Technical overview of brake performance testing for Original Equipment and Aftermarket industries in the US and European markets

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ABSTRACT

This paper presents an overview of the main test protocols used by the friction industry to assess performance. Brake performance primarily measures stopping distance, brake output torque, or effectiveness (also referred as friction level or BEF for drum brakes). The two main types of tests used to evaluate performance under different loading, speed, temperature and pedal force/brake pressure are vehicle-level and inertia-dynamometer testing. The paper presents the main test protocols along with key sections of the test report, typical test conditions, and test equipment used for: passenger cars, Sport Utility Vehicle —SUV, light duty trucks, and commercial vehicles. The main test procedures, publicly available, for this purpose are:

- Federal Motor Vehicle Safety Standards —FMVSS from the National Highway Traffic Safety Administration —NHTSA
- J Standards or Recommended Practices from the Society of Automotive Engineers —SAE
- International Standards from the International Organization for Standardization —ISO
- ECE Regulations from the United Nations Economic Commission for Europe —UNECE

Neither proprietary test procedures nor test protocols to assess other brake characteristics like wear, noise, judder, vibration, disc thickness variation—DTV, brake drag, corrosion-removal, lot-rot or unintentional drive-away are included.

The paper first discusses test procedures for passenger cars followed by commercial vehicle testing. The reader is encouraged to stay aware of updates, proposals, and amendments to any of the test protocols or regulations presented by logging on the different websites available.

INTRODUCTION

Brake performance depends upon the region and market it will address. Most of the current regulations address the same basic set of requirements to ensure a safe braking operation. Specific markets or regions use different approaches with different sets of test protocols.

Friction behavior evaluation and overall brake system performance testing determine to which extent a given brake corner —inertia-dynamometer test— or brake system —vehicle-level test— will meet certain criteria.

For vehicle-level testing, brake performance is a measurement of stopping distance or deceleration as a function of brake pedal force or air pressure when applicable. The test can measure the stopping distance or deceleration for a given brake pedal force or air pressure, or the brake pedal force or pressure required to attain a certain stopping distance or deceleration. For inertia-dynamometer testing, brake output torque or deceleration replaces stopping distance, and brake pressure replaces brake pedal force. Using the appropriate modeling for a given vehicle application, these values can be converted with good accuracy from vehicle-level to inertia-dynamometer or vice versa. Other conditions that determine the specific brake application include:

- Total vehicle weight
- Vehicle weight distribution on the different axles
- Braking speed
- Release speed
- Control parameter: brake pedal force, parking brake control force, brake pressure, output torque or deceleration
- Initial brake temperature
- Cycle-time between brake applications
- Brake history or condition during the brake application: green, post-burnish, pre-fade, hot, post-fade, and post-recovery.

VEHICLE CLASSIFICATION

Different vehicle categories have different applicable brake system requirements and regulations. The US has the Federal Highway Administration from the Department of Transportation for highway-related vehicle classification and the European Community has the ECE Consolidated Resolution on the Construction of Vehicles (R.E.3) TRANS/WP.29/78/Rev.1/Amend. 2. Other regions or countries based to some extent their own classifications on either of the two.

For brake-related performance testing, the National Highway Traffic Safety Administration —NHTSA— uses the following classification:

- Passenger cars and light duty trucks up to 3,500 kg GVW per FMVSS 135
- Passenger cars and light duty trucks above 3,500 kg and up to 4,540 kg of GVW per FMVSS 105
- Trucks and buses above 4,540 kg of GVW with hydraulic brakes per FMVSS 105
- Trucks and buses equipped with air brakes per FMVSS 121.

FHWA vehicle classes and definitions. See table 1.

NOTE: In reporting information on trucks, the following criteria are used:

a. Truck-tractor units traveling without a trailer are single-unit trucks.

b. A truck tractor unit pulling other such units in a "saddle mount" configuration is one single-unit truck counting only the axles on the pulling unit.

c. The number of axles in contact with the road defines the vehicles. Therefore, "liftable" axles count only when in the down position.

d. The term "trailer" includes both semi- and full trailers.

Table 1. US Department of Transportation. Federal Highway Administration Vehicle Classes (simplified)

FHWA Class and definition	Description
1. Motorcycles (Optional)	All two or three-wheeled motorized vehicles including motorcycles, motor scooters, mopeds, motor-powered bicycles, and three-wheel motorcycles.
2. Passenger Cars	All sedans, coupes, and station wagons manufactured primarily for the purpose of carrying passengers or passenger cars pulling recreational or other light trailers. — Passenger cars – mini (PC/Mi) (1,500-1,999 lbs. curb weight) — Passenger cars – light (PC/L) (2,000-2,499 lbs. curb weight) — Passenger cars – compact (PC/C) (2,500-2,999 lbs. curb weight) — Passenger cars – medium (PC/Me) (3,000-3,499 lbs. curb weight) — Passenger cars – heavy (PC/H) (3,500 lbs. and over. curb weight.) — Sport utility vehicles (SUV) — Pickup trucks (PU) — Vans (VAN)
3. Other Two-Axle, Four-Tire Single Unit Vehicles *Class 2 can include class 3.*	All two-axle, four-tire, vehicles, other than passenger cars Included in this classification are pickups, panels, vans, and other vehicles such as campers, motor homes, ambulances, hearses, carryalls, and minibuses. Other two-axle, four-tire single-unit vehicles pulling recreational or other light trailers are included in this classification.
4. Buses	All vehicles manufactured as traditional passenger-carrying buses with two axles and six tires or three or more axles including only traditional buses (including school buses) functioning as passenger-carrying vehicles. A modified bus is a truck with a different classification.
5. Two-Axle, Six-Tire, Single-Unit Trucks	All vehicles on a single frame including trucks, camping and recreational vehicles, motor homes, etc., with two axles and dual rear wheels.
6. Three-Axle Single-Unit Trucks	All vehicles on a single frame including trucks, camping and recreational vehicles, motor homes, etc., with three axles.
7. Four or More Axle Single-Unit Trucks	All trucks on a single frame with four or more axles.
8. Four or Fewer Axle Single-Trailer Trucks	All vehicles with four or fewer axles consisting of two units, one of which is a tractor or straight truck power unit.
9. Five-Axle Single-Trailer Trucks	All five-axle vehicles consisting of two units, one of which is a tractor or straight truck power unit.
10. Six or More Axle Single-Trailer Trucks	All vehicles with six or more axles consisting of two units, one of which is a tractor or straight truck power unit.
11. Five or fewer Axle Multi-Trailer Trucks	All vehicles with five or fewer axles consisting of three or more units, one of which is a tractor or straight truck power unit.
12. Six-Axle Multi-Trailer Trucks	All six-axle vehicles consisting of three or more units, one of which is a tractor or straight truck power unit.
13. Seven or More Axle Multi-Trailer Trucks	All vehicles with seven or more axles consisting of three or more units, one of which is a tractor or straight truck power unit.

ECE Consolidated Resolution on the Construction of Vehicles (R.E.3) TRANS/WP.29/78/Rev.1/Amend.2. Annex 7.	Used for ECE Reg.13 and Reg. 90 type-approval testing. See table 2

Table 2. ECE Classification and Definition of Power-driven Vehicles and Trailers (simplified)

ECE Classification and definition	**Description**
Category L: Motor vehicles with less than four wheels	
L_1	Two-wheeled vehicles with engine size less than 50 cm^3 and maximum speed less than 50 km/h
L_2	Three-wheeled vehicle with engine size less than 50 cm3 and maximum speed less than 50 km/h
L_3	Two-wheeled vehicles with engine size exceeding 50 cm^3 and maximum speed exceeding 50 km/h
L_4	Three-wheels asymmetrically arranged vehicles with engine size exceeding 50 cm^3 and maximum speed exceeding 50 km/h (motorcycles with sidecars)
L_5	Three-wheels asymmetrically arranged vehicles with engine size exceeding 50 cm^3 and maximum speed exceeding 50 km/h
Category M: Power-driven vehicles having at least four wheels and used for the carriage of passengers	
M_1	Passenger cars with no more than eight seats in addition to the driver's seat — AA Saloon including vehicles with more than four side windows — AB Hatchback: Saloon (AA) with a hatch at the rear end of the vehicle — AC Station Wagon –Estate car — AD Coupé — AE Convertible — AF Multi-purpose vehicle: other than those mentioned in AA to AC unless the number of seats, excluding the driver is not more than six and $P-(M+68 \cdot N) > 68 \cdot N$, where: P = technically permissible maximum laden mass in kg M = mass in running order in kg N = number of seating positions excluding the driver
M_2	Passenger cars having more than eight seats in addition to the driver's seat and a maximum mass not exceeding 5 tons. Can be classified further per Reg. 36 and 107 (Class I, II or III) or per Reg. 52 (Class A or B)
M_3	Passenger cars with more than eight seats in addition to the driver's seat and a maximum mass exceeding 5 tons. Can be classified further per Reg. 36 and 107 (Class I, II or III) or per Reg. 52 (Class A or B)
Category N: Power-driven vehicles having at least four wheels and used for the carriage of goods	
N_1	Goods transportation vehicles with a maximum mass not exceeding 3.5 tons
N_2	Goods transportation vehicles with a maximum mass exceeding 3.5 tons but not exceeding 10 tons
N_3	Goods transportation vehicles with a maximum mass exceeding 10 tons
Category O: Trailers (including semi-trailers) — ***Semi-trailer:*** towed vehicle with the axle(s) behind the center of gravity of the vehicle uniformly loaded. It is equipped with means to transmit forces to the towing vehicle. One of more axles can be driven — ***Full trailer:*** towed vehicle with at least two axles equipped with a towing device that moves vertically and controls the direction of he front axle(s), but does not transmit a significant static load to the towing vehicle. One of more axles can be driven — ***Center-axle trailer:*** towed vehicle equipped with a towing device that cannot move vertically. The axle(s) are located close to the center of gravity of the vehicle uniformly loaded. It transmits only a small amount of load to the towing vehicle, not exceeding 10% of the maximum mass of the trailer or 1,000 daN (whichever is less). One of more axles can be driven	
O_1	Trailers with a maximum mass not exceeding 0.75 tons
O_2	Trailers with a maximum mass exceeding 0.75 tons but not exceeding 3.5 tons
O_3	Trailers with a maximum mass exceeding 3.5 tons but not exceeding 10 tons
O_4	Trailers with a maximum mass exceeding 10 tons

Table 2 (continued). ECE Classification and Definition of Power-driven Vehicles and Trailers (simplified)

Remarks: a vehicle of category M, N or O can perform a special function with special body arrangement and/or special equipment as necessary for:

- SA Motor caravan (M_1) with seats, tables, sleeping accommodations, cooking and storage facilities rigidly fixed
- SB Armored vehicle for passenger or goods protection and complying with armor-plating for bullet-proof requirements
- SC Ambulance (M) for transport of sick or injured people equipped with special equipment for this purpose
- SD Hearse for the transport of deceased peoples equipped with special equipment for this purpose

Category T: Agricultural and forestry tractors

- power-driven vehicle, wheeled or with tracks
- at least two axles that provide the basic traction-power function
- typical functions include pull, push, carry or actuate certain implements, machines or trailers for agricultural or forestry

Category G: Off-road vehicles

- vehicle of category M_1 or N_1 with maximum mass not exceeding 2 tons
  - at least one front and one rear axle can be driven simultaneously
  - drive to one of the axles can be disengaged
  - differential locking or similar mechanism
  - ability to climb a 30 % gradient for a solo vehicle
  - ability to meet at least five of the following six requirements:
    - approach angle at least 25^o
    - departure angle of at least 20^o
    - ramp angle of at least 20^o
    - ground clearance under front axle of at least 180 mm
    - ground clearance under rear axle of at least 180 mm
    - ground clearance between the axles of at least 200 mm
- vehicle of category N_1 with maximum mass exceeding 2 tons or category N_2, M_2 or M_3 with maximum mass not exceeding 12 tons with at least one of the following:
  - all their wheels can be driven simultaneously where one of the axles can be disengaged
  - ability to meet the following three:
    - at least one front and one rear axle can be driven simultaneously and the drive to one of the axles can be disengaged
    - differential locking or similar mechanism
    - ability to climb a 30 % gradient for a solo vehicle
- vehicle of category N_3 or M_3 or with maximum mass exceeding 12 tons with at least one of the following:
  - wheels are designed to be driven simultaneously
  - drive to one of the axles can be disengaged
  - ability to meet the following:
    - at least half the wheels are driven
    - at least one differential locking or similar mechanism
    - ability to climb a 25 % gradient for a solo vehicle
    - ability to meet at least four of the following six requirements:
      - approach angle at least 25^o
      - departure angle of at least 25^o
      - ramp angle of at least 25^o
      - ground clearance under front axle of at least 250 mm
      - ground clearance under rear axle of at least 250 mm
      - ground clearance between the axles of at least 300 mm

TEST INTRUMENTATION

The key factors required for measuring and acquiring data during a vehicle-level or an inertia-dynamometer test are:

- channels measured and sensors used as a function of the test protocol, the vehicle or corner under testing and specific customer requirements
- physical room and connections required and available for each channel
- data storage, sampling rates and software available for data review and analysis
- full-scales required, resolution, accuracy, and combined uncertainty of measurement budget for each channel or sensor
- the environment, temperature, humidity and other conditions surrounding the test and the test site
- availability of spare sensors
- water soaking/splash during the test
- devices required to simulate particular failure modes or isolate certain sections of the brake system

Channels or sensors used for testing

The following are main channels or sensors used during brake performance testing at vehicle-level or inertia-dynamometer testing. Note that not all tests require all the sensors listed. See table 3

Table 3. Typical channels and sensors

Vehicle-level test	Inertia-dynamometer test
Time elapsed during the brake application	
Wheel torque at each axle (optional)	Shaft torque or reaction torque
Linear speed	Shaft rotational speed
Brake line pressure, usually in the least favorable actuator or optional on all wheels	Brake line pressure
Control force for service brake — pedal-force	—
Control force for parking brake— pedal or hand-force	Parking brake cable load
Control force for secondary braking if different from service/parking	—
Control force actuator travel for service brake (optional)	Brake fluid displacement (optional)
Control force actuator travel for parking brake (optional)	Parking brake cable travel (optional)
Deceleration (optional)	Deceleration per Indirect measurement as a function of speed or torque versus time
Stopping distance (optional)	Revolutions during brake application
Brake temperatures. Typical the friction materials as the non-rotating element	Brake temperatures: rotor and/or friction material
Wheel lock (optional)	—
Steering wheel angle (optional for vehicle with category 1 ABS)	—
Steering wheel torque (optional)	—
Vacuum level (not for air braked vehicles)	—
Ambient temperature	Ambient temperature

TEST PROCEDURES

The test procedure outlines the following parameters for each section during the test: Number of stops/snubs, braking-release speed, control level, initial brake temperature for the brake application or cycle time/distance between brake applications, and performance requirements when applicable.

- **Section:** a group of brake applications that have test conditions in common. *Brake performance requirements are always related to a specific section or for a given brake application inside the section*
- **Stop:** brake application with a nominal release speed of 0
- **Snub:** brake application with a nominal release speed > 0
- **Control:** modulation used during the brake application (deceleration, control-force, brake pressure, brake torque)
- **Initial brake temperature**: the temperature required at the brake (rotor/drum or friction material) before the application of the control-force or brake pressure. Some specifications indicate the initial brake temperature at a certain distance or time before the actual brake application occurs
- **Cycle time:** time elapsed between the start of two consecutive brake applications. It can be the time between the end of one brake application and the start of the next.
- **Performance requirements:** minimum performance level expected for some or all of the brake applications during a certain section of the test. Not all sections have performance criteria.

VEHICLE-LEVEL TESTS FOR PASSENGER CARS WITH HYDRAULIC OR AIR BRAKES

49 CFR Chapter V. 571.135 FMVSS Standard 135. Passenger car brake system

Scope and purpose

The FMVSS 135 is a vehicle-level test that specifies the requirements for the hydraulic service and parking brake systems to ensure stable braking performance during normal and emergency driving conditions. The FMVSS 135 is a self-certification test that all vehicle manufacturers conduct on a regular basis before vehicle release to the market.

Applicability

- passenger cars manufactured after September 1, 2000
- multi-purpose passenger vehicles, truck and buses with a Gross Vehicle Weight Rating —GVWR of 3,500 kg or less, manufactured after September 1, 2002

Figure 1 shows a SUV instrumented with torque-wheels for FMVSS 135 vehicle testing.

Figure 1. Vehicle instrumented for FMVSS 135

Test procedure

Table 4 summarizes the standard test sequence for an FMVSS 135 vehicle test.

Table 4. FMVSS 135 simplified test procedure

Section	Number of stops/snubs	Brake-release speed –km/h	Control	Initial brake temperature-°C/ Cycle time	Performance requirement
Burnish at GVW	200 stops	80-0	3 m/s^2	<100 °C or 2 km	-
Wheel lock sequence at LLVW/GVW 50 km/h	3 to 6 stops	50-0	pedal-force ramp up to 1,000 N or lock-up in 0.5-1.5 sec	<100 °C	Wheel lock-up 0.5-1.5 sec from 0.15-0.8 adhesion
Wheel lock sequence at LLVW/GVW 100 km/h	3 to 6 stops	100-0	pedal-force ramp up to 1,000 N or lock-up in 0.5-1.5 sec	<100 °C	Wheel lock-up 0.5-1.5 sec from 0.15-0.8 adhesion
Adhesion utilization (torque-wheel method) at LLVW/GVW	10 stops	100-0 and 50-0	pedal-force ramp 100-200 N/s until lock-up or 1,000 N	<100 °C	No rear lock-up first 0.15-0.8 g
Cold effectiveness at GVW	6 stops	100-0	65-500 N pedal-force	65-100 °C	70 m
High speed effectiveness at GVW	6 stops	80% of Vmax but not > 160	65-500 N pedal-force	65-100 °C	153 m
Stops with engine off at GVW	6 stops	100-0	65-500 N pedal-force	65-100 °C	70 m
Cold effectiveness at LLVW	6 stops	100-0	65-500 N pedal-force	65-100 °C	70 m
High speed effectiveness at LLVW	6 stops	80% of Vmax but not > 160	65-500 N pedal-force	65-100 °C	153 m
Failed antilock at LLVW	6 stops	100-0	65-500 N pedal-force	65-100 °C	85 m
Failed proportioning valve at LLVW	6 stops	100-0	65-500 N pedal-force	65-100 °C	110 m
Hydraulic circuit failure at LLVW	4 stops	100-0	65-500 N pedal-force	65-100 °C	168 m
Hydraulic circuit failure at GVW	4 stops	100-0	65-500 N pedal-force	65-100 °C	168 m
Failed antilock at GVW	6 stops	100-0	65-500 N pedal-force	65-100 °C	85 m
Failed proportioning valve at GVW	6 stops	100-0	65-500 N pedal-force	65-100 °C	110 m
Power brake unit failure at GVW	6 stops	100-0	65-500 N pedal-force	65-100 °C	168 m
Parking brake at GVW	Up to 2 uphill and 2 downhill	0	500 N pedal-force or 400 N hand-force	65-100 °C	Hold vehicle stationary > 5 min
Fade heating snubs at GVW	15 snubs	120-60 typical	3 m/s^2	55-65 °C for first then 45 sec	
Hot performance at GVW	2 stops	100-0	#1 pedal-force shortest cold effectiveness #2 500 N pedal-force	#1 immediately #2 1.5 km after #1	Stop #1: deceleration 60% of shortest cold effectiveness Stop #1 or 2: 89 m
Cooling stops at GVW	4 stops	50-0	3 m/s^2	1.5 km after previous stops	-
Recovery at GVW	2 stops	100-0	pedal-force shortest cold effectiveness	1.5 km after previous stops	deceleration 70-150% of shortest cold effectiveness
Final inspection	Check corner assembly, brake system and indicators				Comply with S.1.17

Note: V_{max} is the maximum attainable speed within 3.2 km from 0 km/h initial speed at maximum acceleration rate and LLVW

FMVSS 135 Sample test data and plots from report

Figures 2 through 6 illustrate summary results for the key sections of a vehicle-level test following the FMVS 135-test protocol.

FMVSS135 Section	Federal Requirement	Performance Attained	**Percentage of Pass** (less than zero indicates failure)
Sec. 7.5 Cold Effects at GVW	70 m	56 m	20%
Sec. 7.5 Cold Effects at LLVW	70 m	50 m	29%
Sec. 7.6 High Speed Effect at GVW	153 m	103 m	33%
Sec. 7.6 High Speed Effect at LLVW	153 m	99 m	35%
Sec. 7.7 Stops with Engine Off	70 m	55 m	22%
Sec. 7.8 Failed Antilock at GVW	85 m	53 m	38%
Sec. 7.8 Failed Antilock at LLVW	85 m	54 m	37%
Sec. 7.10 Fronts Only at LLVW	168 m	98 m	42%
Sec. 7.10 Rears Only at LLVW	168 m	98 m	42%
Sec. 7.10 Fronts Only at GVW	168 m	103 m	39%
Sec. 7.10 Rears Only at GVW	168 m	107 m	37%
Sec. 7.11 Inoperative Booster	168 m	185 m	-10%
Sec. 7.13 Parking Brake Hill Hold--Uphill	5 Minutes @ 500 N	Did not hold	N/A
Sec. 7.13 Parking Brake Hill Hold--Downhill	5 Minutes @ 500 N	Did not hold	N/A
Sec. 7.14 Hot Performance (req. #1)	87 m	55 m	36%
Sec. 7.14 Hot Performance (req. #2)	89 m	55 m	38%
Sec. 7.16 Recovery Performance	76 m	51 m	33%

Figure 2. Summary table for FMVSS 135 vehicle-test results

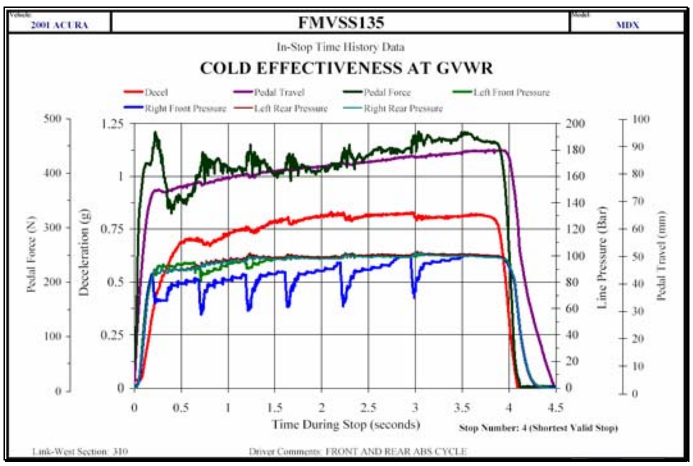


Figure 3. Cold effectiveness at GVW

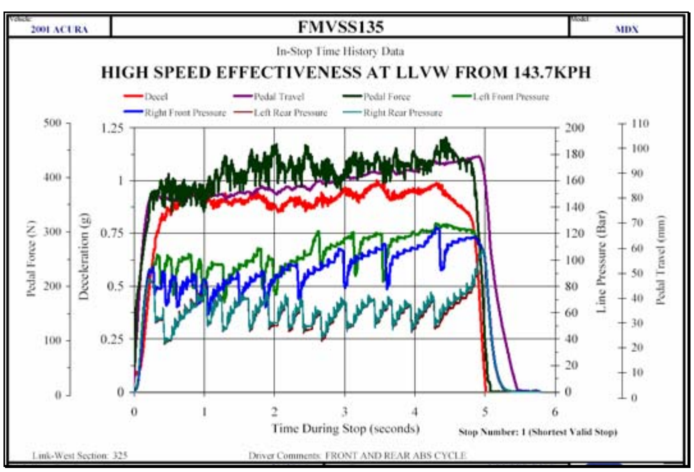


Figure 4. High-speed effectiveness at GVW

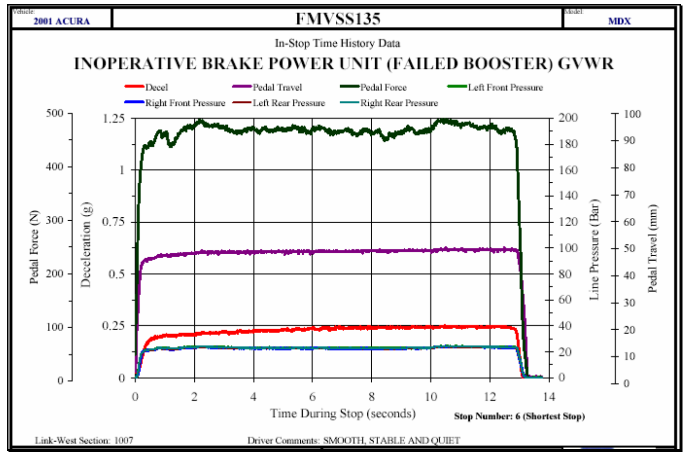


Figure 5. Inoperative brake power at GVW

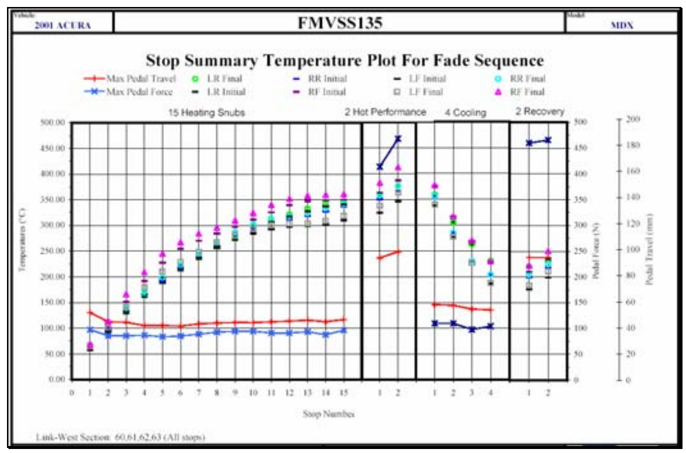


Figure 6. Fade snubs, hot performance and brake recovery AT GVW

49 CFR Chapter V. 571.105 FMVSS Standard 105. Hydraulic and electric brake systems

Scope and purpose

The FMVSS 105 is a vehicle-level test that specifies the requirements for the service and parking brake systems to ensure stable braking performance during normal and emergency driving conditions. Like the FMVSS 135, the FMVSS 105 is a self-certification test that all vehicle manufacturers conduct on a regular basis before vehicle release to the market.

Applicability

- hydraulically-braked vehicles with GVWR greater than 3,500 kg

Test procedure

Table 5 summarizes the standard FMVSS 105 test sequence for vehicles with a GVWR larger than 4,540 kg. The actual sequence to follow will vary depending upon:

- if GVW is less, at, or above 4,540 kg of GVWR
- type of application (school bus or dump-truck)

- specific customer needs that normally requires slight modification of the test sequence or the addition/deletion of some sections
- type of brakes, electric or hydraulic
- after the actual FMVSS 105 sequence, there can be sections to evaluate a particular feature of the brake system or component.

Table 5. FMVSS 105 simplified test procedure for GVWR > 4,540 kg

Section	Number of stops /snubs	Brake-release speed- km/h	Control	Initial brake temperature -°C/ Cycle time	Performance requirement
Service brake system- GVW burnish procedure	500	64-32	0.31g	2.41 km	-
Service brake system- GVW effectiveness test 48 km/h	6	48-0	6 stops equally spaced from 67 N to 667 N	65-95	23.8 m Note 3
Service brake system- GVW effectiveness test 96 km/h	6	96-0	6 stops equally spaced from 67 N to 667 N	65-95	94.5 m
First reburnish -GVW	35	64-32	0.31g	<285 or 2.41 km	-
Service brake system-LLVW (third effectiveness) test 96 km/h	6	96-0	6 stops equally spaced from 67 N to 667 N	65-95	102.1 m
Service brake system-partial system failure-LLVW	4 failed fronts 4 failed rears	96-0	667 N with leakage or failure	65-95	186.8 m
Parking brake test -LLVW	1 forward 1 reverse	0	Drive up 20% grade. Apply 667N service brake. Apply 667 N for foot- operated or 556 N for hand-operated. Release service brake and hold for 5 min	65	Hold vehicle stationary > 5 min Note 3
Parking brake test -GVW	1 forward 1 reverse	0	Drive up 20% grade. Apply 667N service brake. Apply 667 N for foot- operated or 556 N for hand-operated. Release service brake and hold for 5 min	65	Hold vehicle stationary > 5 min Note 3
Service brake system-partial system failure-GVW	4 failed fronts 4 failed rears	96-0	667 N with leakage or failure	65-95	186.8 m
Service brake system- inoperative power unit assist unit test-GVW	4	96-0	667 N with power-assist fully depleted	65-95	186.8 m
Service brake system- failed ABS-GVW	4	96-0	667 N with power-assist fully depleted	65-95	186.8 m
Baseline check snubs (school buses only)	3	64-32	0.31g	65-95	control force 45-400 N
Fade snubs	10	64-32	0.31g	55-65 first snub then 30 sec	control force 45-400 N Note 3
Recovery snubs	5	64-32	0.31g	For first snub, 135 sec after end of last fade snub	Note 1 Note 3
Service brake system-second reburnish	35	64-32	0.31g	<285 or 2.41 km	- Note 3
Baseline check snubs	3	64-32	0.31g	65-95	- Note 3
Fade snubs	20	64-32	0.31g	55-65 first snub then 30 sec	control force 45-400 N Note 3
Service brake system-third reburnish	35	64-32	0.31g	<285 or 2.41 km	- Note 3
Baseline check stops	3	48-5	0.31g	65	- Note 3
Water soaking	1	8-8	Brake fully released	65	Soak for 2 min. Note 3
Wet brake recovery stops	5	48-0	0.31g	As fast as possible after soaking	Note 2 Note 3

Note 1: maximum control force: 667N for first four. 269 N above the average from baseline check snubs without exceeding 493 N total for the fifth snub. Minimum control force: the lowest from 45 N below the average from the baseline check snubs, or 60% of average from baseline check snubs, or 22N

Note 2: maximum control force: 667 N for first four. 90 N above the average from baseline check snubs without exceeding 445N total for the fifth snub. Minimum control force: the lowest from 45 N below the average from the baseline check snubs, or 60% of average from baseline check snubs, or 22 N

Note 3: apply only to school buses

FMVSS 105-sample test report summary page

Figure 7 illustrates a commercial step-truck for testing.

Figure 7. Delivery truck with GVWR of 8,800 kg for FMVSS 105

An FMVSS 105 test reports typically includes:

- test results summary
- test vehicle description
- description of actual test sequence
- tabular and graphical results versus FMVSS 105 limits

Figure 8 shows an example of test sequence used for the step-truck from figure 7. Figures 9 and 10 provide examples of test results.

- Instrument vehicle & load to GVWR
- Burnish w/ 500 snubs
- Roller brake test
- Six 60 mph stops w/ full service brakes
- 35 snub reburnish
- Unload vehicle
- Six 60 mph stops w/ full service brakes
- Four 60 mph stops – failed fronts
- Four 60 mph stops – failed rears
- Wet Jennite Curve
  -Determine Max. Drive-Through Speed
  -Four Stops at 75% Drive-Through Speed
  -Stops to Determine Max. Braking Speed
- 20% grade hold both directions empty
- Load vehicle to GVWR
- 20% grade hold both directions loaded
- Failure indicator lamp check
- Four 60 mph stops on dry pavement – failed fronts
- Four 60 mph stops on dry pavement – failed rears
- Four 60 mph stops on dry pavement – failed power assist
- Four 60 mph stops on dry pavement – failed ABS
- Unload vehicle
- Final Tear down & Inspection

Figure 8. Test sequence used for a step-truck per FMVSS 105

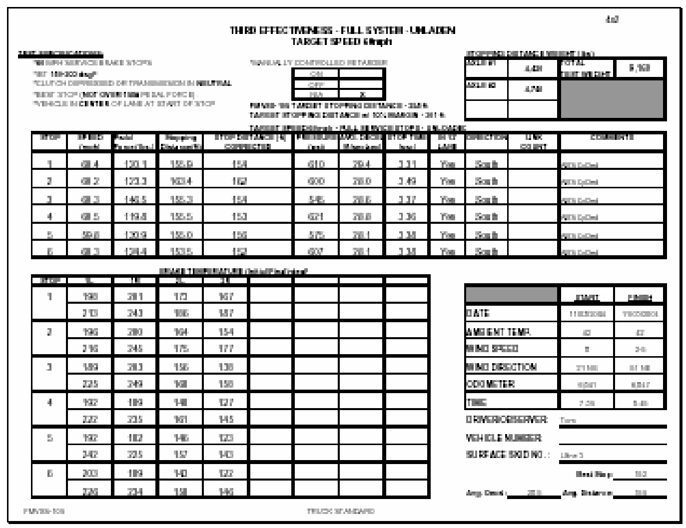
Table 3 - Summary of Results - FMVSS 105 Tests

Chassis #: ________ Model: Step Van Test #: ________
Body #: ________

Test	Load	Parameter	Actual Perf.	FMVSS 105 Req.
60 mph-Service Brakes	GVWR	Best of 6 S.D., ft	179	310
		Avg. S.D., ft	190	NA
60 mph-Service Brakes	Empty	Best of 6 S.D., ft	152	335
		Avg. S.D., ft	155	NA
60 mph-Failed Front Brakes	Empty	Best of 4 S.D., ft	353	613
		Avg. S.D., ft	359	NA
60 mph-Failed Rear Brakes	Empty	Best of 4 S.D., ft	261	613
		Avg. S.D., ft	270	NA
60 mph-Failed Front Brakes	GVWR	Best of 4 S.D., ft	321	613
		Avg. S.D., ft	330	NA
60 mph-Failed Rear Brakes	GVWR	Best of 4 S.D., ft	394	613
		Avg. S.D., ft	400	NA
60 mph-Failed Power Assist	GVWR	Best of 4 S.D., ft	234	613
		Avg. S.D., ft	239	NA
60 mph-Failed ABS	GVWR	Best of 4 S.D., ft	230	613
		Avg. S.D., ft	256	NA
Stability and Control	Empty	Max Drive Through, mph	31	NA
		Max Brake Speed, mph	31	23
Failure Warning Activation	N/A	max PF, lb	19	25

Note: Stopping Distances shown are corrected to 60 mph using SAE J299

Figure 9. Summary test results versus FMVSS 105 limits



THIRD EFFECTIVENESS - FULL SYSTEM - UNLADEN
TARGET SPEED 60mph

AXLE #1	4,420	TOTAL TEST WEIGHT	9,160
AXLE #2	4,740		

STOP	SPEED (mph)	[illegible]	[illegible]	STOP DISTANCE (ft) CORRECTED	[illegible]	[illegible]	STOP TIME (sec)	[illegible]	DIRECTION	LINK COUNT	COMMENTS
1	60.4	120.1	155.9	154	610	29.4	3.31	Yes	South		[illegible]
2	60.2	123.3	163.4	162	600	28.0	3.49	Yes	South		[illegible]
3	60.3	146.5	155.3	154	545	28.6	3.37	Yes	South		[illegible]
4	60.5	119.8	155.5	153	621	28.8	3.36	Yes	South		[illegible]
5	59.8	120.9	155.0	156	575	28.1	3.38	Yes	South		[illegible]
6	60.3	128.4	153.5	152	607	28.1	3.38	Yes	South		[illegible]

BRAKE TEMPERATURE

STOP	1L	1R	2L	2R				
1	198	281	173	167				
	213	243	186	187				
2	196	280	164	154				
	216	245	175	177				
3	189	283	156	138				
	225	249	168	158				
4	192	189	148	127				
	222	235	161	145				
5	192	182	146	123				
	242	225	157	143				
6	203	189	140	122				
	226	234	158	146				

	START	FINISH
DATE	[illegible]	[illegible]
AMBIENT TEMP.	[illegible]	[illegible]
WIND SPEED	[illegible]	[illegible]
WIND DIRECTION	[illegible]	[illegible]
ODOMETER	[illegible]	[illegible]
TIME	[illegible]	[illegible]

DRIVER/OBSERVER:
VEHICLE NUMBER:
SURFACE SKID NO.:

FMVSS-105 TRUCK STANDARD

Figure 10. Third effectiveness at LLVW

UNITED NATIONS AGREEMENT Addendum 12: Regulation 13 Revision 5: UNIFORM PROVISIONS CONCERNING THE APPROVAL OF VEHICLES OF CATEGORIES M, N AND O WITH REGARD TO BRAKING

The Regulation 13 from the UNECE, commonly referred to as the ECE R13, is the current mechanism to obtain the type approval or authorization to drive a new vehicle on public roads in countries of the European Community. Varying interpretations of the ECE R13 can cause disagreements on the validity or applicability of the test results obtained.

Since the performance requirements and the prescribed tests are category-specific, a thorough and appropriate understanding of the regulation is critical for a successful type-approval exercise. This is also applicable to companies seeking ECE R90 type-approval since depending upon the vehicle category, vehicle-level testing is mandatory to demonstrate compliance with the minimum requirements of the ECE R13. This regulation is slightly different from the ECE R13H that applies specifically to vehicles category M_1. Currently an informal working group for further harmonization between the ECE R13H and the FMVSS 135 is underway.

Scope and purpose

ECE R13 applies to the braking performance of power-driven vehicles of categories M, N, and O or trailers individually. The ECE R13 does not allow asbestos-based friction materials. The ECE R13 does not cover:

- vehicles with design speed less than 25 km/h
- trailers that can not be coupled to vehicles with design speed above 25 km/h
- vehicles fitted for handicapped or invalid people

Applicability

Due to the dynamic nature of this series of regulations, the applicability, specific test procedures to use, and performance requirements will depend on the current regulation at the time of the application for the type-approval. The ECE R13 and the ECE R90 have revisions or amendments at least once per year.

Besides the vehicle-level testing, inertia-dynamometer, roller-tester, and sample testing for compressibility and shear strength are part of the Regulation and the type-approval process. Any company pursuing a type-approval also needs to establish a formal and ongoing Conformity of Production program. Regular audits, at least every two years, as also part of the regulation and the type-approval process. Contrary to the self-regulation structure of the US, the type-approval (ECE R13 and R90) process is mandatory in the European Community.

Test procedure

Table 6 summarizes the basic elements related to test sequence, test conditions, and minimum requirements for all vehicle categories included on the ECE R13. It shows all the different categories in one table to allow easy comparisons and summary. Some of the sections apply to the vehicle-level testing during ECE R90 type-approval for replacement linings.

Table 6 does not include all the applicable requirements and does not specifically cover ABS, inertia-overrun-brakes or electric vehicle braking requirements.

Since the ECE R13 does not prescribe a fixed burnish cycle, test duration and brake performance can vary significantly. A prior discussion with the technical service conducting the test will determine the appropriate burnish cycle.

The Regulation includes provisions concerning the approval of other brake components like air actuators, spring brakes, and inertia-overrun brakes among others.

ISO 6297:2002 describes a suggested test sequence for vehicles with hydraulic brakes on Categories M and N like the one illustrated on figure 11.

ISO 11157:1999 specifies an inertia-dynamometer test to homologate alternative brake linings and brake pads mounted on original equipment for vehicles categories M, N, and O, in accordance to the ECE R13 Annex 15. The test compares the results of 5 current OE friction sets versus 5 sets of the proposed alternative.

Figure 11. Category M_3 vehicle during roller brake test

The ECE R13 and ECE R90 allow the use of inertia-dynamometer testing to perform some sections or the entire test depending upon the vehicle category or the type of test. Figure 12 shows a diagram for a inertia-dynamometer to test commercial vehicle brakes or components.

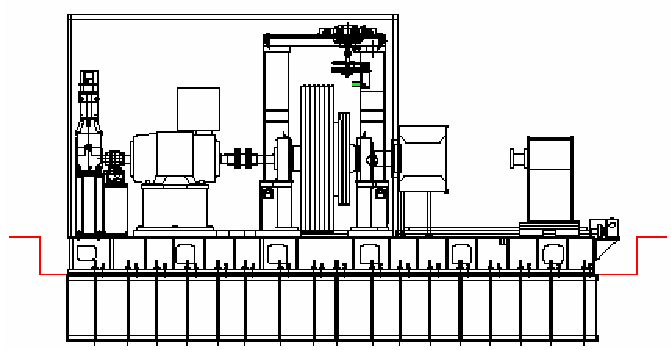


Figure 12. Inertia-dynamometer for commercial vehicle brakes testing

Other types of tests included on the ECE R13 are component type-approval for air brake systems including brake actuators and spring brakes used for parking brake or emergency braking operation. The calculation of brake characteristics regarding hold-off values and parking brake-holding ability uses results from tests conducted on laboratory benches specifically designed and configured for this purpose.

Inertia-overrun brakes characterization also utilizes specialized test equipment capable of measuring different system travel while imposing inertia and tongue loading to the brake.

Table 6. *Addendum 12: Regulation 13 Revision 5: Uniform provisions concerning the approval of vehicles of categories M, N and O with regard to braking*

ECE REGULATION No. 13										
Test sequence and performance requirements **Vehicle Category**	**Passenger cars and buses**			**Cargo vans and trucks**			**Trailers and semi-trailers**			
	M_1	**M_2**	**M_3**	**N_1**	**N_2**	**N_3**	**O_1**	**O_2**	**O_3**	**O_4**
Notation: GVW= fully laden LLVW= unladen — No. of passengers (driver not included)	≤ 8	> 8	> 8							
Maximum vehicle weight (tons)	≤ 5	≤ 5	> 5	≤ 3.5	>3.5 ≤10	> 10	< 0.75	>0.75 ≤ 3.5	> 3.5 ≤ 10	> 10
Service brake	Acting on all wheels, properly distributed and symmetrical across the vehicle, unless special controls exist. Braking distribution per Annex 10									
1. Type – O Test in Neutral. Prescribed Speed km/h	80	60	60	80	60	60	Service brake is optional	60 Brake force ≥ 50% of Trailer max. axle wt. (45% for semi-trailers) using ≤ 6.5 bar		
Stopping Distance m ≤ Cold Brakes GVW & LLVW	0.1v + v^2/150	0.1v + v^2/150								
MFDD m/sec^2 ≥	5.8	5.0								
Pedal Effort daN ≤	50	70					Overrun brakes permitted for O_1 & O_2 only			
2. Type – O Test in Gear Cold Brakes GVW & LLVW	Effectiveness tests from various speeds (30% to 80% of v max) Check vehicle behavior									
3. Type – O Test in Gear Prescribed Speed = 80% v max, but km/h ≤	160	100	90	120	100	90				
Stopping Distance m ≤ Cold Brakes GVW & LLVW	0.1v + v^2/130	0.1v + v^2/103.5								
MFDD m/sec^2 ≥	5.0	4.0								
Pedal Effort daN ≤	50	70								
4. Type – 1 Test by repeated braking V_1 = 80% Vmax but km/h ≤ $V_2 = 0.5V_1$	120	100	60	120	60	60				
In gear Time Interval secs	45	55	60	55	60	60				
GVW Number of cycles	15	15	20	15	20	20				
Note First snub at 3.0 m/s^2 deceleration; remaining snubs at same pedal force.										
5. Type – 1 Test by continuous braking GVW (For Category O_4 Trailers see 7A – Type III Tests)								Drag test at 40km/h for 1.7 km on 7% slope		
6. Hot Effectiveness after Type – 1 Tests Hot Brakes GVW Prescribed speed and pedal effort – as Test 1:	Performance to be ≥ 80% of Type O test requirement and ≥ 60% of type O achievement.							40 km/h		60km/h
								Braking Force		
								36%		40%
								of trailer max. axle wt. and ≥ 60% of Type O achievement		
7. Type – II Test - for long descents In gear GVW For M_3 and N_3 vehicles only	Drag test at 30 km/h for 6km on 6% slope (or 0.5 m/s^2 by engine alone)									
7A. Type – III Test for O_4 Trailers only GVW	20 Snubs from 60 km/h on 60 second cycle at fixed pedal input giving 3.0 m/s^2 on first application									
7B. Type – IIA (BIS) Test for 'Retarders' In gear For M_3 long distance buses, N_3 trucks GVW to tow O_4 trailers, ADR vehicles	Drag test at 30 km/h for 6km on 7% slope (or 0.6m/s^2 by engine alone) – without using service, emergency or parking brake									

Table 6. (continued) Addendum 12: Regulation 13 Revision 5: Uniform provisions concerning the approval of vehicles of categories M, N and O with regard to braking

ECE REGULATION No. 13										
Test sequence and performance requirements Vehicle Category	Passenger cars and buses			Cargo vans and trucks			Trailers and semi-trailers			
	M_1	M_2	M_3	N_1	N_2	N_3	O_1	O_2	O_3	O_4
8. Hot Effectiveness . after Type – II Tests Prescribed Speed km/h and pedal effort – as Test 1 Hot Brakes GVW Stopping Distance m ≤ MFDD m/sec^2 ≥			60 $0.15+1.33v^2/130$ 3.75			60 $0.15v+1.33v^2/115$ 3.3				
Secondary Brake (EB) **(Service Brake circuit failure)**	May be operated by Service or other Brake control. Must provide “graduated” braking – ‘indefinitely’.									
9. Type – O Test in neutral Initial Speed km/h Stopping Distance m ≤ Cold Brakes MFDD m/sec^2 ≥ GVW & LLVW Pedal Effort daN ≤ Hand-Lever Effort daN ≤ N.B. Same performance required for Power-assistant failure (GVW only) and LSV control failure N.B. EB (and divided-circuits) of tractors for O_3 & O_4 trailers must also provide graduated trailer braking	80 $0.1v+v^2/75$ 2.9 50 40	60 $0.15v+v^2/65$ 2.5 70 60		70	50 $0.15v+2v^2/115$ 2.2 70 60	40				≥ 30% of Type O requirement
Parking Brake (PB)	Control must be independent from Service Brake Control. Must be held “on” mechanically.						Must be operable from outside – In addition, from within on P.S.V.			
10. Hill – Holding Test Up & Down gradient % Cold Brakes Hand-Lever Effort daN ≤ GVW & LLVW Pedal Effort daN ≤ Note: Parking Brake of towing vehicles must also hold combinations on 12% gradient	18 40 50	18 60 70		18 60 70			Parking Brake is optional .	18 60 With Trailer Coupled and Uncoupled		
11. Dynamic Test – Type O Test in neutral Initial Speed km/h MFDD m/sec^2 ≥ Cold Brakes Deceleration on halting m/sec^2 ≥ GVW Pedal Effort daN ≤ Hand-Lever Effort daN ≤ N.B. one stop only	30 1.5 1.5 50 40	30 1.5 1.5 70 60		30 1.5 1.5 70 60	30 1.5 1.5 70 60	30 1.5 1.5 70 60				
Residual Brake (RB) **(Circuit failure or Power-assist failure)**	Operated by Service Brake Control. Must provide “graduated” braking (‘indefinitely’ according to ECE/R.13).									
12. Type - O Test in neutral Prescribed speed km/h Cold Brakes MFDD (m/sec^2) ≥ GVW & LLVW with ≤ 70 daN Pedal Effort LLVW ≥ Stopping Distance (GVW) m≤ Stopping Distance (LLVW) m≤	80 1.7 1.5 $0.1v+3.33v^2/150$ $0.1v+4v^2/150$	60 1.5 1.3 $15v+3.33v^2/130$ $0.15v+4v^2/130$	60 1.5 1.5 $0.15v^2+33v^2/130$	70 1.3 1.1 $0.15v+3.33(v^2/115)$ $0.15v+4v^2/115$	50 1.3 1.1 $0.15v+4v^2/115$	40 1.3 1.3 $0.15v+3.33v^2/115$				
Automatic Brake (AB) (Total pressure loss in air supply line)							40 km/h Brake force ≥ 13.5% of Trailer maximum axle weight.			

ECE R13 partial type-approval for axles on trailers Category O_4

Appendix 19 from the Regulation indicates the use of an inertia-dynamometer for partial type approval testing for trailer axles Category O_4. Figures 13 and 14 illustrate two sections of the test report for this application. Parking brake grade holding performance is a calculation, not a measurement. ECE R13 testing also uses portable roller-type testers. It is a portable unit and it is equipped with an automatic data collection system configured specifically for ECE R13 testing. Other parameters measured are:

- rolling resistance (post hot-performance)
- brake balance
- parking brake force (secondary braking system)
- ABS operation

Figure 15 shows a typical performance inertia-dynamometer capable of performing different types of tests required per ECE R13, ECE R90, inertia-simulation of FMVSS 135, 105 and a series of other performance tests procedures like SAE J2522, SAE J2430, SAE J2681 (Draft), ISO 11157.

2.1. In case of vehicles category O_4						
Test type:		**0**	**III**		**Emergency Brake**
Annex 11, Appendix 2 Paragraph:		3.5.1.2	3.5.3.1	3.5.3.2	
Test speed initial	km/h	60	60	60	40
final	km/h	0	30	0	0
Brake actuator pressure P_E	bar	5.02	2.87	5.02	-
Number of brake applications	-	-	20	-	3
Duration of braking cycle	s	-	60	-	4.44
Brake force developed T_e	daN	2573	1365	2068	1042
Brake Efficiency T_e/P_e	-	0.57	0.30	0.46	0.24
Actuator stroke s_e	mm	28.6	-	0.0	27.07
Brake Input Torque	Nm	1480	-	1480	7580
Co Measurement		7.476	N*m		
Brake factor BF:		8.3 - 9.55			

Figure 13. Partial type-approval for category O_4 trailer axle

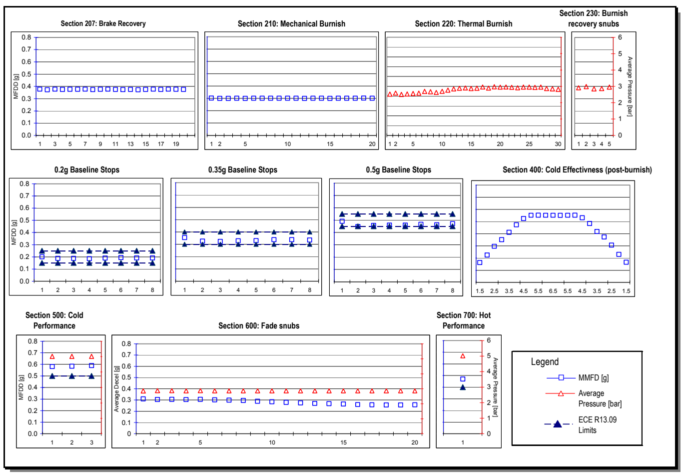


Figure 14. Summary plots for category O_4

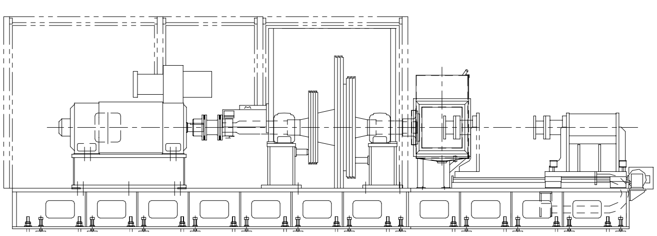


Figure 15. Performance inertia-dynamometer

UNITED NATIONS AGREEMENT Addendum 89: Regulation 90. Revision 1—Amendment 1: UNIFORM PROVISIONS CONCERNING THE APPROVAL REPLACEMENT LININGS ASSEMBLIES AND DRUM BRAKE LINING FOR POWER-DRIVEN VEHICLES AND THEIR TRAILERS

The ECE R90 applies to friction products for power-driven vehicles used in public roads in the European Community. Table 7 indicates a summary of the different test prescribed on the ECE R90. Figures 15 through 18 show partial reports for vehicles categories M_1 and O_4.

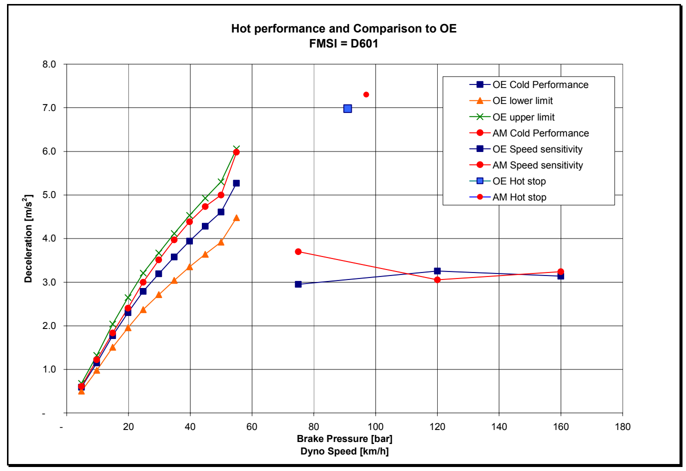


Figure 16. M_1 cold performance, hot performance, and speed sensitivity R90 report per ECE formatting

Link Test #:	**Brake Dynamometer Test Report**	Cust Ref:
Date: 08/23/04	**per ECE Reg 90.01 Annex 6 Cat O_4**	Page # 2 of 17

1. IDENTIFICATION

1.1. Axle		30 (GF 201 517 09)	
Manufacturer:		BPW Bergische Achsen KG Ohlerhammer. D-51674 Wiehl. Germany	
Make:		BPW	
Type:		Type 115	
Model:		-	
Technically permissible axle load (P_e):		11333	
1.2. Brake			
Manufacturer:		KNORR Bremse	
Make:		KNORR	
Type:		BPW Type 115 axle	
Model:		-	
Method of construction:		Floating caliper brake (pneumatic)	
Technically permissible camshaft input torque (C_{max}):		1334 Nm (for calculation: 1078 Nm at 6,5 bar)	
Automatic brake adjustment device:		integrated / ~~non-integrated~~	
Brake disc	Outside diameter:	430 mm	
	Effective radius (r_e):	173 mm	
	Thickness:	45 mm	
	Mass:	34 kg	
	Material:	Grey cast iron	
Brake lining	Manufacturer:		
	Type:		
	Identification:	Type identification on backing plate	
	Width:	248 mm	
	Thickness:	30 mm (including 9 mm backing plate)	
	Surface area:	187 cm^2	
	Method of attachment:	Friction material integrally moulded	
-	Brake geometry:	See annex 2	
1.3. Wheel			
~~Single~~/Twin		see appendix 1 dated	8/23/2004
Rim diameter (D):		see appendix 1 dated	8/23/2004
Dimensions:		see appendix 1 dated	8/23/2004
1.4. Tires			
Reference rolling radius (Re) at reference reaction (P_e):		546 mm	

Figure 17. Sample ECE R90 report per the ECE formatting. Part 1

Link Test #:	Brake Dynamometer Test Report	Cust Ref:
Date: 08/23/04	per ECE Reg 90.01 Annex 6 Cat O_4	Page # 4 of 17

Test type:		**0**	**III**		
ECE R13.09, Annex:		11-App. 2	4		
Item:		3.5.1.2	1.7.1.	1.7.2.	Replacement lining
Test speed initial	km/h	60	60	60	
final	km/h	0	30 (GF 201 517 09)	0	
Brake actuator pressure	bar	4.48	2.60	4.46	
Number of brake applications	-	3	1	5	
Duration of braking cycle	s	-	60	-	
Brake force developed T_e	daN	5686	3399	4523	
Brake Efficiency T_e/P_e	**-**	**0.50**	**0.30**	**0.40**	**does not meet criteria**
Allowable minimum efficiency T_e/P_e	-	-	-	0.45	
Actuator stroke s_e	**mm**	**44.7**	**-**	**38.6**	**meets criteria**
Allowable maximum stroke s_e	mm	-	-	41.6	
Input torque at brake lever C_e	**Nm**	**732**	**-**	**729**	**meets criteria**
Allowable maximum input torque C_e		-	-	1078	

2.3.Performance of the automatic brake ajuster device

2.3.1. Free running according to paragraph 1.7.3. of Annex 4, ECE R13.01: yes/~~no~~

Link Testing Laboratories, Inc.
13840 Elmira Ave.
Detroit, MI 48227

4. DATE OF TEST 08/18/04

5. This test has been carried out and the results reported in accordance with ECE Regulation No. 90 incorporating all valid text up to Supplement 4 of the series 01 of ammendements.

6. At the end of the test defined in paragraph 2 of Annex 6 of ECE Regulation No. 90 incorporating all valid text up to Supplement 4 of the series 01 of ammendements, the requirements were deemed to be: ~~fulfilled~~/not fulfilled

Detroit, 8/23/2004

LABORATORY FOR VEHICLE AND DINAMOMETER TESTING
Testing Laboratory for Vehicle and inertia dynamometer for Braking systems according to ECE Regulation 13 and 90.

-

Eng. Carlos E. Agudelo

7. TEST DOCUMENTS
Appendix 1: Representation brake/wheel/tire
Appendix 2: Schematic representation brake lining

Figure 18. Sample ECE R90 report per the ECE formatting. Part 2

Table 7. ECE R90 summary tests

Test	Annex 3 M_1, M_2 and N_1	Annex 4 M_3, N_2 and N_3	Annex 5 O_1 and 0_2	Annex 6 O_3 and 0_4
CONFORMITY WITH ECE R13				
SERVICE BRAKE	**VEHICLE TEST** Type-O GVW and LLVW Type-I Hot effectiveness	**VEHICLE TEST** Type-O GVW and LLVW Type-I / Type-II Hot effectiveness **INERTIA-DYNO** Type-O at increasing pressure MFDD < 5 m/s^2 High-speed performance MFDD >4 m/s^2 Type-I Hot effectiveness >60% Type-O or 4 m/s^2 Type-II Hot Effectiveness MFDD > 3.75 m/s^2	**VEHICLE TEST/** **ROLLER DYNO/** **SHAFT DYNO** Type-0 test-6 stops GVW increasing MFDD < 6 m/s^2 Type-I Hot effectiveness MFDD > 3.5 m/s^2 or 60% of cold effectiveness	**VEHICLE TEST/** **ROLLER DYNO/** **SHAFT DYNO** Type-O Type-I Type-II Hot performance higher then OE or 90% of Type-O Stroke <1.1 OE
SECONDARY BRAKE	**VEHICLE TEST** Type-O at GVW	**VEHICLE TEST** Type-O at GVW –optional-		
PARKING BRAKE –optional-	**VEHICLE TEST** Downhill 18% GVW	**VEHICLE TEST** Downhill 18% GVW **INERTIA-DYNO** Parking brake > 18%		

Table 7 (continued). ECE R90 summary tests

Test	Annex 3 M_1, M_2 and N_1	Annex 4 M_3, N_2 and N_3	Annex 5 O_1 and O_2	Annex 6 O_3 and O_4
COMPARISON TESTING WITH THE OE LINING				
COLD PERFORMANCE EQUIVALENCE	**VEHICLE TEST** **INERTIA-DYNO** 6 stops GVW increasing MFDD < 6 m/s^2 Within 15% of OE on upper two thirds	**VEHICLE TEST** **INERTIA-DYNO** 6 stops GVW increasing MFDD < 3.5 m/s^2 Within 15% of OE on upper two thirds	**VEHICLE TEST** **INERTIA-DYNO** 6 stops GVW increasing MFDD < 6 m/s^2 Within 15% of OE on upper two thirds	**VEHICLE TEST/** **ROLLER DYNO/** **SHAFT DYNO** 6 stops GVW increasing MFDD < 6 m/s^2 Within -5 to +15% of OE on upper two thirds
SPEED SENSITIVITY	**VEHICLE TEST** **INERTIA-DYNO** 3 Stops at 3 increasing speeds MFDD at high speed within 15% of MFDD at low speed	**VEHICLE TEST** **INERTIA-DYNO** 3 Stops at 3 increasing speeds MFDD at high speed within 25% of MFDD at low speed		
COMFORMITY OF PRODUCTION				
FRICTION BEHAVIOR	**DRAG FRICTION TEST USING VEHICLE HARDWARE** 600 RPM For pad assemblies: μ_{op} $\pm$15% of registered value $\mu_{min} \geq$ registered value $\mu_{max} \leq$ registered value For drum assemblies: M_{mean} $\pm$ 20% registered value $M_{hot} \geq$ registered value	**DRAG FRICTION TEST USING REFERENCE HARDWARE** 600 RPM μ_{op1}, μ_{op2} $\pm$15% of registered value $\mu_{min} \geq$ registered value $\mu_{max} \leq$ registered value For drum assemblies: M_{mean} $\pm$ 20% registered value $M_{hot} \geq$ registered value	**DRAG FRICTION TEST USING VEHICLE HARDWARE** 600 RPM For pad assemblies: μ_{op} $\pm$15% of registered value $\mu_{min} \geq$ registered value $\mu_{max} \leq$ registered value For drum assemblies: M_{mean} $\pm$ 20% registered value $M_{hot} \geq$ registered value	**DRAG FRICTION TEST USING REFERENCE HARDWARE** 600 RPM μ_{op1}, μ_{op2} $\pm$15% of registered value $\mu_{min} \geq$ registered value $\mu_{max} \leq$ registered value For drum assemblies: M_{mean} $\pm$ 20% registered value $M_{hot} \geq$ registered value
COMPRESSIBILITY ISO 6310	Pad assemblies: < 2% at ambient temperature; < 5% at 400 °C Shoe assemblies: < 2% at ambient temperature; < 4% at 200 °C			
SHEAR STRENGTH ISO 6312	Pad assemblies 250 N/cm^2 Shoe assemblies 100 N/cm^2	Pad assemblies 250 N/cm^2	Pad assemblies 250 N/cm^2 Shoe assemblies 100 N/cm^2	Pad assemblies 250 N/cm^2
HARDNESS ISO 2039		Report average of 5 samples		Report average of 5 samples

INERTIA-DYNAMOMETER TESTS FOR PASSENGER CARS WITH HYDRAULIC OR AIR BRAKES

SAE J2522 Dynamometer Global Brake Effectiveness

Scope and purpose

This SAE Recommended Practice defines an inertia-dynamometer test procedure to assess the effectiveness behavior of a friction material with regard to pressure, temperature and speed for motor vehicles fitted with hydraulic brake actuation. The SAE J2522 as its previous version, AK Master, is not a certification test. SAE J2522 is a universal effectiveness test that is useful only when target friction levels for specific sections or a baseline material is available for comparison. The SAE J2522 has become the baseline for several test versions with cold temperature, wet effectiveness, parking brake evaluation and ramp applications. Specific companies have found to be useful friction behavior evaluation regarding:

- Green effectiveness
- Speed sensitivity
- Fade resistance
- Friction recovery
- Friction stability

Applicability

Engineers use the SAE J2522 primarily for passenger cars, SUV's, light and medium duty trucks evaluation. It is widely spread among European and US companies. Developed initially as a partnership of European vehicle manufactures, brake and friction suppliers, it migrated to the US market and became a formal SAE Recommended Practice in 2003.

Table 8 shows the different sections during the SAE J2522-AK Master test.

Table 8. SAE J2522 Dynamometer Global Brake Effectiveness

Section	Number of Stops/snubs	Braking-release Speed -kph	Control	Initial brake temperature -°C
Green Effectiveness	30	80-30	30 bar	100
Burnish (or Bedding)	192	80-30	Various pressures	100
Characteristic Check	6	80-30	30 bar	100
Speed/Pressure Sensitivity	8	40-<5	10,20, … 80 bar	100
Speed/Pressure Sensitivity	8	80-40	10,20, … 80 bar	100
Speed/Pressure Sensitivity	8	120-80	10,20, … 80 bar	100
Speed/Pressure Sensitivity	8	160-130	10,20, … 80 bar	100
Speed/Pressure Sensitivity	8	200-170	10,20, … 80 bar	100
Characteristic Check	6	80-30	30 bar	100
Cold Braking Check	1	40-<5	30 bar	40
Motorway Braking Check #1	1	100-5	0.6 g	50
Motorway Braking Check #2	1	0.9-0.5 V_{max}	0.6 g	50
Characteristic Check	6	80-30	30 bar	100
1^{st} Fade (maximum 160 Bar)	15	100 -<5	0.4 g	100-500 disc 100-300 drum
Recovery	18	80-30	30 bar	100
Pressure Sensitivity	8	80-30	10,20, … 80 bar	100
Increasing Temperature Sensitivity (500 °C/300 °C)	9	80-30	30 bar	100,150, … 500
Pressure Sensitivity (500°C)	8	80-30	10,20, … 80 bar	500
Recovery 2	18	80-30	30 bar	100
2^{nd} Fade (maximum 160 Bar)	15	100 -<5	0.4 g	100-500 disc 100-300 drum
Characteristic Check	18	80-30	30 bar	100

SAE J2522 sample report

Figures 19 through 21 show the graphical output of the standard SAE J2522.

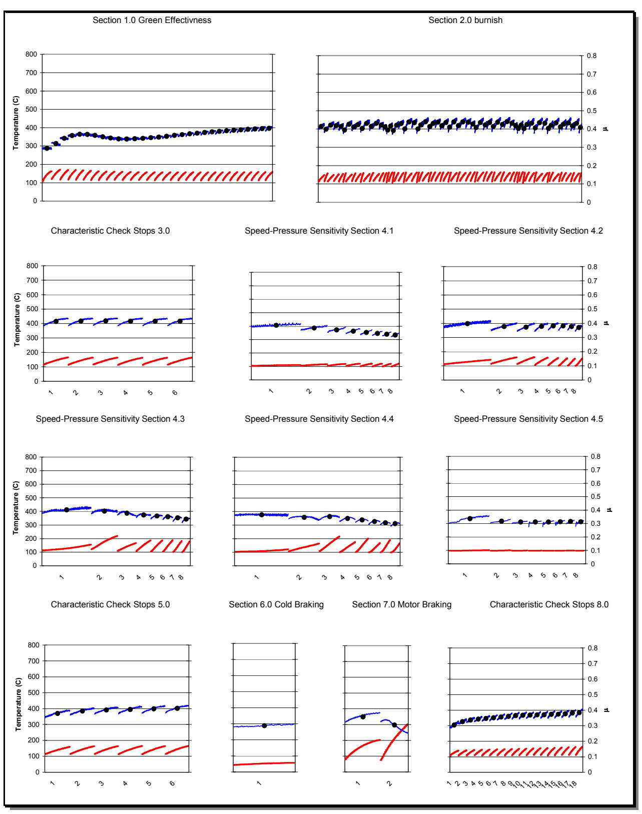


Figure 19. Graphical report SAE J2522. Part 1

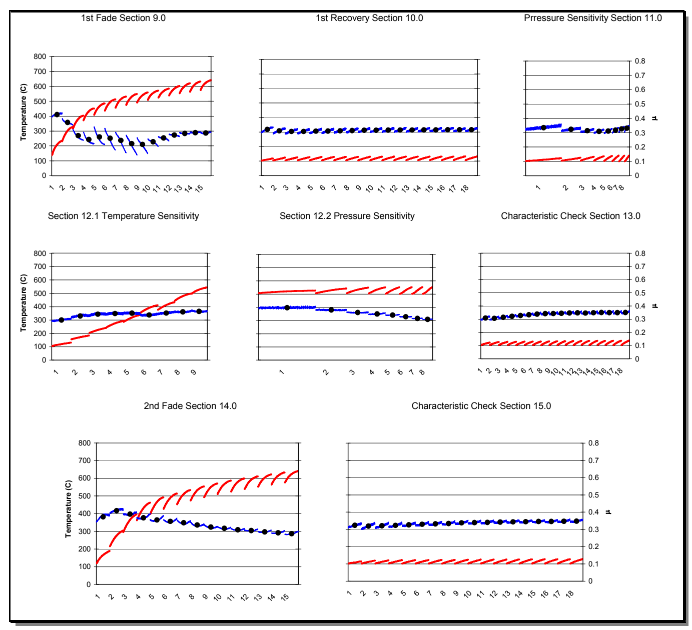
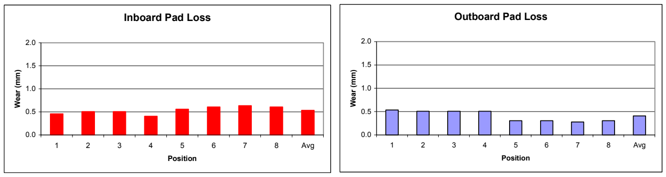


Figure 20. Graphical report SAE J2522. Part 2



Characteristic Values μ			AVG	MIN
Green Eff	(1)		0.358	
Burnish	(2)		0.419	
Char. Value	(3)	μ0P6	0.413	
Speed/Pressure	(4.3)	μv120	0.371	
Speed/Pressure	(4.5)	μvmax	0.328	
Char. Value	(5)	μ0P6	0.388	
40° C Brake Apply	(6)	μT40	0.290	
Second Motorway Apply	(7)	μMW2	0.282	
Char. Value	(8)	μ0P18	0.358	
Fade 1	(9)	μF1		0.194
Char. Value	(10)	μ0P18	0.313	
Temperature	(12)	T500/μT300		0.302
Char. Value	(13)	μ0P18	0.340	
Fade 2	(14)	μF2		0.293
Char. Value	(15)	μ0P18	0.338	

Figure 21. Graphical report SAE J2522. Part 3

SAE J2430 Dynamometer Effectiveness Characterization Test for Passenger Cars and Light Truck Brake Friction Products—Brake Evaluation Procedure—BEEP®

This single-ended inertia-dynamometer has the following advantages over other procedures available:

- It uses vehicle-specific parameters acquired during floor-check measurements on an actual vehicle
- The test replicates the key section of the FMVSS 105/135
- It is a single-ended inertia-dynamometer test so it does not have a reference material on the other axle
- The brake balance, using actual testing with OE hardware and brake lining, is the base to determine the correct inertia-split for the test. This has proven correlation with actual vehicle data even during wear testing and city driving
- Follows the technological trend of conducting simulations of different performance tests on an inertia-dynamometer
- It provides a one page summary with the main results and the pass/fail criteria evaluation
- It measures speed sensitivity and effectiveness stability during the test. these two parameters are very useful when comparing with a baseline material or the OE friction
- Provides the basis for the voluntary certification program launched by the Brake Manufacturers Council — BMC.

Scope and purpose

SAE J2430 is a single-ended inertia-dynamometer test to characterize the effectiveness of friction products used on passenger cars and light duty trucks up to 3,500 kg of GVW. It uses vehicle-specific parts and measurements to determine the test settings. The BMC-BEEP® software uses data acquired during a SAE J2430 test to determine the material's consistency with the Federal codes applicable to the particular vehicle.

Even though SAE J2430-BEEP® provides a pass/fail assessment, the test results are also useful for detailed evaluation of different parameters ad brake performance. Some parameters that the test or application engineer needs to evaluate are:

- Effectiveness stability 25% or less
- Speed sensitivity of 25% or less
- Effectiveness fall-off during the fade heating snubs
- Low hold-off pressure values. A positive hold-off pressure might mean in-stop fade
- High R^2 factor. The closer to 1 it is, the more stable the effectiveness during the brake application
- Overall effectiveness level within the required or desired range
- A safety margin on calculated pedal forces or pressures during: cold effectiveness, fade heating snubs, and the two hot performance stops
- Lowest averaged regressed specific torque with a safety margin above the minimum value required for the application

Test procedure

Table 9 shows the main conditions and settings during the SAE J2430-BEEP® testing.

SAE J2430-BEEP® sample test report

Figure 22 illustrates a typical summary page where all the test results include the pass/fail criteria evaluation.

Figure 23 shows a certification report provided to the manufacturer of the certified part number.

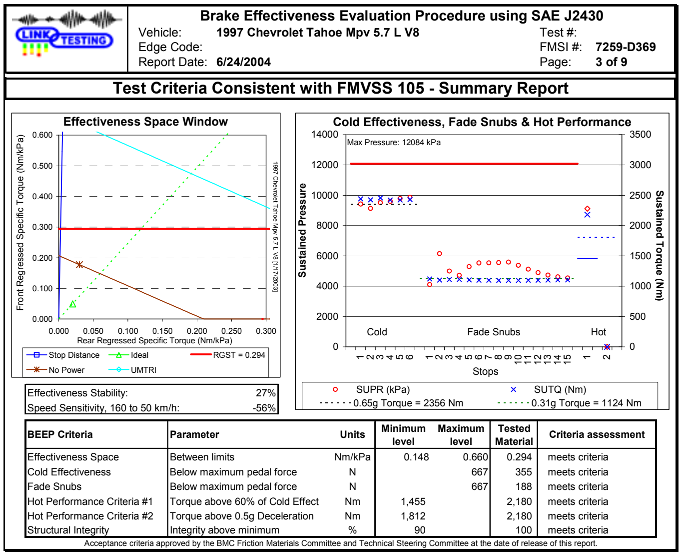
BEEP® voluntary certification program

As a self-policing measure, the industry through the BMC established a voluntary certification. The technical requirements for a company to have BEEP®-certified products are:

- Have a quality system in place per ISO/QS 9000 with the corresponding test plan for the product to be certified
- Demonstrate the ability to produce a range of applications by successfully passing ten SAE J2430-BEEP® tests with at least 8-out-of-10 on front axle applications
- Successfully pass audit testing every year.

Table 9. SAE 2430 Dynamometer Effectiveness Characterization

Section	Number of Stops/snubs	Braking-Release Speed -km/h	Control	IBT -°C	Cycle Time (s)
I.C. 50 kph Torque Control	5	50-3	Torque @ 0.31g	<100	
I.C. 100 kph Torque Control	5	100-3	Torque @ 0.31g	100	
I.C. Pressure Control	3	50-3	Pressure @ 75 N Pedal Force	100	
I.C. 50 kph Ramp	5	50-[0.8 g, 1000 N or 3 km/h]	135N/s Pedal Apply rate	100	
I.C. 100 kph Ramp	5	100-[0.8 g, 1000 N or 3 km/h]	135N/s Pedal Apply rate	100	
I.C. Cooling Curve 80 kph	18	80-80	Within Cooling Band	200 for Front 150 for Rear	15
Burnish	200	80-3	Torque @ 0.31g	100 °C First Stop 100 °C or 97s	
Effect. #1. Post Burnish 50 kph Ramp	5	50-[0.8 g, 1000 N or 3 km/h]	135N/s Pedal Apply rate	100	
Effect. #1. Post Burnish 100 kph Ramp	5	100-[0.8 g, 1000 N or 3 km/h]	135N/s Pedal Apply rate	100	
Post Burnish Cold Effectiveness	6	100-3	Torque @ 0.65 g	100	
Fade Heating Cycles	15	120-56	Torque @ 0.31g	55 First Snub	45
Hot Performance Effectiveness	2	100-3	1st at min. pressure from Cold effect. Section 2nd at pressure @ 500 N Pedal Force for 135 Test / 667N for 105 Test	-	1st at 35 2nd at 30
Cooling Cycles	4	50-3	Torque @ 0.31g	-	120
Recovery 100 kph Ramp	2	100-[0.8 g, 1000 N or 3 km/h]	135N/s Pedal Apply rate	-	60
Reburnish	35	80-3	Torque @ 0.31g	100 °C First Stop 100 °C or 97s	
Final Effectiveness 50 kph Ramp	5	50-[0.8 g, 1000 N or 3 km/h]	135N/s Pedal Apply rate	100	
Final Effectiveness 100 kph Ramp	5	100-[0.8 g, 1000 N or 3 km/h]	135N/s Pedal Apply rate	100	
Final Effectiveness 160 kph Ramp	5	160-[0.8 g, 1000 N or 3 kph]	135N/s Pedal Apply rate	100	
P.T. Cooling Curve 80 kph	18	80-80	Within Cooling Band	200 for Front 150 for Rear	15
P.T. Cooling Curve 112 kph	18	112-112	Within Cooling Band	200 for Front 150 for Rear	15



Brake Effectiveness Evaluation Procedure using SAE J2430

Vehicle: 1997 Chevrolet Tahoe Mpv 5.7 L V8 | Test #:
Edge Code: | FMSI #: 7259-D369
Report Date: 6/24/2004 | Page: 3 of 9

Test Criteria Consistent with FMVSS 105 - Summary Report

Effectiveness Stability:	27%
Speed Sensitivity, 160 to 50 km/h:	-56%

BEEP Criteria	Parameter	Units	Minimum level	Maximum level	Tested Material	Criteria assessment
Effectiveness Space	Between limits	Nm/kPa	0.148	0.660	0.294	meets criteria
Cold Effectiveness	Below maximum pedal force	N		667	355	meets criteria
Fade Snubs	Below maximum pedal force	N		667	188	meets criteria
Hot Performance Criteria #1	Torque above 60% of Cold Effect	Nm	1,455		2,180	meets criteria
Hot Performance Criteria #2	Torque above 0.5g Deceleration	Nm	1,812		2,180	meets criteria
Structural Integrity	Integrity above minimum	%	90		100	meets criteria

Acceptance criteria approved by the BMC Friction Materials Committee and Technical Steering Committee at the date of release of this report.

Figure 22. SAE J2430-BEEP sample test report summary

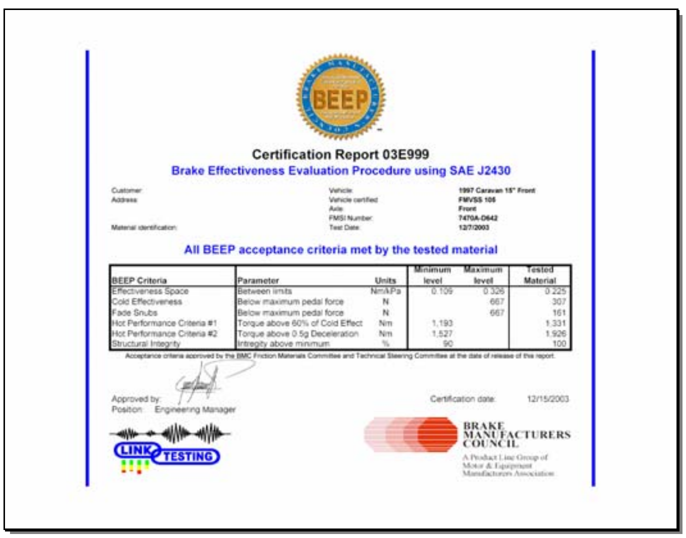


Figure 23. Sample BEEP certification report

SAE J2681 -Inertia Dynamometer Friction Behavior Assessment for Automotive Brake Systems-Draft

The automotive industry has relied on drag friction testing for quality control purposes for many years. Some companies still use it as their main friction characterization test.

Friction evaluation and characterization using drag applications, once a valid replacement for sample and scale testing, are of limited value. Drag applications do not correlate with real world driving conditions, brake system characteristics, or vehicle dynamics. Industry research has demonstrated that lining transfer-layer properties are heavily dependant upon the type of brake application. Simple drag-based test procedures cannot account for the varying brake energy resulting from the weight distribution and dynamic weight transfer of the vehicle. These variables relate directly to the vehicle's wheelbase and center of gravity height.

The SAE J2681-draft is a state-of-the-art test procedure used by several companies in Europe, North, and South America and more recently in China. Companies utilizing J2681 include raw materials suppliers, automotive manufacturers, aftermarket friction products manufacturers, rotor casting foundries and large OE service divisions.

Some benefits of this new procedure that provides a thorough testing approach for the automotive brake industry are:

- Cost-effective test with a total run-time of less than half on any other technically comparable inertia-dynamometer performance test
- Effective, standardized, and efficient approach to determining friction characteristics and consistency in a manufacturing environment during early screening or benchmarking programs
- Torque and pressure results averaged by distance
- Includes one of the key sections from the FMVSS 135: the inoperative power assist evaluation
- Use of low energy brake applications to investigate friction behavior and its potential influence on noise characteristics
- Use of in-stop friction statistics to evaluate part-to-part and batch-to-batch effectiveness stability and repeatability. See figure 24
- stopping distance estimation using mean fully developed deceleration — MFDD
- Controlled and recorded environmental conditions.

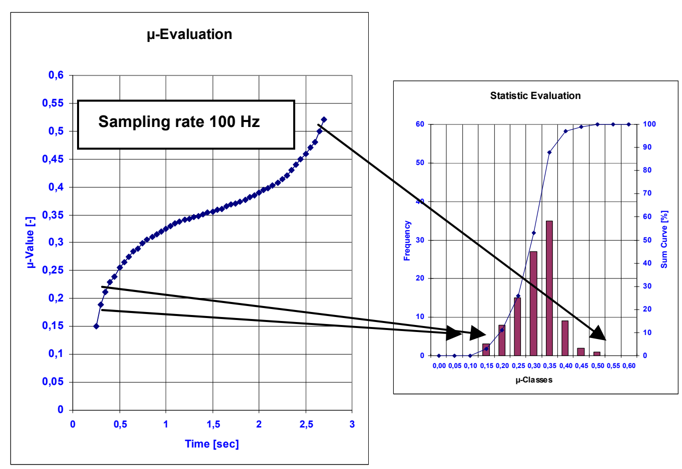


Figure 24. Histogram for in-stop friction evaluation

SCOPE AND PURPOSE

The SAE J2681 inertia-dynamometer procedure evaluates the influence of pressure, temperature, and linear speed on the coefficient of friction of the material tested. The procedure is a useful tool to compare different friction materials under identical test conditions. To take into account the different types of dynamometer cooling systems, the fade sections are temperature-controlled. The types of brakes and discs used will vary according to individual projects.

Production verification testing should be part of a statistical process control system included in the quality assurance plan. Detailed limits and assessment criteria need a prior definition for the specific project, program, and manufacturing process.

SAE J2681-draft applies to passenger cars, light and medium duty vehicles with hydraulic brake systems.

MFDD

The mean fully developed deceleration, or MFDD, is the average by distance deceleration calculated for a certain portion of the brake application. The stopping distance calculation defined in SAE J2681 is a derived quantity resulting from post processing of the acquired test data. This value is included on the test report as a reference value. Even though the actual stopping distance on the vehicle changes due to the tire-to-road adhesion, tire stiffness, and brake force distribution, SAE J2681 defines an approximation of this value through a calculated quantity referred to as MFFD. The mean fully developed deceleration uses the nominal vehicle test conditions like reaction time (equivalent to pressure buildup during the brake application) and the nominal braking speed during the vehicle test FMVSS 135. Tire-slip should not be a critical factor since typical deceleration levels during this section is close to 0.3 g and the required tire-to-road adhesion is 90% or better. The use of these three parameters (MFDD, 0.72 s reaction time, and 100 km/h braking speed) helps to reduce test-to-test variation. Equations 1 and 2 provide the calculation for the MFDD and the equivalent stopping distance using:

v_p — Prescribed or braking speed for the brake application.[km/h]
v_b — Linear speed at $0.8 \cdot v_p$. [km/h]
v_e — Linear speed at $0.1 \cdot v_p$ for brake stops with release speed less than 0.5 km/h or the release speed for brake snubs with release speed between 0.5 km/h and $0.5 \cdot v_p$. [km/h]
s_b — distance traveled between v_p and v_b. [m]
s_e — distance traveled between v_p and v_e. [m]
mfdd — Mean fully developed deceleration. When the release speed v_e is higher than $0.5 \cdot v_p$, the mfdd calculation does not apply. Use equation 1. [m/s^2]
S_{norm}— calculated stopping distance. Use equation 2 [m]

$$mfdd = \frac{v_b^2 - v_e^2}{25.92 \cdot (s_e - s_b)} \qquad \text{Equation [1]}$$

$$S_{norm} = 10 + \frac{386.7}{mfdd} \qquad \text{Equation [2]}$$

Figure 25 shows a compact inertia-dynamometer with inertia-simulation used during this type of testing.

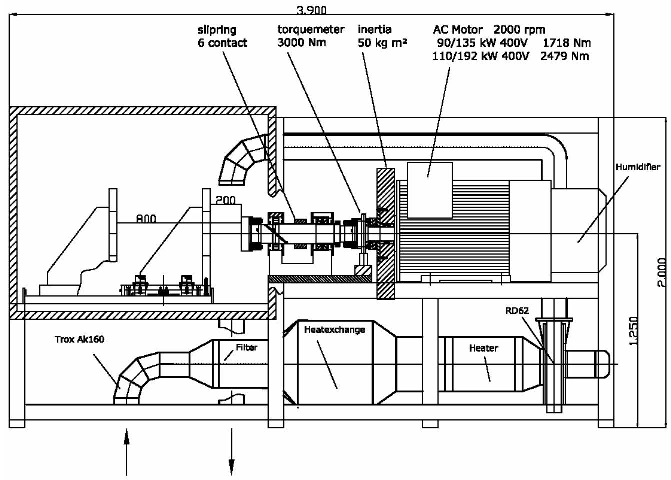


Figure 25. Inertia-dynamometer with inertia-simulation

Test procedure

Table 10 illustrates the different sections and the main test conditions used for a SAE J2681-draft test.

SAE J2681-draft sample test report

Figures 26 and 27 illustrate the typical layout and results provided for a SAE J2681-draft test report. Note the friction-histograms start at 95% of the set-point during the initial ramp to level, and end when the controlled parameter (torque/deceleration or pressure) falls below 95% of the set-point during the brake release.

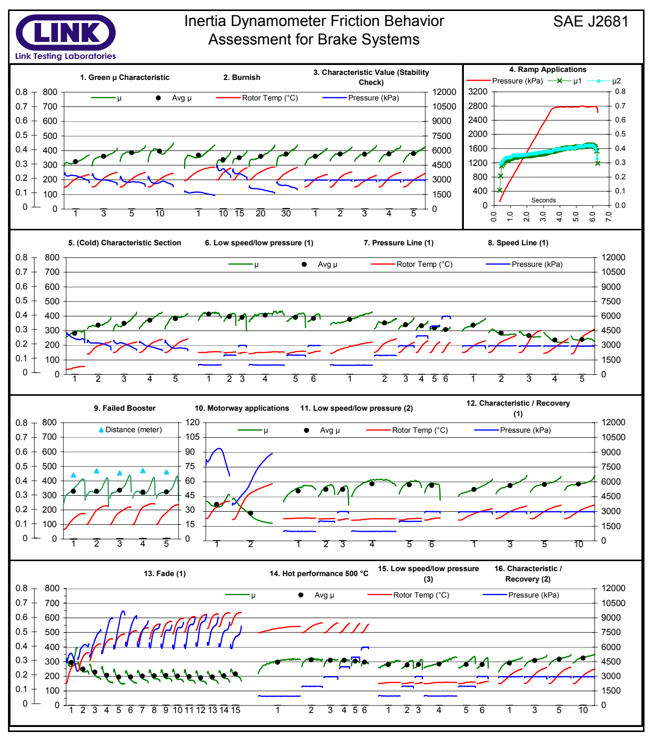
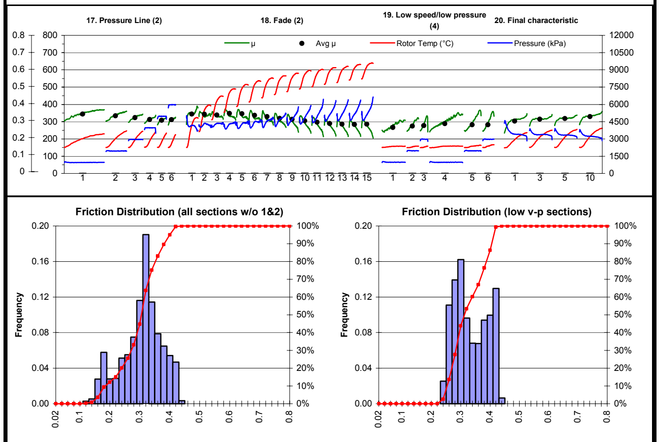


Figure 26. Sample test report for SAE J2681-draft. Part 1

LINK — Link Testing Laboratories | Inertia Dynamometer Friction Behavior Assessment for Brake Systems | SAE J2681



Description	Value
Nominal μ	0.331
Minimum μ	0.188
Maximum μ	0.412
Green effectiveness minimum μ	0.324
Post - burnish average μ (Stability check)	0.373
Low v-p maximum μ (all low spd-low prs)	0.412
Low v-p minimum μ (all low spd-low prs)	0.267
Speed sensitivity (%) (160 vs. 80 km/h)	43
High speed minimum μ (180 & 200 km/h)	0.236
Pre-fade pressure sensitivity (%)	-13
Post-fade pressure sensitivity (%)	-7
Fade (1) minimum μ	0.190
Hot performance 500 °C minimum μ	0.296
Fade (2) minimum μ	0.284
Post fades average μ, Final characteristic	0.316

Description	Value
Test Duration	6 hrs
Brake Cooling Time	350 sec
Air Temperature	30 °C
Relative Humidity	60 %RH

Wear	Value
Thickness loss:	
Inner/Leading	1.213 mm
Outer/Trailing	0.911 mm
Rotor	0.0076 mm
Weight loss:	
Inner/Leading	12.1 gram
Outer/Trailing	15.2 gram
Rotor	1.5 gram

Figure 27. Sample test report for SAE J2681-draft. Part 2

Table 10. SAE J2681-draft summary procedure

Section	Number of brake applications	Brake-release speed Km/h	Brake application control	Initial rotor temperature °C
Green μ Characteristic	10	80-30	3 000 kPa	150
Burnish	32	80-30	0.17, 0.35, 0.17, 0.20, 0.25, 0.42, 0.17, 0.30, 0.20, 0.37, 0.17, 0.30, 0.17, 0.25, 0.35, 0.50, 0.30, 0.57, 0.25, 0.20, 0.47, 0.17, 0.20, 0.50, 0.30, 0.17, 0.37, 0.25, 0.20, 0.25, 0.20, 0.42 g	200
Characteristic Value (Stability Check)	5	80-30	3 000 kPa	150
Ramp applications	2	50-0	2 800 kPa at 700 kPa/s	100
(Cold) Characteristic Section	1	40-5	3 000 kPa	40
	5	80-30	3 000 kPa	150
Low speed/low pressure (1)	3	20-0.5	1 000, 2 000, 3 000 kPa	150
	3	30-0.5	1 000, 2 000, 3 000 kPa	150
Pressure line (1)	6	80-40	1 000 to 6 000 in 1 000 kPa increments	150
Speed line (1)	5	80-40, 120-80, 160-130, 180-150, 200-170	3 000 kPa	150
Failed booster	1	100-0.5	2 800 kPa or vehicle specific	65
	6	100-0.5	2 800 kPa or vehicle specific	100
Motorway applications	1	100-0.5	0.60 g	150
	1	90 %-50% V_{max}	0.30 g	150
Low speed/low pressure (2)	3	20-0.5	1 000, 2 000, 3 000 kPa	150
	3	30-0.5	1 000, 2 000, 3 000 kPa	150
Characteristic/Recovery	10	80-30	3 000 kPa	150
Fade 1	15	100-5	0.40 g	150 to 550 for disc. 100-330 for drum
Hot performance 500°C	6	80-40	1 000 to 6 000 in 1 000 kPa increments	500
Low speed/low pressure (3)	3	20-0.5	1 000, 2 000, 3 000 kPa	150
	3	30-0.5	1 000, 2 000, 3 000 kPa	150
Characteristic/Recovery	10	80-0.5	3 000 kPa	150
Pressure line (2)	6	80-40	1 000 to 6 000 in 1 000 kPa increments	150
Fade 2	15	100-5	0.40 g	150 to 550 for disc. 100-330 for drum
Low speed/low pressure (4)	3	20-0.5	1 000, 2 000, 3 000 kPa	150
	3	30-0.5	1 000, 2 000, 3 000 kPa	150
Final characteristic	5	80-30	3 000 kPa	150

US DOT-NHTSA FMVSS/TP 121D-01:1990 and PRI-RP628 for Air Brake Systems—Dynamometer

Purpose and application

The Office of Vehicle Safety Compliance — OVSC — provides contractor laboratories with laboratory test procedures as guidelines for obtaining compliance test data. The data indicates if a specific vehicle or item of a motor vehicle meets the minimum performance requirements of the subject Federal Motor Vehicle Safety Standard —FMVSS. The purpose of the OVSC laboratory test procedures is to present a uniform testing and data-recording format and provide suggestions for the use of specific equipment and procedures.

The laboratory test procedures do not limit the requirements of the applicable FMVSS(s). In some cases, the OVSC laboratory test procedures do not include all of the various FMVSS minimum performance requirements.

Applicability

The FMVSS/TP 121D standard establishes performance and equipment requirements for braking systems on trucks, buses, and trailers equipped with air brakes. Testing to the standard requires both vehicle and dynamometer tests. A test procedure is available for each category. The test procedure illustrated in table 11 is for testing brake assemblies on an inertia-dynamometer.

The FMVSS 121 does not cover:

- Trailers with a width of more than 102.36 in [2,600 mm] with extendable equipment and with two short-track axles in a line across the width of the trailer
- Any vehicle with an axle with GVWR of 29,000 lbs [13,150 kg] or more
- Any truck or bus that cannot attain a speed of 33 mph [53 km/h] in two miles [3.2 km]
- Any truck that cannot attain a speed of 45 mph [72 km/h] in two miles [3.2 km], has an unloaded vehicle weight not less than 95% of its GVWR and no capacity to carry occupants other than the driver and operating crew
- Heavy-hauler trailers with GVWR of 120,000 lbs [54,400 kg] or more
- Any trailer that has an unloaded vehicle weight not less than 95% of its GVWR
- Any load divider dolly

Test procedure

Table 11 summarizes the test procedure. Units for the test procedure are the same as their original English units to ensure consistency with the actual FMVSS/TP 121D-01 test protocol.

Table 11. FMVSS/TP-121D-01:1990

Section	Number of Stops/snubs	Brake-release speed -mph	Control	Initial brake temperature –°F/ Cycle time	Performance requirement
350F Burnish	200	40-0.5	10 ft/sec^2	350	-
500F Burnish	200	40-0.5	10 ft/sec^2	500	-
Brake Power Check Stops	2	50-0.5	9 ft/sec^2	<350	-
Hot Stop Check Stops	2	20-0.5	14 ft/sec^2	<350	-
Brake Recovery Check Stops	2	20-.5	12 ft/sec^2	<350	-
Brake Retardation	7	50-0.5	20, 30, 40, 50, 60, 70, and 80 psi	170	Minimum retardation 0.05, 0.12, 0.18, 0.25, 0.31, 0.37 and 0.41 respectively
Brake Power	10	50-15	9 ft/sec^2	150 for first stop then every 72 sec	< 100 psi
Hot Stop	1	20-0.5	14 ft/sec^2	60 sec from end of last brake power snub	-
Brake Recovery	20	20-0.5	12 ft/sec^2	1st stop 120sec from end of Hot Stop. 2nd-20th every 60sec	20-85 psi for non ABS 12-85 psi for ABS <85 psi for front axle bus/truck N/A for front axle truck-tractor
End of test. final inspection					

PRI-TMC RP628A Qualification

As an independent technical body, the Performance Review Institute — PRI — from the Society of Automotive Engineers — SAE — manages a qualification program based on the FMVSS/TP-121D-01 and the TMC Recommended Practice RP 628A for the aftermarket suppliers of drum brake friction materials. The torque rating reported for the friction material is the torque developed at 40 psi during the brake retardation section of the test.

The basic requirements to obtain a PRI qualification are:

- Submit three test results on the TP-121D-01 meeting all the applicable criteria for the application
- Conduct these three tests on an inertia-dynamometer approved by PRI
- Conduct the test for any of the brake combinations approved by PRI. See figure 28
- Successfully pass audit testing when scheduled
- Fulfill other administrative requirements from PRI

LINING TEST CONDITIONS AND THE VEHICLE CONFIGURATIONS THEY REPRESENT

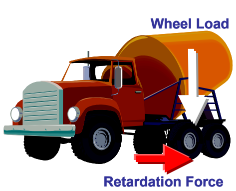
Test Conditions			
Cam Brake Manufacturers	Various	Various	Various
Brake Size (Diameter/Width, in.)	16.5 x 7	16.5 x 7	16.5 x 7
GAWR (lbs.)	20,000	20,000	23,000
Air Chamber Size (sq. in.)	30	24	30
Slack Adjuster Size (in.)	5.5	5.5	5.5
Tire Size, Rolling Radius (in.)	19.6	19.6	19.6
General Vehicle Conditions			
Cam Brake Manufacturers	Various	Various	Various
Brake Size (Diameter/Width, in.)	16.5 x 7	16.5 x 7	16.5 x 7
GAWR (lbs.)	17-20000	17-20000	22-23000
Air Chamber Size (sq. in.)	30	24	30
Slack Adjuster Size (in.)	5.5 or 6.0	5.5 or 6.0	5.5 or 6.0
Tire Size, Rolling Radius (in.)	18.5-21.0	18.5-21.0	18.5-21.0

The above three sets of FMVSS 121 test conditions—which depend on gross axle weight rating (GAWR) and air chamber size—can be used to test and evaluate brake lining friction materials. The test conditions simulate vehicle configurations (also shown above) which are commonly used in on-highway tractor-trailer operations.

Figure 28. TMC RP 628A test conditions and vehicle configuration

Retardation ratio

Figure 29 explains the physical interpretation of the retardation force and ratio indicated on the TP 121D-01.



$$RetardationRatio = \frac{BrakeTorque}{WheelLoad \times SLR}$$

figure 29. Retardation force and Retardation ratio

FMVSS/TP 121D-01 test report

Figures 30 and 31 show sample pages from a complete inertia-dynamometer test.

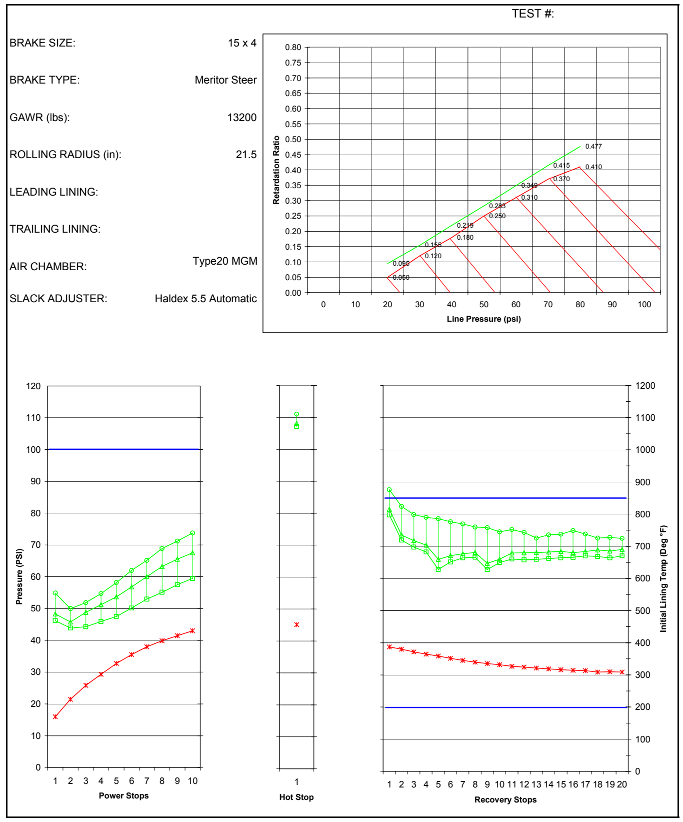


Figure 30. Graphical summary of FMVSS/TP 121D-01 test results

Stop Num	Brake Speed mph	Rel. Speed mph	Stop Time sec	Avg Decel ft/sec²	Torq. Min lb*ft	Torq. Avg lb*ft	Torq. Max lb*ft	Press Min psi	Press Avg psi	Press Max psi	Stroke Min Inch	Stroke Avg Inch	Stroke Max Inch	Lead Init F	Lead Final F	Drum Init F	Drum Final F
Brake Power Fade Test																	
1	50.0	15.0	5.65	9.10	3174	3532	4011	46.2	48.3	54.9	0.965	1.016	1.066	160	238	167	505
2	50.0	15.0	5.70	9.03	3212	3506	3909	43.9	45.8	50.0	0.998	1.055	1.115	215	303	251	501
3	49.9	15.0	5.71	8.97	3185	3486	4019	44.3	48.8	51.8	1.050	1.134	1.204	259	340	309	562
4	49.9	15.0	5.70	8.99	3166	3500	4069	45.9	51.2	54.7	1.119	1.199	1.272	293	379	358	613
5	50.0	15.0	5.72	8.98	3150	3495	4071	47.5	53.7	58.2	1.174	1.252	1.329	328	411	397	661
6	50.0	15.0	5.72	8.99	3201	3508	4065	50.2	56.8	62.0	1.219	1.299	1.375	355	437	431	698
7	50.0	15.0	5.74	8.95	3303	3506	3854	53.0	60.0	65.2	1.241	1.337	1.409	380	452	456	715
8	50.0	15.0	5.68	9.05	3331	3546	3934	55.1	63.2	68.8	1.277	1.377	1.453	399	467	477	732
9	50.0	15.0	5.66	9.09	3347	3565	3955	57.5	65.5	71.2	1.315	1.406	1.477	414	482	497	740
10	50.0	15.0	5.62	9.14	3367	3584	4026	59.5	67.5	73.7	1.341	1.432	1.506	430	496	512	750
Brake Power Hot Stop																	
1	20.0	1.0	2.12	13.09	5597	6110	6350	107.1	108.1	111.0	1.660	1.671	1.679	451	460	540	582
Brake Recovery																	
1	29.9	1.0	3.40	12.48	4845	5221	5435	79.7	81.5	87.6	1.424	1.440	1.454	387	409	429	529
2	30.1	1.0	3.53	12.08	4663	4986	5277	71.9	73.5	82.4	1.360	1.381	1.393	380	403	419	515
3	29.9	1.0	3.53	12.03	4597	4986	5247	69.8	71.7	79.9	1.339	1.361	1.369	371	394	408	504
4	29.9	1.0	3.52	12.04	4588	4990	5260	68.3	70.3	79.0	1.330	1.344	1.355	365	387	397	497
5	29.9	1.0	3.48	12.20	4762	5026	5428	62.8	65.9	78.6	1.279	1.304	1.327	359	379	387	489
6	29.9	1.0	3.49	12.15	4819	5011	5316	65.1	67.1	77.6	1.281	1.297	1.310	351	374	382	482
7	30.1	1.0	3.65	11.67	4715	4959	5257	66.4	67.7	76.9	1.271	1.290	1.302	345	368	376	478
8	30.1	1.0	3.51	12.15	4794	4982	5248	66.6	68.0	76.0	1.268	1.290	1.300	339	363	369	474
9	30.1	1.0	3.52	12.09	4702	4968	5395	62.8	64.7	75.8	1.266	1.284	1.303	335	359	365	471
10	29.9	1.0	3.55	11.95	4650	4936	5347	64.9	66.0	74.5	1.264	1.282	1.296	332	355	363	467
11	30.1	1.0	3.51	12.15	4801	4967	5239	66.0	67.9	75.2	1.272	1.286	1.299	327	350	359	463
12	30.1	1.0	3.52	12.10	4776	4962	5195	65.8	68.0	74.3	1.270	1.286	1.294	324	347	354	461
13	30.1	1.0	3.53	12.08	4732	4952	5222	65.9	68.0	72.5	1.264	1.286	1.303	321	343	353	459
14	30.1	1.0	3.51	12.13	4743	4957	5196	66.2	68.2	73.6	1.258	1.287	1.304	319	342	349	456
15	30.1	0.9	3.52	12.14	4742	4956	5225	66.4	68.4	73.7	1.259	1.288	1.304	316	339	347	453
16	30.1	1.0	3.53	12.05	4732	4938	5406	66.6	68.0	74.9	1.274	1.290	1.306	315	337	345	452
17	29.9	1.0	3.52	12.06	4732	4947	5372	67.0	68.4	73.8	1.270	1.292	1.309	313	335	344	451
18	29.9	1.0	3.53	12.03	4710	4957	5209	66.8	68.9	72.5	1.254	1.290	1.303	309	333	341	452
19	30.1	1.0	3.53	12.06	4710	4939	5320	66.4	68.5	72.8	1.258	1.289	1.309	310	332	341	452
20	29.9	0.9	3.52	12.10	4696	4946	5206	67.0	69.0	72.4	1.258	1.289	1.308	309	329	341	452

Figure 31. Tabular section of an FMVSS/TP 121D-01 test

TEST EQUIPMENT USED FOR BRAKE PERFORMANCE TESTING

The main factors that determine the type of test equipment used for testing are:

- vehicle application
- purpose of the test
- the test protocol used
- test project schedule and budget

The matrix on figure 32 gives an overall view of the possible systems used to execute brake performance testing.

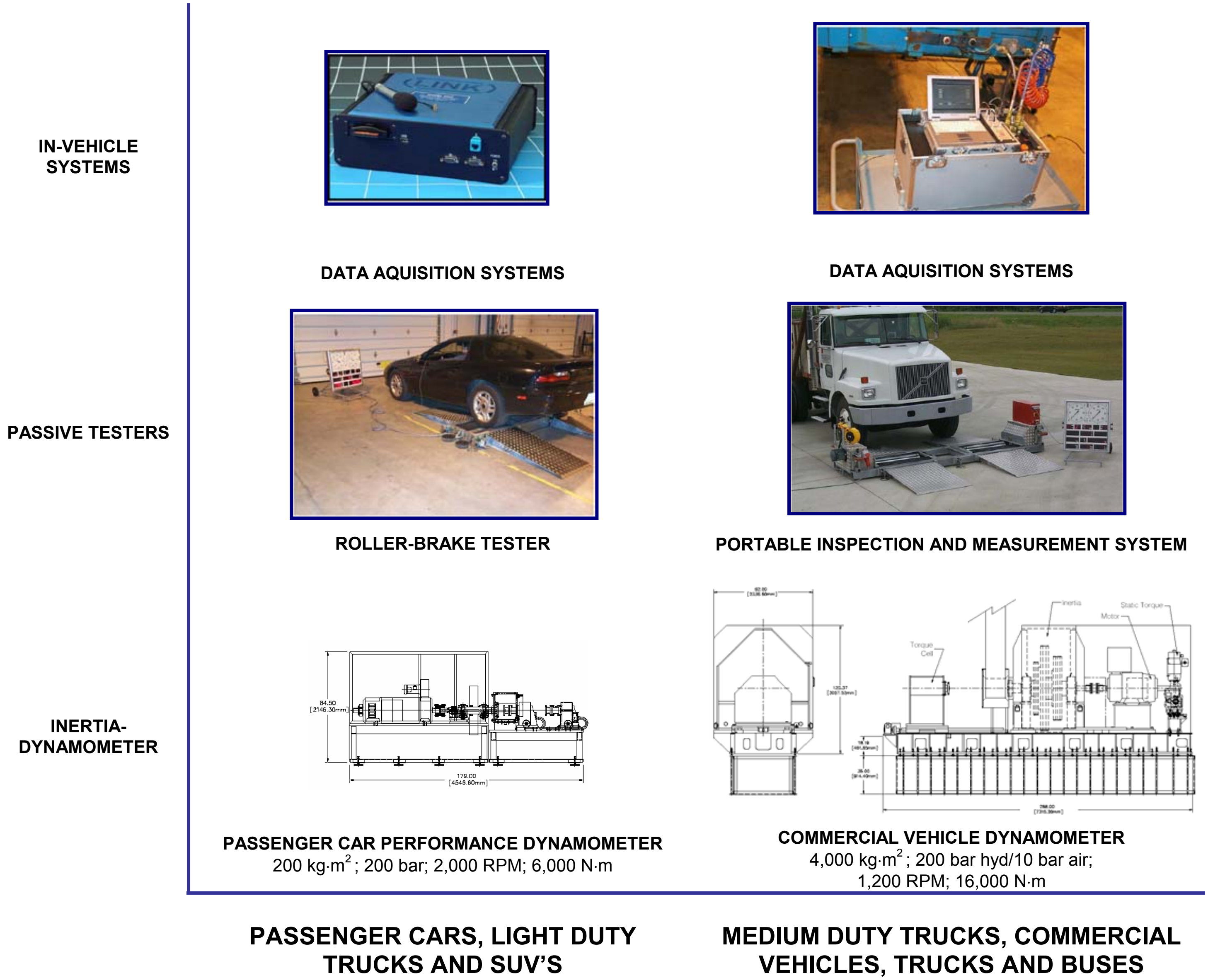


Figure 32. Test system versus application matrix

CURRENT AND FUTURE ACTIVITIES REGARDING BRAKE PERFORMANCE TESTING

Even though the concept of friction is as old as engineering, it is still far from being a closed-case. There are many different developments and efforts under way regarding friction performance testing. Companies will continue to investigate and develop internal and proprietary approaches and testing techniques for obtaining a market edge based on test results or as a problem-solving tool. Some of the items that may become common-practice for testing, publicly available standards, or regulations include:

- Release of the ISO 15484 standard: Road vehicles — Brake linings — Friction Materials — Product definition and assurance. It is a global effort to harmonize test procedures for passenger cars and commercial vehicles. The ISO Working Group WG 2 from the TC 22-SC 2 includes task forces in Europe, the Americas, and Japan. The work is structured as sub-working groups covering:
  - SWG 1: Product definition and assurance
  - SWG 2: Visual inspection
  - SWG 3: Physical characteristics

- SWG 4: Friction and wear
- SWG 5:Corrosion and aging
- SWG 6: Noise and vibration

- Continue research and consultation efforts to establish a recommended set of environmental conditions for standard performance and NVH testing. This could lead to the next generation of testing equipment fully capable of conditioning temperature and relative humidity inside the brake enclosure
- Continuation of the informal working group established for further harmonization between the ECE R13H and the FMVSS 135. This effort will provide a simpler and more reliably structured test sequence. A “Premium Braking Standard” is one possible outcome of the effort
- Release of the revised FMVSS 121 with expected reduction in the stopping distance requirements
- Release of a new ISO standard for inertia-dynamometer performance testing of commercial vehicle applications. It includes key sections from ECE R13 and ECE R90. and provides an effectiveness test matrix regarding:
  - speed sensitivity [40 to 120 km/h],
  - pressure sensitivity [1,5 to 9 bar],
  - temperature sensitivity [100 to 500 ^{o}C],
  - green, post-burnish, fade, hot and post-fade conditions
- Release of the revised FMVSS 105 with parking brake requirements for vehicles above 4,540 GVW other than school buses
- Revision of the ECE R90 per the following proposals:
  - Germany. Include brake rotors and drums to the type-approval process
  - Russia. Allow inertia-dynamometer testing only for type-approval of vehicles category M_1
- Revision of SAE recommended practice for a more accurate inertia-dynamometer simulation of the FMVSS 135
- Introduction of new single-ended inertia-dynamometer tests procedures as better vehicle-modeling technologies exist. This is also driven by cost-reduction efforts, the need to reduce time-to-market and current inertia-dynamometer technology
- Further development and refinement of test protocols and requirements for parking brake systems
- Research on the tribological relationship between friction, noise, low energy brake application, temperature, humidity, environment and corrosion effect
- Possible introduction of air-disc brakes to the RP628A program

CONCLUSIONS

Vehicle-level testing is the ultimate judge for overall brake performance evaluation. Different regions and markets have differing requirements that may conflict with other existing regulations. Considerations include the automotive technologies developed or available, regulations or standards in place, customer preferences and needs, driving styles, public road infrastructure and maintenance practices, testing technologies and sheer size of the market. There is an ongoing effort for harmonization between two official entities, ECE and NHTSA. The industry is also pursuing harmonization through the Working Group 2 that combines representatives from ISO, SAE, and JIS. These efforts seek to standardize test procedures, performance requirements, and test reports for vehicle-level testing and inertia-dynamometer evaluation.

Another major trend, as a cost-effective method to evaluate brake performance in a laboratory-controlled environment, is the development of inertia-dynamometer test procedures or vehicle testing simulation. As a common practice today, the industry uses inertia-dynamometer testing for screening, development, fingerprinting, and regular audit testing.

This paper is not an all-inclusive description of the different regulations or test procedures for all vehicles. Vehicle and inertia-dynamometer testing are very dynamic and complex in nature. Almost every week there is a new or revised test protocols introduced somewhere in the automotive industry. The reader is strongly encouraged to get involved in international, regional, or local developments.

PASSENGER CAR TEST MATRIX

Appendix A presents a summarized table with the most common test procedures used to assess different characteristics of a brake system or brake components. The matrix is structured per development phase and includes sample, scale, inertia-dynamometer and vehicle-level testing.

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Appendix A
(informative)

Test matrix for passenger cars and light duty trucks with hydraulic braking systems

● Main test used to assess condition or performance

◉ Replacement test with proven efficiency, consistency or availability advantages. General good correlation can be achived

○ limited correlation with no widespread approval or acceptance. Some companies migth use internally

Test equipment used	Test procedure (*) proprietary testing used	coefficient of friction evaluation	Edge code certification	specific wear rate	compressibility at ambient temperature	compressibility at high temperature	heat transfer rate	swell under temperature	growth after heating	friction material internal shear strength	shear strength at the bonding layer	structural integrity with dynamic loading	friction behavior	FMVSS 105 & 135 prediction	fade behavior	wear at different temperatures	wear at driving conditions	squeal noise evaluation	squeal noise at low temperature	squeal evaluation at driving conditions	moan and groan evaluation	wheel dust generation	Off-Brake DTV generation	Wear-induced DTV	Off-Brake drag	pedal feel	parking lot rust	rust removal characterization	hot judder	brake balance front-to-rear	parking brake performance	parking brake drive-away abuse	normal stopping distance performance	hot stopping distance	failed systems stopping distance	heavy loaded stopping distance	high speed stopping distance	European regulation compliance	US Federal Code compliance
		Fingerprinting/ Regular QC										Fingerprinting, production validation, audit testing																										Cert.	
sample testing	SAE J661A quality control	●	●	●									○																										
sample testing	AMECA Certification	●	●										○																										
sample testing	JASO C-444-78 Physical properties									●																													
sample testing / scale testing	ISO 6310 Compressibility				●	●	●	●	●									○	○	○						◉													
sample testing / scale testing	SAE J 2468 Compressibility				●	●												○	○	○						◉													
sample testing / scale testing	SAE J160 Dimensional Stability						●	●	●																	◉													
sample testing / scale testing	SAE J840 bonding strenght										●																												
sample testing / scale testing	ISO 6312 bonding strenght										●																												
dynamometer testing	SAE J2522 global effectiveness evaluation	●								◉	◉	◉	●	○	●	○										○							◉	◉	◉	◉	◉	○	○
dynamometer testing	SAE J2681 friction behavior assessment	●								◉	◉	◉	●	○	●	○		◉		◉						○							◉	◉	◉	◉	◉	○	○
dynamometer testing	SAE J2430-BEEP Certification	●								◉	◉	●	●	●	●	○										○				◉			◉	◉	◉	◉	◉	○	◉
dynamometer testing	SAE J2707 wear evaluation			●									◉			●	●																						
dynamometer testing	SAE J2521 brake squeal matrix												◉					●		◉																			
dynamometer testing	SAE J2521 with cold sections												◉					●	●	◉																			
dynamometer testing	chassis dynamometer testing*																◉	●	●	●	●	◉																	
dynamometer testing	inertia dynamometer testing*	●		●						◉	◉	◉	◉	◉	●	●	◉	●	●	◉	◉	◉	◉	◉	◉	◉	◉	◉	◉	◉	◉	◉	◉	◉	◉	◉	◉	◉	◉
vehicle testing	vehicle testing on test track*									◉	◉	◉	●	●	●	◉		●	●	●	●				●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
vehicle testing	highway vehicle testing *												◉				●	◉	◉	◉			●	◉	●														
vehicle testing	city traffic vehicle testing*			●													●	●	●	●	●	●		●		●		●											
vehicle testing	AMS fade vehicle testing					◉						◉	◉		●										◉	◉			◉										
vehicle testing	mountain descent vehicle testing*					◉	●	◉	◉			●			●										◉	●			●										
vehicle testing	FMVSS 105 braking system >3,500 kg											●			●										○					●	●		●	●	●	●	●		●
vehicle testing	FMVSS 135 braking system < 3,500 kg									◉	◉	●			●										○					●	●		●	●	●	●	●		●
vehicle testing	ECE Reg 13 original vehicle type approval				◉	◉									●										○					●	●		●	●	●	●	●	●	
vehicle testing	ECE Reg 90 replacement lining approval		◉		●	●					●		●		●															●	●		●	●	●	●	●	●	

* proprietary test procedures