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SURFACE VEHICLE RECOMMENDED PRACTICE

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FMVSS 135 Inertia Dynamometer Test Procedure

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RATIONALE

This Recommended Practice is the result of an industry effort to develop an inertia-dynamometer test procedure based upon the FMVSS 135 vehicle test. Results from this test provide a laboratory assessment of the brake corner performance. Data from this Recommended Practice may be combined with other brake system and vehicle characteristics to predict vehicle performance.

The conditions defined in this Recommended Practice are drawn from FMVSS 135 vehicle test experience. The deceleration levels are not necessarily based on those needed to meet the requirements of the FMVSS 135. This procedure is intended to properly represent the lining conditioning which occurs during an FMVSS 135 vehicle test.

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1. SCOPE

This Recommended Practice is derived from the Federal Motor Vehicle Safety Standard 135 vehicle test protocol as a single-ended inertia-dynamometer test procedure. It measures brake output, friction material effectiveness, and corner performance in a controlled and repeatable environment. The test procedure also includes optional sections for parking brake output performance for rear brakes. It is applicable to brake corners from vehicles covered by the FMVSS 135 when using the appropriate brake hardware and test parameters. This procedure is applicable to all passenger cars and light trucks up to 3500 kg of GVWR.

1.1 Purpose

The purpose of this procedure is to assess the performance of a brake corner assembly during conditions that correspond to the FMVSS 135 vehicle test procedure.

2. REFERENCES

2.1 Applicable Publications

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

2.1.1 ISO Publications

Available from ANSI, 25 West 43rd Street, New York, NY 10036-8002, Tel: 212-642-4900, www.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 document.

2.2.1 Government Publications

Available from NHTSA Headquarters, 400 Seventh Street, SW, Washington, DC 20590, Tel: 888-327-4236 or TTY: 1-800-424-9153, www.nhtsa.dot.gov.

571.135 Standard No. 135—Light Vehicle Brake Systems

TP-135-01 Dec 5, 2005 NHTSA—OVSC Laboratory Test Procedure for FMVSS 135 Light Vehicle Brake Systems

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]

3.2 Drum Brake Effectiveness (C*)

Per Equation 2:

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

where:

C^* = effectiveness for drum brakes. [unitless]
T = output torque. [N·m]
p = brake pressure. [kPa]

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$p_{Threshold}$ = minimum pressure required to start developing braking torque. Unless otherwise directed, use threshold pressure derived from Table 2 Section 20. [kPa]

A_P = total piston area acting on one side of the caliper for disc brakes; total wheel cylinder area for drum brakes [mm^2]

r_{eff} = radial distance from centerline of the piston to the axis of rotation for disc brakes; internal drum diameter divided by 2 for drum brakes, unless other dimensions are provided by the requestor. [mm]

3.3 Breakaway Torque

Torque required to initiate brake rotation after cable tension is applied to the parking brake. [N·m]

3.4 Deceleration-Controlled Brake Application

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

3.5 Initial Brake Temperature – IBT

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

3.6 Pressure-Controlled Brake Application

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

3.7 Gross Vehicle Weight – GVWR

Maximum vehicle weight indicated by the manufacturer. [kgf]

3.8 Lightly Loaded Vehicle Weight – LLVW

Unloaded vehicle weight plus 180 kg for driver and test instrumentation. [kgf]

3.9 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. [km/h]

3.10 Pressure Level at 500 N Pedal Force with Brake Power Assist System Operational–$p_{500N\ operational}$

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

3.11 Pressure Level at 500 N Pedal Force with Brake Power Assist System Fully Depleted–$p_{500N\ depleted}$

Brake system pressure at the front or rear corner with 500 N of pedal force applied and the power assist unit fully depleted. [kPa]

3.12 Pressure Level During Best Cold Effectiveness Stop–$p_{best\ cold\ effect}$

Lowest distance-weighted average brake pressure from all the brake applications on Section 40, Table 2, Cold Effectiveness. [kPa]

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3.13 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 3. Use the tire dynamic rolling radius to calculate the dynamometer rotational speed for a given linear vehicle speed. [mm]

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

where:

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

4. TEST CYCLES

4.1 Dynamic Brake Application

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

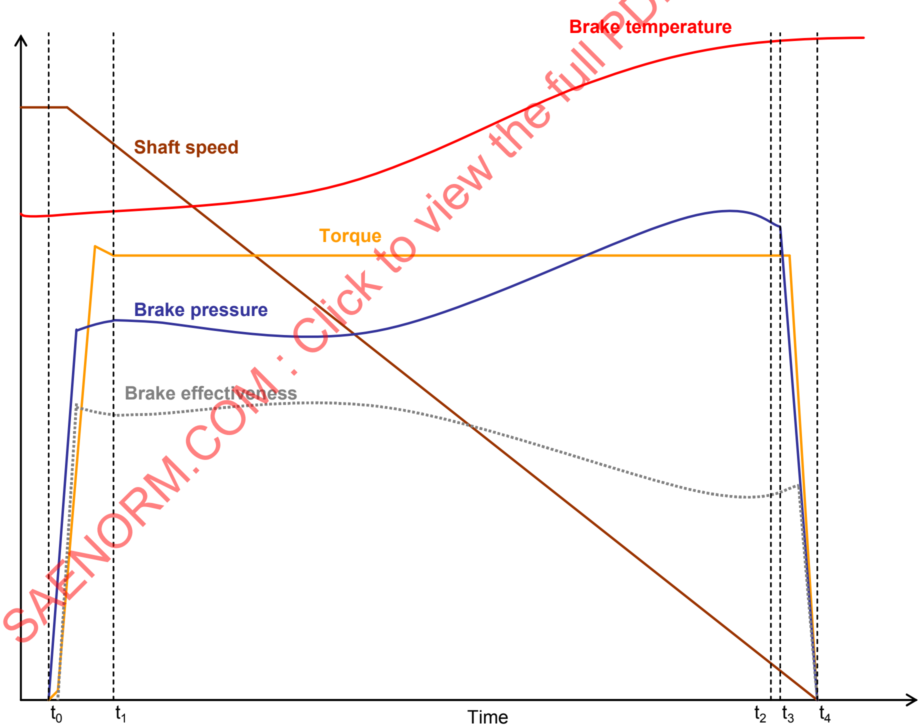

FIGURE 1 - TYPICAL BRAKE APPLICATION TIME-STAMPS

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 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.

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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. t_2 is defined as the time at which 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 Single-ended brake inertia-dynamometer capable of performing deceleration and pressure controlled brake applications.

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

5.2.1 Brake equivalent linear speed. [km/h]

5.2.2 Brake input pressure. [kPa]

5.2.3 Brake output torque. [N·m]

5.2.4 Brake fluid displacement. [mm^3]

5.2.5 Parking brake cable tension (rear brakes testing only). [N]

5.2.6 Parking brake cable travel (rear brakes testing only). [mm]

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

5.3.1 Brake rotor or drum temperature. [°C]

5.3.2 Brake pad or brake shoe temperature. [°C]

5.3.3 Cooling air temperature, relative humidity, and speed.

5.4 Control brake cooling air temperature 25 ± 5 °C, and humidity to 9.92 g/kg (11.57 g/m^3) at sea level. Use a psychrometric chart to find acceptable air temperature and relative humidity conditions to meet absolute humidity requirements.

5.5 Park brake testing capabilities (for rear brakes).

5.5.1 Ability to apply torque from zero shaft rotational speed sufficient to cause breakaway.

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5.5.2 Mechanism to apply and control input cable tension.

5.5.3 Mechanism to lock the parking brake cable travel in position during parking brake output evaluation.

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 thermocouple at a depth of 1.0 mm 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 µm when measured on the outboard surface and 10 mm from the outside diameter.

6.5 For brake drums, install 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 For drum brakes, set the diametric cage clearance to the value indicated by the test requestor, the vehicle service manual, or the brake assembly print. If no other information is available, set the diametric cage clearance to 0.6-0.8 mm, measured at the center of the shoes. Rotate the drum to check for excessive drag and adjust if necessary.

6.8 Calculate dynamometer rotational speed based on the tire dynamic rolling radius.

6.9 Set cooling air temperature and humidity per 5.4.

6.10 Measure the lining thickness of each disc brake pad or shoe at 8 points.

6.11 Weight the rotor and pads or the drum and shoes.

7. DYNAMOMETER TEST INERTIA

Table 1 indicates the equations to calculate inertia levels for the different sections of the test. The values for X_1, X_2, Y_1, and Y_2 are not equivalent to the static vehicle weight distribution. The correct values are a function of the dynamic vehicle braking torque distribution.

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TABLE 1 - EQUATIONS TO CALCULATE CORNER TEST INERTIA PER SECTION AND AXLE

Vehicle Test Weight and Brake System Condition	Front Brake Test	Rear Brake Test
GVWR Brake system fully operational	$I_{front\ GVWR} = \frac{1}{2} \cdot X_1 \cdot GVWR \cdot RR^2$ (Eq. 4)	$I_{rear\ GVWR} = \frac{1}{2} \cdot Y_1 \cdot GVWR \cdot RR^2$ (Eq. 5)
LLVW Brake system fully operational	$I_{front\ LLVW} = \frac{1}{2} \cdot X_2 \cdot LLVW \cdot RR^2$ (Eq. 6)	$I_{rear\ LLVW} = \frac{1}{2} \cdot Y_2 \cdot LLVW \cdot RR^2$ (Eq. 7)
GVWR Brake system with front-to-rear split Partial circuit failure	$I_{front\ GVWR\ FR\ Split} = \frac{1}{2} \cdot GVWR \cdot RR^2$ (Eq. 8)	Use Equation 8
LLVW Brake system with front-to-rear split Partial circuit failure	$I_{front\ LLVW\ FR\ Split} = \frac{1}{2} \cdot LLVW \cdot RR^2$ (Eq. 9)	Use Equation 9
GVWR Brake system with diagonal split Partial circuit failure	$I_{front\ GVWR\ Diag\ Split} = 2 \cdot I_{front\ GVWR}$ (Eq. 10)	$I_{rear\ GVWR\ Diag\ Split} = 2 \cdot I_{rear\ GVWR}$ (Eq. 11)
LLVW Brake system with diagonal split Partial circuit failure	$I_{front\ LLVW\ Diag\ Split} = 2 \cdot I_{front\ LLVW}$ (Eq. 12)	$I_{rear\ LLVW\ Diag\ Split} = 2 \cdot I_{rear\ LLVW}$ (Eq. 13)

where:

I = test inertia calculated using Equations 4 thru 13. [kg·m²]

NOTE: Verify with test requestor if a loss factor is required to adjust the calculated inertia from Equations 4 thru 13.

X_1 = ratio of vehicle mass braked by the front axle at GVWR with brake system fully operational

X_2 = ratio of vehicle mass braked by the front axle at LLVW with brake system fully operational

Y_1 = ratio of vehicle mass braked by the rear axle at GVWR with brake system fully operational

Y_2 = ratio of vehicle mass braked by the rear axle at LLVW with brake system fully operational

NOTE: Values for X_1, X_2, Y_1, and Y_2 are provided by the test requestor.

RR = tire dynamic rolling radius calculated per Equation 3.

8. TEST PROCEDURE

8.1 Test service brakes per Table 2 Service Brake Test Procedure.

8.1.1 Use cooling air speed equal to 30 km/h at the brake for all sections except: 50 km/h for Section 10, Burnish; and 5 km/h for Section 160, 170, and 180, Fade Heating Snubs, First Hot Stop, and Second Hot Stop, respectively.

8.1.2 The dynamometer shaft rotational speed during cooling between brake events equals 50% of the braking speed for the next brake application, except for Sections 160, 170, 180 and 190, where it shall be equal to the braking speed for the next brake application.

8.1.3 The dynamometer release speed is 3 km/h, except for Section 160 which uses 60 km/h and Section 140 which is a full stop to 0 km/h.

8.1.4 Section 10, Burnish, use the first five stops as the Instrument Check Stops.

8.1.5 Sections 20 and 30, Adhesion Utilization Ramps, release the brake when the brake pressure reaches the pressure limit.

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8.1.6 Section 140, Failed Power-Brake Unit, if the brake pressure at a pedal force of 500 N with the power assist fully depleted ($p_{500N\ depleted}$) is not available, perform stops as torque control with a deceleration level of 0.26 g.

8.1.7 Sections 150 and 155 are performed on rear brakes following the test sequence described in Appendix A.

8.1.8 Sections 170 and 200, First Hot Stop and Recovery Performance respectively, perform stops as pressure-controlled using the lowest distance weighted average pressure ($p_{best\ cold\ effect}$) from Section 40, Cold Effectiveness

8.1.9 For all brake applications the end of the stop or snub is defined as time T_4 per Figure 1.

TABLE 2 - SERVICE BRAKES TEST PROCEDURE

Section Number	FMVSS 135 Reference	Inertia Level [Equation from Table 1]	Braking Speed [km/h]	Brake Application Control (IBT, Cycle Time, or Distance)	Pressure Apply Rate [kPa/sec]	Pressure Limit [kPa]	Decel Level [g]	# of Stops/ Snubs
10	7.1 Burnish at GVWR	Eq. 4 or 5	80	IBT = 100 °C	20 000	$p_{500N\ operational}$	0.31	200
20	7.4 (1) 3 500 kPa Adhesion Utilization Ramps at GVWR	Eq. 4 or 5	50	IBT = 65 °C first, then 100 °C	700-2000	3500 kPa	—	3
30	7.4 (2) 12 000 kPa Adhesion Utilization Ramps at GVWR	Eq. 4 or 5	100	IBT = 65 °C first, then 100 °C	5000	12 000 kPa	—	3
40	7.5 Cold Effectiveness at GVWR	Eq. 4 or 5	100	IBT = 100 °C	20 000	$p_{500N\ operational}$	0.90	6
50	7.6 High Speed Effectiveness at GVWR	Eq. 4 or 5	160 (80% V_{max} for V_{max} < 200 km/h)	IBT = 100 °C	20 000	$p_{500N\ operational}$	0.80	6
60	7.5 Cold Effectiveness at LLVW	Eq. 6 or 7	100	IBT = 100 °C	20 000	$p_{500N\ operational}$	0.90	6
70	7.6 High Speed Effectiveness at LLVW	Eq. 6 or 7	160 (80% V_{max} for V_{max} < 200 km/h)	IBT = 100 °C	20 000	$p_{500N\ operational}$	0.80	6
80	7.8 Failed Antilock System at LLVW	Eq. 6 or 7	100	IBT = 100 °C	20 000	$p_{500N\ operational}$	0.60	6
90.a	7.10 Hydraulic Circuit Failure at LLVW for front brakes	Eq. 9 for front-to-rear split Eq. 12 or 13 for diagonal split	100	IBT = 100 °C	20 000	$p_{500N\ operational}$	0.70 front-to-rear split 0.45 diagonal split	4
90.b	7.10 Hydraulic Circuit Failure at LLVW for rear brakes	Eq. 9 for front-to-rear split Eq. 12 or 13 for diagonal split	100	IBT = 100 °C	20 000	$p_{500N\ operational}$	0.35 front-to-rear split 0.45 diagonal split	4
100.a	7.10 Hydraulic Circuit Failure at GVWR for front brakes	Eq. 8 for front-to-rear split Eq. 10 or 11 for diagonal split	100	IBT = 100 °C	20 000	$p_{500N\ operational}$	0.60 front-to-rear split 0.40 diagonal split	4
100.b	7.10 Hydraulic Circuit Failure at GVWR for rear brakes	Eq. 8 for front-to-rear split Eq. 10 or 11 for diagonal split	100	IBT = 100 °C	20 000	$p_{500N\ operational}$	0.40 front-to-rear split 0.40 diagonal split	4
110	7.8 Failed Antilock System at GVWR	Eq. 4 or 5	100	IBT = 100 °C	20 000	$p_{500N\ operational}$	0.60	6
120	Cool Down at GVWR	Eq. 4 or 5	5	Until 5 °C above cooling air temp	—	—	—	—

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TABLE 2 - SERVICE BRAKES TEST PROCEDURE (CONTINUED)

Section Number	FMVSS 135 Reference	Inertia Level [Equation from Table 1]	Braking Speed [km/h]	Brake Application Control (IBT, Cycle Time, or Distance)	Pressure Apply Rate [kPa/sec]	Pressure Limit [kPa]	Decel Level [g]	# of Stops/ Snubs
130	Warm Up at GVWR	Eq. 4 or 5	50	Until 65° at 60 seconds cycle time	20 000	$p_{500N\ operational}$	0.31	As needed
140	7.11 Failed Power-Brake Unit at GVWR	Eq. 4 or 5	100	IBT = 65 °C first, then 100 °C	20 000	$p_{500N\ depleted}$	—	6
150	7.12 Parking Brake forward	—	Reserved for rear brakes; See appendix A					
155	7.12 Parking Brake reverse	—	Reserved for rear brakes; See appendix A					
160	7.13 Heating Snubs at GVWR	Eq. 4 or 5	120-60	IBT = 55 °C first, then cycle time of 45 seconds	20 000	$p_{500N\ operational}$	0.31	15
170	7.14-1 First Hot Stop at GVWR	Eq. 4 or 5	100	20 seconds after the end of the last snub from section 160	20 000	$p_{best\ cold\ effect}$	—	1
180	7.14-2 Second Hot Stop at GVWR	Eq. 4 or 5	100	20 seconds after the end of section 170	20 000	$p_{500N\ operational}$	0.90	1
190	7.15 Brake Cooling Stops at GVWR	Eq. 4 or 5	50	Cycle distance = 1.5 km after the end of section 180	20 000	$p_{500N\ operational}$	0.31	4
200	7.16 Recovery Performance at GVWR	Eq. 4 or 5	100	Cycle distance = 1.5 km after the start last stop of section 190	20 000	$p_{best\ cold\ effect}$	—	1
				20 seconds after the end of stop 1 of this section				1
210	7.17 Final Inspection	Perform final inspection and measurements						

9. TEST REPORT

9.1 Graphs

For the entire test present the following:

In-stop pressure, brake temperature, and effectiveness for all brake applications. Applicable effectiveness value can be included on the corresponding graph. For Section 10 graph every tenth stop. See Appendix C.

9.2 Tabular Data

For each brake application indicate with the appropriate units of measure. See Appendix C:

9.2.1 Braking application initial and release speed.

9.2.2 Cycle time.

9.2.3 Average by distance effectiveness, torque and pressure.

9.2.4 Initial effectiveness at time t_1 and final effectiveness at time t_2.

9.2.5 Minimum and maximum torque and pressure between time t_1 and time t_2.

9.2.6 Brake temperature of the rotor or drum and optionally the lining at time t_0 and time t_4.

9.2.7 Maximum fluid displacement.

9.3 Cooling Air Temperature and Humidity for Each Section of the Test

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9.4 Wear Measurements and Final Integrity Inspection

Measure and report initial and final rotor or drum and lining thickness and weight loss. Record and report cracks, detachment, delaminating, brake fluid leaks, or any unusual condition on the rotor or drum.

9.5 Test Conditions

Record and report brake parameters, brake hand, rotor or drum and lining identification, test conditions, and total test run-time.

9.6 Cooling Air Conditions

Report cooling air direction and orientation.

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APPENDIX A - PARKING BRAKE TEST SEQUENCE

A.1 SCOPE

The following paragraphs describe an inertia-dynamometer based park brake test procedure based on the FMVSS 135 vehicle test. The following additional vehicle information is required to conduct the parking brake test:

A.1.1 Tire static loaded radius.

A.1.2 The maximum cable tension that can be applied to the rear brake without damage.

A.2 TEST CYCLE

Figure A1 illustrates the main steps followed during the execution of a static parking brake test sequence described in Section A.5:

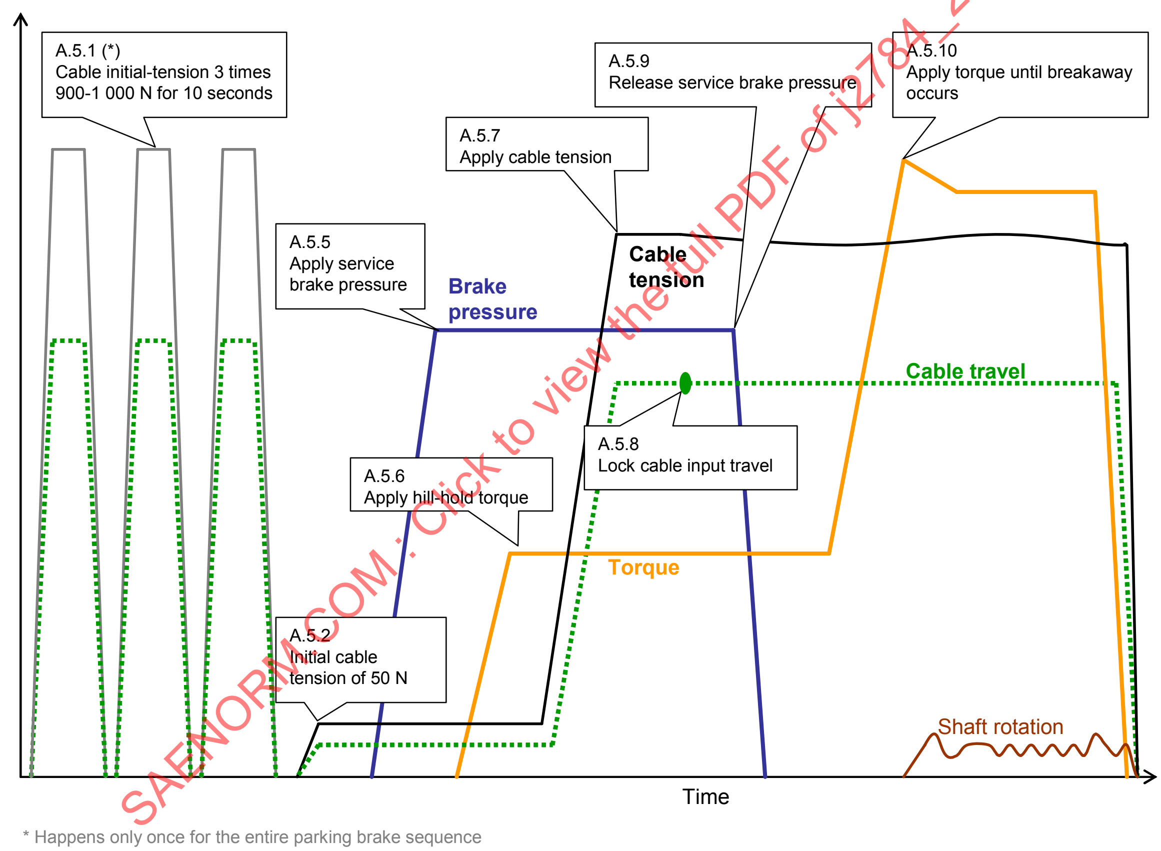

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FIGURE A1 - TYPICAL STATIC PARKING BRAKE APPLICATION SEQUENCE

A.3 TEST CONDITIONS AND SAMPLE PREPARATION

A.3.1 For drum-in-hat rear disc brakes, conduct the burnish sequence indicated by the test requestor. If no instructions are provided by the test requestor, do not conduct any burnish operation.

A.4 TORQUE AND PRESSURE CALCULATIONS FOR SERVICE BRAKE HILL-HOLD

Calculate the total braking torque required to hold the vehicle on a hill using Figure A2 and Equation A1.

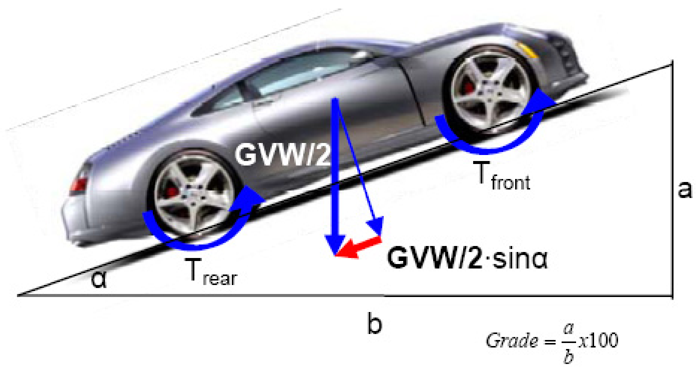

FIGURE A2 - HILL-HOLD ACTING FORCES AND TORQUES

$$T_{HH} = (9.81 \cdot GVWR/2) \cdot \sin[\tan^{-1}(Grade/100)] \cdot SLR \qquad \text{(Eq. A1)}$$

where:

T_{HH} = Total brake torque required to hold half the vehicle on a hill of a given grade
Grade = a/b. [unitless]
SLR = Tire static loaded radius is the vertical distance from the tire center of rotation to the ground calculated from Equation A2 when the tire is at its maximum load capacity at the specified inflation pressure. [m]

$$SLR = \frac{dr}{2} + 0.78 \cdot (w \cdot ar) \qquad \text{(Eq. A2)}$$

where:

dr = nominal rim diameter. [m]
w = nominal section width of the tire. [m]
ar = aspect ratio of the tire. [unitless]

Table A1 shows example calculations for two vehicle weights and three grade levels.

TABLE A1 - EXAMPLE CALCULATIONS FOR HILL-HOLD TORQUE VALUES

Grade	Vehicle GVWR [kg]	Rear Tire SLR [m]	Torque Required to Hold Half Vehicle Stationary T_{HH} [N·m]
10%	2000	0.325	317
20%	2000	0.325	625
30%	2000	0.325	915
10%	3000	0.325	476
20%	3000	0.325	937
30%	3000	0.325	1373

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Calculate the specific torque for the rear brake using Equation A3.

$$RT_{SP} = T / p \quad \text{(Eq. A3)}$$

where:

RT_{SP} = rear brake specific torque. [Nm/kPa]

T = average by distance torque from last ten brake application from Table 2 Section 10. [N·m]

p = average by distance pressure from last ten brake application from Table 2 Section 10. [kPa]

Calculate total vehicle specific torque assuming a torque split equal to the inertia split at GVWR with the brake system fully operational using Equation A4.

$$TT_{SP} = RT_{SP} / Y_1 \quad \text{(Eq. A4)}$$

where:

TT_{SP} = total vehicle specific torque. [N·m/kPa]

Y_1 = rear axle torque split per Equation 5

Calculate rear brake pressure to hold half vehicle on a hill using Equation A5.

$$P_{HH} = T_{HH} / TT_{SP} \quad \text{(Eq. A5)}$$

where:

P_{HH} = brake pressure. [kPa]

Alternatively, when front and rear specific torques values are available, calculate brake pressure for the rear corner to hold half vehicle on a hill using Equation A6.

$$P_{HH} = \frac{T_{HH}}{FT_{SP} + RT_{SP}} \quad \text{(Eq. A6)}$$

where:

FT_{SP} = front brake specific torque. [Nm/kPa]

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A.5 TEST PROCEDURE

A.5.1 Apply cable tension between 900 and 1000 N, hold for 10 seconds, and then release. Repeat for a total of three tensioning cycles.

A.5.2 Set park brake cable initial tension to 50 N unless otherwise specified by the test requestor.

A.5.3 Zero the cable travel measurement device.

A.5.4 Start continuous data collection for torque, pressure, tension, and cable travel.

A.5.5 Apply service brake pressure to P_{HH}.

A.5.6 Apply static torque to T_{HH}. Verify that the brake assembly remains stationary and no rotor/drum rotation occurs. If rotor/drum rotation occurs, increase service brake pressure by 20% and apply static torque T_{HH} again. Continue increasing the service brake pressure until the brake assembly remains stationary.

A.5.7 Apply cable tension to 250 N.

A.5.8 Lock the cable input travel.

A.5.9 Release the service brake pressure.

A.5.10 If breakaway has not yet occurred, apply torque to the brake at a rate not to exceed 1000 N·m/second until breakaway is achieved. Limit the amount of brake rotation to 20° to limit the bedding effect.

A.5.11 Repeat A.5.3 through A.5.10 at 750 N cable tension.

A.5.12 Repeat A.5.2 through A.5.11 in the reverse vehicle direction.

A.6 TEST REPORT

A.6.1 Graphs

A.6.1.1 Breakaway toque, equivalent percent grade, and cable travel versus the average static input cable tension for each cable tension level for both forward and reverse directions.

A.6.2 Tabular Data

For each static brake application report:

A.6.2.1 Input cable tension.

A.6.2.2 Input cable travel.

A.6.2.3 Breakaway torque.

A.6.2.4 Equivalent percent grade.

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APPENDIX B - EXPLANATORY NOTES

B.1 START TIME FOR BRAKE APPLICATION

During an FMVSS 135 vehicle sequence, the brake application start time, t_0, is taken as the time when the pedal force reaches or exceeds 22 N. During inertia-dynamometer testing this pedal force can be entered as the equivalent brake pressure. This pressure setpoint becomes the brake threshold pressure for the different calculations and time marks.

B.2 ROTOR/DRUM VERSUS LINING/SHOE TEMPERATURE

Even though the vehicle test is executed using thermocouples on the stationary components (brake lining or brake shoe), the Task Force recommends thermocoupling the rotors or drums and using those temperatures for test control. The thermal properties of cast iron rotors and drums are more stable and predictable than those of the linings. Since most brake dynamometer air cooling systems do not duplicate the actual cooling environment of the vehicle, it was determined that having accurate and repeatable temperature profiles outweighed the concerns of controlling off rotors/drums rather than linings/shoes. The task force recommends lining/shoe temperatures be measured for reference.

B.3 DECELERATION CONTROL

The FMVSS 135 vehicle test limits the maximum pedal force applied during the different brake events, which becomes input brake pressure, and evaluates the stopping distance for the vehicle, which can be converted into an equivalent deceleration level. Based on the experience gathered during the development of this Recommended Practice, controlling brake deceleration level for most of the sections during the test and limiting the brake pressure provides a more accurate representation of the lining conditioning observed during the actual vehicle test as compared to pressure control alone.

B.4 20-SECOND CYCLE TIME DURING HOT PERFORMANCE SECTION

The FMVSS 135 specifies that the vehicle shall accelerate as rapidly as possible after the 15th heating snub and after the first hot performance stop. The vehicle-to-dyno and the vehicle-to-vehicle variation on acceleration times are eliminated by introducing a constant cycle time that most modern inertia-dynamometers can meet.

B.5 INERTIA-DYNAMOMETER COOLING SPEED

One of the critical elements during inertia-dynamometer testing is the efficiency and the time required to execute the test. This efficiency is improved by minimizing the amount of time the brake takes to cool down to the required temperature for the next brake event. It is common-practice to use 50% of the braking speed for the next brake event as an efficient speed for sections controlled by initial brake temperature at the start of the brake application. Using this cooling speed also allows the inertia-dynamometer to accelerate to the braking speed using normal drive capabilities and does not compromise the initial temperature for the next brake event.

During vehicle testing factors such as brake drag, brake cooling capacity, thermal conductivity of the friction material, rotor thermal mass distribution and fin design, drum design and thermal characteristics, air circulation around the brake components, and brake position (front or rear) affect the actual temperature at the beginning of the brake application. Another source of standardization is the definition of brake initial temperature as the temperature at the start of the brake application instead of the average temperature of the service brake 0.32 km before any brake application used during an actual FMVSS 135 vehicle test. Spinning the brake for extended periods can ultimately alter the transfer layer or extend the test duration.

B.6 PRESSURE RAMP RATES

The FMVSS 135 protocol requires best driver effort without exceeding the pedal force limit for the specific section. Repeating this during the inertia-dynamometer test would require prior knowledge of the vehicle actuation system gain and response times. The use of standard ramp rates during the inertia-dynamometer test enables better control, simplifies the information required to conduct the test, and allows the test facility to fine-tune and better control the pressure rise portion of the brake application. The ramp rates indicated on the test procedure are fast enough to build pressure while the brake is still close to the initial temperature and braking speed, hence improving the consistency during the data analysis phase.

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