A different take on the Festool +3 series of battery operated drills

Text and photos by Jerry Work

Since their introduction much has been written about the Festool brushless motor battery operated drills.

Beginning with the "D" handle style C-12 which used nickel metal hydride (NiMH) battery technology [shown left] on through the "T" handle 12 + 3 and 15 + 3 models which use lithium ion (Li-Ion) battery technology [T15+3 shown right], these drills have been widely praised for their combination of small size, powerful performance, longevity and the versatility of the interchangeable chuck system.

I have used these drills every day, all day, in my one-man fine furniture business since they first became available in the U.S. market. That is why they may look a bit beat up but certainly none the worse for wear in the picture above! From my experience they deserve all the praise they have been given. They simply are superior in most all ways to any other battery operated drills I have used over the years. I employ two C-12s, a T 12 + 3. and a T 15 + 3, and seldom does a day go by that all four don't find their way into my hands for one reason or another.

Rather than writing about all the features, functions and benefits which have been covered well in other stories, I am electing to take a different approach to sharing my experiences with these outstanding drills. I want to start from the inside - what makes them tick so very well - and then move to the outside - why that matters to a user.

Before we can go very far in talking about battery operated drills, we need to first get a good handle on the different battery technologies that are used and why. Most woodworkers tend to believe that lithium based batteries (Li-Ion in our case) are somehow superior to their nickel metal hydride (NiMH) or nickel cadmium (NiCad) cousins. While it is true that Li-Ion technology offers more energy density per unit of both weight and volume, they are much harder to manage in high current draw, multiple charge/discharge applications as we will detail in a moment.

So, what is a battery, anyway? Well, a practical battery was first described by Alessandro Volta (shown right) in 1800 in a paper he delivered to the British Royal Academy of Sciences outlining how to generate electricity through a chemical process.

Volta showed that if you select two dissimilar metals, one with an affinity for giving up positive electrons and the other with an affinity for giving up negative electrons, and suspend them in a chemical that will promote the exchange (an “electrolyte”), then the electrons will naturally flow from one of the metals to the other producing electricity through this chemical process.

In the simplest terms electricity is the flow of electrons through a conductor interrupted by a device designed to use those electrons to do useful work for us, such as the drill motor in our case. The pressure with which the electrons are pushed through the conductor is named after our friend Alessandro and is called “voltage”. The number of electrons that will fit in a cross section of the conductor is called “amperage”.

The amount of work the electrons can do is a function of how many pass through the device in a given period of time and how efficient the device is at converting those electrons to do work for us. The total number of electrons available is volts times amps or what are called “watts”. You can get the same number of electrons - watts - to the device with low amperage and high voltage as with high voltage and low amperage.

It doesn’t matter whether that electricity is direct current - the kind of electricity generated by a battery - or alternating current - the kind of electricity available via the wall plugs in our shop or studio, the work is done by the number of watts the device is capable of employing without overheating.

A typical battery operated drill employs a DC brush style motor. There are permanent magnets on the outside that are stationary. There is a spinning armature on the inside which contains an electromagnet that is charged by electricity carried to the electromagnet by carbon “brushes”. As the armature spins, segmented conductors deliver the electricity in a manner which alternately changes the polarity of the electromagnet from negative to positive drawing the armature shaft towards the stationary permanent magnet with the opposite polarity.

While cheap to build, these brush style electric motors have a lot of problems. Because the brushes are making/breaking connections all the time as the motor shaft spins, the motor produces sparking and heat which wastes some of the electrons and eventually wears out the brushes. They are also harder to cool since the electromagnet, where most of the heat is generated, is in the center of the motor.

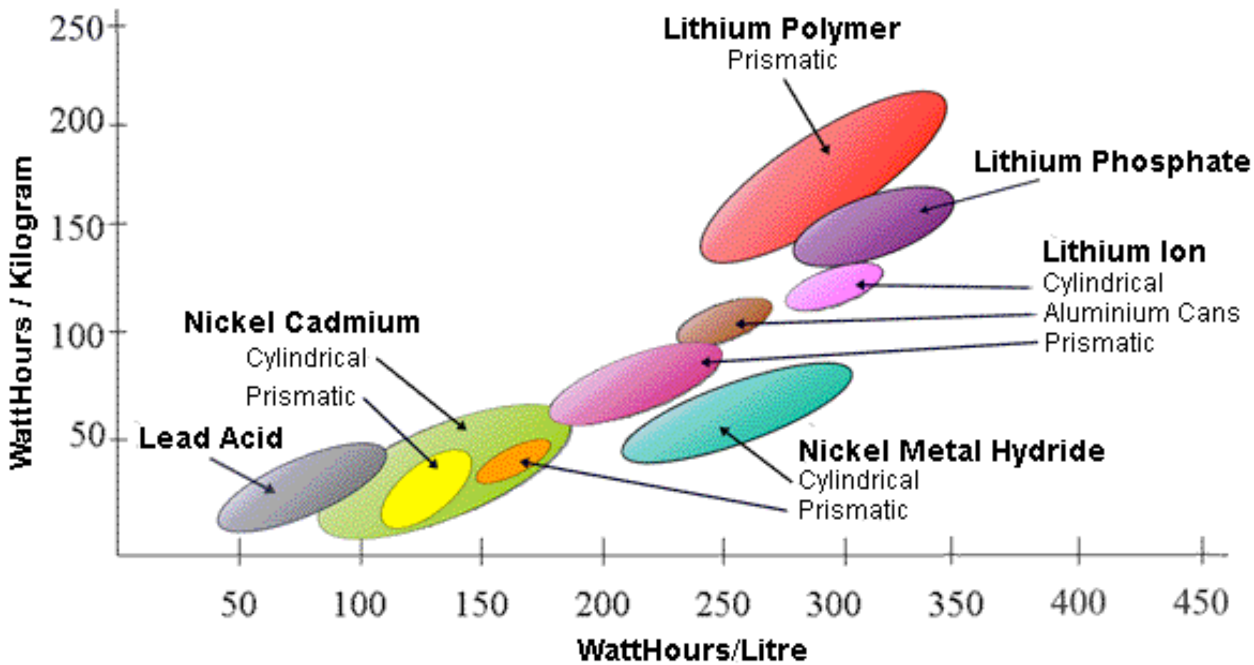
If you turn the electric motor inside out by putting the electromagnets on the outside and the permanent magnets on the motor shaft, then by using a computer connected to high-power transistors to switch the polarity on the electromagnets as the shaft spins, you gain all kinds of advantages. The electrons wasted by sparking in the brush style motor can now be used to power the brushless motor, making it more powerful and more efficient at the same time. With a computer controlling when and how fast the electromagnets are energized, you can control the speed of the motor far more precisely and over a greater range. The heat generated by the electromagnets is now on the outside where it is easier to dissipate or control. And, with no brushes to wear out and no mechanical contact between the motor shaft and anything else other than the bearings, the motor can be made to last far longer.

This is one good case where truly better technology produces very significant gains, even in something as plebeian as spinning a drill or a screw driver bit. The implementation of very efficient brushless electric motors allows the Festool engineers to put more of the battery capacity to work and to work more powerfully for you because that brushless motor can draw more watts over a longer period of time without over heating. For these same reasons, a brushless motor can be made smaller and lighter than its brush style predecessor.

So, you wind up with a smaller, more powerful, more efficient drill regardless of the battery technology used to power it!

Now let's return to the questions about the batteries and why one technology may be better or worse than another for a given load, charge and discharge profile.

There are several different types of batteries in common use. Remember from our earlier discussion that to work, a battery needs two dissimilar materials, one with an affinity for giving up positive electrons and one with an affinity for giving up negative electrons and some kind of chemical electrolyte to promote that exchange. Here is a chart showing the energy density potential of different battery technologies:

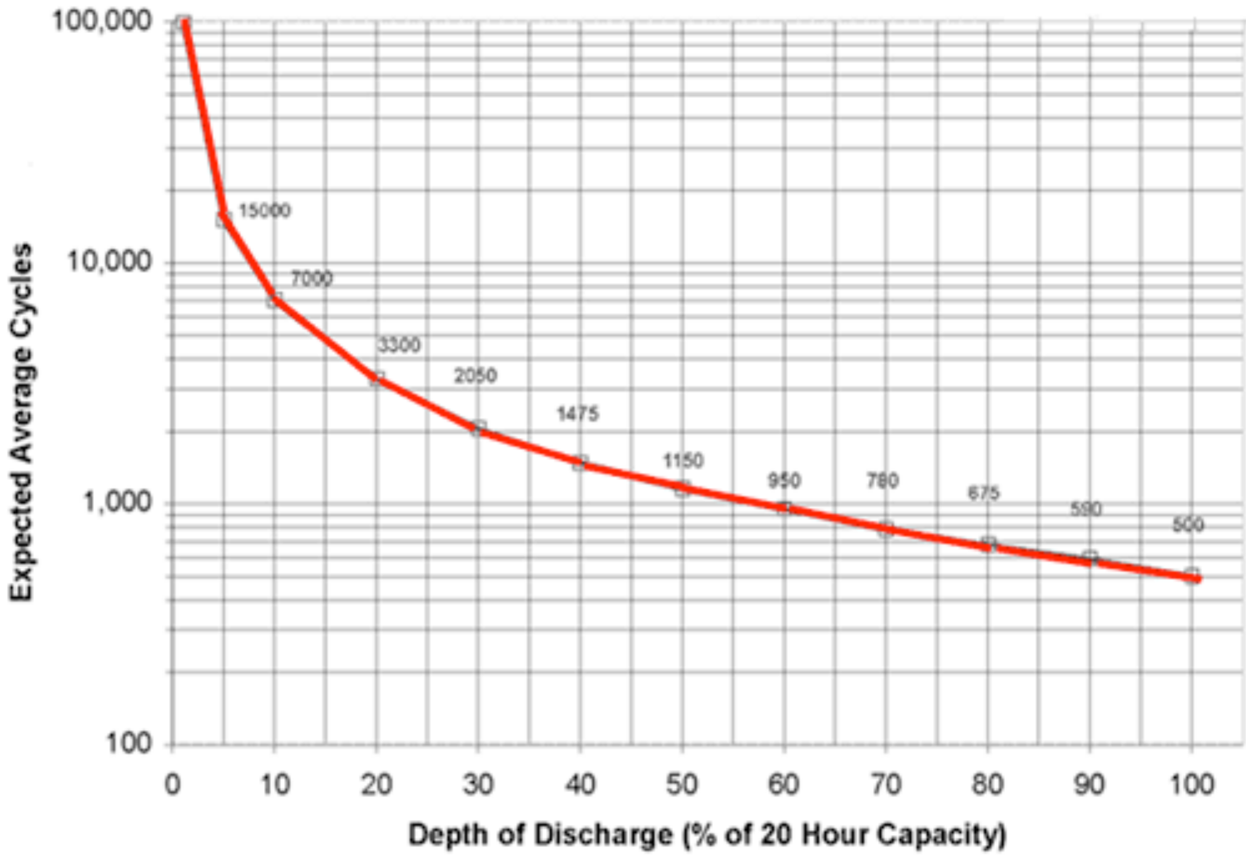


The vertical axis shows the energy density per unit of weight while the horizontal axis shows the energy density per unit of volume. A technology that is higher and to the right has greater energy density than one that is lower and to the left. Notice that lead acid technology, commonly used in our cars and trucks, is quite anemic in terms of the number of electrons it can deliver per unit of size but has only a little less energy density than nickel cadmium technology per unit of weight. Both are heavy for the amount of energy they can produce. In a car or truck application this is not overly important, but, in terms of a battery operated drill, weight is very important.

Notice that the NiMH technology is 50% to as much as 100% better per unit of weight than either lead acid or NiCad, and it is 3 to 6 times better per unit of size. You can make a NiMH battery that is much smaller and a fair bit lighter than its NiCad cousin for a given amount of electron capacity. The cylindrical style of Li-Ion has much greater energy density per unit of weight than the other three and is also smaller. Hence, a Li-Ion battery with a given capacity can be made both somewhat smaller and far lighter than either NiCad or NiMH batteries. Or, stated the other way, it can have greater energy density at the same size and weight, and that is how this advantage plays out in these Festool T + 3 drills.

From this chart it is easy to see all the recent interest in lithium technology for batteries, but energy density per unit of weight and/or size is but one factor to be considered. It is also important to consider the life expectancy of the battery technology. For an application such as driving drill bits or screw driver bits where the load can vary significantly, it is very important to know how far and how fast the battery can be discharged without harm, how fast and how full the battery can be recharged without harm, and the number of times the battery can be discharged and recharged before it looses its ability to perform well for the task at hand.

In a moment we will look at some of the advantages and disadvantages of each of the three major battery technologies used for battery operated drills: NiCad, NiMH and Li-Ion. But first, let's look at a chart of the type engineers use when trying to match a battery technology to the expected service life and loads. This chart is for common lead acid batteries, but the shape is similar to what you find for the other battery technologies as well.



On the vertical axis is the total number of discharge/recharge cycles the battery can stand before it fails. On the horizontal axis is the depth to which the battery is discharged before recharging. Notice that if you discharge a lead acid battery all the way to fully discharged each time you use it, it's life will only be about half as long (~500 cycles) as if you discharge that same battery to 50% of capacity before recharging (~1150 cycles). If you manage the battery to allow it to discharge to 75% of capacity (25% depth of discharge) before recharging it, it will last more than five times as long (~2700 cycles) as if you discharged it all the way each time.

The different battery technologies also differ in terms of the number of volts each cell puts out. Lead acid puts out about 2 volts per cell, NiCad and NiMH put out about 1.2 volts per cell while Li-Ion puts out about 3.6 volts per cell. The greater the voltage, the lower the amperage draw required to produce a given number of watts from that cell. Another important factor is the rate at which these different batteries discharge while sitting idle. NiCad looses about 15% to 20% per month. NiMH looses about 30% of its charge per month. Li-Ion self-discharges very slowly, and looses only 2% to 3% of its capacity per month.

So, Li-Ion has four major advantages over the other technologies: it is lighter as well as smaller for a given energy density, it operates at a higher per cell voltage so requires fewer amps per cell to deliver a given number of watts to do the work for us, and it doesn't discharge nearly as much while sitting idle.

Unfortunately those advantages are offset by some difficult energy management issues. If you try to take electrons out of a Li-Ion battery too quickly, you can kill the cell. That affects the total watt draw per unit of time which, all else being equal, would mean affecting the total torque available per unit of time. If you try to take too many electrons out (ie, discharge it too much) you can kill the cell. That affects how long the battery can be in use between recharge cycles. If you try to recharge a Li-Ion cell too quickly, you can kill the cell. Finally, if you try to recharge too much (put too many electrons back into place,) you can kill the cell. And, these same conditions can dramatically affect the temperature at which the cell operates which, in turn, can affect it's service life.

As a result, the electronics inside drills which uses Li-Ion batteries have to be very sophisticated to carefully manage the number of electrons being used and how quickly they are used under a wide range of load (torque) conditions. The recharger also has to be very sophisticated to make sure the recharge cycle does not harm the Li-Ion battery. Battery temperature must be continuously monitored both during use and during recharge. The charger and the drill both have to act as parts of one system to allow the drill to provide optimum performance while also optimizing battery life.

The ***quality*** of the Li-Ion cell also plays a major role. It is possible to make Li-Ion cells that may have an initially high energy density but which break down quickly under use. High quality cells are significantly more expensive to make than the poor quality ones, but you, the user, will never know which is in your drill until you experience a Li-Ion battery failure. The drill manufacturer's warrantee period will speak reams about whether the cheap or high quality cells are employed in their product. Festool warrantees both the drill and the Li-Ion batteries for three full years of professional use.

Earlier we said that because of the higher energy density, there was a tendency for woodworkers to presume Li-Ion is a superior battery technology for use in portable power tools. ***That is not necessarily true.*** If the other parts of the system (the control electronics inside the drill, the sophistication of the drill motor and drive train, the control electronics inside the recharger, or the quality of the cells themselves) are sub-par then in actual use one drill with NiMH technology may perform far better and last far longer than another drill using Li-Ion technology.

Similarly, some may assume that because two drills each use Li-Ion technology, they should be equal in performance and longevity, so they might be motivated to purchase the cheaper of the two. I think you can easily conclude from what we have discussed so far that that is simply not true at all. One drill may cost twice what the other does but last ten times longer, do far more work before recharging, or have batteries that last far longer than the cheaper one. Now which is the less expensive?

It is also important to come back to the point made earlier about brushless vs brush style motors. Remember that one very positive trait of the brushless motor was its computer control which allowed far better management of speed over a much wider range of speeds. That really comes into play in building fine furniture where precise ***low*** speed control is mandatory to keep from stripping small screws, breaking ones made from brass, breaking drill bits or drilling clear through a piece instead of only part way, all of which can really ruin your piece and your day.

This computer control over speed is also advantageous in terms of giving the drill the ability to deliver precise torque settings time after time to make sure all your screws set to the same level on your project. Brush style drills and cheap brushless motor drills rely on a mechanical clutch to provide those torque settings which can vary widely depending on the quality of the mechanical clutch and how worn it is.

Isn’t it interesting to look back on most magazine battery operated drill “reviews” or comparison tests? How many consider all these important things? Virtually none. Most start and end with the nearly meaningless “test” of how many 3” deck screws the drill can drive before it smokes itself or kills its battery. Or, how many 1.5” forstner bit holes can be drilled before the drill simply gives up the ghost.

The reviewer/tester, likely facing a publication deadline, simply would not or could not take the time or have the knowledge to determine the really important things such as ultimate battery, motor, and drive-train life per dollar of initial purchase cost. If they had, there would be a huge gap between the high quality, best-in-class drills and the retail price driven majority of drills. From my real world, day in, day out, use of battery operated drills for many years, Festool offerings are among the very best in the world in all of these really important performance and life cycle aspects, and the T + 3‘s are the best to date. As an aside, Festool drills also usually fare well in the far less meaningful “how many” type “tests”.

Are they for everyone? Nope. If you only intend to use your drill infrequently and for short periods of time, if precise control over speed is unimportant, if battery use before recharging or how long your batteries last are not material to you, or if you don’t care about the convenience of interchangeable chucks, or a three year warrantee on both the drill and the batteries isn’t important to you, then look elsewhere. But, if you want to buy it once, have it perform at the highest level each and every time you pick up your drill and you enjoy light-weight, long battery life, rapid recharging, and all the other good stuff offered by these Festool T +3 drills, then I think they deserve a close look.

Earlier I said that I use two of the C-12s (which employ NiMH battery technology), the T 12 + 3 and the T 15 + 3 (each of which employ Li-Ion battery technology) every day in my work, and I used all their Festool predecessors for years before these. A positive initial impression is one thing, but how you feel about something such as a drill after a year or two of continuous use is something else.

What strikes me now is how similar the T + 3 and C-12 drills feel to me in terms of light-weight, small physical size and balance. Yes, there are

some differences, but not nearly as much as you would expect from drills that range from 12 volts to 18 volt equivalent.

Here and on the previous page are photos of the two extremes, a NiMH C-12 and a Li-Ion T 15 + 3. They are surprisingly similar in terms of size, weight, and balance even though they employ completely different form factors and different battery technology.

In building fine furniture the T + 3 and C-12 drills are able to do everything nearly equally as well. The C-12 is a bit smaller, especially with the small 1.3 amp hour NiMH battery pack, but that only matters in the tightest of spaces. The T 15 + 3, even with the much higher capacity 3 amp hour and higher voltage 15 volt battery is actually lighter, but not by a huge amount. I seldom even think about the weight difference as most of the time I just grab the one closest at hand. The T 12 + 3 is a bit lighter and a bit smaller yet, but the difference between these two + 3 drills, or between the + 3 and the C-12's is not much.

I do like the bit holder on the C-12 better as it holds more bits more securely for my kind of use.

The T + 3 drills do exhibit longer actual use battery life over the C-12, but, again, the difference is not huge. Part of that may be attributed to my natural tendency to use the T + 3 for heavier load applications which would require more total watts of power. Another factor may be that I seldom let either the NiMH C-12 or the T + 3's sit long enough that the much faster self-discharge rate of the NiMH becomes an issue. If you regularly wait a month or so between uses, the T + 3 with it's Li-Ion batteries would be much better for you. A fully charged NiMH battery that sits for a month will only have about 70% of its charge left while the Li-Ion battery will still be nearly fully charged.

Both the C-12 and the T + 3 drills have real-world battery life much longer than the earlier generation Festool drills and much, much longer than other brand drills I used in the past. The greater efficiency of the Festool brushless motor coupled with the sophisticated control electronics used to drive it, really make a ***big difference*** over anybody's brush style drill. I would never go back to a battery operated drill with a brush style drill motor, no matter what the cost difference.

The other thing that struck me as I thought about writing this piece is how very much better the C-12 and T + 3 drills are relative to their earlier Festool counterparts. I had occasion recently to pull out the older Festool drills which I had not used since the advent of the C-12 and T + 3 offerings and could use both old and new side by side. I was shocked by my perception of the differences today. When those earlier generation Festool drills first became available, I raved about how much better they were than the other brand drills they replaced in my studio, and, as I used them over the years, that perception never changed. It really didn't change very much even when the first C-12 was put into use here. Yeah, the C-12 was better, but I liked the other Festool drills I had been using so much that the improvements seemed more like good continuous improvement product engineering than revolutionary change.

When the T + 3 and the second C-12 came in, the older generation drills were put away and my frame of reference became just the differences between the + 3 and C-12's. As indicated earlier, the differences are not great and the C-12's, the T 12 + 3 and T 15 + 3 just blended together in my mind. When I took out the older generation offerings and used them once more, they seemed very much like a whole generation back in terms of design - heavier, larger, not as well balanced in my hands and certainly not as long a use cycle between recharging. And, I could tell that overall battery life was becoming an issue, especially with the NiCad batteries on the previous generation of D handle drills.

It will be interesting to see how I feel a year or two from now. If the C-12 and T + 3 are still going strong towards the end of their warrantee cycles, I guess I will have to wonder how it will be possible for Festool to improve upon them, at least for my kind of use.

Addendum A:

On the next page are photos of the brushless Festool motor drills (top) and their previous generation brushed drills (bottom) in both the T handle and D handle configurations sitting on a balanced beam scale. These photos show the differences in weight, physical size, form factor and design. As much as I enjoyed using the previous generation drills shown in the bottom photos, the new generation brushless drills are clearly superior in every way.

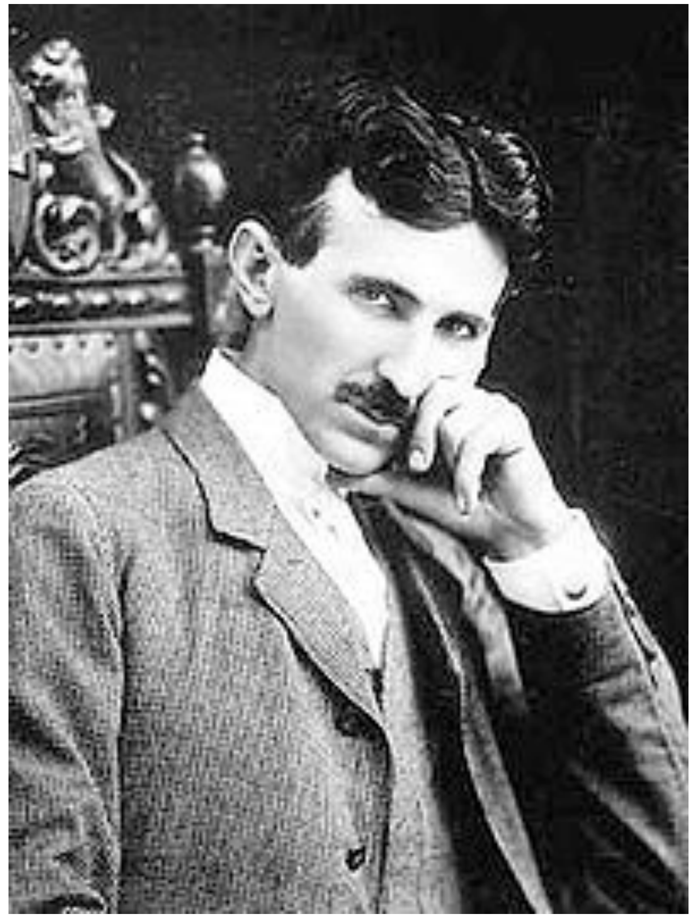

FESTOOL
T 15+3
Li-Ion


FESTOOL


FESTOOL
TDK 15.6


BPH 12 C
FESTOOL

Addendum B: How & why brushless motors work



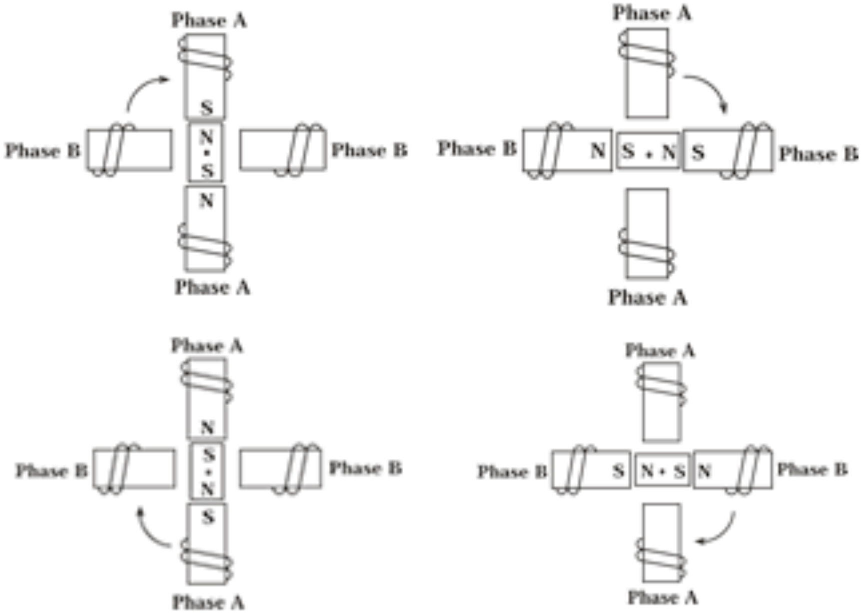
We owe much of what we know about electric motors of all kinds - brush type or brushless - to this interesting character, Nikola Tesla (1856-1943, shown here circa 1896). In fact, Tesla's work in the late 1800's and early 1900's underpins much of the technology used to generate, transmit and distribute electricity around the world, yet he remains a largely unheralded source for so much of what is so important in our everyday life. A lot of his work, theories and inventions involved magnetism which is the heart of any electric motor.

In a ***brush style*** electric motor stationary permanent magnets surround the rotating motor shaft. Electromagnets are mounted to the rotating shaft. When one of the shaft mounted electromagnets is energized by flowing electrons through it, it's north pole will be attracted by the south pole of the surrounding stationary permanent magnets and the south pole of the electromagnet will be attracted to the north pole of the permanent magnets, thereby causing the motor shaft to turn. When that electromagnet is turned off and a second electromagnet is energized, the shaft will rotate again to bring the north and south poles on the electromagnet and the permanent magnet into alignment. The mechanism for energizing first one and then the next electromagnet is by surrounding one end of the motor shaft with a series of conductive segments and delivering electricity to each segment via a carbon conductor, called a "brush", which is spring loaded to contact the conductive segments one at a time. As the shaft spins, the segments come into contact with the brushes sequentially, thereby rotating the motor shaft.

In a ***brushless motor***, stationary electromagnets surround the motor shaft which has mounted on it a series of permanent magnets. As one of the surrounding electromagnets is energized, the north and south poles on the permanent magnet are attracted to the south and north poles on the electromagnet. The mechanism for energizing first one and then the next electromagnet is by the use of solid state switches controlled by a computer.

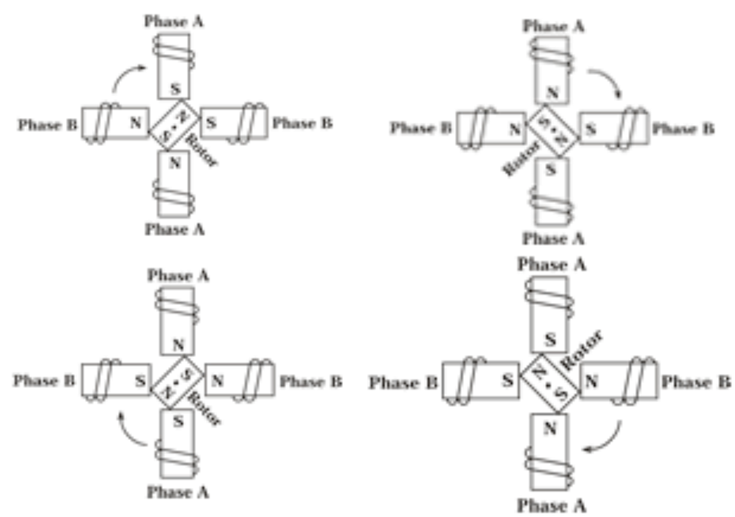
With permanent magnets on the motor shaft surrounded by four fixed electromagnets, the motor shaft will turn in one-quarter rotational steps as shown in this diagram (source Haydon Kerk Motion Solutions).

Figure 2. "One phase on" stepping sequence for two phase motor.



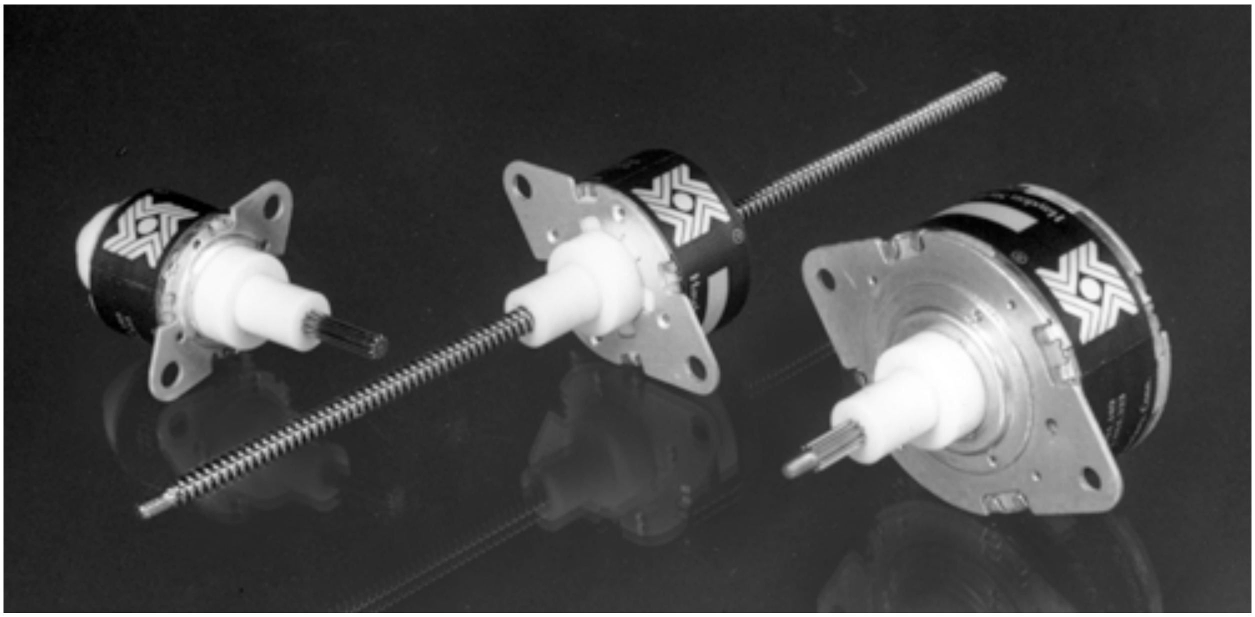
If you were to energize two of the electromagnets at the same time, the north and south poles on the permanent magnet would experience a greater magnetic attractive force creating more turning force or torque, about 40% more. But, since two, rather than one, of the electromagnets is energized at the same time the motor will consume twice the number of electrons. Each rotational step of the motor shaft would be at 45 degrees to the poles of the stationary magnets as shown right.

Figure 3. "Two phase on" stepping sequence for two phase motor.



By adding more electromagnets you can increase the number of steps in one rotation resulting in a smoother and more powerful rotational movement of the motor shaft. To turn the shaft faster would require faster switching from one electromagnet to the next, hence the need for a computer to control the switching and very fast, high current capacity switches to conduct the power to the electromagnets. To turn the shaft more slowly, the computer simply slows down the rate at which the switching from one electromagnet to the next takes place. Since brushless motors move in a series of steps from one electromagnet to the next, they are often called, “stepper motors”.

If you attach a gear to the motor shaft which engages another gear on a different shaft, by counting the number of steps the motor shaft turns you can calculate very precisely the number of turns the driven shaft will make. If the motor shaft is hollow with gears



cut on the interior and the threaded second shaft runs through the motor, then either the motor assembly will move along the threaded second shaft a known distance by counting the number of steps the motor shaft turns, or the shaft itself will move a known distance relative to the position of the motor assembly. This is commonly referred to as a “linear actuator” motor. Both stepper motors and linear actuator motors are widely used in many industrial applications such as driving the bed very precisely on CNC milling machines. (Haydon Kerk Motion Solutions photo shown above)

In Festool brushless motor drills, the computer controlling the current going to the electromagnets can cause the motor shaft to spin at very precise and easily controlled speeds. By sensing changes in the current draw of the motor as it tries to overcome the changing workload of driving screws, the computer can stop the motor at very precise, predictable, and repeatable torque settings. By sensing the heat build up in both the motor and the Li-Ion battery, the computer can also stop the drill before high torque load conditions could damage either the drill or the battery.