Automobile Electrics: The Battery and Starting System

A. Battery Theory and Evolution

Starting power: You can't leave home without it. Ever since the 1912 Cadillac appeared with the first electrical cranking system, it's been provided by lead and acid, but if you think that means not much technological development has gone into batteries, you'd better keep reading.

Chemistry, anatomy

A quick recap of battery theory and anatomy will help you understand the changes that are going on. If two dissimilar metals are placed in an electrolyte that can attack them, voltage potential is created. Electrons will flow if a connection is made between the metals, and that's what electricity is.

In a wet cell, the metals are sponge lead (Pb) and lead peroxide (PbO_2), and the electrolyte is dilute sulfuric acid (H_2SO_4). The reaction begins as sulfate (SO_4) breaks away from the acid and unites with the lead of both the positive and negative plates to form lead sulfate ($PbSO_4$). The oxygen (O_2) is thereby liberated from the lead peroxide and joins with the hydrogen (H_2 -- what's left over after the sulfate left the acid) to produce ordinary water (H_2O), which dilutes the electrolyte.

Eventually, both the plates turn into lead sulfate, the electrolyte becomes very weak, and current stops flowing.

But reversibility is the wet cell's most important characteristic. When an outside power source pushes electrons through the cell in the opposite direction to that of discharge, sulfate separates from both plates to rejoin the hydrogen in the water, forming a new batch of sulfuric acid. The oxygen goes back to the positive plate to recreate lead peroxide, and the electrical potential is restored. If charging continues after all the sulfate has gone into the electrolyte, the water starts to decompose, releasing free hydrogen and oxygen, an explosive couple.

The traditional automotive battery has plates made of a combination of lead and antimony impregnated with the metals involved in the reaction. The positive plates are separated from the negatives by sheets of porous material that insulates them electrically from each other, but allows the electrolyte to pass (although such things as balsa wood have been used, sealing the positive plates in plastic envelopes is commonly done today to keep the active material in place that had previously been allowed to drop piece by piece into the space under the elements, lowering the cell's capacity and sometimes shorting out the plates). Numerous plates of each metal are interlaced within one cell, but whether two or a dozen are used the cell produces a "pressure" of 2.1 volts. Six cells are connected in series to give the 12.6 volts almost all cars have needed since the fifties.

Strength specs

You've got to understand performance ratings to be able to choose exactly what you need. The old ampere hour standard isn't used much anymore. In its place, we have the Battery Council International rating, which tells you how many amperes a full-charged battery can deliver a 0 deg. F. for 30 seconds without going below 7.2 volts. This is called "CCA" (Cold Cranking Amps) and should be at least as high a number as the cubic inch displacement figure of the engine.

Then there's the Reserve Capacity Rating -- the number of minutes a new, juiced-up battery at 80 deg. F. can sustain a 25 amp drain before dropping to 10.5 volts.

There's a good chance that you're familiar with these two measurements, but most people don't realize that there's a trade-off relationship between them. If the first is pushed up in a particular design, the second has to go down, and vice versa. In other words, you might find a battery with a macho CCA number, but a wimpy RC. Compare them before buying.

No antimony

One of the biggest departures occurred in 1972 when the maintenance-free battery appeared. Its plate grids are made of calcium lead alloy with no antimony, which reduces gassing by up to 97%, and cuts water loss and terminal corrosion. It also prevents thermal runaway, a condition wherein conventional plates destroy themselves by overheating when fed too much power. Also, there's very little self-discharge, so an M-F unit can retain enough wallop to start a car after sitting for up to a year (that is, if it's disconnected -- the parasitic drain of the vehicle's electronic systems will run any battery down in a matter of months).

Sounds great, right? But there's more to the story. As one expert told me, "There's really no such thing as maintenance-free. Every battery will evaporate some water from heat, and gas a little from electrolysis." In the battery business, M-F's with non-removable cell caps are frequently referred to as "maintenance impossible."

L-M and hybrid

Which brings us to the low-maintenance type. It has a little antimony in both its negative and positive plates, which results in slightly more gassing and self-discharge than with M-F. But an L-M unit is better at withstanding deep discharge, its cell caps are removable, and it requires lower voltage during charge, which reduces the potential for heat damage. It's a very forgiving battery.

Between the two, there's the hybrid or dual-alloy. It uses calcium for the negative grid, but retains a small amount of antimony in the positive. It gasses but very little, has better "bounce back" than the calcium/calcium type, and you can add water.

Pulsar

I should mention a unique design that looked for a while like it was going to take over: Pulsar. Instead of using positive and negative plates and insulators stacked like a deck of cards and welded together at the top to form separate two-volt cells, it has modular injection-molded "power panels." Each panel has six vertical sectors, three negatives alternating with three positives. Two panels are mated with an insulating layer between, which creates a complete 12-volt battery half an inch thick. Any number of modules can be joined to produce the desired amperage capacity -- one example has 18 pairs. Along each side of the stacked panels is a brass bus bar, one positive and one negative, which shortens the power path. Also, internal copper bus strips are used because that metal has less resistance than lead.

Great claims were made for this innovation in construction, which was developed by Australian Bill McDowall of Pacific Dunlop in 1972. Exceptional vibration resistance, for example. In lab tests at three G's/50Hz, regular batteries failed in 20 minutes, while Pulsar units were doing fine after 40 hours. Light weight is another advantage -- 25% less for the same capacity. Then there's design freedom. Separate small, thin batteries could easily be manufactured to handle various power consumers (starter, computer, stereo, etc.), and be mounted wherever practical, which would leave more room in that cramped engine compartment. Also, if the car makers move to higher voltage systems, Pulsars could be hooked in series more conveniently than traditional units. Manufacturing is highly automated, too.

But there's never a rose without a thorn, and this new approach has a couple of sharp ones. Relatively low reserve capacity, for example -- 108 minutes for a 640 CCA specimen. But that's not as troubling as the fact that it's difficult to recycle a Pulsar. While nobody would've cared much about that in the past, recycling is one of the major issues in the battery industry today because of existing and pending regulations. There's no problem recovering almost 100% of the materials in conventional units, so they'll continue to dominate.

More can be less

The equivalent of a horsepower race is going on among battery manufacturers where CCA is concerned. Passenger car units with ratings of up to 1,000 are on the market, and that's enough to crank a semi on a frigid morning.

But, as I said above, there's a trade-off between CCA and RC ratings. This is because the more numerous plates used to increase cold cranking are by necessity thinner, so the overall proportion of reactive material is smaller and reserve capacity goes down. Another problem with thin plates is that they're more apt to buckle at high temperatures.

Sauna survival

Speaking of heat, some manufacturers are addressing the fact that it's way up in today's cars, which causes all kinds of problems. Besides the buckled plates just mentioned, there's the chronic undercharge condition that occurs because a hot battery will produce higher voltage than a cool one at the same state of charge. The voltage regulator doesn't know the temperature, so it assumes the cells have a full dose of juice when in fact they may be down 25%.

High heat and a continual low state of charge makes hard sulfation build up, and crystallization starts breaking the bond between the active material and the grid. The lead becomes so soluble it attaches to the separators forming a "tree" that can short out the plates right through the pores in the plastic envelope. Specific gravity rises too far because the water evaporates while the acid stays, and separators can become "charred."

All this adds up to a surprising statistic: Average battery life is actually shorter in the south (30 months) than in the north (38 months). So, there are batteries on the market designed specifically to combat heat, and they employ both new and old technology to do this -- efficient radial grids, but thicker plates. This lowers CCA, but who needs all that zero weather kick in the sunbelt? What's really necessary where warm weather prevails is plenty of HCA (Hot Cranking Amps -- the discharge load in amps a new, fully- charged battery at 32 deg. F. can deliver for 30 seconds while maintaining 1.2 volts per cell) and RC (how about 130 minutes?).

Another feature is a thermal insulation blanket made of a plastic foam that floats on top of the electrolyte, displacing the air so there's less gassing and evaporation.

Invisible spare

Computer-designed radial grids, thinner plates, and other refinements greatly increase the energy density of modern batteries. To illustrate, a typical old-fashioned unit could deliver maybe ten cold cranking amps per pound, whereas a more highly-evolved specimen might produce 18.

This has made a neat new feature possible: a back-up reservoir of starting power right inside a normal size-battery. If you ever come out in the morning to find that your energizer is just too run down to crank the engine, just pop the hood, flip a switch and try again. The back-up (275 CCA in one specimen) is separated from the rest of the battery by a diode (a one-way valve for electrons), which allows current to flow in only until the switch is thrown. That means sufficient juice will be available for starting even if you've left the lights or that megawatt ear-blaster on all night.

Making water

Ever hear of the recombinant battery? The idea here is to immobilize the electrolyte and keep the moisture level stable by forcing the hydrogen and oxygen to recombine into water. This is accomplished by using a different type of insulator and by keeping the interior of the unit under pressure. Because this type of battery is insensitive to severe angles, it's particularly applicable to marine use.

The concept's biggest problem is the relief valve that maintains pressure. It's hard to keep its calibration accurate in mass production, so you might end up with a battery that looks like a bowling ball. Also, it takes twice as long to recharge as a regular "flooded" unit. The first recombinant to hit the market in the U.S. promptly failed, but others are available now, and the European aftermarket is showing considerable interest in the principle. I'm not going to hold my breath waiting for it to take over, though.

New standard, new couples

One big change we'll probably be seeing in the not-too-distant future is a switch to higher voltage systems -- most likely 24, but maybe 36 or even 48. Why tamper with a standard that's been around for 40 years? Because using electric motors to drive such things as A/C compressors and rack-and-pinion steering gears is becoming a fashionable idea among car designers, and that'll draw plenty of amps. Instead of resorting to gigantic cables to deliver the juice, increased voltage can be enlisted.

Finally, are there any new combinations of active materials (called "couples" in the industry) that show promise as a practical replacement for lead-acid? In a word, no. As one of the battery engineers I interviewed for this section put it, "I don't think we'll see a switch from lead-acid. Its cost is low relative to any other couple, nicad for instance. And lead-acid is eminently recyclable."

B. Battery Testing

There it sits, unwilling and unable. All its advanced engineering and high performance are absolutely and totally defeated by the failure of one of its most basic components -- the battery. Without this reservoir of electrical potential, the best car in the world is as immobile as your average tree, as useful as a piece of metal sculpture. True, it's been proved that bad plugs are the most common cause of no-starts, but battery problems are a close second.

This automotive prime mover operates on the same electro-chemical principles it always has, but its design and testing procedures have changed in several ways over the last couple of decades. One battery maker claims that only half of its returned units are actually bad, so its important that you understand current (no pun intended) troubleshooting.

Prelims

Before you jump to the conclusion that the battery itself is the cause of a no-crank or slow-crank condition, make sure its cables and connections (emergency clamps are, after all, just that) are in decent shape and that the fusible link isn't blown. Then there's the starter (is it drawing an inordinate number of amps?) and the charging system (is the belt okay, and is voltage being produced?), both of which are covered in other sections. Next, look for cracks in the battery case and observe the liquid level in all the cells.

Underweight?

Your great-grandfather probably determined the health of a battery by "weighing" the electrolyte with a hydrometer, then comparing the readings of the individual cells. Since sulfuric acid is 1.835 times as heavy as water, you can tell how much is present, hence how strong the charge is, by measuring the specific gravity of the water/acid mixture. At 80 deg. F., a reading of 1.260-1.270 (subtract .004 for every 10 deg. below 80) corresponds to the proportions that constitute a full charge -- 24% acid by volume, 35% by weight. If the float only rises to, say, a piddling 1.120, enough acid has turned to water to render the battery deceased for all practical purposes. Charge it (I'll get to that subject shortly) and try again. If any cell reads .050 less than its mates, and doesn't shape up after another blast on the charger, replacement is the only remedy. By the way, hydrometer testing isn't accurate immediately after adding water, if there's been a recent heavy discharge, and during charging.

This is still a valuable check, but many of today's batteries don't allow you to do it because they're sealed (I've seen some butchered, even drilled tops, which were the result of somebody's refusal to accept this situation).

Maybe, maybe not

Checking the voltage across the posts is simple and fast, but just because you get a reasonable reading doesn't mean the unit has the ability to supply a useful amount of amperage. To explain, if your meter shows less than the 12.6 volts that indicates full charge (it can even be slightly higher -- say, 12.8 -- just after being rejuvenated), two conditions may be present: All the cells have a low charge, or five have 2.1 and the last has something less, maybe 1.7, so you see 12.2 volts. Using a hydrometer would let you find out if there's a weak link, but how about those sealed units?

Load mode

Well, a careful capacity or load test is the only answer. In fact, even in cases where you were able to measure specific gravity and found it okay, but are dubious about the battery's capacity because of its age or suspicious symptoms, this procedure is necessary. The way it gets right down to the truth makes a professional-quality VAT (Volt/Amp Tester) attractive, although it's too expensive for the typical do-it-yourselfer.

Don't even bother with this if you're not going to do it accurately and completely. First, there's the side-terminal connection problem. Don't just use a bolt because the thread contact area is too small to carry enough current for either load testing or charging. Either screw in an adapter or, if one's not handy, a 3/8 in. coarse bolt with a nut on it. Bottom out the bolt, back it off a turn, then tighten the nut against the contact and attach the lead to the nut.

Chargification

Then there's the question of charging. Those cells have to be right up there before doing a capacity test. And charging is actually part of the testing. If the battery seems not to accept this infusion of electrons, you might jump to the conclusion that it's bad. You might be wrong. The problem is that the electrolyte in a really low battery is mostly water, which is a poor conductor, so initial current flow will be minuscule. It can be a long time before enough acid is present to allow a decent amount of amperage to move. A typical charger that provides 16 volts will have to run for four hours before the ammeter will start to register. A cold battery will be reluctant to take on juice, too.

Volt and amp readings during the charge can give you a rough, preliminary indication of the battery's condition. The combination of low volts and high amps suggests an internal short, while the opposite situation should make you think sulfation of the plates or cold electrolyte (reduce the rate and charge longer). If both the volts and amps are low, perhaps the unit's totally discharged, very cold or frozen, or maybe you've made a poor connection.

Another possible impediment is the polarity protection circuit present in some chargers. A completely dead battery won't have enough voltage to activate this feature, so it will appear that it's unchargeable when it's really just run down. You'll have to follow the manufacturer's recommendation on how to override this circuit and force electrons to start moving.

The Battery Council International says you should never load test a sealed-top battery if it's temperature is below 60 deg. F. So, if it's cold out, you'll have to bring the unit inside for several hours.

Step by step by step . . .

Here's the proper procedure for a capacity test (also known as a variable load or high rate discharge test), for which you can use a VAT, or a separate voltmeter, ammeter, and variable resistor or carbon pile:

1. If you've charged the battery recently, remove the surface charge by applying a 150 amp load for 15 seconds, or by disabling the ignition and cranking the engine for that length of time (it'll dissipate by itself, but that'll take two hours).

2. With the load off, connect your tester to the battery. An inductive pickup must surround all the wires from the negative terminal.

3. Turn the amp and volt knobs to the appropriate settings, and adjust the temperature scale, if present.

4. Adjust the carbon pile until the ammeter reads 1/2 the CCA rating of the battery. If you can't find that number anywhere, use the car maker's recommendation. Or, you can multiply the amp hour rating by three.

5. Apply this load for 15 seconds (some testers have a convenient timer button for this), then, with the load still on, note the voltmeter reading and turn off the load.

6. At 70 deg. F., the voltage shouldn't have dropped below 9.6 (or, 9.1 at 30 deg., 8.5 at zero). And here's where some judgment comes in. If the reading exceeded the spec by a volt or more, it's got some safety margin. On the other hand, if it's right on, it may not have the reserve necessary to do the job in tough conditions. Keep in mind that this varies with the state of charge you determined with the hydrometer. If the battery was only at 75%, yet it met the spec, it's probably in good shape.

7. If the voltage was below the temperature-corrected minimum, continue to watch the voltmeter after removing the load. If it rises above 12.4, the battery is bad -- it can hold a charge, but has insufficient CCA. Recharge and do the test again if you want, but there's little hope. In cases where it doesn't reach 12.4, a low charge is probably the only trouble. Feed it another good dose of juice, then retest.

Since you probably don't have access to a VAT, you can approximate this test in a quick and dirty way with just a voltmeter across the battery. Disable the ignition (traditionally, of course, this was done by removing the coil wire from the cap and grounding it, but with plenty of modern electronic systems you'll have to find out which wire must be disconnected to stop the primary voltage feed, or you might want to kill fuel injection instead), and crank the engine for 15 seconds. If voltage doesn't dip below 9.6 (again, corrected for temperature), the battery's probably okay.

A safety note: According to the National Society to Prevent Blindness, 14,238 Americans suffered serious eye damage from wet cell batteries in a recent year. Wear your goggles or glasses!

C. Starting System Diagnosis

If it hadn't been for the invention of the self starter, automotive history would've been profoundly different. Hand cranking would've limited the use of big, high-compression engines to body builders and gorillas, and even small, wimpy powerplants would require more physical effort than could be mustered by the frail, the elderly, and (dare I say it in this age of political correctness?) most women.

But engineering, like nature, abhors a vacuum. The need was clearly recognized by the right person in 1911 -- Henry Leland, founder of Cadillac, was badly injured when he tried to restart his car on a bridge. So, he commissioned Charles "Boss" Kettering, head of Dayton Electrical Co. (Delco to you), to come up with a dependable cranking system that didn't involve human sinews. The next year, all Cadillacs had electric starting as standard equipment.

So we exchanged sprained wrists and ruined backs for another set of troubles. Starting system malfunctions range from a total lack of rotation to noisy engagement and slow cranking, none of which can be tolerated for long. The actual replacement of the parts involved doesn't require any special skill, but finding out the exact cause of the problem sure does -- without it, there's a good chance that perfectly healthy components will be replaced unnecessarily. This section is intended to help you insure against embarrassing and expensive mistakes.

Read my sound

The first step in the investigation of a starting complaint is to listen while you twist the key. If there's silence, turn on the headlights. If they're dim or don't go on at all, the battery and/or the connections are probably at fault. The same is true in cases where the lights get noticeably dimmer when the ignition switch is turned to the Start position. In a complete no-crank situation, if they continue to shine brightly when you turn the key, there's an open in the circuit somewhere.

If the solenoid clicks once, but the starter doesn't run, the battery and its cables should again be suspect, but a jammed engagement mechanism or a seized engine could be the problem. A chattering solenoid is either not getting sufficient current, or has a faulty hold-in winding.

Slow cranking may be the result of high electrical resistance, a low battery, a bad starter motor, or excessive internal engine friction. If lethargy is accompanied by unevenness, incorrect valve timing due to a broken or jumped camshaft drive belt, chain, sprocket, or gear is a distinct, if unpleasant, possibility.

If the starter motor spins freely, but doesn't turn the engine, or you hear a grating, grinding, gnashing noise that stands your hair on end, your on-car troubleshooting efforts can stop here. You know immediately that the starter has to come out so you can examine the pinion and flywheel teeth and the engagement mechanism.

If you haven't isolated the offending component yet, it's time to check the battery as explained in the preceding section.

Draw conclusions

Nothing will give you more useful info on the condition of that husky electric motor than a starter draw test. The simplest way to do this is to kill the spark, then use an inductive ammeter around the cable. A more comprehensive procedure involves a load tester, to wit:

1. Run the engine until it's thoroughly warmed up, disable the ignition, and hook up your tester (load off). If you should happen to be using separate meters, put the carbon pile in series between the ammeter's negative lead and the battery.
2. Crank the engine for 10 seconds and note the battery voltage reading just before you stop.
3. Turn the variable resistor/carbon pile knob until you get the same voltmeter reading obtained in step 2.
4. At this point, the ammeter will indicate the starter's current draw.

If more than the specified number of amperes is being consumed, the possible culprits are a bad starter motor, a cable that's shorting to ground, or high internal engine drag (if the complaint is slow cranking when hot, the lube may be draining off the cylinder walls, and, if flooding is involved, the gas may be washing that precious oil film away).

On the other hand, if the draw is below specifications and the engine cranks slowly, you've found high resistance in the cables (watch out for cheapo replacements that are more insulation than copper, and a cable repair that involves one of those resistance- and corrosion-prone emergency clamps), engine ground, solenoid contacts, or the starter motor itself (slow hot cranking with low draw may due to a missing starter/solenoid heat shield). A related indication is a battery voltage reading that doesn't drop a normal amount while the starter's engaged (in other words, it stays above 11).

Drop

While cranking, voltage at the starter motor's hot terminal should be the same as that at the battery. If not, you're losing something between the juice source and the motor. For example, say the battery dips to 11 volts while the starter's running, but you only see seven volts at the motor stud. Four volts aren't making it to their appointed destination, whereas the max allowable loss is half a volt.

Which brings us to voltage drop testing, something that's often misunderstood. What you're looking for is an unintended load in the form of resistance. It'll show up on an accurate, low-reading voltmeter because it requires juice. The meter will detect an electrical potential across it (only while the starter is cranking, of course). Why not use an ohmmeter to measure resistance directly? It won't tell you anything useful because it can't assess the connection or cable during heavy amperage flow.

To check the drop of the entire starter motor feed circuit, connect your meter's leads to the battery plus post and the positive terminal of the motor itself. Anything more than .5 means you've found unacceptable resistance.

Now, cut it up into segments. Put the voltmeter between the battery's positive post and the solenoid's battery terminal, the negative post and the starter motor housing, and the solenoid's battery and motor terminals. Any reading of over 0.3 volts indicates excessive resistance somewhere in the circuit between the two points.

Other angles

In cases where you haven't found anything amiss yet, but the solenoid doesn't click, check the voltage drop between the solenoid's battery and switch terminals. If it's over 3.5, the starter control circuit has a problem. Use a jumper wire of adequate capacity to bypass the neutral or clutch safety switch, ignition switch, or related wiring. If the problem disappears when one component is thus taken out of the circuit, you've fingered the culprit.

Measuring the voltage available at various points in the system is another important diagnostic procedure. For instance, at normal temperatures a typical solenoid will operate when it receives eight volts at its switch terminal, or somewhat more if it's very hot. If you find more voltage than that, but hear no click, the solenoid's defunct.

It shouldn't take more than eight volts at the motor's armature terminal to make the starter run. If more than that amount of voltage is present, but the motor won't spin, the most likely causes are bad brushes or windings. Or, maybe the engagement mechanism is jammed. Either way, the starter must be removed for further examination. Unfortunately, there's another possibility: a seized engine. Try to rotate the crankshaft using a socket and bar at the pulley or damper bolt. If it won't budge, the car is suffering from a much more serious ailment than a problem in the starting system.