Technical Review of Festool's EC-TEC® Cordless Drills

Revised

By Rick Christopherson

Rarely is it that the tool industry is shaken to its foundation with revolutionary new technology. Arthur Arnot did it when he developed the first motor driven drill over a century ago. Wilhelm Fein did it when he took that drill and made it portable. Festool did it when they developed the EC-TEC motor and Controller. I know that's a pretty bold statement, but EC-TEC is a pretty bold advancement in drill technology.

EC-TEC Motor Technology

The heart of EC-TEC drill is the revolutionary brushless motor. This isn't just your run-of-the-mill drill motor. This is a *permanent magnet, remotely commutated, 3-phase, AC motor*. Yes, a tool operated from a DC battery has an AC motor! This is the same type of motor used as servo motors in robotic systems where high torque, high speed, and extreme durability are crucial.

For years, the motor technology of cordless tools has not changed. The brushed DC motor has been the staple—albeit inefficient—motor for ages. The old brushed motor is simple, compact, and inexpensive, but it suffers from inefficient use of limited battery power. The greatest weakness of the brushed motor is that the electricity to the motor's windings passes through an electrical connection that is constantly changing and moving—the brushes. Every time you see the brushes spark inside of a brushed motor, it is a waste of energy that is not available for use by the motor. The purpose of the brushes is to reverse the polarity of the motor's windings in synchronization with the rotation of the motor—called commutation.

To circumvent the losses of the brushed motor, Festool incorporated a brushless DC motor† into the new EC-TEC drills. The electrical connections to the windings are permanent and don't suffer from the inefficiencies of constantly connecting and disconnecting as the motor rotates. Unlike the mechanical commutation of a brushed motor, a brushless motor uses electronic commutation. Three sensors inside the motor detect the position of the rotor so the electronic Controller knows when to activate each set of windings. This active feedback allows the Controller to know exactly what the motor is doing, and has some startling benefits.

Festool is one of the few tool manufacturers with the capabilities to design and manufacture their own motors. The newest generation of EC-TEC motors is custom designed to exactly match the performance of the battery and Controller combination. What is immediately striking about the new EC-TEC motors is the size of the windings (lower left image). This heavy gauge wire is what I would expect to find in the motor of a corded drill, not a cordless drill. This is what allows the motor to develop maximum torque at any speed without risk of damaging the motor.

EC-TEC Controller

The EC-TEC Controller is what makes a Festool drill an intelligent drill. The primary function of the Controller is a servo drive for the motor, but it also monitors the health of the entire drill as well. These two functions are what separates a Festool drill from any other drill.

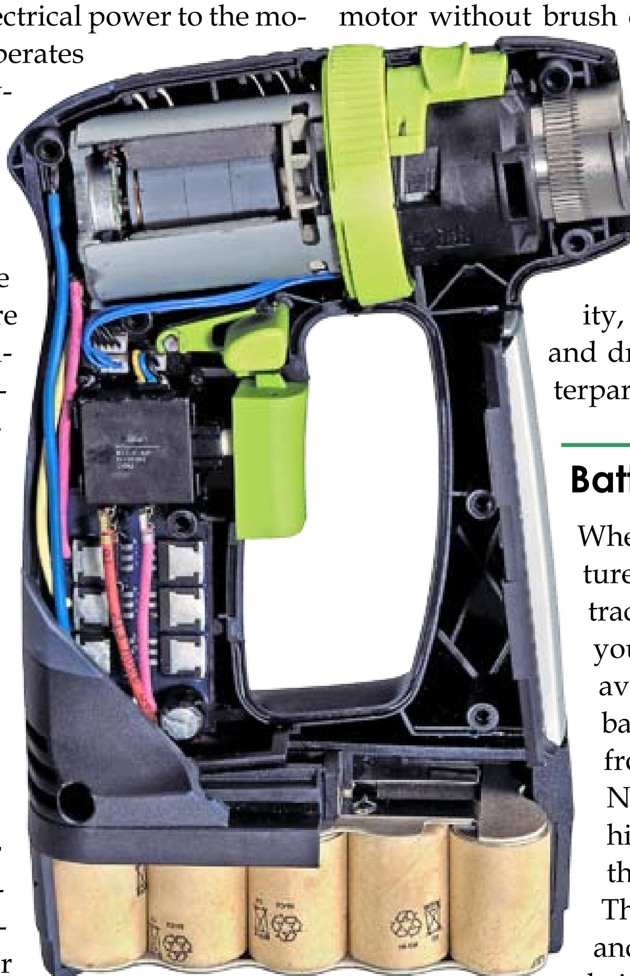
There are some popular brand-name drills on the market that are known to destroy themselves under a heavy load. I know this first-hand because during some dynamometer testing, several top name drills began to emit smoke from their motors within seconds of being fully loaded.

A powerful drill is of little value if it is easily damaged. The EC-TEC is an intelligent electronic Controller that not only powers the motor, but more importantly, monitors the health of the motor, battery, and even the EC-TEC Controller itself. Unlike other drills

† *Even though this is a 3-phase, AC motor; it is the electronic industry's practice to refer to this as a Brushless DC (BLDC) motor because the AC power signal is electronically created and controlled from a DC (battery) power source.*

on the market, EC-TEC drills won't let you destroy the drill (or the battery) no matter how hard you try.

The Controller monitors the electrical power to the motor to ensure that the motor operates within safe parameters. However, make no mistake; the drill was designed properly in the first place, so it won't overheat under normal use. The drills mentioned above (the ones that self-destructed) were under-engineered so the manufacturer could claim higher performance than the drill is realistically capable of providing.†



Power Control

Virtually all other drills on the market (including AC and DC motors) use a similar design for controlling the power to the motor. The trigger switch contains the only electronic control. This means that all of the battery's power passes through the small mechanical switch of the trigger. Putting a lot of power into a small space is not good.

The EC-TEC is different. The only control circuit inside the power trigger is a small, solid-state resistor that is part of a frequency generator circuit. The drill uses six high power amplifiers to control the power to the three phases of the motor, and the power trigger controls only the switching speed of these amplifiers. This keeps the high power of the battery in the main handle where heatsinks can safely dissipate the heat.

Even the forward/reverse control of the EC-TEC is solidstate. There are no moving electrical parts or contacts to fail. The mechanical button moves a small rare-earth magnet, and a sensor on the Control board detects the magnet's position.

One of the most important aspects of having a 3-phase motor without brush contacts and with all solidstate controls, is that all of the power available from the battery is more efficiently converted into the mechanical energy at the driver tip. This means that for the same battery capacity, an EC-TEC drill will run longer and drive more screws than its counterpart that uses the old technology.

Battery Flexibility

Whether you're an occasional picture hanger or a professional contractor, there's a drill battery to suit your needs. The EC-TEC drills are available with a large variety of battery sizes and types, ranging from 1.3 Ah to 3 Ah and NiCd, NiMH, or Li-Ion technologies. The higher the amp-hour (Ah) rating, the longer the battery will last. This broad range of battery sizes and types allows the user to tailor their drill to their specific needs.

Each of the three battery technologies also has its benefits. NiCd batteries can deliver the highest amperage rate for heavy drilling, and for the intermittent user, will have the longest battery lifespan. NiMH batteries are more compact for their given power output and provide a good amperage rate. Li-Ion batteries are the smallest for the given power output, and their lifespan is more dependant on time than the number of charge cycles, so they can be recharged more frequently with less degradation.

Battery Protection

There are two common ways that battery life gets shortened; over-charging, and over-discharging. The EC-TEC battery charger prevents over-charging, and the EC-TEC drill prevents over-discharging. The microprocessor controlled charger rapidly charges the battery, and when full charge is detected, the charger switches over to maintenance mode.‡

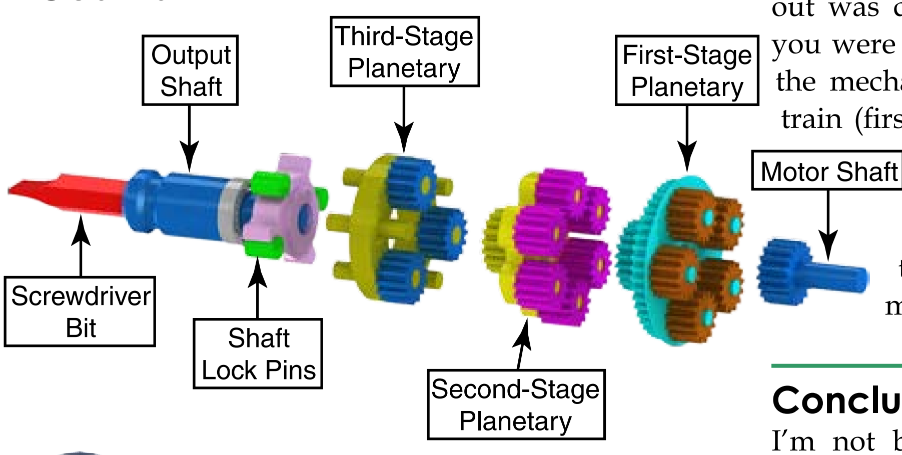
† This is not a new concept. U.S. tool manufacturers frequently overstate their claims for marketing purposes. Festool does not use these marketing techniques.

‡ With daily use, the batteries can be left in the charger until needed. However, the charger should not be used for long-term storage of infrequently used batteries.

It doesn't get mentioned very often, but the best way to prevent the so-called battery "memory" effect with NiCd batteries is through rapid charging. The high current during charging breaks down the crystalline tendrils that form between the battery plates that are sometimes referred to as "memory". The intelligent EC-TEC chargers are designed to keep this often over-stated concern in check.

During use, the EC-TEC drill's controller monitors the battery to determine if it is capable of providing the power required. If the battery cannot supply the power asked of it, the drill will shut down to protect the battery. This is an important feature that might be misunderstood by some users. Even though the drill has plenty of power for a moderate load, if you try to take a heavy load from a low battery, it will shut down the motor to protect the battery. Other drills only detect when a battery is dead. But if you try to take too much power out of a non-dead battery, it will still damage the battery as if it were dead.

Geartrain



The EC-TEC gearbox is virtually bulletproof. To harness the power of the motor, the EC-TEC uses a 3-stage planetary geartrain. This is the same type of gear set used in automotive transmissions for its strength and versatility.

In a planetary drive, the power of the motor is shared by dozens of gear teeth instead of just a couple. It also allows for a very high gear ratio in a small amount of space.

This type of geartrain allows the motor to spin at very high RPM and produce very high torque levels at the output shaft via gear reduction. Switching between high-speed and low-speed gears simply disables or enables the mid-stage planetary gear set.

Another feature of the gearbox is the integral shaft-lock to assist in bit changing. This makes a one-way drivetrain. The motor can rotate the drill chuck, but the drill chuck cannot rotate the motor. With the shaft-lock, you can tighten the chuck as hard as you want, and the gearbox will hold fast.

Electronic Clutch and Motor Cut-Out

For many people, myself included, the sound of a drill's mechanical clutch slipping is like fingernails on a chalkboard. No more, do we need to tolerate the "grind." The EC-TEC's on-board controller monitors the power going to the motor and accurately limits the output torque to the setting you select with a 25-position torque clutch selector (lower left). When the torque level has been reached, the motor simply turns off and the drill beeps to tell you that you've reached your torque limit.

In the past, with mechanical clutches, the torque cut-out was drastically different depending on whether you were in first gear or second gear. That's because the mechanical clutch was at the front of the geartrain (first-stage planetary set). Because the EC-TEC clutch is computer-controlled, and the controller knows which gear you have selected, the computer compensates for the gear change, and the torque cut-out remains consistent from high and low gears.

Conclusion

I'm not big on drawing conclusions for others to follow. I am more comfortable writing fact-based information. So instead, I will use this space to provide some of the opinion-based information I came across during my examination of the EC-TEC drills. It might be a hodge-podge of ideas, but I guess that's what opinions are supposed to be.

I first saw a cutaway model of a C12 drill at the AWFS trade show in Las Vegas the summer before they came out. It was so new that no one at the booth knew anything about it yet, but I noticed the third wire leading to the motor, and that was my "holy cow!" moment. I was so fascinated with the idea that a 3-phase motor was being used in a battery operated tool that I volunteered to write this technical review and give it to Festool without taking my normal fee for my work.

With technology this cutting-edge, I knew there would be a lot of people that were not yet familiar with it (including myself). Besides, I was dying for a chance to tear this drill apart to see how it worked. And that I have done—more times than I should admit, as it would bring tears to a lot of woodworker's eyes to learn how many of these drills are scattered in pieces throughout my workshop.

This is a technology that I so firmly believe in that I even cannibalized a C12 so I could use the motor and controller in an elaborate woodworking project. A couple years ago I was even contacted by a military contractor that wanted advice for also using the motor and controller in a piece of their hardware. It's incredibly robust and makes for a great servo motor (not to mention a drill too).

Back to the story. While it wasn't very scientific, one of the first things I did when the drill arrived was to try to drive a 4-inch screw into a block of wood; except I wanted to see what would happen at ultra-ultra-low speed—about 1 revolution per second. I carefully held the trigger in a fixed position so the bit was spinning at a constant speed, and then started the screw into the wood. I can't even begin to tell you just how blown away I was when the drill kept plodding along until the entire 4-inch screw was sunk into the wood. I tried the same thing with one of my other drills, and it stalled after just 1 inch.

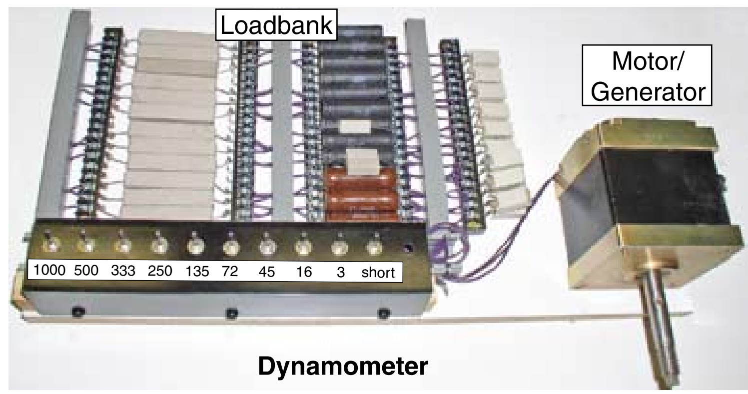
A cool side effect of having a PWM motor with remote commutation is that it will deliver near constant torque for a given speed. This is because the Controller knows more than just the speed of the motor, but even knows its exact rotational position too. If the motor has not made it to the next position in its rotation, the controller just keeps giving it power until the motor catches up to where the Controller is expecting it to be. The motor is in sync with the Controller, and that is why it doesn't just stall at low speed.

My excitement just kept escalating from there on. So the next thing I did was build a dynamometer so I could compare the power of this drill against several popular drills I bought at my local home center.

Ironically, the dynamometer used the same type of motor as the drill, but just a bigger version (at 300 volts). Spinning the shaft of this type of motor turns it into a 3-phase generator, and measuring the voltage, current, and frequency produced by the generator would tell me exactly how much power and torque the drill was producing.

All was going to plan, until the three biggest brands of drills started to let the "magic smoke" out. The drills kept turning, but within seconds of switching the dynamometer to maximum load, the other drills began to emit smoke from the motor. I could get in legal trouble publishing results like that, so I decided to abandon the results.

What is most interesting about this, however, is that the Festool drills I was testing ran for several minutes at this same maximum load and never once showed signs of overheating. They did eventually turn off and beep to tell me that I was overloading them, but no smoke.



Supplement: How Variable Speed Controllers Work

Controlling the speed of a motor with a variable resistor is very inefficient because the energy lost in the resistor is just wasted. A more efficient way to control the speed of a motor is to turn it on and off very rapidly. The more the motor is turned on, versus turned off, the faster it spins.

This type of motor speed control is called *Pulse Width Modulation* (PWM), and is also used in many other applications to control power. With a PWM motor control, the power pulses turn on at a constant interval, but the duration of the pulse is varied, as shown below. The longer the pulses, the more current flowing through the motor, and the faster it spins. When full power is needed, the PWM circuitry is bypassed, and full battery power is delivered to the motor.