SURFACE VEHICLE RECOMMENDED PRACTICE	J1634™	APR2021
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(R) Battery Electric Vehicle Energy Consumption and Range Test Procedure

RATIONALE

Battery electric vehicle (BEV) technology has continued to progress since SAE J1634 was revised to include the multi-cycle test (MCT). BEV driving ranges and capabilities continue to increase along with the addition of many new BEV models in the marketplace, further taxing lab testing.

In order to reduce lab test burden, a short multi-cycle test (SMCT) is introduced to allow longer range BEVs to perform a fixed distance test in approximately 50% of the dynamometer time of an MCT test, while achieving comparable range and energy consumption results. This method utilizes an off-board discharge process to determine remaining energy in the battery pack.

A short multi-cycle test plus steady state (SMCT+) is also introduced to provide driver flexibility for longer range BEVs to perform testing for range, energy consumption, and five-cycle test data simultaneously without the need for additional off-board discharge equipment.

Single-cycle test (SCT), MCT, SMCT, SMCT+, and BEV five-cycle testing (Appendix B) have also been amended to allow thermal conditioning prior to driving, a desired customer feature in today's BEV marketplace to improve vehicle range.

FOREWORD

Historically, the determination of range and energy consumption for battery electric vehicles (BEV) has relied on the SCT methodology. The SCT requires that a vehicle be repeatedly driven over the same speed versus time profile (i.e., drive cycle) until the vehicle's battery energy is completely exhausted. The long and indeterminate nature of the SCT places significant logistical strains on test facilities, a situation that will worsen as battery technology advancements enable even greater range capability. It is also possible that additional test cycles—beyond the currently required UDDS ("city") and HFEDS ("highway") cycles—will be necessary in order to better characterize the effects of temperature and accessory loads on range performance, making the SCT paradigm even less practical. For these reasons, a multi-cycle test (MCT) procedure was been developed.

The MCT method enables range and alternating current (AC) energy consumption determinations for multiple drive cycle types using a single full depletion test. This is accomplished by measuring: (1) the DC energy consumption for each included cycle type, and (2) the battery's useable direct current (DC) energy content. Given the total energy content of the battery, the range for each drive cycle type follows directly from its respective energy consumption. Similarly, the appropriate quantity of AC recharge energy attributable to each drive cycle can be determined according to its respective DC energy consumption. The MCT method is applicable to vehicles powered by lithium ion batteries and tested using the existing standard drive cycles; new battery technologies, new drive schedules, or significantly different vehicle designs should be evaluated to determine if this method adds test burden over time. Significant reductions in the testing resources needed to produce both a city and highway range determination are possible using the MCT method as compared to the SCT method. For example, a BEV with a 150 mile unadjusted UDDS range would consume about 18-1/2 hours of total dynamometer test time in order to perform the necessary city and highway SCT tests. The same city and highway range determinations could be accomplished in about 4-1/2 hours using a single MCT (a reduction of over 75%). Given a 200 mile UDDS range, the differential between the on-dyno test times increases further to 24-1/2 hours and 5-1/2 hours, respectively, for the SCT and MCT. These estimates do not account for the additional savings that accrue from the elimination of one of the two recharging periods required by the SCT procedure.

As vehicles powered by new battery technologies continue to evolve into longer range vehicles, the SMCT method enables range and AC energy consumption determination by means of a shorter test method as compared to the MCT method. While the recorded data elements of the testing remain similar, dynamometer usage may be reduced by approximately 50% using the SMCT method, allowing longer lead time measurements (e.g., useable battery energy) to conclude in a soak room setting using on-board discharging capability to a load device. Additionally, all vehicles are subjected to the same drive cycle duration, which avoids the need for iterative steady state calculations and unique drive profiles that are required by the MCT cycle. The SMCT cycle also avoids additional test days to quantify FTP, HFEDS, and US06 data required when five-cycle testing is applied by combining these cycles within the SMCT cycle profile.

To further reduce test burden for long-range BEV vehicles that do not have on-board discharging capability to a device, the SMCT+ test is introduced. The phase testing of the SMCT+ test remains the same as SMCT, a fixed distance, which eliminates the need for a variable mid-test depletion required on MCT. The SMCT and SMCT+ tests allow the variable depletion portion of the test to occur after the specific phase measurements are completed.

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1. SCOPE

This SAE Recommended Practice establishes uniform procedures for testing battery electric vehicles (BEVs) which are capable of being operated on public and private roads. The procedure applies only to vehicles using batteries as their sole source of power. It is the intent of this document to provide standard tests which will allow for the determination of energy consumption and range for light-duty vehicles (LDVs) based on the federal emission test procedure (FTP) using the urban dynamometer driving schedule (UDDS) and the highway fuel economy driving schedule (HFEDS) and provide a flexible testing methodology that is capable of accommodating additional test cycles as needed. Additionally, this SAE Recommended Practice provides five-cycle testing guidelines for vehicles performing supplementary testing on the US06, SC03, and cold FTP procedure. Realistic alternatives should be allowed for new technology. Evaluations are based on the total vehicle system's performance and not on subsystems apart from the vehicle.

NOTE: The range and energy consumption values specified in this document are the raw, test-derived values. Additional corrections are typically applied to these quantities when used for regulatory purposes (corporate average fuel economy, vehicle labeling, etc.).

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 J1263 Road Load Measurement and Dynamometer Simulation Using Coastdown Techniques

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 J1772 SAE Electric Vehicle and Plug-in Hybrid Electric Vehicle Conductive Charge Coupler

SAE J2263 Road Load Measurement Using Onboard Anemometry and Coastdown Techniques

SAE J2264 Chassis Dynamometer Simulation of Road Load Using Coastdown Techniques

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.

40 CFR § 86 EPA; Control of Emissions from New and In-Use Highway Vehicles and Engines

40 CFR § 600 EPA; Fuel Economy and Carbon-Related Exhaust Emissions of Motor Vehicles

40 CFR § 1066 EPA; Vehicle-Testing Procedures

2.1.3 Other Publications

United States Advanced Battery Consortium, Electric Vehicle Battery Test Procedures Manual

United States Environmental Protection Agency, Specifications for Electric Chassis Dynamometers, Attachment A, RFP C100081T1, 1991

3. DEFINITIONS

3.1 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 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 BATTERY

A device, consisting of one or more electrochemical cells electrically connected in a series and/or parallel arrangement. Often used as shorthand for traction battery, a battery that provides power to propel a vehicle. Traction batteries are typically electrically rechargeable, with charge power supplied from the electrical grid through a charger or from energy captured through regenerative braking.

3.2.1 BATTERY AMPERE-HOUR CAPACITY

The capacity of a battery in A•h obtained from a battery discharged at the manufacturer’s recommended discharge rate such that a specified cut-off terminal voltage (see 3.2.3) is reached. This is generally provided as guidance for battery size and is not intended to replace measured data from testing within this procedure.

3.2.2 STATE OF CHARGE (SOC)

The percentage of useable energy remaining in the battery pack relative to the battery pack’s full charge useable energy.

3.2.3 CUT-OFF TERMINAL VOLTAGE

The manufacturer-recommended minimum operating voltage of the battery. This voltage can be either a function of load and/or temperature, or an absolute minimum.

3.2.4 FULL CHARGE (FC)

The battery state associated with maximum off-board stored energy capacity established by using the manufacturer’s recommended AC charging procedure and appropriate equipment. The charger should indicate full charge by an easily read indicator somewhere in or on the vehicle and/or charger connections. The state must be indicated to the vehicle tester and also be achieved repeatedly from test to test for accurate and reliable calculations of AC kW•h energy consumption.

3.3 THERMAL CONDITIONING

Thermal conditioning consists of either heating or cooling of the propulsion components (HV battery, motors, drive units, etc.) and/or heating or cooling of the vehicle’s interior cabin during the following three events: (1) vehicle charging period, (2) the soak period after charging while vehicle is connected to AC charging, and/or (3) prior to test with the vehicle loaded on the dynamometer and connected to AC charging. 12 V battery maintenance is not considered as thermal conditioning unless it leads to a significant change in propulsion component temperatures. Thermal conditioning, as defined in this paragraph, should not be performed when the vehicle is un-plugged. All tests utilizing thermal conditioning require monitoring of the pre-test AC recharge energy.

3.4 DIRECT CURRENT FAST CHARGE (DCFC) CONTACTORS

A direct connection between the fast charge port external to the vehicle and the high voltage battery pack can be completed with a secondary set of battery contactors.

3.5 HV BATTERY NOMINAL VOLTAGE (V_{nom})

The open circuit voltage (OCV) of a battery at a point which results in approximately 50% of the useable battery energy remaining.

3.6 FULL DEPLETION TEST (FDT)

A test sequence that fully depletes the useable energy content of a vehicle's battery. The test begins with the battery at FC and terminates when the remaining battery energy is insufficient to allow the vehicle to satisfactorily maintain the prescribed drive trace. Alternatively, a test that in one or more steps will fully deplete the useable energy content of a vehicle's battery if a partial depletion test is followed by further discharging of the battery.

3.7 PARTIAL DEPLETION TEST (PDT)

A dynamometer sequence that does not fully deplete the useable energy content of a vehicle's battery.

3.8 SINGLE-CYCLE TEST (SCT)

An FDT consisting of multiple phases of the same drive cycle (i.e., drive schedule).

3.9 MULTI-CYCLE TEST (MCT)

An FDT consisting of multiple phases of one or more drive cycles. The MCT enables the determination of range and energy consumption for multiple drive cycles using a single FDT. Data from the MCT can also be used to make range determinations for additional drive cycles that are not included in the MCT, but that are run in a standalone PDT.

3.10 SHORT MULTI-CYCLE TEST (SMCT)

The SMCT is an FDT consisting of seven phases which can be used as an optional procedure instead of the MCT. The SMCT allows for determination of range and energy consumption for multiple drive cycles using a two-step discharge process. An additional DC discharge test procedure is required and performed as a static measurement to complete the useable battery energy (UBE) determination. As such, the SMCT test requires use of an off-board discharge unit or cycler to complete the DC discharge test procedure.

3.11 SHORT MULTI-CYCLE TEST PLUS STEADY STATE (SMCT+)

The SMCT+ is an FDT consisting of eight phases which can be used as an optional procedure instead of the MCT. The SMCT+ allows for determination of range and energy consumption for multiple drive cycles using a single FDT. The SMCT+ parallels the SMCT test with the exception of the final depletion phase performed on the dynamometer at a constant speed.

3.12 DC DISCHARGE TEST

A test that discharges the remaining useable energy content of a vehicle's battery through the use of an off-board battery cycler or other means.

3.13 ELECTRIC VEHICLE SUPPLY EQUIPMENT (EVSE)

The conductors, including the ungrounded, grounded, and equipment grounding conductors and the electric vehicle connectors, attachment plugs, and all other fittings, devices, power outlets, or apparatuses installed specifically for the purpose of delivering energy from the premises wiring to the electric vehicle.

3.14 POST-TEST AC RECHARGE ENERGY (Eac_{post})

The AC energy, measured in AC Wh, from the power outlet required to return the battery to full charge after a drive cycle test, with the high voltage (HV) battery starting the charge event from a fully depleted state. This measurement must include energy needed to power charging equipment (e.g., EVSE).

3.15 PRE-TEST AC RECHARGE ENERGY (Eac_{pre})

The AC energy, measured in AC Wh, from the power outlet required to return the battery to full charge before a drive cycle test, with the HV battery starting the charge event from a fully depleted state. This measurement must include energy needed to power charging equipment (e.g., EVSE). This measurement method must be used when thermal conditioning is present before a test cycle.