Technical Review of the C12 EC-TEC Cordless Drill

By Rick Christopherson

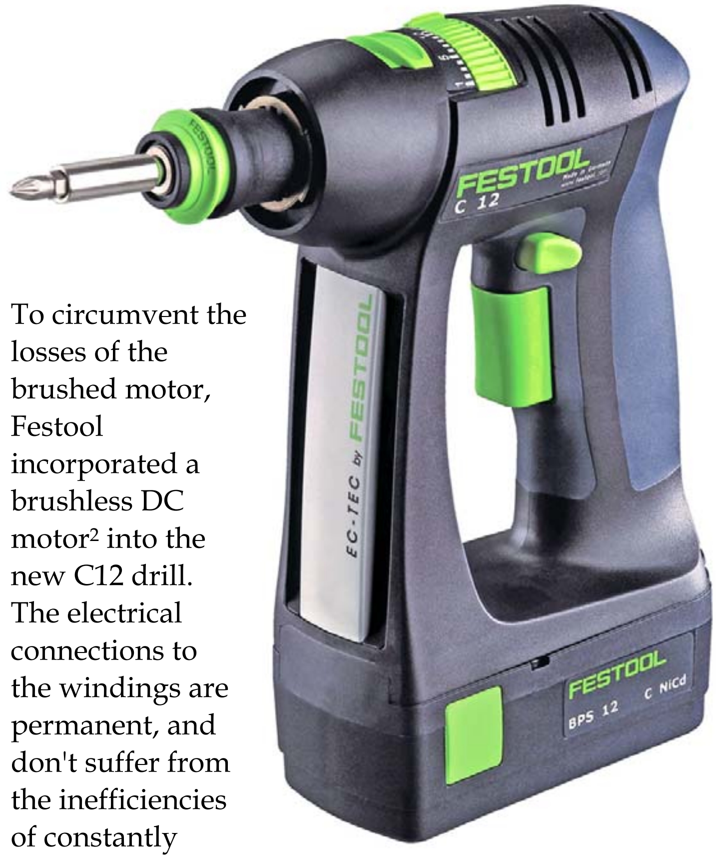
Once again, Festool has shattered the expectations of the drill industry with the release of the new C12 cordless drill. The C12 is not just a cosmetic change made to an existing design. The C12 is packed with revolutionary motor and control technology on several levels. Festool didn't just leap forward in one area of this drill; they made huge leaps forward in **ALL** areas of this drill. From the motor, to the electronics, to the geartrain; this drill raised the bar just past the fingertips of the competition.

EC-TEC® Motor Technology

The heart of the C12 is the revolutionary EC-TEC brushless motor. This isn't just your run-of-the-mill motor. This is a *permanent magnet, remotely commutated, 3-phase, 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.

So just how unique is this motor? Well, if you mechanically turned the motor, it would generate a 3-phase, sinusoidal AC output; just like industrial diesel-electric generators do. (Do not attempt this.[1])

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 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. 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.



To circumvent the losses of the brushed motor, Festool incorporated a brushless DC motor[2] into the new C12 drill. The electrical connections to the windings are permanent, and don't suffer from the inefficiencies of constantly connecting and disconnecting as the motor rotates.

The brushless DC motor lasts longer, and requires no maintenance, as compared to the brushed motor. It is also smoother and quieter.

Electronics

There are some popular brand drills on the market that are known to destroy themselves under a normal, but heavy load. I know this first-hand because I "smoked" a couple drills during my investigation of drills (including the most expensive drill my local home center carried).

A powerful drill is of little value if it is easily damaged. The C12 has an intelligent electronic controller that not only powers the motor, but more importantly, monitors its health. Unlike other drills on the market, the C12 won't let you destroy the drill (or the battery) no matter how hard you try.

It took less that 30 seconds to destroy a $270, 18-volt drill, yet the 12-volt C12 handled the same

[1] Never attempt to manually turn the output shaft of any Festool drill or connect this drill to the output shaft of another drill. The C12's output shaft has a mechanical lock for bit changing and cannot be rotated manually.

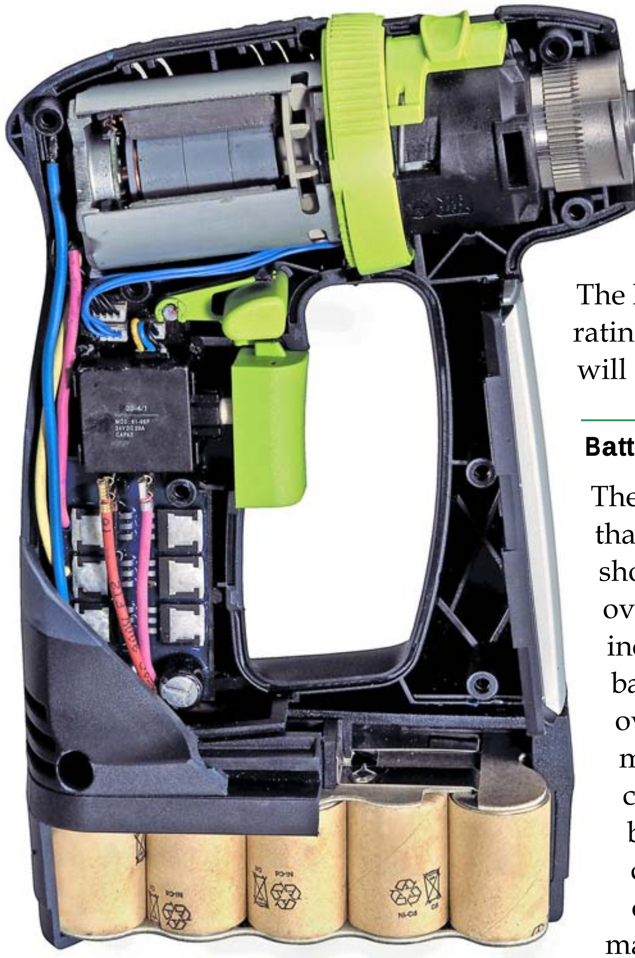
[2] Even though this is a 3-phase, AC motor; it is the electronic industry's practice to refer to this as a brushless DC (BLDC) motor because the AC power signal is electronically created and controlled from a DC (battery) power source.

load without causing damage.

The C12 monitors the electrical power to the motor to ensure that the motor operates within safe parameters. However, make no mistake; the C12 was designed properly in the first place, so it won't overheat under normal use. The drills mentioned above were under-engineered so the manufacturer could claim higher performance than the drill is realistically capable of providing.[1]

Power Control

Virtually all drills on the market (including AC and DC motors) use a similar design for controlling the power to the motor. The trigger switch contains all of the electronic controls.



A small electronic circuit creates a pulsating signal for controlling the speed of the motor, and a mechanical switch controls the motor's direction (refer to *How Variable Speed Controllers Work* on page 5). All of the power to the motor passes through this small circuit, and what's more, passes through the mechanical contacts of the forward/reverse switch.

The C12 uses six high power amplifiers to control the power to the three phases of the motor. These are located on the main control board where there is ample room for a heatsink. The only control circuit inside the power trigger is a small, solidstate resistor that is part of the frequency generator circuit.

Even the forward/reverse control of the C12 is solidstate. There are no moving parts or contacts to fail. It is a sensor that detects the position of a rare earth magnet located on the push button. More importantly, the electrical power of the motor is not flowing through a set of switch contacts like it does with other drills.

Battery Sizes

Whether you're an occasional picture hanger, or a professional contractor, the C12 is flexible enough to meet everyone's needs. The C12 is available with three sizes of batteries to choose from: 1.3 Ah NiCd, 2.4 Ah NiCd, and 3.0 Ah NiMH.

The higher the amp-hour (Ah) rating, the longer the battery will last.

Battery Protection

There are two common ways that battery life gets shortened; over-charging, and over-discharging. The C12 includes an intelligent battery charger to prevent over charging. The microprocessor controlled charger rapidly charges the battery, and when full charge is detected, the charger switches over to maintenance mode.[2]

A common misconception with tool batteries is that they should be fully discharged before recharging. While there is some truth to this, fully draining a battery to the point of stalling the motor can actually cause permanent damage to the battery. The cells inside the battery pack can actually change polarity, called *cell reversal*, under deep cycling. The C12 monitors the battery to determine if it is capable of providing the power required. If the battery cannot supply the power

[1] This is not a new concept. U.S. tool manufacturers frequently overstate their claims for marketing purposes. Festool does not play these marketing games.

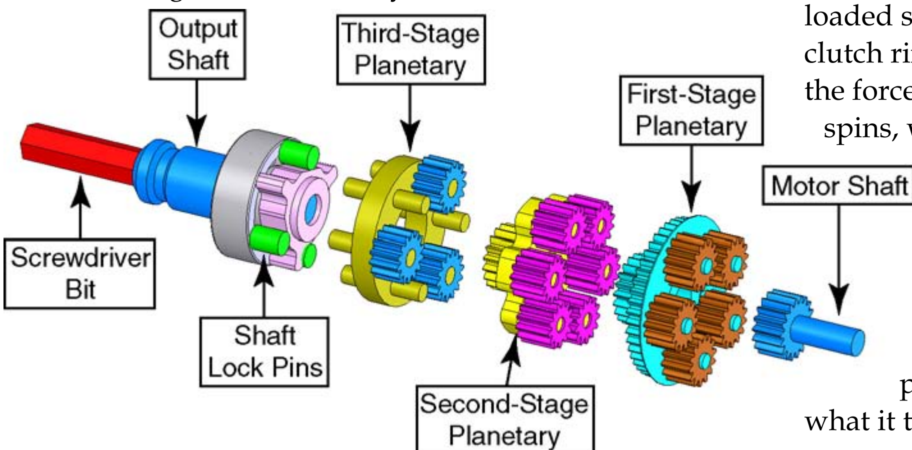
[2] With daily use, the batteries can be left in the charger until needed. However, the charger should not be used for long-term storage of infrequently used batteries.

asked of it, the drill will shut down to protect the battery.

This is an important feature that might be misunderstood by many users. Even though the drill seems to have 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 will allow you to over-draw the battery and shorten its life.

Gearbox

The C12 gearbox is virtually bulletproof. To harness the power of the motor, the C12 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 permits 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.

Electromechanical Clutch and Motor Cut-Out

For driving screws, the C12 has a 24-position torque clutch selector. This allows you to determine at what power level the drill stops turning to prevent breaking or stripping screws. This is nothing new, as most drills have a slip-clutch for this purpose. What is new is how Festool has implemented a motor cut-out feature into the slip clutch.

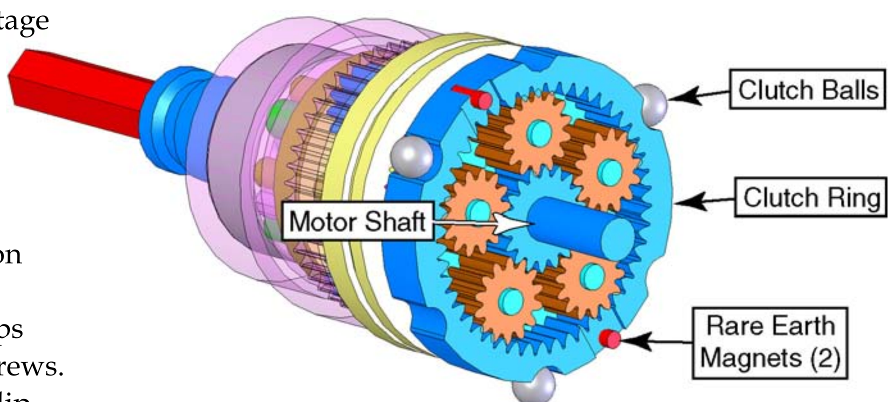
If you are anything like me, the grinding sound of a slipping torque clutch is like fingernails on a blackboard. I hate that sound so much that I refuse to use the torque cut-out feature on a drill. Much to my elation, Festool has found a unique way to ease my pain.

The slip clutch on the C12 will slip only half a revolution before the motor detects the slippage and shuts down. No more do I have to put up with the endless grinding sound from the slip clutch.

For reliability, the C12 still uses the common slip clutch design found on many other drills. Spring loaded steel balls press against the recesses of the clutch ring. When the torque of the motor exceeds the force of the spring loaded balls, the clutch ring spins, which disables the first-stage planetary gear set.

This design is commonly used because it is robust, and only a tiny fraction of the motor's power is needed to disengage the clutch ring. As a matter of fact, the pressure on the clutch balls is less than what it takes to click a ballpoint pen.

To detect when the clutch ring is slipping (rotating), two small, rare earth magnets are inserted into the clutch ring. When these pass by a sensor located inside the motor housing, a signal is sent to the controller, and the controller turns off the motor.



Another feature of the C12 gearbox is the integral shaft-lock to assist in bit changing. 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.

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. 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 the C12 at the AWFS trade show in Las Vegas this summer (see the cutaway picture on page 2). 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 a 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 (I am a card-carrying member of *tool-junkies anonymous*).

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.

Oh by the way, I wasn’t doing this in low-gear like you would expect. The drill was in high-gear! The motor appears to deliver a constant torque at any speed or load. However, without seeing the schematic of the motor's electronic controller I cannot state this as fact, so I am leaving it as just my opinion.

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 12-volt drill against several 14 and 18-volt drills I bought at my local home center.

Unfortunately, when the three most popular drills on the market (names withheld) started smoking under my dynamometer's load, I decided it would not be wise to publish this data, lest I wanted a lawsuit. However, I found it very curious that the only drills with torque curves higher than the C12 were also the ones that allowed their motors to self-destruct.

I could have legitimately published the rest of the data, and throw out outlying data because the drills destroyed themselves to achieve their results. Instead, I decided to throw out the entire test, because trying to explain the outliers might have sounded like I was playing games with the data; and I refuse to publish anything that sounds misleading.

Finally, there are a lot of intangibles about this drill that don’t fit neatly into a technical review. Here are some other quick observations:

- The motor is extremely smooth and quiet; noticeably so over other cordless drills.
- The drill is perfectly balanced, with the center of balance right over the trigger—you can balance the drill on your index finger.
- Even with the largest optional batteries, the drill is still very light.
- Changing batteries is very easy because the batteries slide in from the front, and the latches don't need to support the weight of the battery like most other drills.

- The C12 comes with the compact Centrotec bit holder, as shown, but also includes the standard keyless chuck (top image of the three attachments). The optional offset and right-angle chucks (lower two images) are awe inspiring, and are a "must have" accessory in my opinion.

My Background: *I am an electrical engineer, and my current occupation is Sr. Technical Writer for an international corporation. I use my engineering background to write technical repair manuals for sophisticated equipment, including such things as lasers, robotic systems, and smartcard programmers, to name a few.*

In the past, I owned and operated a custom cabinet shop, and am the true definition of a "tool junkie". I also use to perform "tool tests" for several woodworking magazines.

A year ago I was introduced to Festool products, and was so impressed with them that I began rewriting some of their owner's manuals in my spare time.

Supplement: How Variable Speed Controllers Work

A common misconception about variable speed tools is that the speed is controlled with a variable resistor, like the dimmer of a light switch. This doesn't work well for motors for two reasons. First, is because energy is wasted pumping current through the resistor. The second reason is that whatever power that is not being used by the motor has to be dissipated by the resistor. This means that the battery would be providing full power at all times, regardless how slow the motor is turning. This would be like driving your car with the gas pedal pressed all the way to the floor, and trying to drive at the speed limit by constantly pressing the brake pedal.

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. Keep in mind that this switching is happening so fast (several hundred times a second) that the inertia of the motor keeps it spinning smoothly.

This type of motor speed control is called *Pulse Width Modulation* (PWM), and is also used in many other applications to control power. Most recently, even the old resistive light dimmers are being replaced by solidstate PWM light dimmers, because they are more efficient and do not pose a fire hazard from overheating.

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.