



SURFACE VEHICLE RECOMMENDED PRACTICE

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(R) Recommended Practice for Measuring Fuel Economy and Emissions
of Hybrid-Electric and Conventional Heavy-Duty Vehicles

RATIONALE

The Code of Federal Regulations defines powertrain testing in 40 CFR §1037.550 as one of the methodologies to establish the fuel consumption maps for a powertrain (§1036.510) over pre-determined duty cycles and vehicle configurations. This technique allows manufacturers to capture the fuel economy benefits realized by optimizing the powertrain as a system, as these gains might not be completely captured when using an engine-only certification approach combined with the EPA's GEM model.

FOREWORD

Most major medium- and heavy-duty truck OEMs and Tier1 suppliers now offer integrated conventional powertrains that have been optimized as a system where their components (engine, transmission, and final drive) have been sized to match the rest of the powertrain and are controlled to maximize engine fuel efficiency and minimize exhaust emissions. Hybrid electric powertrains are also relying on a system approach to operate as efficiently as possible.

It therefore makes sense to test these powertrains as a system to capture the gains that they enable and that might be otherwise overlooked when testing a stand-alone engine.

The SAE Truck and Bus Hybrid and Electric Vehicle Committee and the Northeast Advanced Vehicle Consortium (NAVC) Hybrid Transit Bus Certification Workgroup collaborated on development of a heavy-duty HEV chassis testing protocol. This Workgroup intends to build on this protocol as well as input from its members to define clear procedures for powertrain testing. The latest revisions to the document reflects the work of the Truck and Bus Powertrain Task Force, which aims to include considerations and requirements for 40 CFR §1037.550.

This document should be viewed as a starting point for standardizing MD/HD powertrain testing. Heavy-duty HEVs are still a relatively new technology. Over the next several years, hybrid-electric systems will be evolving and many new types of hybrid drive systems may become commercially available. It is likely, therefore, that this testing protocol will need to be revisited and, possibly, revised, as the MD/HD HEV industry matures. In the meantime, this document will focus on conventional powertrains as integrated powertrains are commercially available and need a testing standard.

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1. SCOPE

This SAE Recommended Practice was established to provide an accurate, uniform, and reproducible procedure for simulating use of MD/HD conventional vehicles (CVs) and hybrid-electric vehicles (HEVs), as well as plug-in hybrid-electric vehicles (PHEVs) and battery electric vehicles (BEVs) on powertrain dynamometers for the purpose of measuring emissions and fuel economy. This document does not specify which emissions constituents to measure (e.g., HC, CO, NOx, PM, CO₂), as that decision will depend on the objectives of the tester. While the main focus of this procedure is for calculating fuel and energy consumption, it is anticipated that emissions may also be recorded during execution of this procedure.

It should be noted that most MD/HD powertrains addressed in this document would be powered by engines that are certified separately for emissions. The engine certification procedure appears in the Code of Federal Regulations, Title 40 §86 and §1065.

1.1 Requirements Used to Develop the Recommended Practice

This document was developed to allow for the fair, representative, repeatable, and accurate testing of medium- and heavy-duty powertrains so that direct comparisons can be made between hybrid-electric and conventional powertrains. To meet this goal, the following guidelines have been followed:

- a. This document will provide a recommended practice to measure CO₂ emissions and fuel economy of any type of conventional and HEV design, including charge depleting and charge sustaining.
- b. Where applicable, driver selectable modes may be evaluated (e.g., turning off regenerative braking).
- c. The use of the existing powertrain test cycles provided with this document is highly recommended, but this document allows for the creation or adjustment of test cycles to better represent the powertrain's in-use application.
- d. Testing shall not require defeating or otherwise forcing a powertrain's control system to perform differently from the way in which it would perform in use (potential exceptions include grade estimation algorithms that may affect dynamometer testing).

2. REFERENCES

2.1 Applicable Documents

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

2.1.1 SAE Publications

Available from SAE International, 400 Commonwealth Drive, Warrendale, PA 15096-0001, Tel: 877-606-7323 (inside USA and Canada) or +1 724-776-4970 (outside USA), www.sae.org.

SAE J1321	Fuel Consumption Test Procedure - Type II
SAE J1634	Battery Electric Vehicle Energy Consumption and Range Test Procedure
SAE J1711	Recommended Practice for Measuring the Exhaust Emissions and Fuel Economy of Hybrid-Electric Vehicles, Including Plug-in Hybrid Vehicles
SAE J1715	Hybrid Electric Vehicle (HEV) and Electric Vehicle (EV) Terminology
SAE J2263	Road Load Measurement Using Onboard Anemometry and Coastdown Techniques
SAE J2264	Chassis Dynamometer Simulation of Road Load Using Coastdown Techniques
SAE J2951	Drive Quality Evaluation for Chassis Dynamometer Testing

2.1.2 Code of Federal Regulations (CFR) Publications

Available from the United States Government Printing Office, 732 North Capitol Street, NW, Washington, DC 20401, Tel: 202-512-1800, www.gpo.gov.

10 CFR §474	Electric and Hybrid Vehicle Research, Development, and Demonstration Program; Petroleum-Equivalent Fuel Economy Calculation
40 CFR §86	Control of Air Pollution from New and In-Use Motor Vehicles and New and In-Use Motor Vehicle Engines; Certification and Test Procedure
40 CFR §600	Fuel Economy of Motor Vehicles
40 CFR §1036	Control of Emissions from New and In-Use Heavy-Duty Highway Engines
40 CFR §1037	Control of Emissions from New Heavy Duty Motor Vehicles
40 CFR §1065	Engine Testing Procedures
40 CFR §1066	Vehicle Testing Procedures

2.1.3 ASTM Publications

Available from ASTM International, 100 Barr Harbor Drive, P.O. Box C700, West Conshohocken, PA 19428-2959, Tel: 610-832-9585, www.astm.org.

ASTM D240-02	Standard Test Method for Heat of Combustion of Liquid Hydrocarbon Fuels by Bomb Calorimeter
ASTM D4809-00	Standard Test Method for Heat of Combustion of Liquid Hydrocarbon Fuels by Bomb Calorimeter (Precision Method)

3. DEFINITIONS

3.1 POWERTRAIN

A group of components that generates power and delivers it to the wheels. It can be made of engines, electric machines, transmissions, final drives, and drive shafts.

3.1.1 ENGINE

A device that converts the energy stored in a consumable fuel into mechanical energy. Examples include, but are not limited to, spark-ignition engines and compression-ignition engines.

NOTE: Although a fuel cell uses a consumable fuel, it is not considered an engine by itself because it does not produce mechanical energy.

3.1.2 ELECTRIC MOTOR-GENERATOR SYSTEM

A device that can convert mechanical energy into electrical energy (e.g., to recharge the RESS), electrical energy into mechanical energy (e.g., to propel the vehicle), or both.

3.1.3 TRANSMISSION

A device that converts the power supplied by an engine or electric machine by adapting its speed to the rotating speed of the drive axle or drive wheels.

3.1.4 DRIVE AXLE

A device that converts the power supplied by the transmission by adapting its speed to the rotating speed of the drive wheels.

3.2 General

3.2.1 CONVENTIONAL VEHICLE (CV)

Defined as a road vehicle that draws propulsion energy from a consumable fuel.

3.2.2 HYBRID ELECTRIC VEHICLE (HEV)

Defined as a road vehicle that can draw propulsion energy from the following sources of stored energy: (1) a consumable fuel, and (2) an RESS that is recharged by an electric motor-generator system, an external electric energy source, or both.

3.2.3 PLUG-IN HYBRID ELECTRIC VEHICLE (PHEV)

A classification describing a HEV with an RESS that is designed to be recharged from an external (off-vehicle) electric energy source, typically an AC electrical power supply system.

NOTE: Equivalent to “off-vehicle charge capable HEV,” “grid-connected HEV,” and “externally chargeable HEV.”

3.2.4 CURB WEIGHT

The total weight of the vehicle with all standard equipment and including batteries, lubricants at nominal capacity and the weight of optional equipment. Incomplete trucks shall have the curb weight specified by the manufacturer.

3.2.5 CONSUMABLE FUEL

Any solid, liquid, or gaseous material that releases energy and whose mass is converted to gaseous or particulate emissions as a result of the test process. Consumable fuels covered by this document are limited to petroleum-based liquid fuels (e.g., gasoline and diesel fuel), alcohol-based liquid fuels (e.g., methanol and ethanol), and hydrocarbon-based gaseous fuels (e.g., compressed natural gas).

3.2.6 FUEL CONSUMPTION (FC)

Amount of fuel used by the powertrain during any cycle in this document. Expressed either as a total amount for a given cycle in units of mass of volume, or as a rate per unit distance, as in gallons/mile (gal/mi), or liters per 100 kilometers (L/100 km).

3.2.7 LOAD-SPECIFIC FUEL/ENERGY CONSUMPTION (LSFC/LSEC) — FUEL OR ELECTRICAL ENERGY

LSFC is the preferred method, in engine dynamometer testing, to express electrical or fuel consumption for a medium-duty vehicle that carries a significant payload. This metric calculates energy consumed per unit of work performed. To avoid simply making heavier vehicles and promote the ability of a comparable vehicle to carry larger payloads, the payload is used for the weight used in the calculations. For fuel, the preferred units are gallons of fuel per ton-mile (gal/ton-mi). For vehicles that have an unloaded versus GVW ratio of 0.8 or above, energy consumption as opposed to load-specific consumption is the preferred metric.

3.2.8 START OF TEST

The point during the test sequence at which the powertrain is powered up (the key switch (or equivalent) is placed in the “on” position).

3.2.9 END OF TEST (EOT)

The point (in time and distance) at which the appropriate test termination criteria have been met (the key switch (or equivalent) is placed in the “off” position).

3.3 Energy Storage Systems

3.3.1 RECHARGEABLE ENERGY STORAGE SYSTEM (RESS)

A component or system of components that stores energy and for which its supply of energy is rechargeable by an electric motor-generator system, an external electric energy source, or both. An example of RESS for HEVs is a battery.

3.3.2 SYSTEM VOLTAGE (V_{system})

The nominal battery voltage associated with the SOC in charge-sustaining operation. This value, as well as the full range of voltage variation, should be supplied by the manufacturer.

3.3.3 RATED AMPERE-HOUR (A·h) CAPACITY

The manufacturer-rated capacity of a battery in ampere-hours obtained from a battery discharged at the manufacturer's recommended discharge rate such that a specified minimum cut-off terminal voltage is reached.

3.3.4 BATTERY CURRENT THROUGHPUT (BCT — A·h)

BCT represents the net change in integrated current of a battery at any given point in time relative to another point in time, expressed in ampere-hours (A·h). The current throughput of the battery in a fully charged state (i.e., RESS off charge and beginning the first cycle of an FCT test) may be defined as zero, or a value representing the measured current into the battery during recharge (where zero BCT is the nominal level during charge-sustaining operation).

NOTE: In this document, the zero-at-charge-sustaining definition is used.

3.3.5 EXTERNAL ELECTRIC ENERGY SOURCE

A source of electric energy that is not connected, or coupled to the RESS in any way, while the vehicle is being driven. An example of an external electric energy source is an electric outlet to which the RESS can be connected for recharging. In contrast, an inductive charger built into the roadway would not fit this definition.

3.3.6 ELECTRICAL ENERGY CONSUMPTION (EC)

Amount of electrical energy used by a powertrain during one or all CD cycles in the FCT. Expressed either as a total amount in watt-hours (W·h) or a rate per unit distance, as in watt-hours/mile (W·h/mi).

NOTE: This can be attributed to the DC W·h measured at the RESS terminals on-board or the AC W·h measured during charging and associated to consumption during driving, thus electrical energy consumption must always be expressed in "DC W·h/mi" or "AC W·h/mi." The "AC" seeks to estimate the losses between the grid supplying the power and the RESS charger. If a direct AC wall measurement is unavailable (for example, certain DC charging scenarios), good engineering judgement may be used to estimate these losses.

3.3.7 CHARGE-SUSTAINING (CS) MODE

Operating mode where the HEV runs by consuming the fuel energy while sustaining the electric energy of the RESS.

3.3.8 CHARGE-DEPLETING (CD) MODE

Operating mode of a HEV in which the powertrain run by consuming only the electric energy from the mains or along with the fuel energy simultaneously or sequentially until the CS mode state.

3.3.9 CHARGE-SUSTAINING TEST OR PARTIAL CHARGE TEST (PCT)

Evaluation of the powertrain operating in charge-sustaining mode.

3.3.10 CHARGE DEPLETING TEST OR FULL CHARGE TEST (FCT)

Evaluation of the powertrain in charge deleting mode.

3.3.11 ALL-ELECTRIC RANGE

The total continuous miles driven for a given FCT prior to the first engine start while the powertrain vehicle is in all-electric mode (i.e., the mode when the powertrain's combustion engine is not operating).

3.3.12 CHARGE BALANCED CYCLE

A drive cycle during which the change (from beginning to end) in SOC of the RESS is maintained within a specified tolerance.

3.3.13 TRANSITION CYCLE

The transition cycle is defined as, in the FCT, the test cycle where the RESS transitions from a CD mode to a CS mode. The transition cycle will end in CS mode but will be net depleting (beyond the EOT criterion) and the following cycle, or cycles, will be charge sustaining. This definition is illustrated in [Figure 1](#).

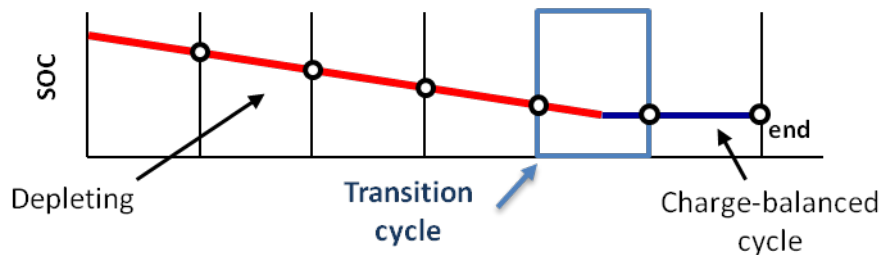


Figure 1 - Transition cycle definition

3.3.14 TRANSITION RANGE

The transition cycle is defined as, in the FCT, if the cycle or cycles prior to the first CS cycle or cycles are anything but CD, then there will be a portion of operation between CD and CS operation; this operation is defined as the transition range. See [Figure 2](#).

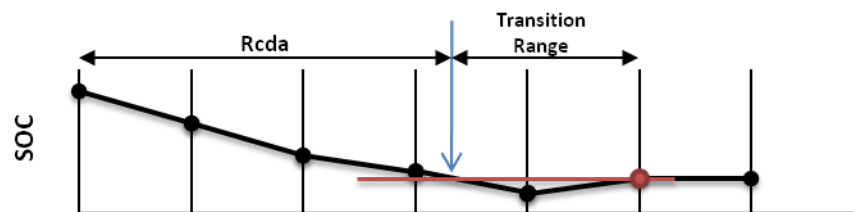


Figure 2 - Transition range

3.3.15 CHARGE-DEPLETING CYCLE RANGE (Rcdc)

For a given test FCT, the total distance traveled in the FCT until the end of the last cycle before the net off-vehicle electrical energy has been exhausted. Typically, all subsequent cycles are charge sustaining. Rcdc range includes the transitional cycle where powertrain may have operated in both depleting and sustaining modes. If the FCT possesses a transitional range, then the Rcdc is the total distance traveled until the end of the last cycle that does not satisfy the NEC tolerance.

3.3.16 ACTUAL CHARGE-DEPLETING RANGE (Rcda)

A prediction of the distance when the off-board energy was exhausted and charge-sustaining operation began. The total distance, measured from the start of the FCT, through any subsequent charge depleting test cycles and ending at a point in the transitional cycle proportional to the change in SOC of the transitional cycle compared to the cycle previous to the transitional cycle.

3.3.17 REGENERATIVE BRAKING

Deceleration of the vehicle caused by operating an electric motor-generator system, thereby providing charge to the RESS.

3.3.18 CHARGER

The component that recharges the RESS by connecting to the offline electrical power source ("wall plug") and converting AC electrical power to DC electrical power at the appropriate voltage and current levels to charge the RESS.

NOTE: For the purposes of this procedure, the charger is considered part of the powertrain system (on- or off-board charger), electrical energy consumption measurements produced from this procedure will include charger performance (charger efficiency).

3.3.19 FULL CHARGE

The RESS state associated with maximum off-board stored energy capacity established by using the manufacturer's recommended charging procedure and appropriate equipment. The charger should indicate full charge by an easily read indicator. The state must be indicated to the powertrain tester and also be achieved consistently from test to test for accurate and reliable calculations of AC kW•h energy consumption.

3.3.20 DC ENERGY CONSUMPTION

The total net direct current energy that was measured leaving the RESS during the entire FCT expressed as a total (DC W•h) or per unit distance (DC W•h/mi).

3.3.21 AC RECHARGE ENERGY

The total electrical energy taken from a wall outlet that powers the charger to recharge the RESS back to the state at which a test started, measured in real AC watt-hours (AC W•h).

3.4 SPEED TOLERANCE

The speed tolerance at any given time on these driving schedules is defined by the upper and lower limits as described in 40 CFR §86.115-78. It should be noted that if a vehicle cannot follow a trace within the prescribed tolerance, a "best-effort" attempt is acceptable. For the "best effort" case, if the vehicle cannot accelerate at the specified rate, operate it at maximum available power until the vehicle speed reaches the value prescribed in the driving schedule. If the vehicle acceleration is limited by a user-selectable mode (i.e., "eco-mode") and not simply available system power, this mode must be documented and reported prior to the start of testing. Documentation of this mode should include the commercial name of the mode as well as a succinct definition of how the mode limits available power.

NOTE: Driving "style" can also have a significant effect on emissions and/or fuel economy results. To address this factor, the EPA has provided guidance per §86.128-00(d): The vehicle shall be driven with appropriate accelerator pedal movement necessary to achieve the speed versus time relationship prescribed by the driving schedule. Both smoothing of speed variations and excessive accelerator pedal perturbations are to be avoided.

The diagrams in [Figure 3](#) show the EPA range of acceptable speed tolerances for typical points, per 40 CFR §86.115-78 and 40 CFR §1066.425: EPA urban dynamometer driving schedules. The curve on the left is typical of portions of the speed curve which are increasing or decreasing throughout the 2 second time interval. The curve on the right is typical of portions of the speed curve which include a maximum or minimum value.

Note that the speed tolerance in 40 CFR §1066.425(b)(1) and (2) are required for GHG Phase 2 transient test cycles. For the GHG highway cruise cycles, vehicle speed must be maintained within +3 mph and -1 mph of the speed setpoint. For further explanation, refer to 40 CFR §1037.510(a)(3)(i) and (ii).

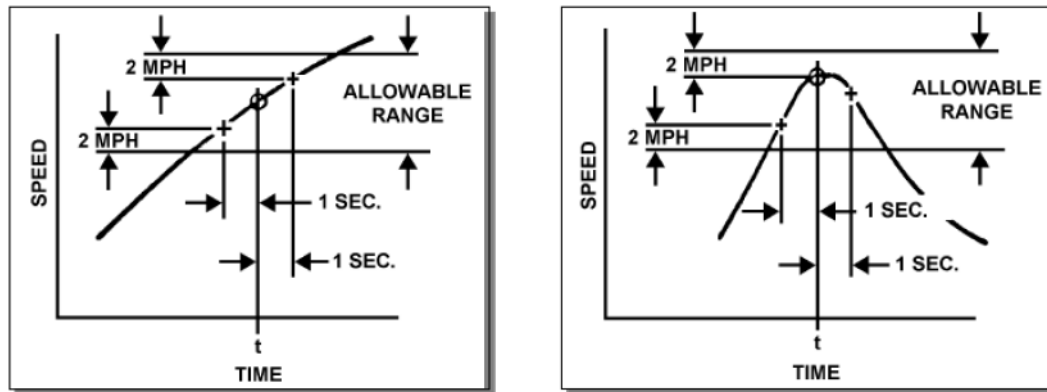


Figure 3 - Speed tolerance definitions

3.4.1 SPEED TOLERANCE VIOLATIONS

During testing, any speed versus time pairs that violate the speed tolerance constitute a speed tolerance violation and must be documented. Documentation for violations should include the time and speed values, the reason for the deviation, and the distance traveled during the violation. Although all violations must be documented, certain violations do not necessarily invalidate a test. Allowable speed violations that do not invalidate a test are as follows:

1. Speed tolerance violations for 2.0 seconds or less on any occasion.
2. For powertrains that are not able to maintain the virtual vehicle acceleration as specified in §1066.415(e)(5), violations due to insufficient best-effort acceleration.

Although the violations specific in this section do not necessarily invalidate a test, care must be exercised when comparing the results of tests with and without significant violations.

In select cases, using good engineering judgement, alternate test cycle, and cycle-validation criteria for powertrains that do not have enough power to follow the specified driving trace may be used. The alternate driving specifications must be based on making best efforts to maintain acceleration and speed to follow the specified test cycle. Alternate driving tolerance specifications must be identified prior to testing.

3.5 NET ENERGY CHANGE (NEC) TOLERANCES

In order to detect CS operation and thus the end of the FCT, the main criterion is that the RESS shall not have an NEC over the test cycle greater than a defined tolerance. The tolerance must be kept small enough to ensure that the powertrain is operated over the test cycle as nearly as possible to CS operation to achieve repeatable test results. However, current RESS and measurement technologies are limited in their abilities to produce repeatable test results. Therefore, some tolerance must be allowed for initial versus final net energy levels to avoid a high rate of invalid tests. For purposes of this document, an objective has been set to be able to measure a value for fuel consumption that is approximately within $\pm 2\%$ of the powertrain's true, representative fuel consumption on any given CS test. Test experience and analysis suggest that this goal can be met by limiting the change in stored RESS electrical energy over the test cycle to $\pm 1\%$ of the total fuel energy consumed over the same cycle. As powertrain technologies change, this tolerance may need to be updated to ensure that the stated 2% error is still within the NEC tolerance. Equation 1 illustrates the basic NEC tolerance.

$$\text{NEC Tolerance: } \left| \frac{\text{NEC}_{\text{battery}}}{\text{NEC}_{\text{fuel}}} \right| \leq 1\% \quad (\text{Eq. 1})$$

In this procedure, the NEC of the RESS is defined as change in BCT over a cycle (or cycles) multiplied by V_{system} as shown in Equation 2. For this document, V_{system} is typically defined as the average of battery terminal voltage at the beginning and end of a particular cycle (or group of cycles). The V_{system} may also be supplied directly by the manufacturer. An additional provision has been included to allow for good engineering judgment if the averaging method is determined to be inaccurate for a particular RESS. If this is true, a suitable dynamic battery model may be selected which includes an open circuit voltage term and this model may be fit for each test and used to provide an improved V_{system} estimate.

Equation 3 for the fuel energy component of the NEC tolerance, fuel energy is defined as net heating value (NHV) multiplied by the mass of fuel consumed during a particular cycle or cycles of interest, as in the following:

$$NEC_{\text{battery}} = (BCT_{\text{final}} - BCT_{\text{initial}}) * V_{\text{system}} \quad (\text{Eq. 2})$$

$$NEC_{\text{fuel}} = NHV_{\text{fuel}} * m_{\text{fuel}} \quad (\text{Eq. 3})$$

For charge-sustaining tests, one of the test validation criteria is that the RESS shall not have a NEC over the test cycle greater than a defined tolerance as shown by Equation 4. The tolerance must be kept small enough to ensure that the powertrain is operated over the test cycle as nearly as possible to charge-sustaining operation to achieve repeatable test results. However, current RESS and measurement technologies are limited in their abilities to produce repeatable test results. Therefore, some tolerance must be allowed in initial versus final net energy levels to avoid a high rate of invalid tests.

Solving for the maximum and minimum allowed final battery NEC gives:

$$(A \bullet h_{\text{final}})_{\text{max}} = (A \bullet h_{\text{initial}}) + \frac{NHV_{\text{fuel}} * m_{\text{fuel}}}{V_{\text{system}} * K_1} * 0.01$$

$$(A \bullet h_{\text{final}})_{\text{min}} = (A \bullet h_{\text{initial}}) - \frac{NHV_{\text{fuel}} * m_{\text{fuel}}}{V_{\text{system}} * K_1} * 0.01$$

Therefore, the NEC tolerance for batteries is:

$$-\frac{NHV_{\text{fuel}} * m_{\text{fuel}}}{K_1} * 0.01 \leq NEC \leq \frac{NHV_{\text{fuel}} * m_{\text{fuel}}}{K_1} * 0.01 \quad (\text{Eq. 4})$$

where:

NEC = net change in battery energy over test, in units of watt-hours

$(A \bullet h_{\text{final}})_{\text{max}}$ = maximum allowed stored battery ampere-hours at the end of the test phase

$(A \bullet h_{\text{final}})_{\text{min}}$ = minimum allowed stored battery ampere-hours at the end of the test phase

$(A \bullet h_{\text{initial}})$ = battery ampere-hours stored at the beginning of the test phase

NHV_{fuel} = net heating value (per consumable fuel analysis), in joules per kilogram

m_{fuel} = total mass of fuel consumed over test phase, in kilograms

V_{system} = battery's DC nominal system voltage

K_1 = conversion factor = 3600 s/h

3.6 FCT END OF TEST (EOT) CRITERION

In the FCT, test cycles are repeated until the powertrain has exhausted the energy designed to be consumed during CD mode. Once CS behavior is observed, there is no reason to continue testing. The manufacturer shall inform the tester if a transitional range (an on-board charging mode) is expected to avoid stopping the test too early. CS operation is validated if the ΔSOC of the last cycle or last series of cycles is less than 2% of the total depleted capacity or the NEC tolerance, whichever is larger. As noted earlier, the NEC tolerance is defined using the consumable fuel found in the CST because during the FCT, the fuel usage calculations during a given cycle are not expected to be found until after the next cycle start is initiated.

The test facility should have an indicating system in place to alert the driver and other testing staff that the FCT ending criterion is achieved during the intra-test pauses for the given cycle or combination of cycles looking backward from the end of the last test. Several examples of this criterion are shown in [Figure 4](#).

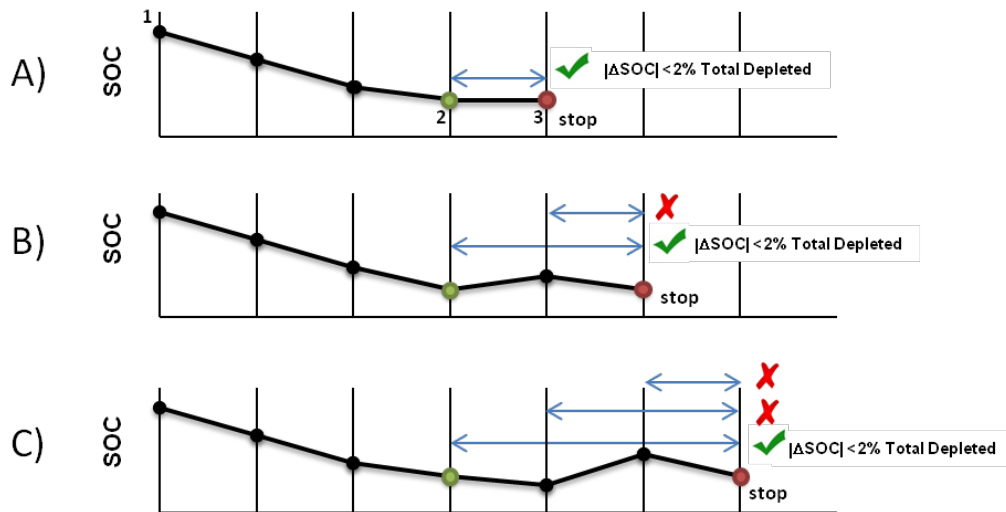


Figure 4 - Several scenarios of end of full charge test criterion

[Figure 4](#) (A) shows the EOT criterion satisfied for the last cycle where the absolute value of SOC_3 minus SOC_2 is less than 2% of SOC_1 minus SOC_3 . (B) and (C) provide additional examples where windows of multiple cycles satisfy the EOT criterion.

4. TEST FACILITIES

4.1 Dynamometer Specifications

The evaluation of the emissions and fuel economy from a heavy-duty conventional or hybrid powertrain should be performed using a laboratory that incorporates a powertrain dynamometer capable of mimicking the transient inertial load and road loads and speeds associated with normal operations of heavy-duty vehicles.

4.1.1 Dynamometer Capabilities

The dynamometer needs to be able to duplicate the inertial and road loads associated with operating a powertrain in actual use. The powertrain operating region can cover a very large speed and load range because of the large gear ratio spread on a HD transmission, which will cause very high torques and low speeds in lower gears and low torques and high speeds in higher gears. Prior to testing, make sure that the powertrain cannot exceed the speed and torque capabilities of the dynamometer.

Also, transient capabilities of the dynamometers have to be checked against transient characteristics of the drive cycles to be performed. A test run should be performed to ensure that the dynamometer can handle the powertrain transients during the complete drive cycle.

If the powertrain is capable of regenerative braking (or even engine braking), the dynamometer has to be able to not only absorb torque from the powertrain but also produce torque representative of vehicle deceleration sequences, that will be absorbed by the powertrain.

4.1.2 Dynamometer Calibrations

The dynamometer laboratory should provide its calibration procedures as recommended in 40 CFR §1065 Subparts D, and by the manufacturer.