



SURFACE VEHICLE RECOMMENDED PRACTICE

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(R) Inertia Dynamometer Brake Squeal Noise Test Procedure for Vehicles without Regenerative Systems

RATIONALE

The current revision of this SAE Recommended Practice includes updates and extensions to (a) reflect the taxonomy and guidelines from the SAE J3152 Information Report for fixture design, fabrication, and installation; (b) expand individual sections with low temperatures and speeds; (c) expand the sections for friction characteristic to include 30 km/h events at colder temperatures (-5 °C and 40 °C), at 10 bar of brake pressure; (d) increase the maximum fade temperature for rear disc brakes to 300 °C and 400 °C, for the standard and optional schedules, respectively; and (e) include metrics to report the coefficient of friction per the VDA 300.

FOREWORD

In the early 1990s, a European working group including car manufacturers, braking system suppliers, and friction material companies developed a dynamometer test procedure known as the AK noise. This procedure uses two main modes: (a) drag mode at low speed with a pressure application profile meant to induce instability and squeal noise, and (b) deceleration braking at moderate speeds at constant brake pressure; a common approach in the U.S., emphasizing the replication of vehicle road test. This document combines braking modes to satisfy the vital need for global standardization of squeal noise dynamometer tests. This procedure was first presented to the SAE working group in 1999 and owed much to the AK noise procedure's previous development. This prior work is gratefully acknowledged.

Both test matrixes (disc and drum) include five main schedules:

- Schedule A—Standard: Standard test sections with deceleration, drag, and backward/forwards braking at various temperatures, pressures, and speeds.
- Schedule B—Optional: Noise during cold modules to assess noise propensity below 50 °C and at or below 0 °C.
- Schedule C—Optional: Noise during modules at mild temperature and high humidity.
- Schedule D—Optional: Noise after a fade to assess the influence of high-temperature excursions on a given brake's noise propensity.
- Schedule E—Optional: Noise during several backward/forward cold modules to assess noise propensity below 25 °C, cooling air at or below 5 °C with high air humidity.

This recommended practice establishes the minimum standard specifications regarding test setup, inertia-dynamometer characteristics, test sequence, and test report items. Deviations from or changes to this procedure to accommodate a specific project are feasible as long as they are discussed and agreed upon among the interested parties before the actual staging and testing activities are completed.

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1. SCOPE

The SAE J2521 procedure applies to high-frequency squeal noise occurrences for on-road passenger cars and light trucks below 4540 kg of GVWR. The procedure incorporates high-temperature and low-temperature test matrixes but does not fully account for the effects of the environment on brake squeal.

For this test procedure, squeal occurs when the peak noise level is at least 70 dB(A) between 1.25 kHz and 16 kHz for tests using full suspension corners or full axle assemblies or between 2 kHz and 16 kHz for brakes not using a full suspension corner.

Before using this recommended practice for chassis dynamometer testing, review in detail the specifics related to at least (a) instrumentation, including in-cabin microphones, (b) threshold levels for noise detection, (c) temperature control priority between the front and rear axles, (d) vehicle loading and load distribution, (e) cooling air and environmental conditioning, and (f) detailed nomenclature and labeling of channels and sensors.

1.1 Purpose

This recommended test practice establishes a standard method for screening test sequences that identify a brake assembly's propensity to generate squeal noise under various test conditions. The result is an evaluation of brake noise under defined braking conditions considered most relevant to automobile braking system development.

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 pressure, temperature, and velocity on squeal noise 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 J2789 Inertia Calculation for Single-Ended Intertia-Dynamometer Testing

2.1.2 VDA Publications

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

VDA 300 Development Guideline on Quality Control of Disc Brake Linings

VDA 303 Description of Noisy Brake Applications Concerning Brake Squeal

VDA 305 Data Exchange Format Description

VDA 306 Definition of Charts for the Evaluation of Brake Noise Data/Dynamometer

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.

SAE J2598	Automotive Disc Brake Pad Natural Frequency and Damping Test
SAE J2625	Automotive Vehicle Brake Squeal Test Recommended Practice
SAE J2786	Automotive Brake Noise and Vibration Standard Nomenclature
SAE J2933	Verification of Brake Rotor Modal Frequencies
SAE J2986	Brake Pads, Lining, Disc, and Drum Wear Measurements
SAE J3001	Brake Insulator Damping Measurement Procedure
SAE J3152	Taxonomy and Guidelines for Design, Fabrication, and Installation of Brake NVH Fixtures for Inertia Dynamometer Testing

2.2.2 IEC Publications

Available from IEC Central Office, 3, rue de Varembe, P.O. Box 131, CH-1211 Geneva 20, Switzerland, Tel: +41 22 919 02 11, www.iec.ch.

IEC 61672-1	Electroacoustics - Sound Level Meters - Part 1: Specifications
IEC 61672-2	Electroacoustics - Sound Level Meters - Part 2: Pattern Evaluation Tests
IEC 61672-3	Electroacoustics - Sound Level Meters - Part 3: Periodic Tests

3. DEFINITIONS

To facilitate the application of this SAE Recommended Practice, the following definitions apply.

3.1 APPARENT FRICTION FOR DISC BRAKES

Per Equation 1:

$$\mu = \frac{10^5 \cdot T}{2 \cdot (P - P_{\text{Threshold}}) \cdot A_p \cdot r_{\text{eff}} \cdot \eta} \quad (\text{Eq. 1})$$

where:

μ = apparent friction for disc brakes, unitless

3.2 DRUM BRAKE EFFECTIVENESS (C^*)

Per Equation 2:

$$C^* = \frac{10^5 \cdot T}{(p - p_{\text{threshold}}) \cdot A_P \cdot r_{\text{eff}} \cdot \eta} \quad (\text{Eq. 2})$$

where:

C^* = effectiveness for drum brakes, unitless

T = output torque, in N·m

p = brake pressure, in kPa

$p_{\text{Threshold}}$ = 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 = brake efficiency; unless otherwise indicated by the test requestor or measured as part of the project, use one (100%)

For dynamic brake applications, calculate the average-by-distance friction coefficient or effectiveness value between t_1 and t_2 per 8.1. For brake drag applications, calculate the average-by-time friction coefficient or effectiveness value between t_1 and t_3 per 8.2.

3.3 GROSS VEHICLE WEIGHT (GVWR)

Maximum vehicle weight indicated by the manufacturer/kgf.

3.4 BRAKING SPEED

Linear speed at the onset of brake pressure when the speed reduces during the brake application.

3.5 DRAG SPEED

Linear speed at the onset of brake pressure when the speed remains constant during the brake application.

3.6 INITIAL BRAKE TEMPERATURE (IBT)

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

3.7 TIRE DYNAMIC ROLLING RADIUS

Equivalent tire radius generating the revolutions per mile (rpm) published by the tire manufacturer for the specific tire size per Equation 3. Use the tire dynamic rolling radius to calculate the dynamometer rotational speed for a given linear vehicle speed/mm.

$$RR = \frac{1609344}{2 \cdot \pi \cdot \text{rpm}} \quad (\text{Eq. 3})$$

where:

RR = tire dynamic rolling radius/mm

rpm = tire manufacturer specification for revolutions per mile indicated by the tire manufacturer

4. TEST EQUIPMENT

4.1 Single-ended brake inertia dynamometer that can perform dynamic brake applications with deceleration- or pressure-controlled brake applications. Also capable of conducting brake drag at constant pressure and brake drag with brake pressure profiles.

4.2 Reversible motor and drive control that can conduct the brake drag applications at no less than 90% of the nominal drag speed.

NOTE: Calculate motor torque based on the highest of the three following values (a) brake drag at base speed and 32.5 bar brake pressure, (b) acceleration rate during brake fade modules, and (c) motor torque used for inertia simulation during dynamic brake applications.

4.3 Control system that can perform brake applications at constant pressure, pressure profiles, or constant deceleration (torque control)

4.3.1 Pressure ramp rate of at least 100 bar/s (see 8.1) and a maximum pressure of at least 160 bar.

4.3.2 Overshoot of less than 1 bar during dynamic brake applications.

4.3.3 Average pressure control within 0.25 bar of the target value (set point) during pressure profiles.

4.3.4 Deceleration control and overshoot within 0.5 m/s² of the target value (set point).

4.4 Cooling air system directed at the brake.

4.4.1 Control the airspeed so it does not blow away wear debris or create noise above the background limit of 64 dB(A) above 900 Hz. The cooling air remains on during the brake events.

NOTE 1: The 64 dB(A) limit provides 6 dB(A) separation, which is a 2:1 separation or half the threshold limit to detect noisy brake events above 70 dB(A).

NOTE 2: Other threshold levels could be more appropriate, like brake noise evaluation for electric vehicles. In such cases, confirm with the test requestor and the testing facility.

4.4.2 Set up the duct outlet (300 to 400 mm) away from the rotor outside diameter with an air duct with a hydraulic diameter (200 to 300 mm). Adjust cooling air to 10 m/s (35 km/h) measured at the duct outlet; if needed, adjust to meet the background noise level from 4.4.1.

NOTE 1: If the above conditions cannot be achieved, agree with the test requestor and document it on the final test report.

NOTE 2: Alternatively, adjust cooling airflow between 1000 m³/h and 2000 m³/h while ensuring background noise level per 4.4.1.

NOTE 3: Since the cooling air setup is a critical subsystem of the inertia dynamometer, which affects test variability and duration, establish proper definitions and test conditions for the test project. Measure airflow, assess cooling rates at specific temperatures and test speeds, and review cycle times and overall temperature regimes during the tests to better understand the conditions and effects on noise and friction behavior.

4.4.3 Climatic Controls and Soak Conditions

4.4.3.1 Table 1 summarizes the conditions for the different soaks during the test schedules. See Figure 1 for two typical setups of cooling air for disc brake assemblies.

4.4.3.2 Document on the test reports the actual cooling air orientation relative to the brake and the brake rotation.

NOTE 1: Allow short excursions beyond the control limits for temperature and humidity when the climatic control unit switches coils to implement the thermodynamic transitions.

NOTE 2: Monitor the climatic control unit's condition and performance for coil or damper freeze when transitioning to temperatures below 5 °C. Hot and high humidity conditions in the laboratory area can exacerbate this behavior.

NOTE 3: During cold modules below the dew point of the environmental control system, control only the cooling air temperature.

4.4.3.3 To keep the same cooling behavior of the brake assembly (including noise insulators or shims) for the same project, keep the cooling air setup the same, and use the same fixture orientation (left- or right-hand) in agreement with the test requestor and the testing facility.

Table 1 - Climatic controls and soak conditions

Schedule	Soak Number	Air Temperature °C	Relative Humidity %RH	Soak Period Minutes	Maximum Time to Reach Conditions Minutes	Brake Speed During Soak Period km/h
A	1	20 ± 2	50 ± 10	20 ± 2	50	5
A	2	10 ± 2	30 ± 10	20 ± 2	50	5
A	3	-5 ± 3	30 ± 15	20 ± 2	60	5
B	4	-20 ± 3	n.a.	60 ± 2	90	0
B	5	-25 ± 3	n.a.	20 ± 2	40	0
C	6	20 ± 2	80 ± 15	60 ± 2	60	5
D	7	20 ± 2	50 ± 10	20 ± 2	50	5
E	8	0 ± 3	80 ± 15	60 ± 2	90	0
E	9	5 ± 3	>75	60 ± 2	60	0
E	10	-5 ± 3	80 ± 15	60 ± 2	60	0

n.a. = not applicable

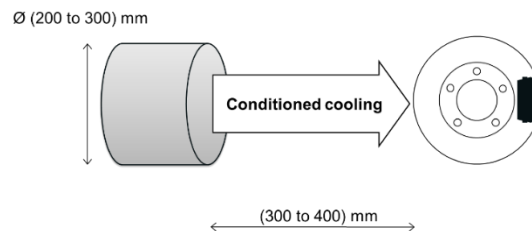


Figure 1A - Horizontal layout

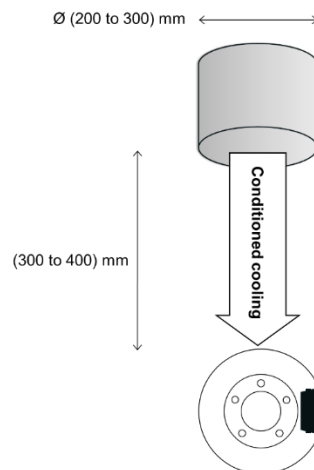


Figure 1B - Vertical layout

Figure 1 - Recommended setup for cooling air

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

4.5.1 Brake equivalent linear speed (km/h).

4.5.2 Brake input pressure (kPa).

4.5.3 Brake output torque (N·m).

4.5.4 Brake apparent friction or effectiveness per 3.1 and 3.2.

4.5.5 (Optional) Brake fluid displacement (mm³).

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

4.6.1 Brake rotor or drum temperature (°C).

4.6.2 (Optional) Brake pad or brake shoe temperature (°C).

4.6.3 Cooling air temperature, relative humidity (or absolute humidity), and speed (or airflow).

5. TEST FIXTURE

5.1 The test fixture significantly influences the test complexity and logistics associated with the test preparation and setup. It ultimately can influence the dominant frequencies and sound pressure levels observed during the test. The fixture level specified for a given project results from many decisions and shall remain the same for the same project or noise investigation. The same approach applies to the preloading method to impose suspension forces on the fixture during testing.

5.2 Refer to SAE J3152 for a detailed description of the different styles, preloading methods, design, manufacturing, assembly, and installation guidelines.

5.3 Review in detail with the test facility and document the project's loading strategy and settings when using an external loading system on the fixture. The loading can be fixed for the entire duration, changing from section to section or with dynamic loading changing in real-time during the test sequence.

5.4 Specify for the project the method required to drive the brake corner (direct connection to the dynamometer shaft, spool-driver in combination with a constant velocity driveshaft, wheel center driver with a constant velocity driveshaft, or driving through the wheel/tire assembly) and the details regarding the driver material and design. See Figure 2.

NOTE 1: The drive system and connection to the main dynamometer can significantly influence a given brake's noise propensity and the dominant frequencies during the test. Document and use the same design and material for the project as a best practice to reduce test-to-test and dyno-to-dyno variability.

NOTE 2: The spool-driver design should mimic a reference wheel design's interface and force distribution when feasible or indicated by the test requestor.

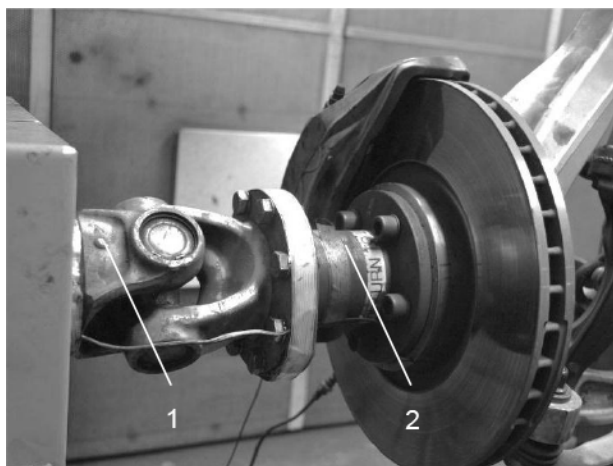


Figure 2A - Spool driver

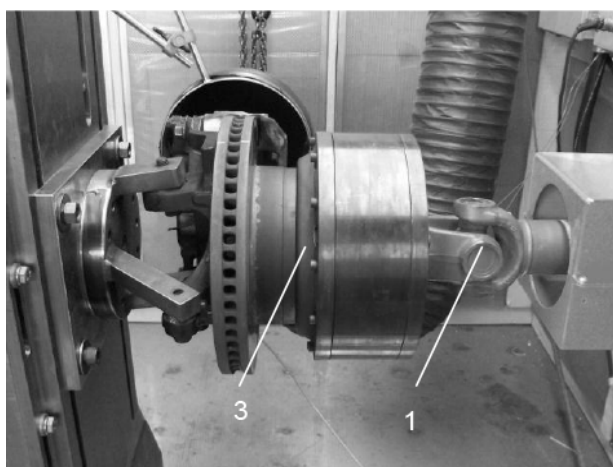


Figure 2B - Wheel center driver

Key:
1 - Constant velocity driveshaft
2 - Spool driver
3 - Wheel center driver

Figure 2 - Brake driving system

5.5 Report the brake fixture level and the drive method used for a test project (refer to EKB 3010).

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 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.

- 7.1.3 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.
- 7.1.4 When conducting schedule C (including fade section), confirm with the test requestor the need and location for an additional thermocouple on the backing plate or noise shim to monitor the temperature.
- 7.1.5 Install a thermocouple at a depth of 1.0 mm for brake drums on the braking surface's centerline.
- 7.1.6 Optional—Install a thermocouple at a depth of 1.0 mm near the center of the most heavily loaded shoe's friction surface for brake shoes.
- 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 Microphone Location

Position the microphone in the vertical plane and perpendicular to the brake axis and pointing downwards. Locate the center of the microphone (a) 100 mm outboard from the wheel hub mounting surface along the centerline of the axle, (b) 500 mm above the brake rotating axis, and (c) on the vertical plane of the rotor or drum axis. See Figure 3.

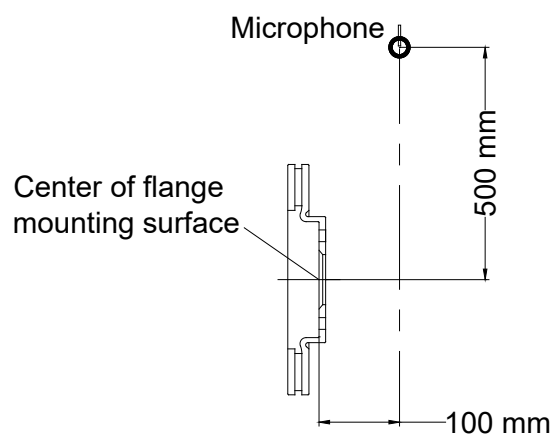


Figure 3 - Microphone orientation and position relative to flange center

7.3 Noise Measurements Settings

- 7.3.1 Unless otherwise specified by the test requestor, use a microphone conforming to IEC 61672-1 Class 2 or better with a corresponding windscreen.
- 7.3.2 Use a calibrator per IEC 60942 of the same microphone class at 1 kHz before and after the test.
- 7.3.3 Use a frequency analyzer or digital data acquisition system to record the sound spectrum in the time domain. The system must compute and record narrowband sound pressure spectra using the following parameters and capabilities:
 - 7.3.3.1 500 to 20000 Hz frequency bandwidth, with a frequency resolution of 25 Hz.
 - 7.3.3.2 Use peak-hold averaging with 66.7% overlap processing.
 - 7.3.3.3 Apply the Hanning windowing method to the time-based records.
 - 7.3.3.4 Anti-aliasing filtering.
 - 7.3.3.5 A-type signal weighting.

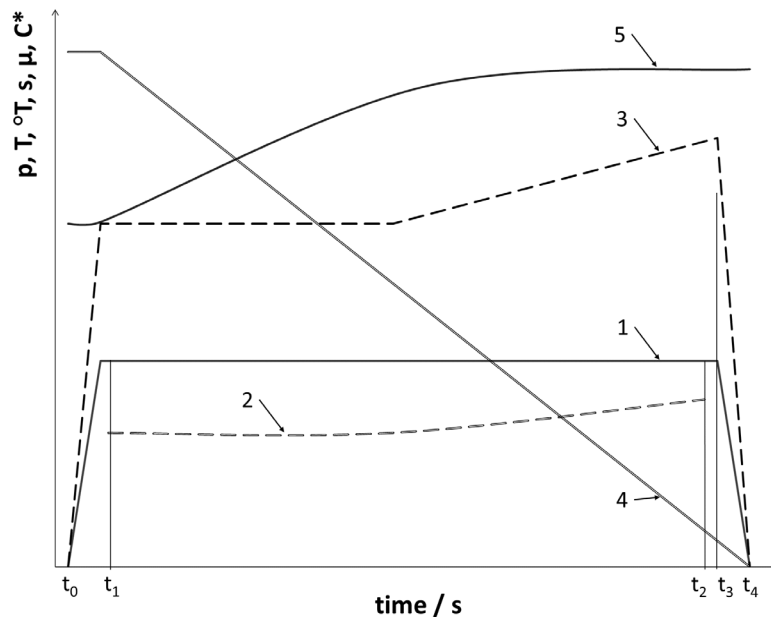
NOTE: Due to the A-weighting method's complexity, ensure the noise analyzer has the proper configuration before testing. Any plausible post-test correction algorithm is beyond the scope of this SAE Recommended Practice.

- 7.3.4 Measure the sound pressure level (SPL) in dB(A) throughout each brake application for all sections.
 - 7.3.5 Ensure the background noise level inside the test chamber with the cooling air system operating does not have peaks above 64 dB(A) above 900 Hz.
 - 7.3.6 Noise measurement duration (recording) is the same as the brake application duration for all sections, from t_0 to t_4 for dynamic and brake drag applications.
 - 7.3.7 Use a noise measurement period for analysis from t_1 to t_3 for dynamic and brake drag applications.
 - 7.3.8 Save microphone information as peak hold spectra, time recordings, peak-hold history at fixed intervals, peak dB(A), and the corresponding frequency at a fixed interval.
 - 7.3.9 Optional—Use accelerometers to validate noisy brake events. Define the quantity, location, and data validation technique with the test requestor before commencing testing.
- 7.4 For disc brakes, the assembled lateral run-out shall not exceed 50 μm when measured on the outboard surface and 10 mm from the outside diameter.
 - 7.5 Set the diametric cage clearance to the value indicated by the test requestor, the vehicle service manual, or the brake assembly print for drum brakes. If no other information is available, set the diametric cage clearance to (0.6 to 0.8 mm), measured at the shoes' center. Rotate to check for excessive drag and adjust if necessary.
 - 7.6 Optional—When requested, measure wear on the components of the friction couple using SAE J2986.

8. TEST CYCLES

8.1 Dynamic Brake Application

To achieve the target pressure or deceleration level during dynamic braking cycles, use a pressure ramp rate of 150 ± 50 bar/s. Figure 4 illustrates the main time-stamps used to characterize the brake application.



Key:
 1 - Brake pressure (p)
 2 - Brake coefficient of friction or drum brake effectiveness (μ , C^*)
 3 - Brake torque output (T)
 4 - Brake speed (s)
 5 - Brake temperature ($^{\circ}T$)

Figure 4 - Typical brake deceleration (constant pressure) 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 which pressure or torque reached the target level. At this time, the brake reaches its target level for torque or pressure control. At time t_1 , calculating the average by time and the average by distance begins.

8.1.3 Time t_2

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

8.1.4 Time t_3

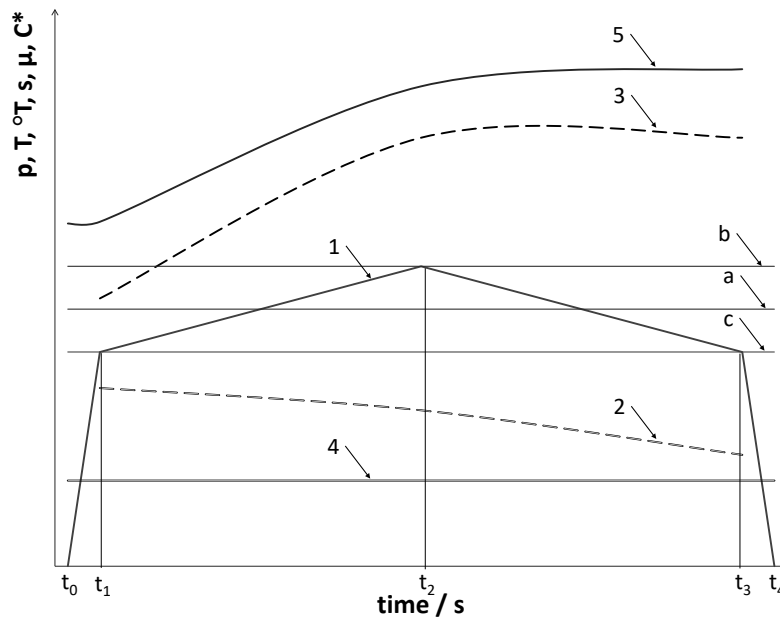
Time at release speed. At time t_3 , the inertia-dynamometer servo controller releases the brake (specified in 8.1.3).

8.1.5 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.

8.2 Brake Profiles During Drag Application for Low-Speed and Backward/Forward Modules

Figure 5 illustrates the main time-stamps used to characterize the brake drag application at constant brake speed.



- Key:
- 1 - Brake pressure (p)
 - 2 - Brake coefficient of friction or drum brake effectiveness (μ , C^*)
 - 3 - Brake torque output (T)
 - 4 - Brake speed (s)
 - 5 - Brake temperature ($^{\circ}T$)
 - a - Nominal brake pressure for the profile
 - b - Nominal brake pressure plus 2.5 bar
 - c - Nominal brake pressure minus 2.5 bar

Figure 5 - Typical brake drag application (pressure profile) with time stamps

8.2.1 Time t_0

Brake application initiation. At this time, the pressure starts to rise. The ramp rate from t_0 to t_1 provides a rise time to the nominal pressure minus 2.5 bar of 0.5 second.

NOTE: 1 bar = 100 kPa = 0.1 MPa = 14.5 psi.

8.2.2 Time t_1

Time at the start of the 1 bar/s pressure profile equals 0.5 second. At time t_1 , brake pressure equals the nominal pressure p minus 2.5 bar, and the calculation of average-by-time effectiveness begins. For the zero-bar pressure profile, t_1 equals 2.5 seconds.

8.2.3 Time t_2

Time in the middle of the 1 bar/s profile equals 5.5 seconds. At time t_2 , brake pressure equals the nominal pressure p plus 2.5 bars. For the zero-bar pressure profile, t_2 equals 5 seconds.

8.2.4 Time t_3

Time at the end of the 1 bar/s pressure profile equals 10.5 seconds. At time t_3 , the brake pressure equals the nominal pressure p minus 2.5 bar. At time t_3 , the calculation of average-by-time effectiveness finishes. For the zero-bar pressure profile, t_3 equals 7.5 seconds.

8.2.5 Time t_4

Time at brake pressure and torque lost, equal to 11 seconds. At time t_4 , pressure and torque are below the minimum thresholds. The inertia-dynamometer considers the braking event complete. For the zero-bar pressure profile, t_4 equals 10 seconds. The ramp rate from t_3 to t_4 provides a pressure release time from the nominal pressure minus 2.5 bar down to zero of 0.5 seconds.

Figure 6 illustrates the pressure profiles during brake drag application. The control system and the inertia dynamometer's servo controller shall follow the brake drag application's pressure trace.

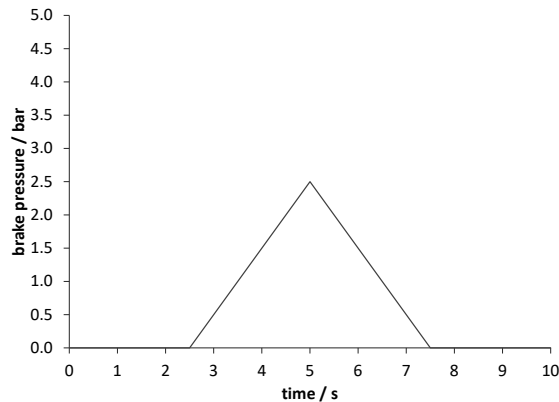


Figure 6A - Zero-bar profile

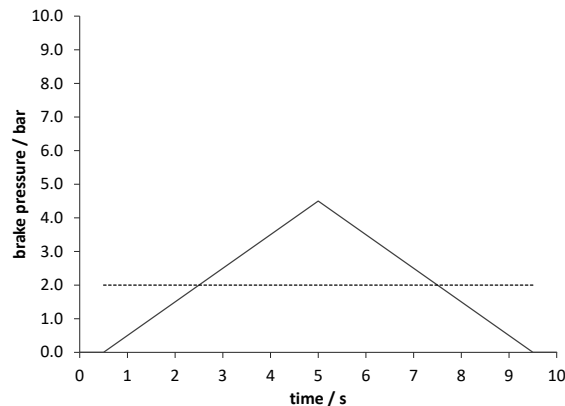


Figure 6B - Non-zero profiles — Example of the 2-bar profile ($p = 2$ bar) indicated by the dashed line

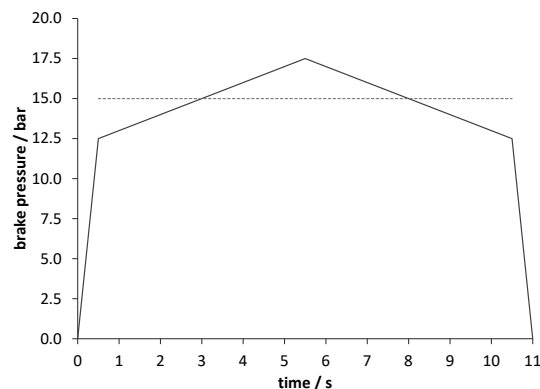


Figure 6C - Non-zero profiles — Example of the 15-bar profile ($p = 15$ bar) indicated by the dashed line

Figure 6 - Pressure profiles during brake drag applications



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8.3 Constant Pressure for Brake Decelerating During Brake Stops or Snubs (Bedding, Intermediate Conditioning, and Deceleration modules)

8.3.1 During brake events where the brake speed reduces as a function of the brake torque under constant pressure, the pressure level is constant after reaching the set point.

8.3.2 Apply a pressure ramp rate to provide a rise time to the nominal pressure of 0.5 second.

8.4 IBT Control

8.4.1 Brake Warm-up Operation for Dynamic or Brake Drag Applications

If the temperature decreases below the IBT for the following braking condition, warm up the brake by conducting brake drag operation at 50 km/h until the brake temperature is 5 °C above the IBT for the next nominal brake application. Control brake pressure at 20 bar for disc brakes and 30 bar for drum brakes. Do not conduct brake warm-up for sections with an IBT at or below 30 °C.

NOTE: In cases when a brake warm-up is required for sections with an IBT at or below 30 °C (e.g., when restarting the test after a test interruption), conduct brake warm-ups at 25 km/h and control brake pressure at 10 bar for disc brakes, and 15 bar for drum brakes.

8.4.2 Brake Warm-up During the Fade Schedules

If the brake does not achieve the IBT (see 8.4), perform a brake drag application at 80 km/h with a torque equivalent to 1.96 m/s² deceleration to warm up the brake. Do not apply the warm-up procedure for more than 20 seconds. Conduct the noise evaluation only during the stops where the initial temperature matches those indicated for the corresponding schedule.

8.4.3 Brake Cool Down

If the brake temperature is 5 °C or above the IBT of the following brake application, rotate the brake at 20 km/h until the brake cools down to within 5 °C of the IBT.

8.5 Brake Fade Temperatures

The brake fade section heats the brake in preparation for the post-fade friction and noise evaluation. The IBTs for each brake application during the fade operation use a logarithmic temperature profile per Equation 4.

$$IBT_n = IBT_1 + \frac{(IBT_{15} - IBT_1) \cdot \ln(n)}{\ln(15)} \quad (\text{Eq. 4})$$

where:

n = brake application number (between one and 15)

IBT_n = initial brake temperature for the nth brake application, in °C

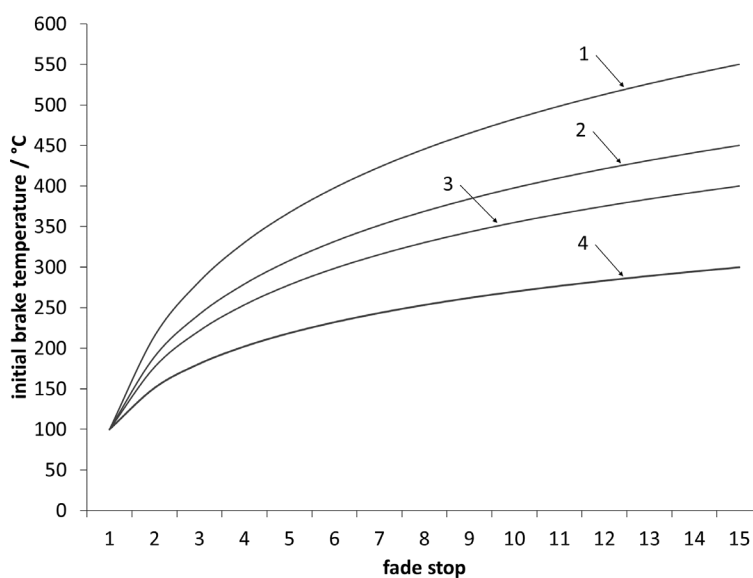
IBT₁ = initial brake temperature for the first brake application, in °C

IBT₁₅ = initial brake temperature for the last brake application, in °C

The different fade schedules for disc or drum and front or rear brakes are shown in Table 2 and depicted in Figure 7. The optional fade schedules are more severe and provide higher temperatures. Unless otherwise specified by the test requestor, conduct the standard fade schedule and keep it the same for a given project.

Table 2 - Initial brake temperatures during fade modules

Brake Type	Disc				Drum	
Axle Position	Front		Rear		Rear	
Schedule	Standard	Optional	Standard	Optional	Standard	Optional
First initial temperature (°C)	100	100	100	100	100	100
Last initial temperature (°C)	450	550	300	400	200	300
Stop Number	Initial Brake Temperature (°C)					
1	100	100	100	100	100	100
2	190	215	151	177	126	151
3	242	283	181	222	141	181
4	279	330	202	254	151	202
5	308	367	219	278	159	219
6	332	398	232	298	166	232
7	351	423	244	316	172	244
8	369	446	254	330	177	254
9	384	465	262	343	181	262
10	398	483	270	355	185	270
11	410	498	277	366	189	277
12	421	513	284	375	192	284
13	432	526	289	384	195	289
14	441	539	295	392	197	295
15	450	550	300	400	200	300



Key:
 1 - Disc FA optional
 2 - Disc FA standard
 3 - Disc RA optional
 4 - Disc RA standard

Figure 7A - Initial brake fade temperatures for disc brakes