



Method to Measure the Dynamic Torsional Stiffness and Dynamic Bending Stiffness of Driveline Isolators

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. This procedure documents a method to measure both the dynamic torsional stiffness and the dynamic bending stiffness of a driveline torsional isolator. This method allows the mapping of isolator behavior for a range of frequencies, static preloads and dynamic vibration amplitudes.

1.2 Applicability. This procedure may be used to measure the dynamic bending and/or torsional stiffness of any flexible driveline torsional isolator. It may also be used to measure the dynamic bending and/or torsional stiffness of other driveline components such as cardan joints or constant velocity joints.

1.3 Remarks. The dynamic stiffness and damping properties measured in this procedure are suitable for use in driveline mathematical simulation models.

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.

None

2.3 Additional References. None.

3 Resources

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

3.1.1 Calibration. The test facilities and equipment shall be in good working order and shall have a valid calibration label.

3.1.2 Alternatives. Alternative test facilities and equipment may also be used. However, all measuring variables as specified in this standard shall be determined correctly with respect to their physical definition.

3.2 Equipment.

3.2.1 Dynamic Torsional Stiffness Test Equipment

3.2.1.1 Electromagnetic Shaker. One (1) electromagnetic shaker capable of producing 2200 N (500 lbf) force or greater.

3.2.1.2 Bungee Cord. A minimum of 2 m of bungee cord with a linear working load capability in excess of 1000 N (225 lbf).

3.2.1.3 Hand Winch. A hand winch capable of a pulling force of 2000 N (250 lbf) or greater and a displacement range of 2 m (6.5 ft) or greater.

3.2.1.4 Purpose Built Strain Gauged Test Fixture. A purpose built strain gauged test fixture was designed and built for this test. It consists of a rotational shaft that is strain gauged. The shaft is held in a pillow block with high precision bearings. A lever arm is attached to the shaft to apply the static and dynamic loads.

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3.2.1.5 Accelerometers. Nine (9) tri-axial low mass accelerometers with flat response from 2 Hz to 2000 Hz and an operating range of 10 °C to 50 °C (50 °F to 122 °F).

3.2.1.6 Data Acquisition Equipment. Data acquisition hardware capable of measuring frequency domain results between 0 Hz and 10 kHz, with a minimum of 80 dB dynamic range. This hardware shall meet Class 1 accuracy corresponding to IEC 651 or be equivalent for the application (precision ± 0.7 dB or $\pm 8\%$). The preferred data acquisition system (DAS) consists of a personal computer running Leuven Measurement System (LMS) Test.Lab software with Step Sine Testing module, connected to a Scadas III frontend.

3.2.2 Dynamic Bending Stiffness Equipment

3.2.2.1 Grounded Test fixture. This fixture receives three (3) bolts going down through test specimen isolator and connects the test specimen to the bedplate. The fixture must be clamped securely to the bedplate. The fixture is shown in Appendix D, Figure D1.

3.2.2.2 Mass Moment of Inertia Fixture. This fixture consists of a plate on top of the test specimen isolator with ring mass hanging down around the isolator, as shown in Appendix D, Figure D2. The center of gravity (CG) of this test fixture must be in line with CG of isolator to result in pure bending of isolator. See Appendix D, Figure D3.

3.2.2.3. Impact Hammer. Standard small impact hammer with nylon tip and added screw-on mass. See Appendix D, Figure D7.

3.2.2.4 Accelerometers. Low sensitivity accelerometers (1mV/m/s^2) with flat response 2 Hz to 2000 Hz.

3.2.2.5 Data Acquisition Equipment. Data acquisition hardware capable of calculating frequency domain results between 2 Hz and 10 kHz, with a minimum of 80 dB dynamic range. This hardware shall meet Class 1 accuracy corresponding to IEC 651 or be equivalent for the application (precision ± 0.7 dB or $\pm 8\%$). The preferred DAS consists of a personal computer running LMS Test.Lab software with Step Sine Testing module, connected to a Scadas III frontend.

3.2.2.6 Miscellaneous Hardware for Test Setup. The test setup requires various hardware pieces to set up the test specimen isolator correctly for testing. Appendix D, Figure D4 shows the test setup with miscellaneous hardware labeled. Miscellaneous hardware includes:

- Six (6) bolts, with three (3) bolts going through down isolator threading into grounded test fixture and three (3) bolts going up through isolator and mass moment of inertia fixture.
- Three (3) nuts on bolts going up through isolator and mass moment of inertia fixture (with washers as required)
- Three (3) cylindrical spacers with thickness as required to get proper spacing between the isolator and the grounded test fixture.

3.3 Test Vehicle/Test Piece. Driveline isolator or similar driveline component.

3.4 Test Time.

3.4.1 Dynamic Torsional Stiffness Test Time.

3.4.1.1 First (1st) Test Component.

Calendar time: 3 to 4 days
Test time: 8 to 16 hours
Coordination time: 16 hours

3.4.1.2 Additional Test Components.

Calendar time: 1 day
Test time: 8 to 12 hours

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3.4.2 Dynamic Bending Stiffness Test Time.

3.4.2.1 First (1st) Test Component.

Calendar time: 2 days
Test time: 4 hours
Coordination time: 4 hours

3.4.2.2 Additional Test Components.

Calendar time: ¼ day
Test time: 2 hours

3.5 Test Required Information. The following information is required to properly and efficiently run this procedure:

3.5.1 Operating Conditions.

3.5.1.1 Dynamic Torsional Operating Conditions.

- The operating amplitude range of static preload torque to be applied to the test component. The static torsional preload may be estimated from the operating condition of interest, gear ratio, and vehicle mass.
- The operating amplitude range of the dynamic torque to be applied to the test component. The dynamic torque amplitude range may be analytically estimated or measured from vehicle level operating data.
- The frequency range of interest for the dynamic torsional operating loads

3.5.1.2 Dynamic Bending Operating Conditions.

- The frequency range of interest for the dynamic bending operating loads

3.5.2 Bolt Pattern. The bolt pattern of the driveline component to be tested.

3.6 Personnel/Skills. One (1) qualified engineer or technician trained in the use of data acquisition and recording equipment and having basic knowledge of digital signal processing of acoustic or vibration signals. Knowledge of LMS Step Sine Test module, LMS Impact Testing module, and Microsoft Excel is required.

4 Procedure

4.1 Preparation.

4.1.1 Dynamic Torsional Stiffness Test Preparation.

4.1.1.1 Test Parameters. Before the test may begin the range of the static and dynamic forces must be determined. These parameters are based on the vehicle-level operating conditions of interest. The operating values may come from either analytical predictions or measurements to be supplied by the test requestor.

4.1.1.1.1 Static Load Range. The results from this procedure will be used in models predicting vehicle Noise and Vibration (N&V) performance. In general, the operating conditions used to determine the static load range are moderate acceleration, cruise, and coast. The maximum and minimum mean torque observed during these operating conditions determine the limits of the static load range. A minimum of three (3) static preloads are recommended.

4.1.1.1.2 Dynamic Load Range. The dynamic load range will be determined from the same operating conditions as the static load range: moderate acceleration, cruise, and coast. One point to note is that during cruise the engine may operate in Active Fuel Management (AFM) Mode. The dynamic loads in AFM Mode are greater than normal engine operating mode and must be considered. A minimum of three (3) dynamic loads are recommended.

4.1.1.2 Test Hardware Setup. Set up the hardware in accordance with Appendix A, Figure A1 and Appendix B, Figures B1 thru B3 with the shaft vertical or Appendix A, Figure A2 and Appendix B, Figures B4 and B5 with the shaft horizontal. Confirm that all test fixtures are securely attached to the bed plate.

4.1.1.2.1 Pillow Block Position. Position the pillow block so the center of the lever arm is aligned with the center line of the shaker. Adjust the height of the pillow block so the center line of the shaker and the attachment point of the lever arm are at the same height when the arm is in the vertical position.

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4.1.1.2.2 Alignment of the Shaker, Lever Arm Attachment and Hand Winch. Carefully align the shaker center line, the attachment point on the lever arm, and the hand winch to prevent damage to the shaker. Misalignment will cause overheating which will quickly damage the shaker.

4.1.2 Dynamic Bending Stiffness Test Preparation.

4.1.2.1 Test Parameters. Prior to setting up the test, the test parameters need to be determined.

4.1.2.1.1 CG Alignment Calculation. Verify that the mass moment of inertia test fixture has the CG of the fixture aligned with the CG of the isolator in the Z direction. See Appendix D, Figure D3. The following equation can be used to calculate the CG of the complete non-grounded portion of the test setup. Note that the mass and CG of miscellaneous hardware, the mass moment of inertia fixture, and non-grounded portion of the isolator are all included in the complete setup CG.

$$\bar{z} = \frac{\sum m_i * z_i}{\sum m_i}$$

Where:

m_i = the mass of an individual part of the setup

z_i = the Z distance between the isolator centerline and the CG of the individual part

If the setup is assembled properly, the calculated setup CG height $\bar{z}$ will coincide with the centerline of the isolator.

4.1.2.1.2 Mass moment of inertia calculation. Calculate the total mass moment of inertia of the non-grounded portion of the setup for later use in processing the data. This calculation must include all parts that are not grounded including miscellaneous hardware, isolator, and mass moment of inertia fixture. Example mass moment of inertia equations using simple shapes to model test hardware are provided in Appendix D, Figure D5.

4.1.2.2 Test Hardware Setup. Set up the hardware in accordance with Appendix D, Figures D1 thru D4.

4.1.2.2.1 Mass of Attachment Hardware. To attach the test mass moment of inertia fixture to the isolator and the isolator to the base use bolts with the lowest mass possible to minimize their mass affect. Measure and record the mass of all attachment hardware in Appendix E, Table E1.

4.1.3 Instrumentation.

4.1.3.1 Dynamic Torsional Stiffness Test Instrumentation.

4.1.3.1.1 Torque Strain Gauge. The strain gauge for measuring torque is located on the shaft of the test fixture (see Appendix A, Figures A1 and A2) and requires connection to the front end of the measurement system. The strain gauge should be recalibrated periodically. Check that the calibration is current.

4.1.3.1.2 Accelerometers. Locate the 1st accelerometer on the end of the lever arm where the shaker attaches. This accelerometer will be used to monitor the shaker displacement. Locate the 2nd thru 5th accelerometers on the load plate of the test fixture to monitor the rotation of the driving side of the driveline component as in Appendix B, Figure B3, or on any require adapter hardware as close to the test component as possible. Locate the 6th thru 9th accelerometer on the base of the test fixture to monitor any motion on the ground side of the test object, or on any require adapter hardware as close to the test component as possible.

4.1.3.1.2.1 Accelerometer Location. Measure the relative position of the 2nd thru 9th accelerometers precisely. These dimensions are used in the calculations of the rotational motion and have a significant influence on the results.

4.1.3.2 Dynamic Bending Stiffness Test Instrumentation.

4.1.3.2.1 Accelerometers. Locate 1st thru 4th accelerometers in accordance with Appendix D, Figure D6 and use local coordinate system as also shown in Appendix D, Figure D6. Locate the 5th and 6th accelerometers on the grounded test fixture base to verify fixture is grounded and aid in identifying modes.

4.2 Conditions.

4.2.1 Environmental Conditions. The ambient air temperature should remain between 15 °C and 25 °C (60 °F and 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.

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4.3 Instructions.

4.3.1 Dynamic Torsional Stiffness Test Instructions.

4.3.1.1 Adjust Fixtures for the Static Preload. This step must be repeated before for each static preload level to be measured. With the test setup aligned and properly secured, but with the shaker disconnected, apply a static load to the system with the hand winch that is 120% of the desired static test load. Wait 15 minutes to allow the winch strap and the bungee cord to stretch and stabilize. This stretching will causes the static load to drop. Using the hand winch, readjust the static load to the desired test static load. The static loading will move the arm from the unloaded position. Measure the loaded displacement angle of the lever arm from the unloaded position. Release the static preload. Then release the clamps holding the base fixture and rotate the base in the opposite direction and equal to the angular deflection of the arm. Retighten the base to ground. Now reload the setup with the hand winch to 120% of the desired static preload and wait 15 minutes to allow the winch strap and the bungee cord to stretch and stabilize again. Adjust the static load to the desired level. The arm should be at 0 degrees from the original unloaded position and the shaker at its neutral point when attached. Attach the shaker's stinger to the lever arm. The setup is now ready for the next measurement.

4.3.1.2 Data Acquisition.

4.3.1.2.1 Measurement Type. The measurement method for this test is step sine testing.

4.3.1.2.2 Initial Measurement Acquisition Parameters. LMS is the standard measurement software for GM N&V and the test parameters listed below are directly applicable for LMS Step Sine package. The parameters are set on the multiple-input/multiple-output (MIMO) page titled "MIMO Sine Setup".

4.3.1.2.2.1 Channel Parameters. On the "MIMO Sine Setup" page within the section titled "Channel Parameters", specify the force channel and the accelerometer channel on the lever as "enabled up abort" channels. Enter the not-to-exceed amplitude levels for these channels.

4.3.1.2.2.2 Source Parameters. In the "Source Parameter" section of the page, select the source channel and enter a not-to-exceed voltage level of 10 V.

4.3.1.2.2.3 Control Panel on the Right Side. The panel on the right side of the page contains many of the important settings. Set these parameters to the following:

MIMO Sine Mode:	Stepped
Control Strategy:	Amplitude
Sweep Mode:	Linear
Range Switch Mode:	Automatic
Number of Periods (Fixed/Tabular):	Fixed
Number of Periods:	10
Number of Sweeps:	3
Start Up Time:	5 s
Shut Down Time:	1 s
Measure/System:	Select: Frequency Response Function(s) (FRF)s and All FRFs
Measure/Structure:	Select: Auto Powers, Cross Powers, FRFs, and Coherence

4.3.1.2.2.4 Table and Window within the Control Panel on the Right Side. Within the control Panel on the right side there is a table and a window that must be set up as follows:

4.3.1.2.2.4.1 Advanced Window. There are several buttons labeled "Advanced" in the control panel. Clicking on any of these opens the "Advanced" window.

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4.3.1.2.2.4.1.1 Control Tab. On the Control Tab of the Advanced Window make the following selections or enter these values:

Confidence in FRF from System Identification:	Medium
System FRF Error Correction:	100%
Maximum control iterations:	10
Action at maximum control iterations:	Continue

4.3.1.2.2.4.1.2 Safety Tab. On the Safety Tab of the Advanced Window make the following selections or enter these values:

Control Channel Overload:	Increase Range
Measurement Channel Overload:	Increase Range
Maximum drive update ratio in one (1) control cycle:	2%
Maximum amplitude variation in one (1) step:	5%
Delay between two (2) steps:	40 Cycles
Minimum Coherence:	70%

4.3.1.2.2.4.1.3 Measure Tab. On the Measure Tab of the Advanced Window make the following settings:

FRF estimator:	H1
Store each sweep:	Select

4.3.1.2.2.4.2 Frequency Ranges. By clicking on the “Define” button next to the “Frequency Range” title opens the “Frequency Ranges Editor” window. On the left side of the window make the following setting and selections:

To clear all entries in the table click on:	Reset Table
For ease of reading the table select:	Sort Table
Delay unit:	Cycles

4.3.1.2.2.4.2.1 Now enter the following values into the table:

Minimum Frequency (Hz):	10
Step (Hz):	0.1
Maximum Frequency (Hz):	1000
Delay (cycles):	40

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4.3.1.2.2.4.3 Profile on Channel Input Forces. By clicking on the “Editing Reference Profile” button the “Profile on Channel Input Forces” window is opened. This is the table where the level for the control channel is defined. The level over the range is controlled by define by defining the levels at each end of the range. The beginning and ending points are entered on their own line. Enter the following values for the lower limit:

	Lower Limit	Upper Limit
Frequency (Hz):	10	
Amplitude (Newton (N)):	Level 1, Level 2, or Level 3	Level 1, Level 2, or Level 3
Upper Tolerance (dB):	0.1	0.1
Lower Tolerance (dB):	0.1	0.1
Upper Abort (dB):	10	10
Reference Phase (degrees):	0	0
Upper Tolerance (degrees):	10	10
Lower Tolerance (degrees):	10	10

4.3.1.2.3 Measurement Acquisition.

4.3.1.2.3.1 Trial Acquisition. Due to the unknown behavior of the driveline component under test, it is very likely that the initial measurement parameters will have to be iteratively adjusted to optimize the measurements. Make a trial measurement and evaluate the results to determine if and what parameters need adjustment.

4.3.1.2.3.2 Acquisition. With measurement parameters optimized, acquire and store the desired measurements with the appropriate static preloads and dynamic loads to cover the desired operating range. Clearly identify each measurement run using unique a LMS run names to label the data according to the applied static and dynamic load conditions.

4.3.1.2.4 Manually Recorded Data.

4.3.1.2.4.1 System Mass Moment of Inertia. The total effective mass moment of inertia of the test system must be calculated as follows in the following steps.

4.3.1.2.4.1.1 Test Fixture Mass Moment of Inertia. The mass moment of inertia of the test fixture from the strain gauge to the load plate is known. This remains the same independent of the tested component and adapters, and the value is 0.00761665 kg*m².

4.3.1.2.4.1.2 Accelerometer Mass Moment of Inertia. The mass moment of inertia of each accelerometer must be calculated and corrected for its location using the parallel axis theorem: $I_{effective} = I + L * M^2$. For a cube-shaped accelerometer, the mass moment of inertia is calculated with the equation:

$$I = \frac{Ml^2}{6}$$

Where:

M = mass of the accelerometer

l = length of the side of the accelerometer

4.3.1.2.4.1.3 Component Mass Moment of Inertia. Fifty percent (50%) of the test component mass moment of inertia is included in the system mass moment of inertia. This calculation will be unique to the test component.

4.3.1.2.4.1.4 Adapter Mass Moment of Inertia. If any adapters are used between the load plate and the test specimen, the mass moment of inertia calculation will be unique to the adapter, and must be included in the system inertia.

4.3.2 Dynamic Bending Stiffness Test Instructions.

4.3.2.1 Data Acquisition. The data acquisition portion of the procedure is an impact test that is repeated for each condition.

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