Battery's 101
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This article was written to share with a friend who was designing a Trail 70 motorcycle and wanted to learn what battery to use. The assumption for this bike was that we needed to keep the batteries very light and small in size to fit on the bike. That is why batteries with a 20Ah size are used for the examples.

Batteries can be put in series to increase their voltage and in parallel to increase their current capacity.

Battery Chemistry

There are many different types of battery chemistries.

For this article I'll refer to two types in general: "Lead" and "Lithium Battery". When I say Lead, I'm referring to an AGM Lead Acid Battery. When I say Lithium Battery, I'm referring to a Lithium Iron Phosphate Battery. The following is a very generalized overview of battery chemistry.

"Lead" is Lead Acid. The primary types are Flooded Lead Acid (they have liquid water with acid in it) like the traditional starter battery in an automobile, and Absorbed Glass Mat (AGM) cells that are sometimes referred to as "Gel Cells". The advantage of AGM cells is that they can be mounted in any orientation without concern for the liquid running out of them. A primary concern when charging Lead Acid batteries is the production of Hydrogen Gas. Hydrogen gas has a huge range of concentration mixture with atmospheric oxygen where it is explosive, so proper ventilation is required when charging these types of cells.

"Lithium" is a battery chemistry containing Lithium. This field is constantly evolving and I fully expect Moores Law to be in effect for pricing and capacity of these cells. Battery chemistry will change more often than your underwear and pricing will plummet as performance goes up. Think about how the pricing of computer memory chips, and Hard Drives changed quickly over time. For simplicity sake I'll just say there three main Lithium battery chemistries: Lithium Ion, Lithium Polymer (LiPO), and Lithium Iron Phosphate (LiFePO4) today.

Lithium Ion is like the battery in your laptop or cell phone and is highly developed and has slight fire risks.

Lithium Polymer is what is used in RC model airplanes/cars and has the highest energy density, extremely fast recharge times, and spectacular power giving ability (20C or more!) – it is also well known for spectacular fires. Extreme caution must be used to not overcharge these batteries due to risk of fire.

Lithium Iron Phosphate is the current state of art for transportation vehicles. It has good energy density and is the safest chemistry for fires. This battery chemistry is sold in cells that have 3.2 volts nominal. To get the voltage and power you want you put these cells in series and parallel.

Battery Energy Capacity (How Many Gallons Does the Tank Hold?)

Battery's are rated for capacity with Amp Hours (AH), Voltage (V), and Kilo Watt – Hours (kW-Hours). A Kilo Watt is 1,000 Watts. A Watt is (Amps) x (Volts).

KW-Hours are a measure of how much energy a battery can store. It's like how many gallons a gas tank can hold.

To calculate the KW-Hours available to use from a battery use these formulas:

Lead Acid Battery Capacity (kW-Hours) = (Voltage x AH) / 1,000 * 50% Depth of Discharge (DoD)

"Lithium Battery" Battery Capacity (kW-Hours) = (Voltage x AH) / 1,000 * 70% Depth of Discharge (DoD)

Note: The 50% DoD for the Lead Acid battery is because while the battery has all that juice in it, it can only give it all up slowly over a span of 20 hours. After 50% DoD of fast discharging the battery just stops giving any more power (the voltage goes low). You can let the Lead Acid battery rest and get some more juice out of it, but practically speaking the way we want the power (draw it out really quickly in a half hour), we can only get 50% of the batteries power during a ride.

Note: The 70% DoD for "Lithium Battery" batteries is because if you draw it down farther than this you get into a danger zone where you might take one of your cells in the pack to a non-rechargeable low voltage state. And with the cost of a battery pack, you don't want to run the batteries past 70% DoD (it's like running a motor without oil in it – you can choose to run it for a few miles and ruin it or to stop and fill it up and get to ride it for thousands of miles).

Example:

B&B (4) 12V, 20 Ah Lead Acid Battery = 48V x 20AH / 1,000 x 50% = .48 kW-Hour

GBS (4) 12V, 20 Ah LiFePO4 = 48V x 20AH / 1,000 x 70% = .67 kW-Hour

Range (How Far Can I Go On a Charge?)

My rule of thumb for an electric motorcycle is to expect 110 Watt Hours per mile (at 45mph or riding like you stole it at Moped speeds). 110 Watt Hours per mile is easily achieved at 55mph with a streamlined bike like the Delta-11 (www.DeltaBike.us).

To determine your range use the following formula:

Range (Range in Miles) = Battery Capacity (kW-Hours) x 1,000 / 110 Watt Hours per mile.

Example:

B&B (4) 12V, 20 Ah Lead Acid Battery = (.48 kW-Hour) x 1000 / (110wH/mile) = 4.36 miles

GBS (4) 12V, 20 Ah LiFePO4 = (.67 kW-Hour) x 1000 / (110wH/mile) = 6.1 miles

Note: A more important question is how far do you need to go? Double that and you will probably have a practical bike for your needs.

The Motorcycle Industry Council has excellent papers on calculating Electric Motorcycle Range:

http://www.mic.org/downloads/MIC_EVCityRidingRangeTestProcedure_Rev042811.pdf

http://www.mic.org/downloads/MIC-recommended-practice-riding-range-test-procedure-for-on-hwy-electric-motorcycles-042412.pdf

Fuel Economy (Converting Wh/Mile to MPGe)

Watt Hours per Mile for electric vehicles is a benchmark measurement useful for comparisons just like Miles Per Gallon (MPG) is with gasoline powered cars. The following Wikipedia article outlines how MPGe (Miles Per Gallon Equivalent) is calculated for Hybrid and Electric cars (http://en.wikipedia.org/wiki/Mpge).

The formula is MPGe = (33,705 watt hours/gallon of gas) / (watt hours/mile consumed during EPA's 5 drive cycle tests for electric cars)

Example: 306MPGe = 33,705 / 110

Cost Per mile (How much will it cost for Electricity/Mile?)

Electric Cost / Mile = (110 Watt Hours/Mile) /1,000 x (Cost of Electricity per kW Hour)
$.0132/Mile = (110Wh/mile) / 1000 x ($.12 /kW Hour)

Cost per Mile (How much will it cost for Battery/Mile)

Battery's have a useful life. They can be recharged only so many times. How deep you discharge a battery will affect how many times the battery can be recharged.

A lead acid battery will get 300 to 500 recharge cycles.
A Lithium-Ion battery will get 3,000-5,000 recharge cycles.

Battery Cost/Mile = Cost of Battery's / Number of Recharge Cycles / Miles per Use

Example: 48volt, 20Ah Battery

B&B (4) 12V, 20 Ah Lead Acid Battery = $85 x 4 = $340 / 300 recharges / 4.36 miles = $.26 / Mile

GBS (4) 12V, 20 Ah LiFePO4 = $160 x 4 = $640 / 3000 recharges / 6.1 miles = $.035 / Mile

Battery Life

Battery Life = (Number of recharge cycles) x (miles per use).

B&B (4) 12V, 20 Ah Lead Acid Battery = 300 recharges x 4.36 miles = 1,308 miles

GBS (4) 12V, 20 Ah LiFePO4 = $160 x 4 = 3000 recharges x 6.1 miles = 18,300 miles

Sizing a Battery

There are four big considerations when sizing a battery.

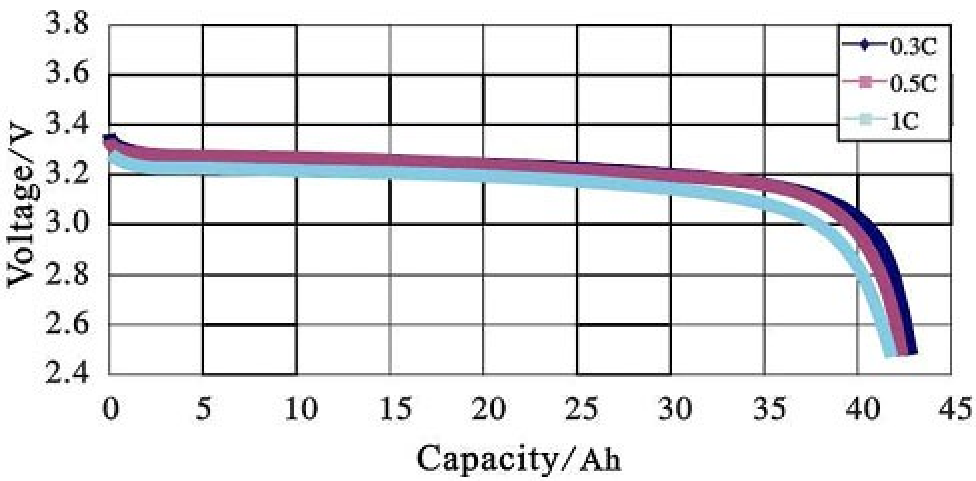
1. Maximum Amp Draw (Amps)
2. Battery Capacity (kW Hours)
3. Physical Size
4. Weight of Batteries

Maximum Amp Draw:
With lead Acid, the best way to determine how much you can pull out of the battery is to get it's technical specification sheet. There will be a discharge curve that shows how many amps and how the voltage decays over time as those amps are drawn. This visual curve will help you understand what the battery will do when you draw power out of it. You pay for what you get in Lead Acid battery's. A good quality battery will have a better discharge curve than a cheap battery.

The battery system must be sized to give enough capacity to maintain a certain voltage under load. Good quality batteries from reputable sources will provide data sheets that show discharge curves, charging curves, and cycle life data.

These charts are critical to selecting and sizing the correct battery pack for your application. If you can't get these types of data sheets for your battery's you should not purchase the batteries from that source.

Here is a discharge curve for a Lithium Calb 40AH battery. You can see at higher C rates the battery can give less Ah at a sustained voltage. When new, this battery pack will give 35 Ah of capacity before it should be recharged. The 70% DoD rule of thumb given earlier would provide a good safety margin to protect the pack from being ruined by over-discharging it (e.g. 70% x 40 = 28).



Example: Our Honda CB-125S (running at 72 volts), using 20 Amp Hour 12v Lead Acid batteries running at 72 volts pulls up to 150 amps during wicked fast take offs. It pulls 80amps or less riding up hills so steep I can't ride my mountain bike up them. It pulls 40 amps while cruising at 40mph on the road.

With Lithium Battery, there is a rating called a "C" Rating. It is a rating of how fast you can draw power out of the battery without "hurting it". A typical Lithium Iron Phosphate battery will have a 3C continuous / 10C pulse rating. "3 C" means you can draw 3 times the Amp Hour rating of the cell.

The Motorcycle Industry Council has an excellent paper on calculating Electric Motorcycle Top Speed that includes some benchmarks about how much raw power is required to push an electric motorcycle down the road:

http://www.mic.org/members/membership/mic_top_speed_test_procedure_for_electric_motorcycles_040412.pdf

Example: 20 amp-hour battery @ 3C continuous means you can pull 20 ah x 3 = 60 amps you can pull from the battery (until it gets to 70% Depth of Discharge, at which time you should stop discharging the battery and recharge it).

<u>Battery Capacity:</u> Obviously, you determine how many miles you want to go, and calculate the kW Hour size of the battery you will need.

<u>Battery Weight:</u> Lithium Battery batteries weigh about ½ of what the same capacity Lead Acid Battery weighs, so you will have better range (due to less rolling resistance), and better acceleration with the same rated capacity battery. Battery weight is extremely important for bikes that will be driven in city traffic. Heavy batteries mean that lots of energy will be wasted by starting and stopping. The energy will be in the form of heat generated by the brakes and the electric motor.

<u>Battery Physical Size:</u> Lithium Battery and Lead take about the same volume space for the same capacity.

Memory

Lead Acid if left in an uncharged state will sulfanate and loose capacity. So, Lead Acid batteries should always be fully recharged as soon as possible after use. They should never be left uncharged for long periods of time.

Lithium Battery has virtually no memory and can be left in any state of charge. So, it can get as little or as much charging as you can give it whenever it's convenient for you. This makes it a perfect battery for transportation where you can charge it whenever you stop for even a few minutes to get a little boost in range.

Recharge Time

You can fast charge lead acid batteries to 85% of their capacity, but then you must slow charge them to get to 100% or you will "boil" them causing them to release hydrogen gas and reduce their life span.

In general, you can recharge a Lithium Battery battery at its rated continuous C Rating. So, this means your charge time will be similar to your ride time if you have a charger or a wall socket with enough "juice" to feed the battery. Refer to the spec. sheets for your batteries for C ratings for recharge. The reason most people don't charge this fast, is that high current chargers are very expensive, they can be heavy and large, and they require high current connections to the grid.

Chargers

Lead or Lithium you will need a good (expensive) charger to charge fast and not damage the batteries. Both Lead and Lithium need chargers that monitor state of charge and carefully cut back and stop the charging when the battery is full. Otherwise, the battery will be overcharged and can be completely ruined.

Chargers typically are heavy, cannot get wet or take a lot of vibration, so it's better for the charger if they are not carried on board the motorcycle. If they are to be carried on board, provision should be made for protecting them from water, vibration, and dirt. Chargers tend to get hot when in use, so good ventilation is required when they are in use.

Chargers and Battery's generate heat during charging. This is empirical evidence that not all the power drawn "from the wall" is being stored in the batteries. Energy retained during the charging cycle is called Charging System Efficiency. In practice, the charging system efficiency for Lithium Battery's is around 75%. It is much worse for Lead Acid, because Lead Acid battery chemistry is much less efficient than Lithium.

Battery Monitoring

The most important thing in using a battery is having instruments that can measure voltage and amp draw real time. I highly recommend the Cycle Analyst instrument from http://www.ebikes.ca/.

With Lithium Battery battery's you need to have a Battery Management System (BMS) in place to protect the batteries from three things: Over-charging, Over-discharging, and Getting out of balance. In extreme use applications (high C ratings), the BMS will also need to monitor battery temperature to prevent damage to the batteries from overheating.

Ideally, you will have a way to monitor each cell in the battery pack individually so that if one cell is going bad you can replace it before it hurts the entire bank of batteries.