SURFACE VEHICLE RECOMMENDED PRACTICE

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Brake Rotor Thermal Cracking Procedure for Vehicles Below 4 540 kg GVWR

RATIONALE

Based on user input, the committee considered that no new technologies or issues with the test method require revision.

STABILIZED NOTICE

This document has been declared “STABILIZED” by SAE Brake Dynamometer Standards Committee and will no longer be subjected to periodic reviews for currency. Users are responsible for verifying references and continued suitability of technical requirements. Newer technology may exist.

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1. SCOPE

This recommended practice is derived from common test sequences used within the industry. This procedure applies to all on-road passenger cars and light trucks up to 4 540 kg of GVWR. This recommended practice does not address other aspects such as performance, NVH, and durability. Test results from this recommended practice should be combined with other measurements and dynamometer tests (or vehicle-level tests), and acceptance criteria to validate a given design or configuration.

1.1 Purpose

This recommended practice establishes a minimum evaluation procedure for brake rotor thermal cracking.

2. REFERENCES

2.1 SAE Publications

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

SAE J2784 FMVSS Inertia Dynamometer Test Procedure for vehicles below 4 540 kg GVWR

SAE J2789 Inertia Calculation for Single-Ended Inertia Dynamometer Testing

2.2 ECE Publications

Available at www.unece.org/trans/main/wp29/meeting_docs_grrf.html?expandable=0&subexpandable=99 under: Working Documents.

ECE-TRANS-WP29-GRRF-2011-09e Replacement brake linings - Proposal for amendment to Regulation No. 90

3. DEFINITIONS

3.1 APPARENT FRICTION FOR DISC BRAKES

Per Equation 1:

$$\mu = \frac{10^5 \cdot T}{2 \cdot (p - p_{Threshold}) \cdot A_P \cdot r_{eff}} \quad \text{(Eq. 1)}$$

where:

μ = apparent friction for disc 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 requestor, use 100 kPa for service-only brake corners and 300 kPa for integral parking brake corners. [kPa]
A_P = total piston area acting on one side of the caliper for disc brakes. [mm^2]
r_{eff} = radial distance from centerline of the piston to the axis of rotation for disc brakes, unless other dimensions are provided by the requestor. [mm]

3.2 DECELERATION-CONTROLLED BRAKE APPLICATION

Inertia dynamometer control algorithm that adjusts brake pressure in real time to maintain a constant torque output calculated from the instantaneous deceleration specified in the test procedure.

3.3 PRESSURE-CONTROLLED BRAKE APPLICATION

Inertia-dynamometer control algorithm that maintains a constant input pressure to the brake independent of the torque output.

3.4 GROSS VEHICLE WEIGHT RATING- GVWR

Maximum vehicle weight indicated by the manufacturer. [kg]

3.5 INITIAL BRAKE TEMPERATURE - IBT

Rotor temperature at the start of the brake application [˚C]

3.6 TIRE DYNAMIC ROLLING RADIUS

Equivalent tire radius that will generate the Revolutions Per Mile (RPM) published by the tire manufacturer for the specific tire size per Equation 2. Use the tire dynamic rolling radius to calculate the dynamometer rotational speed for a given linear vehicle speed. [mm] where

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

RR = tire dynamic rolling radius [mm]
RPM = tire manufacturer specification for revolutions per mile. Typically shown for the tire size on the manufacturer's website

3.7 PRESSURE LIMIT

Maximum allowable pressure during a brake application

3.8 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 at GVWR for vehicles per FMVSS 105. For electric vehicles, the speed attainable is determined with the propulsion batteries at a state of charge of not less than 95% at the beginning of the run. [km/h]

3.9 ROTOR GOOSENECK

On integral rotor designs, a cast or machined groove at the transition from the inboard braking surface to the cylindrical (or conical) portion of the rotor that connects to the wheel hub/bearing unit.

4. ROTOR CHARACTERIZATION

4.1 Record and report features that characterize the rotor such as:

4.1.1 Rotor mass

4.1.2 Vane count and configuration (straight radial vanes, straight slanted vanes, curved slanted vanes, multiple straight slanted vanes, rung shaped blades, or pillars)

4.1.3 Cross-drills or slots

4.1.4 Surface treatment or coating

4.1.5 Rotor thickness variation measured 10 mm from the outside diameter

4.1.6 Cheek thickness variation measured every 90° on both friction surfaces (for vented rotors only)

4.1.7 Mounted lateral run-out measured 10 mm from the outside diameter on the outboard cheek

4.1.8 Friction surface finish R_a measured every 90° on both friction surfaces for non-coated rotors

4.1.9 Hardness of friction surface measured every 90° on both friction surfaces

4.1.10 Basic material description

4.1.11 Rotor design/type (standard vented, inverted, standard solid, solid drum-in-hat, vented drum-in-hat, or solid single flange rotor)

5. TEST CYCLES

5.1 Dynamic Brake Application

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

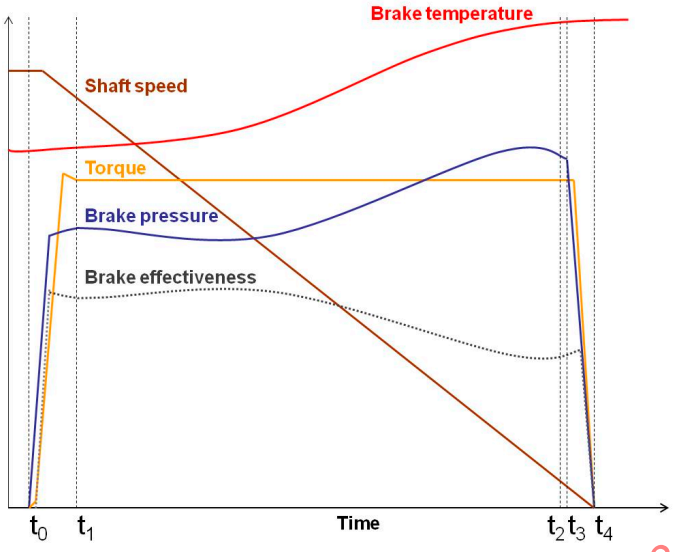

FIGURE 1 - TYPICAL BRAKE APPLICATION TIME STAMPS

5.1.1 Time t_0

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

5.1.2 Time t_1

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

5.1.3 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. t_2 is defined as the time at which speed is 0.5 km/h above the release speed (t_3).

5.1.4 Time t_3

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

5.1.5 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.

6. TEST EQUIPMENT

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

6.2 Enclosure or cage to safely contain any debris or broken test components during testing

6.3 Automatic data collection system capable of recording the following channels at 100 Hz minimum sample rate

6.3.1 Brake equivalent linear speed. [km/h]

6.3.2 Brake input pressure. [kPa]

6.3.3 Brake output torque. [N·m]

6.4 Automatic data collection system capable of recording brake rotor temperature at 50 Hz minimum sample rate. [˚C]

7. TEST CONDITIONS AND SAMPLE PREPARATION

7.1 For disc brakes, the assembled rotor lateral run-out shall not exceed 50 microns when measured on the outboard surface and 10 mm from the outside diameter when coupled to the dynamometer shaft.

7.2 Use a new rotor as received and new brake pads for each test

7.3 Additional pads sets may be required. This will depend on individual brake platforms

7.4 Cooling air shall remain enabled per item 9.5 and 9.6 during the entire test sequence

7.5 Use OEM (or OES) friction material. If the OEM (or OES) friction material is not available alternatives are permitted in agreement with the requestor. Include the actual friction material edge code used for the test on the final test report.

7.6 Temperature measurement

7.6.1 For vented rotors use a welded thermocouple on the outboard brake cheek between fins (black dot on Figure 2). An alternative method is to use a rubbing thermocouple on the outboard rotor face located at the effective radius (black square on Figure 2).

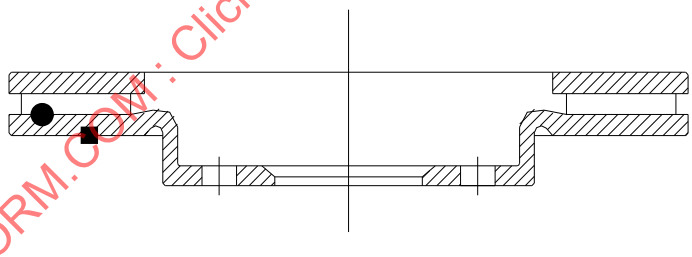

FIGURE 2 - THERMOCOUPLE LOCATION FOR VENTED ROTORS

7.6.2 For solid rotors use a welded thermocouple in the relief groove (black triangle on Figure 3). An alternative method is to use a rubbing thermocouple on the outboard brake cheek (black square on Figure 3).

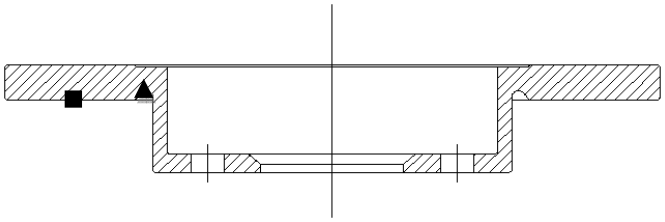

FIGURE 3 - THERMOCOUPLE LOCATION FOR SOLID ROTORS

8. TEST INERTIA

Calculate the test inertia according to the default values indicated on Tables 1 and 2 of SAE J2789 for deceleration < 0.65 g, with the vehicle loaded at GVWR.

9. TEST PROCEDURE AND CONDITIONS

9.1 Test sequence per table 1

9.2 Use a release speed of 0.5 km/h for all brake applications

9.3 Pressure ramp rate 20 000 kPa/s

9.4 Cooling air speed of 50 km/h measured approximately 200 mm from the rotor outside diameter in front of the incoming cooling air. Unless otherwise specified by the test requestor, direct the cooling air on the opposite side of the caliper.

NOTE: Monitor final rotor temperature. After final rotor temperature stabilizes, cast iron or steel rotors achieve typical temperatures of approximately (500-600) °C. Rotor temperatures above this range may cause premature failure or damage to other brake components.

9.5 Control cooling air temperature to (25 ± 10) °C

9.6 Control deceleration levels within ± 10% of the set-point.

9.7 Cycle time is controlled from the start of the first brake application of the cycle to the start of the second brake application during the same cycle.

9.8 In the event the brake corner does not achieve target deceleration, perform the following sequence:

9.8.1 Increase maximum brake pressure above 14 000 kPa, as long as the new pressure is not above brake corner maximum operating pressure

9.8.2 Continue testing as-is, with the understanding the deceleration levels will not be achieved and add the corresponding note on the final test report

9.8.3 Change the friction material to a different type or formulation (edge-code). In the case when the friction material is changed, a new test series is required using new rotors in agreement with the test requestor.

9.9 Unless otherwise indicated by the test requestor, replace with friction material of the same edge-code when one of the following items applies. When replacing the friction material, conduct 50 burnish stops per step 1 on Table 1:

9.9.1 The minimum usable thickness is 3 mm or less at the thinnest position

9.9.2 The friction material exhibits structural damage (example: a loss of 10% of more of the working area)

9.9.3 Detachment of friction from the backing plate

9.9.4 Permanent and significant deflection of the backing plate

9.9.5 Cracks across the friction material thickness

9.10 At each Inspection check for rotor cracks, record length of longest crack, verify pad life (minimum thickness), and conduct a visual inspection of the brake corner per item 9.10 and update the inspection log per Table 2. Crack classification and structural failure criteria are indicated in Appendix A.

TABLE 1 - ROTOR CRACK TEST SEQUENCE

Step	Description	Braking Speed [km/h]	Brake Application Control (IBT, Cycle Time)	Deceleration level [m/s^2]	Number of Stops per Cycle	Number of Cycles
1	Burnish	80	IBT= 100 °C	3	200	1
2	Rotor Crack Sequence (1-25)	160	IBT=100 °C first, then 70 s	5	2	25
3	Planned Inspection	Perform inspection per 9.10				
4	Rotor Crack Sequence (26-50)	160	IBT=100 °C first, then 70 s	5	2	25
5	Planned Inspection	Perform inspection per 9.10				
6	Rotor Crack Sequence (51-70)	160	IBT=100 °C first, then 70 s	5	2	20
7	Planned Inspection	Perform inspection per 9.10				
8	Rotor Crack Sequence (71-80)	160	IBT=100 °C first, then 70 s	5	2	10
9	Planned Inspection	Perform inspection per 9.10				
10	Rotor Crack Sequence (81-90)	160	IBT=100 °C first, then 70 s	5	2	10
11	Planned Inspection	Perform inspection per 9.10				
12	Rotor Crack Sequence (91-100)	160	IBT=100 °C first, then 70 s	5	2	10
13	Planned Inspection	Perform inspection per 9.10				
14	Rotor Crack Sequence (101-110)	160	IBT=100 °C first, then 70 s	5	2	10
15	Planned Inspection	Perform inspection per 9.10				
16	Rotor Crack Sequence (111-120)	160	IBT=100 °C first, then 70 s	5	2	10
17	Planned Inspection	Perform inspection per 9.10				
18	Rotor Crack Sequence (121-130)	160	IBT=100 °C first, then 70 s	5	2	10
19	Planned Inspection	Perform inspection per 9.10				
20	Rotor Crack Sequence (131-140)	160	IBT=100 °C first, then 70 s	5	2	10
21	Planned Inspection	Perform inspection per 9.10				
22	Rotor Crack Sequence (141-150)	160	IBT=100 °C first, then 70 s	5	2	10
23	Final inspection	Perform inspection per 9.10 and take final measurements including photographs				

TABLE 2 - INSPECTION LOG FOR CRACKS AND PAD REPLACEMENT

Step	Cycles	Pad replacements [yes/no]	Crack/failure classification [A1, A2, A3, A4]	Crack type	Length of longest crack [mm]	Comments
3	Post 1-25					
5	Post 26-50					
7	Post 51-70					
9	Post 71-80					
11	Post 81-90					
13	Post 91-100					
15	Post 101-110					
17	Post 111-120					
19	Post 121-130					
21	Post 131-140					
23	Post 141-150					

10. TEST REPORT

10.1 General Information

10.1.1 Vehicle information and test parameters

10.1.2 Main rotor dimensions

10.1.3 Physical characteristics

10.1.4 Thermocouple location per 7.6

10.1.5 Cooling air per 9.5

10.1.6 Application Number (reference to OE if available)

10.1.7 Brake pads used and its edge code

10.1.8 Crack initiation, propagation, and pad replacement per Table 2

10.1.9 Digital photographs showing the general condition of the rotor, braking surfaces, cracks, and failure modes per Appendix B.

10.2 Tabular Data

10.2.1 Include a tabular section for the following brake applications:

10.2.1.1 First ten burnish brake applications

10.2.1.2 Every fifth burnish brake application (between the 15^{th} and 185^{th} brake application)

10.2.1.3 Last ten burnish brake applications

10.2.1.4 Every brake application during the crack cycles for the entire test

10.2.2 For each brake application per item 12.2.1 report:

10.2.2.1.1 Braking speed

10.2.2.2 Release speed

10.2.2.3 Cycle Time

10.2.2.4 Average by distance effectiveness, deceleration (or torque), and pressure per item 6.1

10.2.2.5 Minimum and maximum deceleration (or torque) between t_1 and t_2 per item 6.1

10.2.2.6 Minimum and maximum pressure between t_1 and t_2 per item 6.1

10.2.2.7 Initial rotor temperature at t_o and final rotor temperature and t_4 per item 6.1

10.2.2.8 Average by time cooling air speed

10.2.2.9 Average by time cooling air temperature

11. NOTES

11.1 Marginal Indicia

A change bar (I) located in the left margin is for the convenience of the user in locating areas where technical revisions, not editorial changes, have been made to the previous issue of this document. An (R) symbol to the left of the document title indicates a complete revision of the document, including technical revisions. Change bars and (R) are not used in original publications, nor in documents that contain editorial changes only.

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