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FMVSS Inertia Dynamometer Test Procedure for Vehicles Below 4540 kg GVWR

RATIONALE

This Recommended Practice is the result of an industry effort to develop inertia-dynamometer test procedures based upon the FMVSS 105 and 135 vehicle tests. Results from these tests provide a laboratory assessment of the brake corner performance. Data from this document may be combined with other brake system and vehicle characteristics to predict vehicle performance.

The conditions defined in this document are drawn from FMVSS 105 or 135 vehicle test experience. The deceleration levels are not necessarily based on those needed to meet the requirements of the FMVSS. These procedures are intended to properly represent the lining conditioning which occurs during an FMVSS vehicle test.

This revised document includes test procedures for vehicles below 4540 kg of Gross Vehicle Weight Rating. FMVSS 135 test procedure is covered by Section 8.1 and Table 2. FMVSS 105 test procedure is covered by Section 8.2 and Table 3. The different items, definitions, and sections indicate clearly whenever it applies only to the FMVSS 105 or the FMVSS 135 test procedure.

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1. SCOPE

This document is derived from the Federal Motor Vehicle Safety Standards 105 and 135 vehicle test protocols as single-ended inertia-dynamometer test procedures. It measures brake output, friction material effectiveness, and corner performance in a controlled and repeatable environment. The test procedures also include optional sections for parking brake output performance for rear brakes. It is applicable to brake corners from vehicles covered by the FMVSS 105 and 135 when using the appropriate brake hardware and test parameters. The FMVSS 135 is applicable to all passenger cars and light trucks up to 3500 kg of GVWR. The FMVSS 105 is applicable to all passenger cars, multi-purpose vehicles, buses, and trucks above 3500 kg of GVWR. This document does not include testing for school bus applications or vehicles equipped with hydraulic brakes with a GVWR above 4540 kg.

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 105 and 135 vehicle test procedures.

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.

571.105   Standard No. 105—Hydraulic and Electric Brake Systems

571.135   Standard No. 135—Light Vehicle Brake Systems

TP-105-03   July 1, 2003 NHTSA—OVSC Laboratory Test Procedure for FMVSS 105 Hydraulic and Electric 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:

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

where:

μ = apparent friction for disc brakes. [unitless]

3.2   Drum Brake Effectiveness (C*)

Per Equation 2:

$$C^* = \frac{10^5 \cdot T}{\left(p - p_{Threshold}\right) \cdot A_P \cdot r_{eff}}$$
(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 directed, use threshold pressure derived from Table 2 Section 20 or Table 3 Section 30. [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   (FMVSS 105) Brake Power Assist Unit

A device installed in a hydraulic brake system to reduce the driver effort required to actuate the system, and that if inoperative does not prevent the driver from braking the vehicle by a continued application of pedal force on the service brake control.

3.4   (FMVSS 105) Brake Power Unit

A device installed in a brake system that provides the energy required to actuate the brakes, either directly or indirectly through an auxiliary device, with the driver action consisting only of modulating the energy application level.

3.5   Breakaway Torque

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

3.6   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.

3.7   Initial Brake Temperature – IBT

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

3.8   Pressure-Controlled Brake Application

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

3.9   Gross Vehicle Weight – GVWR

Maximum vehicle weight indicated by the manufacturer. [kgf]

3.10   Lightly Loaded Vehicle Weight – LLVW

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

3.11   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. See sections 50 and 70 on Table 2 and sections 70 and 250 on Table 3. [km/h]

3.12   (FMVSS 135) 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]

3.13   (FMVSS 135) 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, including rear brake proportioning. [kPa]

3.14   (FMVSS 105) Pressure Level at 667 N Pedal Force with Brake Power Assist or Brake Power Unit System Operational – $p_{667N\ operational}$

Brake system pressure at the front or rear corner with 667 N of pedal force applied and the brake system and power assist unit fully operational including rear brake proportioning. [kPa]

3.15   (FMVSS 105) Pressure Level at 667 N Pedal Force with Brake Power Assist System Fully Depleted – $p_{667N\ depleted}$

Brake system pressure at the front or rear corner with 667 N of pedal force applied and the power assist unit fully depleted, including rear brake proportioning. [kPa]

3.16   (FMVSS 105) Pressure Level at 890 N Pedal Force with Brake Power Assist or Brake Power Unit System Operational – $p_{890N\ operational}$

Brake system pressure at the front or rear corner with 890 N of pedal force applied and the brake system and power assist unit fully operational including rear brake proportioning. This load level is required for the Spike Stops Section. [kPa]

3.17 (FMVSS 135) 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]

3.18 (FMVSS 105) Spike Stop

A stop resulting from the application of a service brake pressure of $p_{890N\ operational}$ in 0.08 seconds.

3.19 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]

$$RR = \frac{1\ 609\ 344}{2 \cdot \pi \cdot RPM}$$
(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

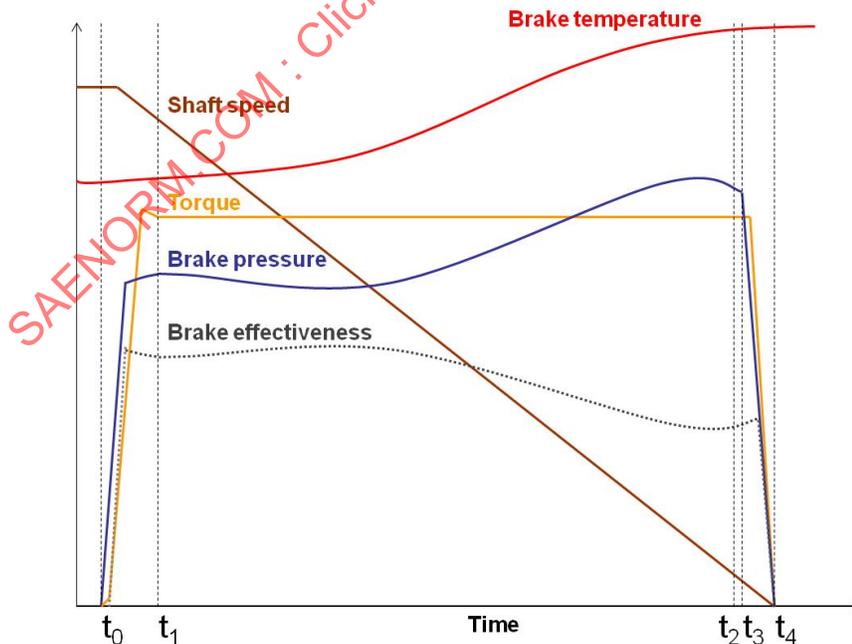Figure 1 illustrates the main time-stamps used to characterize the brake application.

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.

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 50 Hz minimum:

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:

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/m³) 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.

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.

5.6   Water spray testing capabilities (for FMVSS 105 testing only).

5.6.1   System to deliver a controlled stream of water on both sides of the rotor or directed into the drum assembly at a rate of 5 ± 2 liters/minute.

5.6.2   System to adjust position, orientation, and distance from the stream of water to the brake assembly. For disc brakes setup the water stream aligned in the radial direction with the center of the rotor and within 50 to 100 mm from the brake on the leading edge of the caliper. See Figure 2.

FIGURE 2 - WATER SPRAY SETUP FOR DISC BRAKES

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 to 0.8 mm, measured at the center of the shoes. Rotate 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 evenly distributed on the pad area.

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 correct values are a function of the dynamic vehicle braking torque distribution.

NOTE: The values of X_1, X_2, Y_1, and Y_2 are not equivalent to the static vehicle weight distribution.

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]

X_1 = percentage of brake torque provided by the front axle at GVWR with brake system fully operational

X_2 = percentage of brake torque provided by the front axle at LLVW with brake system fully operational

Y_1 = percentage of brake torque provided by the rear axle at GVWR with brake system fully operational

Y_2 = percentage of brake torque provided by the rear axle at LLVW with brake system fully operational

RR = tire dynamic rolling radius calculated per Equation 3.

NOTES:

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

b. Verify with the test requestor if for vehicles equipped with ABS or Electronic Brake Proportioning during sections with a deceleration level of 0.8 g or higher (typically above g-critical, which is the deceleration above which braking becomes unstable), the values of X_1, X_2, Y_1, and Y_2 are based on the dynamic weight transfer instead of brake torque split. Use for the calculation 0.9 g, which is the typical deceleration for key sections during the tests.

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

8. TEST PROCEDURES

8.1 Test service brakes per Table 2 – Service Brake Test Procedure for vehicles per FMVSS 135.

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.

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.

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 If the value of $p_{500N\ operational}$ is not available, use a pressure limit of 12 000 kPa for front brakes, or rear brakes on vehicles with electronic brake distribution. Use 7000 kPa for rear brakes on vehicles with fixed brake proportioning.

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

8.1.9 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.

8.1.10 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 - FMVSS 135

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) 3500 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
55	7.7 Stops with engine off at GVWR	Eq. 4 or 5	100	IBT = 100 °C	20 000	$p_{500N\ operational}$	0.90	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	100	IBT = 100 °C	20 000	$p_{500N\ operational}$	0.70 front-to-rear split	4
		Eq. 12 or 13 for diagonal split					0.45 diagonal split	
90.b	7.10 Hydraulic Circuit Failure at LLVW for rear brakes	Eq. 9 for front-to-rear split	100	IBT = 100 °C	20 000	$p_{500N\ operational}$	0.35 front-to-rear split	4
		Eq. 12 or 13 for diagonal split					0.45 diagonal split	
100.a	7.10 Hydraulic Circuit Failure at GVWR for front brakes	Eq. 8 for front-to-rear split	100	IBT = 100 °C	20 000	$p_{500N\ operational}$	0.60 front-to-rear split	4
		Eq. 10 or 11 for diagonal split					0.40 diagonal split	
100.b	7.10 Hydraulic Circuit Failure at GVWR for rear brakes	Eq. 8 for front-to-rear split	100	IBT = 100 °C	20 000	$p_{500N\ operational}$	0.40 front-to-rear split	4
		Eq. 10 or 11 for diagonal split					0.40 diagonal split	
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	—	—	—	—
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

TABLE 2 - SERVICE BRAKES TEST PROCEDURE - FMVSS 135 (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
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						

8.2   Test service brakes per Table 3 – Service Brake Test Procedure for vehicles per FMVSS 105 (Except school buses).

8.2.1   Use cooling air speed equal to 30 km/h at the brake for all sections except: 50 km/h for Section 40, Burnish.

8.2.2   The dynamometer shaft rotational speed during cooling between brake events equals 50% of the braking speed for the next brake application, except for Sections 150, 160, 170, 190, 200, 210, 280, and 290 where it shall be equal to the braking speed for the next brake application.

8.2.3   The dynamometer release speed is 3 km/h, except for Sections 280 and 290 which is a full stop to 0 km/h.

8.2.4   Section 10, Instrument Check Stops, if instrument repair, replacement, or adjustment is necessary, make not more than 10 additional stops.

8.2.5   Sections 70 and 250 applies only to vehicles with a maximum speed of 135 km/h or higher.

8.2.6   Section 100 applies only to vehicles with a GVWR of less than 3630 kg.

8.2.7   Section 140, Failed Power-Brake Unit, if the brake pressure at a pedal force of 667 N with the power assist fully depleted ($p_{667N\ depleted}$) is not available, perform stops as torque control with a deceleration level of 0.34 g. Other optional test sequences allowed by the FMVSS 105 are not included.

8.2.8   If the value of $p_{667N\ operational}$ is not available, use a pressure limit of 12 000 kPa for front brakes, or rear brakes on vehicles with electronic brake distribution. Use 7000 kPa for rear brakes on vehicles with fixed brake proportioning

8.2.9   Sections 90 and 95 are performed on rear brakes following the test sequence described in Appendix A.

8.2.10 For all brake applications the end of the stop or snub is defined as time t_4 per Figure 1.

8.2.11 If the initial brake temperature for the first stop in a test section (other than 7.7 – parking brake and 7.16 – water recovery test) has not been reached, heat the brakes to the initial brake temperature by making not more than 10 snubs from not more than 65 to 20 km/h, at a deceleration not greater than 0.31 g.

TABLE 3 - SERVICE BRAKES TEST PROCEDURE - FMVSS 105 (EXCEPT SCHOOL BUSES)

Section Number	FMVSS 105 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]	Deceleration Level [g]	# of Stops/ Snubs
10	7.2 Instrumentation Check at GVWR	Eq. 4 or 5	48	IBT = Ambient or less than 100 °C	20 000	$P_{667N\ operational}$	0.31	10
20	7.3 First Effectiveness Test (Preburnish) at GVWR 48 km/h	Eq. 4 or 5	48	IBT = 100 °C	20 000	$P_{667N\ operational}$	0.90	6
30	7.3 First Effectiveness Test (Preburnish) at GVWR 97 km/h	Eq. 4 or 5	97	IBT = 100 °C	20 000	$P_{667N\ operational}$	0.90	6
40	7.4 Burnish at GVWR	Eq. 4 or 5	64	IBT = 100 °C or 1.6 km cycle distance	20 000	$P_{667N\ operational}$	0.37	200
50	7.5 Second Effectiveness at GVWR 48 km/h	Eq. 4 or 5	48	IBT = 100 °C	20 000	$P_{667N\ operational}$	0.95	6
60	7.5 Second Effectiveness at GVWR 97 km/h	Eq. 4 or 5	97	IBT = 100 °C	20 000	$P_{667N\ operational}$	0.95	6
70	7.5 Second Effectiveness at GVWR 130 km/h	Eq. 4 or 5	130	IBT = 100 °C	20 000	$P_{667N\ operational}$	0.90	6
80	7.6 First Reburnish at GVWR	Eq. 4 or 5	64	IBT = 100 °C or 1.6 km cycle distance	20 000	$P_{667N\ operational}$	0.37	35
90	7.7 Parking Brake forward	—	Reserved for rear brakes; See appendix A					
95	7.7 Parking Brake reverse	—	Reserved for rear brakes; See appendix A					
100	7.8 Third Effectiveness at LLVW 97 km/h	Eq. 6 or 7	97	IBT = 100 °C	20 000	$P_{667N\ operational}$	0.95	6
110.a	7.9 Hydraulic Partial Failure at LLVW for front brakes	Eq. 9 for front-to-rear split	97	IBT = 100 °C	20 000	$P_{667N\ operational}$	0.70 front-to-rear split	4
		Eq. 12 or 13 for diagonal split					0.45 diagonal split	
110.b	7.9 Hydraulic Partial Failure at LLVW for Rear brakes	Eq. 9 for front-to-rear split	97	IBT = 100 °C	20 000	$P_{667N\ operational}$	0.40 front-to-rear split	4
		Eq. 12 or 13 for diagonal split					0.45 diagonal split	
120.a	7.9 Hydraulic Partial Failure at GVWR for front brakes	Eq. 8 for front-to-rear split	97	IBT = 100 °C	20 000	$P_{667N\ operational}$	0.60 front-to-rear split	4
		Eq. 10 or 11 for diagonal split					0.40 diagonal split	
120.b	7.9 Hydraulic Partial Failure at GVWR for Rear brakes	Eq. 8 for front-to-rear split	97	IBT = 100 °C	20 000	$P_{667N\ operational}$	0.40 front-to-rear split	4
		Eq. 10 or 11 for diagonal split					0.40 diagonal split	
130	7.9 Failed Antilock System at GVWR	Eq. 4 or 5	97	IBT = 100 °C	20 000	$P_{667N\ operational}$	0.75	4
140	7.10 Inoperative Brake Power or Power Assist Unit at GVWR	Eq. 4 or 5	97	IBT = 100 °C	20 000	$P_{667N\ depleted}$	—	4
150	7.11 First Fade and Recovery at GVWR – Baseline stops	Eq. 4 or 5	48	IBT = 100 °C	20 000	$P_{667N\ operational}$	0.31	6
160	7.11 First Fade and Recovery at GVWR – Fade stops	Eq. 4 or 5	97	IBT = 55 °C first, then cycle distance of 0.64 km	20 000	$P_{667N\ operational}$	0.47	10
170	7.11 First Fade and Recovery at GVWR – Recovery stops	Eq. 4 or 5	48	First 1.6 km after the end of section 160, then 60 seconds cycle time	20 000	$P_{667N\ operational}$	0.31	5
180	7.12 Second Reburnish at GVWR	Eq. 4 or 5	64	IBT = 100 °C or 1.6 km cycle distance	20 000	$P_{667N\ operational}$	0.37	35

TABLE 3 - SERVICE BRAKES TEST PROCEDURE - FMVSS 105 (EXCEPT SCHOOL BUSES) (CONTINUED)

Section Number	FMVSS 105 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]	Deceleration Level [g]	# of Stops/ Snubs
190	7.13 Second Fade and Recovery at GVWR – Baseline stops	Eq. 4 or 5	48	IBT = 100 °C	20 000	$P_{667N\ operational}$	0.31	6
200	7.13 Second Fade and Recovery at GVWR – Fade stops	Eq. 4 or 5	97	IBT = 55 °C first, then cycle distance of 0.64 km	20 000	$P_{667N\ operational}$	0.47	15
210	7.13 Second Fade and Recovery at GVWR – Recovery stops	Eq. 4 or 5	48	First 1.6 km after the end of section 160, then 60 seconds cycle time	20 000	$P_{667N\ operational}$	0.31	5
220	7.14 Third Reburnish at GVWR	Eq. 4 or 5	64	IBT = 100 °C or 1.6 km cycle distance	20 000	$P_{667N\ operational}$	0.37	35
230	7.15 Fourth Effectiveness at GVWR 48 km/h	Eq. 4 or 5	48	IBT = 100 °C	20 000	$P_{667N\ operational}$	0.95	6
240	7. 15 Fourth Effectiveness at GVWR 97 km/h	Eq. 4 or 5	97	IBT = 100 °C	20 000	$P_{667N\ operational}$	0.95	6
250	7. 15 Fourth Effectiveness at GVWR 130 km/h	Eq. 4 or 5	130	IBT = 100 °C	20 000	$P_{667N\ operational}$	0.95	6
260	7.16 Water Recovery at GVWR – Baseline check stops	Eq. 4 or 5	48	IBT = 100 °C	20 000	$P_{667N\ operational}$	0.31	3
270	7.16 Water Recovery at GVWR – Water spray	Eq. 4 or 5	8 for 2 minutes	IBT < 100 °C with no warm-up	20 000	—	—	1
280	7.16 Water Recovery at GVWR – Recovery stops	Eq. 4 or 5	48	First, immediately after end of section 270, then 20 seconds cycle time	20 000	$P_{667N\ operational}$	0.31	5
290	7.17 Spike Stops at GVWR	Eq. 4 or 5	48	IBT = 100 °C	P_{890N}/0.08 seconds	$P_{890N\ operational}$	0.95	10
300	7.17 Post Spike Stops Effectiveness at GVWR 97 km/h	Eq. 4 or 5	97	IBT = 100 °C	20 000	$P_{667N\ operational}$	0.95	6
310	7.18 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 the Burnish Section 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

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.

10. NOTES

10.1   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.

PREPARED BY THE SAE BRAKE DYNAMOMETER TEST CODE TASK FORCE
OF THE SAE BRAKE DYNAMOMETER STANDARDS COMMITTEE

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 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:
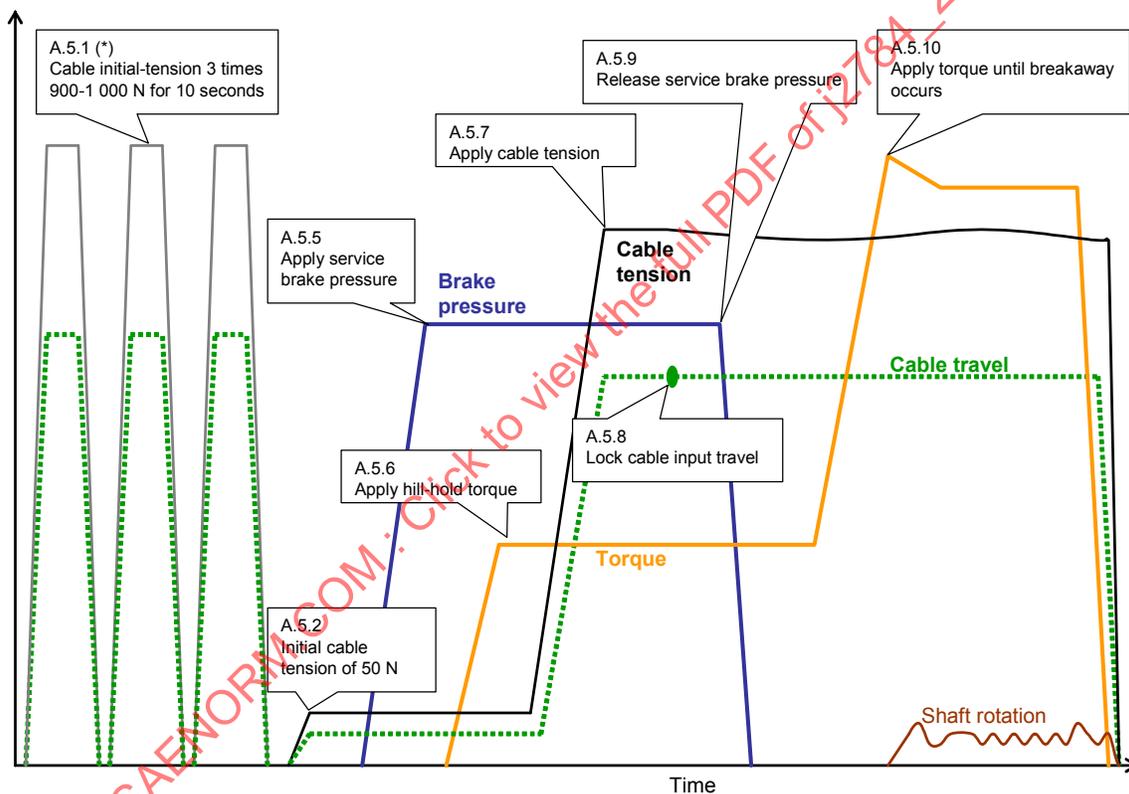
FIGURE A1 - TYPICAL STATIC PARKING BRAKE APPLICATION SEQUENCE

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.
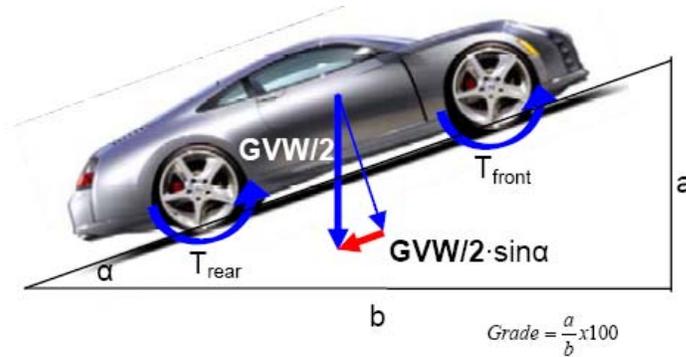
FIGURE A2 - HILL-HOLD ACTING FORCES AND TORQUES

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

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

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

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

where:

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

T = average by distance torque from last ten brake application from Table 2 Section 10 or from Table 3 Section 40. [N·m]

p = average by distance pressure from last ten brake application from Table 2 Section 10 or from Table 3 Section 40. [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.

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

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.

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

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.

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

where:

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

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.

NOTE: Other cable loads different from 250 N and 750 N are allowed if indicated by the requestor.

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.

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 vehicle tests limit 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 document, 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 FOR FMVSS 135

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.