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⊲ Nickel Metal Hydride Rechargeable Cell – Sub C size commonly used in battery packs.

Rechargeable Batteries in Portable Power Tools

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What is the most useful portable power tool you own? I bet it is your battery operated drill/driver. The convenience of cordless drills was a revelation to me – not having a mains power cord getting in the way. There are a few drilling/screwing jobs that it can't cope with, but then my trusty corded drill is brought into use, extension cords and all.

The downside of cordless power tools is the battery pack. As it ages, tt needs charging more and more frequently and eventually fails. My drill driver is an AEG, 14.4V model with a 1.4Ah battery. It has served me well since 2000, but recently the battery pack wore out – just before I fitted a set of drawers with slides to a cabinet, when I needed something compact and cordless!

Now I have a dilemma – buy a new drill or rebuild the battery pack?

This is an interesting topic: Jan Ferreira from Bosch expressed the opinion that when the battery dies on a cordless power tool, it is time to buy another complete tool, as the mechanical components are probably close to being worn out. The cost of the battery pack is often half that of a new unit, so he has a point. If the tool is professionally used, then I think he is right, however for the average home user, the battery pack probably dies of old age before the mechanicals are worn out. To illustrate why I think that Jan has a case, consider that a professional user, such as a cupboard installer, will probably buy two battery packs, so that one is charging, while the other is in use. Good quality NiCd or NiMH cells are good for 500 to 1000 charge/discharge cycles with the right charger and usage. So even if both packs are cycled once per day, between two and five years of battery use can be expected, by which time, the mechanicals will probably be worn out.

For hobby use, we have a different scenario – even if the pack is run flat once a week, that is 50 cycles per year. To reach 500 to 1000 cycles would take ten to twenty years. Battery packs don't usually last that long, because other wear-out mechanisms lead to failure. The mechanicals of a unit designed for **professional** use will definitely outlast the battery for hobby use.

Based on this, I decided to investigate rebuilding the pack on my AEG. (Also being an engineer, I like a technical challenge, and I don't like throwing things away.)

The first fact became apparent – I can't buy a set of cells for the price of a replacement "Hobby" spec cordless drill. The Black & Decker 18V unit shown at the middle right is R500- at Makro and the Ryobi below it is R350-. Bearing in mind that you get what you pay for, one must question how long these units will last in practise – pause for thought.

Some theory:

The first rechargeable batteries were Lead-acid and these are still in widespread use. There is one in your car and probably others in your alarm system, gate-motor and camping lantern. Lead acid batteries are well suited to standby use, but are rather heavy for their capacity. They are slow to charge, but they are relatively cheap for their capacity.

So it wasn't until the widespread availability of the next technology - Nickel Cadmium (NiCd) - that portable, battery operated power tools came into widespread use. NiCd batteries can tolerate deep discharges and provide very high peak currents. This made them ideal for battery drills. Early NiCd batteries did have some problems: self discharging quite quickly; memory effects and a limited number of charge/discharge cycles. These have been largely addressed nowadays, so they are capable of years of trouble free operation.

The next technology to come along was Nickel-Metal Hydride (NiMH). This is similar to NiCd, with increased capacities, but lower peak current capability. In many case NiMH cells can be used directly in place of NiCd, the exceptions

being in some high performance applications. NiMH are also Cadmium free – NiCd cells have been banned in the EU, except for special applications, due to concerns about environmental contamination when they are not disposed of correctly.

The current hot technology is Lithium in various forms. Lithium Ion (Li-ion) has the same volumetric power density as NiMH, but significantly better mass power density, so there are significant weight savings. Li-ion technology is much more expensive than NiMH and NiCd, and needs a special charger which is more complex.

The capacity of batteries is quoted in amp-hours (Ah). In theory a cell rated at 1 Ah will provide one amp of current for one hour, but in practice at one amp, it is slightly less. Generally the capacity (C) is quoted at the ten hour rate (C/10) which means it is discharged at 1/10 of the capacity for ten hours. A 1 Ah cell should provide 0.1 A for 10 hours when it is new. At higher currents the capacity drops significantly due to a combination of reasons – resistive and electrochemical.

When the battery is charged, the electrochemical processes that provide power output are effectively reversed, albeit imperfectly. Theoretically, to recharge a cell, current equivalent to amount discharged needs to flow back into the cell from an external source. So if 1 Ah was drained, then 1 Ah needs to be put back. However, there are losses during the recharging process due to heat amongst other things, so in practice about 140 to 160% is needed. So if 1.0 Ah was drained, about 1.4 to 1.6 Ah needs to be put back. In practice one doesn't know exactly how much current was drained. There are indications from the cell voltage, but this varies with temperature and the condition of the battery, so the battery is usually assumed to be empty and given a full charge. Most batteries are designed to be charged at the ten hour rate (C/10) for 14 to 16 hours. So for a 1.0 Ah battery, it will be charged at 0.1 A for 14 to 16 hours, and then we know it will be fully charged.

For battery power tools, recharge time is important. Nobody wants to sit around for hours waiting for batteries to recharge when there is work to be done. Hence, the fast charge cycle was invented. For portable power tools, most chargers are fast chargers, and will reach 80% of capacity or better within an hour. The battery will be charged at something like the C rate for one hour and then the charge rate will taper off until a full charge has been delivered. Some precautions need to be taken as NiCd and NiMH cells heat up significantly when under fast charge. Most packs have a temperature sensor of some sort included to limit the temperature rise. This is to avoid thermal runaway, and damaged cells or worse. (Thermal runaway occurs when the battery temperature rises, and the terminal voltage drops, increasing the current, increasing the temperature in a vicious cycle, until the battery bursts.) If you examine the connections to the battery pack, you will see at least three wires, two for the battery and a third to some sort of sensor. The sensor could be as simple as a bi-metallic strip contact that opens when a threshold temperature is exceeded, thereby limiting charge current. More sophisticated sensors are thermistors, allowing the temperature to be measured and the charge current to be throttled back appropriately. It also allows the charger to take account of ambient temperature and the temperature of the pack at the start of the charge cycle, which may be significant if it has been used hard prior to charging.

If a NiCd battery pack contained a single cell, discharging and recharging would be relatively simple. However they consist of a string of cells. Due to manufacturing tolerances and aging, there are variances between the cells, one of which is the capacity of the individual cells. As the pack is discharged, all the cells drain simultaneously, however the cell with the lowest capacity discharges first. Then as the pack continues to be used, the discharged cells are driven in reverse, called reverse charging. This is particularly damaging to Nickel Cadmium (NiCd) and Nickel Metal Hydride (NiMH) cells and is a major cause of failure of packs. In use, NiCd and NiMH packs have a relatively constant voltage output, but it drops suddenly as the cells discharge. This can happen rapidly - within a couple of minutes after an hour of use.

DO NOT ATTEMPT TO USE THE PACK FURTHER without recharging it. If you continue to drain the pack, the weakest cells will be driven into reverse, and after a few cycles may suffer irreversible damage. Your 10 cell pack will have only 9 cells contributing and then 8 and then 7 as the weakest cells are damaged first. The cells are designed to tolerate a limited amount of reverse charging, so they will not fail immediately, but don't push your luck. There are a variety of failure mechanisms, but reverse charging is one you can avoid. I know from experience that the pack usually seems to run down just as you are trying to drill the last hole, and you don't want to wait an hour for a recharge. The temptation is push on, but don't – you may be damaging the pack.

So, your battery pack is not holding a charge - what are your options? The easiest is to buy a new pack. The price is likely to be high, and then you need to decide whether the state of the mechanicals warrant a replacement battery. A little investigation is called for.

Perhaps you decide to go for the option of repacking the battery – there are some companies who will do this for you – but again you need to be aware of the costs and limited guarantees. You may be better off buying a new unit.

If you decide to repack your own battery, you need to have some soldering and electrical wiring skills. Firstly, you must source the replacement cells at the right price. The label on the pack will tell you the technology – NiCd, NiMH or Li-Ion, the voltage and the capacity. You need to open up the pack to measure the sizes of the replacement cells and count the number.
I have not replaced any Li-Ion batteries, so I can't give you any specific advice. There are some replacement cells available, but you need to check if they are suitable for portable power tools. Some power tools use a particular variety of Li-Ion called a Lithium-phosphate cell that is better suited to power tool demands. It may not be easy to source the right cells. Every battery must have an associated protection circuit that prevents overcharging and discharging. Using a Li-Ion battery without a protection circuit is strongly discouraged, as you risk provoking a catastrophic melt-down of the cells, and a fire. Because of the risks, some battery suppliers will only sell Li-Ion cells to qualified rebuilders.

NiCd and NiMH cells are generally rated at 1.2V, so the voltage of the pack, divided by 1.2 will give you the number of cells. Li-ion cells are rated at 3.6V, so there are fewer. My AEG battery pack said 14.4V. 14.4V ÷ 1.2 V per cell = 12 cells in the pack.

Open up the pack. Hopefully your pack will be held together with screws as was my AEG. Some are welded together – this makes disassembly tricky, and it is not going to look very nice when you put it back to together – See right for an example of a Makita battery that was cut open. (Image from http://gmansdiggerexperiment.com/416/how-to-repack-a-makita-cordless-drill-battery-pack/)

Count the number of cells, and measure the size. A typical size is Sub C which is about 22,5mm diam by 43mm high. This is important to ensure that the batteries will fit into the case once they have been assembled into a pack. There are several sizes, so you must check.

With improving technology, it is likely that the replacement NiCd or NiMH cells will have higher capacities, which you can happily use. I would be cautious going to cells of lower capacity, particularly with fast chargers. Don't mix cells of different capacities or technologies or vintages. It is important to replace all the cells, otherwise you may have a mixture of capacities, and the risk of reverse charging will occur.

I was faced with the option of replacing the NiCd cells with NiMH. For conventional charging, they are basically equivalent. However for fast charging, they do behave slightly differently. The important difference is when the cells are approaching capacity under a fast charge, they behave differently. In my case, the NiCd cells I was replacing were rated at 1400 mAh, (1000 mAh = 1.0 Ah) and the NiMH cells I had in mind were rated at 3000 mAh. I decided to take a chance, because when the old NiCd cells would be approaching capacity, the higher capacity NiMH cells would only be half full, and not in the region where the difference would arise. Also the battery pack has a sensor to guard against thermal runaway. The NiMH batteries I used are rated for fast charging at the rate provided by the AEG charger. In my case, NiCd batteries are significantly more expensive than NiMH, which also alters the economics of process – is it worth doing?

I selected and bought 12 Sub C cells from RS Electronics at R38- ea plus VAT = R520-. Not cheap, but the new replacement drill from AEG that is roughly equivalent to mine is about R1500-, so I thought it was worth doing. These cells are NiMH with a capacity of 3000mAh as shown on the right. They come with tags that can be soldered.

You can use cells without tags, soldering direct to the cells, but I don't recommend it, as there is the risk of overheating and damaging the cells. Better to get the tagged cells – they are freely available.

I could probably have saved some money by shopping around, perhaps as much as 50%, but RS had the right cells in stock. They have an excellent web site with lots of data on what they sell. Some of other suppliers only have a limited selection and no data sheets.

Doing the work

The standard of workmanship is important when repacking a battery pack. You don't want any short circuits, because of the high currents that NiCd batteries can deliver (40A!). If there is a short there may be high temperatures, melted plastic, damaged batteries and perhaps even a fire. Make sure all the tags are sleeved where they can touch. Ensure that the positive tags do not make contact with the negative casings of the same cell. The RS cells have a sleeve on the positive tag. When dismantling the pack, make careful note of the arrangement of the cells and their interconnections, so that they will fit back into the same casing. In use, the pack will receive many shocks and may even be dropped, so make sure all the connections are robustly soldered – no wires twisted together. Carefully extract the temperature sensor from the old pack and insert it into the same place in the new pack, avoiding any damage to the wiring.
Make sure all the polarities of the cells are correct, positive to negative. Use a voltmeter to ensure that voltages increase along the string of cells. Ensure there are no unexplained drops due to a cell being connected in reverse.

When fitting the assembled pack back into the casing, make sure that no shorts can develop – if in doubt, put some insulation in place. Don't use cheap insulation tape. The battery pack can get warm and you don't want the tape to slide off, leaving no insulation and a sticky mess. Good quality duct tape will do.

When charging the battery for the first time, watch carefully for excessive temperature rises and then leave the battery pack overnight on a long equalizing charge to bring all the cells up to full capacity. Take precautions against failure, perhaps by standing the charger and battery in a metal pan away from anything flammable, so if there is melting and fire, it is safely contained.

I checked the voltages of the cells that I bought. As delivered they varied quite a bit, due to varying states of charge. When a fast charger operates, it provides a high current to the pack until it reaches a voltage or temperature that indicates that the pack is about 80% charged. It then changes over to a low rate charge. This low rate charge is what will equalise all the cells in the pack over a few days. The cells will equalise over time with normal use, but I prefer to ensure that they were all equalised from the start, so I left the pack on charge for a couple of days.

If you are careful, you should have many more long years of service from your tool. You also have the pleasure of knowing that this is one less thing on the dump and you may have saved some money as well. If my new pack lasts another 10 years, I will be well satisfied – I think the mechanicals may be shot by then!

Dispose of the old cells correctly in a battery recycling centre container, particularly for NiCd cells. Cadmium is particularly poisonous and must be kept out of landfills, so that it doesn't leach into the groundwater.

Sources: www.wikipedia.org www.batteryuniversity.com RS Electronics: www.rsonline.co.za