Rechargeable Batteries

We continue our look at batteries with a description of rechargeable types and how to use them.

ROBERT GROSSBLATT

Part 2

THIS MONTH, WE CONCLUDE our two-part look at batteries and battery technology by turning our attention to rechargeable (lead-acid and nickel-cadmium) cells, and how to choose the type you need.

Lead-acid batteries

The modern lead-acid cell is a far cry from its predecessors. Its open-circuit voltage is about 2 volts, which means that it has the second-highest energy capacity of the commercially available batteries, both disposable and rechargeable. Only a lithium-thionyl chloride cell, with an open-circuit voltage of 3.7 volts, has a higher energy-density—and it's not rechargeable! The drawbacks to lead-acid batteries—leakage, highly corrosive acid electrolyte, evaporation, and a host of other problems—have been eliminated in the designs of more modern cells. Lead-acid batteries come in a variety of sizes, voltages, and energy capacities and have characteristics that make them the ideal energy source for applications requiring the use of rechargeable batteries.

So, you may well ask, if they're so wonderful why aren't they more available? The answer to that is...Well, I haven't the vaguest idea and would appreciate finding out why. Possibly the answer has something to do with the ready availability of nickel-cadmium batteries, the other major type of rechargeable battery. Before we start comparing the two technologies, let's take the time to find out how each is used. Once that's done, we'll list the advantages and disadvantages of both types and you'll be able to make your own decisions.

Lead-acid batteries are easy to use. Anyone who owns a car knows that those batteries can operate successfully under the most adverse conditions and are extremely forgiving when it comes to things like accidental deep discharge and constantly repeated partial discharge.

Figure 6 is a cutaway view of a typical lead-acid cell. Although there are variations from manufacturer to manufacturer, most of the batteries use the basic construction shown. The electrolyte is an acid that is permanently sealed in the body of the cell. It's worth nothing at this point that that technique (permanently sealing in the electrolyte) is starting to be found in car batteries as well. Some companies that make lead-acid batteries "immobilize" the electrolyte by gelling it. This means that the cell can be used in any position without any risk of the electrolyte leaking out. Even though the construction of the cell usually involves several heavy-duty seals and double-walled insulation, the acid is extremely corrosive and anything that helps maintain the integrity of the battery is a good idea.

Rechargeable lead-acid batteries are available in voltages ranging from 2 to 24 volts and they can be used in any configuration you want. Unlike some other batteries, you can either parallel them to increase the current or put them in series to increase the voltage. Since the energy density in lead-acid cells is very high, you can get really impressive amounts of power by packing together a number of

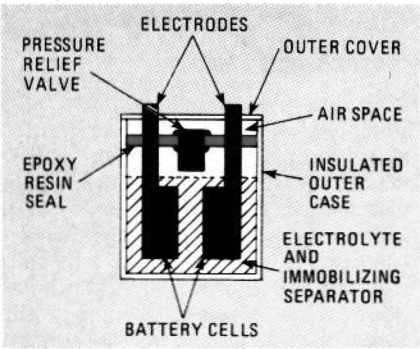

FIG. 6—CUTAWAY VIEW OF A MODERN LEAD-ACID CELL. Some batteries use a gelled electrolyte.

TABLE 4—LEAD-ACID BATTERY CHARGING PARAMETERS

Type of charge	Charging voltage (volts DC per cell)	Charging current (percent of cell capacity)	Charging time
RAPID	2.55 - 2.65	100%	1 - 3 hours
QUICK	2.50 - 2.55	20% - 50%	12 - 20 hours
STANDARD	2.45 - 2.50	10% - 40%	10 - 18 hours
TRICKLE	2.28 - 2.32	10% - 20%	Continuous

cells. And how much power the battery can deliver has nothing to do with how the battery was used previously.

A battery that is normally charged after only a small part of its stored energy has been used can still deliver its total power whenever the situation calls for it. That is a common scenario in applications where rechargeable batteries are used as emergency backups in case the primary power fails. Batteries that are constantly charged can similarly always be counted on to deliver their full power if the circumstances require it. In other words, lead-acid batteries have no "memory" of their previous use.

The charging circuits for these batteries can be as simple or sophisticated as you like. They are capable of being charged at extremely high rates if the proper safeguards are taken. How you charge them depends on how you plan to use them. Table 4 gives you the recommended charging rates and other information you'll need to be able to safely recharge the batteries. It's important to stay within the guidelines shown—overcharging can have catastrophic results.

Even though the chemistry of the cells is designed to be reversible (which is what makes the cells rechargeable), overcharging them carries the same sort of dangers as trying to charge the throw away batteries we discussed last month. During the charging cycle of *any* battery, gas is produced. A major functions of the electrolyte is to act as a "depolarizer"—a rather fancy way of saying that it's designed to absorb the gas produced during a charge. However, and this is a really big however, the electrolyte can only absorb gas at a certain rate. If the gas is produced faster that it can be absorbed, then **BOOM!**. Good-bye battery and anything else that happens to be around *and that can include you, too!* Make sure you don't exceed the recommendations for the charging rates and times given in Table 4. A lot of batteries were blown up to compile those figures.

Nickel-cadmium batteries

Nickel-cadmium (NiCd) batteries are the most popular rechargeable batteries on the market today. They are packaged in all the standard sizes and the cell's open-circuit voltage is 1.25 volts (which makes them a close match for most of the applications where throw-away batteries are used.) Prices depend on where you buy them but, in general, it's safe to say that they're more expensive than alkaline and lead-acid batteries, but cheaper than lithium and silver-oxide batteries. The voltage-discharge curve is nice and flat, meaning that the battery will have a constant voltage for most of its discharge cycle. Unlike lead-acid cells, nickel-cadmium cells are not designed to be used in a parallel configuration. The normal method of use is to decide what your current requirements are and then get cells of the needed ampere-hour capacity and connect a number of them in series to build up the voltage you need for your system.

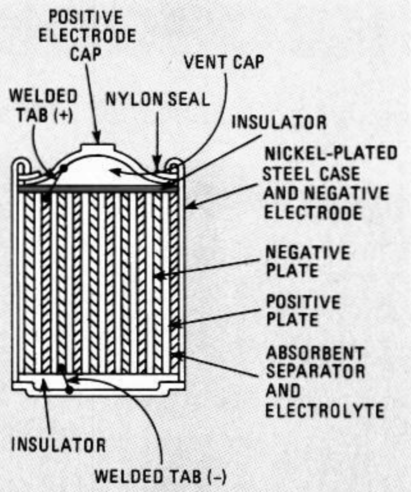

FIG. 7—A NICKEL-CADMIUM CELL consists of nickel and cadmium strips wound together and separated by absorbent nylon.

Figure 7 is a cutaway view of a typical cylindrical NiCd cell. The nickel anode and cadmium cathode are made in strips that are wound together into a coil with an absorbent nylon separator between them. The separator is used to absorb the alkaline electrolyte. It is also permeable to oxygen (the gas produced during the charge cycle). The assembled battery is packed into the outer case, usually made of nickel-plated steel, the external positive and negative contacts are welded to the electrodes, and the cell is finally sealed. The seals keep the electrolyte from drying out and are designed to act as pressure-relief valves. If the internal buildup of gas gets excessive, the seal will open and vent the extra pressure. How well the battery functions afterward depends on how much electrolyte is lost. In any event, you can bet that the battery will be but a shadow of its former self.

The internal resistance of the average NiCd cell is very low—usually less than 100 milliohms—which means they can be used in circuits where high discharge-rates are required. Some NiCd cells, however, are specifically designed with a higher internal resistance that, although lowering the maximum discharge rate, increases the cells ability to retain a charge. Button cells and 9-volt "transistor battery" substitutes are usually manufactured like that. The internal resistance of the cell is a good guide to the charging rate: The higher the value, the lower the charging rate. The most common cause of NiCd cell failure is an improper charging rate.

A dead NiCd will be either an open or short-circuited cell. Open circuits are usually the result of electrolyte loss and this is directly caused by constant rapid discharging, constantly high charge-rates, or anything else that will make the cell blow its seal. Remember that by the time the cell parameters are exceeded enough to make the seal open, the high current rate that caused it in the first place will have made the battery heat up, and that will make the electrolyte evaporate at a greater rate. In any event, there's no way to replace the electrolyte, so if you measure the internal resistance of the battery with a multimeter and find it to be an open circuit, the battery is gone forever.

Short-circuited cells are another story. Sometimes the separator will get ruptured and metallic salts will form a small bridge that shunts the current around the rest of the plate. A high current pulse can burn out the short and the cell can then be charged, since the correct current path has been restored. Commercial "zap" circuits use this technique by charging a large capacitor and then discharging it through the cell. If you monitor the battery's voltage, you'll see the voltage start to increase as all the internal shorts are cleared out. If the separator has deteriorated in the cell, the battery is beyond salvage and should be replaced.

Recharging batteries

So now that we know everything about lead-acid and nickel-cadmium cells, let's find out about how to charge them. The circuits needed can be as sophisticated—or as simple—as you like. Which circuit you want to use depends on which cells you use, now fast you want to charge them, and how you want to use them.

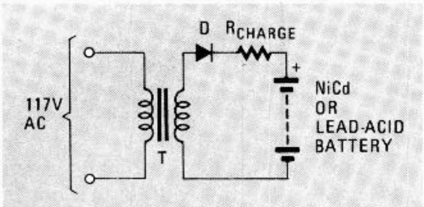

FIG. 8—A SIMPLE CHARGING CIRCUIT for nickel-cadmium or lead-acid batteries.

The simplest charging circuit you can have is illustrated in Fig. 8. Calculating the resistor value and which diode to use is simple. First, let's lay down some general guidelines. The transformer you use should have a voltage at its secondary at least twice the open circuit voltage of the battery you want to charge and the diode should have a PIV (*P*eak *I*nverse *V*oltage) rating at least twice that. The resistor has to be able to handle the charging current at the open-circuit voltage of the battery. To be on the safe side, let's use the voltage of the transformer's secondary. Now that we have those things out of the way, let's use Ohm's law to fill in the blanks.

$$V_{system} = V_{transformer} - (V_{battery} + V_{diode})$$

$$R_{charge} = V_{system}/I_{charge}$$

$$WATTAGE_R = V_{transformer} \times I_{charge}$$

The key here is deciding what you want the charging current (I_{CHARGE}) to be. The rate of current flow through a rechargeable battery is referred to in terms of the total capacity of the cell. The rate of charge or discharge for a particular battery is usually given in the C-rate. The C-rate is the current rate in amperes numerically equal to the rated minimum amp-hour capacity. If the recommended charging rate for a cell is listed as 0.1C, for example, that would tell you that the maximum current you can use to charge the battery is numerically equal to 1/10 the total amp-hour capacity of the cell. If the cell was rated at 500 milliamp-hours, 0.1C would translate into a charging current of 50 milliamps.

Table 5 shows the various rates of charge and how long it will take to fully charge a cell. It's important to remember that not all cells can be charged at the higher rates. Nickel-cadmium cells are too expensive to risk destroying by impatience. All the cells, however can withstand the standard 0.1C rate. But let's get back to our example.

TABLE 5—NICKEL-CADMIUM BATTERY CHARGING PARAMETERS

Type of charge	Charging voltage (volts per cell)	Charging current (percent of cell capacity)	Charging time
RAPID	Depends on Cell	Depends on Cell	1 - 3 hours
QUICK	2.50 - 3.00	20%	3 - 5 hours
STANDARD	2.50 - 3.00	10%	14 hours
TRICKLE	2.50 - 3.00	5%	Continuous

If we're going to charge a 4.8 volt series of batteries that have a 1.2 amp-hour capacity at the standard 0.1C rate and are using a transformer with a 9 volt secondary:

$$V_{system} = V_{transformer} - V_{battery}$$
$$= 9 - 4.8 = 4.2 \text{ Volts}$$

$$I_{charge} = 0.1C = (0.1)(1.2) = 120mA$$

$$R_{charge} = V_{system}/I_{charge}$$
$$= 4.2/.12 = 35\Omega$$

$$WATTAGE_R = (V_{transformer})(I_{charge})$$
$$= 9 \times .12 = 1.08 \text{ WATTS}$$

Finding a resistor with a rating of 1.08 watts is going to be difficult, so let's make a general rule: we'll always bump the value up to the next available size. That means a 35-ohm, 2-watt resistor. The PIV rating of the diode has to be at least twice the transformer secondary or 18 volts and it has to be able to handle at least .12 amps. Any of the family of 1N4xxx diodes is a good choice for the circuit. In this particular case, the 1N4001 is fine. It should be noted that we did not take the voltage drop across the diode into account when we calculated the parameters of the circuit. Since the diode drop is going to be small compared to the other voltages, and our assumptions have built-in safety margins, it can reasonably be ignored. If you're building a charger for battery systems that have lower voltages and are looking for larger charging currents, the diode drop should be considered in calculating the overall system voltage. By the same token, if the charging current you need is really small, the diode's forward resistance will have to be taken into account and subtracted from the calculated value of the current limiting resistor. If the value of the calculated resistor is small enough you can do away with it altogether and let the diode serve as the current limiter.

A more efficient charger can be built using a full-wave rectifier. The math is exactly the same as in our example. Just get the values of the circuit parameters and plug them into the formulas. More elaborate chargers will monitor the state of charge of the battery and automatically switch over to trickle charging when the battery is fully charged. These circuits are used when the initial charge rate is going to be in the "quick" or "rapid" range. How the circuit is put together will depend on the batteries that are being charged and what the initial charging rate is going to be. The actual design of these circuits is involved because it's a good idea to have several levels of protection for the battery. That way if the primary switchover circuit fails, other parts of the circuit will save the day.

The dangers here shouldn't be minimized. If you overcharge a cell at a high rate of charge, you can, of course, kiss the battery good-bye. But we've already seen that you're running the risk of explosive rupture of the cell from the accumulated gas and that can destroy a lot more than just the battery. I overcharged a 20-milliamp NiCd button cell—the smallest nickel-cadmium battery you can buy. When it exploded it blew a hole in the side of the charger's plastic case! Be warned and be careful to follow the manufacturer's recommendation.

There have been charging circuits published repeatedly in any number of magazines, data books, and so on. Look them up and decide which one you want to use in your particular application. I can offer you a few general rules and a couple of useful tips.

The overall system voltage in your charging circuit will decrease as the cell charges up and the current flowing in the circuit will, naturally enough, start to drop until it reaches a steady state. This is because a discharged cell will rapidly regain enough energy to be at its nominal voltage.

For this reason you shouldn't be alarmed if you measure the current flow in your circuit and find it a lot higher at the beginning of the charge cycle. It will soon drop to a point as close to your calculated value as your component values are close to their calculated values. If your charger is designed for the standard rate, you shouldn't have any problems.

If you use a full-wave rectifier and put the current-limiting resistor between the transformer and the rectifier, you will have a variable-current charger. Current flow will continue to decrease as the cell takes on more and more of a charge. That circuit arrangement is shown in Fig. 9. Figure 10 is a handy circuit that you can use to monitor the current flow. If it looks familiar, it's because you've already seen it in the June installment of the "Designer's Notebook" and you'll find a full description of it there.

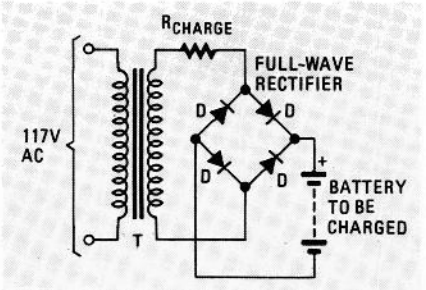

FIG. 9—AS THE BATTERY CHARGES, the current rate will decrease.

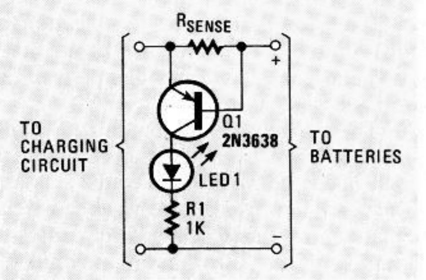

FIG. 10—YOU CAN MONITOR THE CHARGING CURRENT with this simple circuit.

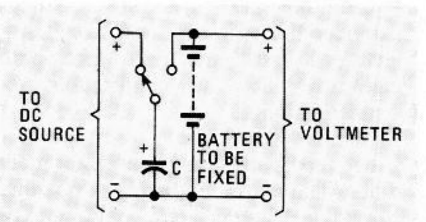

FIG. 11—YOU CAN CLEAR SMALL SHORT-CIRCUITS made up of metallic salts in NiCd batteries.

Basically the small voltage across R_{SENSE} turns on Q1 and the transistor turns on the LED. (Anything you want can be substituted for the LED. A relay, for example could put another resistor in series with the current-limiting resistor and cut the charging current down to a trickle charge.) The formula for calculating the value of R_{SENSE} is: $R_{SENSE} = 0.65/I_{CHARGE}$, where 0.65 volt is the voltage needed to turn on the transistor. If you're really a whiz at working out circuit parameters, you could get the value of R_{CHARGE} to equal R_{SENSE} and do the whole job with just one resistor. I can't work things out for you because the values for the components depend on the batteries you use, the charging rate, and many other factors. If you're careful though, you should be able to build yourself a charger that has several charging rates and can automatically switch over to over to trickle charge when a predetermined point is reached.

Rapid charging of cells should not be tried unless the cell is specifically designed to handle very high charging-currents and lots of safeguards are built into the charger. This kind of charging takes place under *very* controlled conditions.

TABLE 6

Parameter	Lead-acid batteries	Nickel-cadmium batteries
Memory	None	Requires Reconditioning
Current Capacity	Generally in Amperes	Generally in Milliamps
Cost	Moderate	High
Weight	Generally over 1 pound	Generally under 1 pound
Configurations	Parallel or Series	Series Only
Availability	Hard to Find	Available Everywhere
Shelf Life	50% Loss in 8 Months	50% Loss in 3 Months

The usual method of operation for this kind of charger is to monitor the *temperature* of the cell and switch to a trickle charge, (or completely off), when the temperature of the cell reaches a certain level. Thermistors and other temperature-sensing components monitor the cell and control logic that switches the charger to a lower rate.

We've already discussed how battery "zapping" can be used to try and clear out small internal shorts and revive cells that are apparently dead. Figure 11 is the basic circuit that's used. When the switch is thrown to the left, the capacitor charges, and when the switch is thrown to the right, the capacitor discharges through the theoretically dead battery and, we hope, burns out the small bridges of metallic salts that are shunting the current in the cell.

If the cell can be saved, after you blast it a few times you should see the voltage starting to rise on the meter. Once that happens, give the cell a few more hits and then charge it normally. It won't be as good as a good cell, but then again, it won't be as bad as a bad cell. You'll notice that I haven't given you any value for the capacitor. Well, the voltage rating should be *at least* as much as the largest voltage in the system, (either the battery or the source), and the capacitance should be as big as you can get. This is one of those instances where bigger *is* better. The more capacitance you have, the larger the blasting current is going to be and the more chance you're going to have of resuscitating the battery.

Our last helpful hint has to do with one of the most common uses for rechargeable cells: memory retention and emergency backup. There are lots of different ways to design a circuit that will do the job, but the basic idea is shown in Fig. 12. When the DC voltage source is present, the batteries charge through R, the current-limiting resistor (because the diode is reverse biased). When the main power supply fails, the diode is forward biased and the NiCd batteries provide power to the load. The calculations for finding the value of R and the considerations for choosing the diode are exactly the same ones we discussed for our simple charger. There are other, more elaborate schemes for using rechargeable batteries like this, but they all use this approach. Diodes are used to steer the current where you want it and the biasing of the diodes is switched by the presence or absence of the main power supply.

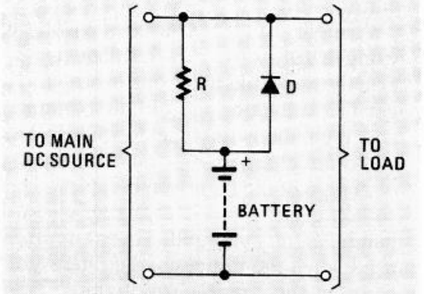

FIG. 12—ONE OF THE MOST POPULAR applications for rechargeable batteries is backing up power supplies.

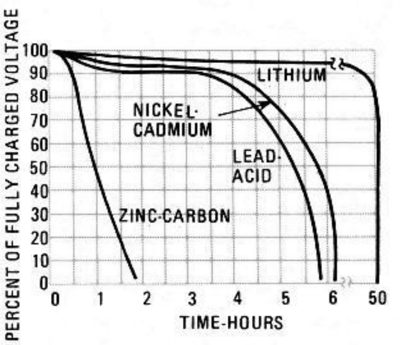

FIG. 13—VOLTAGE DISCHARGE CURVES for various types of batteries discharged at the 0.2C rate. Note the break in the hours scale.

We now come to the question of which battery type you should use. Well, the answer is, as we saw with disposable batteries last month, it depends. As a general rule, lead-acid batteries are used where the current draw is going to be heavy and NiCd's are used where it's not. Now I know that these are all relative terms but, like I said, it depends. For practical purposes, let's just say that if the current draw is going to be consistently in the multi-ampere range, go for lead-acid. If it's under an amp, look at NiCd cells. The relative merits of each system are summed up in Table 6 and the voltage-discharge curves for some of the various batteries are shown in Fig. 13. I've put in the curves for some of the lithium-based batteries as well as the zinc-carbon ones so you can make an overall comparison.

continued on page 113