



Inertial Properties Evaluation Procedure

1 Scope

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 experimentally determine the mass, center of gravity, and inertial properties of a symmetric or irregularly shaped object.

1.2 Foreword. The properties of a rigid body that are significant in dynamics and vibration are the mass, center of gravity, the moments of inertia, the products of inertia and the directions of the principal inertial axes with respect to a set of reference axes. For example, in the design of a powertrain mounting system, this information is needed to accurately predict the inherent rigid body modes of this system.

Three (3) separate tests are performed to measure an object's mass, center of gravity and inertia. The mass of an object is seldom measured directly. More commonly, the weight of the object is measured and its mass is inferred from that. Using this procedure, an object will be weighed in units of kilogram force and its mass will be represented in units of kilograms. At sea level: 1 kg force = 1 kg. At higher altitudes it is usually assumed that this is still true. The amount of error due to this depends on the altitude but is usually less than 1%.

The center of gravity of an object is that single point where all the mass of the object could be considered to be concentrated when performing static calculations. This point is determined by the intersection of three planes, each of which is known to contain the point. For a homogeneous (or symmetric) shape like a brake rotor, this point is the geometric center of the object. For an irregularly shaped object like an engine, the location of this point will not be obvious. An object's center of gravity may be located within the object or in "midair". For example, the center of gravity of an engine cradle will not be located on the cradle.

The inertia of any object about some chosen axis through its center of gravity may be expressed mathematically in terms of its mass and its natural frequency of oscillation, when suspended as a torsional pendulum whose axis is coincident with the chosen axis. A computer program is available that calculates the principal moments of inertia and the design axis moments of inertia if a test object is suspended in several carefully chosen positions and accurate measurements are made of the following: the object's angular orientation with respect to the torsional axis and its period of oscillation.

To define the moments and products of inertia the object has to be oscillated about a minimum of six axes. Data about additional axes will improve the accuracy of the calculation reducing experimental error. For a homogeneous (or symmetric) shape it may be desirable to measure only the three moments of inertia. These will also represent the principal inertias if the axes chosen are the axes of symmetry.

Mass properties other than weight have no meaning unless the data includes the reference axes used in their calculation. For an engine or transmission, there is a well-defined coordinate system whose origin is at the centerline of the crankshaft at the rear face of the engine block. For any other object, the person performing this test must define three mutually perpendicular reference axes. These axes are usually selected to coincide with controlled design features like edges of the object or attachment interfaces.

1.3 Applicability. This procedure is applicable for measuring the mass objects of most automotive components. This procedure puts an emphasis on the details necessary to measure an engine or transmission.

It should be noted that when an object is oscillated about several different axes it must not contain any mass which will change position when the object is orientated differently. As a result of this, the object's mass reported using this test procedure may not be exactly what the design weight of the object is. For example, with an engine the water jackets are filled completely so that the water is

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contained, but the oil is drained because it will change position during the test.

2 References

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

2.1 External Standards/Specifications.

SAE J670e

2.2 GM Standards/Specifications.

None

2.3 Additional References.

- Procedure for Determination of Center of Gravity and Moments of Inertia, D. L. Hill, Noise and Vibration Laboratory, GM Proving Ground Engineering Report No. PG-22081, June 29, 1973.
- SAE International (SAE) Engine Coordinate System – SAE Standard J670e "Vehicle Dynamics Terminology", July 1, 1976.

3 Resources

3.1 Facilities. The facility must include one or more trifilar pendulums which are suspended from appropriate structure on the ceiling of the building. The length of the cables should be long enough to minimize experimental errors due to nonlinearities and the small angle approximation inherent in the calculations. In general, the longer the cables, the better. The desired cable length will depend on the mass of the pendulum and the radius of the cables. For a pendulum capable of measuring an engine, the cables should be at least 3 m in length.

The inertia measurements done using this procedure will directly measure the inertia of the object and the pendulum together as one object. The inertia of the pendulum by itself must be known and subtracted from the measured inertia. Therefore, it is desirable to have a pendulum whose inertia is as small as possible with respect to the object being measured but is also capable of supporting the static weight of the object.

For the facility to be capable of measuring a wide range of automotive components, multiple pendulums will be necessary. For an irregularly shaped object, it is best to use a trifilar pendulum that allows the object to be oriented easily in several carefully chosen positions (see Appendix A, Figure A1). This pendulum is constructed as follows: The bottom of the three cables are connected by bars to a universal joint, below the universal joint is a beam in the shape of an inverted T, from either end of the beam are two

cables which attach to the test object, and both sets of cables are on trolleys which are adjustable along the beam. The advantage of this type of pendulum is that when the beam is level, the test object may be suspended in any orientation with the assurance that its center of gravity lies along the central axis of the pendulum.

For a symmetric object that will be tested about only a few axes, it may be desirable to use an inertia table or simpler pendulum that only has a platform connected to the three cables (see Appendix A, Figure A2 and Figure A3). For such an object, it can be placed on top of the table or platform with reasonable assurance that its center of gravity lies along the central axis.

The facility should be in a stable environment with respect to temperature and humidity. It should be free of vibration and air movement which would interact with the measurements. There should be an unobstructed line of sight to the test area of at least 12 m.

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 Trifilar pendulum.

3.2.2 Hand tools.

3.2.3 Miscellaneous bolts, nuts, stoppers, etc.

3.2.4 Accurate weight scale.

3.2.5 Bench level and protractor.

3.2.6 Reference "angle block", see Appendix A, Figure A4.

3.2.7 Cable system with three turnbuckles and a center support cable.

3.2.8 Overhead crane.

3.2.9 Surveyor's transit.

3.2.10 Ruler.

3.2.11 Inclinometers with two direction level (see Appendix A, Figure A5).

3.2.12 Stop watch/timing mechanism.

3.2.13 Photographic equipment.

3.2.14 Oven/paraffin wax or grease.

3.2.15 Three (3) plumb bobs.

3.2.16 Software to calculate inertia properties.

3.2.17 Calibration mass of known inertia.

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3.2.18 Test object.

3.3 Test Vehicle/Test Piece. A test object is required. The object should be qualified to represent model year design content. Any development addition or modification should be noted on the test report.

3.4 Test Time.

Calendar time:	4 days
Test hours:	30 hours
Coordination hours:	4 hours

3.5 Test Required Information. There should be a test request associated with each test. This request form should specify as much information as possible about the object. This will be used to verify that the object is in the correct condition to be tested and it will also provide useful information to associate with the test results when they are put into a database. For an engine, this information should include: number of cylinders, displacement, configuration, Regular Production Option (RPO) Code, engine name, build level, program for which it will be used, etc.

Any discrepancies between the intended content of the object and its "as received" content should either be corrected or the engineer overseeing the test should give approval to proceed and document the changes.

3.6 Personnel/Skills. A trained technician should be able to complete this test. An engineer should be available to oversee the test.

The technician conducting this test should possess the following skills/traits: familiarity with engine and transmission components, ability to judge which locations on an engine or transmission can be used to safely support its weight, hoist and rigging training, willingness to pay attention to detail so that accurate measurements are made and there is no damage to test objects, ability to work independently.

4 Procedure

4.1 Preparation. Most of the preparation listed here refers to an engine or transmission. A test may be done on one of them separately so that the results can be analytically combined with other test results, or an engine and transmission can be tested together as a complete powertrain.

If an engine is tested by itself it should not have a flywheel or flex plate bolted to the crankshaft. The flywheel or flex plate should be attached to the transmission when it is tested. This enables the

engine test results to be added to either a manual or automatic transmission. If a complete powertrain is tested, it may be necessary to split it apart during the preparation and reassemble it before testing.

For an engine or transmission, every attempt should be made to include components which will move as a rigid body with the test object. This includes: the exhaust up to a flex coupling or ball and socket connection and the powertrain half of the drive shaft which includes the constant velocity joints.

4.1.1 Test Object Preparation.

4.1.1.1 Drain any fluid from the object which is not completely captured. This includes the engine and transmission oil, power steering fluid, etc.

4.1.1.2 On an engine, fill the water jackets completely with water and seal them off.

4.1.1.3 On an engine, install grease or wax filled oil filter. If one is not available, drain the engine oil filter and fill with grease or paraffin wax.

4.1.1.4 On an automatic transmission, install grease or wax filled torque converter that equals the wet weight of the converter. If one is not available, drain the torque converter and fill with grease or paraffin wax.

4.1.1.5 On an engine, rotate the crankshaft so that piston number one (1) is located at Top Dead Center.

4.1.1.6 Fasten any wiring harnesses, cables or loose parts.

4.1.1.7 On a powertrain, at the front of the crankshaft, locate the center and scribe a (+) at this point. Determine an identical point at the rear and scribe another (+).

4.1.2 Calibration.

4.1.2.1 Trifilar Pendulum Calibration. The inertia of the pendulum without a test object must be known. After this is measured, an object of known inertia should be tested and the test results should agree with the known value within an acceptable amount. This process needs to be done only upon installing the pendulum or when any repair/alteration has occurred.

For a platform type pendulum, the inertia of an empty platform is calculated by measuring the period of oscillation of an empty platform and solving for the pendulum inertia using the equation found in 7.1 (Equation to Calculate Inertia from a Trifilar Pendulum).

For a trolley type pendulum, the inertia of the pendulum will increase as the trolleys are moved

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outboard. To develop a correction for this, the empty pendulum should be calibrated as follows:

4.1.2.1.1 Start with both trolleys at equal inner positions. The lower beam should be exactly level. Wrap the slack cables around the horizontal beam close to the center of the pendulum.

4.1.2.1.2 Excite the pendulum in torsion about its vertical axis. Care must be taken to avoid exciting any modes other than the desired torsional oscillation. The torsional oscillation should be less than ± 8 degrees.

4.1.2.1.3 Measure the period of oscillation in seconds. Repeat to verify consistency. Record the period and trolley position.

4.1.2.1.4 Move the trolleys outboard together $\frac{1}{2}$ of the available travel taking care to move the wrapped cable along with the corresponding trolley. Repeat steps 4.1.2.1.2 through 4.1.2.1.3.

4.1.2.1.5 Move the trolleys outboard together equal outer positions travel taking care to move the wrapped cable along with the corresponding trolley. Repeat steps 4.1.2.1.2 through 4.1.2.1.3.

4.1.2.1.6 Enter the data sets into the supplied program along with the other swing parameters, and the software will calculate the following:

- The average period of the pendulum across all the trolley positions.
- The difference between the measured period and the average period at each trolley location.
- The three coefficients necessary to correct a period and corresponding swing inertia measured during an actual test. These coefficients apply to each of the trolleys and are of the polynomial equation:

$$T_{\text{correction}} = C_1 + C_2X + C_3X^2$$

The software used during a test will correct the average period of the empty pendulum with the correction factor for each trolley position. This corrected period will then be used in the equation found in 7.1 (Equation to Calculate Inertia from a Trifilar Pendulum) to calculate the inertia of the empty swing.

To calibrate the swing, the trolleys must be at equal positions so that the pendulum is level. During an actual test, each trolley will be located as required to position the object and level the swing.

4.1.2.2 Weight Scale Calibration. The appropriate instrumentation group should perform periodic calibration of the weight scale.

4.2 Conditions.

4.2.1 Environmental Conditions. The test environment should be free of vibration and air movement which would interact with the measurements.

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. To follow this procedure, it is necessary to hang the test object from cables. It is necessary to choose multiple locations on the object to connect the cables to. Verify the cables, pendulum and support structures are certified to support the weight of the test object. At each location that the tester chooses to attach the cables, the tester must be confident that the attachment has sufficient strength. The considerations include: weight of the object, material properties of the connecting objects, thread size, etc.

If there is any doubt, the tester should seek advice from their local safety coordinator. In the following sections of this procedure, the phrase "suspend the test object" implies that these considerations have been met.

4.3.1 Weight Test Procedure. The test object should be weighed accurately to determine its mass. It should be in the exact condition that will be used for the inertia test. Care should be taken to subtract the weight of any miscellaneous cables that may be used to hang the object below a scale.

4.3.2 See the SAE engine coordinate system preparation procedure, SAE J670e "Vehicle Dynamics Terminology", July 1, 1976.

4.3.2.1 For an engine or transmission, the SAE engine coordinate system should be used. Instructions are given below to define that coordinate system. For an object that is not an engine or transmission, a similar process must be followed.

The SAE engine coordinate system can be described as follows: The origin is at the centerline of the crankshaft at the engine/transmission split line (note that this point exists on either an engine or transmission by itself). It is a right handed coordinate system. The X axis is parallel to the crankshaft and positive towards the front of the engine (i.e., away from the transmission). When looking from the origin in the positive X direction, the Y axis is positive to the right and the Z axis is positive downward. Unless otherwise noted, the Z axis is collinear with the cylinder bores of an in-

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line engine and splits the "V" of a "V-engine". See Appendix A, Figure A6.

To accurately define this reference coordinate system on an engine or transmission, two perpendicular machined surfaces must be used. The bellhousing can be used to define the Y-Z plane. Another one or two surfaces must be used to define a perpendicular plane.

4.3.2.1.1 Suspend the test object (powertrain). This can be done two ways. The first way is to use the cable system with three turnbuckles and a center support cable. The second way is to suspend the object from the pendulum. The tester must decide which technique to use.

4.3.2.1.2 Adjust the cables and/or trolley positions so that the powertrain is square to the world (use the bench level on the machined surfaces). If the pendulum is used, it must also be level.

4.3.2.1.3 Attach the angle block to the engine or transmission. The location of the angle block must be such that the block is accessible for measurements with the inclinometer. Use the bench level to orient the angle block so that it is also square to the world. The attachment of the block must be solid so that it will not move for the remainder of the testing.

4.3.2.1.4 Mark the coordinates (+X, +Y, +Z) on the angle block or object near the angle block.

4.3.2.2 Center of Gravity Test Procedure

4.3.2.2.1 There are two ways to measure the center of gravity. They are similar but slightly different. The first technique is done while the powertrain is suspended under the pendulum. The second is done using the cable system with three turnbuckles and a center support cable. The tester must decide which technique to use.

For documentation purposes, high quality digital photographs must be taken of the test object. Photographs of all six views are necessary unless symmetry makes a view redundant.

4.3.2.2.2 Procedure Using the Cables. When an object is suspended from a point, its center of gravity lies along a vertical axis which passes through that point. If an observer sights this line through a surveyor's transit, the center of gravity will lie in a plane defined by this vertical axis and the line of sight.

4.3.2.2.3 Suspend the test object by the three cables which are connected to one cable at the other end.

4.3.2.2.4 Position the test object so that the X and Y axis lie in a horizontal plane. Use the bench level

or the protractor with two direction level and the angle block to ensure that this is true.

4.3.2.2.5 Hang a plumb bob from the center of the crankshaft at the front of the engine or transmission.

4.3.2.2.6 Hang a plumb bob from the center of the crankshaft at the rear of the engine or transmission.

4.3.2.2.7 Fasten a scale to the object, parallel to the Y axis so that it is visible from a transit at least 20 m away. The scale must overlap the main suspension cable and the crankshaft.

4.3.2.2.8 With the transit at least 12 m away, sight the transit exactly parallel to the X axis (one plumb bob string should be behind the other). The distance, as read from the scale between the reference coordinate system origin and the vertical defined by the main suspension cable, is the Y coordinate of the center of gravity. See Appendix A, Figure A7.

4.3.2.2.9 Move the two plumb bobs so that they are hanging from either side of the bellhousing.

4.3.2.2.10 Fasten a scale to the object, parallel to the X axis. The scale must overlap the center of the three cables and the plumb bobs.

4.3.2.2.11 With the transit at least 12 m away, sight the transit exactly parallel to the Y axis (one plumb bob string should be behind the other). Either the object can be rotated 90 degrees about the vertical axis or the transit can be moved. The distance as read from the scale between the reference coordinate system origin and the vertical defined by the main suspension cable is the X coordinate of the center of gravity.

4.3.2.2.12 Suspend the test object so that the Y axis is pointed vertically. Up to three new locations must be selected to attach the cables to.

4.3.2.2.13 Position the test object so that the X and Z axis lie in a horizontal plane. Use the bench level or the protractor with two direction level and the angle block to ensure that this is true.

4.3.2.2.14 Hang a plumb bob from the center of the crankshaft at the front of the engine or transmission.

4.3.2.2.15 Hang a plumb bob from the center of the crankshaft at the rear of the engine or transmission.

4.3.2.2.16 Fasten a scale to the object, parallel to the Z axis, so that it is visible from a transit at least 12 m away. The scale must overlap the main suspension cable and the crankshaft.

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