Mini-sledge Impact Hammer.

3.2.2.9 Shaker Stands. Shaker blocks. See Appendix A, Figures A2 and A7.

3.2.2.10 Miscellaneous Equipment. Including, but not limited to appropriate cables, adapters, adhesive substances, and transducer signal conditioning. Choose adhesive substance for transducers (input and response) based on frequency range and availability. See Appendix A, Figures A8, A9 and A10.

3.3 Test Vehicle/Test Piece. Test piece shall be any trimmed structure (see 7.1) that represents current release status for the vehicle platform being evaluated. Deviations shall either be corrected or noted. Deviations not corrected shall be agreed upon with the test requester prior to test. The requester shall fully describe the condition of the trimmed structure, if it features non-standard content.

3.4 Test Time.

Calendar time: 4 to 5 days

Test time: 32 to 40 hours

Coordination time: 8 hours

3.5 Test Required Information. The trimmed structure should be verified to ensure that there are no system groundouts or extra mass/parts in the interior or in the trunk.

3.6 Personnel/Skills. To complete this test, one (1) technician and/or one (1) engineer skilled in vibration data acquisition, analysis, equipment use and test setup is required.

4 Procedure

4.1 Preparation. Obtain trimmed structure Description, Test Data Log and Transducer Location forms, see Appendix C, Data Sheets C1, C2 and C3. Enter appropriate information.

4.1.1 Document Trimmed Structure Content.

4.1.2 Trimmed Structure Preparation.

4.1.2.1 Thoroughly inspect the trimmed structure to ensure that requirements specified in 3.3 and 3.5 are met.

4.1.2.2 Fill all fluid reservoirs in the trimmed structure, including fuel tank, radiator, overflow tank, brake fluid reservoirs, power steering reservoir and urea tank, etc.

4.1.2.3 Weigh the trimmed structure. Record weight in the test data log, see Appendix C, Data Sheet C1 for Trimmed Structure Description data log form.

Note: Test weight does not include instrumentation.

4.1.2.4 Wash the trimmed structure, prior to disassembly if possible, to ensure clean surfaces for adhesion of transducers.

4.1.2.5 Trimmed Structure shall have a Free-Free Boundary Condition. Lift the trimmed structure and install pneumatic isolators, see Appendix A, Section A1 for sample isolator locations and also Appendix A, Figure A6. Slowly lower the trimmed structure to ground. Adjust the air pressure in all pneumatic isolators to stabilize the structure.

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Note: Pneumatic isolators are typically installed at locations of relatively low impedance (high stiffness). For BOF structures, they are located at body mount and/or suspension attachment locations. For BFI structures, they are located at cradle and/or suspension attachment locations, see Appendix A.

To simulate the ideal free-free boundary condition, the air pressure shall be further adjusted such that the highest rigid body natural frequency is the lower of the following:

- a. 0.25 times the first flexure natural frequency or
- b. 8 Hz.

4.1.3 Component Preparation.

4.1.3.1 Adjust Steering Column (if applicable). Adjust tilt steering columns to mid tilt position. For a telescoping column, locate the column at the midpoint of its travel.

4.1.3.2 Adjust steering wheel to the center position so that the steering rotation is not locked.

4.1.3.3 Set the fore/aft seat adjustments fully rearward.

4.1.3.4 Close all doors, windows, and hatches tightly.

4.1.4 Verify Instrumentation Calibration.

4.1.4.1 Verify Transducer System Calibration. Reference GMW14172.

4.2 Conditions.

4.2.1 Environmental Conditions. The ambient temperature should be between 18 °C and 29 °C and temperatures shall not vary more than 6 °C during a given test unless otherwise specified. If ambient temperature is out of this range, make a note in the test data 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.

4.3 Instructions.

4.3.1 Shaker Location Determination. Shakers should be placed at areas of high stiffness (low structural impedance). Also, shakers should be placed with respect to isolated structural elements (frame, cradle) to minimize the effects of isolation.

4.3.1.1 BFI Structures. Identify potential body structure shaker locations on the undersides of the left front rail, right rear rail and left center midrail (optional location) near the B pillar. If this is not possible because of obstructions, use left front and rear, and right center rail locations. Choose locations based upon:

1. Furthest longitudinal extremities (for front and rear locations),
2. Estimated structural impedance, and
3. Ability to locate, orient and secure the shakers.

4.3.1.2 BOF Structures. Identify body structure shaker locations on the undersides of the right front motor compartment rail and left rear D pillar at or near body mount locations (C-pillar for pick-up trucks). Identify potential frame shaker location(s) near the left front end sheet metal mount. Choose locations based upon:

1. Estimated structural impedance (see Appendix A, Section A3.1) and
2. Ability to locate, orient and secure the shakers. Record shaker locations in the test data log.

4.3.1.3 Orient the Shaker Inputs. Choose inputs to be nearly vertical with 10 degrees to 20 degrees offset in the y-z plane and 5 degrees to 10 degrees offset in x-z plane. For BFI structures, orient center shaker primarily vertical with 10 degrees to 20 degrees offset in the y-z plane. For BOF pick-ups, orient rear most body shaker with 30 degrees to 45 degrees offset in the y-z plane.

4.3.1.4 Attach Driving Point Blocks. Mount to chosen locations with dental cement, epoxy or hot glue. Mechanical attachment may also be used if convenient. Attach the blocks so that the force line of action is centered on the structural member to avoid rocking due to local compliance. An example of driving point block is shown in Appendix A, Figure A3.

4.3.1.5 Attach Force Transducers and Driving Point Accelerometers to the Driving Point Blocks.

4.3.1.6 Determine Requirements for Shaker Stinger Lengths and Shaker Stand Heights. Stinger length should be short enough to minimize stinger resonance, and long enough to minimize the magnitude of moment input to the structure.

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4.3.1.7 Connect Force Transducers to Shaker Stingers; Secure Shaker to Shaker Stands and Secure Stands to Test Floor. An example of a shaker stand is shown in Appendix A, Figures A2 and A7.

4.3.2 Force Level Determination. Force levels should be selected that put enough energy into the structure to excite it and yet do not overdrive the trimmed structure beyond the acceptable linear range.

4.3.2.1 Set and Maintain Acquisition Parameters. Starting with the front body structure shaker, set shaker input voltage to achieve the threshold of sensation (i.e., increase voltage until you can just feel the trimmed structure vibrating at a point furthest from the shaker). Note the input voltage setting(s) and return to zero. Repeat the process for each of the remaining shakers.

Increase shaker input voltage to previously noted levels, then adjust until the force time traces indicate the levels are approximately equal (to the higher level).

Set and maintain the following acquisition parameters:

4.3.2.1.1 One percent (1%) of (time block) trigger delay (pre-trigger) for all channels.

Note: A trigger delay should be implemented so that the analyzer recalls buffered time data and considers the input and response data starting from rest. It is typically set as a negative number, (i.e., -40 ms), and may vary in sign depending on the type of analyzer used.

4.3.2.1.2 A 0 Hz to 64 Hz acquisition bandwidth (minimum).

4.3.2.1.3 A 0.125 Hz frequency resolution (minimum).

4.3.2.1.4 Approximately 80% burst length.

Note: Burst random excitation frequency bandwidth should be within the acquisition bandwidth. Set burst length to completely observe the event. To prevent leakage, the response must decay to approximately 95% within the acquisition window. If the response does not sufficiently decay, reduce the burst length accordingly.

4.3.2.1.5 Uniform Windows.

4.3.2.1.6 AC Coupled (1 Hz high pass filter).

4.3.2.1.7 Enable overload detection.

4.3.2.1.8 Twenty-five (25) averages (minimum), 100 averages (typical).

Note: The number of averages used may also vary depending on the number needed to obtain a consistent Frequency Response Function (FRF).

4.3.2.1.9 Zero percent (0%) overlap.

4.3.2.1.10 H₁ or H_v FRF estimator.

4.3.2.1.11 Clear up to the first 1% of bandwidth.

4.3.2.2 Set Initial Excitation Amplitude.

4.3.2.3 Acquire Input Autopower Spectra. Use the parameters specified in 4.3.2.1.

4.3.2.4 Determine the root mean square (RMS) Force Level. (See Appendix B, Section B2.4.2) from each input autopower spectrum for the 5 Hz to 50 Hz frequency span and note these values next to their respective input voltage. Note the source with the largest RMS force level. Adjust the input voltage settings and re acquire the input autopower spectra for input locations until the force RMS levels are approximately equal (to the higher level).

Force level “drop-outs” may be ignored if they significantly degrade the overlay comparison. If a force balance is not possible or realistic be sure that the highest level force cross-driving point crosspower spectrum is at least three (3) orders of magnitude (1000 times) less than the lowest level input autopower spectrum.

4.3.2.5 Acquire Driving Point Measurements. Use the parameters specified in 4.3.2.1.

4.3.2.6 Verify FRF Quality. Determine if the driving point FRFs are correct. If not, make appropriate adjustments and repeat process, see Appendix B, Section B2.1.

4.3.2.7 Verify Reciprocal Relationships. Verify that the FRFs across driving points are reciprocal. The number of sets of reciprocal measurements is given by the following equation.

$$\#sets = \sum_{i=0}^{n-1} i$$

Where:

n = Number of inputs

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If the measured reciprocity is not acceptable, make appropriate adjustments and repeat the process. For troubleshooting procedures, reference Appendix B.

4.3.2.8 Save Input Autopower Spectra and Driving Point and Cross Driving Point FRFs.

4.3.2.9 Set Final Excitation Amplitude. Increase the output of each shaker by approximately 10% (estimate using gain control knobs, time domain data, etc.), and repeat 4.3.2.3 thru 4.3.2.8. Do an “overlay” comparison of the new measurements to original measurements. Record the amplifier and source output settings for each iteration. These will be used later.

4.3.2.10 Repeat 4.3.2.9 until new and original measurements and/or the reciprocal measurements do not compare, see Appendix B, Section B2.4.2.

Note: Shifts in frequency and amplitude indicate an unacceptable non-linear structural response resulting from the changes in excitation amplitude.

4.3.2.11 Reduce the force levels to that of the previous iteration(s) until the new and original measurements compare well again. Due to the inconsistent behavior of non-linear structures, this step may require several iterations.

4.3.2.12 Check for Squeaks and Rattles. Ensure that no low-mass components are vibrating excessively. Tie or tape any buzzing or rattling brackets, wiring, headlights, etc. If these measures do not work, you may have to reduce the force levels further. Record the final (5 Hz to 50 Hz) RMS force level for each input in the test data log.

4.3.3 Response Transducer Placement. Transducers should be placed at a minimum of 100 locations on the trimmed structure (Appendix A, Figures A4, A5 and A6). The criteria for choosing locations are:

- The animated mode shape should be representative of the trimmed structure (i.e., the shape should look like the trimmed structure).
- Sufficient points should be included to fully identify the structural modes in the 0 Hz to 50 Hz range as well as component modes that may appear as structural modes.
- For math model correlation, points shall be selected that spatially coincide with points in the model. A maximum spacing of 100 cm is required between points. The intersection of all structural members and body mount locations should be included.

4.3.3.1 Locate Responses. See Appendix A, Section A4. Mark the following locations (see Table 1) on the trimmed structure (using a wax pencil, sticker or other non-permanent technique) for subsequent transducer placement:

Table 1: Response Locations

Description	Minimum Number Points
Midrails/Longitudinal	4 each
Rockers	3 each
Rear Rails	4 each
A-Pillars	3 each
B-Pillars	2 each
C-Pillars	2 each
Headers	3 each
Front Quarters	2 each
Rear Quarters	4 each
Bumpers (not fascia)	3 each

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Description	Minimum Number Points
Front Seat Backs	2 each
Note: Response transducers should be attached directly to the seat frame where possible. Otherwise, bind the seat back with string or tape and attach the transducer at a firm location.	
Hood	4
Deck Lid/Rear Closure	6
Roof	5
Steering Column	2
Steering Wheel	3 (1 each at 12, 3, 9 O'clock)
Center Floor Console	4
Cradle (if applicable)	4
Frame (if applicable)	12
Side Doors	3 each
Spare Tire	3
Spare Tire Tub (if applicable)	3
Battery	2
CRFM/Radiator	4
Brake Booster	1
Instrument Panel	3

Note: CRFM = Condenser, Radiator and Fan Module

Additional components as required.

Note: The purpose of this test procedure is to determine major trimmed structure modes; however, component dominant modes often exist in the same frequency range as the major trimmed structure modes. If an unobserved (not measured during the test) component has significant contribution (large amplitude motion and significant mass) to the mode shape, the mode may be incorrectly identified as a redundant structure mode. These components may include the fuel tank, CRFM/radiator, battery, spare tire, instrument panel, washer bottle, seats, etc.

4.3.3.2 Record Geometry. Record geometry with respect to a global coordinate system. Prepare the Transducer Location form with the relative locations of each transducer attachment point in a global coordinate system (Appendix C, Data Sheet C3). Measurements should be accurate to 5 cm.

For Finite Element (FE) correlation purposes the accuracy shall be within 5 mm. The model shall reflect the transducer center point (which must also be reflected in the FE model.)

4.3.4 Data Acquisition.

4.3.4.1 Ensure that trimmed structure has reached ambient temperature.

4.3.4.2 Maintain the acquisition parameters specified in 4.3.2.1 and note any deviations in the test data log.

4.3.4.3 Set amplitude of driving forces as determined in 4.3.2.

4.3.4.4 Acquire frequency response functions for transducer locations specified in 4.3.3.

4.3.4.5 Verify FRF quality, see Appendix B, Section B2.1.

4.3.4.6 Verify Coherence quality, see Appendix B, Section B1.4.

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4.3.4.7 Check data for temporal effects. Repeat acquisition of frequency response functions for the first transducer location. Compare to original data to identify potential temporal effects. If any significant changes have occurred, investigate and take appropriate action.

4.3.4.8 Record any problems or comments in the test data log.

4.3.5 Test Techniques/Suggestions.

4.3.5.1 Response Transducer Roving Techniques. Ideally, mount response transducers at all measurement locations prior to test. This will eliminate changing the mass distribution during testing. If pre-mounting all transducers is not possible and transducer roving is required, minimize mass loading effects by placing pairs of triaxial sets in symmetric cross car locations. If more than two (2) triaxial sets are used, spread the sets along the length of the trimmed structure.

4.3.5.2 Suggestions for Opening Closures. Opening and closing doors, hood and/or deck lid may change the dynamic behavior of the trimmed structure, measurements at locations that can only be accessed by opening these components should be made at the end of the measurement sequence.

4.3.5.3 Verify Response Transducer Orientations. Ensure that accelerometer axes are aligned with global coordinate system.

4.3.5.4 Verify FRF Quality. View FRFs for each measurement and look for expected characteristics.

4.3.5.5 Verify Coherence Quality. View coherence functions for each measurement and look for expected characteristics. See Appendix B, B1.4 and B2.1 for more details.

4.3.5.6 Minimize Total Elapsed Time for Data Acquisition. Ideally, this should be less than 5 h. Do not discontinue testing unless there is an equipment or software problem. If the problem causes a 1 h delay (or more), the entire data acquisition sequence should be repeated.

5 Data

5.1 Calculations.

5.1.1 Create Geometry. Recall the record of transducer locations and generate the geometric representation of these locations.

5.1.2 Sums and Mode Indicator Functions (MIF)s. Compute and store a sum (straight sum, imaginary squared sum, etc.) of the measured FRFs and, if applicable, MIFs.

Note: To develop an understanding of the trimmed structure system and the interaction between local and global modes, it is useful to examine sums for individual components.

5.1.3 Parameter Estimation. Use a global multiple degree of freedom modal parameter estimation technique (time or frequency domain) to estimate the natural frequencies and corresponding mode shapes. Typically, time domain based modal parameter estimation works well for lightly damped modes and low modal density. Frequency domain based modal parameter estimation works well for more heavily damped modes and higher modal density. Local modal parameter estimation may be used if global is not available or if it improved the modal parameter estimates. Do not specify "normal/real modes", i.e., specify complex modes.

5.1.3.1 Check for Normal/Real Modes Necessity. For correlation of math models to experimental data, specifying "normal/real modes" may be necessary.

5.1.4 Verify Poles. Compare the summation of all measurements to the individual measurements, paying special attention to estimation of natural frequencies. Do this to ensure that no natural frequencies were overlooked. Reference GMW14229.

5.1.5 Save Results. Store the natural frequency and mode shape information.

5.1.6 Compare Experimental Data to Synthesized Data. Reference GMW14229.

5.1.7 Independently Inspect/Describe Each Estimated Mode Shape. Reference GMW14229.

5.1.8 Account for Component Contribution. Inspect mode shapes (possibly in conjunction with FRFs) for local modes of vibration. If the following components are observed to be moving independently of the global structure (local deflection), include a description of the component deflection in the description field of the modal description summary table, see Appendix D, Data Sheet D1:

- Battery.
- Brake Booster.

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- Bumper (not fascia).
- Fuel tank.
- Hood.
- Rear closure (deck lid/hatch/cargo doors).
- Side doors.
- Spare tire/tub.
- Additional components as required.

Note: The purpose of this test procedure is to determine major trimmed structure modes; however, component dominant modes often exist in the same frequency range as the major trimmed structure modes. If an unobserved (not measured during the test) component has significant contribution (large amplitude motion and significant mass) to the mode shape, the mode may be incorrectly identified as a redundant structure mode. These components may include the instrument panel, washer bottle, seats, etc.

5.1.8.1 If no local deflection is observed in any or all of these components, note this in the notes section of the modal description summary table.

5.2 Interpretation of Results. Not applicable.

5.3 Test Documentation. All test documentation shall contain: contact name, number and organization; date; data type; trimmed structure build description (including all variations); correct axis labels (where appropriate); data storage path and/or archive location, and project name.

5.3.1 Prepare a summary table with natural frequencies, percent (%) critical damping, and mode shape descriptions determined in 5.1.7. An example summary table is shown in Appendix D, Data Sheet D1.

5.3.2 Generate mode shape plots. Animated mode shapes are also commonly presented in databases, memos and presentations. For example many software packages can generate .AVI or .GIF files that can be animated in Microsoft products.

5.3.3 Generate plots of comparison between experimental and synthesized data. Overlay plots featuring the sum of the actual measurements, the sum of the synthesized measurements and also, the measured and synthesized MIF(s).

5.3.4 Take pictures/notes of test setup prior to tear down. Document vehicle content via digital pictures and/or text description. This may include descriptions and/or pictures of the test, sample, test conditions, measurement degrees of freedom, etc.

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.

Audio Video Interleave (AVI): A multimedia container format.

Autopower Spectrum: The magnitude squared of the linear spectrum.

Chassis Structure: Frame or cradle with non-isolated bolt-on structure, e.g., transmission cross member, spare tire support, Original Equipment Manufacturer (OEM) trailer hitch, bumpers. Vehicle Partitioning and Product Structure (VPPS 25).

Crosspower Spectrum: The product of two (2) frequency spectra from two (2) different transducers. Typically, for modal analysis, these are the product of a force spectrum and the complex conjugate of an acceleration spectrum.

Driving Point Measurement: The driving point measurement is defined as the measurement where the response degree of freedom (location and direction) is the same as the excitation degree of freedom.

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