



Brake Corner Performance Inertia Dynamometer

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 standard is an inertia dynamometer test procedure to assess brake corner performance during various brake conditions.

1.2 Applicability. This procedure is applicable to all passenger car and light truck.

1.3 Remarks. This standard assesses brake corner performance with green (new) brakes, during a brake burnish schedule, with burnished brakes, during various FMVSS 135 conditions, and with post fade brakes. For rear brakes, park brake performance is also assessed.

2 References

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

2.1 External Standards/Specifications.

FMVSS 135

2.2 GM Standards/Specifications.

GMW14933

GMW14986

GMW15391

GMW15392

GMW14974

GMW15142

2.3 Additional References.

- Appendix C2 of the Statement of Requirements (SOR): Rear Drum Brake corner Assembly

3 Resources

3.1 Facilities. Milford Proving Ground Brake Component Development inertia brake dynamometer or equivalent Test Improvement Process (TIP) accredited test dynamometer shall be used. Dyno must be certified for this procedure.

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.

Note: Alternative test facilities and equipment must obtain an official GM TIP accreditation prior to submitting test data to GM.

3.2 Equipment.

3.2.1 An inertia brake dynamometer capable of performing torque control, pressure control, corrected pressure control, ramp, and modulated brake applies. The inertia dynamometer should have environmental control capabilities for both temperature and humidity.

3.2.2 The following measurements shall be made and digitally recorded at 500 Hz during each brake apply and for 0.5 s prior to the start of the apply and for 0.5 s after release of brake pressure:

- Dynamometer speed (km/h).

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- Brake apply pressure (kPa).
- Brake torque (N·m).
- Brake rotor/drum temperature (°C).
- Fluid displacement (mm³).

Note: Use compensated fluid displacement data (see glossary).

- Cooling air temperature (°C).
- Cooling air humidity, percent (%) Relative Humidity (RH).

In addition, the above channels should also be recorded continuously at a 0.5 Hz rate for the full test (Global Slow recording).

3.2.3 The following measurements shall be made and digitally recorded at 1000 Hz during the Park Brake sections:

- Dynamometer speed (rpm).
- Brake apply pressure (kPa).
- Brake torque (N·m).
- Cable Travel (mm).
- Cable Force (N).
- Optional: Rotor or Drum positional marker voltage (shaft position), (degrees).

3.3 Test Vehicle/Test Piece. Production representative hardware shall be used to produce the tailstock assembly. One set of pads/shoes will be required per rotor/drum sample. If the test is conducted for the purpose of validation, the number of samples and requirements to be met are defined in GMW15392.

3.4 Test Time.

Calendar time: 1 day to 2 days

Test time: 2 h to 4 h

Coordination time: 10 h to 24 h

3.5 Test Required Information. Not applicable.

3.6 Personnel/Skills. One (1) technician trained for the operation of an inertia brake dynamometer and to perform the duties described in 4 is required.

4 Procedure

4.1 Preparation.

4.1.1 Rotor or drum embedded thermocouple shall be installed per GMW14974.

4.2 Conditions.

4.2.1 Environmental Conditions. Cooling air temperature shall be controlled, as defined below. RH percent (%) humidity and Temperature must be recorded for all stop conditions. Cooling air should be maintained at the given conditions for the entire test, as defined below.

4.2.1.1 Nominal condition. This is the default condition. If the test request does not specify, this is the condition that should be run. Nominal condition is defined as cooling air at a temperature of 22 °C and 60% RH.

4.2.1.2 Dry condition. If specified, the dry condition is defined as cooling air at a temperature of 3 °C and 20% relative humidity.

4.2.1.3 Humid condition. If specified, the humid condition is defined as cooling air at a temperature of 30 °C and 80% RH.

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.

4.2.2.1 The dynamometer inertia shall be set as described in GMW15142 using Gross Vehicle Weight (GVW) parameters.

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4.2.2.2 For vehicles that use regenerative braking systems, the dynamometer inertia shall be set according to 4.2.2.1 for all sections, except for the 200 stop burnish (section 4.3.5 of Appendix A, Table A1). The regenerative braking inertia level, per GMW15142, shall be used for the 200 stop burnish section only.

4.2.2.3 For rotors, the Assembled Lateral Run Out (ALRO) shall not exceed 50 µm ALRO and should be measured per GMW14933 and recorded in the test documentation. For the drum only measurement, the runout and roundness shall not exceed print specifications for the component and shall be recorded in the test documentation (pretest component measurement).

4.2.2.4 For drum brake assemblies tested using this procedure, drum brake centerline clearances should be set to a nominal centerline clearance condition (see definition in Glossary). If drum brake backing plate assemblies are received from a production source, already assembled and used "as received", centerline clearances should be measured and recorded, but not adjusted unless out of specification range. If drum brake shoes are installed at the testing facility, assembly should be set using proper service procedures to the nominal production intent centerline clearance.

4.2.2.5 Friction material (i.e., caliper or drum linings) should be measured for lining thickness prior to start of test and at the conclusion of the test. Measurements should be taken per GMW14986, except lining insulators should NOT be removed and the measurement points should be marked rather than drilled into the backing plate.

4.3 Instructions. The instructions for the testing are in Appendix A, Tables A1 thru A8.

5 Data

5.1 Calculations.

5.1.1 Digital Signal Processing Rate. Park Brake sections are processed at 1000 Hz. All other test data are processed at 200 Hz.

5.1.2 Digital Signal Zeroing. Brake pressure and torque channels are digitally zeroed based on 0.5 s of digitally recorded data prior to each brake apply.

5.1.3 Hysteresis. For the second modulation, during each modulated apply, determine the maximum difference in braking torque between the hydraulic release and apply conditions at a given pressure. Divide this difference by the peak torque and multiply by 100 to determine the percent torque hysteresis.

5.1.4 Apparent Friction.

Apparent Friction (disc brake):

Constant Deceleration Apply:

$$AF = \frac{\left(\frac{T}{2 * r_e} \right)}{P * A_p}$$

Ramp Apply:

$$AF = \frac{\left(\frac{T}{2 * r_e} \right)}{(P - P_{ho}) * A_p}$$

Where:

A_F = Apparent Friction

A_p = Effective Piston Area (m²)

P = Hydraulic Pressure (kPa)

P_{ho} = Holdoff Pressure (kPa)

T = Braking Torque (N·m)

r_e = Effective Radius (mm) = Radius to the center of the piston pressure

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Apparent Friction Variation (disc brake): The apparent friction variation is the variation of friction level from the average friction level. It is calculated as follows: Percent Variation equals [(apparent friction range) divided by (average friction)] multiplied by 100.

Drum Brake Output:

$$Output = \frac{T}{(r_e) * (P - P_{ho}) * (A_p)}$$

Where:

- A_p = Effective Wheel Cylinder Area, square meter (m²)
- P = Hydraulic Pressure, kilopascal (kPa)
- P_{ho} = Holdoff Pressure, kilopascal (kPa)
- T = Braking Torque, Newton meter (N·m)
- r_e = Effective Radius, millimeter (mm) = Drum Diameter divided by 2

Grade:

$$Grade = 100 * \left[\tan \left(\arcsin \left(\frac{2 * T}{(GVM * g) * (SLR)} \right) \right) \right]$$

Where:

- T = Breakaway Torque, Newton meter (N·m)
- GVM = Gross Vehicle Mass, kilogram (kg)
- g = gravitational constant, meter per second squared (m/s²)
- SLR = Static Load Radius, meter (m)

5.2 Interpretation of Results. Reference GMW15392 or GMW15391 and appendix C2 of the Statement of Requirements (SOR) for brake corner performance requirements.

5.2.1 Graphical Summaries.

5.2.1.1 Ramp Applies. Graph Apparent Friction versus Hydraulic Apply Pressure between 0 kPa and 12 000 kPa for each ramp apply. Graph green, burnished, and post fade sections in the cold and warm conditions on separate graphs (five (5) graphs total). Also graph average apparent friction, Initial Brake Temperature (IBT), and maximum brake temperature versus stop number for each brake apply. (See example plots in Appendix B, Figure B1 and Figure B2.)

5.2.1.2 Burnish Schedule. Graph average apparent friction, IBT, and maximum brake temperature for every 10th brake apply during the burnish schedule. (See example graph in Appendix B, Figure B2.)

5.2.1.3 FMVSS 135 Sections. Graph average apparent friction, IBT, and maximum brake temperature versus stop number for each brake apply for the following FMVSS 135 sections. (See example graph in Appendix B, Figure B2.):

- Cold Effectiveness.
- High Speed Effectiveness.
- Failed System (2 Wheel Operation) – 0.26G target (formerly Hydraulic Circuit Failure).
- Failed System (2 Wheel Operation) – 0.5G target.
- Failed System (4 Wheel Operation) at 65 °C – 0.26G target (formerly 65 °C Power Brake Unit Failure).
- Failed System (4 Wheel Operation) at 65 °C – 0.5G target.
- Failed System (4 Wheel Operation) at 100 °C - 0.26G target (formerly 100 °C Power Brake Unit Failure).
- Failed System (4 Wheel Operation) at 100 °C - 0.5G target.
- Heating Snubs.

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- 1st and 2nd Hot Stops.
- Brake Cooling.
- Recovery Performance.

5.2.1.4 Park Brake Performance. For cable pull systems, see below. For electric park brake systems (non-cable puller designs), graphs are not required.

5.2.1.4.1 Graph the average wheel breakaway torque, N·m versus the average static input cable force, N for each cable force increment for both forward and reverse directions. (See example graph in Appendix B, Figure B3.)

5.2.1.4.2 Graph the percent grade versus the average static input cable force, N for both forward and reverse directions. (See example graph in Appendix B, Figure B3.)

5.2.1.4.3 Graph the average input cable travel, mm versus average static and dynamic cable force, N for the forward direction. (See example graph in Appendix B, Figure B4.)

5.2.1.4.4 Graph the average input cable travel, mm versus average static and dynamic cable force, Newton (N) after breakaway has been achieved for the reverse direction. (See example graph in Appendix B, Figure B5.)

5.2.1.5 Apparent Piston Travel (APT) with Pre-conditioning. For Apparent Piston Travel (APT) calculations, use the compensated fluid displacement channel for these calculations. See glossary for definition/procedure. Graph the APT, mm versus hydraulic pressure, kPa between 0 kPa and 12 000 kPa for each APT with Pre-conditioning ramp apply. Graph burnished warm and post fade warm APT ramp applies on separate graphs (see example graph displayed in Appendix B, Figure B6). Two (2) graphs total.

5.2.1.6 Hysteresis. Graph braking torque, Newton meter (N·m) versus apply pressure, kilopascal (kPa) for the second in-stop modulation of each modulated apply. Graph green, burnished and post fade applies on separate graphs. (See example graph in Appendix B, Figure B7) Three (3) graphs total.

5.2.2 Tabular Summaries.

5.2.2.1 Apparent Friction or Drum Brake Output.

5.2.2.1.1 Ramp Applies. Create a table with the average apparent friction of the runs at 500 kPa, 1000 kPa, 5000 kPa, and 12 000 kPa for all stops, excluding the initial stop, at each brake condition (green, burnished, and post fade) for cold and warm. Include the numerical average of the pressure based average apparent friction values for each apply between 500 kPa and 12 000 kPa (or maximum attained pressure), the range and the variation between 500 kPa and 12 000 kPa at each brake condition. Also determine within condition apparent friction range and variation. (See example data in Appendix B, Table B1.) If the ramp applies utilized the 10.8 m/s² (1.1G) cutoff prior to attaining the 12 000 kPa data point, the apparent friction value for the highest pressure attained (rounded down to the nearest 1000 kPa value) should be reported with the corresponding pressure value.

5.2.2.1.2 Constant Deceleration/Corrected Pressure Applies. For the constant decel and corrected pressure control brake applies, determine the apparent friction at first wheel departure, the 80% distance-weighted mean apparent friction, the within apply apparent friction range, the within condition average apparent friction range, the IBT, the maximum brake rotor temperature, and the percent peak-to-peak Brake Torque Variation (BTV) for each apply. Create a table with the mean apparent friction at first wheel departure, the mean average apparent friction, the average within apply apparent friction range, the within condition average apparent friction range, the mean IBT, the mean maximum brake temperature, the mean Overall peak-to-peak percent BTV, and the mean Maximum peak-to-peak percent BTV. (See example data in Appendix B, Table B2.)

5.2.2.1.2.1 Burnish Schedule. Calculate the data from 5.2.2.1.2 for every 10th stop in the burnish section. See example data in Appendix B, Table B2.

5.2.2.1.2.2 FMVSS 135 Schedules. Calculate the above data for all stops in the FMVSS 135 schedule sections. See example data in Appendix B, Table B2.

5.2.2.2 Parking Brake Schedule. For each park brake apply force increment within a cable pull system, calculate the average static input cable force, average input cable travel, average dynamic cable force, average breakaway torque, and gradability. Average data shall be reported for both the forward and reverse directions. (See example data in Appendix B, Table B3.) For electric park brake systems (non-cable puller designs), report average breakaway torque, N·m for each voltage and current condition tested.

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5.2.2.3 Apparent Piston Travel with Pre-conditioning. For APT calculations, use the compensated fluid displacement channel for these calculations. See glossary for definition/procedure. Report average apparent piston travel at 500 kPa, 1000 kPa, 5000 kPa, and 12 000 kPa using each of the first and second ramp applies of Apparent Piston Travel with Pre-conditioning test in the burnished and post fade conditions. (See example data in Appendix B, Table B4.) If the ramp applies utilized the 10.8 m/s² (1.1G) cutoff prior to attaining the 12 000 kPa data point, APT values for 12 000 kPa should be extrapolated from a regression analysis of the existing data. A notation should be made in the table that the value was extrapolated.

5.2.2.4 Holdoff Pressure. Report average holdoff pressure for all ramp applies, excluding the initial stop, at each ramp apply condition (green, burnished, and post fade conditions, warm and cold). (See example data in Appendix B, Table B5.)

5.2.2.5 Hysteresis. Report average maximum torque difference and average percent torque hysteresis (average maximum torque difference divided by maximum torque) for the green, burnished, and post fade brake conditions. Also include in the table, the within condition torque hysteresis range and the pressure at the maximum torque hysteresis. Then calculate the average torque difference and average percent (%) torque hysteresis (average torque difference divided by maximum torque) within a lower pressure bound of 25% of maximum pressure and an upper pressure bound of 75% of maximum pressure. Report the pressure values used for the analysis (lower and upper). In all cases, the table should be an average of the data for the three (3) runs. (See example data in Appendix B, Table B6).

5.2.2.6 Lining Measurement Summary. Report the start of test and end of test lining measurements.

5.2.2.7 Channel Summary. A table with channel summary information should be included in the test report. The following data should be included for each stop in the test (labeled by test section and stop number):

- Initial speed (kph).
- Release speed (kph).
- Initial brake rotor temperature (°C).
- Maximum brake rotor temperature (°C).
- Cycle time (second – start of brake apply to start of brake apply).
- Stop time (seconds).
- Time-based average brake pressure (kPa).
- Maximum brake pressure (kPa).
- Time-based average torque (N·m).
- Maximum torque (N·m).
- Torque-based average deceleration (g).
- Maximum fluid displacement (mm³).
- Average Apparent Friction (unitless – 80% distance weighted value for step apply, 500 kPa to 12 000 kPa average if ramp apply).
- Cooling air temperature (°C).
- Cooling air humidity (%RH).
- Cooling air speed at the brake enclosure outlet (kph).
- See example data in Appendix B, Table B7.

5.3 Test Documentation. Publish test information and results according to General Motors company protocol using the Evaluation Report template and Global Document Management (GDM) system or its successor.

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6 Safety

This Engineering Standard may involve safety requirements for hazardous materials, the method of operations and equipment. This standard does not propose to address all the safety issues associated with its use. It is the responsibility of the user of this standard to ensure compliance with all appropriate safety and health practices. This would include any specific training that may be required. The safety and health standards include site specific rules and procedures, company rules and procedures, and Government Standards. Contact shall be made with the appropriate site Safety and Health personnel for further direction and guidance in these matters.

7 Notes

7.1 Glossary.

Apparent Friction at First Wheel Departure: This value is intended to provide an assessment of the Apparent Friction just prior to reaching the peak pressure target for a given brake apply (assumed to be at or near the point where the tire first becomes adhesion limited on a high coefficient surface during a vehicle assessment). It is calculated by taking the average apparent friction between 85% and 95% of the peak pressure during the ramp portion of the apply. Use the calculation for ramp applies (see 5.1.4) to calculate this average.

Apparent Piston Travel: Apparent piston travel is the measured fluid displacement divided by the piston or drum cylinder area. Use the compensated fluid displacement measurement for this calculation.

Average Apparent Friction or Drum Brake Output: The distance-weighted average of the instantaneous friction or output. For constant deceleration brake applies, this is determined during the steady state portion of the braking event. This excludes the initial 10% of the stop after hydraulic pressure/torque has reached steady state level and the final 10% of the stop before pressure release as the dynamometer speed approaches zero. For ramp applies, average apparent friction or output is determined according to details specified in 5.1.4.

Brake Temperature: Brake temperature in this standard refers to rotor or drum temperature.

Brake Torque Variation: The peak-to-peak BTV refers to the difference between the maximum and minimum braking torque during one (1) rotor/drum revolution. Peak-to-peak BTV for the stop is determined by performing order tracking on torque data during the steady state portion of the braking event (perform Fast Fourier Transform (FFT) of Torque vs. Revolution data).

Overall peak-to-peak BTV is determined by transforming the first four (4) integer order peaks from the tracking results back to the revolution domain and calculating the peak-to-peak BTV for a single revolution of the resultant signal.

Percentile overall BTV is reported as a percentage of the average steady state torque: [overall BTV divided by average torque] multiplied by 100.

The order tracking method also determines the order content and resulting peak-to-peak BTV of each revolution. *Maximum peak-to-peak BTV* is reported as the maximum individual revolution BTV within the steady state portion of the braking event.

Percentile maximum peak-to-peak BTV is reported as a percentage of the average steady state torque: [peak-to-peak BTV divided by average torque] multiplied by 100.

Brake Warmup Stops: Torque controlled stops are made from 50 km/h at 3.04 m/s² (0.31G) deceleration rate until the specified IBT +10 °C has been reached for a given braking condition.

Breakaway Torque: Maximum brake torque experienced while rotating the rotor/drum with the park brake applied.

Compensated Fluid Displacement: A Fluid displacement measurement that subtracts the dynamometer apply system compliance from the full system measured test data. The displacement reported for this procedure should be for the brake hose and corner system under evaluation. The Dynamometer apply system contribution should be determined prior to the start of test by blocking the hydraulic system (dead-heading) between the hard line and the corner brake hose and performing a static ramp apply up to a 12 000 kPa pressure limit and recording the resultant displacement. The compensated displacement values would be the full system measurement minus the blocked displacement measurement at the given pressure.

Corrected Pressure Control: Dynamometer pressure control algorithm that calculates the average deceleration attained during a constant pressure apply and corrects the pressure level for the next stop to attain a desired deceleration level.

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Drum Brake Centerline Clearance: The difference between the brake drum inner diameter and the brake shoe assembly outer diameter. Measure the widest point of the brake drum inside diameter and the widest point of the brake shoe assembly outer diameter. The difference between these two (2) diameters is the drum brake centerline clearance.

Dynamic Park Brake Cable Force: The park brake cable force average value in the first two degrees of rotation after the breakaway point has occurred (position based average).

Holdoff Pressure: The line pressure required to initiate braking torque.

Initial Brake Temperature: The brake rotor or drum temperature at the start of the braking event.

Pressure Control: Dynamometer control algorithm that maintains the brake pressure at a constant level during an apply.

Static Input Cable Force: Cable force after the cable travel is locked and prior to rotating the rotor/drum.

Torque Control: Dynamometer control algorithm that maintains the brake torque during a pressure apply at a constant level.

Torque Hysteresis: The maximum difference in torque at a given pressure during a modulated pressure apply.

Within Apply Apparent Friction or Output Range: Within apply apparent friction range is the maximum instantaneous friction minus the minimum instantaneous friction. For constant deceleration brake applies, maximum and minimum instantaneous friction are determined over the portion of the brake apply which excludes the initial 10% and final 10% of the apply. For ramp applies, maximum and minimum instantaneous friction are determined over the portion of the apply between 500 kPa and 12 000 kPa.

Within Condition Apparent Friction or Output Range: The maximum average apparent friction minus the minimum average apparent friction for a given braking condition listed in 4.3.

7.2 Acronyms, Abbreviations, and Symbols.

AF	Apparent Friction
ALRO	Assembled Lateral Run Out
APT	Apparent Piston Travel
BCATS	Brake Corner Assembly Technical Specification
BTV	Brake Torque Variation
FFT	Fast Fourier Transform
GDM	Global Document Management
GSSLT	Global Subsystem Leadership Team
GVW	Gross Vehicle Weight
IBT	Initial Brake Temperature
RH	Relative Humidity
TIP	Test Improvement Process

8 Coding System

This standard shall be referenced in other documents, drawings, etc., as follows:

Test to GMW14925

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