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MULTI-SPEED POWER TOOL WITH ELECTRONIC CLUTCH

Abstract

A power tool and a method of operating a power tool including a motor, a clutch collar including a plurality of settings, a wireless transceiver operable to form a wireless connection with a remote device, and a processor coupled to the clutch collar and the wireless transceiver. The processor receives, via the wireless transceiver, a mapping including a plurality of torque levels corresponding to the plurality of settings. The processor detects that the clutch collar is set to a setting of the plurality of settings. The processor determines the torque level for the setting from the mapping and detects, during the operation of the power tool, that a torque of the power tool exceeds the torque level. The processor is also configured to generate an indication that the torque exceeds the torque level. The indication may include flashing a light, ratcheting the motor, and stopping the motor.

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Background/Summary

RELATED APPLICATIONS [0001] This application is a continuation of U.S. patent application Ser. No. 17/106,806, filed Nov. 30, 2020, which is a continuation of U.S. patent application Ser. No. 15/146,547, filed on May 4, 2016, now U.S. Pat. No. 10,850,380, which claims priority to U.S. Provisional Patent Application No. 62/169,671, filed on Jun. 2, 2015, and U.S. Provisional Patent Application No. 62/180,586, filed on Jun. 16, 2015, the entire content of each of which is hereby incorporated by reference.

FIELD OF THE INVENTION
[0002] The present invention relates to an electronic clutch for a power tool.
SUMMARY
[0003] One embodiment provides a power tool including a housing, a motor within the housing, a clutch collar on the housing including a plurality of settings, a wireless transceiver operable to form a wireless connection with a remote device, and a processor coupled to the clutch collar and the wireless transceiver. The processor is configured to receive, via the wireless transceiver, a mapping including a plurality of torque levels corresponding to the plurality of settings and detect that the clutch collar is set to a setting of the plurality of settings. The processor is further configured to determine the torque level for the setting from the mapping and detect, during the operation of the power tool, that a torque of the power tool exceeds the torque level. The processor is also configured to generate an indication that the torque exceeds the torque level.
[0004] Another embodiment provides a method of operating a power tool including a housing, a motor within the housing, a clutch collar on the housing including a plurality of settings, and an electronic clutch. The method includes receiving, with a processor via a wireless transceiver, a mapping including a plurality of torque levels corresponding to the plurality of settings and detecting, with the processor, that the clutch collar is set to a setting from the plurality of settings. The method also includes determining, with the processor, the torque level for the setting from the mapping, and detecting, with the processor, that a torque of the power tool exceeds the torque level during operation of the power tool. The method further includes generating, with the processor, an indication that the torque exceeds the torque level.
[0005] Another embodiment provides a method of operating a housing, a motor within the housing, a clutch collar on the housing including a plurality of settings, and an electronic clutch. The method includes receiving, with a processor via a wireless transceiver, a first torque value generated by a remote device based on user input and wirelessly transmitted by the remote device to the wireless transceiver. The method further includes the processor detecting that the clutch collar is set to a setting of the plurality of settings. The processor calculates a torque level for the setting based on

the position of the setting among the plurality of settings and the first torque value. The method further includes controlling the motor based on the torque level.

Description

BRIEF DESCRIPTION OF THE DRAWINGS

[0006] FIGS. **1**A and **1**B illustrate a power tool according to some embodiments.

[0007] FIG. **2** illustrates a block diagram of the power tool according to some embodiments.

[0008] FIGS. **3**A and **3**B illustrate a printed circuit board assembly associated with the power tool of FIGS. **1**A and **1**B according to some embodiments.

[0009] FIG. **4** illustrates a circuit diagram of the printed circuit board assembly of FIGS. **3**A and **3**B according to some embodiments.

[0010] FIG. **5** illustrates a block diagram of a remote device according to some embodiments.

[0011] FIGS. **6**A and **6**B illustrate a graphical user interface of a remote device associated with the power tool of FIGS. **1**A and **1**B according to some embodiments.

[0012] FIG. **7** illustrates a graphical user interface of a remote device associated with the power tool of FIGS. **1**A and **1**B according to some embodiments.

[0013] FIG. **8** illustrates a flowchart of a method of operating a power tool having an electronic clutch according to some embodiments.

DETAILED DESCRIPTION

[0014] Before any embodiments of the invention are explained in detail, it is to be understood that the invention is not limited in its application to the details of construction and the arrangement of components set forth in the following description or illustrated in the following drawings. The invention is capable of other embodiments and of being practiced or of being carried out in various ways.

[0015] FIGS. **1**A-B illustrate a power tool **100** incorporating a brushless direct current (DC) motor. In a brushless motor power tool, such as power tool **100**, switching elements are selectively enabled and disabled by control signals from a controller to selectively apply power from a power source (e.g., battery pack) to drive a brushless motor. The power tool **100** is a brushless hammer drill having a housing **102** with a handle portion **104** and motor housing portion **106**. The power tool **100** further includes an output unit **107**, a clutch selector ring (or clutch collar) **108**, a mode selector ring **109**, forward/reverse selector **110**, speed select switch **111**, trigger **112**, a mode selector pushbutton **113**, a battery interface **114**, and light **116**. The mode selector ring **109** allows a user to select between a drilling mode, a driving mode, a hammering mode, and an adaptive mode. When in the adaptive mode, the mode selector pushbutton **113** may be activated (e.g., pushed) to cycle through adaptive modes defined by control profiles of the tool **100**. The clutch collar **108** allows a user to select between various clutch settings, such as settings 1-13 or the even values between 2-26 (i.e., settings 2, 4, 6, 8, 24, 26). Other embodiments include a clutch collar **108** having fewer or more setting options. The speed select switch **111** is a two-position switch that slides between a high speed and a low speed. In some embodiments, the speed select switch **111** includes additional speed settings (e.g., high, medium, and low).

[0016] FIG. **2** illustrates a simplified block diagram **120** of the power tool **100**, which includes a power source **122**, field effect transistors (FETs) **124**, a motor **126**, Hall sensors **128**, a motor control unit **130**, user input **132**, and other components **133** (battery pack fuel gauge, work lights (e.g., light emitting diodes (LEDs), such as the light **116**), a current sensor **135**, a voltage sensor **136**, and a wireless transceiver **137**). The power source **122** provides DC power to the various components of the power tool **100** and may be a power tool battery pack that is rechargeable and uses, for instance, lithium ion cell technology. In some instances, the power source **122** may receive alternating current (AC) power (e.g., 120V/60 Hz) from a tool plug that is coupled to a standard wall outlet, and then filter, condition, and rectify the received power to output DC power.

[0017] Each of the Hall sensors **128** outputs motor feedback information, such as an indication (e.g., a pulse) when a magnet of the motor's rotor rotates across the face of that Hall sensor. Based on the motor feedback information from the Hall sensors **128**, the motor control unit **130** can determine the position, velocity, and acceleration of the rotor. The motor control unit **130** also receives user controls from user input **132**, such as by depressing the trigger **112** or shifting the forward/reverse selector **110**. In response to the motor feedback information and user controls, the motor control unit **130** transmits control signals to control the FETs **124** to drive the motor **126**. By selectively enabling and disabling the FETs **124**, power from the power source **122** is selectively applied to stator coils of the motor **126** to cause rotation of a rotor. Although not shown, the motor control unit **130** and other components of the power tool **100** are electrically coupled to the power source **122** such that the power source **122** provides power thereto.

[0018] The current sensor **135** detects current to the motor, for example, by detecting current flowing between the power source **122** and the FETS **124** or between the FETS **124** and the motor **126**, and provides an indication of the current sensed to the motor control unit **130**. The voltage sensor **136** detects voltages of the power tool **100**, such as a voltage level of the power source **122** and a voltage across the motor **126**. The wireless transceiver **137** provides a wireless connection between the motor control unit **130** and an external device to enable wireless communication with the external device, such as a remote device **140**.

[0019] In some embodiments, the motor control unit **130** includes a memory and an electronic processor configured to execute instructions stored on the memory to effect the functionality of the motor control unit **130** described herein.

[0020] The tool **100** includes an electronic clutch, also referred to as an e-clutch. More particularly, the tool **100** includes an e-clutch control module **134**. The e-clutch control module **134** may be implemented in hardware, software, or a combination thereof. In the illustrated embodiment, the e-clutch control module **134** includes instructions stored on and executed by the motor control unit **130** to implement the e-clutch functionality described herein. The e-clutch control module **134** takes input from a user from the clutch collar **108**. As will be discussed in more detail below, the clutch collar **108** provides the user a rotatable selector that provides an electrical signal indicative of the user selection to the e-clutch control module **134**. The position of the speed select switch **111**, which a user can toggle between two settings (for example, a high speed setting ("1") and a low speed setting ("2")), is monitored by the e-clutch control module **134** as well.

[0021] The user selection on the clutch collar **108** is translated into a desired/target torque output level for the tool **100**. Then, when the tool **100** is in operation, the e-clutch control module **134** calculates an output torque of the power tool by taking into account one or more of a gear ratio, battery current, effect of speed control or pulse-width-modulation (PWM) on root mean squared (RMS) current, and changes in motor velocity and acceleration. For example, the e-clutch control module **134** calculates the output torque based on a current flowing to the motor **126** as sensed by the current sensor **135**. When the target torque is reached, the motor control unit **130** generates an indication of reaching the target torque by one or more of stopping the tool **100** from further driving, shaking (i.e., ratcheting) the motor **126** to indicate that the target torque has been reached, and flashing the light **116** to indicate that the target torque has been reached.

[0022] The clutch collar **108** allows the user to select the desired torque level at which the tool **100** clutches. The clutch collar **108** is able to rotate continuously and is not limited, for example, to a single revolution or 360 degrees of rotation. In other words, the clutch collar **108** is able to be rotated multiple revolutions (i.e., more than 360 degrees of rotation). The continuous rotation feature allows the clutch collar **108** to go from a maximum torque setting (e.g., at a 0 degree rotational position) to the minimum torque setting (e.g., at a 359 degree rotational position), which are adjacent, more quickly than if the clutch collar **108** had to rotate back through the various intervening settings between the maximum and minimum setting.

[0023] In other embodiments, the clutch collar **108** is limited in rotation, for example, by a rotational stop physically blocking rotation beyond a certain point (e.g., 180 degrees, 270 degrees, 300 degrees, 360 degrees, 540 degrees, 720 degrees, an amount between 300 and 360 degrees, or another degree amount). As an example, the clutch collar **108** may include a projection that rotates with the collar and the motor housing **106** may have a fixed tab (i.e., a rotational stop). The clutch collar **108** is free to rotate until the projection abuts the fixed tab. The projection and tab may be internal (i.e., inside the clutch collar **108** and motor housing **106**, respectively) or external (i.e., on an outside surface of the clutch collar **108** and the motor housing **106**, respectively).
[0024] The clutch collar **108** includes a wiper (not shown) that contacts one of several resistive elements, each associated with a particular clutch setting. The particular resistive element contacted by the wiper depends on the rotational position of the clutch collar **108**.
[0025] For instance, FIGS. **3**A-B illustrate a front side and a back side, respectively, of a printed circuit board assembly (PCBA) **200** associated with the clutch collar **108**, and FIG. **4** illustrates a circuit diagram **201** of the PCBA **200** coupled to the motor control unit **130**. The PCBA **200** includes a mode pin **202**, an e-clutch (EC) pin **204**, a power pin (Vcc) **206**, and a ground pin (GND) **208**. As shown in FIG. **5**, the mode pin **202** and the e-clutch pin **204** are coupled to input pins of the motor control unit **130**. The PCBA **200** also includes thirteen surface mount resistors, R**1**-R**13**, each having a different resistance value and conductively coupled to a different one of thirteen wiper connection points (S**1**-S**13**) and being associated with a different one of the thirteen clutch settings (1-13). When a user rotates the clutch collar **108** and stops at a particular clutch setting (e.g., **2**), the wiper contacts a conductive PCBA track (e.g., wiper connection point S**2**) of the associated resistor (e.g., R**2**) to complete a circuit including the e-clutch pin **204**. The conductive tracks for the thirteen resistors are viewable on the front side of the PCBA **200** in FIG. **3**A. The motor control unit **130** and, particularly, the e-clutch control module **134**, receives an electronic signal indicating that the wiper has contacted the particular resistor (e.g., R**2**). The e-clutch control module **134** interprets the signal and determines that the user has selected a particular setting (e.g., **2**). From the user perspective, the clutch collar has an interface similar to a mechanical clutch, ensuring that the user will understand how to use the clutch.
[0026] In some embodiments, the ability to continuously rotate the clutch collar **108** (e.g., multiple revolutions in the clockwise direction, and the counter-clockwise direction), allows the clutch collar **108** to specify more settings than wiper-resistor positions on the PCBA **200**. For instance, when rotating the clutch collar **108** so that the wiper moves clockwise on the PCBA **200** shown in FIG. **3**A (going from S**1** to S**2** through S**13**), if the user continues to rotate the clutch collar **108** past position S**13**, eventually the wiper will again contact position S**1**. The e-clutch control module **134** determines, based on outputs from the e-clutch pin **204**, that the clutch collar **108** went from position S**13** to S**1** without going through positions S**12**-S**2**. Thus, this position S**1** can be treated as a fourteenth position (S**14**). If the clutch collar **108** continues to rotate in the clockwise direction, each subsequent position is likewise treated as a new position. For example, S**2** would be a fifteenth position (S**15**), S**3** would be a sixteenth position (S**16**), and so on. A similar expansion of positions is provided through rotating the clutch collar **108** counter clockwise to go directly from position S**1** to S**13**, without going through intervening positions S**2**-S**12**.
[0027] Accordingly, the continuously rotating clutch collar **108** essentially allows an infinite number of settings to be indicated, as a user can continuously rotate in a first direction to continuously increment the torque setting, and continuously rotate in the opposition direction to decrement the torque setting. In turn, the e-clutch control module **134** can provide a maximum and minimum torque setting (e.g., in software) where, for instance, further increments from the clutch collar **108** are ignored because the maximum setting has been reached. Additionally, the increased number of setting positions allows tuning of a torque setting with finer granularity. For instance, rather than dividing up the potential torque settings among thirteen positions, the e-clutch control module **134** can divide the same range of potential torque settings among 26, 39, 50, 100, or

another number of positions.

[0028] The PCBA **200** is further associated with the mode selector ring **109** to allow a user to select between the drilling mode, driving mode, hammering mode, and adaptive mode. The PCBA **200** includes further surface mount resistors R**31**, R**32**, R**33**, and R**34** on the bottom portion of the PCBA **200**, each resistor being conductively coupled to a wiper connection point (M**1**-M**4**) and being associated with one of the four modes for selection. Similar to the clutch collar **108**, the mode selector ring **109** includes a wiper that contacts a resistive element (R**31**-R**34**) to complete a circuit and indicate the mode selection to the motor control unit **130**, albeit the signal is output via the mode pin **202**, rather than the e-clutch pin **204**.

[0029] The position of the speed select switch **111**, which a user can toggle between two settings (e.g., a “1” and “2”), is monitored by the e-clutch control module **134** as well. A similar resistor, wiper, and PCBA track setup as described with respect to FIGS. **3**A, **3**B, and **4** is used to track the position of the speed select switch **111** and, therefore, the user's selection of the speed setting (gear ratio) of the tool **100**. In some embodiments, the e-clutch control module **134** receives the speed setting and accounts for the gear ratio of the speed setting such that a consistent output torque for a given clutch setting is obtained regardless of the of speed setting selected. In other embodiments, the e-clutch control module **134** applies a different target torque dependent on the speed setting such that a different output torque is obtained for a given clutch setting at different speed settings.

[0030] In other embodiments, rather than a wiper-resistor ring technique, different clutch collar selection and mode selection user interface technology is used, such as inputs using mutual inductive sensing and capacitive sensing.

[0031] The e-clutch control module **134** estimates the output torque of the tool **100** (torque at the shaft) using a measurement of battery current. The current sensor **135**, or another sensor used to infer battery current, provides a measurement to the e-clutch control module **134**. For instance, to determine battery current, the current sensor **135** may be positioned to measure the current along the connection between the power source **122** and the FETs **124** labeled “power” in FIG. **2**.

[0032] The current-torque relationship is fairly linear, and the relationship depends on a motor constant (e.g., torque per unit current (k_t)), gear ratio, gear friction, motor speed and other factors. Determining the output torque of the tool **100** based on current may be improved by subtracting current that is due to motor inertia from the measured battery current. The inertia is specific to the motor used and takes into account the effects of velocity and acceleration. Taking motor inertia into consideration when estimating torque assists in preventing inadvertent shutdowns on startup or due to changes in the trigger position, where the current-torque relationship can sometimes be non-linear, unreliable, or both. The current-to-torque calculation may also be improved by calculating an RMS current based on the measured battery current, a PWM duty ratio, and motor design characteristics. This calculation helps maintain a similar torque output across different PWM duty ratios. The output torque calculation may also account for the gear ratio of the power tool **100**, which is selected by the user via the speed select switch **111**. For example, the output torque calculation includes one or more of different offsets and constants, which may be empirically determined, to compensate for the different speed settings (i.e., gear ratios) selectable by the speed select switch **111**.

[0033] The calculated output torque is compared against the threshold torque level set by the user (e.g., via the clutch collar **108**) and the tool **100** provides feedback when the threshold torque level is met or exceeded. In some embodiments, because the output torque calculation takes into consideration and accounts for the gear ratio indicated by the speed select switch **111**, regardless of the particular speed setting selected, the tool **100** achieves approximately the same torque output for a particular torque setting (e.g., “2”) selected by the user via the clutch collar **108**. A torque level (or, torque value) that is considered approximately the same as another torque level may vary by embodiment and may be, for example, within 2% of the other torque level, within 5% of the other torque level, or within 10% of the other torque level.

[0034] The tool **100** indicates to the user that the desired torque has been reached by ratcheting the motor and flashing the light **116**. By ratcheting the motor **126**, the e-clutch control module **134** simulates to the user the ratcheting feel and sound of a mechanical clutch. This technique makes the experience for the user similar to a mechanical clutch and it is also cost effective because no additional hardware is needed. The e-clutch control module **134** will also control the light **116** to blink when the tool **100** has reached the selected target torque.

[0035] The feedback (e.g., ratcheting) intensity is scaled up and down with the desired output torque to prevent the ratcheting from being stronger than the target torque, while maximizing or ensuring the effectiveness of the feedback to the user. The ratcheting of the motor **126** is implemented by controlling a pulse-width modulated (PWM) signal generated by the motor control unit **130** to drive the motor **126** (via the FETS **124**) to be output in short bursts. For instance, the PWM signal generated by the motor control unit **130** cycles between an active state with a non-zero percent duty cycle for a first time period, and an inactive (off) state with a zero or near zero percent duty cycle for a second time period. In some instances, the frequency and duty cycles for the active and inactive periods of the PWM signal may vary during the course of ratcheting. The amount of motor ratcheting generated is based on the target torque selected by the user. More particularly, the higher the target torque selected (e.g., as indicted by the clutch collar **108** and determined by the motor control unit **130**), the more motor ratcheting generated by the tool **100** to indicate when the target torque is reached. Similarly, the lower the target torque selected, the less motor ratcheting generated by the tool **100** to indicate when the target torque is reached. Scaling the motor ratcheting in accordance with the selected target torque level 1) prevents over-torqueing a fastener from the ratcheting motion itself, which could occur if the amount of motor ratcheting is too high; and 2) allows a level of motor ratcheting commensurate with the driving action so as to be low enough at low torques to not startle the user and high enough at high torques to be felt and recognized by the user.

[0036] To scale the intensity of the motor ratcheting, the length of time that the PWM signal is active and not active can be adjusted. Generally, the longer the active time period, the more intense the ratcheting effect. Similarly, the duration of the inactive time period of the PWM signal can be adjusted to increase and decrease the intensity of the ratcheting feedback. Generally, the longer the PWM signal is inactive, the less intense the ratcheting feedback. For instance, to increase the intensity of the ratcheting, the time period that the PWM signal is active is increased, the time period that the PWM signal is inactive is decreased, or both.

[0037] The particular threshold torque level used by the tool **100** varies depending on the selected mode of the tool **100**. When in the drilling mode and the hammering mode, as selected via the mode selector ring **109**, the tool **100** generally does not implement threshold torque levels as described above. When in the driving mode, the e-clutch control module **134** uses the default threshold torque level setting assigned to the currently selected torque setting indicated by the rotational position of the clutch collar **108**. The e-clutch control module **134** may include a mapping of default threshold torque levels corresponding to the settings of the clutch collar **108**. When in the adaptive mode, as indicated by the mode selector ring **109** based on a user selection, the tool **100** may operate implement threshold torque levels as described above. The threshold torque levels may be set through wireless communications between the power tool **100** and the remote device **140**, as described in further detail below.

[0038] FIG. **5** illustrates a block diagram of the remote device **140**. The remote device **140** may be, for example, a smart phone, laptop, tablet, desktop, or other computing device. The remote device **140** includes a memory **145**, an electronic processor **150**, a touchscreen display **155**, and a wireless transceiver **160** coupled by a bus **165**. The memory **145** stores instructions, including those for a graphical user interface, that are executed by the electronic processor **150** to perform the processing functions of the remote device **140** described herein. The touchscreen display **155** displays information for a user and receives input from a user. The touchscreen display **155** is one example of a user interface and, in some embodiments further or alternative user interface elements are included in the remote device **140**, such as pushbuttons, speakers, keyboards, and the like. The electronic processor **150** is operable to execute instructions of the memory **145** to generate a graphical user interface (GUI) on the touchscreen display **155**, such as the GUIs **250** and **300** described in further detail below. The wireless transceiver **160** is configured to form a wireless communication link with the wireless transceiver **137** of the power tool **100** (FIG. **2**) to enable the electronic processor **150** to communicate with the motor control unit **130** (and the e-clutch control module **134** thereof) of the power tool **100**. The wireless transceivers **137**, **160** may use the Bluetooth® communication protocol, Wi-Fi® communication protocol, or another wireless protocol.

[0039] FIGS. **6**A and **6**B illustrate a GUI **250** generated by the remote device **140** and configured to receive user input specifying a control provide (e.g., a custom drive control profile), and to generate and transmit to the motor control unit **130** the custom drive control profile to configure operation of the power tool **100**. The power tool **100** and, in particular, the motor control unit **130**, may store multiple control profiles, which may be provided and updated by the remote device **140**. A control profile includes various tool operating parameters used by the motor control unit **130** to control the power tool **100**. When in the adaptive mode, as indicated by the mode selector ring **109**, the motor control unit **130** may cycle through and select the particular control profile to employ for operation of the power tool **100** in response to depressions of the mode selector pushbutton **113** by a user. For example, the power tool **100** may include four control profiles at a given moment, and each time the mode selector pushbutton **113** is depressed, the selected control profile used by the motor control unit **130** to control the power tool changes (e.g., from profile one, to profile two, to control profile three, to profile four, back to profile one, and so on). In other embodiments, more or less control profiles are stored on the power tool **100**, or only a single control profile is stored on the power tool **100**.

[0040] The GUI **250** is operable to receive a user selection of the adjustable mode or the fixed mode via a clutch ring settings selector **255** (see, e.g., FIGS. **6**A and **6**B). For the fixed mode, a set-up screen of which is shown in FIG. **6**B, the remote device **140** receives a user selection, via a slider **260** or text box **265**, of a particular fixed torque level (e.g., 75 in-lbs.) or a particular percentage of available torque (e.g., 75% (of maximum available torque)). The selected fixed torque level, along with an indication of the fixed torque mode, is part of a custom drive control profile that is then wirelessly communicated to the tool **100** and, more particularly, to the e-clutch control module **134**. This selected torque level is then used by the e-clutch control module **134** as the torque threshold for the tool **100**, regardless of the position of the clutch collar **108**.

[0041] Alternatively, the power tool **100** may receive a custom drive control profile from the remote device **140** indicating that the tool **100** is to operate in the adjustable mode. In the adjustable mode, a set-up screen of which is shown in FIG. **6**A, the torque threshold used by the e-clutch control module **134** is the torque level assigned to the currently selected torque setting indicated by the rotational position of the clutch collar **108**. Initially, the torque levels assigned to the various torque settings of the clutch collar **108** are the default torque levels that are also used in the driving mode. However, via the remote device **140**, the user can assign new torque levels to the various settings available to be selected by the clutch collar **108**, over-writing or being used in place of the default torque levels. The GUI **250** receives the user assignment of torque levels to settings of the clutch collar **108** (a mapping), and provides the mapping via the wireless transceiver **160** to the e-clutch control module **134** as part of a control profile. The e-clutch control module **134** may store the mapping to a memory of the motor control unit**130**.

[0042] In an example mapping generation by the GUI **250**, the user is able to assign a maximum and minimum torque level (via the slider **260** or text boxes **265**) that can be selected via the clutch collar **108**, such that the lowest torque setting of the clutch collar **108** is assigned the minimum torque level selected and the highest torque setting of the clutch collar **108** is assigned the maximum torque level selected. The remaining intermediate torque settings are then assigned a proportional torque level between the minimum and maximum torque levels. For instance, assuming thirteen torque settings (1-13) on the clutch collar **108** and a user selecting a minimum torque level of 50 inch-pounds (in.-lbs.) and a maximum torque level of 110 in.-lbs., the remote device **140** will assign the following torque levels to the tool **100**, in some embodiments: TABLE-US-00001 TABLE I Torque Setting Torque level Torque level (Clutch Collar Position) (in-lbs.) (% of maximum torque) 1 50 29% 2 55 32% 3 60 35% 4 65 38% 5 70 41% 6 75 44% 7 80 47% 8 85 50% 9 90 53% 10 95 56% 11 100 59% 12 105 62% 13 110 65%

[0043] These assigned values assume a linear scale between minimum and maximum values. However, in some instances, non-linear scales are used, such as an exponential scale. In some embodiments, the GUI **250** may receive a selection of the scale to apply via user input. The maximum and minimum selected torque levels can also be expressed as a percentage of the maximum torque available. For instance, the right column of the above table illustrates the torque levels expressed as a percentage. Furthermore, as noted above with respect to the continuously rotating feature of the clutch collar **108**, more or fewer than 13 torque setting positions are assigned a torque level in some embodiments. For instance, each increment or decrement of the position of the clutch collar **108** can increment or decrement, respectively, the torque level by 1 in-lb (or by 1% of maximum torque) until the maximum or minimum torque levels are reached.

[0044] The GUI **250** further includes a speed setting selector **270** to select between a high speed mapping and a low speed mapping. In other words, the GUI **250** is operable to receive torque levels for a first mapping when the high speed mapping is selected via the speed setting selector **270**, and to receive torque levels for a second mapping when the low speed mapping is selected via the speed setting selector **270**. The remote device **140** is further operable to generate and provide to the motor control unit **130** a profile including the first mapping applicable when the power tool is in the high speed setting and the second mapping applicable when the power tool is in the low speed setting (selected via the speed select switch **111**).

[0045] In some embodiments, the profile provided to the power tool **100** based on user input received by the GUI **250** may indicate that, in one of the speed settings (e.g., the high speed setting), the power tool **100** is in the adjustable mode and, in the other of the speed settings (e.g., the low speed setting), the power tool is in the fixed mode. For example, with the low speed mapping selected on the GUI **250** via the speed setting selector **270**, the GUI **250** may receive a selection of the adjustable mode via the clutch ring settings selector **255**. Further, with the high speed mapping selected on the GUI **250** via the speed setting selector **270**, the GUI **250** may receive a selection of the fixed mode via the clutch ring settings selector **255**. The remote device **140** then generates a profile including a first mapping and the adjustable mode for the low speed setting and a fixed torque level and the fixed mode indication for the high speed setting. Accordingly, a user is operable to cycle the power tool **100**, by moving the speed select switch **111**, between an adjustable mode whereby the user may specify a torque level via the clutch collar **108** and a fixed mode whereby the torque level is fixed (based on input via the GUI **250**).

[0046] The profile generated by the remote device **140** and provided to the power tool **100** based on the GUI **250** may further include a maximum speed for the motor **126** (one for each of the high and low speed setting), a trigger ramp up parameter indicating a pace at which the motor **126** should ramp up to a desired speed, a work light duration indicating how long to keep the light **116** enabled (e.g., after the trigger **112** is pressed or released), and a work light brightness level.

[0047] Using the e-clutch control module **134**, clutch collar **108**, and remote device **140**, rather than a traditional mechanical clutch, allows for more sophisticated mappings of torque control. A mechanical input (clutch collar **108**) provides the user with a mechanical input mechanism on the tool **100** that is coupled with programmable electronic control to provide greater tool customization, intelligence, and usability. The ability to remap the torque settings selectable by the clutch collar **108** results in a tool **100** having an extended user interface, where the indications that are provided by the mechanical input are programmable and are not fixed. For instance, torque setting “2” is not fixed to indicate **55** in-lbs. (or another value) of torque. Rather, via the remote device **140**, the meaning of a particular output signal from the mechanical input can be remapped by the user to indicate something different to the motor control unit **130** and e-clutch control module **134**. The particular indication from the mechanical input, specified through the mapping, is then used to control the motor in a certain predetermined manner. This extended user interface provided by the remote device **140** provides extended functionality and customization of the tool **100**, which has limited surface real estate for additional user interface components.

[0048] In some embodiments, the e-clutch control module **134** limits the maximum allowable torque setting to be that which is allowable according to applicable laws, rules, or regulations for a driving tool without a side handle. In some embodiments, the e-clutch control module **134** receives an input regarding whether a side handle is present on the tool and limits the maximum allowable torque setting based on the input. More particularly, when the e-clutch control module **134** determines that the side handle is not present, the maximum allowable torque setting is limited to that which is permitted according to applicable laws, rules, or regulations. When the e-clutch control module **134** determines that the side handle is present, the maximum torque setting allowable is permitted to be higher than when the side handle is not present. The higher maximum torque setting may again be limited by applicable laws, rules, or regulations for a driving tool with a side handle.

[0049] In some embodiments, a switch on the tool **100** allows a user to indicate to the e-clutch control module **134** whether a side handle is present. The switch may be similar in function and structure to the speed select switch **111**, may be a push button, or another electro-mechanical input device that provides an output to the e-clutch control module **134** indicative of whether a side handle is present. In another embodiment, attaching the side handle to the tool itself actuates a switch that provides an indication to the e-clutch control module **134** of the presence of the side handle, and removal of the handle provides an indication to the e-clutch control module **134** that that the side handle has been removed. In another embodiment, the GUI of the remote device **140** includes an input (e.g., radio buttons or two-position slider) enabling a user to select or toggle between a side handle on indication and a side handle off indication. This selection is then communicated to the e-clutch control module **134** and used as described above to set the maximum allowable torque setting.

[0050] As noted above, the tool includes a speed selector switch **111** allowing the user to select between two gear ratios, which results in a different output speed range. Generally, a high gear ratio allows for higher maximum speed, but lower maximum torque, while a low gear ratio allows for a higher maximum torque, but lower maximum speed. In tools with traditional mechanical clutches, the maximum torque allowable is typically limited to a maximum torque to be provided in the high gear ratio (high speed) mode. As a result, while the low gear ratio mode would allow for a higher maximum torque absent the mechanical clutch, the mechanical clutch limits the maximum torque allowable in the low gear ratio (low speed) mode to the maximum torque to be provided in the high gear ratio mode. As such, the higher torques of the low gear ratio mode remain unavailable in a clutching mode. In contrast, the tool **100** includes an e-clutch rather than a mechanical clutch. The configurability of the e-clutch control module **134** removes the torque limit imposed by the higher gear ratio to be able to take advantage of the extra torque levels available by the low gear ratio.

[0051] Accordingly, in some embodiments, the e-clutch control module **134** allows a user to specify a higher torque level for the low speed mode than is selectable for the high speed mode. For instance, in FIGS. **6**A-B, the low speed mode is selected and the maximum torque allowed is approximately 175 in-lbs., which is the same maximum torque allowed in the high speed mode. However, in some embodiments, the tool **100** can achieve a higher torque output while in the low speed mode. Accordingly, in some embodiments, the maximum selectable torque level is a first value (e.g., 175 in-lbs.) when in the high speed mode; but, in the low speed mode, the maximum selectable torque level is a greater value (e.g., 300 in-lbs. or 1000 in-lbs.).

[0052] In some embodiments, the e-clutch control module **134** allows a user to individually provide a torque level for each setting of the clutch collar **108**. A GUI of the remote device **140** may include a text box, slider, or other input mechanism, for each setting of the clutch collar **108** to enable a user to enter a custom torque level for each clutch collar setting. For example, the user may enter 200 in-lbs for setting 1, 150 in-lbs for setting 2, and 700 in-lbs for setting 3. In other embodiments, the GUI of the remote device **140** may receive, from a user, custom values for a subset of the settings, and a range for the other settings. For instance, for a clutch collar **108** having thirteen settings (e.g. 1-13), the GUI may receive custom torque levels for settings the three settings (e.g., 1-3), and a range for the remaining settings (e.g., 4-13) defined by a maximum value and a minimum value. The remote device **140** may, in turn, divide the range among the remaining settings (e.g., 4-13), similar to as described above with respect to Table I.

[0053] In some embodiments, the e-clutch control module **134** receives via a GUI of the remote device **140** different ranges for different subsets of the settings of the clutch collar **108**. For example, the GUI may provide a mapping of torque levels to the e-clutch control module **134**, based on received user input, specifying a first range of torques for a first group of settings (e.g., 1-5) of the clutch collar and a second range of torques for a second group of settings (e.g., 6-13) of the clutch collar, the ranges each defined by maximum and minimum torque levels similar to as described above.

[0054] FIG. **7** illustrates another graphical user interface, GIU **300**, generated by the remote device **140** and used to configure the tool **100**. The GUI **300** is configured to receive user input specifying a custom drill control profile, which is then transmitted by the remote device **140** to the power tool **100** to configure operation of the power tool **100**. The GUI **300** is similar to the GUI **250** of FIGS. **6**A-B, but includes different features, including an anti-kickback feature block **301**. More particularly, the GUI **300** includes an anti-kickback toggle **302** that has an enable and a disable position, selectable by the user. For instance, as illustrated in FIG. **7**, the anti-kickback toggle **302** is in the enabled position, but is switched to the disabled position by swiping to the left on the GUI **300** (e.g., on a touch screen of the remote device **140**). When enabled, the user is operable to set the sensitivity of the anti-kickback feature by setting a torque shutoff level (i.e., an anti-kickback torque level). In the illustrated example, the user may adjust the torque shutoff level between level 1 and level 10 by sliding the slider **304**. The GUI **300** also includes a torque shutoff level indicator **306** indicating the currently selected torque shutoff setting, which is set to level 3 in FIG. **7**. After the remote device **140** receives the user settings of the custom drill profile via GUI **300**, the remote device **140** transmits the profile (configuration data) to the power tool **100** wirelessly or via a wired connection, which is received by the motor control unit **130**. As previously described, the mode selector pushbutton **113** may be pressed to cycle through profiles of the tool **100** and to select the custom drill control profile having the anti-kickback feature enabled.

[0055] In operation, while the power tool **100** is performing a drilling operation with the anti-kickback feature is enabled, the e-clutch control module **134** monitors the battery current to the motor **126** using the current sensor **135**, as described above. The e-clutch control module **134** also determines a current threshold based on the selected torque shutoff setting (e.g., using a look up table mapping each torque shutoff setting to a current value). When the e-clutch control module **134** determines that the battery current level reaches the current threshold, the motor control unit **130** ceases driving the motor **126** to bring the motor **126** to a quick stop. Thus, the motor control unit **130** infers that a kickback situation is occurring based on an increase in motor torque, which is inferred via battery current, and shuts down the motor **126**.

[0056] When the anti-kickback toggle **302** is disabled, and the remote device **140** communicates the custom drill profile configuration data to the power tool with the disabled feature status, the power tool **100** proceeds without a torque shutoff as described.

[0057] As illustrated in FIG. **7**, other tool operation parameters may be specified via the GUI **300**.

For example, the GUI **300** is operable to receive a maximum speed for the motor **126** (for both the high and low speed setting), a trigger ramp up parameter indicating a pace at which the motor **126** should ramp up to a desired speed, a work light duration indicating how long to keep the light **116** enabled (e.g., after the trigger **112** is pressed or released), and a work light brightness level. The GUI **300**, in turn, generates a custom drill control profile including the specified parameters, which is transmitted to the motor control unit **130**. The profile may be stored in a memory of the motor control unit **130**. The motor control unit **130**, in turn, controls the power tool **100** in accordance with the parameters specified by the custom drill control profile.

[0058] FIG. **8** illustrates a flowchart of a method **700** of operating a power tool **100** having an electronic clutch. The method **700** includes receiving a mapping for the clutch collar **108** (at step **710**). For example, the mapping may be part of a profile generated by the remote device **140** in response to user inputs received by the GUI **250** (FIGS. **6**A and **6**B). The profile may also include an indication of a mode specified via the GUI **250**, such as an adjustable mode or a fixed mode. The mapping indicates or assigns a torque level for each of the plurality of positions (that is, plurality of settings) of the clutch collar **108**. The motor control unit **130** receives and stores the mapping from the remote device **140** via the wireless transceiver **137**. A processor of the motor control unit **130** may store the mapping in a memory of the motor control unit **130**.

[0059] In some embodiments, as described above, the mapping includes torque levels for two or more revolutions of the clutch collar **108**. For example, the mapping may include torque levels corresponding to a plurality of settings for a first revolution of the clutch collar and a second plurality of torque levels corresponding to the plurality of settings for a second revolution of the clutch collar. Assuming that the clutch collar **108** includes thirteen settings for one revolution of the clutch collar **108**, this mapping may include twenty-six torque levels, one for each setting (or, position) of the clutch collar **108** over two revolutions. In some embodiments, torque levels for more than two revolutions of settings of the clutch collar are provided. In some embodiments, the mapping specifies a maximum torque level, and minimum torque level, and an increment/decrement level indicating the change in target torque levels between settings of the clutch collar **108**.

[0060] At step **720**, the motor control unit **130** detects the clutch collar **108** position selected by the user of the power tool **100**. As described above with respect to FIGS. **3**A, **3**B, and **4**, the user may rotate the clutch collar **108** to select a particular torque level. At step **730**, the motor control unit **130** determines the torque level for the position of clutch collar **108** selected by the user. The motor control unit **130** determines this torque level based on the mapping received at step **710**. As described above, in some embodiments, the remote device **140** may transmit a profile to the power tool **100** including a user-specified fixed torque level. In these embodiments, the motor control unit determines the torque level to be the fixed torque level received from the remote device **140**, which may occur by the motor control unit **130** ignoring the position of the clutch collar **108**, ignoring the speed setting, or assigning the fixed torque level to each of the positions of the clutch collar **108** such that the fixed torque level is selected regardless of the position of the clutch collar **108**.

[0061] At step **740**, the motor control unit **130** detects a torque of the power tool **100**. The motor control unit **130** detects the torque, for example, based on motor current. For example, the current sensor **135** senses the current flowing to the motor **126** and provides a signal indicative of the current to the motor control unit **130**. The motor control unit **130** may use techniques described above to determine the torque based on the signal received from the current sensor **135**.

[0062] At step **750**, the motor control unit **130** determines whether the toque of the power tool **100** exceeds the torque level determined at step **730**. In some embodiments, this determination may involve a comparison of torque levels (e.g., in inch-pounds or Newton-meters), and, in other embodiments, the determination may involve a comparison of current values indicative of a torque (e.g., in Amperes). When the torque detected in step **740** exceeds the torque level determined at step **730**, the motor control unit **130** generates an indication (at step **760**). The indication includes, for example, flashing the light **116**, ratcheting the motor **126**, and/or stopping the motor **126**. In other words, in response to determining that the detected torque of the power tool exceeds the torque level, the motor control unit **130** may stop the motor **126** to provide the indication, for instance, by ceasing the sending of driving signals to the FETs **124** or by controlling the FETs **124** to actively brake the motor **124**. In some embodiments, the motor control unit **130** may ratchet the motor **126** to provide the indication in step **750**. In some embodiments, the motor control unit **130** may control the light **116** to flash to provide the indication. In yet further embodiments, the motor control unit **130** generates the indication by using a combination of flashing the light **116**, ratcheting the motor **126**, and stopping the motor **126**. For example, the control unit **130** may flash the light **116** and ratchet the motor **126** for a first period of time, and then stop the motor **126**. The method **700** repeats steps **740** and **750** until the torque exceeds the torque level determined in step **730**, until a new position of the clutch collar **108** is selected, or until the trigger **112** is released.

[0063] In some embodiments, the mapping received in step **710** includes a first mapping for a high speed setting and a second mapping for a low speed setting. When the power tool **100** is in the high speed setting, indicated by the speed select switch **111**, the first mapping is used by the e-clutch control module **134** (e.g., in step **730** for determining the torque level). However, when the power tool is in the low speed setting, indicated by the speed select switch **111**, the second mapping is used by the e-clutch control module **134**. Accordingly, the clutch collar **108** may indicate different desired torque levels at same rotational position depending on the position for the speed select switch **111**. In some embodiments, the maximum torque level of the first mapping is less than the maximum torque level of the second mapping.

[0064] In some embodiments, the method includes receiving, from a speed select switch, a speed setting. The method further includes compensating for the speed setting in detecting the torque of the power tool in step **740** or in calculating the torque level in step **730** to provide similar performance regardless of the speed setting. For example, through the compensation, the torque of the power tool upon generating the indication in step **750** for a particular setting of the clutch collar **108** is approximately the same regardless of the speed setting.

[0065] In some embodiments, the method **700** includes a further step of receiving, via the wireless transceiver, a request to enter a fixed torque mode and a fixed torque level. The request and the fixed torque level may be provided by the remote device **140** as part of a control profile generated based on user input on the GUI **250**. In a subsequent operation of the power tool, the e-clutch control module **134** detects, during a subsequent operation of the power tool, that a subsequent torque of the power tool exceeds the fixed torque level. The subsequent torque of the power tool is detected similar to the torque detection of step **740**. The motor control unit **130** then generates a second indication that the subsequent torque exceeds the fixed torque level. The second indication is generated similar to the indication of step **760**, and may include one or more of stopping the motor **126**, ratcheting the motor **126**, and flashing the light **116**.

[0066] In some embodiments, the mapping received in step **710** includes a first torque value generated by the remote device **140** based on user input, for example, received via the GUI **250**. The motor control unit **130** uses the first torque value and calculates, in advance or as needed, torque levels for the plurality of settings. For example, in step **730**, the motor control unit **130** calculates a torque level for the clutch collar setting detected in step **720** based on the position of the clutch collar setting among the plurality of settings and the first torque value. The first torque value may indicate a maximum torque level or a minimum torque level. Taking, for example, the first torque value as indicative of a minimum torque level, the motor control unit **130** may calculate the torque level of the setting by assuming a particular torque increment and incrementing the minimum torque level by the number of settings that the clutch collar setting is above the minimum clutch collar setting. Alternatively, the motor control unit **130** may use a default maximum torque level in combination with the received minimum torque level and calculate the torque level for the clutch collar setting to be a value proportional or corresponding to the position of the clutch setting among the plurality of settings. For example, a clutch collar setting of six out of thirteen possible settings would result in a torque level that is greater than the mid-point between the minimum and maximum torque levels, assuming a linear scale, and a clutch collar setting of five out of thirteen settings would result in a torque level that is below the mid-point. The motor control unit proceeds to control the motor based on the calculated torque level. For example, the motor control unit **130** proceeds to execute steps **740**, **750**, and **760**, in some embodiments, and uses the calculated torque level in the determination of step **750**.

[0067] In some embodiments, in step **710**, a first torque value and a second torque value are received, and calculating the torque level is further based on the second torque value. In some examples, the first torque value is indicative of a minimum torque level and the second torque value is indicative of a maximum torque level. Similar to as described immediately above, the motor control unit **130** uses the first torque value and the second torque value to calculate, in advance or as needed, torque levels for the plurality of settings. In some examples, the first torque value is indicative of a first torque level for a first setting, the second torque value is indicative of a second torque level for a second setting, the method further includes associating remaining settings of the plurality of settings with torque levels between the first torque level and the second torque level.

[0068] Although the flow chart of FIG. **8** is illustrated and described as steps performed in a serial manner, one or more blocks of the method **700** may be executed in parallel or in a different order than described. Further, the processor of the motor control unit **130** may execute instructions to implement the steps and functions of the method **700** attributable to the motor control unit **130**.

[0069] Although the tool **100** is described as a hammer drill, in some embodiments, the tool **100** is a standard, non-hammering drill/driver, or another drill/driving tool, such as an angle driver or an impact driver.

[0070] Thus, the invention provides, among other things, a power tool having a configurable electronic clutch and methods of configuring an electronic clutch. Various features and advantages of the invention are set forth in the following claims.

Claims

1-20. (canceled)

21. A power tool comprising: a housing including a front portion; a motor disposed within the housing; a collar positioned on the front portion of the housing and configured to select among a plurality of rotationally selectable settings, the plurality of rotationally selectable settings including a plurality of torque settings and a plurality of operating mode settings; and a printed circuit board assembly (“PCBA”) disposed within the housing, the PCBA including: a first plurality of resistive elements, each of the first plurality of resistive elements associated with a torque setting of the plurality of torque settings; a second plurality of resistive elements, each of the second plurality of resistive elements associated with an operating mode setting of the plurality of operating mode settings; a plurality of conductive tracks, each conductive track of the plurality of conductive tracks electrically connected to a resistive element of the first plurality of resistive elements or the second plurality of resistive elements; and a signal output configured to output an electrical signal based on contact between the collar and one of the plurality of conductive tracks, wherein the collar is rotatable with respect to the PCBA to select one of the plurality of rotationally selectable settings.

22. The power tool of claim 21, wherein the PCBA includes a wiper connected to the collar, the wiper configured to rotate with the collar to electrically contact one of the plurality of conductive tracks.

23. The power tool of claim 22, wherein: the first plurality of resistive elements are arranged in a semi-circular pattern on the PCBA; and the wiper is configured to electrically connect to one of the first plurality of resistive elements or one of the second plurality of resistive elements.

24. The power tool of claim 21, wherein the collar includes a first rotational ring corresponding to the plurality of torque settings and a second rotational ring corresponding to the plurality of operating mode settings.
25. The power tool of claim 21, wherein the collar is continuously rotatable.
26. The power tool of claim 21, wherein the signal output is configured to output a distinct voltage level corresponding to each of the plurality of rotationally selectable settings.
27. The power tool of claim 21, wherein the second plurality of resistive elements includes fewer resistive elements than the first plurality of resistive elements.
28. The power tool of claim 21, wherein the PCBA is electrically connected to an electronic processor, the electronic processor is configured to: receive the electrical signal from the signal output; set, in response to the collar corresponding to one of the plurality of torque settings, a torque level of the motor, and set, in response to the collar corresponding to one of the plurality of operating mode settings, an operating mode of the power tool.
29. The power tool of claim 21, wherein: the first plurality of resistive elements includes five or more resistive elements; and the second plurality of resistive elements includes three or more resistive elements.
30. The power tool of claim 21, wherein the collar is configured such that further increments are ignored in response to a maximum torque setting being reached, and further decrements are ignored in response to a minimum torque setting being reached.
31. The power tool of claim 21, wherein the plurality of operating mode settings includes a drilling mode, a driving mode, and a hammer mode.
32. The power tool of claim 21, wherein the signal output includes a mode pin configured to output a signal indicative of an operating mode selection and an e-clutch pin configured to output a signal indicative of a torque setting selection.
33. The power tool of claim 21, wherein a mapping of torque levels corresponding to the plurality of torque settings includes torque levels assigned to respective ones of the first plurality of resistive elements based on a maximum torque value and a minimum torque value.
34. The power tool of claim 33, wherein each of plurality of torque settings is proportionally distributed between the minimum torque value and the maximum torque value.
35. A method of controlling a power tool comprising: rotating a collar relative to a printed circuit board assembly (“PCBA”), contacting, with the collar, one of a plurality of conductive tracks on the PCBA, each conductive track electrically connected to a respective one of a plurality of resistive elements; generating an electrical signal at a signal output of the PCBA in response to the collar contacting one of the plurality of conductive tracks; determining, by a processor, whether the collar is set to one of a plurality of operating mode settings based on the electrical signal; determining, by the processor, whether the collar is set to one of a plurality of torque settings based on the electrical signal; determining, by the processor during operation of the power tool, a torque of the power tool, comparing, by the processor and in response to the collar being set to the one of the plurality of torque settings, the torque of the power tool to a threshold torque level corresponding to the one of the plurality of torque settings; determining, by the processor, whether the torque of the power tool is greater than or equal to the threshold torque level; and generating, by the processor in response to the torque of the power tool being greater than or equal to the threshold torque level, an indication that the torque of the power tool has reached the one of the plurality of torque settings.
36. The method of claim 35, further comprising: rotating, with the collar, a wiper mechanically coupled to the collar, the wiper electrically contacting one of the plurality of conductive tracks on the PCBA.
37. The method of claim 35, further comprising: rotating the collar continuously beyond a full revolution.
38. The method of claim 35, wherein: a first plurality of resistive elements includes five or more

resistive elements, each of the five or more resistive elements corresponding to one torque setting of the plurality of torque settings; and a second plurality of resistive elements includes three or more resistive elements, each of the three or more resistive elements corresponding to one of the plurality of operating mode settings.

39. The method of claim 35, further comprising: receiving, by the processor, a mapping of torque levels corresponding to the plurality of torque settings; assigning, by the processor, torque levels to respective ones of the plurality of resistive elements based on a minimum torque value and a maximum torque value; and proportionally distributing, by the processor, the torque levels between the minimum torque value and the maximum torque value.

40. A printed circuit board assembly ("PCBA") for a power tool, the PCBA comprising: a first plurality of resistive elements, each of the first plurality of resistive elements associated with a torque setting of a plurality of torque settings; a second plurality of resistive elements, each of the second plurality of resistive elements associated with an operating mode setting of a plurality of operating mode settings; a plurality of conductive tracks, each conductive track of the plurality of conductive tracks electrically connected to a resistive element of the first plurality of resistive elements or the second plurality of resistive elements; and a signal output configured to output an electrical signal based on contact between a collar and one of the plurality of conductive tracks, wherein the collar is rotatable with respect to the PCBA to select one of the plurality of torque settings or one of the plurality of operating mode settings.