



SURFACE VEHICLE RECOMMENDED PRACTICE

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(R) Inertia Dynamometer Disc and Drum Brake Effectiveness Test Procedure

RATIONALE

This document has been revised to be consistent with recent changes made to SAE J2521 and SAE J2784.

FOREWORD

The globalization trend in the automotive industry necessitates the proper definition of applicable test procedures for assessment and comparison of different friction materials. These comparison tests should prove useful as a common ground for the development, selection, and quality assurance of friction linings.

The AK Working Group, which represents European manufacturers of friction linings and passenger car brakes, has developed an "AK Master" standard in recent years. The SAE Brake Dynamometer Test Code Standards Committee considers this standard useful in supporting the technological efforts intended to improve motor vehicle braking systems overall performance and safety. Therefore, this committee is making the AK Master standard available to the industry as an SAE Recommended Practice.

This document should be used in conjunction with other applicable standards or test procedures (SAE, federal codes, or other specific testing programs) to fully assess a friction material's adequacy for a certain application or vehicle platform.

This revision harmonizes cooling air speed with other SAE inertia dynamometer test procedures and also reflects standard testing practices from several laboratories which conduct the test on a regular basis.

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Documents

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1. SCOPE

This SAE Recommended Practice establishes a standard method to perform screening test sequences that identify a brake friction material's effectiveness under various test conditions. The result is an evaluation of brake friction material effectiveness under a set of defined braking conditions considered most relevant to automobile braking system development.

1.1 Purpose

This SAE Recommended Practice defines an inertia dynamometer test procedure that assesses the effectiveness behavior of a friction material with regard to pressure, temperature, and speed for motor vehicles fitted with hydraulic brake actuation and to compare friction materials under the most equal conditions possible. To account for the cooling behavior of different test stands, the fade sections are temperature controlled. A disc brake application matrix and a drum brake application matrix are defined to describe the test conditions and steps to investigate the influence of burnish, pressure, temperature, and velocity on brake friction material effectiveness behavior. Each matrix intends to replicate vehicle tests to get a fair comparison for different brake corner components.

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 J2521	Inertia Dynamometer Brake Squeal Noise Test Procedure for Vehicles without Regenerative Systems
SAE J2784	FMVSS Inertia Dynamometer Test Procedure for Vehicles Below 4540 kg GVWR
SAE J2789	Inertia Calculation for Single-Ended Intertia-Dynamometer Testing
SAE J2986	Brake Pads, Lining, Disc, and Drum Wear Measurements

Yuan, Y. and Halloran, P. (1999). *Calculation of average coefficient of friction during braking* (Paper no. 1999-01-3410). SAE International. <https://doi.org/10.4271/1999-01-3410>.

2.1.2 VDA Publications

Available from the German Association of the Automotive Industry VDA (Verband der Automobilindustrie e.V.), Behrenstr. 35, 10117, Berlin, http://www.vda.de/en/publikationen/publikationen_downloads/.

VDA 300	Development Guideline on Quality Control of Disc Brake Linings
VDA 305	Data Exchange Format Description

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 ISO Publications

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

ISO/TR 13487:1997 Braking of road vehicles - Considerations on the definition of mean fully developed deceleration.

2.2.2 U.S. Department of Transportation Publications

Available from U.S. Department of Transportation, Bureau of Transportation Statistics, 1200 New Jersey Avenue, SE, Washington, D.C. 20590, Tel: 800-823-1351, National Transportation Library Repository and Open Science Access Portal <https://rosap.ntl.bts.gov/contact>.

FMVSS 105	Hydraulic and Electric Brake Systems
FMVSS 135	Light Vehicle Brake Systems
TP-105-03	NHTSA - OVSC Laboratory Test Procedure for FMVSS 105 Hydraulic and Electric Brake Systems (July 1, 2003)
TP-135-01	NHTSA - OVSC Laboratory Test Procedure for FMVSS 135 Light Vehicle Brake Systems (Dec 5, 2005)

3. DEFINITIONS

To facilitate the application of this document, the following terms and definitions should apply.

3.1 APPARENT COEFFICIENT OF FRICTION

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 indicated by the test requestor or measured as part of the project, use a zero value (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; unless otherwise indicated by the test requestor or measured as part of the project, use 1.0 (100%)

3.2 FRICTION VALUE FOR A BRAKE APPLY

For each individual dynamic brake application, calculate the average-by-distance friction coefficient or effectiveness value between t_1 and t_2 per [Figure 1](#).

3.2.1.1 NOMINAL FRICTION VALUE

Average value of all of the average-by-distance friction coefficients or effectiveness values between t_1 and t_2 per [Figure 1](#) in each section.

3.2.1.2 MINIMUM FRICTION VALUE

Minimum value of the average-by-distance friction coefficients or effectiveness values between t_1 and t_2 per [Figure 1](#) in each section.

3.2.1.3 MAXIMUM FRICTION VALUE

Maximum value of the average-by-distance friction coefficients or effectiveness values between t_1 and t_2 per [Figure 1](#) in each section.

3.2.2 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 exhibits a higher correlation to the vehicle stopping distance and the mean fully developed deceleration (see references in [2.1.1](#) and [2.2.1](#)). This value yields the same result as the integration between two distance points per Equation 3A as indicated in the literature. 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 measurand between two consecutive averaging points. The numerator's second and third terms provide the distance between two measurement points (distance = speed × 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 (Hz)

3.3 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.

3.4 PRESSURE CONTROLLED BRAKE APPLICATION

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

3.5 INITIAL BRAKE TEMPERATURE (IBT)

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

3.6 GROSS VEHICLE WEIGHT (GVWR)

Maximum vehicle weight indicated by the manufacturer (kgf).

3.7 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. If maximum vehicle speed is below 200 km/h use vehicle top speed minus 30 km/h.

3.8 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 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 revolutions per mile; typically available on the manufacturer's website

4. SYMBOLS AND ABBREVIATIONS

The following symbols and abbreviations are used in order to perform the calculations needed during the test.

4.1 μ

Friction value (unitless).

4.2 M_{Brake}

Measured torque (N·m).

4.3 p

Applied pressure (kPa).

4.4 $p_{500N_operational}$

The pressure that would be observed on a vehicle with 500 N of brake pedal force (kPa).

4.5 A_p

Piston area (mm²).

4.6 r_{eff}

Effective radius (mm).

4.7 η

Efficiency 100%.

4.8 μ_{0P6}

Average value of the friction values of the first to sixth application in [10.5](#).

4.9 μ_{v120}

Average value of the friction values of the applications at 2000, 3000, and 4000 kPa in [10.6.3](#).

4.10 μ_{vmax}

Average value of the friction values of the applications at 2000, 3000, and 4000 kPa in [10.6.5](#).

4.11 μ_{0P6}

Average value of the friction values of the first to sixth application in [10.7](#).

4.12 μ_{T40}

Friction value of the first application in [10.8](#).

4.13 μ_{MW2}

Friction value of the second application in [10.9](#).

4.14 μ_{0P18}

Average value of the friction values of the first to eighteenth application in [10.10](#).

4.15 μ_{F1}

Minimum friction value of the first to fifteenth application in [10.11](#).

4.16 μ_{0P18}

Average value of the friction values of the first to eighteenth application in [10.13](#).

4.17 μ_{T500}/μ_{T300}

Minimum friction value of the friction values of the temperature series in [10.15.1](#) and [10.15.2](#).

4.18 μ_{0P18}

Average value of the friction values of the first to eighteenth application in [10.16](#).

4.19 μ_{F2}

Minimum friction value of the first to fifteenth application in [10.17](#).

4.20 μ 0P18

Average value of the friction values of the first to eighteenth application in [10.18](#).

5. TEST EQUIPMENT

- 5.1 Single-ended brake inertia dynamometer that can perform dynamic brake applications with deceleration- or pressure-controlled brake applications.
- 5.2 Control system that can perform brake applications at constant pressure, or constant deceleration (torque control).
- 5.3 Automatic data collection system capable of recording the following channels at 50 Hz minimum:
 - 5.3.1 Brake equivalent linear speed (km/h).
 - 5.3.2 Brake input pressure (kPa).
 - 5.3.3 Brake output torque (N·m).
 - 5.3.4 Brake apparent friction or effectiveness per [3.1.1](#) and [3.1.2](#).
 - 5.3.5 Brake fluid displacement (mm³).
- 5.4 Automatic data collection system capable of recording the following channels at 10 Hz minimum:
 - 5.4.1 Brake rotor or drum temperature (°C).
 - 5.4.2 (Optional) Brake pad or brake shoe temperature (°C).
 - 5.4.3 Cooling air temperature, relative humidity (or absolute humidity), and speed (or airflow).

6. TEST INERTIA

Unless otherwise indicated by the test requestor, determine the test inertia per the default or the torque index methods on SAE J2789 with the vehicle loaded at GVWR for decelerations below 0.65 g.

7. PARTS PREPARATION AND TEST SETUP

- 7.1 Temperature Measurement
 - 7.1.1 Unless otherwise specified by the test requestor, use a new rotor and brake pads or new drum and brake shoe linings for each test.
 - 7.1.2 Measure brake pad/lining wear per SAE J2986.
 - 7.1.3 For brake discs, install a thermocouple at a depth of 1.0 mm on the outboard face, at the braking surface's centerline.

NOTE: As an alternative method for measuring rotor temperature and in agreement with the test requestor, use an infrared measurement on the outside diameter of the inboard face of the disc. Using infrared measurements, the outside diameter of the rotor coat with a heat-resistant black non-reflective paint provides an emissivity consistent with that required by the infrared measurement system. Obtain the correct emissivity settings from the test requestor or use an agreed-upon method. Unless readily available for the rotor design, this method performs a trial test to establish the infrared reading correlation with the embedded thermocouple. At appropriate intervals during testing, ensure dust or debris does not accumulate on the lens.

- 7.1.4 Optional—For brake pads, install one thermocouple at a depth of 2.0 mm near the center of each pad's 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. Install the thermocouple between 3 mm and 4 mm on the leading side from the piston outside diameter near the friction surface center for inboard pads on single-piston calipers.
- 7.1.5 For brake drums, install a thermocouple at a depth of 1.0 mm on the braking surface's centerline.
- 7.1.6 Optional—For brake shoes, install a thermocouple at a depth of 1.0 mm near the center of the most heavily loaded shoe's friction surface.
- 7.1.7 Use the same temperature measurement and location for the same project.
- 7.1.8 Document and report on the final test report when using a different control thermocouple for the test.
- 7.1.9 The installation of redundant temperature measurements can prevent accidental overheating due to thermocouple or wiring failures.
- 7.2 Document brake hose part number used for testing.
- 7.3 Ensure appropriate bleed is performed prior to starting the test

8. TEST CYCLES

8.1 Dynamic Brake Application

[Figure 1](#) illustrates the main time-stamps used to characterize the brake application.

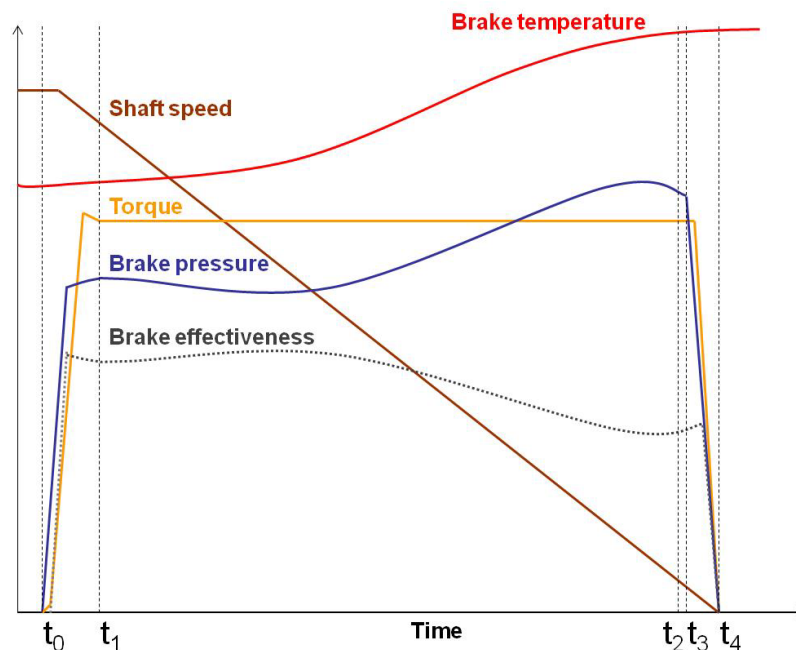


Figure 1 - Typical brake application time stamps

8.1.1 Time t_0

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

8.1.2 Time t_1

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