



Turbocharger Shaft Motion Test Procedure (Vendor Version)

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 test procedure is used to address the rotor/bearing system sensitivity to bearing clearances, rotor balancing, oil supply variations, engine induced vibrations, and other turbo excitation influences. The purpose of this test is to assess the turbocharger rotor shaft behavior and turbo assembly vibration as installed on the engine. To better comprehend the forces due to rotor system vibration, optional pressure sensors can be placed in communication with the journal bearing out films on both turbine and compressor sides.

1.2 Applicability. This test procedure is applicable to exhaust gas driven turbochargers for diesel and gasoline engines. This procedure applies to rotor shaft displacement measurement in front of the compressor, with the use of a specialized instrumentation nut and eddy current proximity sensors. The test is intended to measure dynamic shaft motion throughout the operating range of the turbo.

2 References

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

2.1 External Standards/Specifications.

None

2.2 GM Standards/Specifications.

None

2.3 Additional References.

AVL North America, Plymouth, Michigan (www.avl.com)

3 Resources

3.1 Facilities. An engine dynamometer test facility capable of testing to the maximum speed and torque of the engine under investigation should be used. It is highly recommended the facility have a combustion air supply capable of maintaining the standard air inlet pressure, temperature and humidity.

The dynamometer engine should be instrumented so parameters can be measured.

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 Engine Cooling and Heating Capability. The test facility shall have the capability of measuring and controlling the engine oil and coolant temperatures to the specified test conditions.

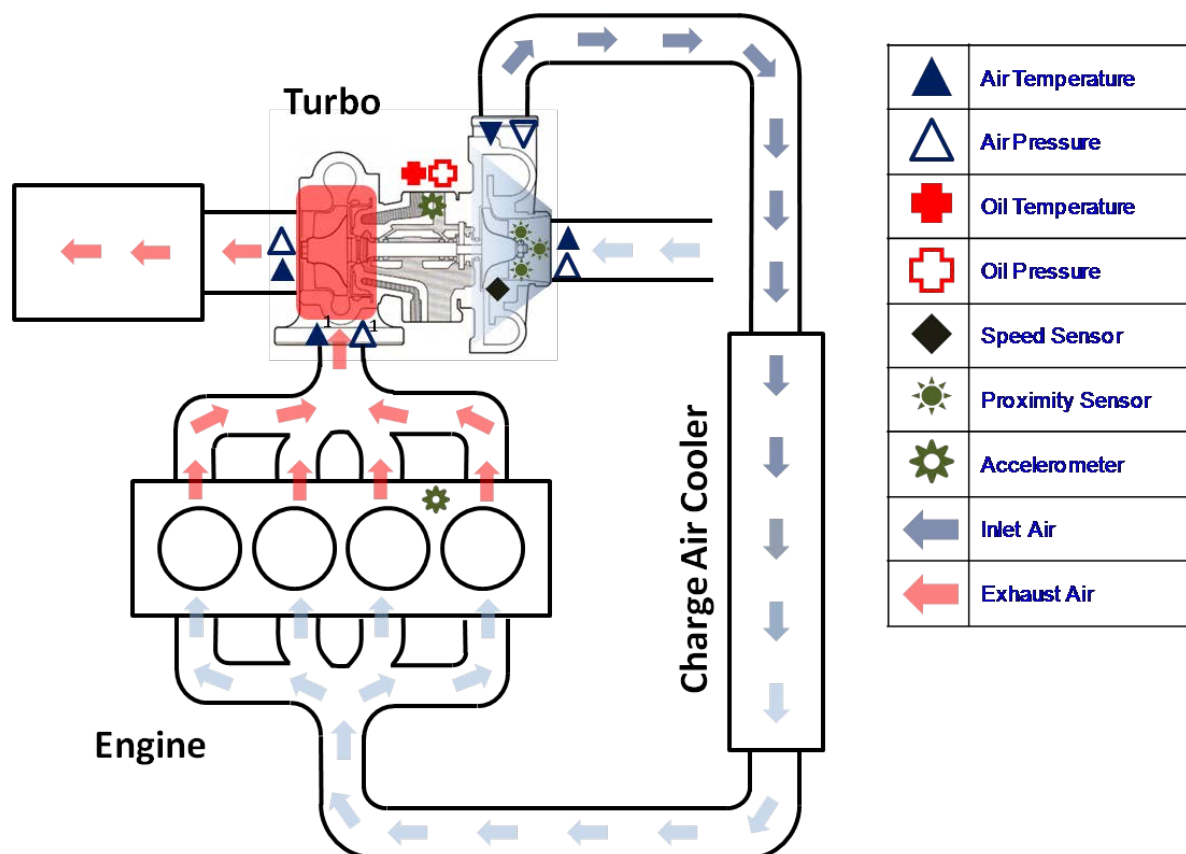
3.2.2 Instrumentation. The instrumentation schematics and specification are included in Figure A1 and Table A1 in Appendix A and a diagram locating the required instrumentation is contained in Figure 1.

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Note: Two sensors are required for dual scroll turbochargers.

Figure 1: Sensor Location on Engine and Turbocharger

3.2.2.1 All instrumentation requires calibration per GM standard practices. Instrumentation attachment to the turbo test article and engine shall be done so as to have minimum effect on engine/turbocharger performance and dynamics. Any holes made for instrumentation access in the oil or coolant cavities of the turbocharger shall be properly sealed accounting for expected temperature and pressure. Appropriate epoxies shall be used realizing the extremes of temperature especially in the area of the turbine. Tack welds shall not be used in high stress areas. Protection against fluids, heat, and vibration shall be used on the instrumentation wires.

3.2.2.2 The turbocharger test articles shall be pre-machined for instrumentation by the supplier. But all required instrumentation shall be installed and calibrated by GM.

3.2.2.3 Typical Instrumentation Locations. Typically the oil feed temperature and pressure sensors are installed on the oil feed pipe banjo bolt or two (2) bolt flange interface to the turbo. The temperature sensor needs to be placed in the flow of oil. The pressure transducer can be located on the console, but should be sensing the oil pressure at the feed pipe connection, as close as possible to the turbo. The accelerometer is typically placed on the center housing water connections, banjo bolt (coolant inlet) or two (2) bolt flange. The accelerometer needs to be connected to the center housing, but the coolant connections will help to prevent overheating of the sensor. On non-water cooled center housings, the accelerometer should be placed on an oil feed connector.

3.2.2.4 Data recording devices shall be able to record the required test data per this procedure.

3.3 Test Vehicle/Test Piece.

3.3.1 Engine shall be run using production intent oil and fuel. The latest engine calibration should be used.

3.3.2 Verify the engine is equipped with exhaust system brackets.

3.3.3 Turbochargers used for shaft motion testing shall be fitted with a rotor shaft sensor nut per Figure A2 in Appendix A to facilitate proximity sensor sensing. Final high speed balancing shall be completed with this nut

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installed. Balance stock removal shall not be done in the smooth area of the nut Outer Diameter (OD) as this is used for motion sensing.

3.3.4 The compressor housing shall be drilled and tapped to accept high resolution eddy current sensors. Two (2) threaded holes shall be located at 90 degrees apart circumferentially and in a plane that locates the center of the sensors with the axial center of the assembled sensor nut within 0.5 mm. Furthermore, true position of the sensor mounting holes shall be within 0.1 mm of the compressor housing center. Due to the curvature of the compressor housing geometry, spot faces are necessary on the OD at the threaded hole exit to facilitate locking the sensors in position.

Because typical sensor threaded lengths may be inadequate to reach the target nut due to relative compressor bore diameters, secondary mounting bolts may be necessary as seen in Figure 2. In these cases, it is recommended to use M8 cap screws of the appropriate length. The cap screws must be drilled and tapped for an M5 thread to accommodate the eddy current sensors. To accommodate installation, locking nuts are used against the bottoms of the cap screws. In these cases, the compressor housing will be drilled and tapped for M8 threads instead of M5.



Figure 2: Turbocharger with Proximity Sensor

3.3.5 To support the axial shaft motion sensor, a cross bar per Figure A3 of Appendix A is required. This cross bar is fixed to the compressor housing in front of the compressor wheel and locates a third proximity sensor at the compressor assembly nut face. The closest edge of the cross bar shall be located 5 mm minimum from the face of the compressor instrumentation nut to facilitate axial eddy current sensor clearance.

3.3.6 Turbocharger rotor speed measurement is required for this test procedure. The compressor housing of the test article shall be drilled and tapped to accommodate the speed sensor. Other methods of speed sensing may be considered with engineering approval.

3.3.7 For the optional turbocharger bearing pressure sensors, additional required machining is necessary to enable the installation of the pressure sensors. Additionally, temperature sensors are required in close proximity to the oil discharge to the outer film which could also require additional machining.

3.3.8 As a minimum, turbine shaft rotors shall be baked for 1 h at 600 °C minimum prior to balancing.

3.3.9 Assembled shaft runout at the rotor shaft sensor nut shall not exceed 5% of the rotor assembly Free Rock. Deviation from this requirement requires engineering approval.

3.3.10 The turbocharger test articles shall be built with limit parts to evaluate worst case conditions. The test configurations in Table 1 are required.

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Table 1: Turbocharger Test Article Specification

	Inner Bearing Clearance	Outer Bearing Clearance	Rotor Unbalance ^{Note}	Test Objective
Turbo 1	Maximum	Maximum	Nominal	Nominal Case
Turbo 2	Minimum	Maximum	Minimum Unbalance	Sub-synchronous (1 st Rigid Body Mode)
Turbo 3	Maximum	Minimum	Minimum Unbalance	Sub-synchronous (2 nd Rigid Body Mode)
Turbo 4	Minimum	Minimum	Maximum Unbalance, Couple (In-Phase)	Critical Speed Margin

Note: Rotor Unbalance: The compressor and turbine wheels shall be limit balanced per stated configuration. Final high speed balance corrections shall be made if necessary to bring the assembled turbo into the "as fired" upper specification limit.

3.3.11 An inspection report (Table B1, Appendix B) together with the high speed balance vibration versus shaft speed plot is required for each turbocharger test article. The following characteristics shall be inspected and the results documented in the inspection report:

- Unbalance level and angle at each balance plane (the component unbalance levels prior to assembly).
- Runout of the rotor assembly sensor nut OD to shaft center at bearings.
- Compressor bearing inner and outer ring clearances.
- Turbine bearing inner and outer ring clearances.
- Rotor assembly end play.
- Rotor assembly Free Rock at the rotor shaft sensor nut.
- Vertical sensor mounting hole true position to shaft center.
- Horizontal sensor mounting hole true position to shaft center.

3.4 Test Time.

Calendar time: 19 days

Test time: 32 h

Coordination time: 120 h

3.5 Test Required Information. To facilitate this test, the following information must be provided:

- Maximum allowable engine speed.
- Catalytic converter warmup engine speed.
- Engine speed at maximum torque.
- Maximum allowable turbocharger speed.
- Target turbocharger idle speed.

3.6 Personnel/Skills. The operator qualifications required are those equivalent to a Measurements Engineer capable of obtaining high speed data acquisition. Specialized turbo data acquisition equipment is necessary for taking the turbo performance data, which requires special technician qualifications.

4 Procedure

4.1 Preparation. Test article setup.

4.1.1 Proximity Sensor Installation and Calibration. Each proximity sensor shall be installed with the appropriate spacers and locking nuts in place. With the shaft displaced at its closest position towards the sensor, the proximity sensor should be adjusted to a minimum distance of 20% of the measured Free Rock value. Feeler

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gages should be used to locate each proximity sensor. Select the appropriate feeler gage thickness based on 20% of the reported Free Rock. While holding the feeler gage between the sensor and the nut OD, carefully push the nut against the gage. Adjust the depth of the sensor so the feeler gage can be easily removed with the nut at its maximum displacement. Lock the sensor in place. Repeat this process for the other sensors. A similar method should be used for the axial sensor using 20% of the Free End Play as a basis for setting the sensor distance. When completed, the typical proximity sensor setup will look similar to Figure 2.

4.1.1.1 After installation, the sensors need to be calibrated and validated for the necessary range of testing. The calibration also verifies the sensors have adequate range. A series of plastic feeler gages with different thicknesses over the range of the Free Rock/Free End Play are required for this calibration. A curve of voltage versus feeler gage thickness shall be created for each of the sensors after the calibration.

4.1.1.2 Mark the top edge of the shaft with a dot from a paint pencil. Rotate the shaft so the dot lines up with a sensor. Make sure both sensors are installed and turned on. Make the first measurement (voltage and distance) at this location. Gently hold the rotor assembly sensor nut against the feeler gage while carefully not applying any sideward force because moving the shaft assembly to either side of the sensor will degrade the accuracy of the reading. The feeler gage should be able to be easily removed. Record the voltage from the sensor. Now, rotate the shaft 90 degrees in a clockwise direction and make another measurement. Continue the rotation and measurement until all four (4) quadrants are measured and recorded for the specific sensor. When finished, four measurements for each gage thickness will be recorded. Average the four (4) voltages measured at each thickness to create a calibration curve. At least three (3) points (three (3) different gage thicknesses) are needed to form the curve.

4.1.1.3 The resulting curve should be smooth and nearly straight. With the increase of feeler gage thickness, a sudden change in the slope of the curve near the maximum Free Rock is an indication the sensor is out of range. Make adjustments as necessary. Use the same procedure for all sensors.

4.1.1.4 After the sensors have been calibrated, gently move the rotor shaft to full travel, and record the maximum and minimum readings of each sensor to attain Free Rock and Free End Play. Be careful not to rotate the shaft during this measurement. The measured Free Rock and Free End Play should be within 5% of the values from the supplier. Otherwise, consult with engineering for further directions.

4.1.2 Turbocharger Bearing Calibration (Optional). Instrumentation and equipment personnel will complete pressure bearing calibration. Test engineer should verify the calibration curve is available for reference.

4.1.3 Rotor Assembly Sensor Nut Runout Verification. For this verification check, the test article turbo assembly shall be positioned on a bench or in a fixture such that the rotor shaft is horizontal. On the compressor wheel, identify an indication or a mark which will be used to reference the angle of the rotor assembly. Use one (1) of the proximity sensors and record at least eight (8) readings to establish a range. For each reading, turn the rotor approximately 90 degrees and lightly tap the turbocharger housing(s) to settle the rotor assembly. Notice, as the turbo is tapped, the displacement will continue to change as the shaft settles in the bearings. Once the displacement reading stabilizes, record the result. Rotate the rotor shaft and repeat the process. The difference between the highest reading and the lowest reading is the indication of shaft runout. If optional turbocharger bearing pressures are being used, ensure the turbocharger bearings are well lubricated during runout measurements.

4.1.3.1 The runout amplitude is the same in the vertical and horizontal directions. Therefore, taking runout readings with only one (1) proximity sensor is adequate.

4.1.3.2 If the shaft runout amplitude is > 5% of the Free Rock, notify engineering to determine if the test article is acceptable for testing.

4.1.4 Engine Setup. Once the test article has been fully instrumented and calibrated, the turbocharger is ready to be installed on the engine.

4.1.4.1 Anchor the wiring harness properly (within 150 mm from the device) so the engine vibration would not affect the accuracy of the reading. The catalyst converter is not a must for this test. However, the back pressure needs to be modeled appropriately to represent the existence of a catalyst converter.

4.1.4.2 Particular caution is necessary for turbo installation as to not damage fragile instrumentation and the instrumentation wiring harness.

4.1.4.3 After the setup is complete, cover the instrumentation cart to prevent any damage from other test cell fluids.

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4.2 Conditions.

4.2.1 Environmental Conditions. This procedure shall be completed on a test bench in a clean environment.

4.2.1.1 The test cell environment should be maintained to a temperature of an air stable room to maintain ambient temperature of $23\text{ }^{\circ}\text{C} \pm 1\text{ }^{\circ}\text{C}$.

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.

Caution: Prior to each test session, the pressure sensors on the exhaust pipe before and after the turbine need to be zeroed in by disconnecting the downpipe. Operation of the engine, turbocharger test article, and all instrumentation shall be verified during the engine check out run. Identify and record each variable/channel name for each required test measurement.

4.3.1 Measurements.

4.3.1.1 Lateral Shaft Motion Measurement, Full Speed Sweep. The objective of this test is to identify peak resonance frequencies and amplitudes within the operating range of the turbocharger.

4.3.1.1.1 Test Conditions. To evaluate turbocharger resonances during engine warmup, the engine gallery oil temperature at the beginning of test shall be below $25\text{ }^{\circ}\text{C}$ in the engine oil gallery. All other engine operation conditions should be as prescribed for normal engine startup. It is acceptable to run the engine before actual test data is taken when it may be necessary to address mechanical or instrumentation concerns. However, the engine shall be allowed to cool down so the oil will be below $25\text{ }^{\circ}\text{C}$ prior to run up testing.

After the cool run up test evaluation is completed, testing will evaluate turbocharger resonances over the entire engine speed and turbo operating speed ranges. Engineering should be notified if the turbocharger maximum speed is exceeded by more than 3%.

4.3.2 Test Procedures.

4.3.2.1 Start Up Speed Sweep, Cool. The objective of this test is to assess the turbocharger resonance frequencies and amplitudes during cold start conditions (below $25\text{ }^{\circ}\text{C}$). This test will be used to evaluate the turbocharger sensitivity under these cold oil operations.

Before this test, determine the lowest idle speed from the calibration and the throttle position at that speed to hold 25 N·m of torque. These values will be used in the "Engine Description, Limits, Parameters" under the Idle parameters tab. Reference the Test Automation System from AVL North America (PUMA) screen in Figure 3.

Note: Verify dynamometer prop shaft can maintain this speed at sustained idle without failure.

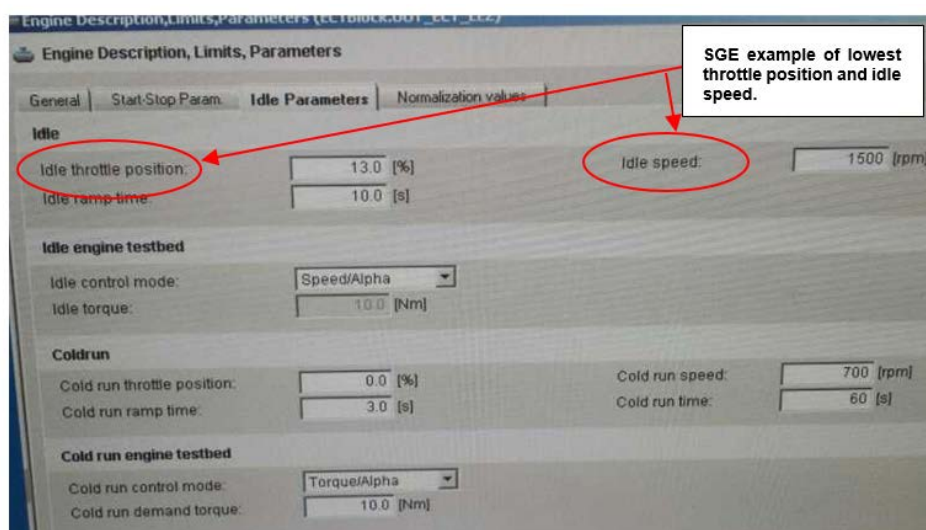


Figure 3: Example of PUMA Engine Description, Limits, Parameters Window

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