



SURFACE VEHICLE RECOMMENDED PRACTICE

J3190™

SEP2025

Issued

2025-09

Brake Inertia Dynamometer Test for Corrosion Effects on Friction Couple Behavior

RATIONALE

Significant gaps exist in the current published procedures for evaluating the corrosion effects on brake performance during vehicle usage, primarily when the brake corner operates with corrosion exposure. The current inertia dynamometer tests published by Standard Development Organizations assess friction behavior, wear, noise, vibration, and harshness under controlled climatic conditions without the effect of prolonged corrosion exposure. Furthermore, when the brake corner is part of a regenerative braking system, newer propulsion technologies (such as those with regenerative braking and reduced use of the friction brake) can magnify the environment's impact on the torque output of the friction brake. Lastly, the engineer has less time and fewer vehicles and field measurements during the development of the brake corner. Still, the development process must produce reliable braking systems to operate in different environments. Some procedures involve transporting the brake fixture (or brake components) from the inertia dynamometer to and from a chamber for corrosion exposure. The dismounting and transferring of the brake corner can disturb the friction couple during the test and create logistical challenges for the testing facility. This document aims to combine dynamic braking on the inertia dynamometer with cyclic corrosion. The driving schedule re-creates regular driving and soak (standstill) times, which can induce or exacerbate corrosion buildup on the brake corner.

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1. SCOPE

This document derives from combining the driving cycle from the European Commission's Worldwide harmonized Light Vehicle Test Procedure (WLTP-Brake cycle) and cyclic corrosion with humidity, temperature, and salt spray from SAE J2334. This document applies to vehicles with an internal combustion engine, a rechargeable energy storage system, or both as a source for propulsion. These cycles apply to passenger and light-duty vehicles with a Gross Vehicle Weight Rating of 3500 kg or below. Before using this document for other vehicle categories, the test requestor shall assess with the test facility the WLTP's applicability, which applies to vehicles category 1-1 (carriage of persons with not more than eight seating positions in addition to the driver) and category 2 (carriage of goods) with a fully laden mass of 3500 kg or below.

1.1 Purpose

This document allows the user of its results to assess: (a) torque output, (b) level and variation of the friction coefficient, (c) surface conditions (on the friction material and the mating disc or drum), and (d) structural integrity, appearance, and ability of the brake corner and its components to operate according to specifications. Acceptance criteria or minimum performance requirements are not part of this document. This document provides a test method that, when combined with other tests, provides a comprehensive assessment of the robustness and stability of the friction couple, the foundation brake, and the braking system during and after exposure to different climatic and usage conditions.

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 J2334	Laboratory Cyclic Corrosion Test
SAE J2522	Inertia Dynamometer Disc and Drum Brake Effectiveness Test Procedure
SAE J2784	FMVSS Inertia Dynamometer Test Procedure for Vehicles Below 4540 kg GVWR
SAE J2789	Inertia Calculation for Single-Ended Inertia-Dynamometer Testing
SAE J2986	Brake Pads, Lining, Disc, and Drum Wear Measurements
SAE J3152	Taxonomy and Guidelines for Design, Fabrication, and Installation of Brake NVH Fixtures for Inertia Dynamometer Testing

2.1.2 ASTM Publications

Available from ASTM International, 100 Barr Harbor Drive, P.O. Box C700, West Conshohocken, PA 19428-2959, Tel: 610-832-9585, www.astm.org.

ASTM D1735 Standard Practice for Testing Water Resistance of Coatings Using Water Fog Apparatus

2.1.3 United Nations Publications

Available from United Nations Economic Commission for Europe, Palais des Nations, CH-1211, Geneva 10, Switzerland, Tel: +41-0-22-917-12-34, www.unece.org.

UN GTR 24 Laboratory Measurement of Brake Emissions for Light-Duty Vehicles

2.1.4 Other Publications

Mathissen, M., et al. (2018). A novel real-world braking cycle for studying brake wear particle emissions. *Wear*, 414, 219-226. <https://www.sciencedirect.com/science/article/abs/pii/S004316481830557X>.

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.

Lutze, F., Smith, K., Mason, R., Nymberg, D. et al., "Update on the Developments of the SAE J2334 Laboratory Cyclic Corrosion Test," SAE Technical Paper 2003-01-1234, 2003, <https://doi.org/10.4271/2003-01-1234>.

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 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

3. DEFINITIONS

3.1 APPLICABLE TO THE GENERAL TEST

3.1.1 Apparent Coefficient of Friction for Hydraulic Disc Brakes

Per Equation 1:

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

where:

μ = apparent friction for disc brakes expressed as unitless

Refer to SAE J2784.

3.1.2 Effectiveness for Hydraulic Drum Brakes (C^*)

Per Equation 2:

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

where:

C^* = effectiveness for drum brakes expressed as unitless

T = output torque expressed in newton-meter

p = brake pressure expressed in kilopascals

$p_{threshold}$ = minimum pressure required to start developing braking torque; unless otherwise directed, use threshold pressure of zero expressed in kilopascals

A_p = total piston area acting on one side of the caliper for disc brakes; total wheel cylinder area for drum brakes expressed in square millimeters

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 expressed in millimeters

η = efficiency of the brake actuator (caliper or wheel cylinder) as a ratio between the actuation and input forces expressed as unitless; unless indicated otherwise by the test requestor, use a value of 1 (100%)

Refer to SAE J2784.

3.1.3 Average by Distance

Averaging method where the sampling frequency for the measurand is a unit of vehicle distance (between data points) traveled during a braking event.

Refer to SAE J2522.

3.1.4 Deceleration-Controlled Brake Application

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

Refer to SAE J2784.

3.1.5 Initial Brake Temperature (IBT)

Brake disc or drum temperature at the start of the brake application expressed in °C.

Refer to SAE J2784.

3.1.6 Tire Dynamic Rolling Radius

Equivalent tire radius generates the revolutions per mile (RPM) for the specific tire size using Equation 3. Use the tire dynamic rolling radius to calculate the dynamometer rotational speed for a given linear vehicle speed expressed in millimeters.

$$RR = \frac{1\,609\,344}{2 \cdot \pi \cdot RPM} \quad (\text{Eq. 3})$$

where:

RR = tire dynamic rolling radius expressed in millimeters

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

Refer to SAE J2784.

3.1.7 Gross Vehicle Weight Rating (GVWR)

Maximum vehicle weight indicated by the manufacturer. In this document, it is equivalent to the mass in running order, the mass of the driver, and the maximum vehicle load expressed in kilograms.

3.2 APPLICABLE TO THE WLTP-BRAKE CYCLE

Refer to UN GTR 24.

3.2.1 Mass in Running Order

Mass of the vehicle, with its fuel tank(s) filled to at least 90% of capacity, including the mass of the driver, fuel, and liquids, fitted with the standard equipment following the manufacturer's specifications and, when they are fitted, the mass of the bodywork, the cabin, the coupling, the spare wheel(s), as well as the tools.

3.2.2 Mass of the Driver

Mass rated at 75 kg located at the driver's seating reference point. In the context of the current regulation, the term "mass of additional 0.5 passengers" means a mass rated at 37.5 kg.

3.2.3 Maximum Vehicle Load

Technically permissible maximum laden mass minus the mass in running order, 25 kg, and the mass of the optional equipment.

3.2.4 Optional Equipment

Features not included in the standard equipment fitted to a vehicle are under the manufacturer's responsibility, and the customer can order them.

3.2.5 Standard Equipment

The basic configuration of a vehicle equipped with all the features required under the regulatory acts of the Contracting Party, including all features fitted without giving rise to any further specifications on configuration or equipment level.

3.2.6 Vehicle Test Mass

Mass in running order plus the mass of the optional fitted equipment to an individual vehicle (kilograms) on which the tested brake mounts plus:

- a. 37.5 kg, corresponding to an additional mass of 0.5 passengers for passenger vehicles with a GVWR (or fully laden mass) below 3500 kg
- b. 25 kg plus 28% of the maximum vehicle load (MVL) for cargo vehicles with a GVWR (or fully laden mass) below 3500 kg

3.2.7 Road Loads

Total force or power required to move the vehicle on a level and smooth surface at a specified speed and mass. Road loads take account of the frictional losses of the drivetrain. In this document, a reduction of the nominal brake inertia by a fixed percentage of 13% is considered to account for road loads in full-friction braking emissions testing expressed in percent.

3.2.8 Test Wheel Load

Equivalent rotating mass as a function of the total vehicle test mass, the axle under test (front or rear), and the brake work distribution among the two axles. It represents the load at the brake corner under testing after accounting for vehicle road loads expressed in kilograms.

3.2.9 Brake Test Inertia

Wheel load's inertia at the gyration radius is equal to the tire dynamic rolling radius, which imposes the same kinetic energy on the brake as in the actual vehicle after subtracting the total road loads for the vehicle. Use Equations 4 and 5.

$$I_{front} = \frac{1}{2} \cdot 0.87 \cdot \frac{X}{100} \cdot W \cdot RR^2 \quad (\text{Eq. 4})$$

$$I_{rear} = \frac{1}{2} \cdot 0.87 \cdot \frac{Y}{100} \cdot W \cdot RR^2 \quad (\text{Eq. 5})$$

where:

I_{front} = test inertia for front brake expressed in kilograms-square meters

I_{rear} = test inertia for rear brake expressed in kilograms-square meters

X and Y = percentage of brake torque the front or rear axle provides, respectively. Unless otherwise indicated by the test requestor, use the default or the torque index methods from SAE J2789.

W = vehicle test mass as the requestor specifies or the default value per 3.2.6, expressed in kilograms

RR = tire dynamic rolling radius per 3.1.6, expressed in meters

3.2.10 Driving Cycle

Series of data points representing the speed of a vehicle versus time. The driving cycle consists of individual trips, and each trip consists of a series of separate and consecutive events. These events include brake dwell, acceleration, cruising, and deceleration.

3.2.11 WLTP-Brake Cycle

The driving cycle, derived from the vehicle activity of the Worldwide Light Vehicle Test Procedure database, has a total duration of 15826 seconds plus the cooling sections between trips. The cycle comprises ten trips and 303 brake deceleration events.

NOTE: Refer to UN GTR 24 and Mathissen et al. (2018) to access the actual WLTP cycle and the speed profile at 1 Hz.

3.2.12 Brake Acceleration Event

Measurable period during which the linear speed increases to a predetermined set value at a known rate. This event always precedes a brake cruising or a brake deceleration event.

3.2.13 Brake Cruising Event

Measurable period during which the (non-zero) linear speed is constant.

3.2.14 Brake Dwell Event

Measurable and predictable brake pauses at zero speed during the cycle.

3.2.15 Brake Deceleration Event

A measurable period during which the linear speed decreases at a known rate to a predetermined release speed during the cycle as the effect of applying a decelerating torque.

3.2.16 Deceleration Rate

Total rate of reduction in the linear speed of the vehicle induced by the application of the service brake, the road loads, and the non-friction torque from the electric machine.

3.2.17 Soaking Section

Time between trips when the brake is rotating at low speed (approximately five or fewer revolutions per minute), waiting for the brake to cool down, and the initial brake temperature to reach the predefined level for commencing the next cycle trip.

3.2.18 Nominal Linear Speed

Vehicle's target (or set) speed at the time i per the WLTP-Brake cycle.

3.2.19 Actual Linear Speed

Linear speed of the vehicle at the time i during the test cycle execution. Also referred to as "measured speed."

3.2.20 Speed Violation

Any instance when the actual dynamometer speed trace exceeds the speed trace tolerances prescribed in UN GTR 24 during the WLTP-Brake cycle.

3.3 APPLICABLE TO THE BRAKE CORROSION CYCLE

Refer to SAE J2334.

3.3.1 Cosmetic Corrosion

Corrosion is caused by the breakdown or damage to a coating system. Typically, this type of corrosion does not impact function but does compromise appearance.