Guide to Battery Testing Technologies

Introduction

How do you determine whether a battery is good or not? How do you know if it will last for several more years—or if it's time to replace it?

Testing a battery for its true health involves more than just checking the voltage or even determining its state of charge. This white paper discusses the various means and technologies available today for testing lead-acid batteries that are commonly found in cars, trucks, battery back-up systems, industrial equipment, recreational vehicles, boats, electric vehicles, and elsewhere. After reading it, you will have a general understanding of the different types and uses of lead-acid batteries, their life cycles, and how to best test them for health.

IN THIS GUIDE

This guide applies to the testing of lead acid batteries and most directly to batteries used in automotive, storage, and deep cycle applications. This guide does not cover other important areas such as battery maintenance or specifying batteries for particular applications.

Battery Types and Uses

What's the difference between a battery used to start an engine and a storage battery, like a "marine deep-cycle" battery?

All lead-acid batteries work on the same general principle. Inside the battery's case, lead alloy plates are suspended in an acid solution ("electrolyte".) The chemical reaction between the metal plates and the electrolyte produces an electrical current, which you can tap into by connecting to the battery's terminals. However, not all lead-acid batteries are exactly alike: by varying the lead alloys, the thickness of the metal plates, and the qualities of the electrolyte, battery manufacturers give lead-acid batteries certain characteristics to make them more suitable for specific purposes.

In general, lead-acid batteries can be divided into two broad purposes: **cranking batteries** (starting batteries), and **deep-cycle batteries** (storage batteries). The difference is the electrical demands made upon the battery and the battery's capacity to withstand discharge.

Cranking batteries are meant to supply *large* amounts of power for brief periods of time, such as the demand of starting a car or truck engine. A properly engineered cranking battery is designed to deliver a few thousand engine starts over its life. While they supply a large amount of power, cranking batteries can do so for only a short period of time before becoming discharged. Cranking batteries are not designed to handle long, steady electrical loads, or for significant discharges between charging cycles. Starting a car, for example, may discharge the battery by only a few percent. It is not designed to, say, power the car's interior lights all night. A cranking battery can withstand only a few total discharges before it becomes permanently damaged and incapable of holding a significant charge.

Deep-cycle batteries, on the other hand, are meant to allow deeper discharges while supplying steady amounts of power over longer periods of time, such as the demand of running an electric golf cart, powering electrical equipment in a yacht or RV, or providing backup power for a computer system. Though they do not supply the same total burst of power as a cranking battery, deep-cycle batteries can handle significant discharges between charging cycles, without long-term damage. A well-engineered and maintained deep cycle battery will handle over 500 deep discharges.

LEAD-ACID BATTERIES COME IN THREE PRIMARY COMPOSITIONS: WET, MAINTENANCE-FREE, AND ABSORBED GLASS MAT

Wet batteries, also known as "flooded", “standard” or “conventional” lead-acid batteries, can be identified by filler caps on the top. They have been commercially available for about a century and are generally the lowest-priced type of batteries. They use lead-antimony/antimony plates, suspended in electrolyte. The principle shortcoming of wet batteries is that water is ‘boiled’ out of the electrolyte over time due to the chemical reaction that occurs while charging the batteries. Therefore, wet batteries require periodic maintenance, replenishing the level of the electrolyte by adding distilled water.

Maintenance-Free Batteries (sometimes called “sealed” batteries), usually do not have electrolyte filler caps and generally cost a bit more than wet batteries. The real advantage of maintenance-free batteries, is in their lead-calcium/calcium plates, which provide the advantage of greatly reducing the evaporation of electrolyte. Because there is usually no need to service the electrolyte, the batteries are designated “maintenance-free.”

Absorbed Glass Mat (AGM) batteries, also called VRLA provide all the advantages of maintenance-free batteries, but are more suitable for rugged applications. This is because they have a fine glass mat (much like fiberglass insulation) between the plates, which keeps the electrolyte from moving around. The glass mat also reduces electrolyte evaporation to the point where AGM batteries are totally sealed and truly maintenance-free.

BATTERY TYPES

		Wet	Maintenance-Free	AGM
Cranking	High power, shallow discharge	Most common, low cost	Common	Growing in popularity, higher cost
Storage/ Deep Cycle	High energy, deep discharge	Common, higher cost	Not common	Common, ruggedized construction, higher cost

Battery Rating Standards

It is important to know how batteries are specified and rated because many of the testers described later will provide test results that must be compared to a battery’s original specification.

Because batteries are used for so many different applications, manufacturers have developed a number of standards for specifying performance. Generally speaking, the standards are divided between cranking performance standards, such as cold-cranking amps (CCA), and storage capacity standards, such as a C/20 rating. Within each category, there are standards for particular applications. To make it even more confusing, European, US, and Japanese battery industries often use different standards for the same application. See the table below for a list of some of the most popular standards.

Each standard has an explicit definition that can be used to evaluate a battery according to the standard. However, generally speaking, an actual standards test can be performed only at a testing laboratory.

Most battery manufacturers guarantee their batteries will maintain a certain level of performance for a limited period of time. For example, a battery might be guaranteed to provide at least 80% of its rated capacity for 24 months. If you want to test a battery to compare its performance to the manufacturer's specification, be sure to use a test that produces results that match the standard used by the manufacturer to rate the battery.

MOST POPULAR BATTERY RATING STANDARDS

CRANKING			STORAGE / DEEP CYCLE		
Name	**Abbr.**	**Primary use**	**Name**	**Abbr.**	**Primary use**
SAE Cold Cranking Amps (CCA)	SAE	USA, Japan, Auto	Reserve Capacity	RC	Global
Cranking Amps	CA	USA, non-auto	Amp Hours	Ah	Global
Marine Cranking Amps	MCA	USA, Global, marine			
Hot Cranking Amps	HCA	USA, non-auto			
Intl. Electrochemical Commission	IEC	Europe (older), auto			
European Norm	EN	Europe, automotive			
German Industry Norm	DIN	Germany (older)			
Japanese Standards Association	JIS	Japan			

Why and How Batteries Fail

Recall that all lead-acid batteries operate on the same general principle—suspending lead-alloy plates in acid to cause a chemical reaction that generates electricity. If the chemical reaction stops, the battery stops too. A lead-acid battery's chemical reaction stops for two main reasons: old age and sulfation.

Old age: During normal use, the lead plates simply wear out. Over time there is less and less effective surface area on the plates, so from a chemical standpoint, the battery becomes smaller. The metal plates wear out by dissolving in the electrolyte to the point where there isn't enough material left to produce a sufficient reaction. Additionally, as they dissolve they leave a residue which builds up as a sediment inside the battery, hindering the chemical reaction. Eventually the residue can pile up to the point that it produces a short within the battery. The wearing out of the metal plates in a lead-acid battery is an unavoidable consequence of the way they work. Because of this characteristic, the maximum life expectancy for a well-maintained lead-acid battery is about five years, and can be considerably less in hot environments.

Sulfation: The second cause of failure, and the largest cause of premature failure, is sulfation. As a battery discharges, a layer of lead sulfate accumulates on the metal plates. Through a discharge cycle, eventually enough lead sulfate builds up that the plates can no longer react with the electrolyte. At this point the battery is completely discharged. It's as though the metal plates inside the battery become covered with insulation. If the battery is not soon recharged, dissolving the sulfur back into the electrolyte, the lead sulfate begins to form into hard crystals that permanently attach to the plates. Over many charge/discharge cycles more crystals form and the battery slowly loses capacity, because the effective surface area for chemical interaction is decreased. Eventually the battery can't store or release enough energy to do its job and the battery fails. More car batteries fail prematurely from sulfation than any other reason.

The primary cause of sulfation is undercharging, or leaving the battery in a discharged state for extended periods of time. A lead-acid battery, as a general rule of thumb, must be kept within a certain charge range and used regularly to keep it happy. If the battery remains discharged for extended periods of time (the actual length of time that causes damage depends on many other factors) sulfation will occur. Other situations also cause battery damage. Overuse, which chronically drains the battery, and lack of use, which also drains the battery (because batteries self-discharge over time, especially in hot weather); corrosion on the battery terminals which prevents the battery from making a good circuit connection; or a fault in the circuit that the battery is part of. Finally, if a battery is overcharged, it will get hot and the electrolyte will boil off, also leading to premature failure.

As a battery ages and is used, all of these mechanisms play a role in decreasing the battery's capability. You can envisage the effects of old age (wear and tear) and sulfation by imagining adding stones to a gas tank. Over time, more and more stones are added to the tank. The tank can still be filled to the top, but eventually the stones occupy most of the volume and the available room for fuel decreases until there is little or no capacity remaining.

Testing Batteries

Why test your battery on a regular basis? There are numerous reasons, but it comes down to being sure the battery will perform a *particular* job when you need it to. Testing reduces the likelihood of costly, unexpected failures that might strand your car on the road, or perhaps leave a computer data center without its emergency backup power supply. Testing also allows you to determine whether a battery meets its warranty specifications. Some test technologies and procedures can be used to predict when a battery will fail, providing the opportunity to fix a problem before it occurs.

RELATIVE VS. ABSOLUTE TESTS

Before performing a battery test, it is important to ask what you would like to learn from the test. Would you like to learn about a battery's capability in absolute terms, or would you like to determine a battery's capability relative to a particular task? An absolute test will result in a number, such as 115A. If you have a point of reference, such as the manufacturer's guaranteed performance level, this number might be useful, but it does not provide any indication of the battery's fitness for a particular purpose. A relative test, on the other hand, will not produce an absolute value but will indicate the battery's fitness to perform a specific job, such as starting an engine.

WHAT TO TEST

1. State of Charge. In nearly all cases, the first piece of information to learn is the battery's state of charge. How full is it? If the battery is empty, it is difficult to determine how healthy it is. To learn the full capability of a battery, test a battery that is fully charged.

2. Relative Test. Once you understand the state of charge, the first test to apply should be a relative test, because the most important question is: How capable is this battery of performing a particular task (like starting your truck)? Learning that a starting battery has 650 Cold Cranking Amps tells you very little about whether or not that battery is good or bad, old or new, or how well it will perform starting the engine it is expected to start.

Specifically, a cranking battery should be tested for its cranking power or cranking health relative to the engine it is starting. How well does this battery start this engine. If you are testing a storage battery, the answer you are looking for is how long will the battery support the load.

3. Absolute Test. If a battery tests poorly using an appropriate relative test, it can be useful to apply an absolute test. If you know the original rating of the battery, you can compare it to the test result to understand if the battery has also failed compared to the manufacturer's specification and guarantee. Be careful that your absolute test result is displayed using the same rating standard the manufacturer used to rate the battery.

RELATIVE VS. ABSOLUTE TESTS

	Absolute Tests	**Relative Tests**
Question to be answered	What is present battery capacity value?	How well is the battery working?
Cranking	CCA, HCA, MCA, etc.	Cranking Performance (%), Cranking Health (%)
Storage/Deep Discharge	Ah, RC	Runtime (hours/mins.)

TESTING METHODS AND TECHNOLOGIES

In nearly all cases, the ideal test, from the point of view of accuracy, is to actually use the battery for its purpose and measure the specific performance. This is the ultimate relative test. Depending upon the application for the battery, an 'actual-use' test can be very expensive and time consuming. At the other end of the spectrum is a voltage test. It is very fast and inexpensive, but it does not offer any information other than raw data used to determine the state of charge. It cannot provide the data necessary to understand capacity or cranking health.

Between these two extremes are a number of testing technologies offering a range of accuracies corresponding generally with cost and complexity. The objective of this section is to enable the reader to choose a test technology that is most appropriate for the battery and application.

Within the broader range of testing methods and technologies, it is useful to make a categorical distinction between technologies optimized for testing cranking batteries and technologies optimized for testing storage batteries. Storage battery analysis is most effectively accomplished by capacity tests, while starting battery analysis is most effectively accomplished by cranking performance tests.

CAPACITY TEST METHODS

When testing batteries used for storage applications, such as marine/ RV deep cycle, or electric vehicle batteries, a capacity test will be most useful. Capacity test methods include: actual discharge tests, static load tests, and a number of ohmic tests.

1. Actual Discharge Test. In the case of a storage battery, the most accurate test is to identify the rate at which the battery will be used in the application, and then discharge the battery completely at that rate while measuring the total energy produced by the battery. While being accurate, actual discharge testing has a number of drawbacks. It can be performed only with very expensive equipment, requires that the battery be removed from service, is very burdensome to the battery, and takes a considerable amount of time to complete.

2. Static Load Test. At the other end of the capacity testing spectrum is the static load test. A basic load tester uses a simple voltmeter and a load element, similar to a toaster coil. The volt meter measures the battery voltage while an arbitrary static load is applied across the terminals. If the voltage falls significantly under the applied test load, a failed battery will be indicated. Most load testers indicate results in a binary (pass/fail) fashion. In the extreme case of a failed battery, this test will provide a correct and unambiguous result. However, in most cases when batteries are operational but performing poorly, the results are ambiguous and often inaccurate. The advantage of the static load test is that the equipment is inexpensive and easy to use. But, you get what you pay for. The shortcomings of the static load test are many. Most importantly, the applied test load is arbitrary, compared to the actual load. As a consequence, the test result is also arbitrary as it does not relate to the specific purpose of the battery. While inexpensive and quick to perform, load test results can be expected to provide a high percentage of false positive and false negative results.

3. Ohmic Tests. All electrical circuits have some degree of resistance (think of it as friction in the system), and batteries are no exception. Electrical resistance is measured in Ohms. It has been widely tested and accepted by the battery industry that the internal resistance and conductance of a battery can be directly related to battery capacity. The lower the internal resistance, or the higher the conductance, the higher the capacity. If the internal resistance or the AC conductance of the battery can be determined, then the capacity of the battery can be estimated.

Generally ohmic test methods can be classified as either AC methods or DC methods. AC methods rely on measuring the AC response to an applied AC forcing function, and determining the AC conductance or AC impedance. DC methods rely on applying or sinking a DC current from the battery and measuring the corresponding DC voltage response or the voltage recovery after removal of the DC load.

Ohmic test devices have grown in popularity over the past 10 to 20 years because they overcome many of the shortcomings of discharge and load testing. While ohmic testers are considerably more expensive than load testers, they are quite accurate and are considerably less expensive and much more convenient to use than discharge testing equipment. Equally important, an ohmic test can be performed in seconds.

While an ohmic tester is relatively accurate and inexpensive ($300 – $5,000), it is important to point out that an ohmic test provides absolute results, not relative results. It does not provide direct information about the battery's ability to perform a particular job. In the case of starting batteries, an ohmic test result is not highly relevant to cranking performance, so using an ohmic tester to predict the performance of a starting battery is not ideal. An ohmic test can, however, be used to determine how a battery's present capacity compares to its specification or to the manufacturer's guarantee.

A few ohmic test methods are described below.

Large Pulse Resistance. The large pulse resistance test method, found in many Argus Analyzers models, is not affected by the load condition of the battery. This means that the test can be performed accurately even if the battery is in the process of being charged or discharged. A major benefit of the large pulse resistance testing method is that this technology can be used to test battery health in real-time while batteries are on-line. This is ideal for testing batteries or monitoring remaining capacity in mission critical applications, such as backup batteries in telecom, computing, and power utility environments.

AC Conductance. The AC conductance method relies on emitting a low level (near battery voltage) AC signal and measuring the battery's AC voltage and AC current response, and then calculating an AC conductance value. One shortcoming of this technology is that the signal response of the battery can be distorted by other circuits and particularly by a load or charger that is attached to the battery. This method requires that the battery be functionally taken 'off-line' for measurement, and so prevents the opportunity for real-time capacity analysis. A similar, but more complex technology uses a multi-frequency AC signal test. This method measures conductance of the battery using a broad set of AC signal frequencies and has the ability to estimate capacity accurately over a broad range of state of charge. But as with the AC conductance test, the multiple frequency technology is also practically limited to 'off-line' tests.

CRANKING TEST METHODS

Any of the methods used for capacity testing can also be used on starting batteries, but the resulting values are measurements of absolute capacity, and not measurements of cranking performance. All of the shortcomings and advantages of the methods described above apply also to testing starting batteries. But using a capacity test to evaluate cranking performance is like estimating the depth of a river by measuring the speed of its current. One is related to the other, but not very directly.

The ideal test for cranking performance is to actually use the battery to crank the engine it is tasked to start. The results of a cranking test are inherently relevant to the primary question (how effective is *this* battery at starting *this* engine?) because the test uses the actual load and measures actual performance. A cranking tester works by monitoring the voltage profile of the battery as it cranks the engine during engine start. By analyzing the voltage profile, a cranking tester can determine the cranking health of the battery as it relates to that particular starting system. Conveniently, a device applying this crank testing technology can be used to test any starting battery whether it is starting a small motorcycle engine or a 600HP diesel generator. The testing time is seconds.

If a battery is determined to have low cranking health using a cranking tester, it would then be appropriate to use an absolute capacity test to determine if the battery has failed inside the manufacturer's warranty. So from a practical standpoint, testing a starting battery should involve two tests. The primary test is a cranking test, and if the battery is determined to be weak or failed, a capacity test should then be used to determine an absolute capacity value that may be compared to the battery specification to understand if warranty replacement is merited.

RULE OF THUMB

Capacity testing is the primary tool for storage batteries. Crank testing is the primary tool for starting batteries. Capacity testing is a secondary tool to determine warranty status.

TEST METHODS

	TEST OBJECTIVE				
	State of charge	**Present capacity**	**Capacity while under load**	**Total capacity**	**Relative cranking capability**
TESTING TECHNOLOGY					
Actual discharge test	High	High	High	High	Low
Static load test	Med	Low	None	Low	None
AC conductance test	High	High	Low	Med	None
Crank performance test	High	None	None	None	High
Large Pulse Resistance test	High	High	High	Med	None
Hydrometer test	Med	None	None	None	None
Voltmeter	Med	None	None	None	None

Factors affecting test results

Battery performance and the accuracy of battery tests are affected by four primary factors: age, wear and tear, present state of charge, and temperature. When testing a battery, it is most helpful to understand and isolate the affects of state of charge and temperature, and focus on the battery performance as determined by age and wear and tear. What we want is a determination of a battery's condition assuming it is 100% charged and adjusted for the effects of temperature.

In an ideal situation, all tests would be performed when the battery is fully charged (100% state of charge) and at the specified temperature for whatever test norm is being used. For example, this is 0°F or -18°C for a CCA test, as defined by the SAE. As a practical matter, except in testing laboratories, batteries are almost never tested under conditions as defined in any of the rating standards. What this means for hand-held testers is that to provide an accurate result, the output of the test must be adjusted for the factors (state of charge and temperature) that are not at the standard.

Nearly all of the battery rating standards assume that a battery is evaluated when it is at 100% state of charge. So the first correction that needs to be applied to any test result is to correct for state of charge. Many of the ohmic test devices include sophisticated microprocessors and, using software algorithms, can adjust the result for the measured state of charge at the beginning of the test. However, this adjustment can be very tricky, and at low state of charge, the potential error in the adjustment is high. Some ohmic test methods have the potential for more accurate state of charge adjustment than others, but it's a good rule of thumb to rely only on test results for batteries that are over 70% state of charge. If the battery you are testing is less than 70% SoC, charge it first and then test.

Adjusting results for temperature is equally important, and without temperature adjustment, test results can be highly distorted in extreme temperature environments. For example, the poor condition of a battery that is sitting in a hot engine compartment under the hood of a black car in Miami on a summer day may be masked by the affect of temperature. Equally problematic are very cold batteries that are measured to be of low capacity. Temperature correction is critical and must be included to be able to rely on a test result.

Temperature correction is handled by test devices in a number of ways. Unfortunately, many test devices (load testers and some of the ohmic testers) fail to include any temperature correction. Many ohmic testers include a manually implemented one step adjustment (cold/off) that is not very accurate because it will not always be activated by the user, and it is also a very course adjustment. A few testers include automatic and continuous temperature adjustment. These devices have a thermocouple that always measures the temperature and can provided a finely tuned temperature adjustment. Depending upon the placement of the thermocouple, the accuracy of these testers may be slightly affected by the difference in temperature between the battery and the thermocouple. Devices with the best capability for temperature adjustment will measure the temperature at the battery itself.

RULE OF THUMB

Avoid testing at extreme temperatures. Use testers with continuous temperature compensation. Tests on fully charged batteries will be more accurate.

Summary

Batteries should be tested regularly to ensure that they are able to perform. The most useful tests provide information that is relevant to the battery's intended job. When testing cranking batteries, choose a test device that provides a cranking health analysis showing a battery's ability to start a specific engine. As a secondary test, use a capacity test device to determine how a poorly performing starting battery compares to its specification and the manufacturer's guarantee.

When evaluating storage/deep cycle batteries, choose a capacity test device that will test the battery without having to take the battery out of service. Avoid full discharge testing to reduce wear and tear on the battery. When testing batteries in mission critical applications, use a test device capable of measuring capacity regardless of the load condition of the battery. For all battery tests, be particularly aware of the how temperature and state of charge may impact the results of the test, and choose a test device that provide effective compensation for these factors.