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BRUSHLESS MOTOR FOR POWER TOOLS

Abstract

A power tool is provided including a tool housing, a motor housing, and a brushless DC motor including a stator and a rotor received within the motor housing. The stator includes a stator lamination stack, an end insulator, and stator terminals supported by the end insulator. A power circuit board including power switching elements is mounted adjacent the motor housing, and tab portion of the stator terminals extend through openings of the motor housing and are physically and electrically coupled with the circuit board.

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Background/Summary

CROSS-REFERENCE TO RELATED APPLICATION [0001] This patent application is a continuation of U.S. patent application Ser. No. 18/597,411 filed Mar. 6, 2024, which is a continuation of U.S. patent application Ser. No. 18/314,352 filed May 9, 2023, which is a continuation of U.S. patent application Ser. No. 17/495,494 filed Oct. 6, 2021, now U.S. Pat. No. 11,691,260, which is a continuation of U.S. patent application Ser. No. 16/580,424 filed Sep. 24, 2019, now U.S. Pat. No. 11,241,781, which is a continuation of U.S. patent application Ser. No. 15/292,568 filed Oct. 13, 2016, now U.S. Pat. No. 10,500,708, which claims the benefit of U.S. Provisional Application No. 62/241,385 filed Oct. 14, 2015, which is incorporated herein by reference in its entirety.

FIELD OF THE DISCLOSURE
[0002] This disclosure relates to cordless power tools. More particularly, the present invention relates to a high-power cordless power tool and a brushless motor for high-power cordless power tools.
BACKGROUND
[0003] Cordless power tools provide many advantages to traditional corded power tools. In particular, cordless tools provide unmatched convenience and portability. An operator can use a cordless power tool anywhere and anytime, regardless of the availability of a power supply. In addition, cordless power tools provide increased safety and reliability because there is no cumbersome cord to maneuver around while working on the job, and no risk of accidently cutting a cord in a hazardous work area.
[0004] However, conventional cordless power tools still have their disadvantages. Typically, cordless power tools provide far less power as compared to their corded counterparts. Today, operators desire power tools that provide the same benefits of convenience and portability, while also providing similar performance as corded power tools.

[0005] Brushless DC (BLDC) motors have been used in recent years in various cordless power tools. While BLDC motors provide many advantages over universal and permanent magnet DC motors, challenges exist in incorporating BLDC motors into many power tools depending on power requirements and specific applications of tool. The power components needed for driving the BLDC motors in high power applications have conventionally generated too much heat, making BLDC motors unfeasible for high-power power tools. This is particularly true for tools used in environments where dust and particulate from the workpiece is abundant, making it difficult to create a clean air flow within the tool to cool the motor and associated components. These challenges need be addressed.

[0006] Furthermore, high power applications typically require larger motors. As power tools have become more ergonomically compact, it has become more desireable to reduce the size of the motor while providing the required power output.

SUMMARY

[0007] According to an embodiment of the invention, a power tool is provided including a tool housing including a motor housing and a handle portion; a battery receptacle disposed at an end of the handle portion opposite the motor housing, the battery receptacle being configured to receive a battery pack; a brushless DC (BLDC) motor including an electronically-commutated stator assembly and a rotor assembly magnetically interacting with the rotor assembly to rotate with respect to the stator assembly, the stator assembly comprising a stator lamination stack supporting a plurality of stator windings, an end insulator mounted on an end of the stator lamination stack to insulate the plurality of stator windings from the stator lamination stack, a plurality of retention members projecting from the end insulator and defining a plurality of receiving slots, and a plurality of input terminals received within the plurality of retention members. The power tool further includes a power switching circuit board including a plurality of solid-state power switches disposed on a current path from the battery pack to the motor, the power switch circuit board including a plurality of slots that electrically couples to the plurality of input terminals to supply electric power to the BLDC motor; an electronic controller configured to switch a switching operation of the plurality of solid-state power switches to regulate supply of electric power from the battery pack to the motor; and an output shaft rotatably driven by the motor. The motor, when powered by the battery pack, produces a maximum power output of at least 1600 watts for driving the output shaft, and/or outputs a maximum torque of at least 30 inch-pounds and a maximum speed of at least 8000 rotations-per-minute for driving the output shaft.

[0008] In an embodiment, the power tool further includes a gear case supporting the output shaft. In an embodiment, the output shaft is substantially perpendicular to a motor shaft rotatably coupled to the rotor assembly.

[0009] In an embodiment, the circumference of the motor housing is in the range of approximately 140 mm to approximately 190, and the handle is attached to a rear end of the motor housing and elongated along a longitudinal axis of the motor housing. In an embodiment, the circumference of the motor housing is approximately 1.5 to 2 times greater than a circumference of a gripping area of the handle. In an embodiment, a ratio of a length of the handle to a length of the motor housing in a direction of the longitudinal axis of the motor is approximately 1.6 to 2.

[0010] In an embodiment, the plurality of input terminals includes a plurality of generally planar retention portions received into the plurality of receiving slot of the end insulator, a plurality of wire receiving members projecting radially outwardly from the plurality of generally planar retention portions that receives portions of the plurality of stator windings to electrically connect the plurality of input terminals to the plurality of stator windings, and a plurality of tab portions that projects axially from the plurality of generally planar retention portions and is received into the plurality of slots of the power switch circuit board.

[0011] In an embodiment, the plurality of slots is oriented along a radial direction and the plurality of tab portions extends from the plurality of generally planar retention portions at an offset angle of

approximately 90 degrees and is received into the plurality of slots.
[0012] In an embodiment, the plurality of slots is located peripherally at equidistant angular positions of the power switch circuit board.
[0013] In an embodiment, the battery pack has a maximum voltage of at least 60 V.

Description

BRIEF DESCRIPTION OF THE DRAWINGS
[0014] In the accompanying drawings which form part of the specification:
[0015] FIG. **1** is a front perspective view of a power tool, in accordance with an embodiment;
[0016] FIG. **2** is a side view of the power tool partially showing internal components of the power tool, in accordance with an embodiment;
[0017] FIGS. **3** and **4** depict front and rear perspective exploded view of the power tool, in accordance with an embodiment;
[0018] FIG. **5** is another side view of the power tool, in accordance with an embodiment;
[0019] FIG. **6** is a rear perspective view of the power tool with filters detached, in accordance with an embodiment;
[0020] FIGS. **7**A and **7**B depict a cut-off perspective view of the tool **10** and an enlarged view of an intake conduit **52** of the air intake **36**, with the filter **38** in a detached position, respectively.
[0021] FIGS. **7**C and **7**D depict a cut-off perspective view of the tool **10** and an enlarged view of the intake conduit **52**, with the filter **38** attached, respectively.
[0022] FIG. **8** is a perspective sectional view illustrating air flow through the air intakes, motor case and gear case assemblies, and exhaust vents, in accordance with an embodiment;
[0023] FIG. **9** is a perspective view of the power tool additionally provided with a flange holder, in accordance with an embodiment;
[0024] FIGS. **10**A and **10**B depict views of the flange holder, in accordance with an embodiment;
[0025] FIG. **11**A is a rear perspective view of the motor assembly, in accordance with an embodiment;
[0026] FIG. **11**B is a front perspective view of the motor assembly, in accordance with an embodiment;
[0027] FIG. **12** is a perspective exploded view of a motor assembly, in accordance with an embodiment;
[0028] FIG. **13** is a perspective exploded view a stator assembly, in accordance with an embodiment;
[0029] FIG. **14** is an enlarged sectional view of the stator assembly being wound, in accordance with an embodiment;
[0030] FIG. **15**A is a perspective view of an end insulator according to a first embodiment;
[0031] FIG. **15**B is a profile sectional view of a portion of the insulator according to the first embodiment;
[0032] FIG. **16**A is a perspective view of an end insulator according to a second embodiment;
[0033] FIG. **16**B is a profile sectional view of a portion of the insulator according to the second embodiment;
[0034] FIG. **17**A is a perspective view of an end insulator according to a third embodiment;
[0035] FIG. **17**B is a profile sectional view of a portion of the insulator according to the third embodiment;
[0036] FIG. **18**A is a perspective view of an end insulator according to a fourth embodiment;
[0037] FIG. **18**B is a profile sectional view of a portion of the insulator according to the fourth embodiment;
[0038] FIG. **19**A is a perspective view of an end insulator according to a fifth embodiment;

[0039] FIG. **19**B is a profile sectional view of a portion of the insulator according to the fifth embodiment;
[0040] FIG. **20**A is a perspective view of an end insulator according to a sixth embodiment;
[0041] FIG. **20**B is a profile sectional view of a portion of the insulator according to the sixth embodiment;
[0042] FIG. **21**A is a perspective view of an end insulator according to a seventh embodiment;
[0043] FIG. **21**B is a profile sectional view of a portion of the insulator according to the seventh embodiment;
[0044] FIG. **22**A is a perspective view of an end insulator according to an eighth embodiment;
[0045] FIG. **22**B is a profile sectional view of a portion of the insulator according to the eighth embodiment;
[0046] FIGS. **23**A-**23**D depict various perspective views of end insulators according to various additional or alternative embodiments;
[0047] FIG. **24** is an end view of the stator assembly including insulating inserts, in accordance with an embodiment;
[0048] FIG. **25**A is a perspective view of the stator assembly with insulating inserts removed, in accordance with an embodiment;
[0049] FIG. **25**B is a perspective view of the stator assembly with insulating inserts installed, in accordance with an embodiment;
[0050] FIG. **26**A depicts a partial cross-sectional view of the stator assembly with an insulating insert, in accordance with an embodiment;
[0051] FIG. **26**B depicts a partial perspective view of the stator assembly with insulating inserts, in accordance with an embodiment;
[0052] FIG. **27** depicts a partial perspective view of the stator assembly with insulating inserts in accordance with an alternative embodiment;
[0053] FIG. **28** depicts a partial perspective view of the stator assembly with insulating inserts in accordance with yet another embodiment;
[0054] FIG. **29** depicts an axial view of the stator assembly with insulating inserts in accordance with yet another alternative and/or additional embodiment;
[0055] FIG. **30**A depicts a partial cut-off perspective view of the motor housing including the seal member integrated therein, according to an embodiment;
[0056] FIG. **30**B depicts a perspective view of the inside of the motor housing including the seal member integrated therein, according to an embodiment;
[0057] FIGS. **31**A and **31**B depict perspective views of the seal member alone, according to an embodiment;
[0058] FIG. **32** is a perspective view of the seal member mating with the stator assembly, in accordance with an embodiment;
[0059] FIGS. **33**A and **33**B depict perspective exploded views of a power module adjacent a motor housing, in accordance with an embodiment;
[0060] FIG. **34** depicts a perspective view of the assembled power module adjacent the motor housing, in accordance with an embodiment;
[0061] FIG. **35** depicts a perspective view of an alternative assembled power module adjacent an alternative motor housing, in accordance with an embodiment;
[0062] FIG. **36** is a partially-exploded perspective view of the motor housing and the power module, with insulator pads disposed therebetween, in accordance with an embodiment;
[0063] FIG. **37**A is an enlarged perspective view of the motor assembly showing insulator pads disposed around input terminals, in accordance with an embodiment;
[0064] FIG. **37**B is an enlarged perspective view of the motor assembly showing insulator pads disposed between the motor housing and power module, in accordance with an embodiment;
[0065] FIG. **38** is a perspective view of the motor assembly including input terminals detached, in

accordance with an embodiment; and
[0066] FIG. **39** is an enlarged perspective view of the motor assembly showing input terminals attached to the power module, in accordance with an embodiment; and
[0067] FIG. **40** depicts a partially-exploded perspective view of the motor assembly showing the relative positions of the power module and the rotor assembly, according to an embodiment;
[0068] FIG. **41** depicts a perspective view of the motor assembly showing the rotor assembly outside the motor housing, according to an embodiment; and
[0069] FIG. **42** depicts a perspective view of the motor assembly showing the rotor assembly fully assembled inside the motor housing, according to an embodiment.
[0070] Corresponding reference numerals indicate corresponding parts throughout the several figures of the drawings.
DETAILED DESCRIPTION
[0071] The following description illustrates the claimed invention by way of example and not by way of limitation. The description clearly enables one skilled in the art to make and use the disclosure, describes several embodiments, adaptations, variations, alternatives, and uses of the disclosure, including what is presently believed to be the best mode of carrying out the claimed invention. Additionally, it is to be understood that the disclosure is not limited in its application to the details of construction and the arrangements of components set forth in the following description or illustrated in the drawings. The disclosure is capable of other embodiments and of being practiced or being carried out in various ways. Also, it is to be understood that the phraseology and terminology used herein is for the purpose of description and should not be regarded as limiting.
[0072] As shown in FIGS. **1-4**, according to an embodiment of the invention, a power tool **10** is provided including a housing **12** having a gear case **14**, a motor case **16**, a handle portion **18**, and a battery receiver **20**. FIG. **1** provides a perspective view of the tool **10**. FIG. **2** provides a side view of tool **10** including its internal components. FIGS. **3** and **4** depict two exploded views of tool **10**. Power tool **10** as shown herein is an angle grinder with the gear case **14** housing a gearset (not shown) that drives a spindle **24** arranged to be coupled to a grinding or cutting disc (not shown) via a flange (or threaded nut) **25** and guarded by a disc guard **26**. It should be understood, however, that the teachings of this disclosure may apply to any other power tool including, but not limited to, a saw, drill, sander, and the like.
[0073] In an embodiment, the motor case **16** attaches to a rear end of the gear case **14** and houses a motor **28** operatively connected to the gear set **22**. The handle portion **18** attaches to a rear end **30** of the motor case **16** and includes a trigger assembly **32** operatively connected to a control module **11** disposed within the handle portion **18** for controlling the operation of the motor **28**. The battery receiver **20** extends from a rear end **31** of the handle portion **18** for detachable engagement with a battery pack (not shown) to provide power to the motor **28**. The control module **11** is electronically coupled to a power module **34** disposed substantially adjacent the motor **28**. The control module **11** controls a switching operation of the power module **34** to regulate a supply of power from the battery pack to the motor **28**. The control module **11** uses the input from the trigger assembly **32** to control the switching operation of the power module **34**. In an exemplary embodiment, the battery pack may be a 60 volt max lithium-ion type battery pack, although battery packs with other battery chemistries, shapes, voltage levels, etc. may be used in other embodiments.
[0074] In various embodiments, the battery receiver **20** and battery pack may be a sliding pack disclosed in U.S. Pat. No. 8,573,324, hereby incorporated by reference. However, any suitable battery receiver and battery back configuration, such as a tower pack or a convertible 20V/60V battery pack as disclosed in U.S. patent application Ser. No. 14/715,258 filed May 18, 2015, also incorporated by reference, can be used. The present embodiment is disclosed as a cordless, battery-powered tool. However, in alternate embodiments power tool can be corded, AC-powered tools. For instance, in place of the battery receiver and battery pack, the power tool **10** include an AC

power cord coupled to a transformer block to condition and transform the AC power for use by the components of the power tools. Power tool **10** may for example include a rectifier circuit adapted to generate a positive current waveform from the AC power line. An example of such a tool and circuit may be found in US Patent Publication No. 2015/0111480, filed Oct. 18, 2013, which is incorporated herein by reference in its entirety.

[0075] Referring to FIG. **2**, the trigger assembly **32** is a switch electrically connected to the control module **11** as discussed above. The trigger assembly **32** in this embodiment is an ON/OFF trigger switch pivotally attached to the handle **18**. The trigger **32** is biased away from the handle **18** to an OFF position. The operator presses the trigger **32** towards the handle to an ON position to initiate operation of the power tool **10**. In various alternate embodiments, the trigger assembly **32** can be a variable speed trigger switch allowing the operator to control the speed of the motor **28** at no-load, similar to variable-speed switch assembly disclosed in U.S. Pat. No. 8,573,324, hereby incorporated by reference. However, any suitable input means can be used including, but not limited to a touch sensor, a capacitive sensor, or a speed dial.

[0076] As shown in FIGS. **2**-**5**, by housing the motor **28** and the power module **34** substantially within the motor case **16** and beyond a gripping area of the handle portion **18**, the handle portion **18** can be ergonomically designed without regards to the physical constraints of the motor **28** and the power module **34** to provide the operator with a more comfortable and effective operation and balance of the power tool during operation. For instance, the handle portion **18** can be provided with reduced girth and contoured for easier and more comfortable gripping by the operator to reduce the user's hand fatigue.

[0077] As shown in FIG. **5**, in various embodiments, the handle portion **18** can have a circumference of approximately 110 to 140 mm (more preferably 120 to 130 mm, e.g. approximately 125 mm) measured at line A proximate the rear end **31** of the handle portion **18**, a circumference of approximately 120 to 150 mm (more preferably 130 to 140 mm, e.g. approximately 135 mm) measured at line B at about a mid-point **33** between the end **31** of the handle portion **18** and the trigger assembly **32**, and a circumference of approximately 140 to 190 mm (more preferably 150 to 180 mm, e.g., approximately 165 mm) measured at line C at the position of the trigger assembly **32**. By contrast, the circumference of the motor case **16** that houses the motor **28** may be over approximately 200 mm, e.g., 245 mm, as measured at line D. This arrangement represents a motor case **16** to handle portion **18** girth ratio of approximately 1.5× to 2×, according to an embodiment.

[0078] As mentioned above and discussed later in detail, according to an embodiment, power tool **10** described herein is high-power power tool configured to receive a 60V max battery pack or a 60V/20V convertible battery pack configured in its 60V high-voltage-rated state. The motor **28** is accordingly configured for a high-power application with a stator stack length of approximately 30 mm. Additionally, as later described in detail, the power module **34**, including its associated heat sink, is located within the motor case **16** in the vicinity of the motor **28**. As shown in FIG. **5**, the relative positions and weight of the gear case **14** and the motor case **16** including the motor **28** and power module **34** allows the center of gravity of the tool **10** with the battery pack attached to the battery receiver **20** to be within the tool handle **18** substantially close to the trigger **32**, despite the heavy weight of the 60V battery pack. Specifically, while using a 60V pack with conventional grinders would place the center of gravity of the tool at the foot of the handle portion **18** near the battery receiver **20** due to the heavy weight of the battery pack, according to an embodiment the center of gravity is around in close proximity to the trigger **32**, i.e., at point E substantially in line with the operator's wrist as the operator grabs the handle portion **32**, which reduces hand fatigue and balances the tool **10** within the operator's hand. In an exemplary embodiment, handle portion **18** has a length of about 130-170 mm (e.g., 150 mm), and the motor case **16** with motor **28** has a length of about 70-100 (e.g., 84 mm), which represents a handle portion **18** to motor case **16** length ratio of approximately 1.3× to 2.5×, preferably 1.6× to 2×, more preferably 1.7× to 1.8×, according to an embodiment.

[0079] The embodiments described herein provide a high-power portable cordless power tool **10**, such as a grinder, that operates with a high voltage battery pack, for example, a battery pack having a maximum voltage of approximately 60V or nominal voltage of approximately 54V, and produces maximum power output of over 1600 Watts, a maximum torque of over 30 inch-pounds (ln*Lbs) and maximum speed of over 8000 rotations-per-minute (RPM). No cordless grinder currently in the marketplace provides such performance parameters, particularly from a small grinder having geometric ergonomics described above.

[0080] Another aspect of the invention is discussed herein with reference to FIGS. **6-8** and continued reference to FIGS. **1-5**. As discussed briefly above and later in detail, power module **34** is provided within the motor case **16** near the motor **28**, or at the end of the handle portion **18** near the motor case **16**. As it is well known in the art, power module **34** switching arrangement generates a considerable amount of heat that should be carried away from the motor case in an effective manner.

[0081] According to an embodiment, referring to FIGS. **2** and **6-8**, the motor case **16** defines a pair of generally oblong air intakes **36** around a periphery of the power module **34**. The air intakes **36** are arranged to direct air flow into the motor case **16** in a manner that air is circulated around the power module **34** as well as the motor **28**. In an embodiment, air intakes **36** are sized and shaped to receive a corresponding pair of air filters **38** and extend the majority of the circumference of the motor case **16**. The intakes **36** are positioned radially about the rear end **30** of the motor case **16** adjacent to the handle **18**, and generally corresponding with the position of the power module **34**. Positioning the intakes **36** forward of the handle portion **18** locates them generally away from the normal trajectory of the grinding particulate caused by grinding operation on a work piece, thus lessening the ingestion of grinding particulate and increasing service and reliability of the tool.

[0082] In addition, in an embodiment, each air intake **36** includes a plurality of intake conduits **52** arranged to receive and direct air from outside the tool **10** into the motor case **16**. Intake conduit **52** are defined by (and separated via) axial walls **53** provided axially within the air intake **36**, and an acruate baffle **54** described below. The angular orientation of the baffles **54** within the intake conduits **52** results in a path of air flow outside the air intakes **36** that is considerably different from the path of the particulate stream caused by the grinding operation on the work piece, and thus prevents a direct path by for the particulate stream to enter into the intakes **36**.

[0083] Referring to FIG. **6**, each filter **38** can include two generally oblong bands **42** with a plurality of ribs **44** extending therebetween. The plurality of ribs **44** generally correspond to the axial walls **53** of the air intakes **36**. Each filter **38** further includes filter material **46** extending between the bands **42**. The filter **38** is arcuate along its length to correspond with intakes **36**. In an embodiment, each filter **38** includes a pair of retaining tabs **48** extend inwardly from each end of the filter **38** that securely mate with (e.g., snap-fit into) the edges of intakes **36**. Each filter **38** may further include a pin **50** extending inwardly from a midpoint of the filter **38** that fits into a corresponding hole **51** provided within the intakes **36**. The filters **38** provide further limit entry of contamination, debris, and grinding particulate from entering through the intakes **36**.

[0084] FIGS. **7**A and **7**B depict a cut-off perspective view of the tool **10** and an enlarged view of the intake conduit **52** of the air intake **36**, with the filter **38** in a detached position, respectively. FIGS. **7**C and **7**D depict a cut-off perspective view of the tool **10** and an enlarged view of the intake conduit **52**, with the filter **38** attached, respectively.

[0085] As shown in these figures, acruate baffle **54** of the air intake **36** extends from a rear edge **59** of the air intake **36** at an angle with respect to an axis of the tool **10**, inwardly towards the motor **28**. Formed between a distal end **57** of the acruate baffle **54** and a front edge **56** of the air intake **36** are inlets **55** radially arranged and separated via axial walls **53**. During operation, the arcuate shape and the angular orientation of the baffle **54** effectively directs incoming air in the direction of the motor **28**, thus created an air flow path outside the tool **10** that is considerably different from the path of the particulate stream caused by the grinding operation.

[0086] In an embodiment, airflow through the air intake **36** is generated via motor fan **37**, which is rotatably attached to the motor **28**. In conventional designs, where power components are disposed within the handle portion **18**, it is important for the air flow generated by the motor fan to circulate through the handle portion **18** as well as the motor case **16** in order to cool the power components and the motor. In the above-described embodiment, by contrast air intakes **36** are positioned near a rear end **30** of the motor case **16** and in much closer proximity to the fan **37** and exhaust vents **58**. The reduced distance between the intakes **36**, fan **37**, and exhaust vents **58** provide better air flow efficiency around the power module **34** and the motor **28**, which generate the most heat, bypassing the control unit **11** and other components within the handle portion **18** that do not generate a considerable amount of heat. In the present exemplary embodiment, while there is still some air leakage through the battery receiver **20** and the handle portion **18**, the airflow through the handle portion **18** is reduced to about 0-2 Cubic Feet per Minute (CFM), which is less than 10% of the total air flow that enters the motor case **16**, while over 90% of the total airflow (e.g., 15-17 CFM) is entered through the air intakes **36**.

[0087] FIG. **8** depicts a partial perspective view of tool **10**, including a cut-off view of the motor **28**, and air flow paths entering the motor case **16** through the air vents **36**. As shown in this figure, the incoming air entering through the air intakes **36** circulates the power module **34**, particularly around the heat sink, before entering the motor **28**. The air then circulates around the motor shaft, the rotor and the stator (as will be described later in detail) before exiting through the exhaust vents **58**. Some of the outgoing air also exits through the gear case and around the spindle (not shown).

[0088] Another aspect of the disclosure is described herein with reference to FIGS. **9**, **10**A and **10**B.

[0089] In conventional power tools, such as grinders, that use rotary accessories, it is common practice to fixedly attach the accessory to the spindle via a backing plate and a threaded nut (referred to as a flange set) provided with the power tool. Alternatively the accessory itself integrally includes a threaded insert that eliminates the need for a flange set. In use, tool operators may variously switch between different grinding and cutting accessories, some of which may require a flange set and some may include integral threads. In practice, the separation of the tool from the flange set may lead to the flange set being lost or misplaced.

[0090] According to an embodiment, to overcome this problem, a flange attachment mechanism is provided on power tool **10** to provide the operator the ability to attach the flange set **25** to the tool **10** at an auxiliary location when the flange set **25** is not needed, i.e., when an accessory with integral threaded insert is being used on the tool **10**, without inhibiting the operator's ability to use the power tool **10**. As shown in FIG. **9**, in an embodiment, a flange holder **400** is provided at the foot of the power tool **10**, e.g., on a side of the battery receiver **20**. The flange holder **400** may alternatively be provided at the end of the handle portion **18**, under the motor case **16**, or any other suitable location where it does not interfere with the operator's handling of the tool **10**. Alternatively, if tool **10** is a corded tool, the flange holder **400** may be provided on the cord.

[0091] FIGS. **10**A and **10**B depict front and back perspective views of the flange holder **400**. As shown herein, flange holder **400** includes a threaded portion **402** extending from a base portion **404**. A back side of the base portion **404** includes pin-shape inserts **406** and a flexible projection **408** arranged to be received or snapped into corresponding openings or retaining features on the tool **10** battery receiver **20**. When tool operator is not using the flange set **25**, he or she may tighten the flange set **25** onto the flange holder **400**.

[0092] Various aspects of the disclosure relating to the motor **28** are discussed herein.

[0093] FIGS. **11**A and **11**B depict two perspective views of motor **28**, according to an embodiment. FIG. **12** depicts an exploded view of the motor **28**, according to an embodiment. As shown in these figures, the motor **28** is a three-phase brushless DC (BLDC) motor having a can or motor housing **29** sized to receive a stator assembly **70** and a rotor assembly **72**. Various aspects and features of the motor **28** are described herein in detail. It is noted that while motor **28** is illustratively shown in FIGS. **1-9** as a part of an angle grinder, motor **28** may be alternatively used in any power tool or any other device or apparatus.

[0094] In an embodiment, rotor assembly **72** includes a rotor shaft **74**, a rotor lamination stack **76** mounted on and rotatably attached to the rotor shaft **74**, a rear bearing **78** arranged to axially secure the rotor shaft **74** to the motor housing **29**, a sense magnet ring **324** attached to a distal end of the rotor shaft **74**, and fan **37** also mounted on and rotatably attached to the rotor shaft **74**. In various implementations, the rotor lamination stack **76** can include a series of flat laminations attached together via, for example, an interlock mechanical, an adhesive, an overmold, etc., that house or hold two or more permanent magnets (PMs) therein. The permanent magnets may be surface mounted on the outer surface of the lamination stack **76** or housed therein. The permanent magnets may be, for example, a set of four PMs that magnetically engage with the stator assembly **70** during operation. Adjacent PMs have opposite polarities such that the four PMs have, for example, an N—S—N—S polar arrangement. The rotor shaft **74** is securely fixed inside the rotor lamination stack **76**. Rear bearing **78** provide longitudinal support for the rotor **74** in a bearing pocket (described later) of the motor housing **29**.

[0095] In an embodiment, fan **37** of the rotor assembly **72** includes a back plate **60** having a first side **62** facing the motor case **16** and a second side **64** facing the gear case **14**. A plurality of blades **66** extend axially outwardly from first side **62** of the back plate **60**. Blades **64** rotate with the rotor shaft **44** to generate an air flow as previously discussed. When motor **28** is fully assembled, fan **37** is located at or outside an open end of the motor housing **28** with a baffle **330** arranged between the stator assembly **70** and the fan **37**. The baffle **330** guides the flow of air from the blades **64** towards the exhaust vents **58**.

[0096] In an embodiment, power module **34** is secured to another end of the motor housing **29**, as will be described later in detail.

[0097] Referring now to the exploded view of FIG. **13** and with continued reference to FIG. **12**, in an embodiment, stator assembly **70** includes a generally cylindrical lamination stack **80** having center bore **88** configured to receive the rotor assembly **72**. Lamination stack **80** further includes a plurality of stator teeth **82** extending inwardly from a stator ring **83** towards the center bore **88**. The stator teeth **82** define a plurality of slots **84** therebetween configured. A plurality of coil windings **86** are wound around the stator teeth **82** into the slots **84**. The stator teeth **82** are generally rectangular-shaped with two tips **85** extending from an end portion **87** thereof. Each slot **84** is generally trapezoidal shaped with a gap **91** extending between opposing tips **85** of end portions **87** of each pair of teeth **82**. An insulating shield **90** is received within each stator slot **84** and generally surrounds each winding **86** to electrically insulate the winding **86** from the lamination stack **80**. In various instances, the insulating shield **90** can be made from flexible insulating material such as paper material.

[0098] In various embodiments, stator assembly **70** further includes a first end insulator **92** and second end insulator **94** attached to respective ends of the lamination stack **80** using any suitable method, such as, snap fit, friction fit, adhesive, or welding to provide electrical insulation between the windings **86** and the lamination stack **80**. Each end insulator **92** and **94** generally corresponds to the shape of end laminations on the lamination stack **80** so that it generally covers the end of the lamination stack **80**. In an embodiment, each insulator includes a generally cylindrical outer ring **96** corresponding to the stator ring **83**, with a plurality of tooth portions **98** extending inwardly from the outer ring **96** towards the center of the end insulator **92** and **94**. Each tooth portion **98** is generally shaped to cover a corresponding tooth **82** of the stator **70** with side walls **100** extending axially inwardly into stator lamination slots **84** for proper alignment and retention of the end insulators **92** and **94** at the ends of the lamination stack **80**, as well as providing further electrical insulation within the slots **84**. A tab **102** extends outwardly away from the lamination stack **80** from an end **101** of each tooth portion **98** corresponding to end portion **87** of respective stator teeth **82**.

The first end insulator **92** includes a plurality of retention members **108** that defines receiving slots **106** for receiving the input terminals **104**, as described later in detail.
[0099] Referring now to FIG. **14**, a partial radial view of the stator lamination stack **80** during a winding of stator windings **86** is depicted, according to an embodiment. Generally, during the winding process of the stator windings **86**, two routers T of a winding machine (not shown) moved longitudinally back and forth within the slots **84** to wind the stator windings **86** around stator teeth **82**. Generally, as the windings **86** are wound, they stack on top of each other around a center portion of the corresponding tooth **82** within the slots **84**, leaving gaps between the windings **86** and the stator ring **83**. This limits the amount of coil that can be wound within each slot **84**, which adversely impacts motor power output.
[0100] Referring now to FIGS. **15**A to **23**D, with continued reference to FIG. **13**, in order to maximize the amount of coil wound in stator slots **84**, according to an embodiment of the invention, the tooth portions **98** of the end insulators **92**, **94** are contoured to include a sloped profile configured to bias the windings **86** away from a center bore **88** of the stator lamination stack **80** and towards the outer circumference of the stator lamination stack **80** (i.e., stator ring **83**) while the windings **86** are being wound around the stator teeth **82**. Specifically, as the winding wire is wound around the teeth portions **98** of the end insulators **92**, **92** at longitudinal ends of the stator teeth **82**, the sloped profile of the teeth portions **98** slidingly bias the winding wire in the direction of the slope and towards the outer ring **96**. Various profiles of the teeth portions **98** are discussed herein, according to various embodiments.
[0101] In a first embodiment shown in FIG. **15**A and the partial side view of FIG. **15**B, each tooth portion **98** includes a sloped portion **112** extending at an angle from the tab **102** downwardly towards the outer ring **96**, and generally flat portion **110** extending around the sloped portion **98** from the tab **102** to the outer ring **96**. In an embodiment, the sloped portion **112** may occupy approximately a third of the total width of the tooth portion **98**. In an embodiment, the sloped portion **112** may extend at an angle of, e.g., 2 to 10 degrees.
[0102] In the second embodiment shown in FIG. **16**A and the partial side view of FIG. **16**B, each tooth portion **98** includes a sloped portion **122** extending at an angle from the tab **102** downwardly towards the outer ring **96**. The sloped portion **122** may occupy approximately the entire total width of the tooth portion **98**. An end portion **124** of the sloped portion **112** near the outer ring **96** may slightly recessed by, e.g., 0.2 to 2 mm, from a plane of the outer ring **96**. Furthermore, in an embodiment, a flat portion **126** may additionally be arranged between the tab **102** and the sloped portion **122**. A radial length of the flat portion **126** may be less than the radial length of the sloped portion **122**, for example, 10% to 40%, preferably 15% to 25%, of the radial length of the sloped portion **122**. The sloped portion **112** may extend from the flat portion **126** at an angle of, e.g., 5 to 15 degrees. In an embodiment, sloped portion **112** may be laterally flat or may include a laterally arcuate surface.
[0103] In the third embodiment shown in FIG. **17**A and the partial side view of FIG. **17**B, each tooth portion **98** includes a sloped portion **132**, a recessed end portion **134**, and a flat portion **136**, similarly to the second embodiment described above, but a radial length of the flat portion **136** is approximately close to or greater than the radial length of the sloped portion **132**. For example, the radial length of the flat portion **136** may be over 40%, preferably 50% to 60%, the radial length of the sloped portion **132**. The sloped portion **112** may extend at an angle of, e.g., 5 to 20 degrees.
[0104] The fourth embodiment shown in FIG. **18**A and the partial side view of FIG. **18**B is a combination of the first and the second embodiments. Specifically, in this embodiment, each tooth portion **98** includes a first sloped portion **142**, a recessed end portion **144**, and a flat portion **146**, similarly to the second embodiment described above. In addition, each tooth portion **98** includes a second sloped portion **148** similar to sloped portion **112** of the first embodiment. The second sloped portion **148** extends from the tab **102** over a middle portion of the flat portion **146** and the first sloped portion **142**, at an angle that is greater than the angle of extension of the first sloped portion

142. In an embodiment, the second sloped surface **148** may have an angle of 1 to 10 degrees with respect to the first sloped surface **142**.
[0105] The fifth embodiment shown in FIG. **19**A and the partial side view of FIG. **19**B is similar to the fourth embodiment above, but the second sloped surface **158** has a greater extension angle. In an embodiment, the second sloped surface **158** may have an angle of 10 to 20 degrees with respect to the first sloped surface **152**.
[0106] The sixth embodiment shown in FIG. **20**A and the partial side view of FIG. **20**B is a combination of the first and the third embodiments. Specifically, in this embodiment, each tooth portion **98** includes a sloped portion **162**, a recessed end portion **164**, and an extended flat portion **166**, similarly to the third embodiment described above. In addition, each tooth portion **98** includes a second sloped portion **168** similar to sloped portion **112** of the first embodiment. The second sloped portion **168** extends from the tab **102** over a middle portion of the flat portion **166** and the first sloped portion **162**, at an angle that is greater than the angle of extension of the first sloped portion **142**. In an embodiment, the second sloped surface **148** may have an angle of 10 to 20 degrees with respect to the first sloped surface **142**.
[0107] The seventh embodiment shown in FIG. **21**A and the partial side view of FIG. **21**B is similar to the sixth embodiment above, but the second sloped surface **178** has a smaller extension angle. In an embodiment, the second sloped surface **178** may have an angle of 0 to 10 degrees with respect to the first sloped surface **152**. The eighth embodiment of shown in FIG. **22**A and the partial side view of FIG. **22**B, is similar to the first embodiment described above, except that sloped portion **182** extends angularly from the outer ring **96** to a flat portion **184** disposed between the sloped portion **182** and the tab **102**. In an embodiment, the sloped portion **182** may have an angle of 20 to 30 degrees with respect to a plane of the outer ring **96**.
[0108] FIGS. **23**A-**23**D depict several other alternative embodiments of the end insulator **92** having various combinations of sloped surfaces discussed above.
[0109] Another aspect of the invention is described herein with reference to FIGS. **24** to **29**.
[0110] Referring to FIG. **24**, in the present embodiment, an axial view of the stator assembly **70** including lamination stack **80**, radial ends **101** of stator teeth **82**, and stator windings **86** wound around stator teeth **82**, according to an embodiment.
[0111] Each winding **86** is distributed around the lamination stack **80** to form an even number of poles. For instance, in a three-phase stator, each winding **86** includes a pair of windings arranged at opposite ends of the lamination stack **80** to face each other. The windings **86** may be connected in a variety of configurations, such as, a series delta configuration, a parallel delta configuration, a series wye configuration, or a parallel wye configuration. Although the present embodiment depicts a respective set of three windings, three retention members, and three input terminals, any suitable number can be used.
[0112] In high power applications, e.g., power tools powered by 120V battery packs or 120V AC power, there are regulatory requirements imposed by safety organizations, i.e., Underwriters Laboratories (“UL”), on insulating distance required between one conductive surface to another. In the stator assembly **70**, the stator windings **86** are insulated from the stator lamination stack **80** via insulating shield **90** previously discussed, but UL standards require 2 mm of insulation clearance between the windings **86** and the exposed area of the stator lamination stack **80**, i.e., at the tips **85** of stator teeth **82**.
[0113] In order to provide sufficient insulation between the tips **85** of stator teeth **82** and the stator windings **86**, according to an embodiment of the invention as shown in perspective views of FIGS. **25**A and **25**B, and zoomed-in views of FIGS. **26**A and **26**B, a plurality of generally rectangular insulating inserts **260** (also referred to as slot wedges) are inserted at respective gaps **91** between the teeth **82**. FIG. **26**A depicts a cross-sectional view of the stator assembly **70** without the end insulators **92**, **94**, whereas FIG. **26**B depicts a perspective view of the stator assembly **70** including the end insulator **92**. The insulating inserts **260** laterally push and bias the windings **86** generally

outwardly away from the tips **85** of the stator teeth **82**.

[0114] While slot wedges are conventionally used in universal motor armatures, insulating inserts **260** are inserted directly above the gaps **91** within each slot **84** of the stator **70** such that each end of the insulating insert **260** is fitted between a tip **85** of the stator tooth **82** and the stator windings **86**. The insulating inserts **260** bias and displace the windings both radially and circumferentially such that, when inserted, the insulating inserts **260** provide a predetermined clearance between the windings **86** and the tips **85** of the teeth **82**, as required for compliance with UL standards.

[0115] In addition, in an embodiment, the insulating inserts **260** may be inserted under the insulating shield **90**, i.e., between the ends of the shield **90** and the teeth tips **85**, to displace the insulating shield **90** laterally as well. In various embodiments, the predetermined clearance is at least equal to the minimum clearance specified under UL standards for high voltage tools (e.g., 2 mm). As arrow **261** of FIG. **26**A, this clearance is measured from the tip **85** of the tooth **82**, around the insulating insert **260** and the tip of the insulating shield **90**, to the windings **86**. It is noted that the distance is not measured as a straight line between the tooth **82** and the windings **86**.

[0116] In an embodiment, in addition to providing electrical insulation between the stator lamination stack **80** and the stator windings **86**, the insulating inserts **260** effectively form a mechanical seal between the stator assembly **70** and the rotor assembly **72** to prevent airflow therebetween. During operation, the insulating inserts **260** substantially prevent air, including particles and contamination, from flowing through the gaps **91** between the end portions **87** of stator teeth **82** (see FIG. **13**), effectively isolating the paths of air flow through the rotor assembly **72** and the stator assembly **70**. This arrangement reduces the chances of air particulate and contamination from bouncing off the rotor assembly **72** at high speed and hitting the stator windings **86**, which would cause substantial damage to the stator windings **86**. In an embodiment, insulating inserts **260** may be made of paper or plastic material.

[0117] In an embodiment, as shown in FIGS. **26**B and **26**C, for end insulator **92**, **94** (only end insulator **92** shown herein), tips **103** of end portions **101** of the end insulator tooth **98** include guides **105** that engage the sides of the insulating inserts **260** and facilitate the insertion of the insulation inserts **260** between the tips **85** of the stator teeth **82** and the insulating shield **90**. The guides **105** make it easier for the insulating inserts **260** to be inserted during the assembly process.

[0118] FIG. **27** shows an alternative embodiment of the invention, where insulating inserts **264** are provided as beaker shaped wedges that can be inserted, such as with a form-fit and/or friction-fit, into respective stator slots **84**. The inserts **264**, includes a wedge portion **263** that, similarly to the above-described embodiment, bias the windings **86** laterally and outwardly to provide a predetermined clearance between the windings **86** and the stator teeth **82**. The inserts **264** in this embodiment additionally include a radially extending portion **265** that extend from the wedge portion **263** toward the stator ring **83** of the stator lamination stack **80** and engage an inner surface of the stator ring **83** within the slot **84**. In this manner, the radially extending portion **265** securely holds the wedge portion **263** in place.

[0119] FIG. **28** depicts yet another embodiment, where insulating inserts **364** are provided with a substantially U-shaped or rectangular-shaped middle portion **366** arranged to be received between respective tips **85** of adjacent stator teeth **82**. The middle portion **366** may be inserted form-fittingly and/or friction-fittingly inside the gap **91** extending between opposing tips **85** of end portions **87** of each pair of teeth **82** in a way to securely retain the wedge portions **368** in place between the stator windings **86** and the tips **85** of stator teeth **82**, as described above.

[0120] FIG. **29** depicts yet another embodiment, where insulating inserts **374** have a rectangular-shaped or U-shaped middle portion **376** and wedge portions **378**, as described above, but additionally includes a projection **379** opposite the middle portion **376** to further straighten insulation inserts **374**.

[0121] Another aspect of the invention is described herein with reference to FIGS. **30**A to **32**.

[0122] As described to above, insulating inserts **260**, **263**, **364**, **374** mechanically seal the gaps **91** between the stator teeth **82**, thus substantially preventing flow of air between the stator windings **86** and the rotor assembly **72** over the length of the stator lamination stack **80**. However, at ends of the stator assembly **70**, particularly at the one of end of the stator housing **70** close to the air intakes **36** where the air first enters the motor **28**, due to the arcuate shape of the ends of the stator windings **86** and the tabs **102** of the end insulator **92**, air can still leak from the stator assembly **70** to the rotor assembly **72** and vice versa. In order to overcome this deficiency, according to an embodiment of the invention, a cylindrical seal member **268** is provided at the end of the stator assembly **70**, described herein.

[0123] FIG. **30**A depicts a partial cut-off perspective view of the motor housing **29** including the seal member **268** integrated therein, according to an embodiment. FIG. **30**B depicts a perspective view of the inside of the motor housing **29** including the seal member **268** integrated therein, according to an embodiment. FIGS. **31**A and **31**B depict perspective views of the seal member **268** alone, according to an embodiment. In these figures, the rear end **267** of the motor housing **29** defines a generally cylindrical rear bearing pocket **266** disposed to receive rear bearing **78** of the rotor assembly **72**, previously described. The motor housing **29** further includes, round a periphery of the bearing pocket **266** and in an axial direction of the motor housing **29** towards the motor **28**, a cylindrical sealing member **268**. In an embodiment, the sealing member **268** includes a crown-shaped cylindrical portion **270** terminating with an annular mating surface **272** defining generally arcuate or semi-circular indents **274** that correspond to the shape of windings **86** and separated by crown teeth **276**. In an embodiment, the inner surface **278** of crown teeth **276** tapers outwardly, thereby reducing the thickness of crown teeth **276** as they approach the end mating surface **272**, effectively forming a wedge or chamfer that enhance the mechanical seal between the windings **86**. Those skilled in the art will recognize that other configurations of the crown teeth **276** can be used, including, but not limited to, rectangular, curved, triangular, and the like. Also, other configurations of the indents **274** can also be used, including to, but not limited to, square, rectangular, curvilinear, and the like. Furthermore, those skilled in the art will recognize that while sealing member **268** is shown as an integral part of the motor housing **29**, sealing member **268** may be provided, integrally or as a separate piece, within any part of the tool, e.g., the tool housing.

[0124] As shown in FIG. **32**, when the motor **28** is assembled into the motor housing **29**, the arcuate or generally semi-circular indents **274** mate with the ends of the stator windings **86**, tabs **102** of the end insulator **92**, or the area in between the stator windings **86** and the tabs **102**. Meanwhile the crown teeth **276** fit into gaps between adjacent stator windings **86**, adjacent tabs **102** of the end insulator **92**, or somewhere in between. In an embodiment, crown teeth **276** rest against or over ends of insulating inserts **260**. In this manner, the sealing member **268** forms a mechanical seal that substantially blocks flow of air between the stator assembly **70** and the rotor assembly **72**, thus reduces entry of debris and contamination from entering the rotor assembly **72**.

[0125] Another aspect of the invention is described herein with reference to FIGS. **33**A-**35**.

[0126] FIGS. **33**A and **33**B depict exploded views of the power module **34** adjacent the motor **28**, according to an embodiment. As shown herein, in an embodiment, power module **34** includes a power board **280**, a thermal interface **282**, and a heat sink **284** which attach to the rear end of the motor housing **29** via fasteners **291**. Power module **34** may be further provided with a clamp ring **290** that acts to clamp and cover the power board **280** and act as a secondary heat sink. Power module **34** may be disc-shaped to match the cylindrical profile of the motor **28**. Additionally, power module **34** may define a center through-hole **292** that extends through the power board **280** to accommodate the rotor shaft **44** in some embodiments. In an embodiment, through-holes **285**, **287**, and **289** similarly extend through the clamp ring **290**, thermal interface **282**, and heat sink **284**, as further described later.

[0127] In an embodiment, power board **280** is a generally disc-shaped printed circuit board (PCB) with six power transistors **294** that power the stator windings **86** of the motor **28**, such as MOSFETs and/or IGTBs, on a first surface **295** thereof. Power board **280** may additionally include other circuitry such as the gate drivers, bootstrap circuit, and all other components needed to drive the MOSFETs and/or IGTBs. In addition, power board **280** includes a series of positional sensors (e.g., Hall sensors) **322** on a second surface **297** thereof, as explained later in detail.

[0128] In an embodiment, power board **280** is electrically coupled to a power source (e.g., a battery pack) via power lines **299** for supplying electric power to the transistors **294**. Power board **280** is also electrically coupled to a controller (e.g., inside control unit **11** in FIG. **2**) via control terminal **293** to receive control signals for controlling the switching operation of the transistors **294**, as well as provide positional signals from the positional sensors **322** to the controller. The transistors **294** may be configured, for example, as a three-phase bridge driver circuit including three high-side and three low-side transistors connected to drive the three phases of the motor **28**, with the gates of the transistors **294** being driven by the control signals from the control terminal **293**. Examples of such a circuit may be found in US Patent Publication No. 2013/0342144, which is incorporated herein by reference in its entirety. In an embodiment, power board **280** includes slots **298** for receiving and electrically connecting to the input terminals **104**. In an embodiment, slots **298** may be defined and spread around an outer periphery of the power board **280**. The outputs of the transistors bridge driver circuit is coupled to the motor **28** phases via these input terminals **104**.

[0129] As those skilled in the art will appreciate, power transistors **294** generate a substantial amount of heat that need to be transferred away from the power module **34** in an effective manner. In an embodiment, heat sink **284** is provided on the second surface **297** of the power board **270** for that purpose. In an embodiment, heat sink **284** is generally disc-shaped, square-shaped, or rectangular shaped, with a generally-planer body having a substantially flat first surface **340** facing the power board **282** and extending parallel thereto. The second surface **341** of the heat sink **284** may also be flat, as depicted herein, though this surface may be provided with fins to increase the overall surface area of the heat sink **284**. The size and width of the heat sink **284** may vary depending on the power requirements of the tool and thus the type and size of transistors **294** being used. It is noted, however, that for most 60V power tool applications, the width of the heat sink **284** is approximately 1-3 mm.

[0130] In an embodiment, thermal interface **282** may be a thin layer made of Sil-Pad® or similar thermally-conductive electrically-insulating material. Thermal interface **282** may be disposed between the heat sink **284** and the power board **280**.

[0131] In an embodiment, heat sink **284** and thermal interface **282** include slots **342** and **343** on their outer periphery to allow a passage for input terminals **104** to be received within slots **298** of the power board **280**. Slots **342** are generally larger than slots **298** to avoid electrical contact between the heat sink **284** and the terminals **104**.

[0132] In an embodiment, positional sensors **322** are disposed at a distant on the second surface **297** of the power board **280**, around a periphery of the through-hole **292**. Where a through-hold **292** does not exist, the positional sensors **322** are still provided at a distant near a middle portion of the second surface **297** of the power board **280** to detect a magnetic position of the rotor assembly **72**, as will be discussed later in detail. In order to allow the positional sensors **322** to have exposure to the motor **28**, irrespective of whether power board **280** includes a through-hole **292**, heat sink **284** and thermal interface **282** are provided with through-holes **287** and **289** large enough to accommodate the positional sensors **322**. In an embodiment, the through-holes may be circular (e.g., through-hole **287**) semi-circular (e.g., through-hole **289**), or any other shape needed to allow the positional sensors **322** to be axially accessible from the motor **22**. In an embodiment, through-hole **287** on the heat sink **284** has a radius that is approximately 1.5 to 3 times the radius of through-hole **292** on the power board **280**.

[0133] FIGS. **34** and **35** depict two alternative exemplary embodiments of the mounting mechanism and associated components of the power module **34** and motor housing **29**.

[0134] In FIG. **34**, where the heat sink **284** is disc-shaped of substantially the same size as the power board **280**, a series of fastener receptacles **359** are provided on rear end of the motor housing

29 approximately half-way between the shaft **44** and the outer periphery of the motor housing **29**. A series of corresponding through-holes **361** are provided on the power module **34**, allowing fasteners **290** to securely fasten the power module **34** to the fastener receptacle **359** of the motor housing **29**. In an embodiment, individual components of the power module **34** may be held together via fasteners **355** prior to assembly of the power module **34** onto the motor housing **29**. Alternatively, the components of the power module **34** may be assembled onto motor housing **29** and held together via fasteners **291** in a single step.

[0135] In FIG. **35**, where the heat sink **284** is rectangular-shaped with a larger surface area than the power board **280**, fastener receptacles **358** are provided near the outer periphery of the motor housing **29**. A series of corresponding through-holes **360** are provided on the four corners of the heat sink **284**. In this embodiment, the components of the power module **34** are held together via fasteners **355** prior to the assembly of the power module **34** onto the motor housing **29**. Then, fasteners **291** are received through the through-holes **260** to securely fasten the power module **34** onto the fastener receptacle **358** of the motor housing **29**.

[0136] In an embodiment, as shown in both FIGS. **34** and **35**, the rear end of the motor housing **29** is provided with alignment posts **350** projecting form its outer periphery towards the power module **34** for proper alignment of the power module **34**. The power module is similarly provided with corresponding slots, or through-holes **352** to receive the posts **350** therein during the assembly process. Also, the rear end of the motor housing **29** is provided with a series of openings **309** through which the input terminals **101** of the stator assembly project outside the rear end of the motor housing **29**.

[0137] According to a further embodiment, as shown in FIGS. **36**, **37**A and **37**B, insulator pads **300** are disposed in between the motor housing **29** and the power module **34** around the input terminals **104**. The pads **300** provide insulation between the input terminals **104** and the heat sink **284** to reduce the risk of electrical short between the two due to contamination of the components. In an embodiment, each pad **300** includes a slot **302** arranged to receive the terminal **101** therethrough. Each pad **300** sits on a substantially planar platform **301** provided on the rear portion of the motor housing **29** with the terminal penetrating therein. In order to prevent the pads **300** to add to the total length of the tool, in an embodiment, the heat sink **284** is provided with cutout regions **302** corresponding to the shape of the pads **300**, typically provided on the outer periphery of the heat sink **284**. The insulator pads **300** are shaped to be contained within the cutout regions **302**, thereby providing electrical insulation between the input terminals **104** and the heat sink **284** in both the axial and radial directions. Each pad **300** is configured to fit into the cutout regions **303** of the heat sink **284**.

[0138] Referring now to FIG. **38**, a perspective view of the stator assembly **70** (not including the stator windings) is depicted with the input terminals **104** disassembled. FIG. **39** depicts a zoomed-in view of the stator assembly **70** showing the interface between the terminals **104** and the power module **34**. According to an embodiment, each input terminal **104** has a generally planar retention portion **306** including two legs **305** configured for coupling with the receiving slot **106** of the retention member **108**, such as with a snap-fit. The retention portion **306** includes a generally J-shaped wire-receiving member **308**. During the assembly process, after an input terminal **104** is inserted into a corresponding receiving slot **106**, an end of a corresponding stator winding (not shown herein) is routed around the end insulator **92** towards the input terminal **104** and wrapped around the wire-receiving member **308** to electrically connect the input terminal **104** with the corresponding winding **86**. A generally rectangular tab portion **310** extends from the retention portion **306** at about a 90° offset for connection to the power module **34**. When the stator assembly **70** is assembled into the motor housing **29**, the tab portions **310** extend through openings **309** (see FIGS. **34** and **35**) of the motor housing **29**. When the power module **34** is assembled at the rear end of the motor housing **29**, the tab portions **310** are tightly received inside slots **298** in the power board **280**, as described above, to operatively connect to the power module **34** for communication of power from the power module **34** to the windings **86**. The power module includes metal routings (not shown) that connect the respective terminal **104** to the appropriate transistors **294**. In this way, the input terminals **104** provide direct power connectivity between the stator assembly **70** and the power module **34** without use of any additional wires, which tend to be difficult to rout and install during the assembly process. In addition, the terminals **101** provide improved alignment for easier and quicker assembly by insuring that the power module **34** is properly orientated with the motor housing **29**.

[0139] Another aspect of the invention is described herein in reference to FIGS. **40-42**.

[0140] As previously discussed, and shown in FIG. **40**, power module **34** is designed to allow positional sensors **322** disposed on the second surface **297** of the power board **280** to be exposed to the motor **28**. Specifically, heat sink **284** and thermal interface **282** include through-holes **287** and **289** shaped and sized to allow the positional sensors **322** to be axially exposed towards the motor **28**.

[0141] Conventionally BLDC motors are provided with sense magnets positioned adjacent the rotor and mounted on the rotor shaft. The sense magnets may include, for example, four magnets disposed on a ring with adjacent magnets having opposite polarities, such that rotation of the magnet ring along with the motor rotor allows positional sensors to sense the change in magnetic polarity their vicinity. The problem with the conventional BLDC motor designs, however, is that positional sensors have to be arranged within the motor in close proximity to the sense magnet ring.

[0142] According to an embodiment, as shown in FIGS. **41** and **42**, in order to provide positional sensors **322** with means to detect the rotational position of the rotor shaft **44**, sense magnet **324** (configured as a sense magnet ring including two or four magnets) is disposed near the end of the rotor shaft **44** such that, when the rotor assembly **72** is assembled into the motor housing **28**, the sense magnet **324** sits within (or projects out of) a corresponding through-hole **320** in the rear end of the motor housing **28**. This arrangement allows the sense magnet **324** to be disposed substantially close to the positional sensors **322**. In an embodiment, the sense magnet **324** may be at least partially received within the through-hole **287** of the heat sink **284**. In an embodiment, the motor housing **28** is provided with a ring-shaped labyrinth **326** around the through-hole **320** to substantially block debris and contamination from entering into the rotor assembly **72** from the area around the sense magnet **324**.

[0143] In an embodiment, in order to facilitate the assembly of the rotor assembly **72** into the motor housing **28** as described above, the rear bearing **78** is disposed between the rotor lamination stack **76** and the sense magnet **324**. The bearing pocket **266** is formed inside the motor housing **28** around the through-hole **320**. As the rear bearing **78** is received and secured inside the bearing pocket **266**, the sense magnet **324** is received inside the through-hole **320**, projecting at least partially out of the rear end of the motor housing **28**.

[0144] Some of the techniques described herein may be implemented by one or more computer programs executed by one or more processors residing, for example on a power tool. The computer programs include processor-executable instructions that are stored on a non-transitory tangible computer readable medium. The computer programs may also include stored data. Non-limiting examples of the non-transitory tangible computer readable medium are nonvolatile memory, magnetic storage, and optical storage.

[0145] Some portions of the above description present the techniques described herein in terms of algorithms and symbolic representations of operations on information. These algorithmic descriptions and representations are the means used by those skilled in the data processing arts to most effectively convey the substance of their work to others skilled in the art. These operations, while described functionally or logically, are understood to be implemented by computer programs. Furthermore, it has also proven convenient at times to refer to these arrangements of operations as modules or by functional names, without loss of generality.

[0146] Certain aspects of the described techniques include process steps and instructions described herein in the form of an algorithm. It should be noted that the described process steps and instructions could be embodied in software, firmware or hardware, and when embodied in software, could be downloaded to reside on and be operated from different platforms used by real time network operating systems.

[0147] The foregoing description of the embodiments has been provided for purposes of illustration and description. It is not intended to be exhaustive or to limit the disclosure. Individual elements or features of a particular embodiment are generally not limited to that particular embodiment, but, where applicable, are interchangeable and can be used in a selected embodiment, even if not specifically shown or described. The same may also be varied in many ways. Such variations are not to be regarded as a departure from the disclosure, and all such modifications are intended to be included within the scope of the disclosure.

[0148] Example embodiments are provided so that this disclosure will be thorough, and will fully convey the scope to those who are skilled in the art. Numerous specific details are set forth such as examples of specific components, devices, and methods, to provide a thorough understanding of embodiments of the present disclosure. It will be apparent to those skilled in the art that specific details need not be employed, that example embodiments may be embodied in many different forms and that neither should be construed to limit the scope of the disclosure. In some example embodiments, well-known processes, well-known device structures, and well-known technologies are not described in detail.

[0149] The terminology used herein is for the purpose of describing particular example embodiments only and is not intended to be limiting. As used herein, the singular forms “a,” “an,” and “the” may be intended to include the plural forms as well, unless the context clearly indicates otherwise. The terms “comprises,” “comprising,” “including,” and “having,” are inclusive and therefore specify the presence of stated features, integers, steps, operations, elements, and/or components, but do not preclude the presence or addition of one or more other features, integers, steps, operations, elements, components, and/or groups thereof. The method steps, processes, and operations described herein are not to be construed as necessarily requiring their performance in the particular order discussed or illustrated, unless specifically identified as an order of performance. It is also to be understood that additional or alternative steps may be employed.

Claims

1. A power tool comprising: a tool housing; a battery receptacle configured to receive a power tool battery pack; a motor housing disposed within the tool housing, the motor housing including a substantially cylindrical body extending around a longitudinal axis between a first end of the motor housing and a second end of the motor housing, wherein a bearing support member supporting a motor bearing is formed proximate the first end; an electric motor disposed within the motor housing, the electric motor comprising: a rotor including a rotor core mounted on a rotor shaft, wherein the rotor shaft is supported along the longitudinal axis by the motor bearing; and a stator including a stator lamination stack supporting a plurality of stator windings disposed within the motor housing in contact with the substantially cylindrical body, an end insulator mounted on an end of the stator lamination stack to insulate the plurality of stator windings from the stator lamination stack, and a plurality of stator terminals mounted to the end insulator and electrically coupled with the plurality of stator windings, wherein each of the plurality of stator terminals includes a body portion having an outer surface facing away from the longitudinal axis, a wire receiving portion extending proximate the outer surface and electrically coupled with a magnet wire that forms at least one of the plurality of stator windings, and a tab portion extending from the body portion away from the stator; and a circuit board disposed on a current path from the battery pack to the electric motor, wherein the circuit board is oriented along a plane that is substantially perpendicular to the longitudinal axis and is fastened to the first end of the motor housing via at

least one fastener, wherein the tab portion of the each of the plurality of stator terminals is physically and electrically coupled with the circuit board.
2. The power tool of claim 1, further comprising a plurality of power switches mounted on the circuit board, an electronic controller disposed within the tool housing and configured to switch a switching operation of the plurality of power switches to regulate supply of electric power from the battery pack to the motor.
3. The power tool of claim 1, further comprising an output member rotatably driven by the rotor shaft, wherein the electric motor, when powered by the battery pack, produces a maximum power output of at least 1600 watts for driving the output member.
4. The power tool of claim 3, further comprising a gear case supporting the output member.
5. The power tool of claim 4, wherein the output member comprises an output spindle that is substantially perpendicular to the rotor shaft.
6. The power tool of claim 1, wherein the circumference of the tool housing around the motor housing in the range of approximately 140 mm to approximately 190.
7. The power tool of claim 1, wherein the end insulator comprises a plurality of retention members projecting substantially axially away from the stator and defining a plurality of receiving slots, wherein the plurality of receiving slots securely receives the plurality of stator terminals.
8. The power tool of claim 7, wherein each of the plurality of stator terminals includes a pair of legs extending from the body portion, wherein the wire receiving portion extends between the pair of legs and is folded over the outer surface of the body portion.
9. The power tool of claim 1, wherein a radial plane that passes through the bearing support member intersects the plurality of stator terminals.
10. The power tool of claim 1, wherein the bearing support member includes a bearing pocket projecting in the direction of the stator and supporting the motor bearing, and a plurality of arms extending radially from the bearing pocket proximate the first end of the motor housing and forming a plurality of openings therebetween, wherein the plurality of stator terminals extends out of the motor housing through the plurality of openings and around at least a portion of the bearing pocket.
11. The power tool of claim 10, wherein the motor housing includes a through-hole proximate the bearing pocket, wherein the rotor shaft extends through the bearing pocket and the through-hole, and wherein a sense magnet ring is mounted on the rotor shaft facing the circuit board.
12. The power tool of claim 11, wherein the circuit board includes a first surface facing away from the first end of the motor housing and a second surface facing the first end of the motor housing, further comprising a plurality of power switches mounted on the first surface of the circuit board and electrically coupled to the plurality of stator terminals, and at least one positional sensor mounted on the second surface of the circuit board in magnetic interaction with the sense magnet ring.
13. The power tool of claim **14**, further comprising a heat sink mounted on the second surface of the circuit board proximate the first end of the motor housing, wherein the heat sink does not cover at least a portion of the second surface of the circuit board on which the at least one positional sensor is mounted.
14. The power tool of claim 1, further comprising a heat sink mounted on the circuit board and covering a substantial portion of the second surface of the circuit board.
16. The power tool of claim **15**, wherein the circuit board comprises a plurality of slots that receive the tab portion of the plurality of stator terminals, wherein the heat sink does not cover at least portions of the second surface of the circuit board around the plurality of slots.
17. The power tool of claim 1, wherein the stator is received through the second end of the motor housing.
18. A power tool comprising: a tool housing; a battery receptacle configured to receive a power tool battery pack; a motor housing disposed within the tool housing, the motor housing including a

substantially cylindrical body extending around a longitudinal axis and a bearing support structure supporting a motor bearing formed at a rear end of the substantially cylindrical body; an electric motor disposed within the motor housing, the electric motor comprising: a rotor including a rotor core mounted on a rotor shaft, wherein the rotor shaft is supported along the longitudinal axis by the motor bearing, and a stator including a stator lamination stack supporting a plurality of stator windings disposed within the motor housing in contact with the substantially cylindrical body, an end insulator mounted on an end of the stator lamination stack to insulate the plurality of stator windings from the stator lamination stack, and a plurality of stator terminals mounted to the end insulator and electrically coupled with the plurality of stator windings; a circuit board including a plurality of power switches disposed a first surface thereof and electrically located a current path from the battery pack to the electric motor, wherein the circuit board is oriented along a plane that is substantially perpendicular to the longitudinal axis and is fastened to the rear end of the motor housing via at least one fastener, wherein the circuit board comprises a plurality of slots, wherein the plurality of stator terminals passes through a plurality of openings formed in the rear end of the motor housing, and an end of the plurality of stator terminals is received into the plurality of slots to be electrically coupled with the circuit board; and a heat sink mounted on a second surface of the circuit board opposite the first surface and proximate the first end of the motor housing, wherein the heat sink covers a substantial portion of the second surface of the circuit board, but it does not cover at least portions of the circuit board around the plurality of slots.

19. The power tool of claim 18, wherein the motor housing includes a through-hole proximate the bearing pocket, wherein the rotor shaft extends through the bearing pocket and the through-hole, and wherein a sense magnet ring is mounted on the rotor shaft facing the circuit board.

20. The power tool of claim 19, further comprising at least one positional sensor mounted on the second surface of the circuit board in magnetic interaction with the sense magnet ring.