GM	WORLDWIDE ENGINEERING STANDARDS	Test Procedure	GMW14902

Vehicle Sensitivity to Powertrain Crank Axis Torque Input 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. The purpose of this test procedure is to determine the vehicle level sensitivity due to the powertrain black crank path axis torsion degree of freedom input in the 1 Hz to 100 Hz range.

1.2 Applicability. This test procedure is appropriate for benchmarking competitive and GM passenger vehicles in the full vehicle state. This procedure is valid for use with both Body Frame Integral and Body on Frame full vehicles.

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

1.3 Remarks. Data from this evaluation procedure can be used to describe idle quality, idle vibration, early Torque Converter Clutch (TCC) lock-up noise and vibration, and active fuel management vehicle level sensitivity to the powertrain block path crank axis degree of freedom torsion input for GM and competitive vehicles.

2 References

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

2.1 External Standards/Specifications.

IEC 651

2.2 GM Standards/Specifications.

GMW8477	GMW8702	GMW14172	GMW14229

3 Resources

3.1 Facilities. The tests shall be performed in the designated testing environment at each GM regional site. The test shall be performed in a semi-anechoic environment, with a hard, flat-floor surface. All facilities shall be free of extraneous noise and vibration sources (i.e., electromagnetic interference, 60 Hz electrical noise). The ambient background noise level must be a minimum of 15 dB below the signal being measured. The ambient temperature shall be between 18 °C and 25 °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. Required equipment types and specifications are given in 3.2.1 thru 3.2.1.6.

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

3.2.1.1 Data Acquisition Equipment. Use the preferred digital data acquisition hardware system and software identified by the Global Noise and Vibration Infrastructure Team to be capable of performing this procedure.

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

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3.2.1.3 Accelerometers. High sensitivity and low mass triaxial accelerometers with a flat frequency response between 1 Hz and 1000 Hz and a temperature range of 18 °C to 30 °C or greater shall be used.

3.2.1.4 Microphones. Random incidence microphones are preferred for vehicle interior locations. Free-field microphones may be used for interior locations if random incidence microphones are not available. All devices shall meet Class 1 accuracy corresponding to IEC 651 or be equivalent for the application (precision ± 0.7 dB or ± 8%).

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

3.2.1.6 Processing Equipment. Use the preferred modal analysis software identified by the Global Noise and Vibration Infrastructure Team to be capable of performing the modal parameter estimation process described in Parameter Estimation section of GMW8477.

3.3 Test Vehicle/Test Piece. The test piece shall be any full vehicle as described in GMW8702 of either Body Frame Integral or Body on Frame construction that represents current release status. Deviations shall either be corrected or noted. The requester shall fully describe the condition of the full vehicle if it features non-standard content.

3.4 Test Time.

Calendar time:	2 to 6 days
Test hours:	8 to 16 hours
Data Analysis hours:	4 hours
Coordination hours:	4 hours

3.5 Test Required Information. The full vehicle 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 Full Vehicle Description, Test Data Log and Transducer Location forms found in Appendix F, Data Sheets F1, F2 and F3. Enter appropriate information.

4.1.1 Full Vehicle Preparation. Thoroughly inspect the full vehicle to ensure that requirements specified in 3.3 and 3.5 are met.

4.1.1.1 Fill all fluid reservoirs in the full vehicle, including fuel tank, radiator, overflow tank, brake fluid reservoirs, engine oil, transaxle fluid, power steering reservoir, etc.

4.1.1.2 Weigh the full vehicle. Record the vehicle weight on the Full Vehicle Description form found in Appendix F, Data Sheet F1.

Note: Test weight does not include test instrumentation.

4.1.1.3 Adjust cold tire pressure to the manufacturer's specifications (allow tires to cool if the vehicle has been recently operated). Record pressures in the comments section of the Full Vehicle Description form in Appendix F, Data Sheet F1.

4.1.1.4 The vehicle should be washed to ensure clean surfaces for adhesion of transducers.

4.1.2 Component Preparation. Adjust tilt steering columns (if so equipped) to eliminate any relative angle between the lower and upper steering column. If equipped with a telescoping column, locate the column at the midpoint of its travel.

4.1.2.1 Adjust steering wheel to the center position with the column lock engaged.

4.1.2.2 Set the fore/aft seat adjustments to design position or to midpoint of travel if design position is unknown.

4.1.2.3 Close all doors, windows and hatches tightly.

4.1.3 Instrumentation Calibration. Transducer System Calibration. The force couple distance between the two (2) shakers is used to scale the force transducer calibration sensitivities to equivalent moment sensitivities. This is done by multiplying the force transducer sensitivities (N/V) by the force couple distance (m) to obtain an equivalent moment sensitivity ((N*m)/V). Also reference GMW14172.

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4.2 Conditions.

4.2.1 Environmental Conditions. Reference GMW8477.

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.

Note: Set the vehicle onto test stands using appropriate non-damaging techniques. Adjust the vehicle and/or the stands to stabilize the stands and to remove any suspension preloads. Install appropriate wheel chocks and apply park brake to prevent vehicle movement. Shift vehicle transmission into neutral.

4.3 Instructions.

4.3.1 Torque Input. The torque input excitation is externally applied to the powertrain using a force couple (see Appendix B and Appendix C).

4.3.1.1 Force Couple Input Location. Torque input to the powertrain should be placed at areas of high stiffness (low structural impedance) that have adequate spacing for shaker force couple. Also, torque input should not be placed near isolated structural elements (frame, cradle) in order to minimize the effects of isolation.

4.3.1.1.1 Typically, the force couple can be directly attached to either the powertrain or transmission by attaching to available bosses or fasteners. A bracket can also be fabricated to facilitate the attachment of the force couple to the powertrain to enable sufficient geometric spacing between the shakers. This bracket must be stiff enough to have inertance comparable of below that of the body structure attachments. The bracket should provide for attachment of force transducers and reference accelerometers (see Appendix D, Figure D1).

4.3.1.1.2 Choose locations base upon:

- Appropriate orientation to excite desired degree of freedom
- Available attachments on powertrain (i.e., unused bosses)
- Ability to locate, orient and secure force couple

4.3.1.2 Force Couple Input Orientation. The purpose of the force couple input is to excite rotation about the powertrain crank axis degree of freedom. The excitation degree of freedom is **pitch** for a transverse mounted powertrain and **roll** for a longitudinal mounted powertrain.

4.3.1.3 Force Couple Alignment. The plane defined by the force couple must be aligned to be perpendicular to the powertrain crank axis. Ensure the line of action for both shakers that make up the force couple are parallel with respect to one another. The shakers do not need to be placed symmetrically about the crank axis.

4.3.1.4 Force Couple Distance. The force couple distance between the two (2) shakers is used to scale the force transducer calibration sensitivities to equivalent moment sensitivities (see 4.1.3). Record the force couple distance on the Test Data Log in Appendix F, Data Sheet F2.

4.3.1.5 Force Couple Input Signal. Only a single source input signal is used in the force couple. The single input signal is replicated and inverted to provide both shakers with the identical input signal that is 180 degrees out of phase.

4.3.1.5.1 A way to replicate and invert the single source signal is to use a T-Bayonet Neill-Concelman (T-BNC) connector along with the polarity reversal of the shaker amplifier output cable to the shaker. The T-BNC connector is used to replicate the single source signal output from the acquisition front end. The input signal polarity for the second shaker is reversed by switching the positive and negative phase of the signal to the first shaker (refer to Appendix E, Figure E1).

4.3.1.5.2 Another way to replicate and invert the single source signal is to use a GMNA Noise and Vibration Center (NVC) Sum Difference Box.

4.3.1.5.3 The original source signal is connected to the first shaker (F_{Z1}) in the force couple. The replicated and inverted signal is connected to the shaker amplifier for the second shaker (F_{Z2}). Shaker amplifier gains for each shaker can them be adjusted to set the force levels as outlined 4.3.1.7.

4.3.1.6 Force Couple Phase. The phase between the two (2) shakers in the force couple must be 180 degrees out of phase. It is critical to verify the phasing to satisfy the force couple requirement. The phase can be verified by reviewing the phase of the F_{Z1}/F_{Z2} Frequency Response Function (FRF) measurement. One indication that the shakers need realignment is when there are several jumps in the F2/F1 phase back and forth between 0 degrees and 180 degrees.

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4.3.1.7 Shaker Stinger Lengths. Determine requirements for shaker stinger lengths and shaker stand heights. Singer length should be short enough to minimize stinger resonance, and long enough to minimize the magnitude of moment input to the structure.

4.3.1.8 Reference Transducers. Connect force couple force transducers to shaker singers; secure shaker to shaker stands and secure stands to test floor.

4.3.1.9 Force Couple Level Input Level Determination. Using the acquisition software, set the input voltage that is applied to both shakers in the force couple to achieve the threshold of sensation (i.e., increase voltage until a tester can just feel the steering wheel and points on the structure vibrating at points furthest from the shakers). Typical input levels are from 5 Nm to 7 Nm Root Mean Square (RMS) from 20 Hz to 80 Hz.

4.3.1.10 Balancing Force Couple Force Levels. Measure the FRF (F_{Z2}/F_{Z1}) for ten (10) averages between the two (2) shakers in the force couple. Adjust the individual shaker amplifier gains to balance the amplitude of the force couple. Use FRF (F_{Z2}/F_{Z1}) as an indicator of balanced levels such that the F_{Z2}/F_{Z1} 20 Hz to 80 Hz RMS is 1.00 ± 0.02.

4.3.2 Rotational Drive Point Response. The rotational drive point is calculated using a pair of accelerometers which are co-located with the force couple transducers (see Appendix B and Appendix C).

4.3.2.1 Rotational Drive Point Location. Each accelerometer in the rotational accelerometer drive point pair is attached to the powertrain and co-located next to a force couple force transducer. The powertrain attachment locations should be placed at areas of high stiffness (low structural impedance).

4.3.2.2 Rotational Drive Point Orientation. The purpose of the rotational drive point response is to measure the rotational acceleration response about the powertrain crank axis degree of freedom. The response degree of freedom is **pitch** for a transverse mounted powertrain and **roll** for a longitudinal mounted powertrain.

4.3.2.3 Rotational Drive Point Alignment. The vertical axis of the accelerometers must align to be parallel to the force couple lines of action. Recall that the force couple is aligned to be perpendicular to the powertrain crank axis. Ensure the accelerometer vertical axes are parallel with respect to one another.

4.3.2.4 Rotational Drive Point Distance. The distance between the two (2) accelerometers in the rotational drive point pair is used to scale the difference in the translational accelerations. Assuming that the accelerometers have the same orientation direction, the scaling is done by subtracting the accelerometers and dividing by the distance between the accelerometers. Record the rotational drive point accelerometer distance on the Test Data Log in Appendix F, Data Sheet F2.

4.3.3 Required Response Transducer Placement. Refer to Table 1 for the minimum required accelerometer response locations.

Table 1: Required Accelerometer Response Transducer Locations

Description (Preferred Component Name)	Minimum Number of Points
Driver Seat Front Outboard Attach (DFOBST)	1
Driver Seat Rear Inboard Attach (DRIBST)	1
Steering Wheel 12 o'clock position (STWH12)	1
Steering Wheel 3 o'clock position (STWH3)	1
Drive Point Rotation Response (AoTPowertrain)	1 pair

Note: Seat response transducers should be attached directly to the seat attachment to body where possible; otherwise, attach to lower seat track channel firm location. See Appendix C, Figures C1, C2 and C3 for seat track attachment sample photos and Appendix C, Figures C4 and C5 for steering wheel attachment photos.

Refer to Table 2 for the minimum required microphone response locations (see also Appendix C, Figure C6). Record response locations on the Transducer Location Log in Appendix F, Data Sheet F3.

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Table 2: Required Microphone Response Transducer Locations

Description (Preferred Component Name)	Minimum Number of Points
Driver Seat Inboard Ear (DRE)	1
2nd Row Passenger Side Center Position Right Rear Ear (RRE)	1

Refer to Appendix C, Figure C7 for a schematic of the required response transducer locations.

4.3.3.1 Additional Response Transducer Placement. Additional accelerometer and microphone response transducer may be added for diagnostic purposes. See Table 3 for a recommended set of additional accelerometers. Record response locations on the Transducer Location Log in Appendix F, Data Sheet F3.

Table 3: Additional Accelerometer Response Transducer Locations

Description (Preferred Component Name)	Minimum Number of Points
Driver Seat Front Inboard Attach (DFIBST)	1
Driver Seat Rear Outboard Attach (DROBST)	1
Driver Seatback (High)	1
Steering Column	2
Powertrain/Transmission	5
Exhaust Major Elements	12
Rockers	3 each
Rear Rails	3 each
Bumpers	2 each
A-pillars	3 each
B-pillars	3 each
C-pillars	3 each

4.3.3.1.1 Transducers should be placed at approximately 50 locations on the body, powertrain, steering column, steering wheel, and exhaust systems. Refer to 4.3.3.1.2 thru 4.3.3.1.5 for the criteria for choosing locations.

4.3.3.1.2 The animated mode shape should be representative of the vehicle structure (i.e., the shape should look like the vehicle).

4.3.3.1.3 Sufficient points should be included to fully identify the structural modes in the 0 Hz to 40 Hz range, as well as component modes that may appear as structural modes.

4.3.3.1.4 A maximum spacing of 100 cm is required between points. The intersection of all structural members should be included.

4.3.3.1.5 Mark the locations on the vehicle (using a wax pencil, sticker or other non-permanent technique) for subsequent transducer placement.

4.3.3.1.6 Additional Comments as Required. Reference GMW8477.

4.3.3.1.7 Record Geometry. Reference GMW8477.

4.3.4 Data Acquisition. Reference GMW8477.

4.3.4.1 Ensure that vehicle has reached ambient temperature. Immediately prior to data acquisition, disconnect the shakers and exercise the front and rear suspensions to remove any “sticktion”. Also exercise the powertrain

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and exhaust mounts by manually shaking the powertrain shaker attachment bracket and the tail pipe(s). Reconnect shakers.

4.3.4.2 Maintain the following acquisition parameters:

- Use Force Couple F1 as the only Reference Channel
- Use Force Couple F2 as the first Response Channel
- Burst Random Input Signal: **Note:** If, due to equipment limitations, another input signal must be used, consult the NVC to determine acceptable alternate acquisition parameters.
- Approximately 80% Burst Length. **Note:** Response must decay approximately 95% within the acquisition window to prevent leakage.
- Trigger Delay: 1% (of Time Block)
- H_1 or H_v FRF Estimator
- Uniform Windows
- Microphone Responses Un-Weighted (A-weighting is applied to microphone measurements during post-processing calculations described in 5.1.1)
- Block Size: 2048 (minimum)
- Alternating Current (AC) Coupled
- Input and Acquisition Range: 0 Hz to 128 Hz (minimum)
- Frequency Resolution: 0.125 Hz (minimum)
- Overlap Processing: 0%
- Clear up to the First 1% of Bandwidth

4.3.4.3 Verify the Force Couple. Compute the 20 Hz to 80 Hz RMS value of the FRF (F_{Z2}/F_{Z1}) between force couple shaker One (F_{Z1}) and shaker Two (F_{Z2}). Use FRF of F_{Z2}/F_{Z1} as an indicator of balanced levels. The F_{Z2}/F_{Z1} FRF 20 Hz to 80 Hz RMS value should be approximately 1.00 ± 0.02. Verify that the two (2) shakers are 180 degrees ± 2 degrees out of phase by checking the measurement phase angle. Record the force couple input level, F_{Z2}/F_{Z1} amplitude level and F_{Z2}/F_{Z1} angle 20 Hz to 80 Hz RMS on the Test Data Log in Appendix F, Data Sheet F2.

4.3.5 Test Techniques/Suggestions. Reference GMW8477.

5 Data

5.1 Calculations.

5.1.1 Calculate the rotational drive point FRF by dividing the difference in the FRF drive point acceleration pair by the measured distance between the accelerometers (see Appendix B, Figures B1 and B2 for diagram).

5.1.1.1 Longitudinal Powertrain:

$FRF(A_{XX}/T_{XX}) = [FRF(A_{Z2}/T_{XX}) – FRF(A_{Z1}/T_{XX})]/d_{YAP}$ with units of $(rad/s^2)/N*m$

[dB re: 1 $(rad/S^2)/N*m$]

Where:

A_{Z1} = Rotation acceleration drive point acceleration Number 1

A_{Z2} = Rotation acceleration drive point acceleration Number 2

FRF = Frequency Response Function

T_{XX} = Torque applied by Force couple

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5.1.1.2 Transverse Powertrain:

$FRF(A_{YY}/T_{YY}) = [FRF(A_{Z2}/T_{YY}) – FRF(A_{Z1}/T_{YY})]/d_{XAP}$ with units of $(rad/s^2)/N*m$

Where:

A_{Z1} = Rotation acceleration drive point acceleration Number 1

A_{Z2} = Rotation acceleration drive point acceleration Number 2

FRF = Frequency Response Function

T_{YY} = Torque applied by Force couple

5.1.2 Create Geometry. Reference GMW8477.

5.1.3 Sums and Mode Indicator Function (MIF) Reference GMW8477.

5.1.4 Parameter Estimation. Reference GMW8477.

5.1.5 Verify Poles. Reference GMW8477.

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

5.1.7 Compare Experimental Data to Synthesized Data. Reference GMW14229.

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

5.2 Interpretation of Results. Verify whether the SSTS and VTS requirements are achieved.

5.3 Test Documentation. Reference GMW8477, Appendix C.

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.

A_{XX}, A_{YY}: Rotation acceleration drive points.

A_{Z1}: Rotation acceleration drive point acceleration Number 1.

A_{Z2}: Rotation acceleration drive point acceleration Number 2.

d_{AP}: Distance between rotation drive point acceleration pair.

d_{FC}: Distance between force couple forces.

F_{Z1}: Force couple Force 1 (from reference shaker Number 1).

F_{Z2}: Force couple Force 2 (from reference shaker Number 2).

Sticktion: Friction in the suspension system strut or shock that causes the unit to lock up or “stick” under the load magnitudes described in this procedure.

T-BNC: An electrical connector that converts a single Bayonet Neill-Concelman (BNC) cable output to dual BNC cable inputs.

T_{XX}, T_{YY}: Torque applied by Force couple.

7.2 Acronyms, Abbreviations, and Symbols.

AC	Alternating Current
AoTPowertrain	Drive Point Rotation Response
A/T	Acceleration over Torque
AWD	All Wheel Drive
BNC	Bayonet Neill-Concelman
dB	Decibel(s)

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