



SURFACE VEHICLE RECOMMENDED PRACTICE	J2784™	MAY2024
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FMVSS Inertia Dynamometer Test Procedure for Vehicles Below 4540 kg GVWR		

RATIONALE

The current version of this recommended practice corrects the calculations for brake effectiveness, provides a definition of average by distance, and clarifies the scope related to tow vehicles and trailering applications. This revision also includes several edits to improve readability. The technical content, the test conditions, and the test sequences from previous versions remain unchanged.

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1. SCOPE

This document derives from the Federal Motor Vehicle Safety Standards (FMVSS) 105 and 135 vehicle test protocols as single-ended inertia-dynamometer test procedures. The test sequences enable brake output measurement, friction material effectiveness, and corner performance in a controlled and repeatable environment. This SAE Document also includes optional sections for parking brake output performance for rear brakes with hydraulic or Electric Park Brakes (EPB). It applies to brake corners from vehicles covered by the FMVSS 105 and 135 when using the appropriate brake hardware and test parameters. The FMVSS 135 applies to all passenger cars and light trucks up to 3500 kg of gross vehicle weight (GVWR). The FMVSS 105 applies to all passenger cars, multi-purpose vehicles, buses, and trucks above 3500 kg of GVWR. This document does not include testing for school bus applications or vehicles equipped with hydraulic brakes with a GVWR above 4540 kg.

This document does not evaluate or quantify other brake system characteristics such as wear, noise, judder, ABS performance, or braking under extreme temperatures or speeds. This document does not include minimum performance requirements. Consistency and margin of pass/fail of the minimum requirements related to stopping distance or equivalent deceleration levels of the FMVSS 105 or FMVSS 135 vehicle test can be assessed as part of the project in coordination with the test requestor when using the appropriate vehicle information and vehicle dynamics modeling. Nevertheless, this procedure and its results do not replace the vehicle-level test to demonstrate compliance with FMVSS for hydraulic brake systems or other mandatory regulations (e.g., ECE R13H or ECE R13).

Towing and trailering applications are not part of this document and require a separate assessment per SAE J2807.

1.1 Purpose

This procedure aims to assess the performance of a brake corner assembly during conditions that correspond to the FMVSS 105 and 135 vehicle test procedures.

2. REFERENCES

2.1 Applicable Documents

The following publications form a part of this specification to the extent specified herein. Unless otherwise indicated, the latest issue of SAE publications shall apply.

2.1.1 SAE Publications

Available from SAE International, 400 Commonwealth Drive, Warrendale, PA 15096-0001, Tel: 877-606-7323 (inside USA and Canada) or +1 724-776-4970 (outside USA), www.sae.org.

SAE J2789 Inertia Calculation for Single-Ended Inertia-Dynamometer Testing

SAE J2807 Performance Requirements for Determining Tow-Vehicle Gross Combination Weight Rating and Trailer Weight Rating

SAE J2986 Brake Pads, Lining, Disc, and Drum Wear Measurements

2.1.2 ISO Publications

Copies of these documents are available online at <https://webstore.ansi.org/>.

ISO/PAS 12158:2002 Road Vehicle - Braking Systems - Temperature Measuring Methods

2.2 Related Publications

The following publications are provided for information purposes only and are not a required part of this SAE Technical Report.

2.2.1 SAE Publications

Available from SAE International, 400 Commonwealth Drive, Warrendale, PA 15096-0001, Tel: 877-606-7323 (inside USA and Canada) or +1 724-776-4970 (outside USA), www.sae.org.

Yuan, Y. and Halloran, P., "Calculation of Average Coefficient of Friction During Braking," SAE Technical Paper 1999-01-3410, 1999, <https://doi.org/10.4271/1999-01-3410>.

2.2.2 NHTSA Publications

Available from National Highway Traffic Safety Administration, 1200 New Jersey Avenue, SE, Washington, DC 20590, Tel: 1-888-327-4236, <https://www.nhtsa.gov/>.

571.105	Standard No. 105 - Hydraulic and Electric Brake Systems
571.135	Standard No. 135 - Light Vehicle Brake Systems
TP-105-03	OVSC Laboratory Test Procedure for FMVSS 105 Hydraulic and Electric Brake Systems
TP-135-01	OVSC Laboratory Test Procedure for FMVSS 135 Light Vehicle Brake Systems

2.2.3 ISO Publications

Copies of these documents are available online at <https://webstore.ansi.org/>.

ISO 611:2003	Road Vehicles - Braking of Automotive Vehicles and Their Trailers - Vocabulary
ISO/TR 13487:1997	Braking of Road Vehicles - Considerations on the Definition of Mean Fully Developed Deceleration

3. DEFINITIONS

3.1 Applicable to Both FMVSS 135 and FMVSS 105

3.1.1 APPARENT COEFFICIENT OF FRICTION FOR DISC BRAKES

Per Equation 1:

$$\mu = \frac{10^6 \cdot T}{2 \cdot (p - p_{Threshold}) \cdot A_p \cdot r_{eff} \cdot \eta} \quad (\text{Eq. 1})$$

where:

μ = apparent friction for disc brakes (unitless)

3.1.2 DRUM BRAKE EFFECTIVENESS (C^*)

Per Equation 2:

$$C^* = \frac{10^6 \cdot T}{(p - p_{threshold}) \cdot A_p \cdot r_{eff} \cdot \eta} \quad (\text{Eq. 2})$$

where:

C^* = effectiveness for drum brakes (unitless)

T = output torque (N·m)

p = brake pressure (kPa)

$p_{threshold}$ = minimum pressure required to start developing braking torque; unless otherwise directed, use threshold pressure derived from Table 3, Section 20 or Table 4, Section 30 (kPa)

A_p = total piston area acting on one side of the caliper for disc brakes; total wheel cylinder area for drum brakes (mm²)

r_{eff} = radial distance from the centerline of the piston to the axis of rotation for disc brakes; internal drum diameter divided by two for drum brakes, unless the requestor provides other dimensions (mm)

η = efficiency (%)

3.1.3 AVERAGE BY DISTANCE

Averaging method where the sampling frequency is a unit of vehicle distance (between data points) traveled during a braking event. The average by distance correlates to the vehicle stopping distance and the mean fully developed deceleration (refer to references in 2.2.1 and 2.2.3). As the literature indicates, this value yields the same result as the integration between two distance points per Equation 3A. The first term in Equation 3A provides the total distance traveled during the averaging period. The integral provides the area under the curve for the measurand in the distance domain for the same averaging period.

Equation 3B provides a working version of Equation 3A relating to the actual calculation as part of the dynamometer data collection or spreadsheet calculations. The first term on the numerator provides the average value of the measurement between two consecutive averaging points. The numerator's second and third terms provide the distance between two measurement points (distance = speed x time). The denominator provides the total distance traveled for the entire period used to compute the average by distance:

$$m_{dist} = \frac{1}{s_e - s_b} \times \int_{s_b}^{s_e} m(d) \cdot d_s \quad (\text{Eq. 3A})$$

$$m_{dist} = \frac{\sum_b^e [(m_i + m_{i+1})/2] \cdot (v_{i+1} - v_i) \cdot \Delta t_i}{\sum_b^e (v_{i+1} - v_i) \cdot \Delta t_i} \quad (\text{Eq. 3B})$$

where:

m_{dist} = average by distance for the measurand (torque, pressure, apparent friction, or brake effectiveness)

s_e = distance traveled from the initiation of the brake application to the time the average ends

s_b = distance traveled from the initiation of the brake application to the time the average begins

$m(d)$ = average value of the measurand during the increment of distance d_s

d_s = distance increment between two sampling points

m_i = measurand value at time i

v_i = speed at time i

Δt_i = increment of time between two consecutive measuring points and equal to 1 divided by the sampling rate in Hz

3.1.4 BREAKAWAY TORQUE

Minimum torque required to initiate brake rotation after applying cable tension or clamping force to the parking brake. (N·m)

3.1.5 DECELERATION-CONTROLLED BRAKE APPLICATION

Control algorithm to adjust the real-time brake pressure to maintain a constant torque output calculated from the instantaneous deceleration specified in the test procedure.

3.1.6 GROSS VEHICLE WEIGHT (GVWR)

Maximum vehicle weight indicated by the manufacturer. (kgf)

3.1.7 INITIAL BRAKE TEMPERATURE (IBT)

Rotor or drum temperature at the start of the brake application. (°C)

3.1.8 LIGHTLY LOADED VEHICLE WEIGHT (LLVW)

Unloaded vehicle weight plus 180 kg for the driver and test instrumentation. (kgf)

3.1.9 MAXIMUM VEHICLE SPEED (V_{MAX})

Highest speed attainable by accelerating at a maximum rate from a standstill to a distance of 3.2 km on a level surface, with the vehicle at LLVW for vehicles per FMVSS 135 or GVWR for vehicles per FMVSS 105. For electric vehicles, ensure the propulsion batteries are at a state of charge of not less than 95% at the beginning of the run. See Sections 50 and 70 in Table 3 and Sections 70 and 250 in Table 4. (km/h)

3.1.10 PRESSURE-CONTROLLED BRAKE APPLICATION

Control algorithm to maintain a constant input pressure to the brake irrespective of the torque output.

3.1.11 TIRE DYNAMIC ROLLING RADIUS

Equivalent tire radius generating the revolutions per mile (RPM) for the specific tire size using Equation 4. Use the tire dynamic rolling radius to calculate the dynamometer rotational speed for a given linear vehicle speed. (mm)

$$RR = \frac{1609344}{2 \cdot \pi \cdot RPM} \quad (\text{Eq. 4})$$

where:

RR = tire dynamic rolling radius (mm)

RPM = tire manufacturer specification for RPM; typically available on the manufacturer's website

3.2 Applicable to FMVSS 135 Only

3.2.1 PRESSURE LEVEL AT 500 N PEDAL FORCE WITH BRAKE POWER ASSIST SYSTEM OPERATIONAL ($p_{500N \text{ OPERATIONAL}}$)

Brake system pressure at the front or rear corner with 500 N of pedal force applied with the brake system and power assist unit fully operational, including rear brake proportioning. (kPa)

NOTE: Determine this value using vehicle measurements or the default value per 8.1.7.

3.2.2 PRESSURE LEVEL AT 500 N PEDAL FORCE WITH BRAKE POWER ASSIST SYSTEM FULLY DEPLETED ($p_{500N \text{ DEPLETED}}$)

Brake system pressure at the front or rear corner with 500 N of pedal force applied and the power assist unit fully depleted, including rear brake proportioning. (kPa)

NOTE: Determine this value using vehicle measurements or the value provided by the test requestor.

3.2.3 PRESSURE LEVEL DURING BEST COLD EFFECTIVENESS STOP ($p_{\text{BEST COLD EFFECT}}$)

The lowest distance-weighted average brake pressure from all the brake applications is in Section 40, Table 3, Cold Effectiveness. (kPa)

3.3 Applicable to FMVSS 105 Only

3.3.1 BRAKE POWER ASSIST UNIT

A device installed in a hydraulic brake system to reduce the driver effort required to actuate the system. If the device is inoperative, it does not prevent the driver from braking the vehicle by a continued application of pedal force on the service brake control.

3.3.2 BRAKE POWER UNIT

A device part of the braking system that provides the energy required to actuate the brakes, directly or indirectly, through an auxiliary device, with the driver action consisting only of modulating the energy application level.

3.3.3 PRESSURE LEVEL AT 667 N PEDAL FORCE WITH BRAKE POWER ASSIST OR BRAKE POWER UNIT SYSTEM OPERATIONAL ($p_{667N \text{ OPERATIONAL}}$)

Brake system pressure at the front or rear corner with 667 N of pedal force applied with the brake system and power assist unit fully operational, including rear brake proportioning. (kPa)

NOTE: Determine this value using vehicle measurements or the default value per 8.2.8.

3.3.4 PRESSURE LEVEL AT 667 N PEDAL FORCE WITH BRAKE POWER ASSIST SYSTEM FULLY DEPLETED ($p_{667N \text{ DEPLETED}}$)

Brake system pressure at the front or rear corner with 667 N of pedal force applied and the power assist unit fully depleted, including rear brake proportioning. (kPa)

NOTE: Determine this value using vehicle measurements or the value provided by the test requestor.

3.3.5 PRESSURE LEVEL AT 890 N PEDAL FORCE WITH BRAKE POWER ASSIST OR BRAKE POWER UNIT SYSTEM OPERATIONAL ($p_{890N \text{ OPERATIONAL}}$)

Brake system pressure at the front or rear corner with 890 N of pedal force applied with the brake system and power assist unit fully operational, including rear brake proportioning. The spike stops section uses this pressure level. (kPa)

NOTE: Determine this value using vehicle measurements or the value provided by the test requestor.

3.3.6 SPIKE STOP

Stop resulting from applying a service brake pressure of $p_{890N \text{ operational}}$ in 0.08 seconds.

4. TEST CYCLES

4.1 Dynamic Brake Application

Figure 1 illustrates the main time stamps used to characterize the brake application.

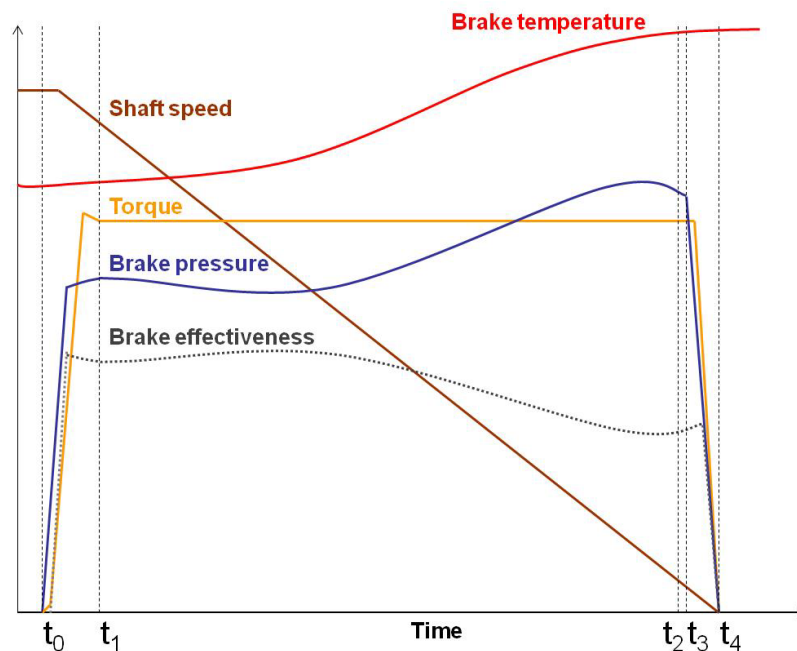


Figure 1 - Typical brake application time stamps

4.1.1 Time t_0

Brake application initiation. At this time, the pressure starts to rise.

4.1.2 Time t_1

Time at the level reached for the setpoint. At this time stamp, the brake reaches its target torque or pressure control level. At time t_1 , calculating the average by time and the average by distance begins.

4.1.3 Time t_2

Time at the end of averages. At time t_2 , the inertia-dynamometer data acquisition system terminates the calculation of average by time and average by distance. Time t_2 is the end of the stable portion of the brake application when the speed is 0.5 km/h above the release speed (t_3).

4.1.4 Time t_3

Time at release speed. At time t_3 , the inertia-dynamometer servo controller releases the brake (specified in 8.1.3).

4.1.5 Time t_4

Time at brake pressure and torque lost. At time t_4 , pressure and torque are below the minimum thresholds. The inertia-dynamometer considers the braking event complete.

4.2 Parking Brake Application

See Appendix A.

5. TEST EQUIPMENT

5.1 Applicable to Both FMVSS 135 and FMVSS 105

5.1.1 Single-ended brake inertia dynamometer capable of performing deceleration and pressure-controlled brake applications.

5.1.1.1 Automatic data collection system capable of recording the following channels digitally at 50 Hz minimum:

5.1.1.1.1 Brake equivalent linear speed. (km/h)

5.1.1.1.2 Brake input pressure. (kPa)

5.1.1.1.3 Brake output torque. (N·m)

5.1.1.1.4 Brake fluid displacement. (mm³)

5.1.1.1.5 Shaft angular position. (degrees)

5.1.1.1.6 Parking brake cable tension for mechanical park brake. (N)

5.1.1.1.7 Parking brake input voltage or current for EPB. (V, A)

5.1.1.1.8 Parking brake cable travel. (mm)

5.1.1.2 Automatic data collection system capable of recording the following channels digitally at 10 Hz minimum:

5.1.1.2.1 Brake rotor or drum temperature. (°C)

5.1.1.2.2 Brake pad or brake shoe temperature. (°C)

5.1.2 Cooling Air Temperature, Relative Humidity, and Speed

5.1.2.1 Control brake cooling air temperature $25\text{ °C} \pm 5\text{ °C}$ and humidity to 9.92 g/kg (11.57 g/m³) at sea level. Use a psychrometric chart to find acceptable air temperature and relative humidity conditions to meet absolute humidity requirements.

5.1.3 Park Brake Testing Capabilities

5.1.3.1 Ability to apply torque from zero shaft rotational speed enough to cause breakaway (Method A) or ability to maintain a static torque for five continuous minutes (Method B).

5.1.3.2 A mechanism to apply and control input cable tension.

5.1.3.3 A mechanism to lock the parking brake cable travel in position during parking brake output evaluation.

5.1.3.4 Have the appropriate electrical input for EPB systems.

5.2 Applicable to FMVSS 135

There are no specific requirements for the test cycle related to this regulation.

5.3 Applicable to FMVSS 105

5.3.1 Water spray testing capabilities (for FMVSS 105 testing only).

5.3.2 System to deliver a steady stream of water on both sides of the rotor or directed into the drum assembly at a rate of 5 L/min $\pm$ 2 L/min.

5.3.3 System to adjust the position, orientation, and distance from the stream of water to the brake assembly. For disc brakes, align the water stream in the radial direction with the center of the rotor and within 50 to 100 mm from the brake on the leading edge of the caliper. See Figure 2.

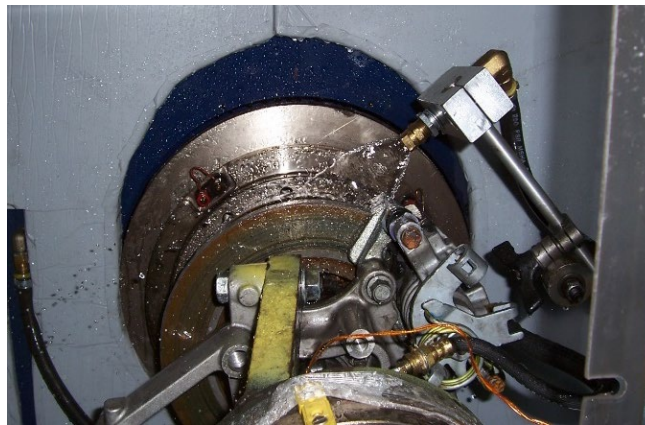


Figure 2 - Water spray setup for disc brakes

6. TEST CONDITIONS AND SAMPLE PREPARATION

6.1 Use new rotor and brake pads or new drum and brake shoe linings for each test.

6.2 For brake rotors, install a thermocouple at a depth of 1.0 mm below the surface. Locate the thermocouple on the outboard face near the centerline of the braking surface.

6.3 For brake pads, install one thermocouple at a depth of 2.0 mm near the center of the friction surface. For disc brake pads with grooves, install the thermocouple at least 4.0 mm from the groove edge on the leading side of the pad.

6.4 For disc brakes, the assembled lateral run-out shall not exceed 50 μ m when measured on the outboard surface and 10 mm from the outside diameter.

6.5 For brake drums, install a thermocouple at a depth of 1.0 mm on the centerline of the braking surface.

6.6 For brake shoes, install a thermocouple at a depth of 1.0 mm near the center of the friction surface of the most heavily loaded shoe.

6.7 Drum roundness (ovality) of 75 μ m for drums under 280 mm diameter and 100 μ m for those over 280 mm diameter.