



Shaker Frequency Response Function (FRF) Acquisition Master Test 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. To provide guidelines for setting up and performing a dynamic, shaker excited Frequency Response Function (FRF) measurement for Noise and Vibration (N&V) evaluation procedures.

1.2 Applicability. This test procedure is appropriate for the evaluation of all subsystems, components and vehicles. This test is applicable to both drive point frequency response function (FRF) measurements as well as transfer FRF measurements.

Note: FRFs at mechanical interface locations in full vehicles or components characterize dynamic structure-borne N&V characteristics.

Note: FRFs between mechanical interface locations and response locations are used for various test based analyses, e.g., experimental modal analysis.

1.3 Remarks. Not applicable.

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

3 Resources

3.1 Facilities. Facility requirements may vary depending on the type of test setup. For example, a hemi-anechoic chamber may be required for noise measurements.

Note: All facilities shall have the ability to create appropriate boundary conditions. Boundary conditions are typically defined as in-situ, to-ground or free-free. See 4.1.1 for more details.

Note: All facilities shall be free of extraneous N&V sources (e.g., electro-magnetic interference (60 Hz in the US)).

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.

3.1.3 Room Properties. N&V test rooms have varying properties based on their function. The following examples are intended to define some different room types and properties.

3.1.3.1 Hemi-Anechoic Chamber (car test room and chassis dynamometer rooms.) The ambient background noise levels measured inside the car shall meet the following criteria:

3.1.3.1.1 Ten (10) dB (Re: 20×10^{-6} Pa) lower than the noise levels measured inside the car during the test in a $\frac{1}{3}$ octave format.

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3.1.3.1.2 Should be no greater than 40 dB (Re: 20×10^{-6} Pa), and should facilitate Pressure/Force (P/F) coherence values of at least 0.95 at all P/F maxima in the frequency range of interest.

3.1.3.2 Bedplate/Test Room. The bedplate/test room facility may be any interior environment with a hard level surface to mount the test piece and test equipment with background vibrations levels that facilitate coherence values greater than 0.95 at all FRF maxima over the frequency range of interest.

3.2 Equipment.

3.2.1 Test Equipment. Appendix A contains more detailed information regarding acquisition system, shaker and transducer requirements and examples.

3.2.1.1 Data Acquisition System (DAS). An acquisition system that features two (2) or more channels of acquisition shall be used.

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

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

3.2.1.4 Appropriate load cell(s) and/or impedance head(s).

3.2.1.5 Accelerometers, microphones or any other appropriate transducer for a response measurement.

3.2.1.6 Miscellaneous equipment including, but not limited to: appropriate cables, adapters, adhesive substances (see Appendix B) and transducer signal conditioning (as required).

3.2.2 Test Fixtures.

3.2.2.1 General Guidelines. The test item shall be constrained in a realistic fashion. The general recommendation is that test fixtures are used which reflect a boundary condition that reflects what the test item experiences in operation. This implies that the force and response are to be located as close as possible to what the test item experience in operation. Appendix E shows examples of fixtures.

Fixtures and other hardware attached to test structures will affect measurement results. For this reason, measurements should be made without the use of fixtures whenever possible.

When fixturing is necessary, vehicle hardware should be used wherever possible. In some cases, however, shop made fixtures will be required to execute the desired measurements. Fixtures should be designed to have minimal influence on the measurement. This is because the measurement should characterize the test structure and not the fixture.

3.2.2.2. Design Guidelines for Fixtures.

3.2.2.2.1 Fixtures shall be lightweight and stiff. The lowers natural frequency of any bracket or fixture should be ten (10) times greater than the frequency range of interest. Bolting the fixture to a bedplate and measuring the FRF can be used to verify that this requirement has been met.

3.2.2.2.2 Fixtures or brackets used to measure vehicle FRF should not significantly alter the local stiffness or mass of the vehicle body. The fixtures would ideally be of infinite stiffness and zero mass.

3.2.2.2.3 Driving Point Blocks. Commonly used to attach force transducers and shakers when acquiring near vehicle level FRF information, see Appendix B.

3.3 Test Vehicle/Test Piece. This test procedure is good for any subsystem, component or vehicle level test. For the purpose of validation, the subsystem, component or vehicle to be tested shall be fully assembled and shall represent design intent. The condition of the subsystem, component or vehicle will be noted on test log sheet.

3.4 Test Time.

Calendar time: 4 days

Test time: 16 hours

Coordination time: 4 hours

3.5 Test Required Information. Not applicable.

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

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4 Procedure

4.1 Preparation.

4.1.1 Boundary Conditions. Choose one of the following which is appropriate for the testing being performed.

4.1.1.1 In-Situ Boundary Condition. Corresponds to testing a component or subsystem in a trimmed body, body structure or vehicle (whichever is appropriate for the component).

Mount the component or subsystem into vehicle per recommended installation, bolt torque should be checked to ensure that the attachment stiffness is correct or production intent.

4.1.1.2 Rigid Fixture Mounting. May require custom fixturing. For example, a fabricated test fixture can be mounted to ground (bedplate or rigid fixture) for component mounting.

The fixture shall have a first mode that is at least ten (10) times the desired flexure natural frequency of the component. If this is not possible, make sure that the fixture and component drive point mobilities have at least 20 dB of separation in all three (3) directions. The first natural frequency of the fixture should be evaluated with a rigid mass equal to that of the component attached to it.

Note: Natural frequencies of test fixtures and free-free components can be evaluated by making driving point measurements in three (3) perpendicular directions at the attachment points between the fixture and the component.

4.1.1.3 Free-Free Mounting. In this condition, the test piece has no constraints. This is not achievable realistically, so free-free mounting is approximated by using compliant springs or pneumatic isolators. Determining spring compliance is dependent on certain test information. For example:

An acoustic sensitivity test requires that the test piece be dynamically isolated from ground by at least one (1) order of magnitude (test piece should be at least ten (10) times stiffer than the compliant spring whenever possible). Isopads (soft rubber pads) suffice for this requirement, since isopad stiffness is typically well below $1/10$ of the test piece stiffness.

A free-free boundary condition in a laboratory can include, but is not limited to, the following suggestions:

4.1.1.3.1 Hanging the test piece from bungee cords or coil springs. The test piece shall be secured appropriately and the loading limits shall not be exceeded.

4.1.1.3.2 For low frequency (0 Hz to 64 Hz) trimmed body or body structure testing, mount the test piece on pneumatic isolators. Due to practical reasons, it is acceptable to have the highest rigid body mode as high as $1/3$ of the lowest flexural body mode.

4.1.1.3.3 For high frequency (50 Hz to 800 Hz) trimmed body or body structure testing, place the test piece on lightweight damped material, e.g., isopads. The test piece should be mounted so that the highest system rigid body mode natural frequency is at most $1/10$ of the lowest flexural natural frequency of the component.

4.1.1.3.4 For some component body attachment point testing, a free-free condition may imply a full vehicle, on its wheels, with the component removed.

4.1.2 Component Preparation.

4.1.2.1 If the component being evaluated features a radiator, coolant bottle, fuel tank, etc., it shall be filled to the desired level per the evaluation procedure.

4.1.2.2 If the component is adjustable (steering column, seat, etc.), set it to the nominal position in all adjustable directions unless otherwise specified in the evaluation procedure.

4.1.2.3 The component (steering column, suspension, powertrain, etc.) should not be bound up or restrained in a way that is not intended by design. This may add non-linear constraints to the system.

4.1.2.4 Any part of the component that rattles shall be secured.

4.1.2.5 In the case of sound pressure measurement, ensure vehicle cavity is sealed (windows up, doors closed, cracks taped, etc.)

4.1.2.6 The test piece temperature shall be at equilibrium with the ambient temperature, see 4.2.1.

4.1.3 Verify Instrument Calibration.

4.1.3.1 Verify Transducer System Calibration. See GMW14172.

4.1.3.2 Verify Acquisition System Calibration. The acquisition system calibration shall be periodically verified by the appropriate instrumentation personnel.

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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.

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 Typically, the cable(s) for the input force(s) should be connected to the first channel(s) of the DAS and the response channels should subsequently follow.

4.3.2 The following acquisition parameters are recommended but may vary depending on the dynamics of the component being tested and the desired frequency span and resolution.

4.3.2.1 Typical Acquisition/Processing Parameters.

- 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.

- Use burst random input signal for broadband excitation.
- Set burst length to completely observe the event in a Uniform Window. If the event cannot be completely observed within the time period, use an appropriate window.

Note: To prevent leakage, the response should decay such that the magnitude of the windowed response signal at the end of the time segment is less than 5% of the magnitude of the peak of the signal. If the accelerometer response has decayed to less than 5% of the magnitude of the peak of the time signal, a uniform window should be used. The burst length should be set to maximize the input energy while allowing enough time for the signal to decay within the window. For vehicle level modal testing the burst length is approximately 80%. If the response does not sufficiently decay by varying the burst length or if burst random excitation cannot be used, a Hanning or similar type of window is recommended to minimize leakage. **Note:** For structures with very low damping, impact excitation may be more appropriate.

- AC Coupled (1 Hz high pass filter).
- Enable overload detection.
- 25 Averages (minimum), 100 Averages (typical).

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

- H_1 or H_v FRF Estimator (see Appendix C, C1.1.3.2).
- 0.125 Hz Frequency Resolution (maximum).

4.3.3 Measurement Location(s). The measurement locations (input and response) and orientations (fore-aft, vertical, etc.) should be selected to excite (input) and capture (response) all the modes of interest of the component.

4.3.3.1 Transducer Mounting.

4.3.3.1.1 Response. Vibration transducers (accelerometers, strain gauges, etc.) should be mounted to a flat surface on the test structure using the appropriate adhesive, see Appendix B. For consistency, it is advised that measurement coordinate axes adhere to standard GM drafting vehicle coordinates, i.e.:

- +X = Longitudinal/rearward
- +Y = Lateral/right hand rule
- +Z = Vertical/upward

For lower frequency measurements (< 64 Hz) clay may be used to keep the measurement axis of the transducer square to the vehicle coordinates.

Microphones should be mounted using a microphone stand or a microphone hanger.

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Note: If the results of this test are used for modal analysis, geometry shall be measured. Record the relative locations and orientation of each response transducer with respect to the global vehicle coordinate system. An example transducer location/orientation recording sheet is contained in Appendix D, Data Sheet D1.

4.3.3.1.2 Input Force. Attach driving point blocks or similar fixtures to chosen excitation locations with dental cement, epoxy or hot glue (dependent on frequency range of interest). Attach blocks so that the force line of action is centered on the structure. Mechanical attachment may also be used if convenient.

Attach force transducers and driving point accelerometers to the driving point blocks. Impedance heads, which are transducers that contain both force and acceleration outputs in one unit are commonly used.

4.3.3.2 Shaker Mounting.

4.3.3.2.1 Determine requirements for shaker stinger lengths and shaker stand heights.

Note: Stingers should be short enough to eliminate (stinger) modes in the frequency range of interest but long enough to properly eliminate torque input.

4.3.3.2.2 Connect force transducers to shaker stingers; secure test stands to test floor or fixture. A horizontal shaker may require additional bracing; additional mass may be required if hanging using a lateral shaker stand.

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

4.3.4.1 Set amplitude of driving force(s) as follows:

1. Starting with one (1) shaker, set the shaker gain to achieve the threshold of sensation (i.e., increase gain until the structure vibrating at a point furthest from the shaker can just be felt).
2. Note the gain setting and return to zero.
3. Repeat the process with the other shaker(s) if applicable.
4. Note the gain setting(s) and return to zero.
5. Turn all shakers on and increase gains to previously noted levels; then adjust until the force time traces indicate that the force levels are approximately equal (to the higher level).

4.3.4.2 Acquire driving point FRF as covered in 4.3.5.

4.3.4.3 For a multiple input test, determine if the force levels for all of the shakers are similar by using an overlay comparison of the input autopower spectra. If the force levels are not equal, adjust the gain settings (within a narrow range) and repeat the process. A comparison of the Root Mean Square (RMS) force levels across the main frequency range of interest may also be useful during the force balance process. 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 spectrum is at least three (3) orders of magnitude (1000 times) less than the lowest level autopower spectrum.

4.3.4.4 Determine if the driving point FRF(s) are correct (see Appendix C). If not, make appropriate adjustments and repeat the process.

4.3.4.5 For multiple input tests, verify that the reciprocity checks are acceptable (see Appendix C).

Typically, reciprocity across isolators will not be perfect due to the non-linearity of the elastomeric mounts. If the measured reciprocity is not acceptable, make appropriate adjustments and repeat the process. For troubleshooting procedures, see Appendix C.

4.3.4.6 Save input autopower spectra and driving point and input cross point FRFs (if applicable).

4.3.4.7 Increase the output of each shaker by approximately 10% (estimate using gain control knobs, time domain data, etc.) and repeat 4.3.4.2 thru 4.3.4.6. Verify reciprocity (where applicable) and do an overlay comparison of the new measurements to original measurements. Record the amplifier and source output setting for each iteration. These will be used later.

4.3.4.8 Repeat 4.3.4.7 until new and original measurements and/or the reciprocal measurements do not compare.

Note: When shifts in frequency and amplitude occur, this indicates your excitation amplitude is resulting in unacceptable non-linear structural response. See Appendix C for more details.

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4.3.4.9 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 reductions.

4.3.4.10 On structures with multiple components, 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, the force levels may have to be reduced further. Record the final RMS force level and bandwidth for each input (see Appendix C) in the test data log.

4.3.5 Data Acquisition.

4.3.5.1 Set acquisition and processing parameters as specified by 4.3.2.

4.3.5.2 Set amplitude of the final driving forces determined in 4.3.4.

4.3.5.3 Setting Dynamic Ranges. Range should be set such that at least half of the Analog-to-Digital Converter (ADC) range is utilized. This is usually done through an auto ranging process of the measurement channels.

4.3.5.4 Observe the windowed time signal of the response transducers. The signal should decay to no greater than approximately 1% of the full-scale value. If the signal has not decayed to this level, see 4.3.2.

4.3.5.5 Acquire FRFs for all transducer locations.

4.3.5.6 Verify the measurement(s). View each FRF and the measurement coherence (see Appendix C).

4.3.5.7 If the data quality is judged to be adequate, save the trace to a file, and record any remarks on the test documentation form.

4.3.5.8 General Measurement Practices.

4.3.5.8.1 Ideally, mount response transducers at all measurement locations prior to test. This will eliminate operator interaction with the structure and also 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 transducers in sets in symmetric locations. If more than two (2) sets are used, spread the sets along the length of the structure.

4.3.5.8.2 Minimize total elapsed time for data acquisition. Do not discontinue testing unless there is an equipment or software problem. If the problem causes a (more than) 1 h delay, the entire data acquisition sequence should be repeated.

5 Data

5.1 Calculations. FRFs are complex numbers. Therefore, they contain real and imaginary information. These can be displayed in several different ways. The following are some common examples:

5.1.1 Real and Imaginary. The imaginary portion of an accelerance FRF contains normal mode information, which can be used to determine mode natural frequency as well as response location amplitude and phase, relative to the excitation.

5.1.2 Amplitude and Phase. Amplitude is the absolute value of the FRF, and phase is the angle. Data are commonly displayed in this format for mobility measurements. Although, phase is generally disregarded for this type of measurement. Amplitude can be displayed in three (3) commonly used formats:

5.1.2.1 Absolute Scale. The square root of the sum of the squares of the real and imaginary portions.

5.1.2.2 Log Scale. Typically log base ten.

5.1.2.3 Decibel Scale. A version of the log scale. Defined as ten (10) times the log base ten of the squared ratio between an absolute and reference value.

Note: If the ratio is in power units, it shall not be squared. Acoustic sensitivity FRFs feature a 10 $\mu\text{Pa}/\text{N}$ reference value.

5.2 Interpretation of Results. Reference referring procedure(s).

5.3 Test Documentation. Data presentation is usually in the form of a plotted FRF. The FRF should contain the information necessary to determine if the component has met its dynamic specification.

5.3.1 All FRF plots shall include the following information:

5.3.1.1 Test Engineer's Name (or initials), phone number and organization.

5.3.1.2 Date.

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5.3.1.3 Type of measurement (accelerance, mobility, etc.)

5.3.1.4 Component, Subsystem or Vehicle Identification. A brief description of the design level of component, subsystem or vehicle shall be included, preferably in the test name (see 5.3.1.5). A more detailed description with data acquisition parameters shall be included in the test documentation form.

5.3.1.5 Project name and test name. The project name shall be specified such that it includes information of interest such as the component, subsystem or vehicle.

5.3.1.6 Axes Labels shall be as follows:

x: Frequency: Hz.

y: Amplitude with metric units (and dB reference, if applicable).

5.3.1.7 Force excitation location and direction.

5.3.1.8 Response location and direction.

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.

7.1.1 Vehicle Construction Types.

- a. **Body-Frame Integral (BFI):** The primary structure for a BFI vehicle is provided by the body. In some cases, this primary structure is complemented by chassis structure at one or both ends of the vehicle (i.e., cradles or cross-members which may be rigidly attached to the body or attached using isolators). The front and rear chassis systems are typically structurally coupled via the body, except in certain cases of driveline configuration such as the drive shaft assembly in a torque tube system (e.g., Corvette platform).
- b. **Body-On-Frame (BOF):** The structure for a BOF vehicle is provided by both the body and frame. The body or cab is attached to the frame at discreet locations using body mounts (isolators). The suspension, powertrain and driveline are typically attached to the frame. If the product is a conventional pickup, the pickup box is generally rigidly attached to the frame structure only. If the product is an Ultimate Utility Vehicle (UUV), the pickup box is typically integral to the body and also attached to the frame using body mounts (isolators). The Front End Sheet Metal (FESM) can be integral to the body (generally welded) or non-integral (bolted to the body), isolators or body mounts also connect the FESM to the frame.

7.1.2 Body Configurations.

- a. **Body-In-White (BIW):** The configuration that leaves the paint booth or the basic structural shell of the vehicle including: floor pan, front of dash, door side ring, front radiator support, doors, FESM and deck lid/hatch prior to topcoat paint and trim.
- b. **Body Structure:**
 1. **BIW** with non-structural closures removed.

Note: A Body Structure typically does not include the hood, doors, deck lid/hatch or bolt-on fender outers unless these are assumed to be structural items. The use of closures as structural elements should be defined in the requirements for the vehicle program, and taken into consideration during development and validation testing.
 2. **Paint**, inclusive of Electrodeposition Primer (ELPO); E-Coat, and other properly cured sealers and adhesive(s).
 3. **Properly Bonded Fixed Glass**, such as windshield, backlight or fixed quarter windows, with any trim needed for glass installation and retention.
 4. **All Non-Isolated Structural Bolt-On Parts.** The specific parts included will vary depending on the vehicle design. Examples include: hard-mounted cradles (with braces if appropriate), non-integral

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FESM, Instrument Panel (IP) beam, pedal support bracket(s), bolt-on radiator supports, rear cross-members, diagonal braces, bumper beam(s) and tunnel straps.

5. **Sunroof Module(s).** Generally included if anticipated to contribute to the structural stiffness.

7.1.3 Trimmed Body Configurations.

- a. **Trimmed Body (BFI):** A full vehicle without chassis, powertrain, exhaust or suspension. The Trimmed Body includes swing metal, reservoirs, body-mounted fuel tank, batteries, glass, seats, doors, interior trim, IP and console, rear window trim panel, acoustic treatments and other items that add mass to the body structure. The fuel tank should be full and all other fluids should be filled to the manufacturer recommended specification.

Note: A trimmed body does not include isolated cradles, but does include cradle bolt stabilizer brackets.

- b. **Trimmed Body (BOF):** The Trimmed Body (BOF) is defined as the collection of sub-assemblies supported by the Body Structure when separated from the frame/chassis at the body mounts. Both integral and non-integral (bolt-on) FESM should be included, together with a Condenser, Radiator, Fan Module (CRFM) if all mounts are to the body or FESM. The fuel tank should be full and all other fluids should be filled to the manufacturer recommended specification.
- c. **Trimmed Body (BOF) Without FESM:** The Trimmed Body without FESM configuration applies only to products with non-integral (bolt-on) FESM. The configuration is achieved by removing the FESM from the Trimmed Body.

7.2 Acronyms, Abbreviations, and Symbols.

ADC	Analog-to-Digital Converter
BFI	Body-Frame Integral
BIW	Body-In-White
BOF	Body-On-Frame
CRFM	Condenser, Radiator, Fan Module
DAS	Data Acquisition System
dim	dimension
ELPO	Electrodeposition Primer
emf	Electromotive Force
FESM	Front End Sheet Metal
FFT	Fast Fourier Transform
FRF	Frequency Response Function
IDSR	Integration Driven Subsystem Requirements
IP	Instrument Panel
N&V	Noise and Vibration
N/A	Not Applicable
OEM	Original Equipment Manufacturer
P/F	Pressure/Force
RMS	Root Mean Square
UUV	Ultimate Utility Vehicle
VPO	Vehicle Performance Owner

8 Coding System

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

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