



Driveline System Level Vibration 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 procedure is to evaluate key vibration characteristics of a driveline system in a driveline dynamometer test cell.

1.2 Applicability. This test procedure is applicable to driveline system level testing in a driveline dynamometer test cell. It is not applicable to vehicle level measurements. As new driveline technologies evolve, additional evaluation variants may be added. This procedure may be used in its entirety or selected sections may be used individually depending on the specific development or validation task to be accomplished.

1.3 Remarks. Driveline system level vibration measurements are necessary to integrate driveline subsystems and to isolate vibration of the driveline system from other vehicle systems.

2 References

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

2.1 External Standards/Specifications.

None

2.2 GM Standards/Specifications.

GMW8477

GMW14179

GMW14382

2.3 Additional References.

Subsystem Technical Specification (SSTS)

3 Resources

3.1 Facilities. The required test facility is the driveline system dynamometer test cell located in the Milford Proving Ground (MPG) Building 94, Test Cell M109 or similar facility.

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. In addition to the dynamometers and control equipment included in the facility, the following equipment is required.

3.2.1 Accelerometers. High sensitivity accelerometers with a flat frequency response between 2 Hz and 2 KHz and a temperature range of 10 °C to 120 °C (50 °F to 248 °F) are required. The quantity of accelerometers required varies based on driveline system configuration.

3.2.2 Video Camera. A high-definition (720p or greater) portable video camera with recording capability is required.

3.2.3 Thermal Enclosures. A controlled thermal conditioning enclosure around the propshaft center bearing(s) is required for driveline configurations with multi-piece propshafts. The thermal enclosure shall allow the center bearing isolator temperature to be controlled between 20 °C and 120 °C (68 °F and 248 °F). A controlled thermal conditioning enclosure around the axle/Rear Differential Module (RDM) is required for thermal sensitivity testing

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of axle/RDM. The axle/RDM thermal enclosure shall allow the axle/RDM temperature to be controlled between 20 °C and 120 °C.

3.2.4 Driveline Controller Module and Interface. For drivelines with controllable torque transfer devices and/or controllable disconnect features, a functional controller module shall be provided, with appropriate digital interface and software to allow both automatically controlled and manual torque commands.

3.3 Test Vehicle/Test Piece. The system under test may include a complete driveline system from transmission to halfshaft/axle output flanges, or some reduced portion of the driveline system as required. For four wheel drive (4WD) and all wheel drive (AWD) systems, the front driveline and rear driveline subsystems may be included. For drivelines with an independent rear drive module mounted to a subframe (cradle), the subframe shall be included when the complete driveline system is to be evaluated.

3.4 Test Time. Test time varies and is influenced by driveline configuration. Calendar time is intended to represent a typical AWD system test series.

Calendar time: 5 days

Test time: 40 hours

Coordination time: 8 hours

3.5 Test Required Information. The following specific information is required to facilitate test setup and execution.

3.5.1 Driveline Geometry Math Data. The dimensions, nominal locations and positional variation of all driveline components are required. This information must be obtained from the latest released Computer Aided Engineering (CAE) math data available for the vehicle and driveline configuration under test.

3.5.2 Propshaft Joint Geometry Variation Data. The net dimensional variation in the driveline interface connections to the vehicle body/chassis must be estimated and provided to the test facility at the time of test fixture design, such that the fixtures are adjustable and capable of simulating the full range of propshaft joint geometry variation expected in the vehicle.

3.5.3 Driveline System Torque and Speed Ranges. The range of driveline input/output torques and speeds are required to enable dynamometer programming. For driveline systems with active-on-demand torque transfer device(s) (TTD), the rated maximum torque capacity of the TTDs must be known.

3.5.4 Engine Dynamic Torque Output. Prior to the start of setup, obtain the engine dynamic torque order map in tabular format from GM Powertrain. The engine dynamic torque order map must include the dynamic torque content for the two (2) highest amplitude engine orders as a function of speed and load. This information is required to program the input dynamometer for engine firing torque pulse simulation. For powertrains with Active Fuel Management (AFM), the engine dynamic torque output order content must be known for both AFM on and off conditions.

3.5.5 Maximum Allowable Driveline System Imbalance. The maximum allowable driveline system imbalance at each balance plane of the driveline is required to conduct the balance sensitivity and propshaft whirl evaluations. The individual component imbalance specification upper limits can be obtained from the Subsystem Technical Specifications (SSTS) for each component. At the propshaft connection plane to axle/RDM the total system allowable imbalance may be obtained from a Variation Simulation Model (VSM) using the component specifications along with match-mounting and runout calculations. This information must be obtained from the driveline design engineer prior to the start of the test.

3.5.6 Subsystem Technical Specifications (SSTS). The program-specific SSTS documents for the individual subsystems under test (propshaft, RDM, etc.) must be obtained and used for reference with this procedure. Some test conditions require torques, speeds, etc., that are specified in the SSTS.

3.6 Personnel/Skills. One (1) qualified engineer or technician trained in noise and vibration data acquisition and signal processing. One (1) qualified driveline dynamometer operator. One (1) qualified engineer or technician trained in modal test data acquisition and modal data analysis.

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4 Procedure

4.1 Preparation. Support the driveline components using appropriate test fixtures. Assemble the driveline and connect to the dynamometers such that the geometric layout of all driveline shafts, joints and components replicates the in-situ geometry established from the driveline math data.

4.2 Conditions.

4.2.1 Environmental Conditions. The test cell temperature shall be between 18 °C (65 °F) and 25 °C (77 °F).

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 Modal Test (Non-operating).

4.3.1.1 Modal Test Setup and Instrumentation. Arrange modal shakers such that the major driveline subsystems are excited in all directions. The specific number and orientation of shakers is driveline-specific and shall be determined prior to test by the program Noise and Vibration (N&V) test engineer and the modal test conductor. Instrument the driveline with accelerometers on all driveline components. For components with suspected flexible modes in the frequency range up to 500 Hz, place accelerometers with sufficient spatial resolution to identify likely mode shapes. For example, all shafts, torque tubes and axle tubes shall have accelerometers placed at each end of span and also at multiple (depending on length) longitudinal locations such that all likely bending mode shapes in the frequency range can be identified. For large diameter (truck) propshafts, place accelerometers circumferentially at multiple longitudinal locations such that likely shell modes in the frequency range can be identified. For generic modal test setup instructions, refer to GMW8477.

4.3.1.2 Low Frequency Modal Test Data Acquisition. Set source frequency band to 128 Hz. Adjust source levels and burst duration to obtain acceptable coherence at all measurement locations. Acquire data and verify data quality by doing a preliminary curve fit, concentrating on expected low-frequency modes such as propshaft center bearing bounce modes, RDM rigid body modes, etc. Store all Frequency Response Function (FRF) and coherence data for subsequent detailed analysis.

4.3.1.3 High Frequency Modal Test Data Acquisition. Set source frequency band to 512 Hz. Adjust source levels and burst duration to obtain acceptable coherence at all measurement locations. Acquire data and verify data quality by doing a preliminary curve fit, concentrating on expected high-frequency modes such as propshaft bending modes, halfshaft bending modes, etc. Store all FRF and coherence data for subsequent detailed analysis.

4.3.1.4 Modal Test Data Processing and Results. Analyze the modal test data, fit mode shapes and calculate frequency and damping results according to standard modal analysis methods specified in GMW8477. Process results for both the low frequency and high frequency bands acquired during data acquisition. Summarize results in a table as shown in Appendix A, Table A1.

4.3.1.5 Modal Test Results Interpretation. Examine the processed modal test results and verify that the following modes have been identified (where applicable depending on specific driveline configuration):

- Propshaft center bearing bounce modes
- Propshaft bending modes
- Torque tube bending modes
- RDM rigid body mounting modes
- Beam axle flexible modes
- Test fixture modes
- Cradle/subframe modes

4.3.2 Driveline System Balance Measurement and Correction. Refer to GMW14382 for three-point balance measurement and correction procedure. Verify that the data acquisition system (DAS) online order resolution is set fine enough to separate possible closely spaced driveline orders (refer to GMW14382). Prior to beginning the balance measurement, verify/establish that any component match marks are aligned properly. Using the three-point balance method, measure and correct the system balance at each propshaft balance plane. Record the amount and location of correction masses for comparison to allowable specifications, as shown in Appendix A, Table A2.

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4.3.3 Driveline System Balance Sensitivity Evaluation. Refer to GMW14382 for balance sensitivity procedure. After the driveline has been balanced at all planes of interest, conduct a sensitivity evaluation at each plane of interest, using a minimum of three (3) known imbalance levels. Recommended levels are $0.5 \times M$, $1.0 \times M$ and $2.0 \times M$, where M = maximum allowable imbalance at the plane of interest. For each imbalance increment, acquire and store first order vibration data on the active and passive side of each balance plane of interest, across the operating speed range of the driveline. Plot results as shown in Appendix A, Figure A1.

4.3.4 RDM Gear Mesh Vibration Evaluation. Refer to GMW14179 for additional background and details. Instrument the RDM with triaxial accelerometers at each mount location, on both the active (RDM) and passive (body/cradle/frame) side of each attachment. Set up the dynamometer to provide road load simulation (RLS) based on the parameters of the vehicle for which the driveline is intended. Set up the DAS to acquire and process propshaft order-tracked vibration data with 0.1 order resolution, and frequency bandwidth sufficient to capture up to the 5th harmonic of the hypoid gear mesh frequency. Acquire online orders for the 1st through 5th gear mesh harmonics, the pinion gear fundamental with ± 2 integer side bands, and the ring gear fundamental with ± 3 integer side bands. Conduct both drive and coast down sweeps as specified in GMW14179. Repeat tests at each drive and coast torque specified in the SSTs. Assess the vibration data to the gear mesh vibration targets specified in the RDM SSTs. Refer to Appendix A, Figure A2 for recommended plot format.

4.3.4.1 Mount Isolation Evaluation. Using the data acquired in the RDM Gear Mesh Evaluation, calculate and plot the isolation ($T = a_{\text{active}}/a_{\text{passive}}$) at each RDM attachment location. Assess isolation relative to the general isolation target of 16 dB or better. Refer to Appendix A, Figure A3 for recommended plot format.

4.3.5 Beam Axle Gear Mesh Vibration Evaluation. For beam axles, vibration response influence from axle mounting fixtures must be minimized. Support the axle at the pinion nose with a lightly damped pinion support and at the wheel ends only (Appendix A, Figure A9). When mounted in the test setup, the pitch frequency of the axle housing should approximate the in-vehicle pitch frequency ± 10 Hz. Instrument the axle with triaxial accelerometers on the bottom of the axle housing pinion nose closest to the hypoid tail bearing (measurement location abbreviation Pinion Nose Vertical (PNV)) and on the on top on the axle housing where the axis of wheel rotation and pinion rotation intersect (measurement location abbreviation Rear Center Line of Carrier (RCLC)). For multilink beam axles, also attach accelerometers at the end of each attachment bracket location. Set up the dynamometer to provide RLS based on the parameters of the vehicle for which the driveline is intended. Refer to GMW14179 for additional background and details. Set up the DAS to acquire and process propshaft order-tracked vibration data with 0.1 order resolution, and frequency bandwidth sufficient to capture up to the 5th harmonic of the hypoid gear mesh frequency. Acquire online orders for the 1st through 5th gear mesh harmonics, the pinion gear fundamental with ± 2 integer side bands, and the ring gear fundamental with ± 3 integer side bands. Conduct both drive and coast down sweeps as specified in GMW14179. Assess the vibration data to the gear mesh vibration targets specified in the Axle SSTs.

4.3.6 Propshaft Center Bearing Dynamic Stability Evaluation. The objective of this evaluation is to measure and video-record the vibration of the propshaft center support bearing(s) across the full range of operating conditions. In particular, this evaluation is intended to identify any instances of high-amplitude orbiting or whirling motion that could result in damage to the center bearing isolator or objectionable N&V disturbance. In order to simulate the variation present in the full-vehicle operating environment, the test conditions cover a wide range of isolator temperature, joint angle and torque.

4.3.6.1 Center Bearing Evaluation Setup. Verify/accomplish that the driveline is mounted in the fixtures such that the propshaft center bearing angles are correctly set at the nominal position per production intent assembly geometry. Install a miniature triaxial accelerometer on the active side of the center bearing isolator, and connect to the DAS. Construct a thermal enclosure around each center bearing mount location to be evaluated. Connect the thermal enclosure to a thermostatically controlled conditioning system. Mount a digital video camera and adjust position such that the field of view includes the propshaft center bearing and the accelerometer.

4.3.6.2 Establish Worst-Case Imbalance. Using the results of the Driveline System Balance Measurement and Correction (see 4.3.2), establish worst-case imbalance condition. This can be accomplished by applying the necessary masses to replicate the highest allowable imbalance at all planes of interest simultaneously. For this step, align the imbalance masses all planes at the same clocking angle, so as to produce an "in-phase" imbalance force. With the worst-case in-phase imbalance established in the previous step, acquire vibration data at ambient temperature during a runup from 10 kph to 160 kph (6.2 mph to 99.5 mph) vehicle-equivalent speeds, at rear axle torque of approximately 500 Nm. Stop the driveline and re-locate alternating imbalance masses from plane to plane such that the masses are 180 degrees out-of-phase from one plane to the next. This will produce

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maximum moment imbalance between the planes. Repeat the ambient temperature runup and compare this data to the data acquired with the in-phase imbalance. Note the configuration that produces the highest vibration amplitude (in-phase or out-of-phase) and use that configuration for all tests to follow.

4.3.6.3 Determine Center Bearing Angle Variation Conditions. Using production-intent math data, determine the high and low limit center bearing three-dimensional angles that could result from production tolerance stack-up. The nominal angle, high and low limit center bearing joint angles are all to be tested. If the angle passes through zero (0) within the tolerance zone, then test at zero (0) angle also.

4.3.6.4 Determine Temperature Variation Conditions. The standard evaluation temperatures are 20 °C, 55 °C and 90 °C (68 °F, 101 °F and 194 °F). If temperatures outside this range are requested by the design group, verify that the thermal control system and enclosure are capable of extending the range to the requested temperature before proceeding.

4.3.6.5 Determine Torque Variation Conditions. The standard evaluation torque increments are 0, 20%, 60% and 100% of production intent maximum commanded torque. For driveline systems where negative torque is present in the propshaft during coast conditions, include a test condition at maximum expected negative (coast) torque. If torques outside this range are requested by the design group, verify that the dynamometer and driveline torque control systems are capable of safely extending the range to the requested torques before proceeding.

4.3.6.6 Conduct Center Bearing Dynamic Stability Test Sequence.

- a. Establish nominal 20 °C ambient temperature.
- b. Establish zero (0) commanded driveline torque.
- c. Conduct runup from 10 kph to 160 kph (6.2 mph to 99.5 mph) while recording vibration and video data.
- d. Repeat for torque increments of 20%, 60% and 100% of production intent driveline torque.
- e. Repeat for maximum negative (coast) torque if applicable.
- f. Increase the center bearing isolator temperature to 55 °C (101 °F) using the thermal enclosure and repeat runup at each torque increment while recording vibration and video data.
- g. Increase the center bearing isolator temperature to 90 °C (194 °F) using the thermal enclosure and repeat runup at each torque increment while recording vibration and video data.
- h. If maximum temperature evaluation is requested by the propshaft Design Responsible Engineer (DRE), increase the center bearing isolator temperature to 120 °C (248 °F) using the thermal enclosure and repeat runup at each torque increment while recording vibration and video data.
- i. Stop the driveline, cool to ambient temperature, then adjust fixturing to establish next center bearing angle increment as established in 4.3.6.3.
- j. Repeat complete test sequence for all center bearing angle variation conditions identified in 4.3.6.3.

4.3.6.7 Center Bearing Dynamic Stability Data Processing and Results. Process the data and produce plots as shown in Appendix A, Figures A4 through A6.

4.3.6.8 Center Bearing Dynamic Stability Results Interpretation. Review the video results and plotted data for evidence of “self-sustaining” orbiting or whirling motion of the center bearing. Self-sustaining whirl is defined as orbital motion that continues at constant frequency and high amplitude for a significant speed range after the propshaft forcing frequency (1st or 2nd order) has passed through the frequency. Presence of any self-sustaining whirl period constitutes a test result of “fail”. In addition, the video and vibration plots from the highest amplitude prop-synchronous (1st and 2nd order) vibration results shall be reviewed with the propshaft DRE for use in durability assessment.

4.3.7 Simulated Engine Firing Torsional Vibration Evaluation. The objective of this evaluation is to measure the response of the driveline when subjected to dynamic torque pulses that simulate engine firing excitation.

4.3.7.1 Torsional Vibration Instrumentation Setup. Mount rotational laser vibrometers at the front and rear of the propshaft. Orient the laser sensor heads such that the revolutions per minute (rpm) readout is positive on both lasers when the driveline is rotating in the direction corresponding to forward vehicle motion. Set the lasers for a sensitivity of 100 degree/s/V and set the Siemens LMS Test.Lab software (or equivalent) laser channel input sensitivity to 573 mV/rad/s. Install a magnetic pickup to generate pulses from flexplate/flywheel ring gear tooth passage and connect to DAS as a tachometer and data channel with appropriate tooth count. Instrument the axle/RDM with triaxial accelerometers at each mount location, on both the active (RDM) and passive (body/cradle/frame) side of each attachment. Instrument the propshaft center bearing with a miniature triaxial

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