



Brake Performance Testing on Race Tracks

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 document describes standard instrumentation, data collection, test methodology, and data processing for assessing brake system performance on the race track.

1.2 Applicability. This test procedure applies to all vehicles undergoing brake system testing on high speed, closed circuit race tracks. Some of the data processing methods require that the test vehicle complete multiple laps before meaningful data can be derived.

1.3 Remarks. Testing at the race track will typically involve testing for many of the commonly affected subsystems simultaneously (e.g., ride and handling, chassis controls, thermal/powertrain cooling, driveline, engine/powertrain, tire/wheel, as well as brake system). The actual testing will often involve an experienced driver attempting to traverse a closed-circuit race track with as short of a lap time as possible. The actual usage of the brake system cannot usually be prescribed; rather, the test driver must be allowed to use the brake system "naturally" to suit their driving style. Acknowledging this, it is important to coordinate instrumentation with other subsystem engineering groups to insure that the data necessary to characterize brake system performance are acquired, and it is important to have a data processing methodology that is flexible to different brake system usage patterns.

2 References

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

2.1 External Standards/Specifications.

None

2.2 GM Standards/Specifications.

GMW14986

2.3 Additional References.

- SAE 2005-01-0790 - Measuring and Characterizing Brake System Performance During Race Track/High Energy Driving Conditions

3 Resources

3.1 Facilities. Any closed-circuit (continuous loop with repeated laps) high speed race track.

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. Following are instrumentation and equipment requirements divided into four (4) categories (test vehicle equipment, basic minimum brake instrumentation, additional brake instrumentation, and non-vehicle mounted equipment).

3.2.1 Test Vehicle Equipment (list is not necessarily comprehensive, check with local General Motors traffic safety department for additional requirements):

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- Roll cage.
- Safety harnesses.
- Fire suppression system.

3.2.2 The basic minimum brake instrumentation; the following list represents the most basic set of instrumentation needed to characterize brake system performance. Temperature channels may be recorded as slow as 0.5 Hz to save data acquisition system storage space. The other external-sensor based signals should be recorded at 50 Hz or faster, depending on data acquisition capabilities and storage space. Local Area Network (LAN)-based signals should be recorded at the fastest rate allowed by the LAN.

Signals that can be measured from on-board sensors via test vehicle network are marked as "LAN." Signals that can be measured from a Global Positioning System (GPS) are marked as "GPS".

- Brake Pad Temperatures at all four (4) corners (outer pads, thermocouples embedded 5 mm below pad surface).
- Brake hydraulic pressure at all four (4) corners (typically at caliper bleeder screw locations if fluid temperature thermocouples are not present, or at junction block at brake hose to pipe connection if fluid temperature thermocouples are present).
- (LAN) Brake Pedal Travel (via Brake Apply Sensor).
- Booster vacuum (if applicable).
- Longitudinal Acceleration/Deceleration.
- (GPS or LAN) Vehicle Speed.

3.2.3 The additional brake instrumentation; the following list represents data that may be of added value in characterizing brake system performance, or that may be useful in diagnosing performance issues. The following external-sensor-based channels should be recorded at 50 Hz or faster; the LAN based channels should be recorded as fast as the LAN allows.

Signals that can be measured from on-board sensors via test vehicle network are marked as "LAN". Signals that can be measured from a GPS are marked as "GPS". Signals that are unique to electronic brake actuation (and usually accessible via the LAN or by special interface) are marked "ELCT".

- Lateral acceleration.
- Brake pad temperatures (inboard pads, thermocouples embedded 5 mm below pad surface).
- Brake fluid temperatures (typically installed through modified bleeder screws).
- Booster apply side pressure (typically requires light machining to install pressure tap).
- Wheel bearing temperatures (typically from sensor epoxied to bearing outer race housing).
- Brake hose temperatures (typically at both end fittings and at center of hose).
- (GPS) vehicle x, y position.
- (GPS) vehicle altitude.
- (LAN) Antilock Braking System (ABS) activation.
- (LAN) Traction Control System (TCS) activation.
- (LAN) Electronic Stability Control (ESC) activation.
- (LAN) wheel speeds (individual).
- (LAN) steering wheel angle.
- (LAN) throttle position.
- (LAN) transmission gear.
- (ELCT) actuation motor speed.
- (ELCT) actuation power supply voltage.
- (ELCT) actuation electric current flow.
- (ELCT) actuation stroke/position.

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- (ELCT) plunger volume.

3.2.4 Other (non-vehicle based) equipment; additional equipment (not installed into test vehicle) may be needed to complete certain measurements that may be of interest. Commonly used equipment includes:

- Micrometer with pointed tip for taking pad wear measurements.
- Coordinate Measurement Machine (CMM) (Rotational, Polar Coordinate system) for measuring brake rotor Lateral Runout (LRO) and Disc Thickness Variation (DTV).
- Digital microscope for evaluating posttest tribofilms (typically on brake rotor surface).
- Digital camera to document appearance of posttest brake hardware (pads, rotors, and calipers).
- Laser-Scanning profilometer for taking detailed measurements of pad wear profiles, including taper wear and cupping wear.

3.3 Test Vehicle/Test Piece. The test vehicle should have (as close to as possible) design representative powertrain (engine and transmission), suspension, tires, and brake cooling (affected by fascia, air dam, underbody air deflector, brake cooling content, such as ducts, ramps, and wheels). It is common for all of these factors to change significantly over the course of a vehicle development program, so a careful record of vehicle configurations tested should be kept with the brake performance data.

3.4 Test Time.

Calendar time: 5 days

Test time: 8 hours

Coordination time: 8 hours

3.5 Test Required Information. Not applicable.

3.6 Personnel/Skills. An experienced, trained driver (certified for driving on high speed race tracks) is needed to drive the test vehicle. An experienced, trained brake technician or brake engineer is needed to perform pre- and posttest inspections and measurements of the brake components. An experienced, trained brake engineer is needed to process and analyze brake test data.

4 Procedure

4.1 Preparation.

4.1.1 Friction Material Burnish. The brake friction material (pads and rotors) must be burnished before race track usage. The burnish allows the brake pad to wear into a full contact pattern with the brake disc, it initiates a buildup of protective tribofilms (transfer films) on the pad and rotor surfaces, and in some cases it allows the curing of the brake pads to be completed. The following burnish procedure is suitable for most cast iron brake rotor-based systems. Brake systems based in other rotor materials (such as carbon-ceramic) may require different burnish procedures, and certain combinations of friction material and brake sizing may also require modifications to achieve a suitable burnish. In such cases, an alternate burnish procedure may be used, as agreed upon between GM and the responsible supplier(s). When an alternate procedure is used, it should be documented in the test report.

4.1.1.1 Track Burnish Instructions. Matched sets of friction material may be burnished in advance of testing at the race track. It is recommended that a sufficient quantity of friction material sets be burnished to cover all of the testing anticipated for a session at the track (which may, for some events, cover a period of days to a week or more). Many race track settings do not offer suitable facilities to conduct the burnish procedure, so advanced preparation will help avoid costly down-time.

4.1.1.2 Perform 25 snubs from 100 km/h to 50 km/h at 3.94 m/s² (0.4G), every 1.0 km.

4.1.1.3 Perform 14 snubs from 160 km/h to 50 km/h at 4.9 m/s² (0.5G), every 1.0 km.

4.1.1.4 Allow the brakes to cool down: 100 km/h for 15 km.

4.1.1.5 Perform 25 snubs from 100 km/h to 50 km/h at 3.94 m/s² (0.4G), every 1.0 km.

4.1.1.6 Repeat 4.1.1.2 through 4.1.1.5 for each new set of friction material.

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4.1.2 Brake Pad Measurement. The initial thickness of the brake pads should be measured per GMW14986. Measurement locations should be paint-marked on the backing plate instead of drilled; and any noise-abatement insulator or cover shim should remain in place.

4.2 Conditions.

4.2.1 Environmental Conditions. Brake testing should take place on dry track conditions. Wet conditions will reduce brake temperatures, both from direct splash/wetting of the brake components, and from limiting the engine power that can be transmitted to ground and carried through turns. This may result in an inaccurate assessment of brake system performance capability.

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. Testing on the race track does not occur in the form of rigidly specified test procedures. It is important to allow the test vehicle to be driven naturally as the driver intends without attempting to specify speed profiles, braking points, or acceleration points. In this section, this document will specify parameters of testing that will insure that data collected during track testing can be used to characterize brake system performance on the race track.

4.3.1 Test Duration. In order to characterize brake system performance, it is important to run multiple laps on a closed-loop track. This allows individual braking events in the track to be repeated, and the trends in braking behavior to be analyzed. A minimum of three (3) consecutive laps at driver's best effort is recommended to assess brake performance, and ideally at least five (5) laps to a full tank of fuel should be run. It should be noted that it is very typical for a driver to take a lap or more to acclimate to the vehicle and/or the track.

4.3.2 Data Acquisition. Data acquisition should generally be started as a vehicle leaves the track pit area, and stopped no sooner than 15 minutes after the vehicle returns to the pit area to stay. This is done in order to record the thermal soak of the brakes, which will lead to peaks in brake fluid temperature. Many test plans will have the vehicle exiting the track into the pit area, and then returning back to the track after a short duration (often for the test driver to communicate with support personnel) or for small adjustments or calibration changes to be made; in these cases a soak should not be imposed.

4.3.3 Post Run Interview. It is important to interview the driver to collect record verbal feedback on brake system performance as soon as practicable after a run. This will be corroborated with the objective data to identify potential brake system performance issues on the race track, and assess their severity. It should be noted that feedback and even description vocabulary will vary by driver, and different drivers have a wide range of tolerance to issues such as brake pedal travel or apply system runout.

5 Data

5.1 Calculations.

5.1.1 Braking Events. The data recorded in a continuous stream over the course of a session on the race track must be separated into individual braking events. Following is the recommended definition of a braking event (which can then be used to separate the data using automated data processing code). A braking event is defined as a continuous period of data for which all of the following are true:

- Front brake hydraulic pressure is above a threshold (recommend 500 kPa).
- (If available) – No ESC or TCS activation flags set (ABS activation is permitted).

5.1.2 Average Deceleration. Compute the averaged longitudinal deceleration over each braking events.

5.1.3 Average Front Brake Hydraulic Pressure. Compute the averaged front (left and right front) brake hydraulic pressure (averaged together for each time step, then averaged over the braking event).

5.1.4 Significant Braking Events. Sort the braking events into significant braking events. Significant braking events are those for which the average deceleration is above a threshold value. The recommended threshold is 3 m/s²; however, the optimal threshold may depend on vehicle and driving style, so the brake development engineer may change this threshold to a value that works for the data set.

5.1.5 Deceleration Gain. Calculate the deceleration gain for each significant braking event. The deceleration gain is defined by the following equation:

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$$\text{Decel Gain} = \frac{\text{Average (longitudinal deceleration)}}{\text{Average(front brake hydraulic pressure)}}$$

As suggested by the equation, typical units of Decel Gain will be meter per second squared per kilopascal.

5.1.6 Apply System Runout or Reserve. Apply system runout or reserve is defined as the difference between instantaneous apply system hydraulic pressure capacity at maximum boost force, and the corresponding peak hydraulic pressure recorded in the brake system. When the hydraulic pressure recorded in the brake system exceeds the pressure of which the apply system is capable, then the apply system is in runout. The difference expresses the hydraulic pressure above and beyond the apply system capacity that is produced by additional force from the driver pushing on the brake pedal. Likewise, when the apply system maximum pressure at maximum boost exceeds the pressure recorded in the brake system, the apply system has reserve, and the difference between the two represents the additional hydraulic pressure that could be generated before reaching runout.

5.1.7 Computation of Apply System Capacity. The following equation is applicable to vacuum-boosted apply systems. For electric boosted systems, the peak apply system pressure will depend more on electrical system volume and operating temperature. For hydraulically boosted apply systems, peak boost pressure will depend on a regulated limit, and to a lesser degree, engine/pump speed. Peak boosted pressures for electric apply systems.

$$\text{Boost}_{\text{Inst_max}} = \left(\frac{\text{Vac}}{\text{Vac}_{\text{Ref}}} \right) \times (\text{Boost}_{\text{Ref_max}} + F_{\text{loss}}) - F_{\text{loss}}$$

$$\text{Pressure}_{\text{Inst_max}} = 1000 \times \left[\frac{\text{Boost}_{\text{Inst_max}}}{\pi \times \left(\frac{D_{\text{Master_cylinder}}}{2} \right)^2} \right]$$

Where:

$\text{Boost}_{\text{Inst_max}}$ (N) = the instantaneous maximum boost force.

Vac (kPa) = the instantaneous booster vacuum level.

Vac_{Ref} (kPa) = the “reference” vacuum at which a previous booster maximum output force measurement was recorded (typical data source is an apply bench test, with a reference vacuum of 68 kPa).

$\text{Boost}_{\text{Ref_max}}$ (N) = the booster maximum amplified output force with supply vacuum Vac_{Ref} (additional force can be generated by the driver pushing the pedal harder, up to the point where the master cylinder stroke limit is reached).

F_{loss} (N) = the booster failed power force loss (representing internal force losses, usually due to a return spring, that must be overcome to produce output).

$\text{Pressure}_{\text{Inst_max}}$ (kPa) = the instantaneous maximum hydraulic pressure in the master cylinder at booster runout. Additional pressure can be generated by the driver pushing the pedal harder, up to the point where the master cylinder stroke limit is reached.

$D_{\text{Master_cylinder}}$ (mm) = the diameter of the master cylinder.

5.1.8 Computation of Apply System Runout or Reserve. The measure of runout or reserve is the difference between the pressure in the brake system achieved by the driver, and the calculated apply system pressure capacity at runout. When the value is negative, there is reserve (the apply system can supply more pressure than was needed by the driver). When the value is positive, there is a condition of apply system runout, and the numeric value is a measure of how far into runout the driver had to push to get the hydraulic pressure that was needed. In mathematical form, the expression is:

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$$\text{Runout (Reserve)} = \text{Pressure}_{\text{inst_recorded}} - \text{Pressure}_{\text{inst_max}}$$

This equation is usually evaluated on a data point by data point basis – one calculation for each time step of recorded data. It is usually convenient to perform this calculation continuously in this manner, and then separate the data into individual braking events per the steps outlined in 5.1.1 through 5.1.4. Runout or reserve is then expressed for reporting purposes as the peak value (maximum runout or minimum reserve) per braking event.

5.1.9 Computation of Pad Wear and Pad Life Projections. Posttest wear of the brake pads should be measured per GMW14986. Pad wear is computed as specified in GMW14986. The following equation (5) should be used to project the brake pad life in terms of laps of the test track:

$$\text{Life}_{\text{Projected}} = \left(\frac{\text{Pad Wear}_{\text{Measured}}}{\text{Useable Pad Thickness}} \right) \times \text{Number of Laps}$$

Where:

$\text{Life}_{\text{Projected}}$ (laps) = projected brake pad life.

$\text{Pad Wear}_{\text{Measured}}$ (mm) = pad wear incurred over the testing session.

Usable Pad Thickness (mm) = the allowable pad wear between the new pad condition and the discard thickness (typically where the wear sensor is positioned, usually 1 mm to 2 mm above the backing plate).

Number of Laps = the number of laps completed during the usage for which the pad wear measurement was taken.

It is common to compare brake pad life to the maximum single-session duration of usage on the race track, which in turn is defined as the number of laps that can be achieved with the useable volume of one (1) tank of fuel (or one (1) full charge of the vehicle's propulsion energy source). For this reason, the test documentation should include a reference of how many laps the tested vehicle achieved or can be projected to achieve on one (1) tank of fuel.

5.1.10 Optional. Diagnostic Procedures and Statistical Tests.

5.1.10.1 Diagnosing Brake Corner Fluid Consumption Issues. There is a very strong correlation between the rates of pressure buildup at each brake corner relative to the pedal travel input to the brake system, and the fluid consumption of each corner. By plotting pressure vs. pedal travel input (in turn a strongly correlated measure to fluid displacement through the brake system) in a baseline, nominal operating condition, and comparing similar plots from braking events where compliance issues are suspected, the major source of the fluid consumption increase can usually be identified. This is useful when issues such as pryback of one or more brake calipers is suspected, or in diagnosing whether a more significant change occurred in the front vs. the rear brake design.

As fluid consumption increases and more fluid must be moved into the brake caliper to generate pressure, the rate of pressure buildup in the caliper relative to the input to the system (pedal travel) will slow down considerably. When plotted this creates a very visible signature.

Appendix A, Figures A8 through A10 show modeled brake pressure vs. pedal travel for a nominal condition brake system, followed by 0.5 mm and then 1.0 mm pryback conditions in the Left Front (LF) caliper. Appendix A, Figures A11 and A12 show data from an actual vehicle test on a race track.

In more detail, Appendix A, Figure A8 shows the "nominal" condition, with brake corner fluid consumption in the warm burnished condition and with no excessive taper wear and no pryback. Here are some differences in the rate of pressure build amongst the four (4) brake corners, due to difference in fluid consumption, pipe lengths and pipe bends, and orificing in the hydraulic control unit of the chassis controls system.

Appendix A, Figure A9 shows the influence of 0.5 mm of pryback on the LF caliper. This flattens out the rate of pressure rise in the LF caliper relative to the others considerably.

Appendix A, Figure A10 shows the influence of 1.0 mm of pryback on the LF caliper. An even further delay in the rate of pressure rise may be seen by examining the LF caliper pressure curve.

5.1.10.2 Diagnosing Brake Roughness Issues. Brake roughness in race track testing is usually recognized through feedback from the driver in the form of complaints of steering wheel vibration during braking, brake pedal

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pulsation during braking, and/or vibration of the vehicle body and seat structures during braking. If such a complaint occurs, then the brake rotors should be removed from the vehicle at the earliest opportunity, and the brake rotor LRO and DTV measured. The braking surfaces should also be examined for visible circumferential non-uniformities (see Appendix A, Figure A13 for an example). Appendix A, Figure A14 shows an example of posttest LRO and DTV measurements.

5.1.10.3 Statistical Tests. There are statistical tests that can be used to compare deceleration gain data from different test runs (and usually from different brake system configurations). Two (2) useful tests include (a) test for coincidence in deceleration gain data, which is used to determine if there is a statistically significant difference in brake system output, and (b) test for parallelism, which is used to determine if there is a statistically significant difference in brake fade behavior (the change in brake system output with brake temperature). Details of these tests are not documented in this standard. For a description of the tests and examples of application, consult the reference noted in 2.3 (SAE 2005-01-0790).

5.2 Interpretation of Results. Not applicable.

5.3 Test Documentation.

5.3.1 Deceleration Gain Plot. Plot the deceleration gain vs. front brake pad temperature and/or the deceleration gain vs. braking event order (example of deceleration gain vs. front pad temperature is shown in Appendix A, Figure A1).

5.3.2 Brake Pad Temperatures. Plot the brake pad (front and rear) temperatures vs. time. See example in Appendix A, Figure A2.

5.3.3 Brake Fluid Temperatures. Plot the brake fluid temperatures vs. time. It is often helpful to plot both with pad temperatures, to see the relationship between the two (see Appendix A, Figure A2) and separately, to see detail (see Appendix A, Figure A3).

5.3.4 Apply System Runout or Reserve. Plot the apply system runout or reserve by braking event (the peak runout or minimum reserve for each braking event is plotted). Appendix A, Figures A4 and A5 show recommended methods of reporting these data.

5.3.5 Pad Wear, Taper Wear, and Projected Life. Plot pad wear as specified in GMW14986 (see Appendix A, Figure A6 for an example). Report projected pad life as shown in Appendix A, Figure A7.

5.3.6 Post-Test Friction Material Photos. Photograph the posttest friction material (pads and rotors). The subjects and quantities of photographs are at the discretion of the test responsible engineer. In many test events, numerous sets of friction material will be used – it is not necessary to photograph every friction material set. It is recommended that at least one (1) set of friction material (front and rear pads and rotors) be photographed and documented to show the test report reader the design and general condition of the friction material, and then additional sets be included if there is visual evidence that relates to or helps explain brake performance on a particular set. Suggested minimum photographic documentation (per brake corner per friction material set) includes (a) Rotor (inner surface), Rotor (outer surface), Pads (axle set together, friction surface), Pads (axle set together, backing plate/noise insulator surface). Close up photos of the rotor friction surface(s) and/or pad surface(s) should be included if it shows relevant detail not visible in the full-surface photo. Examples of posttest photos (for one (1) brake corner) appear in Appendix A, Figure A15.

5.3.7 Post-Test Inspection (brakes). Review the condition of all other brake corner and apply system area components (in addition to the friction material). A partial list of areas that are usually at elevated risk for issues during race track testing that bear special attention during posttest inspection include:

- Brake calipers (hydraulic sealing areas near pistons, brake hose interface).
- Brake hoses (look for signs of leakage, blistering).
- Wheelspeed sensors (look for signs of heat damage to wires and sensor head).
- Fasteners (look for signs of torque loss/movement on all highly stressed brake corner area fasteners, including calipers, guide pin bolts, and wheel bearing bolts).

5.3.8 Record of Lap Times and Vehicle Driver. A record of lap times and the driver of the vehicle should be documented. Powertrain performance and tire performance can vary considerably with ambient conditions, which can affect brake system performance. Different driving styles can also affect brake system performance. An example lap time record is shown in Appendix A, Figure A16.

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