



SURFACE VEHICLE RECOMMENDED PRACTICE

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(R) Storage Batteries for Start-Stop Operations

RATIONALE

Increased demands for fuel efficiency and lower environmental impact have fostered efficiency changes in the ways internal combustion engine (ICE) vehicles operate. In particular, time spent stopped in traffic with the vehicle engine at idle is recognized as a key source of wasted fuel together with CO₂ and other emissions. Many newer vehicles therefore utilize a relatively cost-efficient method of improving fuel efficiency by stopping the engine when the vehicle is temporarily halted and restarting it when the vehicle needs to be driven or after a limited discharge time. This has come to be called start-stop operation (often also called stop-start, auto-stop, idling stop, idle stop and go, and micro-hybrid). Start-stop operation offers no alternate vehicle propulsion.

Start-stop operation puts increased demands on a vehicle battery. During the many stop periods when there is no output coming from the vehicle charging system, it must exclusively power the various loads in the vehicle system. These include the traditional loads such as lights, fans, entertainment, sensors, and the ignition system, but with increasingly added loads such as electrical steering and brakes. The battery must also provide many more cranking starts compared to conventional vehicle operation in which the engine stays in continuous charging operation during a driving cycle. Once the engine has restarted from a stop event, the generating system must recharge the battery sufficiently to keep it in continuous operating condition. Because of the extra discharges in urban or suburban traffic, start-stop batteries typically operate in a partially discharged condition that leads to an increased charge acceptance during charging opportunities. However, this remaining discharge from partial discharge tends to become more resistant to charge with stand unless special charge enhancement properties are added to stop-start batteries or special charging methods are added periodically.

Batteries that satisfy the demands for this type of operation need to have enhanced electrical properties compared to typical batteries used in traditional internal combustion vehicles. Key performance features of start-stop batteries are power to provide instantaneous starting, sufficient capacity to supply electrical power during limited stops, good charge acceptance to keep the battery in acceptable operating condition, and resistance to cranking and capacity loss in partial discharge shallow cycling. Besides enhanced batteries, vehicles with start-stop operation need more robust starting, charging, and control systems that work to keep the battery and vehicle in proper start-stop operation to achieve the vehicle fuel efficiency/emissions ratings. Start-stop vehicles may also stop the engine in a position to restart more rapidly and delay recharging after starts to allow more power for early acceleration.

A battery employed in a start-stop application may be asked to:

- Support the total electrical load demand during the drive cycle each time the internal combustion engine (ICE) is temporarily stopped (such as at a stop light).
- Be able to restart a “warm” engine in a reduced charge state multiple times over a drive cycle.
- Accept recharge energy as efficiently and quickly as possible in order to maintain sufficient power for future electrical demand events.

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- Work in conjunction with a Battery Management System (BMS) that includes a battery status monitoring device that supplies information to the vehicle computer to only allow start-stop activity when the battery is in a satisfactory condition and there are no compromises to the vehicle performance and the safety and comfort of vehicle occupants. It is typically seen that start-stop functions in a temperature range that is neither too cold nor too warm for vehicle occupants unless other means are provided to keep the occupants comfortable.
- The BMS should also determine battery defects and end of life if a replacement is needed. The BMS ensures the battery gives reliable starting and is safe and non-intrusive for start-stop functioning and normal vehicle operation.
- It is also a general expectation that start-stop batteries provide similar or better service life than the batteries serving traditional ICE vehicles.
- Of course, like a traditional ICE vehicle battery, the start-stop battery needs to be able to support the vehicle loads during an emergency or the loss of the vehicle charging system.

This document of recommended practices therefore focuses on functional definitions and tests of those batteries that reflect the demands for usage in start-stop operation. Batteries with various chemistries or combinations of batteries have been proposed for this type of operation. Flooded lead-acid batteries used in traditional vehicles without start-stop have been found to give inadequate life performance in start-stop operation. Therefore, start-stop vehicle manufacturers almost entirely specify more robust 12-volt lead-acid battery variations (AGM - absorbent glassmat batteries or EFB - enhanced flooded batteries). Testing as outlined in this document has been targeted at these lead-acid battery characteristics. If there is a battery combination other than a single battery intended to be used in a start-stop vehicle, it should be tested as a single unit rather than separate items with the agreement of the supplier and user.

It has been observed that there are normally two types of start-stop vehicle systems. The typical type uses the same cabling and starter path for warm and cold starting. The second type uses a separate higher resistance route to reduce the starter current for warm starts while using the normal route for cold starts.

Technology to increase vehicle and battery efficiencies is changing rapidly. It is expected that batteries related to start-stop performance will have increased performance to meet these demands. It is therefore recommended that this document be reviewed as needed to keep it relevant.

1. SCOPE

This SAE Standard applies to 12-volt lead-acid storage batteries that are designed specifically for start-stop operations in on-road passenger vehicles or light trucks. Included are definitions of terms, general testing recommendations, key performance characteristics, and life testing. Properties not unique to start-stop batteries should be tested according to SAE J537 or other applicable testing protocols.

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: 1-877-606-7323 (U.S. and Canada only) or 1-724-776-4970 (outside U.S. and Canada), www.sae.org.

SAE J537_202309 Storage Batteries

2.1.2 Battery Association of Japan (BAJ) Publications

Available from Battery Association of Japan (BAJ), Kikai Shinkokaikan Building, 3-5-8, Shiba koen, Minato ku, Tokyo 105 0011, Japan, www.baj.or.jp/e/.

SBA-S-0101:2014 Lead-acid batteries for Idling Stop Vehicle: The methods, performance, dimension and marking

2.1.3 European Committee for Electrotechnical Standardization (CEN) Publications

Available from CEN-CENELEC Management Center, Rue de la Science 23, B-1000, Brussels, Belgium, www.cenelec.eu.

EN 50342-1:2015/A2:2021 Lead-acid Starter Batteries – Part 1: General Requirements and Methods of Test

EN 50342-6:A1:20 Lead-acid Starter Batteries – Part 6: Batteries for Micro-Cycle Applications

3. DEFINITIONS PERTAINING TO START-STOP OPERATION

3.1 CAPACITY

Capacity is the amount of usable (voltage-limited) charge (ampere-hours) that can be extracted from a battery. Batteries have capacity ratings using standard discharge currents and temperature conditions, but usable capacity varies with battery temperature and discharge rates seen under various vehicle operating conditions. Manufacturers are to provide capacity rating values that their new, fully charged batteries should meet or exceed. Capacity ratings provided by battery manufacturers are to be statistically compliant when tested according to the relevant test standard. Capacity will ultimately decline with age and use. As with conventional vehicle batteries, those in start-stop operation deliver limited discharge capacity with each cycle except under failed charging system conditions or under extended stand with parasitic loads.

3.1.1 20-HOUR CAPACITY (C_{20})

The capacity (in ampere-hours) obtained from a fully charged battery discharged at a constant current to an end-of-discharge condition (i.e., discharge cutoff voltage of 10.5 V) in 20 hours at 25 °C. (Refer to SAE J1715/2.) The constant current I_{20} (also listed as I_n) is the nominally rated C_{20} capacity divided by 20 hours. Discharge rates may be set as multiples of I_{20} such as $5I_{20}$ and will result in different capacity values. C_{20} (also listed as C_n) capacity represents the maximum practical capacity for a battery by slow discharge under ideal conditions. Discharge rates in start-stop operation needed to supply the vehicle electrical system during stop periods are normally much higher than I_{20} .

3.1.2 RESERVE CAPACITY (RC)

The amount of time (minutes) a fully charged battery can discharge at a constant current of 25 A to an end-of-discharge condition (i.e., discharge cutoff voltage of 10.5 V) at 27 °C. (Refer to SAE J537.) The Reserve Capacity test was developed to better represent enhanced load discharge conditions (lights, fans, etc.) in a vehicle electrical system without an operating alternator. It is also more typical of loads in start-stop operation. Wherever possible, discharges used in this start-stop battery testing document use the RC rating or measured capacity and discharge rate.

3.1.3 RESIDUAL or REMAINING CAPACITY

Capacity measured using one of the above testing methods to determine the remaining charge in batteries that have been subjected to cycling, stand testing, or other service-related conditions listed in the testing specifications. Residual capacity shall be run at one of the rated currents established for new batteries.

3.2 COLD CRANKING TEST AT -18 °C

This test represents the ability of a new, fully charged and conditioned battery at a test temperature of -18 °C to sustain a rated high-rate cold cranking current (CCA) at a measured battery voltage above a minimum value of 7.20 V for a period of 30 seconds. (Refer to SAE J537.) This is a pass/fail rating that has a greatly extended discharge time in comparison with a typical vehicle starting time (<1 second) even under severe conditions. In this recommended practice, focus shall also be made on the initial part of this test in addition to the extended discharge time which ensures adequate residual cranking during service.

3.3 STATE OF CHARGE (SOC)

The percentage of remaining discharge capacity or discharge time available in a battery under prevailing conditions of discharge compared to a fully charged battery under the same conditions:

$$SOC = 100\% \times C_{\text{remaining}} / C_{\text{charged}} \quad (\text{Eq. 1})$$

In the absence of true capacity data under prevailing conditions, the SOC is often depicted by comparing the discharge to a reference capacity value.

$$SOC = 100\% \times (C_{\text{ref}} - Q) / C_{\text{ref}} \quad (\text{Eq. 2})$$

where:

Q = amount of discharge capacity left uncharged in the battery

C_{ref} = referenced full charged capacity, often the rated 20-hour capacity

NOTE: Using the C₂₀ rating is convenient but not accurate for SOC determination for batteries in actual use or test conditions that vary in capacity with temperature, discharge rate, and capacity degradation. SOC is therefore an ambiguous factor (except at 100%) that is minimized in this recommended procedure. It can be used in agreement between supplier and user.

3.4 OPEN-CIRCUIT VOLTAGE (OCV)

The stable voltage of a battery measured after an extended rest period in the absence of charge or discharge current and other polarizations. (Refer to SAE J1715/2.) OCV is a function of the battery sulfuric acid electrolyte concentration and is often used to assess the amount of discharge in a battery if battery voltage versus discharge factors are known. A stability period of 24 hours and often much longer may be necessary to get a reasonably stable reading, especially with fully charged flooded batteries and batteries in cold conditions. Flooded batteries with non-uniform electrolyte concentration within their cells (stratification) deviate in voltage from those with uniform electrolyte concentration and those voltages should be used with caution because they have inflated, non-equilibrium values.

3.5 SPECIFIC GRAVITY (SG)

Electrolyte specific gravity is the ratio of the density of the sulfuric acid electrolyte solution at a specific temperature (T₁) to water at a specific temperature (T₂). Typical devices used for measuring electrolyte have T₁/T₂ values of 27 °C/27 °C or 25 °C/4 °C and should be referenced. Like OCV, the specific gravity in flooded batteries has often been used to assess the discharge condition of a battery if it is uniform and the ratio of electrolyte concentration versus discharge is known. Many flooded starting batteries limit measuring access to their free electrolyte for safety and to prevent contamination and drilling temporary holes is the only way to get access. Stratification in flooded batteries also affects the measured specific gravity giving weaker SG on the top of the cell compared to the bottom thus giving a lower estimated charge level. There is no way to measure SG in AGM batteries.

3.6 BATTERY TEMPERATURE (T)

Battery temperature is critical to performance. The temperature of the internal components of the battery is generally measured by a thermometer placed in a center cell of a flooded electrolyte battery, if accessible, or by an externally insulated thermocouple or other temperature sensitive device attached directly to the surface of the side of the battery adjacent to the bulk internal components of the battery. If a battery that has not been charging or discharging and is exposed to a constant ambient temperature equal over its entire surface for a long period, one can infer that its core temperature is identical to the ambient temperature of the medium where the battery is stored. (Refer to SAE J537.)

3.7 INTERNAL RESISTANCE (R) or CONDUCTANCE (G)

Battery internal resistance and conductance are ohmic measurements that, coupled with voltage and temperature factors, determine the ability of a battery to deliver cranking power for the short durations typically seen in starting ICE vehicles. At high cranking rates when coupled with the polarized voltage of the battery, the discharge current multiplied by the internal resistance ($I \times R$) relates to the voltage drop within the battery during cranking thus affecting the effective cranking voltage and ultimately the rotation speed of the starter.

Resistance (measured in units of ohms or milliohms) in batteries is a measure of the rapid change in voltage with respect to the simultaneous rapid change in current. Battery internal resistance can be measured by probing a battery using quickly varying high rate currents versus voltage (dynamic resistance) or by using special meters that measure small AC voltage versus AC current changes at certain frequencies. Ohmic values can also be expressed in terms of conductance (measured in units of siemens [S]) which is the reciprocal of resistance and is more predictive of battery current output capabilities.

Ohmic measurements often differ by the device or method of measurement as well as the temperature and charge condition of the battery. The recommended ohmic measurement device or method should be made in agreement between the supplier and end user. It should also be understood that untested new batteries, even when fully charged, often show diminished ohmic values compared to batteries that have been subjected to deep conditioning discharges seen in qualifying testing. The values are still real and reflect an initial diminished cranking ability determined by actual discharge measurements.

3.8 INRUSH CURRENT

The inrush or peak current during a starting sequence is the large instantaneous current that occurs just before the beginning of starter motor rotation. It is a function of the battery voltage, temperature and the resistance of the battery, starter, and cabling. Inrush starter current properties can be somewhat simulated by discharging for a short duration at a fixed voltage or resistance.

3.9 MINIMUM VOLTAGE

The minimum voltage during a starting sequence is the instantaneous voltage that normally occurs at peak inrush current. This voltage supplied by a start-stop battery under various temperatures and discharge conditions must be high enough to overcome the voltage drop across the starter and cabling to provide starter rotation sufficient to start the engine. Starting characteristics of start-stop batteries necessitate a testing focus on properties that pertain to this area of starting performance. This minimum starting voltage is often referred to as state of function (SOF).

3.10 CHARGE ACCEPTANCE

Start-stop operations are very dynamic with frequent discharges during stop events and cranking. Batteries in start-stop applications have many more discharges than those in conventional vehicles and need to accept sufficient charge during recharging opportunities during various vehicle operating conditions to maintain adequate battery charge level for vehicle operation. Therefore, it is necessary to determine their charge acceptance capability.

Charge acceptance is the amount of charge that a battery can accept using voltage-limited charging under various conditions of operation. Charge acceptance is often represented by both the magnitude of charge accepted (Ah) or the charging current after a fixed period of time with the battery under a generated discharge condition. Charge acceptance for start-stop operation should be related to the expected condition of the battery in operation.

Charge acceptance is not a fixed value. It is affected by the amount of discharge, temperature, the magnitude of the previous discharge current, the time and temperature of stand after discharge, charge enhancing additives, and the history of previous charging in addition to the voltage and current limit of the charging source. Freshly discharged batteries such as seen during start-stop operating stops readily recharge that amount of discharge even at high charge levels, whereas accumulated discharge that is allowed to stand is more difficult to recharge. While specific tests are presented in this recommended procedure, no single test can define charge acceptance under the constantly varying actual vehicle operating conditions.

When charge acceptance is very low while the battery is in a significant discharged condition, the battery is said to be sulfated, although there is no industry defined quantitative level or measurement procedure to determine sulfation. In other words, sulfation is another term for low charge acceptance.