SAE International™

SURFACE VEHICLE RECOMMENDED PRACTICE

SAE J1666

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Electric Vehicle Acceleration, Gradeability, and Deceleration Test Procedure

1. Scope—This SAE Recommended Practice establishes uniform procedures for testing electric battery-powered vehicles which are capable of being operated on public and private roads. It is the intent of this document to provide standard tests which will allow various performance characteristics of electric vehicles to be cross-compared on a common basis in specifications, technical papers, and engineering discussions. The tests concern attributes of the total vehicle system rather than those of its subsystems and components. Tests of components such as batteries are the subject of separate procedures.

The road tests specified in this document are recommended for use whenever possible particularly to establish vehicle performance specifications. The dynamometer procedures are included primarily to facilitate development testing.

Section 3 provides definitions of terminology used in this document. Section 4 specifies test conditions and instrumentation which are to be used for all the tests specified in this document while Section 5 identifies the data which are to be recorded for all tests. The specific tests covered by this document are:

a. Acceleration Characteristics on a Level Road (Section 6)
b. Gradeability Limit (Section 7)
c. Gradeability at Speed (Section 8)
d. Deceleration (Section 9)
e. Coastdown Testing (Section 10)

2. References

2.1 Applicable Publications—The following publications form a part of the specification to the extent specified herein. Unless otherwise indicated, the latest revision of SAE publications shall apply.

2.1.1 SAE PUBLICATIONS—Available from SAE, 400 Commonwealth Drive, Warrendale, PA 15096-0001.

SAE J688—Truck Ability Prediction Procedure
SAE J843—Brake System Road Test Code—Passenger Car and Light-Duty Truck
SAE J992—Brake System Performance Requirements—Truck, Bus, and Combination of Vehicles
SAE J1263—Road Load Measurement and Dynamometer Simulation Using Coastdown Techniques
SAE J1634—Electric Vehicle Energy Consumption and Range Test Procedure
SAE J2264—Chassis Dynamometer Simulation of Road Load Using Coastdown Technique

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2.1.2 CFR PUBLICATION—Available from the Superintendent of Documents, U.S. Government Printing Office, Washington, DC 20402.

40 CFR 86. 129-80

3. Definitions

3.1 Curb Vehicle Weight—The toal weight of the vehicle with all standard equipment and including batteries, lubricants at nominal capacity, and the weight of optional equipment that is expected to be installed on more than 33% of the vehicle line, but excluding the driver, passengers, and other payloads; incomplete light-duty trucks shall have the curb weight specified by the manufacturer.

3.2 Driveline Ratio—The motor shaft rpm divided by the rpm of the traction wheels of the vehicle.

3.3 Gradeability—The maximum percent grade which the vehicle can traverse for a specified time at specified speed. The gradeability limit is the grade upon which the vehicle can just move forward.

3.4 State of Charge (SOC)—The residual capacity in ampere-hours of a battery after a discharge (full or partial) expressed as a percent of the battery ampere-hour capacity determined in 3.9. Initial State of Charge is the SOC at the beginning of a test.

3.5 Projected Frontal Area—The total frontal area of the vehicle obtained by projecting its image on a vertical plane normal to its direction of travel.

3.6 Tractive Force—The force available from the driving wheels at the driving wheel/ground interface.

3.7 C/3 Rate—The constant current at which the battery can be discharged to 100% DOD (see 3.8) from battery ampere-hour capacity in 3 h.

3.8 Depth of Discharge (DOD)—The ampere-hours removed from a battery expressed as a percentage of the battery ampere-hour capacity as determined in 3.9.

3.9 Battery Ampere-Hour Capacity—The capacity of a battery in ampere-hours obtained from a battery discharged at a C/3 current (see 3.7) such that a specified minimum cut-off voltage is reached.

3.10 Cut-Off Terminal Voltage—The manufacturer-recommended minimum voltage as a function of load after which battery damage could occur.

4. Test Conditions and Instrumentation Common to All Tests—The following conditions shall apply to all tests defined in this document unless otherwise stated in specific test procedures.

4.1 Condition of Vehicle

4.1.1 Vehicles shall be stablized as determined by the manufacturer and shall have accumulated a minimum of 1600 km (1000 miles), or the battery has been conditioned as specified in 4.2.1, but no more than 9978 km (6200 miles) on the Durability Driving Schedule as defined in 40 CFR Part 86, Appendix IV, Section (a) or an equivalent driving schedule.

4.1.2 Vehicle shall be tested in its normal configuration with normal appendages (mirrors, bumpers, hub caps, etc.). Certain items (e.g., hub caps) may be removed where necessary for safety on the dynamometer.

4.1.3 The vehicle shall be tested at curb weight plus 300 lb.

4.1.4 Manufacturer's recommended tires shall be used. For dynamometer testing, tire pressures shall not exceed levels normally used in dynamometer testing (SAE J1263 or SAE J2264) and necessary for safe operation. Dynamometer tire pressure should be the same pressure as used to establish the dynamometer road load power setting.

4.1.5 Normal manufacturer's recommended lubricants shall be employed.

4.1.6 The vehicle shall be stored for a minimum 8-h soak at ambient temperature (4.3.1.1) before tests, which start with a fully charged battery.

4.2 Condition of Battery

4.2.1 The battery shall have been aged with the vehicle as defined in 4.1.1, or equivalent conditioning. The battery aging may be performed either with the vehicle or by using an equivalent bench aging procedure (Test Procedure #2, Constant Current Discharge Test Series, in the United States Advanced Battery Consortium EV Battery Test Procedures Manual, Revision 2.) The number of charge/discharge cycles for bench aging a lead-acid battery shall be equivalent to at least 1000 vehicle miles. Other battery technologies may use different battery aging periods, if supported by the manufacturer as being equivalent. If batteries have been subject to extended storage, batteries shall be cycled per manufacturer's recommendation before starting test.

4.2.2 A minimum 8-h soak period at ambient temperature (4.3.1.1) shall be allowed after completion of charging and before starting tests initiated with fully charged battery.

4.2.3 Full charge is to be established using manufacturer's recommended charging procedure and equipment.

4.2.4 For tests requiring an X% discharged battery at the start (for example, gradeability tests), the required initial state-of-charge will be established as follows. The battery shall be drained at the C/3 rate and the watt-hours consumed determined. To achieve X% discharge of a fully charged battery, the battery will be discharged for X% of the end-point time either by driving the vehicle at recommended maximum cruise speed or by discharging the battery through a load at an equivalent constant power. Tests conducted with the battery partially discharged at the start must be initiated no longer than 10 min after the desired initial state-of-discharge is reached.

4.2.5 For tests in which the effects of battery initial state-of-charge are to be investigated, tests should be conducted with the propulsion batteries 0%, 40%, and 80% discharged.

4.3 Environmental Conditions

4.3.1 GENERAL

4.3.1.1 Temperature during vehicle and battery ambient soak period shall be within the range of 16 to 32 °C (60 to 90 °F). Ambient temperature during road testing shall be in the range of 5 to 32 °C (40 to 90 °F).

4.3.2 ROAD TESTS

4.3.2.1 Road tests are to be performed on a road which is level to within ±1% and having a hard, dry surface. Tests shall be run in opposite directions when they are performed on a road test route. The direction of travel need not be reversed when operating on a closed test track.

4.3.2.2 The recorded wind speed at the test site during test shall not exceed 16 km/h (10 mph).

4.3.3 DYNAMOMETER TESTS

4.3.3.1 Dynamometer load must be programmable at various vehicle speeds to simulate vehicle road load versus speed characteristics.

4.3.3.2 Dynamometer road load power settings shall be made based on SAE J1263 as modified in Section 10. Alternatively, the road load power setting using the frontal area method in 40 CFR 86.129-80, as detailed in Appendix B, may be used.

NOTE—SAE J1263, in its current state, may not fully apply to electric dynamometers—revisions may be needed.

4.3.3.3 Dynamometer flywheel shall be engaged with the nearest available dynamometer inertia weight which equals or exceeds the rated gross vehicle weight.

4.3.3.4 During dynamometer operation, a fixed speed cooling fan shall be positioned so as to direct cooling air to the vehicle in a manner consistent with the accepted practices for simulating road conditions. The fan capacity in general shall not exceed 2.5 m^3/s (5300 ft^3/min), but auxiliary fans may be employed if needed to more closely duplicate on-road conditions.

4.4 Test Instrumentation—This section provides a list of instruments which are required to perform the tests specified in this document. The overall error in recording or indicating instruments shall not exceed ±2% of the maximum value of the variable to be measured (not including reading errors). Periodic calibration shall be performed and documented to insure compliance with this requirement.

4.4.1 GENERAL INSTRUMENTATION—The following classes of instruments are required for the purpose of tests outlined in this procedure.

a. DC watt-hour meter or watt-time recorder
b. Vehicle speed versus time recorder
c. Distance versus time recorder
d. Tire pressure gauge
e. Ambient temperature versus time indicator
f. DC watt meter
g. AC kilowatt-hour meter

4.4.2 ROAD TESTS

a. Wind speed and direction measurement versus time
b. Means for determining grades of test route segments
c. Fifth wheel for measuring vehicle speed and distance

5. Data to be Recorded for All Tests

5.1 General

5.1.1 Vehicle identification

5.1.2 Overall maximum dimensions (including projected frontal area).

5.1.3 Gross vehicle weight and test weight to within ±2%.

5.1.4 Battery

a. Manufacturer
b. Type and normal rating at specified discharge rate.
c. Previous history of the battery including chronological age, number and nature of charge/discharge cycles, description of the last discharge and recharge processes, and a brief description of known adverse usage conditions.
d. State of initial charge using the definition of percent charge presented in 4.2.3 and 4.2.4. Where meaningful, other parameters such as open circuit voltage, electrolyte specific gravity, etc., shall also be stated.

5.1.5 Motor type and rating.

5.1.6 Overall drive train ratio(s) available, and those used during test, plus vehicle speeds at shift points if manual transmission.

5.1.7 Tire manufacturer, design, size, and pressure at the start of the test.

5.1.8 Power consumption of individual accessories, and times when each accessory was on during the test.

5.1.9 Environmental Conditions

a. Range of ambient temperature during test
b. Range of wind velocities during test
c. Range of wind direction during test
d. Mean test site altitude relative to sea level

5.1.10 Running surface (road surface or dynamometer wheel).

5.1.11 Description of test route or dynamometer load program-road class, road surface type and condition (Table 9 of SAE J688), and lengths and grades of test route.

5.1.12 Date and starting and ending times of test.

5.1.13 List of all instrumentation used in test (manufacturer, model number, serial number) and their last calibration date.

5.1.14 Any deviation from test procedure and reason for deviation.

5.2 Road Tests

5.2.1 Data shall be recorded and averaged for tests in opposite directions when tests are run on a road test route. The date reported shall be the average of at least two test runs in each direction. The range of test results and the number of test runs also shall be reported.

5.3 Dynamometer Tests

5.3.1 Description of dynamometer used (including drum or roll diameter and number of tire contact points).

5.3.2 Road load power set points.

5.3.3 Dynamometer inertia weight.

5.3.4 Vehicle speed from dynamometer roll.

6. Acceleration Characteristics on a Level Road

6.1 Purpose of Test—The purpose of this test is to determine the maximum acceleration the vehicle can achieve on a level road with the propulsion battery at various initial states-of-charge.

6.2 Test Procedure—The road and dynamometer tests defined in this section are to be conducted to the test conditions, instrumentation, and data recording requirements of Sections 4 and 5. Repetitive tests are to be conducted without recharging the battery.

6.3 Road Test Procedure

6.3.1 A suitable, straight, paved test route shall be selected upon which the vehicle can be safely accelerated to speeds near its peak speed.

6.3.2 The test vehicle is to be accelerated from a standing start at its maximum attainable, or permissible, acceleration rate until either the vehicle's peak speed is reached or until a safe limit speed is attained.

6.3.3 At least two successive runs shall be made in opposite directions over the test course to establish the vehicle's maximum acceleration characteristics at each of the three battery states-of-charge specified in 4.2.5 as achieved by the procedure 4.2.4. The time interval from the end of the acceleration portion of one run to the beginning of the next successive acceleration run at each battery state-of-charge shall not exceed 5 min.

6.4 Dynamometer Tests—Dynamometer test conditions are defined in 4.3.3. Vehicle speed shall be determined for these tests from measurements of the dynamometer drum or roller speed.

6.5 Special Data Recording—In addition to recording the data specified in Section 5, the following special data shall be reported.

6.5.1 The vehicle's acceleration characteristics shall be plotted as speed versus time for each of the initial states-of-charge as illustrated in Figure 1. For each state-of-charge, the data to be plotted shall be the average results of at least two runs for that initial state-of-charge. When reporting these data, it shall be specified whether they are based upon road test or dynamometer test results.

7. Gradeability Limit

7.1 Purpose of Test—The purpose of this test is to determine the maximum grade on which the test vehicle can just move forward.

7.2 Test Procedure—Direct measurement of gradeability limit on steep test grades generally is impractical. Therefore, the gradeability limit is to be calculated from the manufacturer's recommended gross vehicle weight and the measured tractive force delivered by the vehicle at a speed near zero.

7.2.1 The tractive force shall be measured on a suitable horizontal surface and is the maximum force which can be maintained by the vehicle propulsion system for a period of 20 s while moving the vehicle at a minimum speed of 1.5 km/h (1 mph).

7.2.2 The tractive force shall be determined for various battery states-of-charge as specified in 4.2.5.

7.2.3 Because the high-rate discharge capability of batteries is time dependent, two tractive force tests are to be made for each battery state-of-charge. The lower of the two tractive force measurements shall be used to determine the gradeability limit.

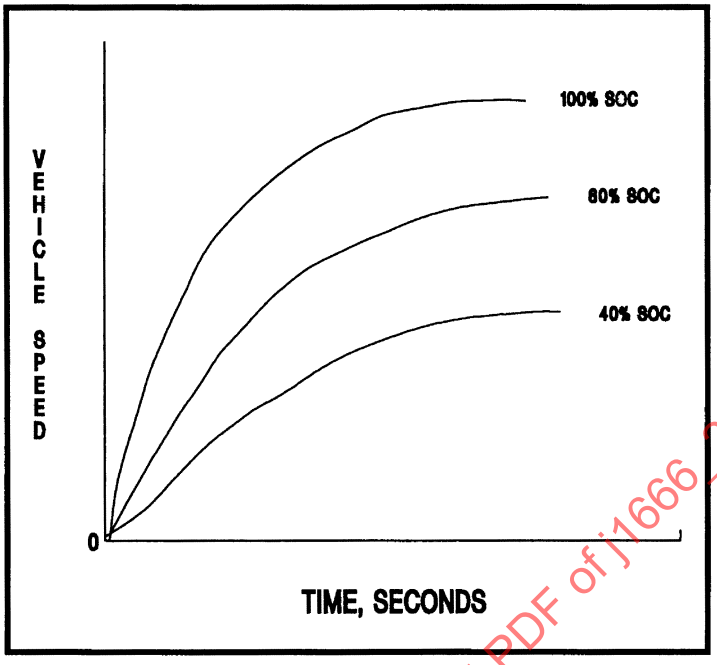

FIGURE 1—ACCELERATION CHARACTERISTICS

7.3 Calculation of Gradeability Limit—The percent gradeability limit is to be determined using the following relationship:

$$\text{Percent Gradeability Limit} = 100 \tan\left(\sin^{-1}\frac{P}{W}\right) \quad \text{(Eq. 1)}$$

where:

P = Measured traction force, N (lb)
W = Manufacturer's rated gross vehicle weight, kg (lb)

7.4 Special Data Requirements—The procedures in Section 7 establish the gradeability limit of the test vehicle as a function of the battery state-of-charge. If the traction force is limited by slippage between the vehicle's drive wheels and the road surface this fact should be recorded.

8. Gradeability at Speed

8.1 Purpose of Test—The purpose of this test is to determine the maximum grade which can be maintained at different vehicle speeds. The effect of battery state-of-charge on this vehicle capability is identified in these tests. Two alternate procedures are described. An analytical method using data collected in Section 6 is described along with a direct dynamometer procedure.

8.2 Analytical Method

8.2.1 Using the speed-time data from the road tests of Section 6, the vehicle's acceleration characteristics shall be plotted as in Figure 2 for each state-of-charge. Data for successive time intervals then are to be used to determine the vehicle's average acceleration during the nth time interval.

$$\bar{a}_n = \frac{V_n - V_{n-1}}{t_n - t_{n-1}} \qquad \text{(Eq. 2)}$$

when the vehicle has reached the average speed,

$$\bar{V} = \frac{V_n + V_{n-1}}{2} \qquad \text{(Eq. 3)}$$

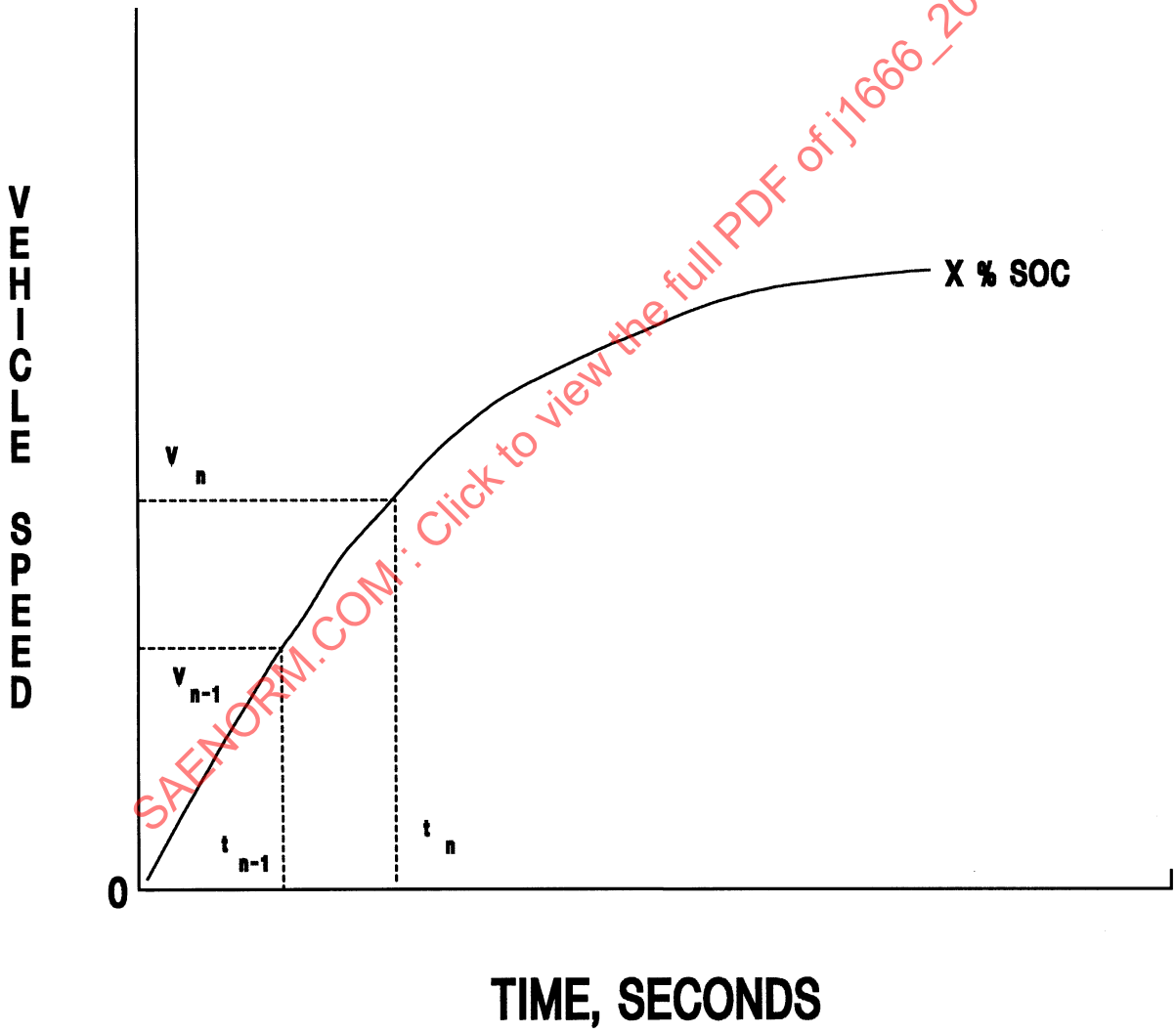

FIGURE 2—VEHICLE SPEED VERSUS TIME DURING ACCELERATION

The data derived from these calculations shall be plotted as average acceleration versus vehicle speed and a smooth curve shall be drawn through the calculated points for each state-of-charge, as shown in Figure 3.

If the test vehicle is equipped with a recording accelerometer as well as speedometer during the test of Section 6, the information of Figure 3 is obtained directly. The percent grade the vehicle is able to traverse at any selected speed is now to be calculated using the following relationship:

$$\text{Percent Gradeability at Speed} = 100 \tan(\sin^{-1} 0.0283a) \quad \text{(Eq. 4)}$$

where:

a = Vehicle acceleration at the selected speed, km/h-s

The constant 0.0283 in this equation becomes 0.0455 when acceleration is determined in English units of mph/s.

8.3 Dynamometer Tests—A chassis dynamometer can also be used to determine gradeability at speed providing that the total road power loss of the vehicle has been established for various vehicle speeds using the procedure of Section 10.

8.3.1 DYNAMOMETER TEST PROCEDURE—Dynamometer tests of vehicle gradeability at speed are to be made for a number of different initial battery states-of-charge. Vehicle and dynamometer test conditions are those presented in Section 4.

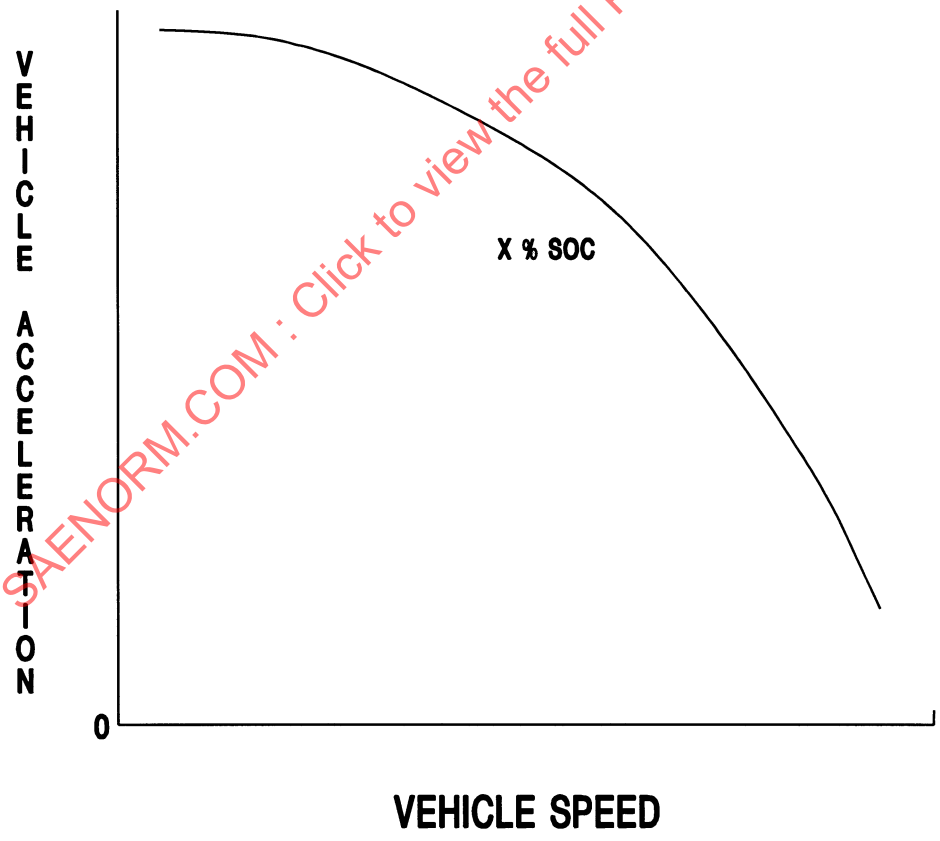

FIGURE 3—VEHICLE MAXIMUM ACCELERATION VERSUS VEHICLE SPEED

8.3.1.1 With a preselected dynamometer load, the vehicle shall be accelerated to a stabilized balance speed which must be maintained for a minimum period of 20 s. Speed variation during the 20-s test interval should not exceed 5%.

8.3.1.2 The dynamometer power consumption shall be determined at various speeds and used to calculate gradeability at speed.

8.3.2 DYNAMOMETER DATA PROCESSING—The percent gradeability at speed for the test vehicle shall be calculated from the dynamometer test data and the road load data of Section 9 using the following relationship:

$$\text{Percent Gradeability at Speed} = 100\tan\left[\sin^{-1}\left(\frac{367.2(p - p_o)}{Wv}\right)\right] \quad \text{(Eq. 5)}$$

where:

p = Power delivered to the dynamometer at test speed, kW (hp)
p_o = Road load power consumed by the vehicle at test speed, kW (hp)
v = Vehicle test speed, km/h (mph)
W = Manufacturer's rated gross vehicle weight, kg (lb)

The constant in Equation 5 is 375 when English units are used.

8.4 Special Data Recording

8.4.1 The calculated percent gradeability of the vehicle shall be recorded for each test speed and for the three battery initial states-of-charge specified in 4.2.5.

8.4.2 When reporting these gradeability data, it shall be specified whether they are based upon road test or dynamometer test results.

9. Deceleration

9.1 The vehicle shall be subjected to the same braking tests as other road vehicles, and existing SAE standard practices shall apply including SAE J843d and J992b, as applicable.

10. Coastdown Testing

10.1 Purpose of Test—The purpose of this procedure is to determine the road load force on a vehicle as a function of vehicle velocity so that accurate simulation of the road load force on a chassis dynamometer can be accomplished.

10.2 Test Procedure—Vehicle road load power and energy consumption at various steady speeds are to be determined from coastdown tests which shall be performed according to SAE J1263 with the following modifications.

10.2.1 Vehicle regenerative braking shall be disabled during coastdown testing; minimizing any changes to the mechanical system (see SAE J1634).

10.2.2 Presently no procedure exists for vehicles that cannot obtain the vehicle speeds required in SAE J1263. When determining the road load power setting for these vehicles, good engineering practice should be used to modify these procedures for the lower speeds to determine the road load power setting. As an alternative, road load power settings may be determined by the frontal area method found in Appendix A.

10.3 Data to be Recorded—Data recording requirements shall be the same as those specified in SAE J1263.

10.4 Data Reduction

10.4.1 The vehicle speed versus time data obtained during the coastdown tests shall be processed as specified in SAE J1263 to calculate the 88 to 72 km/h (55 to 45 mph) coastdown time for use in chassis dynamometer simulation of vehicle road load.

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