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Inventor(s)	Sprague; Connor P. et al.

BATTERY-POWERED STAND-ALONE MOTOR UNIT

Abstract

A motor unit includes a housing, an electric motor arranged in the housing, a battery pack, a first plurality of holes defining a first hole pattern, a first power take-off shaft, a gearbox with a first gear train, and an external gearbox with a second gear train configured to receive torque from the first power take-off shaft. The external gearbox includes a second plurality of holes defining a second hole pattern, a second power take-off shaft receiving torque from the second gear train, and a third plurality of holes defining a third hole pattern that is identical to a fourth hole pattern on the piece of power equipment. When the external gearbox is coupled to the side of the housing and the piece of power equipment, the second power take-off shaft receives torque from the motor via the first gear train, first power take-off shaft, and second gear train.

Inventors: **Sprague; Connor P. (Milwaukee, WI), Glanzer; Evan M. (Milwaukee, WI), Koller; John E. (Waukesha, WI)**

Applicant: **MILWAUKEE ELECTRIC TOOL CORPORATION** (Brookfield, WI)

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Background/Summary

CROSS-REFERENCE TO RELATED APPLICATIONS [0001] This application is a continuation of co-pending U.S. patent application Ser. No. 18/133,017 filed on Apr. 11, 2023, which is a continuation of U.S. patent application Ser. No. 17/092,917 filed on Nov. 9, 2020, now U.S. Pat. No. 11,658,546, which claims priority to U.S. Provisional Patent Application No. 62/952,566 filed on Dec. 23, 2019 and to U.S. Provisional Patent Application No. 62/932,703 filed on Nov. 8, 2019, the entire contents of all of which are incorporated herein by reference.

FIELD OF THE INVENTION

[0002] The present invention relates to motor units, and more particularly to motor units for use with power equipment.

BACKGROUND OF THE INVENTION

[0003] Small, single or multi-cylinder gasoline engines can be mounted to power equipment to drive the equipment with a power take-off shaft.

SUMMARY OF THE INVENTION

[0004] In some aspects, the techniques described herein relate to a stand-alone motor unit for use with a piece of power equipment, the motor unit including: a housing; an electric motor arranged in the housing; a battery pack to provide power to the electric motor; a first plurality of holes in a side of the housing, the first plurality of holes defining a first hole pattern; a first power take-off shaft extending from the side of the housing; a gearbox including a first gear train configured to transfer torque from the motor to the first power take-off shaft; and an external gearbox including a second gear train configured to receive torque from the first power take-off shaft, a second plurality of holes defining a second hole pattern that is identical to the first hole pattern, such that the external gearbox is configured to be coupled to the side of the housing when the first hole pattern is aligned with the second hole pattern, a second power take-off shaft receiving torque from the second gear train, and a third plurality of holes defining a third hole pattern that is identical to a fourth hole pattern on the piece of power equipment, such that the piece of power equipment is configured to be coupled to the external gearbox when the third hole pattern is aligned with the fourth hole pattern, wherein when the external gearbox is coupled to the side of the housing and the piece of power equipment, the second power take-off shaft is configured to receive torque from the motor via the first gear train, first power take-off shaft, and second gear train.

[0005] In some aspects, the techniques described herein relate to a stand-alone motor unit for use with a piece of power equipment, the motor unit including: a housing; an electric motor arranged in the housing; a battery pack to provide power to the electric motor; a first plurality of holes in a side of the housing, the first plurality of holes defining a first hole pattern; a first power take-off shaft extending from the side of the housing; and an external gearbox including a gear train configured to

receive torque from the first power take-off shaft, a second plurality of holes defining a second hole pattern that is identical to the first hole pattern, such that the external gearbox is configured to be coupled to the side of the housing when the first hole pattern is aligned with the second hole pattern, a second power take-off shaft receiving torque from the gear train, and a third plurality of holes defining a third hole pattern that is identical to a fourth hole pattern on the piece of power equipment, such that the piece of power equipment is configured to be coupled to the external gearbox when the third hole pattern is aligned with the fourth hole pattern, wherein when the external gearbox is coupled to the side of the housing and the piece of power equipment, the second power take-off shaft is configured to receive torque from the motor via the first power take-off shaft and the gear train.
[0006] In some aspects, the techniques described herein relate to a stand-alone motor unit for use with a piece of power equipment, the motor unit including: a housing; an electric motor arranged in the housing; a battery pack to provide power to the electric motor; a first plurality of holes in a side of the housing, the first plurality of holes defining a first hole pattern; a gearbox including a first gear train configured to transfer torque from the motor; and an external gearbox including a second gear train configured to receive torque from the first gear train, a second plurality of holes defining a second hole pattern that is identical to the first hole pattern, such that the external gearbox is configured to be coupled to the side of the housing when the first hole pattern is aligned with the second hole pattern, a power take-off shaft receiving torque from the second gear train, and a third plurality of holes defining a third hole pattern that is identical to a fourth hole pattern on the piece of power equipment, such that the piece of power equipment is configured to be coupled to the external gearbox when the third hole pattern is aligned with the fourth hole pattern, wherein when the external gearbox is coupled to the side of the housing and the piece of power equipment, the power take-off shaft is configured to receive torque from the motor via the first gear train and the second gear train.
[0007] Other features and aspects of the invention will become apparent by consideration of the following detailed description and accompanying drawings.

Description

BRIEF DESCRIPTION OF THE DRAWINGS
[0008] FIG. **1** is a perspective view of a stand-alone motor unit in accordance with an embodiment of the invention.
[0009] FIG. **2** is a plan view of the stand-alone motor unit of FIG. **1**.
[0010] FIG. **3** is a schematic view of the stand-alone motor unit of FIG. **1**.
[0011] FIG. **4** is a perspective view of a battery pack of the stand-alone motor unit of FIG. **1**.
[0012] FIG. **5** is a cross-sectional view of the battery pack of FIG. **4**.
[0013] FIG. **6** is a cross-sectional view of a battery receptacle of the stand-alone motor unit of FIG. **1**.
[0014] FIG. **7** is a cross-sectional view of a motor of the stand-alone motor unit of FIG. **1**.
[0015] FIG. **8** is a schematic view of a motor of the stand-alone motor unit of FIG. **1**.
[0016] FIG. **9** is a schematic view of a motor, a gear train, and a power take-off shaft of the stand-alone motor unit of FIG. **1**.
[0017] FIG. **10** is a schematic view of a motor, a gear train, and a power take-off shaft of the stand-alone motor unit of FIG. **1** in a first configuration.
[0018] FIG. **11** is a schematic view of a motor, a gear train, and a power take-off shaft of the stand-alone motor unit of FIG. **1** in a second configuration.
[0019] FIG. **12** is a schematic view of a motor, a gear train, and a power take-off shaft of the stand-alone motor unit of FIG. **1** in a third configuration.

[0020] FIG. **13** is a plan view of a stand-alone motor unit in accordance with another embodiment of the invention.
[0021] FIG. **14** is a plan view of the stand-alone motor unit of FIG. **13**.
[0022] FIG. **15** is a schematic view of a first side of the stand-alone motor unit of FIG. **1**.
[0023] FIG. **16** is a schematic view of a second side of the stand-alone motor unit of FIG. **1**.
[0024] FIG. **17** is an enlarged plan view of a first slot of the stand-alone motor unit of FIG. **1**.
[0025] FIG. **18** is an enlarged plan view of a second slot of the stand-alone motor unit of FIG. **1**.
[0026] FIG. **19** is a schematic view of a motor, a gear train, and a power take-off shaft of the stand-alone motor unit of FIG. **1** in a fourth configuration.
[0027] FIG. **20** is a block diagram of the stand-alone motor unit of FIG. **1**.
[0028] FIG. **21** is a block diagram of a user equipment communicating with the motor unit of FIG. **1**.
[0029] FIG. **22** is a flowchart of a method for no-load operation of the motor unit of FIG. **1**.
[0030] FIG. **23** is a graphical illustration of power savings offered by the motor unit of FIG. **1** implementing the method of FIG. **22**.
[0031] FIG. **24** is a flowchart of a method for providing simulated bog-down operation of the motor unit of FIG. **1** that is similar to actual bog-down experienced by gas engines.
[0032] FIG. **25** is a schematic diagram of the motor unit of FIG. **1** that shows how an electronic processor of the motor unit implements the methods of FIG. **24**.
[0033] FIG. **26** is a schematic diagram of the motor unit of FIG. **1** that shows how an electronic processor of the motor unit implements the method of FIG. **24** with user customization.
[0034] FIG. **27** is a flowchart of a method for checking compatibility of the motor unit of FIG. **1** for a user-selected application.
[0035] FIG. **28** is a perspective view of a pump system including a stand-alone motor unit of FIG. **42**.
[0036] FIG. **29** is a perspective view of a jetter including the stand-alone motor unit of FIG. **42**.
[0037] FIG. **30** is a perspective view of a compactor including the stand-alone motor unit of FIG. **42**.
[0038] FIG. **31** is a schematic view of a vibration mechanism of the compactor of FIG. **30**.
[0039] FIG. **32** is a perspective view of a rammer including the stand-alone motor unit of FIG. **42**.
[0040] FIG. **33** is a schematic view of coupling arrangement for a gear train of the motor unit of FIG. **42** and a female shaft subassembly.
[0041] FIG. **34** is a schematic view of coupling arrangement for a gear train of the motor unit of FIG. **42** and a male shaft subassembly.
[0042] FIG. **35** is a perspective view of a half-circle shaft with female bore coupling arrangement for the coupling mechanism of FIG. **33** or **34**.
[0043] FIG. **36** is a perspective view of a tongue and groove coupling arrangement for the coupling mechanism of FIG. **33** or **34**.
[0044] FIG. **37** is a perspective view of a double D coupling arrangement for the coupling mechanism of FIG. **33** or **34**.
[0045] FIG. **38** is a perspective view of a serrated coupling arrangement for the coupling mechanism of FIG. **33** or **34**.
[0046] FIG. **39** is a perspective view of a peg coupling arrangement for the coupling mechanism of FIG. **33** or **34**.
[0047] FIG. **40** is a perspective view of a female collar with radial fasteners coupling arrangement for the coupling mechanism of FIG. **33** or **34**.
[0048] FIG. **41** is a cross-sectional view of a coupling arrangement for a gear train of the motor unit of FIG. **1** and a male shaft subassembly.
[0049] FIG. **42** is a perspective view of a motor unit according to another embodiment of the invention.

[0050] FIG. **42***a* is another perspective view of the motor unit of FIG. **42**
[0051] FIG. **43** is a cross-sectional view of a coupling arrangement for a gear train of the motor unit of FIG. **1** and a shaft subassembly.
[0052] FIG. **44** is a cross-sectional view of a coupling arrangement for a gear train of the motor unit of FIG. **1** and a shaft subassembly.
[0053] FIG. **45** is a schematic view of a mounting arrangement for a motor and a gearbox of the motor unit of FIG. **42**.
[0054] FIG. **46** is a schematic view of a gearbox and geartrain of the motor unit of FIG. **42**.
[0055] FIG. **47** is a perspective view of an arrangement of a motor and a geartrain of the motor unit of FIG. **42**.
[0056] FIG. **48** is a perspective view of a motor unit according to another embodiment of the invention.
[0057] FIG. **49** is a schematic view of a coupling arrangement between a power take-off shaft of the motor unit of FIG. **42** and a tool input shaft.
[0058] FIG. **50** is a schematic view of a gearbox of the motor unit of FIG. **42**.
[0059] FIG. **51** is a perspective view of the battery of FIG. **4** in a cover.
[0060] FIG. **52** is a perspective view of a battery for the motor unit of FIG. **42**.
[0061] FIG. **53** is a plan view of a remote control for use with the motor unit of FIG. **42**.
[0062] FIG. **54** is a perspective view of a stand-alone motor unit according to another embodiment of the invention, with a battery module in a first position.
[0063] FIG. **55** is a perspective view of the stand-alone motor unit of FIG. **54**, with a battery module removed from a base.
[0064] FIG. **56** is a perspective view of the stand-alone motor unit of FIG. **54**, with a battery module in a second position, for a horizontal mounting application.
[0065] FIG. **57** is a perspective view of the stand-alone motor unit of FIG. **54**, with a battery module in a second position, for a vertical mounting application.
[0066] FIG. **58** is a plan view of the stand-alone motor unit of FIG. **54**, with a battery module removed from a base.
[0067] FIG. **59** is a perspective view of another embodiment of a motor of the stand-alone motor unit of FIG. **1**.
[0068] FIG. **60** is a plan view of the motor of FIG. **59**.
[0069] FIG. **61** is a cross-sectional view of the motor of FIG. **59**.
[0070] FIG. **62** is a plan view of the motor of FIG. **59** coupled to a first gearbox.
[0071] FIG. **63** is a plan view of the motor of FIG. **59** coupled to a second gearbox.
[0072] FIG. **64** is a plan view of the motor of FIG. **59** coupled to a third gearbox.
[0073] FIG. **65** is a plan view of the motor of FIG. **59** coupled to a piece of power equipment.
[0074] FIG. **66** is a plan view of the motor of FIG. **59** coupled to a piece of power equipment.
[0075] FIG. **67** is a cross-sectional view of the stand-alone motor unit of FIG. **42**.
[0076] FIG. **68** is a cross-sectional view of a stand-alone motor unit of FIG. **54**.
[0077] FIG. **69** is a perspective view of the stand-alone motor unit of FIG. **42** with an adapter plate configured to be coupled thereto.
[0078] FIG. **70** is a perspective view of the adapter plate of FIG. **69**.
[0079] FIG. **71** is a perspective view of the stand-alone motor unit of FIG. **42** with an another embodiment of an adapter plate coupled thereto.
[0080] FIG. **71***a* is a perspective view of the stand-alone motor unit of FIG. **42** with a a pair of power-take off shafts configured to be coupled removably thereto.
[0081] FIG. **72** is a cross-sectional view of a power take-off shaft coupled to a drive gear of the stand-alone motor unit of FIG. **42**.
[0082] FIG. **73** is a cross-sectional view of a power take-off shaft coupled to another embodiment of a drive gear of the stand-alone motor unit of FIG. **42**.

[0083] FIG. **74** is a cross-sectional view of a power take-off shaft coupled to another embodiment of a drive gear of the stand-alone motor unit of FIG. **42**.
[0084] FIG. **75** is a cross-sectional view of a power take-off shaft coupled to another embodiment of a drive gear of the stand-alone motor unit of FIG. **42**.
[0085] FIG. **76** is a cross-sectional view of a power take-off shaft coupled to another embodiment of a drive gear of the stand-alone motor unit of FIG. **42**.
[0086] FIG. **77** is a perspective view of an adapter plate configured to be coupled to the stand-alone motor unit of FIG. **42**.
[0087] FIG. **78** is a perspective view a stand-alone motor unit according to another embodiment of the invention, with an external gearbox configured to be coupled thereto.
[0088] FIG. **79** is a schematic view of a stand-alone motor unit according to another embodiment of the invention, with a legacy gearbox configured to be coupled thereto.
[0089] FIG. **80** is a perspective view of the stand-alone motor unit of FIG. **79**, with the legacy gearbox configured to be coupled thereto.
[0090] FIG. **81** is a schematic view of a stand-alone motor unit according to another embodiment of the invention, with an gearbox configured to be coupled thereto.
[0091] FIG. **82** is a perspective view of the stand-alone motor unit of FIG. **81**, with the external gearbox configured to be coupled thereto.
[0092] FIG. **83** is a schematic view of a motor, a multi stage spur gear train, and a power take-off shaft of the stand-alone motor unit of FIG. **1**.
[0093] FIG. **84** is a schematic view of motor, a gear train, and a power take-off shaft of the stand-alone motor unit of FIG. **1**.
[0094] 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. 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.

DETAILED DESCRIPTION

[0095] As shown in FIGS. **1**, **2**, **14** and **15**, a stand-alone motor unit **10** for use with a piece of power equipment includes a housing **14** with a first side **18**, a second side **22** adjacent the first side **18**, a third side **26** opposite the second side **22**, a fourth side **28** opposite the first side **18**, a fifth side **30** extending between the second and third sides **22**, **26**, and a sixth side **32** opposite the fifth side **30**. The motor unit **10** also includes a flange **34** coupled to the housing **14** on the first side **18**, an electric motor **36** located within the housing **14**, and a power take-off shaft **38** that protrudes from the second side **22** and receives torque from the motor **36**. As explained in further detail below, in some embodiments, the power take-off shaft **38** protrudes from the first side **18** and from the flange **34**. As shown in FIGS. **3** and **16**, the motor unit **10** also includes control electronics **42** positioned within the housing **14** and including wiring and a controller **46** that is electrically connected to the motor **36**. In some embodiments, the control electronics **42** has a volume of up to about 820 mm.sup.3. In some embodiments, the control electronics **42** has a weight of up to about 830 g. FIGS. **42** and **42***a* illustrate another embodiment of the motor unit **10**, described in greater detail below.
[0096] As shown in FIGS. **1-6**, the motor unit **10** also includes a battery pack **50** that is removably received in a battery receptacle **54** in the housing **14** to transfer current from the battery pack **50** to the motor **36** via the control electronics **42**. With reference to FIGS. **4-6**, the battery pack **50** includes a battery pack housing **58** with a support portion **62** and a first terminal **66** that is electrically connected to a plurality of battery cells **68** supported by the pack housing **58**. The support portion **62** provides a slide-on arrangement with a projection/recess portion **70** cooperating with a complementary projection/recess portion **74** (shown in FIG. **6**) of the battery receptacle **54**.

In the embodiment illustrated in FIGS. **4-6**, the projection/recess portion **70** of the battery pack **50** is a guide rail and the projection/recess portion **74** of the battery receptacle **54** is a guide recess. A similar battery pack is described and illustrated in U.S. patent application Ser. No. 16/025,491 filed Jul. 2, 2018, the entire content of which is incorporated herein by reference. In some embodiments, the battery cells **68** have a nominal voltage of up to about 80 V. In some embodiments, the battery cells **68** have a nominal voltage of up to about 120 V. In some embodiments, the battery pack **50** has a weight of up to about 6 lb. In some embodiments, each of the battery cells **68** has a diameter of up to 21 mm and a length of up to about 71 mm. In some embodiments, the battery pack **50** includes up to twenty battery cells **68**. In some embodiments, the battery cells **68** are connected in series. In some embodiments, the battery cells **68** are operable to output a sustained operating discharge current of between about 40 A and about 60 A. In some embodiments, each of the battery cells **68** has a capacity of between about 3.0 Ah and about 5.0 Ah.

[0097] FIG. **6** illustrates the battery receptacle **54** of the motor unit **10** in accordance with some embodiments. The battery receptacle **54** includes the projection/recess **74**, a second terminal **78**, a latching mechanism **82**, and a power disconnect switch **86**. The projection/recess **74** cooperates with the projection/recess **70** of the battery pack **50** to attach the battery pack **50** to the battery receptacle **54** of the motor unit **10**. When the battery pack **50** is attached to the motor unit **10**, the second terminal **78** and the first terminal **66** are electrically connected to each other. The latching mechanism **82** protrudes from a surface of the battery receptacle **54** and is configured to engage the battery pack **50** to maintain engagement between the battery pack **50** and the battery receptacle **54**. Thus, the battery pack **50** is connectable to and supportable by the battery receptacle **54** such that the battery pack **50** is supportable by the housing **14** of the stand-alone motor unit **10**. In some embodiments, the battery pack receptacle **54** is arranged on the housing **14** in a position to create a maximum possible distance of separation between the motor **36** and the battery pack **50**, in order to inhibit vibration transferred from the motor **36** to the battery pack **50**. In some embodiments, elastomeric members are positioned on the battery pack receptacle **54** in order to inhibit vibration transferred from the motor **36**, via the housing **14**, to the battery pack **50**.

[0098] In other embodiments (not shown), the latching mechanism **82** may be disposed at various locations (e.g., on a sidewall, an end wall, an upper end wall etc., of the battery receptacle **54**) such that the latching mechanism **82** engages corresponding structure on the battery pack **50** to maintain engagement between the battery pack **50** and the battery receptacle **54**. The latching mechanism **82** includes a pivotable actuator or handle **90** operatively engaging a latch member **94**. The latch member **94** is slidably disposed in a bore **98** of the receptacle **54** and is biased toward a latching position by a biasing member **102** (e.g., a spring) to protrude through a surface of the battery receptacle **54** and into a cavity in the battery pack **50**.

[0099] The latching mechanism also **82** includes the power disconnect switch **86** (e.g., a micro-switch) facilitating electrical connecting/disconnecting the battery pack **50** from the battery receptacle **54** during actuation of the handle **90** to withdraw the latch member **94** from the battery pack **50**. The power disconnect switch **86** may act to electrically disconnect the battery pack **50** from the motor unit **10** prior to removal of the battery pack **50** from the battery receptacle **54**. The power disconnect switch **86** is actuated when the latch member **94** is moved from the latched position (i.e., when the latch member **94** is completely within the cavity of the battery pack **50**) to an intermediate position. The power disconnect switch **86** is electrically connected to the controller **46** and may generate an interrupt to indicate that the battery pack **50** is being disconnected from the motor unit **10**. When the controller **46** receives the interrupt, the controller **46** begins a power down operation to safely power down the control electronics **42** of the motor unit **10**. A similar latching mechanism and disconnect switch is described and illustrated in U.S. patent application Ser. No. 16/025,491, which has been incorporated herein by reference.

[0100] As shown in FIG. **7**, the motor **36** includes a motor housing **96** having an outer diameter **97**, a stator **98** having a nominal outer diameter **102** of up to about 80 mm, a rotor **102** having an output shaft **106** and supported for rotation within the stator **98**, and a fan **108**. A similar motor is described and illustrated in U.S. patent application Ser. No. 16/025,491, which has been incorporated herein by reference. In some embodiments, the motor **36** is a brushless direct current motor. In some embodiments, the motor **36** has a power output of at least about 2760 W. In some embodiments, the power output of the motor **36** may drop below 2760 W during operation. In some embodiments, the fan **108** has a diameter **109** that is larger than the diameter **97** of the motor housing **96**. In some embodiments, the motor **36** can be stopped with an electronic clutch (not shown) for quick overload control. In some embodiments, the motor **36** has a volume of up to about 443,619 mm.sup.3. In some embodiments, the motor has a weight of up to about 4.6 lb. The housing **14** includes an inlet vent and an outlet vent, such that the motor fan **108** pulls air through the inlet vent and along the control electronics **42** to cool the control electronics **42**, before the air is exhausted through the outlet vent. In the embodiment illustrated in FIG. **7**, the motor is a 36 is an internal rotor motor, but in other embodiments, the motor **36** can be an outer rotor motor with a nominal outer diameter (i.e. the nominal outer diameter of the rotor) of up to about 80 mm.

[0101] With reference to FIGS. **8-12**, the motor **36** can transfer torque to the power take-off shaft **38** in a variety of configurations. In the embodiment shown in FIG. **8**, the output shaft **106** is also the power take-off shaft **38**, such that the motor **36** directly drives the power take-off shaft **38** without any intermediate gear train. For example, the motor **36** may be a direct drive high pole count motor. As shown in FIG. **9**, in other embodiments, the motor unit **10** includes a gear train **110** that transfers torque from the motor **36** to the power take-off shaft **38**. In some embodiments, the gear train **110** can include a mechanical clutch (not shown) to discontinue the transfer of torque from the motor **36** to the power take-off shaft **38**. In the embodiment shown in FIG. **10**, the gear train **110** includes a planetary transmission **114** that transfers torque from the output shaft **106** to the power take-off shaft **38**, and a rotational axis **118** of the output shaft **106** is coaxial with a rotational axis **122** of the power take-off shaft **38**. In the embodiment shown in FIG. **11**, the gear train **110** includes a spur gear **126** engaged with a motor pinion **128** on the output shaft **106** of the rotor, such that the rotational axis **118** of the output shaft **106** is offset from and parallel to the rotational axis **122** of the power take-off shaft **38**, allowing for a more compact design envelope for the housing **14**. The single stage spur gear train **110** of FIG. **11** reduces the speed and increases the torque of the power take-off shaft **38** relative to the motor pinion **128**. The single stage spur gear train **110** arrangement also reduces parts and costs. In some embodiments of the single stage spur gear train **110**, the motor pinion **128** and the spur gear **126** are straight cut, external, or internal tooth gears.

[0102] In the embodiment shown in FIG. **12**, the gear train **110** includes a bevel gear **130**, such that the rotational axis **118** of the output shaft **106** is perpendicular to the rotational axis **122** of the power take-off shaft **38**. Thus, in the embodiment of FIG. **12**, the rotational axis **118** of the output shaft **106** intersects the second side **22** of the housing **14** and the power take-off shaft **38** protrudes from the flange **34**. In other embodiments utilizing a bevel gear, the rotational axis **118** of the output shaft **106** is not perpendicular, parallel, or coaxial to the rotational axis **122** of the power take-off shaft **38**, and the power-take off shaft **38** protrudes from the flange **34**.

[0103] In the embodiment illustrated in FIG. **19**, the gear train **110** includes a first gear **111** and a second gear **112** making up a first gear set **113** with a first reduction stage **115**, and a third gear **116** and a fourth gear **117** making up second gear set **119** with a second reduction stage **120**. The first gear **111** has a rotational center C**1** and is coupled for rotation with the output shaft **106** of the motor **36**. The second and third gears **112**, **116** have respective rotational centers C**2**, C**3** and are coupled for rotation with a second shaft **121** that is parallel to the output shaft **106** and the power take-off shaft **38**. The power take-off shaft **38** is coupled for rotation with the fourth gear **117**, which has a rotational center C**4**. A first center distance CD**1** is defined between the rotational centers C**1** and C**2** of the first and second gears **111**, **112**. A second center distance CD**2** is defined between the rotational centers C**3** and C**4** of the third and fourth gears **116**, **117**. In the illustrated embodiment, the first center distance CD**1** is equal to the second center distance CD**2**. However, in other embodiments, the first center distance CD**1** may be different than the second center distance CD**2**.

[0104] With continued reference to the embodiment illustrated in FIG. **19**, the housing **14** includes a removable faceplate **124** that allows the operator to remove the faceplate **124** to access the first, second, third, and fourth gears **111**, **112**, **115**, **116** and to slide them off the output shaft **106**, the second shaft **120** and the power take-off shaft **38**. Thus, the operator may replace the first gear set **113** with a different gear set with two gears having the same first center distance CD**1** between their rotational centers to change the reduction ratio of the first reduction stage **115**. Similarly, the operator may replace the second gear set **119** with a different gear set with two gears having the same second center distance CD**2** between their rotational centers to change the reduction ratio of the second reduction stage **120**. Thus, the motor unit **10** can implement a variety of reduction ratios to work with a broad range of power equipment, and the removable faceplate **124** makes it easy for an operator to quickly change these reduction ratios. Also the faceplate **124** makes it easy for an operator to change out the power take-off shaft **38** to replace it with a custom power take-off shaft for any given application. Also, the faceplate **124** is easily replaced with a different faceplate to fit a unique or custom mounting configuration.

[0105] In the embodiment shown in FIGS. **13** and **14**, the power-take off shaft **38** is a first power take-off shaft and the motor unit **10** includes a second power take-off shaft **134** that also extends along the rotational axis **122** of the first power take off shaft **38**. The motor **36** drives the first and second power take-off shafts **38**, **134** simultaneously, such that the motor unit **10** can be used with, for example, tillers, saws, and snow blowers.

[0106] FIGS. **15** and **16** illustrate embodiments of the motor unit **10** in which the power take-off shaft **38** protrudes through the second side **22** of the housing **14**. As shown in FIG. **15**, a plane **138** is defined on the first side **18** of the housing **14** on which the flange **34** is coupled. The plane **138** contains orthogonal X and Y axes that intersect at an origin O. As shown in FIG. **16**, the power take-off shaft **38** extends parallel to the Y-axis and as shown in FIG. **15**, the power take-off shaft **38** has an end **140**. The X-axis extends parallel to the second and third sides **22**, **26** and the Y-axis extends parallel to the fifth and sixth sides **30**, **32**.

[0107] With continued reference to FIG. **15**, the flange **34** includes a plurality of apertures therethrough, including a first hole **142** having a center **144**, a second hole **146** having a center **148**, a first slot **150**, and a second slot **154**. The plurality of apertures collectively define a first bolt pattern that matches an “identical”, second bolt pattern defined in a piece of power equipment to which the motor unit **10** can be mounted. “Identical” does not mean that each of the plurality of apertures defining the first bolt pattern identically aligns with each of the plurality of apertures defining the second bolt pattern. In other words, not all of the first hole **142**, second hole **146**, first slot **150**, and second slot **154** need align with a corresponding aperture in the second bolt pattern. Rather, at least two of the first hole **142**, second hole **146**, first slot **150**, and second slot **154** will at least partially align with two corresponding apertures in the second bolt pattern, such that at least two fasteners, such as bolts, may be respectively inserted through at least two of the at least partially-aligned respective apertures of the first and second bolt patterns in order to couple the motor unit **10** to the piece of power equipment. Thus, for the first bolt pattern to match an “identical” second bolt pattern, at least two apertures in the first bolt pattern are configured to at least partially align with two apertures of the second bolt pattern. In the disclosed embodiment, the plurality of apertures defining the first bolt pattern includes four apertures (first hole **142**, second hole **146**, first slot **150**, and second slot **154**) but in other embodiments, the plurality of apertures defining the first bolt pattern could include more or fewer apertures.

[0108] In some embodiments, the flange **34** may include one or more intermediate mounting members or adapters arranged between the flange **34** itself and the flange of the piece of power equipment having the second bolt pattern, such that the adapter(s) couple the flange **34** to the piece of power equipment. In these embodiments, the adapter includes both the second bolt pattern and the first bolt pattern, such that the first bolt pattern of the flange **34** aligns with the first bolt pattern of the adapter and the second bolt pattern of the adapter aligns with the second bolt pattern defined in the piece of power equipment, thereby allowing the flange **34** of the motor unit **10** to be coupled to the piece of power equipment.

[0109] As shown in FIG. **17**, the first slot **150** includes a first semi-circular portion **158** having a radius R**1**, a second semi-circular portion **162** having a radius R**2**, and a straight portion **166** that connects the first and second semi-circular portions **158**, **162**. The first semi-circular portion **158** has a center **170** from which radius R**1** is defined and the second semi-circular portion **162** has a center **174** from which radius R**2** is defined. The centers **170**, **174** can define points where a bolt is inserted through the first slot **150** when the first slot **150** is aligned with a corresponding aperture in the second bolt pattern in the piece of power equipment, but the bolt may also be inserted anywhere along the straight portion **166**.

[0110] As also shown in FIG. **18**, the second slot **154** includes a first semi-circular portion **178** having a radius R**3**, a second semi-circular portion **182** having a radius R**4**, and a straight portion **186** that connects the first and second semi-circular portions **178**, **182**. The first semi-circular portion **178** has a center **190** from which radius R**3** is defined and the second semi-circular portion **182** has a center **194** from which radius R**4** is defined. The centers **170**, **174** can define points where a bolt is inserted through the second slot **154** when the second slot **154** is aligned with a corresponding aperture in the second bolt pattern in the piece of power equipment, but the bolt may also be inserted anywhere along the straight portion **186**. In the embodiment illustrated in FIGS. **15** and **17**, R**1**, R**2**, R**3**, and R**4** are all equal, but in other embodiments, one or more of the radii R**1**, R**2**, R**3**, R**4** may be different from one another.

[0111] With reference again to FIG. **15**, Table 1 below lists the distances of various components and reference points with respect to the X-axis and the Y-axis.

TABLE-US-00001 TABLE 1 Distance from X-axis Distance from Y-axis Center 144 of first hole 142 E G Center 148 of second hole 146 E H Center 170 of first semi-circular portion C G 158 of first slot 150 Center 174 of second semi-circular D G portion 162 of first slot 150 Center 190 of first semi-circular portion C H 178 of second slot 154 Center 194 of second semi-circular D H portion 182 of second slot 154 Second side 22 of housing 14 A Perpendicular to Y-axis Third side 26 of housing 14 B Perpendicular to Y-axis End 140 of power take-off shaft 38 F Perpendicular to Y-axis Fifth side 30 of housing 14 Perpendicular to X-axis I Sixth side 32 of housing 14 Perpendicular to X-axis J

[0112] Table 2 below lists five different embodiments of the stand-alone motor unit **10** of FIG. **1**, which is also schematically illustrated in FIGS. **15** and **16**, in which the values of the distances from Table 1, in millimeters, are provided:

TABLE-US-00002 TABLE 2 A B C D E F G H I J Embodiment 1 75.2-75.5 168.6 34.5 39.5 40.5 115.4 66 96 115 231 Embodiment 2 75.2-75.5 175.6 34.5 39.5 40.5 139.9 66 96 123 239 Embodiment 3 75.2-75.5 184.6 34.5 39.5 40.5 136.9 66 96 123 253 Embodiment 4 75.2-75.5 203.1 34.5 39.5 40.5 128.4 66 96 135.3 278.3 Embodiment 5 75.2-75.5 221.5 34.5 39.5 40.5 128.4 66 96 147.6 303.6

[0113] In some embodiments, dimension F, the length to the end **140** of the power take-off shaft **38**, can be modified or customized besides the dimensions listed in Table 2.

[0114] As shown in FIG. **16**, a Z-axis intersects the origin O of plane **138** and the first and fourth sides **18**, **28** of the housing **14**. The Z-axis is arranged perpendicular to the X-axis and Y-axis of the plane **138**. The Z-axis is also arranged perpendicular to the first and fourth **18**, **28** sides of the housing **14**. The Z-axis is also arranged parallel to the fifth and sixth sides **30**, **32** of the housing **14**. As also shown in FIG. **16**, a radius R**5** extending from the rotational axis **122** of the power take-off shaft **38** defines a circle **198**. The rotational axis **118** of the output shaft **106** of the rotor **102** is intersected by the circle **198**, such that a distance R**5** is defined between the rotational axis **118** of

the output shaft **106** and the rotational axis **122** of the power take-off shaft **38**. Table 3 below identifies the distances of various components and reference points with respect to the X-axis and Z-axis.
TABLE-US-00003 TABLE 3 Distance from X-axis Distance from Z-axis Rotational axis 118 of output shaft 106 L K Rotational axis 122 of power take-off shaft 38 M Intersected by Z-axis Fourth side 28 of housing 14 N Perpendicular to Z-axis Fifth side 30 of housing 14 Perpendicular to X-axis I Sixth side 32 of housing 14 Perpendicular to X-axis J
[0115] Table 4 below lists the five different embodiments from Table 2 and provides the values of the distances from Table 3, as well as R**5**, in millimeters, for each embodiment:
TABLE-US-00004 TABLE 4 K L M N I J R5 Embodiment 1 46.9 95.3 106 329 115 231 48.1 Embodiment 2 46.9 95.3 106 346 123 239 48.1 Embodiment 3 46.9 95.3 106 346 123 253 48.1 Embodiment 4 46.9 95.3 106 380.6 135.3 278.3 48.1 Embodiment 5 46.9 95.3 106 415.2 147.6 303.6 48.1
[0116] With continued reference to the embodiment illustrated in FIG. **16**, the control electronics **42** are vertically oriented relative to flange **34** and positioned between the Z-axis and the fifth side **30** of the housing **14**, while being closer to the fifth side **30** of the housing **14**. As also shown in the embodiment illustrated in FIG. **16**, the battery pack **50** is horizontally oriented relative to flange **34** and positioned between the rotational axis **122** of the power take-off shaft **38** and the fourth side **28** of the housing **14**, while being closer to the fourth side **28** of the housing **14**. However, in other embodiments, the battery pack **50** may be closer to the rotational axis **122** of the power take-off shaft **38**. Thus, in all five embodiments, even when the design envelope of the housing **14** of the motor unit **10** is changed, each of the battery **50**, the battery receptacle **54**, the control electronics **42**, and the motor **36** fit within the housing **14**. In some embodiments, the total weight of the motor unit **10** including each of the battery **50**, the battery receptacle **54**, the control electronics **42**, and the motor **36**, is 37.05 lbs. In contrast, when fully loaded with fluids, some 120 cc gas engine units can weigh up to 33.50 lbs, some 160 cc gas engine units can weigh up to 40.10 lbs, and some 200 cc gas engine units can weigh up to 41.30 lbs.
[0117] In some embodiments, the motor unit **10** includes a “kill switch” (not shown) that can be used when the motor unit **10** is coupled to, e.g., a riding lawnmower with a seat. Thus, when an operator intentionally or inadvertently gets off the seat, the kill switch discontinues power to the motor **36** and/or control electronics **42**. In some embodiments, the kill switch stops the motor **36** and/or power take-off shaft **38**, but maintains power to the power electronics **42** so that the motor unit **10** may be kept in an armed or ready state. In some embodiments, the motor unit **10** requires two or more actions required to turn on the motor **36** because unlike a gas engine, it may be difficult to determine whether the electric motor **36** is on or not. Specifically, the electric motor **36** is much quieter than a gas engine. Thus, simply hitting an “on” switch may not be enough to indicate to the operator that the motor **36** has been turned on, because of its relative silence. Thus, by forcing the operator to make two actions, such as holding an “on” switch and then depressing a second actuator, the operator is made to feel more certain that the motor **36** has been turned on.
[0118] In some embodiments, a control interface to control the power equipment and/or the motor unit **10** is built into the motor unit **10**. In some embodiments, the motor unit **10** includes a communication port and a wiring harness electrically connects the motor unit **10** to the piece of power equipment, thus allowing the operator to control the motor unit **10** from the piece of power equipment **10**, or vice versa. For example, if the motor unit **10** is mounted to a lawn mower, the operator may arrange the wiring harness between the lawn mower and the communication port on the motor unit **10**. The wiring harness could electrically connect a kill switch on a handlebar of the lawnmower, for example, to the motor **36** of the motor unit **10**. Thus, if the kill switch is intentionally or inadvertently released during operation of the lawn mower, the motor **36** of the motor unit **10** stops via the electrical communication through the wiring harness and communication port on the motor unit **10**. Thus, the control interface and communication port

allow the operator flexibility in controlling the motor unit **10** and/or the piece of power equipment.

[0119] In some embodiments, the motor unit **10** includes ON/OFF indicators (not shown). In some embodiments, the motor unit **10** includes a filter (not shown) to keep airborne debris out of the motor **36** and control electronics **42**. In some embodiments, the filter includes a dirty filter sensor (not shown) and a self-cleaning mechanism (not shown). In some embodiments, the motor **36** will mimic a gas engine response when encountering resistance, such as slowing down or bogging. In some embodiments, the motor unit **10** includes a heat sink **202** in the housing **14** for air-cooling the control electronics **42** (FIGS. **1** and **2**). In some embodiments, the motor unit **10** is liquid cooled.

[0120] In some embodiments, the output shaft **106** of the rotor **102** has both forward and reverse capability. In some embodiments, the forward and reverse capability is controllable without shifting gears of the gear train **110**, in comparison to gas engines, which cannot achieve forward/reverse capability without extra gearing and time delay. Thus, the motor unit **10** provides increased speed, lower weight, and lower cost. Because the motor unit **10** has fewer moving parts and no combustion system, as compared with a gas engine, it also provides additional speed, weight, and cost advantages.

[0121] In some embodiments, the motor unit **10** is able to start under a “heavy” load. For example, when the motor unit **10** is mounted to a riding lawnmower and the lawnmower is started over a patch of thick grass, the motor unit **10** is able to start the motor **36** in the thick grass. Thus, unlike gas engines, the motor unit **10** does not require a centripetal clutch. Rather, the motor **36** would always be engaged. Additionally, the motor unit **10** does not need a centrifugal clutch, in comparison to gas engines, which need a centrifugal clutch to idle and disengage from the load, or risk stalling.

[0122] The motor unit **10** is able to operate in any orientation (vertical, horizontal, upside down) with respect to a ground surface for a prolonged period of time, giving it an advantage over four-cycle gas engines, which can only be operated in one orientation and at slight inclines for a shorter period of time. Because the motor unit **10** does not require gas, oil, or other fluids, it can run, be transported, and be stored upside down or on any given side without leaking or flooding

[0123] In operation, the motor unit **10** can be used to replace a gas engine system. Specifically, the motor unit **10** can be mounted to the piece of power equipment having the second bolt pattern by aligning the first bolt pattern defined by the plurality of apertures in the flange **34** with the second bolt pattern. Thus, the power take-off shaft **38** of the motor unit **10** can be used to drive the equipment.

[0124] During operation, the housing **14** of the motor unit **10** is comparably much cooler than the housing of an internal combustion unit because there is no combustion in the motor unit **10**. Specifically, when a gas engine unit runs, the housing of the gas engine unit is 220 degrees Celsius or higher. In contrast, when the motor unit **10** runs, all of the exterior surfaces of the housing **14** are less than 95 degrees Celsius. Tables 5 and 6 below list with further specificity the temperature limits of different components on the housing **14** of the motor unit **10**.

[0125] Table 5 below lists the Underwriter's Laboratories (UL) temperature limits of different components typically used in power tools, with respect to whether those components are formed of metal, plastic, rubber, wood, porcelain, or vitreous. The plastic rated temperatures are never exceeded.

TABLE-US-00005 TABLE 5 Plastic/ Rubber/ Porcelain/ Metal Wood Vitreous Casual Contact 85° C. 85° C. 85° C. Handles and knobs that 55° C. 75° C. 65° C. are continuously held Handles and knobs 60° C. 80° C. 70° C. that are only briefly held (i.e. switches)

[0126] Table 6 below lists the UL temperature limits of different components of the battery pack housing **58** of the battery pack **50**, with respect to whether those components are formed of metal, plastic or rubber. The plastic rated temperatures are never exceeded.

TABLE-US-00006 TABLE 6 Metal Plastic/Rubber Casual Contact 70° C. 95° C. Handles and knobs that are 55° C. 75° C. continuously held Handles and knobs that are 60° C. 85° C. only briefly held (i.e. switches)

[0127] FIG. **20** illustrates a simplified block diagram of the motor unit **10** according to one example embodiment. As shown in FIG. **20**, the motor unit **10** includes an electronic processor **302**, a memory **306**, the battery pack **50**, a power switching network **310**, the motor **36**, a rotor position sensor **314**, a current sensor **318**, a user input device (e.g., a trigger or power button) **322**, a transceiver **326**, and indicators (e.g., light-emitting diodes) **330**. In some embodiments, the motor unit **10** includes fewer or additional components than those shown in FIG. **20**. For example, the motor unit **10** may include a battery pack fuel gauge, work lights, additional sensors, kill switch, the power disconnect switch **86**, etc. In some embodiments, elements of the motor unit **10** illustrated in FIG. **20** including one or more of the electronic processor **302**, memory **306**, power switching network **310**, rotor position sensor **314**, current sensor **318**, user input device (e.g., a trigger or power button) **322**, transceiver **326**, and indicators (e.g., light-emitting diodes) **330** form at least part of the control electronics **42** shown in FIG. **3**, with the electronic processor **302** and the memory **306** forming at least part of the controller **46** shown in FIG. **3**.

[0128] The memory **306** includes read only memory (ROM), random access memory (RAM), other non-transitory computer-readable media, or a combination thereof. The electronic processor **302** is configured to communicate with the memory **306** to store data and retrieve stored data. The electronic processor **302** is configured to receive instructions and data from the memory **306** and execute, among other things, the instructions. In particular, the electronic processor **302** executes instructions stored in the memory **306** to perform the methods described herein.

[0129] As described above, in some embodiments, the battery pack **50** is removably attached to the housing of the motor unit **10** such that a different battery pack **50** may be attached and removed to the motor unit **10** to provide different amount of power to the motor unit **10**. Further description of the battery pack **50** (e.g., nominal voltage, sustained operating discharge current, size, number of cells, operation, and the like), as well as the motor **36** (e.g., power output, size, operation, and the like), is provided above with respect to FIGS. **1-19**.

[0130] The power switching network **310** enables the electronic processor **302** to control the operation of the motor **36**. Generally, when the user input device **322** is depressed (or otherwise actuated), electrical current is supplied from the battery pack **50** to the motor **36**, via the power switching network **310**. When the user input device **322** is not depressed (or otherwise actuated), electrical current is not supplied from the battery pack **50** to the motor **36**. In some embodiments, the amount in which the user input device **322** is depressed is related to or corresponds to a desired speed of rotation of the motor **36**. In other embodiments, the amount in which the user input device **322** is depressed is related to or corresponds to a desired torque. In other embodiments, a separate input device (e.g., slider, dial, or the like) is included on the motor unit **10** in communication with the electronic processor **302** to provide a desired speed of rotation or torque for the motor **36**.

[0131] In response to the electronic processor **302** receiving a drive request signal from the user input device **322**, the electronic processor **302** activates the power switching network **310** to provide power to the motor **36**. Through the power switching network **310**, the electronic processor **302** controls the amount of current available to the motor **36** and thereby controls the speed and torque output of the motor **36**. The power switching network **310** may include numerous field-effect transistors (FETs), bipolar transistors, or other types of electrical switches. For instance, the power switching network **310** may include a six-FET bridge that receives pulse-width modulated (PWM) signals from the electronic processor **302** to drive the motor **36**.

[0132] The rotor position sensor **314** and the current sensor **318** are coupled to the electronic processor **302** and communicate to the electronic processor **302** various control signals indicative of different parameters of the motor unit **10** or the motor **36**. In some embodiments, the rotor position sensor **314** includes a Hall sensor or a plurality of Hall sensors. In other embodiments, the rotor position sensor **314** includes a quadrature encoder attached to the motor **36**. The rotor position sensor **314** outputs motor feedback information to the electronic processor **302**, such as an indication (e.g., a pulse) when a magnet of a rotor of the motor **36** rotates across the face of a Hall sensor. In yet other embodiments, the rotor position sensor **314** includes, for example, a voltage or a current sensor that provides an indication of a back electro-motive force (back emf) generated in the motor coils. The electronic processor **302** may determine the rotor position, the rotor speed, and the rotor acceleration based on the back emf signals received from the rotor position sensor **314**, that is, the voltage or the current sensor. The rotor position sensor **314** can be combined with the current sensor **318** to form a combined current and rotor position sensor. In this example, the combined sensor provides a current flowing to the active phase coil(s) of the motor **36** and also provides a current in one or more of the inactive phase coil(s) of the motor **36**. The electronic processor **302** measures the current flowing to the motor based on the current flowing to the active phase coils and measures the motor speed based on the current in the inactive phase coils.

[0133] Based on the motor feedback information from the rotor position sensor **314**, the electronic processor **302** can determine the position, velocity, and acceleration of the rotor. In response to the motor feedback information and the signals from the user input device **322**, the electronic processor **302** transmits control signals to control the power switching network **310** to drive the motor **36**. For instance, by selectively enabling and disabling the FETs of the power switching network **310**, power received from the battery pack **50** is selectively applied to stator windings of the motor **36** in a cyclic manner to cause rotation of the rotor of the motor **36**. The motor feedback information is used by the electronic processor **302** to ensure proper timing of control signals to the power switching network **310** and, in some instances, to provide closed-loop feedback to control the speed of the motor **36** to be at a desired level. For example, to drive the motor **36**, using the motor positioning information from the rotor position sensor **314**, the electronic processor **302** determines where the rotor magnets are in relation to the stator windings and (a) energizes a next stator winding pair (or pairs) in the predetermined pattern to provide magnetic force to the rotor magnets in a direct of desired rotation, and (b) de-energizes the previously energized stator winding pair (or pairs) to prevent application of magnetic forces on the rotor magnets that are opposite the direction of rotation of the rotor.

[0134] The current sensor **318** monitors or detects a current level of the motor **36** during operation of the motor unit **10** and provides control signals to the electronic processor **302** that are indicative of the detected current level. The electronic processor **302** may use the detected current level to control the power switching network **310** as explained in greater detail below.

[0135] The transceiver **326** allows for communication between the electronic processor **302** and an external device (for example, the user equipment **338** of FIG. **21**) over a wired or wireless communication network **334**. In some embodiments, the transceiver **326** may comprise separate transmitting and receiving components. In some embodiments, the transceiver **326** may comprise a wireless adapter attached to the motor unit **10**. In some embodiments, the transceiver **326** is a wireless transceiver that encodes information received from the electronic processor **302** into a carrier wireless signal and transmits the encoded wireless signal to the user equipment **338** over the communication network **334**. The transceiver **326** also decodes information from a wireless signal received from the user equipment **338** over the communication network **334** and provides the decoded information to the electronic processor **302**.

[0136] The communication network **334** provides a wired or wireless connection between the motor unit **10** and the user equipment **338**. The communication network **334** may comprise a short range network, for example, a BLUETOOTH network, a Wi-Fi network or the like, or a long range network, for example, the Internet, a cellular network, or the like.

[0137] As shown in FIG. **20**, the indicators **330** are also coupled to the electronic processor **302** and receive control signals from the electronic processor **302** to turn on and off or otherwise convey information based on different states of the motor unit **10**. The indicators **330** include, for example, one or more light-emitting diodes (“LEDs”), or a display screen. The indicators **330** can be configured to display conditions of, or information associated with, the motor unit **10**. For example, the indicators **330** are configured to indicate measured electrical characteristics of the motor unit **10**, the status of the motor unit **10**, the mode of the motor unit **10**, etc. The indicators **330** may also include elements to convey information to a user through audible or tactile outputs. In some embodiments, the indicators **330** include an eco-indicator that indicates an amount of power being used by the load during operation.

[0138] The connections shown between components of the motor unit **10** are simplified in FIG. **20**. In practice, the wiring of the motor unit **10** is more complex, as the components of a motor unit are interconnected by several wires for power and control signals. For instance, each FET of the power switching network **310** is separately connected to the electronic processor **302** by a control line; each FET of the power switching network **310** is connected to a terminal of the motor **36**; the power line from the battery pack **50** to the power switching network **310** includes a positive wire and a negative/ground wire; etc. Additionally, the power wires can have a large gauge/diameter to handle increased current. Further, although not shown, additional control signal and power lines are used to interconnect additional components of the motor unit **10**.

[0139] FIG. **21** illustrates a simplified block diagram of the user equipment **338** according to one example embodiment. The user equipment **338** is, for example, a smart telephone, a tablet computer, a laptop computer, a personal digital assistant, and the like, and may also be referred to as a personal electronic communication device. The user equipment **338** allows the user to customize settings of the motor unit **10** and receive operation information from the motor unit **10**. As shown in FIG. **20**, the user equipment **338** includes an equipment electronic processor **342**, an equipment memory **346**, an equipment transceiver **350**, and an input/output interface **354**. The equipment electronic processor **342**, the equipment memory **346**, the equipment transceiver **350**, and the input/output interface **354** communicate over one or more control and/or data buses (e.g., a communication bus **358**). The equipment electronic processor **342**, the equipment memory **346**, and the equipment transceiver **350** may be implemented similar to the electronic processor **302**, the memory **306**, and the transceiver **326** of the motor unit **10**. Particularly, the equipment electronic processor **342** executed a motor unit application stored on the equipment memory **346** to perform functionality described herein. The input/output interface **354** includes one or more input components (e.g., a keypad, a mouse, and the like), one or more output components (e.g., a speaker, a display, and the like), or both (e.g., a touch screen display).

[0140] FIG. **22** illustrates a flowchart of a method **362** for no-load operation of the motor unit **10**. In the example illustrated, the method **362** includes measuring, using the current sensor **318**, a motor current (at block **366**). The electronic processor **302** detects the current flowing through the motor using the current sensor **318** as described above. The current sensor **318** may detect the current level at discrete time intervals, for example, every 2 milli-seconds, and provide the control signals indicating the current level at the discrete time intervals to the electronic processor **302**. The method **362** also includes measuring, using the rotor position sensor **314**, the motor speed (at block **370**). The electronic processor **302** receives feedback from the rotor position sensor **314** when a magnet of the rotor rotates across the face of a Hall sensor. The electronic processor **302** determines the speed of the motor **36** based on the frequency of the pulses received from the rotor position sensor **314**.

[0141] The method **362** further includes determining, using the electronic processor **302**, a point on the motor power curve corresponding to the measured motor current and the measured motor speed (at block **374**). In one example, the electronic processor **302** constructs a motor power graph having motor speed on the X-axis and motor current on the Y-axis. The point on the motor power curve is the point corresponding to the measured motor current and the measured motor speed on the motor power graph.

[0142] The method **362** also includes determining, using the electronic processor **302**, whether the motor unit **10** is operating in a no-load condition for a pre-determined period of time based on the point on the motor power curve (at block **378**). The motor **36** may be operating at full power (or

100% duty cycle) or at a selected power or duty cycle corresponding to the position of the user input device **322**. The amount of current flowing to the motor **36** is proportional to the load on the motor **36**. That is, when there is a high load on the motor unit **10**, the motor **36** draws higher current from the battery pack **50** and when there is a lighter load on the motor unit **10**, the motor **36** draws lower current from the battery pack **50**. The electronic processor **302** determines the load on the motor unit **10** based on the point on the motor power curve. For example, for a measured speed, the electronic processor **302** determines whether the measured current is below a current threshold corresponding to the measured speed. When the measured current is below the current threshold, the electronic processor **302** determines that the motor unit **10** is operating in a no-load condition and, when the measured current is above the current threshold, the electronic processor **302** determines that the motor unit **10** is not operating in a no-load condition. The electronic processor **302** may then further determine whether the motor unit **10** is operating in the no-load condition for the pre-determined period of time. For example, the electronic processor **302** determines whether the measured current is below the current threshold corresponding to the measured speed for the pre-determined period of time.

[0143] The method **362** further includes, in response to determining that the motor unit **10** is operating in the no-load condition for a pre-determined period of time, reducing, using the electronic processor **302**, the motor speed of the motor **36** to a no-load speed (at block **382**). As discussed above, the electronic processor **302** may provide control signals to the power switching network **310** to control the speed of the motor **36** by selecting a particular pulse width modulated (PWM) duty cycle for driving the power switching network **310**. The speed control may be open loop or closed loop. The electronic processor **302** may also shut-off (i.e., reduce the duty cycle to zero) the motor when the electronic processor **302** determines that the motor unit **10** is operating in the no-load condition for the pre-determined period of time. In one example, the electronic processor **302** reduces the speed of the motor **36** to a no-load speed by reducing a duty cycle of the pulse width modulated signals provided to the power switching network **310** to 5%, 10%, or 15%. The method **362** also includes, in response to determining that the motor unit **10** is not operating in the no-load condition for the pre-determined period of time, operating, using the electronic processor **302**, the motor **36** at a loaded speed that is greater than the no-load speed (at block **386**). For example, to operate at the loaded speed, the electronic processor **302** controls the power switching network **310** to operate the motor **36** according to the power or speed corresponding to the position of the user input device **322** or at full power (i.e., 100% duty cycle) (for example, when the motor unit **10** does not include a variable speed trigger). After block **382** and **386**, respectively, the electronic processor **302** may loop back to execute block **366**, thus providing continued load-based operation control throughout an operation of the motor unit **10**.

[0144] Typical gasoline engines that drive power equipment are not controlled to reduce speed or power when the gasoline engine is operating in a no-load condition. Accordingly, gasoline engines continue to burn excess amounts of fuel and expend energy even when the gasoline engines are operating under no-load. The electronic processor **302** executing the method **362** detects when the motor unit **10** is operating under no-load and reduces the motor speed or power to provide additional energy savings and then returns to normal power when loaded to meet the demand of a task. In one example, as shown in FIG. **23**, by reducing the duty cycle to 10% in the no-load condition, the motor unit **10** provides energy savings of about 5 times that of a gasoline engine operating at no-load. Energy saving resulting from other reduced duty cycle levels are also illustrated in FIG. **23**.

[0145] During operation of gas engines, an excessive input force exerted on the gas engine or a large load encountered by the power equipment powered by the gas engine may cause a resistive force impeding further operation of the gas engine. For example, a gas engine encountering higher than usual loads may have its motor slowed or bogged-down because of the excessive load. This bog-down of the motor can be sensed (e.g., felt and heard) by a user, and is a helpful indication that an excessive input, which may potentially damage the gas engine or the power equipment, has been encountered. In contrast, high-powered electric motor driven units, similar to the motor unit **10**, for example, do not innately provide the bog-down feedback to the user. Rather, in these high-powered electric motor driven units, excessive loading of the motor unit **10** causes the motor to draw excess current from the power source or battery pack **50**. Drawing excess current from the battery pack **50** may cause quick and potentially detrimental depletion of the battery pack **50**.

[0146] Accordingly, in some embodiments, the motor unit **10** includes a simulated bog-down feature to provide an indication to the user that excessive loading of the motor unit **10** or power equipment is occurring during operation. FIG. **24** illustrates a flowchart of a method **390** for providing simulated bog-down operation of the motor unit **10** that is similar to actual bog-down experienced by gas engines.

[0147] The method **390** includes controlling, using the electronic processor **302**, the power switching network **310** to provide power to the motor **36** in response to determining that the user input device **322** has been actuated (at block **394**). For example, the electronic processor **302** provides a PWM signal to the FETs of the power switching network **310** to drive the motor **36** in accordance with the drive request signal from the user input device **322**. The method **390** further includes detecting, using the current sensor **318**, a current level of the motor **36** (at block **398**). Block **398**, at least in some embodiments, may be performed using similar techniques as described above for block **366** with respect to FIG. **22**. The method **390** also includes comparing, using the electronic processor **302**, the current level to a bog-down current threshold (at block **402**). In response to determining that the current level is lower than the bog-down current threshold, the method **390** proceeds back to block **398** such that the electronic processor **302** repeats blocks **398** and **402** until the current level is greater than the bog-down current threshold.

[0148] In response to determining that the current level is greater than the bog-down current threshold, the method **390** includes controlling, using the electronic processor **302**, the power switching network **310** to simulate bog-down (at block **406**). In some embodiments, the electronic processor **302** controls the power switching network **310** to decrease the speed of the motor **36** to a non-zero value. For example, the electronic processor **302** reduces a duty cycle of the PWM signal provided to the FETs of the power switching network **302**. In some embodiments, the reduction in the duty cycle (i.e., the speed of the motor **36**) is proportional to an amount that the current level is above the bog-down current threshold (i.e., an amount of excessive load). In other words, the more excessive the load of the motor unit **10**, the further the speed of the motor **36** is reduced by the electronic processor **302**. For example, in some embodiments, the electronic processor **302** determines, at block **406**, the difference between the current level of the motor **36** and the bog-down current threshold to determine a difference value. The electronic processor **302** determines the amount of reduction in the duty cycle based on the difference value (e.g., by using a look-up table that maps the difference value to a motor speed or duty cycle).

[0149] In some embodiments, at block **406**, the electronic processor **302** controls the power switching network **310** in a different or additional manner to provide an indication to the user that excessive loading of the motor unit **10** is occurring during operation. In such embodiments, the behavior of the motor **36** may provide a more noticeable indication to the user that excessive loading of the motor unit **10** is occurring than the simulated bog-down described above. As one example, the electronic processor **302** controls the power switching network **310** to oscillate between different motor speeds. Such motor control may be similar to a gas engine-powered power equipment stalling and may provide haptic feedback to the user to indicate that excessive loading of the motor unit **10** is occurring. In some embodiments, the electronic processor **302** controls the power switching network **310** to oscillate between different motor speeds to provide an indication to the user that very excessive loading of the motor unit **10** is occurring. For example, the electronic processor **302** controls the power switching network **310** to oscillate between different motor speeds in response to determining that the current level of the motor **36** is greater than a second bog-down current threshold that is greater than the bog-down current threshold described above with respect to simulated bog-down. As another example, the electronic processor **302** controls the power switching network **310** to oscillate between different motor speeds in response to determining that the current level of the motor **36** has been greater than the bog-down current threshold described above with respect to simulated bog-down for a predetermined time period (e.g., two seconds). In other words, the electronic processor **302** may control the power switching network **310** to simulate bog-down when excessive loading of the motor unit **10** is detected and may control the power switching network **310** to simulate stalling when excessive loading is prolonged or increases beyond a second bog-down current threshold.

[0150] With respect to any of the embodiments described above with respect to block **406**, other characteristics of the motor unit **10** and the motor **36** may provide indications to the user that excessive loading of the motor unit **10** is occurring (e.g., tool vibration, resonant sound of a shaft of the motor **36**, and sound of the motor **36**). In some embodiments, these characteristics change as the electronic processor **302** controls the power switching network **310** to simulate bog-down or to oscillate between different motor speeds as described above.

[0151] The method **390** further includes detecting, using the electronic processor **302**, the current level of the motor **36** (at block **410**). The method **390** also includes comparing, using the electronic processor **302**, the current level of the motor **36** to the bog-down current threshold (at block **414**). When the current level remains above the bog-down current threshold, the method **362** proceeds back to block **402** such that the electronic processor **302** repeats blocks **402** through **414** until the current level decreases below the bog-down current threshold. In other words, the electronic processor **302** continues to simulate bog-down until the current level decreases below the bog-down current threshold. Repetition of blocks **402** through **414** allows the electronic processor **302** to simulate bog-down differently as the current level changes but remains above the bog-down current threshold (e.g., as mentioned previously regarding proportional adjustment of the duty cycle of the PWM provided to the FETs).

[0152] When the current level of the motor **36** decreases below the bog-down current threshold (e.g., in response to the user reducing the load on the motor unit **10**), the method **390** includes controlling, using the electronic processor **302**, the power switching network **310** to cease simulating bog-down and operate in accordance with the actuation of the user input device **322** (i.e., in accordance with the drive request signal from the user input device **322**) (at block **416**). In other words, the electronic processor **302** controls the power switching network **310** to increase the speed of the motor **36** from the reduced simulated bog-down speed to a speed corresponding to the drive request signal from the user input device **322**. For example, the electronic processor **302** increases the duty cycle of the PWM signal provided to the FETs of the power switching network **310**. In some embodiments, the electronic processor **302** gradually ramps the speed of the motor **36** up from the reduced simulated bog-down speed to the speed corresponding to the drive request signal from the user input device **322**. Then, the method **390** proceeds back to block **394** to allow the electronic processor **302** to continue to monitor the motor unit **10** for excessive load conditions. In some embodiments of the method **390**, in block **414**, a second current threshold different than the bog-down threshold of block **402** is used. For example, in some embodiments, the bog-down threshold is greater than the second current threshold.

[0153] FIG. **25** illustrates a schematic control diagram of the motor unit **10** that shows how the electronic processor **302** implements the method **390** according to one example embodiment. The electronic processor **302** receives numerous inputs, makes determinations based on the inputs, and controls the power switching network **310** based on the inputs and determinations. As shown in FIG. **25**, the electronic processor **302** receives a drive request signal **418** from the user input device **322** as explained previously herein. In some embodiments, the motor unit **10** includes a slew rate limiter **422** to condition the drive request signal **418** before the drive request signal **418** is provided to the electronic processor **302**. The drive request signal **418** corresponds to a first drive speed of the motor **36** (i.e., a desired speed of the motor **36** based on an amount of depression of the user input device **322** or based on the setting of a secondary input device). In some embodiments, the drive request signal **418** is a desired duty ratio (e.g., a value between 0-100%) of the PWM signal for controlling the power switching network **310**.

[0154] The electronic processor **302** also receives a motor unit current limit **426** and a battery pack current available limit **430**. The motor unit current limit **426** is a predetermined current limit that is, for example, stored in and obtained from the memory **306**. The motor unit current limit **426** indicates a maximum current level that can be drawn by the motor unit **10** from the battery pack **50**. In some embodiments, the motor unit current limit **426** is stored in the memory **306** during manufacturing of the motor unit **10**. The battery pack current available limit **430** is a current limit provided by the battery pack **50** to the electronic processor **302**. The battery pack current available limit **430** indicates a maximum current that the battery pack **50** is capable of providing to the motor unit **10**. In some embodiments, the battery pack current available limit **430** changes during operation of the motor unit **10**. For example, as the battery pack **50** becomes depleted, the maximum current that the battery pack **50** is capable of providing decreases, and accordingly, as does the battery pack current available limit **430**. The battery pack current available limit **430** may also be different depending on the temperature of the battery pack **50** and/or the type of battery pack **50**. Although the limits **426** and **430** are described as maximum current levels for the motor unit **10** and battery pack **50**, in some embodiments, these are firmware-coded suggested maximums or rated values that are, in practice, lower than true maximum levels of these devices.

[0155] As indicated by floor select block **434** in FIG. **25**, the electronic processor **302** compares the motor unit current limit **426** and the battery pack current available limit **430** and determines a lower limit **438** using the lower of the two signals **426** and **430**. In other words, the electronic processor **302** implementing a function, floor select **434**, determines which of the two signals **426** and **430** is lower, and then uses that lower signal as the lower limit **438**. The electronic processor **302** also receives a detected current level of the motor **36** from the current sensor **318**. At node **442** of the schematic diagram, the electronic processor **302** determines an error (i.e., a difference) **446** between the detected current level of the motor **36** and the lower limit **438**. The electronic processor **302** then applies a proportional gain to the error **446** to generate a proportional component **450**. The electronic processor **302** also calculates an integral of the error **446** to generate an integral component **454**. At node **458**, the electronic processor **302** combines the proportional component **450** and the integral component **454** to generate a current limit signal **462**. The current limit signal **462** corresponds to a drive speed of the motor **36** (i.e., a second drive speed) that is based on the detected current level of the motor **36** and one of the motor unit current limit **426** and the battery pack current available limit **430** (whichever of the two limits **426** and **430** is lower). In some embodiments, the current limit signal **462** is in the form of a duty ratio (e.g., a value between 0-100%) for the PWM signal for controlling the power switching network **310**.

[0156] As indicated by floor select block **466** in FIG. **25**, the electronic processor **302** compares the current limit signal **462** and the drive request signal **418** and determines a target PWM signal **470** using the lower of the two signals **462** and **418**. In other words, the electronic processor **302** determines which of the first drive speed of the motor **36** corresponding to the drive request signal **418** and the second drive speed of the motor **36** corresponding to the current limit signal **462** is less. The electronic processor **302** then uses the signal **418** or **462** corresponding to the lowest drive speed of the motor **36** to generate the target PWM signal **470**.

[0157] The electronic processor **302** also receives a measured rotational speed of the motor **36**, for example, from the rotor position sensor **314**. At node **474** of the schematic diagram, the electronic processor **302** determines an error (i.e., a difference) **478** between the measured speed of the motor **36** and a speed corresponding to the target PWM signal **470**. The electronic processor **302** then applies a proportional gain to the error **478** to generate a proportional component **482**. The electronic processor **302** also calculates an integral of the error **478** to generate an integral

component **486**. At node **490**, the electronic processor **302** combines the proportional component **482** and the integral component **486** to generate an adjusted PWM signal **494** that is provided to the power switching network **310** to control the speed of the motor **36**. The components of the schematic diagram implemented by the electronic processor **302** as explained above allow the electronic processor **302** to provide simulated bog-down operation of the motor unit **10** that is similar to actual bog-down experienced by gas engines. In other words, in some embodiments, by adjusting the PWM signal **494** in accordance with the schematic control diagram, the motor unit **10** lowers and raises the motor speed in accordance with the load on the motor unit **10**, which is perceived by the user audibly and tactilely, to thereby simulate bog down. FIGS. **25** and **26** illustrate a closed loop speed control of the motor **36**. In some embodiments, the method **390** uses open loop speed control of the motor **36**. For example, in FIGS. **25** and **26**, the method **390** can be adapted for open loop speed control by eliminating node **474**, the proportional component **482**, the integral component **486**, the node **490**, and the feedback signal from the rotor positions sensor **314**.
[0158] FIG. **26** illustrates a schematic control diagram of the motor unit **10** that shows how the electronic processor **302** implements the method **390** according to another example embodiment. The control process illustrated in FIG. **26** is similar to the control process illustrated in FIG. **25**. However, rather than determining the lower limit **438** based on the motor unit current limit **426** and the battery pack current available limit **430**, the electronic processor **302** determines the lower limit **438** based on an input received from the user equipment **338**. For example, the user may define the motor performance on the user equipment **338** by providing current, power, torque, or performance parameters (referred to as motor performance parameters) over the input/output interface of the user equipment **338**. The user equipment **338** communicates the motor performance parameters defined by the user to the electronic processor **302** over the communication network **334**. The electronic processor **302** determines the lower limit **438** based on the motor performance parameters. For example, the electronic processor **302** uses the current defined in the motor performance parameters as the lower limit **438**. The control process shown in FIG. **26** provides the user the ability to customize performance of the motor unit **10** according to the needs of the power equipment.
[0159] In some embodiments, the motor performance parameters may be defined based on an application of the motor unit **10**. The motor unit **10** may be used to power different kinds of power equipment for different applications. The user may select the application that the motor unit **10** is being used for on the input/output interface **354** of the user equipment **338**. The equipment electronic processor **342** may determine the motor performance parameters based on the application selected by the user. For example, the equipment electronic processor **342** may refer to a look-up table in the equipment memory **346** mapping each application of the motor unit **10** to a set of motor performance parameters. The equipment electronic processor **342** may then provide the motor performance parameters to the electronic processor **302**. In some embodiments, the user equipment **338** may provide the application selected by the user to the electronic processor **302**. The electronic processor **302**, rather than the equipment electronic processor **338**, may determine the motor performance parameters based on the application selected by the user. For example, the electronic processor **302** may refer a look-up table in the memory **306** mapping each application of the motor unit **10** to a set of motor performance parameters.
[0160] In some embodiments, the electronic processor **302** may perform a system compatibility check prior to each power-up to determine whether the motor unit **10** is capable of the power outputs defined by the user. FIG. **27** is a flowchart of a method **498** for system compatibility check according to one example embodiment. As shown in FIG. **27**, the method **498** includes receiving, via the transceiver **326**, a load command from the user equipment **338** (at block **502**). For example, the electronic processor **302** receives the motor performance parameters from the equipment electronic processor **342** as described above. The motor performance parameters may include an output power requirement (i.e., the load command) of the motor unit **10**. In some embodiments, the

load command is a rotation speed of the motor unit **10** (e.g., 5000 RPM). For example, the user may select the rotation speed or an application that maps to the rotation speed on the user equipment **338**. The electronic processor **302** determines the amount of load or current draw required to operate the motor at the selected speed (i.e., the load command). The method **498** also includes determining, using the electronic processor **302**, a load limit of the battery pack **50** (at block **506**). The electronic processor **302** determines the load limit based on, for example, battery type, battery state of charge, battery age, and the like. In some embodiments, the electronic processor **302** determines the load limit based on the battery pack current available limit **430**. In some embodiments, the load limit is a maximum speed that can be attained based on the battery conditions. For example, the electronic processor may determine that the maximum rotational speed that can be achieved based on the power available through the battery pack **50** is 4000 RPM.
[0161] The method **498** further includes determining, using the electronic processor **302**, whether the load command exceeds the load limit (at block **510**). The electronic processor **302** compares the load command to the load limit to determine whether the load command exceeds the load limit. In response to determining that the load command does not exceed the load limit, the method **498** includes performing, using the electronic processor **302**, normal operation of the motor unit **10** (at block **514**). Performing normal operation of the motor unit **10** includes controlling the power switching network **310** to operate the motor **36** according to the load command provided by the user and the input from the user input device **322**. For example, the electronic processor **302** provides a PWM signal to the FETs of the power switching network **310** to drive the motor **36** in accordance with the drive request signal from the user input device **322**. In response to determining that the load command exceeds the load limit, the method **498** includes performing, using the electronic processor **302**, limited operation of the motor unit **10** (at block **518**). Performing limited operation may include for example, turning off the motor **36**, running the motor **36** with limited power within the load limit of the battery pack **50**, or the like. In one example, performing limited operation may include simulating bog-down of the motor unit **10** as described above. In some embodiments, the electronic processor **302** may also warn the user that the load command exceeds the load limit. For example, the electronic processor **302** may provide an indication to the user equipment **338** that the load command exceeds the load limit. The user equipment **338** in response to receiving the indication from the electronic processor **302** provides an audible, tactile, or visual feedback to the user indicating that the load command exceeds the load limit. For example, the user equipment **338** displays a warning text on the input/output interface **354** that the load command exceeds the load limit. In some embodiments, the electronic processor **302** activates the indicators **330** to warn the user that the load command exceeds the load limit. The user may then adjust the load command based on the warning received from the electronic processor **302**. After block **514** and **518**, respectively, the electronic processor **302** loops back to the block **502**.
[0162] FIG. **28** illustrates a pump system **520** including a frame **524** supporting the stand-alone motor unit **10** and a pump **528** with the motor unit **10** operable to drive the pump **528**. The illustrated pump **528** is a centrifugal pump having an impeller positioned within a housing **532** of the pump **528** that is rotatable about an axis to move material from an inlet **536** of the pump **528** to an outlet **540** of the pump **528**. Specifically, the pump **528** is a “trash pump” that includes enough clearance between the impeller of the pump **528** and the housing **532** (e.g., 8 millimeters) to provide a mixture of a liquid (e.g., water) and debris (e.g., solid material like mud, small rocks, leases, sand, sludge, etc.) to pass through the pump **528** from the inlet **536** to the outlet **540** without the debris getting trapped within the pump **528** and decreasing the performance of the pump system **520**. The pump system **520** driven by the motor unit **10** includes many advantages over a conventional pump driven by an internal combustion engine, some of which are discussed below.
[0163] The motor unit **10** of the pump system **520**: [0164] drives the pump **528** in two different directions to clear the pump **528** if debris is stuck within the pump **528** (without utilizing a transmission including a forward gear and a rearward gear); [0165] is operable by AC power (e.g.,

from a standard 120 volt outlet) or DC power (e.g., from a battery pack) to drive the pump **528** to eliminate a downtime refueling period of the internal combustion engine; [0166] eliminates an air intake and an exhaust outlet such that the motor unit **10** can be fluidly sealed in a water proof housing; [0167] is operable in a wider speed range than a comparable internal combustion engine, for example, the motor unit **10** is operable at a lower speed range (e.g., less than 2,000 revolutions per minute) than a comparable internal combustion engine to increase runtime of the motor unit **10**, and the motor unit **10** is also operable at a higher speed range (e.g., greater than 3,600 revolutions per minute) than a comparable internal combustion engine to provide a broader output capability; [0168] operates the pump **528** regardless of the orientation of the motor unit **10**, unlike an internal combustion engine that can only can operate in one orientation (e.g., an upright orientation); and [0169] eliminates fuel and oil to operate unlike an internal combustion engine-allowing the pump system **520** to run, be transported, or stored at any orientation (e.g., upside down or on its side) without the motor unit **10** leaking oil or flooding with fuel.
[0170] In addition, the electronic processor **302** of the motor unit **10** can, for example: [0171] via first sensors **541** in the pump **528** that are in communication with the electronic processor **302**, detect an amount of liquid being moved through the pump **528** to enable operation of the pump **528** if the amount of liquid is at or above a threshold level and automatically stops operation of the pump **528** if the amount of liquid is below the threshold level. However, in other embodiments, the electronic processor **302** can simply monitor the current drawn by the motor **36** to determine whether to slow down or stop the motor **36**; [0172] provide a battery status that at least represents a power level of the battery pack of the motor unit **10**; [0173] be in communication with a remote control to start or stop the motor unit **10** remotely with the remote control including status indicators of the motor unit **10**; [0174] turn ON/OFF the motor unit **10**—and ultimately the pump **528**, change a speed of the motor unit **10**, change a flow rate of liquid and debris exiting the outlet **540**, provide a timer (e.g., automatically turn OFF the motor unit **10**), provide a delayed start of the motor unit **10**—all of which can occur without direct user input (e.g., via sensors or programs); [0175] be in communication with other power tools to provide tool-to-tool communication and coordination; [0176] be in communication with a wireless network to track the location of the pump system **520**, report the pump system **520** usage and performance data, disable/enable the pump system **520** remotely, change the performance of the pump system **520** remotely, etc.; [0177] be in communication with digital controls on a customizable user interface (e.g., a touch display) that control, regulate, measure different aspects of the motor unit **10** and/or the pump **528**; [0178] via second sensors **542** on the pump **528** that are in communication with the electronic processor **302** and arranged in an impeller reservoir, monitor suction or fluid level in the impeller reservoir and signal that the pump **528** is not adequately primed or automatically shut off the pump **528** to protect the pump system **520**; [0179] electronically control a valve **543** on the pump **528** to adjust an exhaust opening to support an auto-priming capability; [0180] electronically control the valve **543** to adjust the exhaust opening so that only air exits and slowly reopen the valve **543** until suction is established; [0181] adjust pressure or flow rate of the pump **528** with the speed of the motor unit **10** instead of a throttle; and [0182] control a priming mode or “soft start” that optimizes the speed of the impeller of the pump **528** for self-priming, and governing to a slower speed until full suction is achieved.
[0183] Test specifications of the pump system **520** appear in Table 7 below:
TABLE-US-00007 TABLE 7 Full Speed Low Speed Motor Speed (RPM) 19,627 7,452 Average Current (Amperes) 38.0 2.11 Peak Current (95%) (Amperes) 43 2 Instantaneous Peak Current 46 43 (Amperes) Average Voltage (V) 69.9 76.41 Average Power (HP) 3.56 0.22 Peak Power (95%) (HP) 4.16 0.23 Runtime (Minutes) 9.20 96.86 Flow Rate (Gallons per Minute) 120.3 48.9 Total Pumped (Gallons) 1,098 4,753
[0184] The values listed in Table 7 were measured during a full discharge cycle of the battery pack **50** (i.e., full charge to shutoff due to the voltage of the battery pack **50** dropping below a

predetermined value).

[0185] FIG. **29** illustrates a jetter **544** including a frame **545** with a pair of wheels **546** and a handle **548**. The frame **545** supports the stand-alone motor unit **10** and a pump **550** driven by the motor unit **10**. The pump **550** includes an inlet **551** that receives fluid from an inlet line **552** connected to a fluid source **553** (e.g. a spigot or reservoir). The pump **550** also includes an outlet **554** from which an outlet line **556** extends. The frame **545** supports a hose reel **558** that supports a hose **559** that is fluidly coupled to the outlet line **556** and includes a jetter nozzle **560**. The hose **559** and jetter nozzle **560** are fluidly coupled with the pump **550** via the outlet line **556**, such that the pump **550** pumps fluid from the fluid source **553** to the jetter nozzle **560**. The jetter nozzle **560** includes back jets **564** and one or more front jets **568**.

[0186] In operation, the motor unit **10** drives the pump **550**, which supplies water or another fluid from the fluid source **553** to the nozzle **560**, such that the back jets **564** of the jetter nozzle **560** propel the jetter nozzle **560** and **559** hose through a plumbing line while front jets **568** of the nozzle **560** are directed forward to break apart clogs in the plumbing line, blasting through sludge, soap, and grease. Once propelled a sufficient distance through the plumbing line, an operator may use the hose reel **558** to retract the hose **559** and jetter nozzle **560** back through the plumbing line, while the pump **550** continues to supply fluid to the back and front jets **564**, **568** to break up debris in the line and flush debris therethrough. The jetter **544** including the motor unit **10** possesses advantages over a conventional jetter with an internal combustion engine, some of which are discussed below. For instance, the motor unit **10** can be pulsed to clear a jam in the plumbing line.

[0187] In addition, the electronic processor **302** of the motor unit **10** can, for example: [0188] Communicate with fluid level sensors **572** on the pump **550** to detect whether an adequate level of fluid is available; [0189] Communicate with inlet and outlet sensors **573**, **574** respectively located at the inlet and outlet lines **552**, **556** to prevent the motor unit **10** from being activated until the inlet and outlet lines **552**, **556** for the pump **550** are sufficiently bled of air; [0190] adjust pressure or flow rate of the pump **550** with the speed of the motor unit **10** instead of a throttle or regulator; and [0191] turn ON/OFF the motor unit **10**—and ultimately the pump **550**, change a speed of the motor unit **10**, change a flow rate of liquid through the pump **550**, provide a timer (e.g., automatically turn OFF the motor unit **10**), provide a delayed start of the motor unit **10**—all of which can occur without direct user input (e.g., via sensors or programs).

[0192] Test specifications of the jetter **544** appear in Table 8 below:

TABLE-US-00008 TABLE 8 Full Speed Motor Speed (RPM) 17,773 Average Current (Amperes) 55.7 Peak Current (95%) (Amperes) 64 Instantaneous Peak Current (Amperes) 67 Average Voltage (V) 65.4 Average Power (HP) 5.29 Peak Power (95%) (HP) 6.18 Runtime (Minutes) 5.7 Peak Jet Pressure (PSI) 2070

[0193] The values listed in Table 8 were measured during a full discharge cycle of the battery pack **50** (i.e., full charge to shutoff due to the voltage of the battery pack **50** dropping below a predetermined value).

[0194] FIG. **30** illustrates a compactor **576** including a frame **580** supporting the stand-alone motor unit **10**, a vibrating plate **584**, and a vibration mechanism **588** intermediate the motor unit **10** and vibrating plate **584**, such that the motor unit **10** can drive the vibration mechanism **588** to drive the vibrating plate **584**. The frame **580** includes a handle **592** and also supports a water tank **596** with a valve **600** through which water or other liquid can be applied to the surface to be compacted or the vibrating plate **584**. In some embodiments, the compactor **576** includes a paint sprayer **604** to spray and demarcate lines or boundaries in and around the compacting operation.

[0195] In operation, an operator can grasp the handle **592** and activate the motor unit **10** to drive the vibrating plate **584** to compact soil or asphalt, including granular, mixed materials that are mostly non-cohesive. During operation, the operator may control the valve **600** to allow water from the water tank **596** to be applied to the compacted surface, such that in some applications, the water allows the compacted particles to create a paste and bond together, forming a denser or tighter finished surface. In addition, the water from the water tank **596** prevents asphalt or other material from adhering to the vibrating plate **584** during operation.

[0196] The compactor **576** can be used in parking lots and on highway or bridge construction. In particular, the compactor **576** can be used in construction areas next to structures, curbs and abutments. The compactor **576** can also be used for landscaping for subbase and paver compaction. The compactor **576** including the motor unit **10** possesses advantages over a conventional compactor with by an internal combustion engine, some of which are discussed below. For instance, the motor **36** of the motor unit **10** can run forward or reverse, allowing the operator to shift directional bias of the vibration mechanism **588**. Thus the vibration mechanism **588** is configured to move or "walk" itself forward or reverse, depending on how the operator has shifted the directional bias of the vibration mechanism **588**.

[0197] In addition, the electronic processor **302** of the motor unit **10** can, for example: [0198] sense the levelness of compaction, such as the grade or pitch, by communicating with an auxiliary sensor device such as a surveying and grading tool **608**; [0199] sense the degree of compactness, such as whether the material being compacted is loose or sufficiently tight, by communicating with an auxiliary or onboard device **610** such as a durometer probe, ultrasound, accelerometer, or gyroscope. However, in other embodiments, the electronic processor **302** can simply monitor the current drawn by the motor **36** to sense the level of compactness; [0200] turn ON/OFF the motor unit **10**—and ultimately the vibration mechanism **588**, change a speed of the motor unit **10**, and output direction and steering of the compactor system **576**; [0201] use sensors **611** on the compactor system **576** that are in communication with the electronic processor **302** to detect where a compacted surface dips and in response, control the paint sprayer **604** to mark where more material is needed at the detected dip; and [0202] control the valve **600** of the water tank **596** to adjust the flow rate to the vibrating plate or compacted surface.

[0203] Test specifications of the compactor **576** appear in Table 9 below:

TABLE-US-00009 TABLE 9 Full Speed Motor Speed (RPM) 19,663 Average Current (Amperes) 26.4 Peak Current (95%) (Amperes) 32 Instantaneous Peak Current (Amperes) 52 Average Voltage (V) 71.9 Average Power (HP) 2.55 Peak Power (95%) (HP) 3.24 Runtime (Minutes) 12.78

[0204] The values listed in Table 9 were measured during a full discharge cycle of the battery pack **50** (i.e., full charge to shutoff due to the voltage of the battery pack **50** dropping below a predetermined value).

[0205] In another embodiment of a compactor **576** shown schematically in FIG. **31**, the vibration mechanism **588** is a multi-motor drive system with four separate vibration mechanisms **588***a*, **588***b*, **588***c*, **588***d*, each having its own motor and each configured to respectively vibrate an individual quadrant **612**, **614**, **616**, **618** of the vibrating plate **584**. Each vibration mechanism **588***a*, **588***b*, **588***c*, **588***d*, is controlled by a controller **620** of the compactor **576**. Thus, depending on readings from the auxiliary or onboard sensor devices **608**, **610** described above, the controller **620** can select which quadrant **612**, **614**, **616**, **618** requires vibration. In some embodiments, the controller **620** may receive instructions from an operator via, e.g., a remote control. In some embodiments, the controller **620** can control the vibration mechanisms **588***a*, **588***b*, **588***c*, **588***d* to move the compactor **576** forward or reverse, as well as steer or turn the compactor **576** via the vibration plate **584**.

[0206] FIG. **32** illustrates a rammer **624** including a body **628** supporting the stand-alone motor unit **10**, a vibrating plate **632**, and a vibration mechanism **636** intermediate the motor **10** and vibrating plate **632**, such that the motor unit **10** can drive the vibration mechanism **636** to drive the vibrating plate **632**. The rammer **624** includes a handle **640** extending from the body **628** to enable an operator to manipulate the rammer **624**.

[0207] In operation, an operator can grasp the handle **640** and activate the motor unit **10** to drive the vibrating plate **632** to compact cohesive and mixed soils in compact areas, such as trenches, foundations and footings. The rammer **624** including the motor unit **10** possesses advantages over a

conventional rammer driven with an internal combustion engine, some of which are discussed below.
[0208] For instance, the electronic processor **302** of the motor unit **10** can, for example: [0209] turn ON/OFF the motor unit **10**—and ultimately the vibration mechanism **636**, change a speed of the motor unit **10**; [0210] provide a delayed start of the motor unit **10**—all of which can occur without direct user input (e.g., via sensors or programs); and [0211] utilize preset modes for compacting soft, hard, loose, or tight material.
[0212] The electronic processor **302** can also input data from sensors **642** on the rammer **624** to detect whether the frequency and/or amplitude of the vibrating plate is within a predetermined range, such that the control electronics **42** can precisely control the speed of the motor unit **10** and adjust the frequency of vibration of the vibration mechanism **636**. In this manner, the electronic processor **302** can prevent amplified vibration or resonance and ensure that the rammer **624** is under control when the operator wishes to lower the output speed and reduce the rate of compaction. Also, this ensures that vibration energy is being efficiently transferred into the surface material instead of the operator.
[0213] Test specifications of the rammer **624** appear in Table 10 below:
TABLE-US-00010 TABLE 10 Full Speed Motor Speed (RPM) 19,863 Average Current (Amperes) 19.7 Peak Current (95%) (Amperes) 28 Instantaneous Peak Current (Amperes) 56 Average Voltage (V) 72.7 Average Power (HP) 1.92 Peak Power (95%) (HP) 2.76 Runtime (Minutes) 15.73
[0214] The values listed in Table 10 were measured during a full discharge cycle of the battery pack **50** (i.e., full charge to shutoff due to the voltage of the battery pack **50** dropping below a predetermined value).
[0215] As shown in FIG. **33**, in some embodiments, the gear train **110** of the motor unit **10** includes a terminal male shaft section **644** to which a first female shaft subassembly **648** can mount within a gearbox **650** of the motor unit **10**. The first female shaft subassembly **648** includes a first power take-off shaft **38***a* configured to drive a first tool and a female socket **652** that mates with the male shaft section **644**. In the embodiment of FIG. **33**, a second female shaft subassembly **656** is provided with the female socket **652** and a second power take-off shaft **38***b* configured to drive a second tool that is different than the first tool. Thus, the first and second female shaft subassemblies **648**, **656** may be conveniently swapped in and out of mating relationship with the male shaft section **644** to allow an operator to quickly and conveniently adapt the motor unit **10** to drive different first and second tools. In contrast, a typical gas engine does not permit such quick or convenient replacement of the power take-off shaft.
[0216] As shown in FIG. **34**, in some embodiments, the gear train **110** of the motor unit **10** includes a terminal female shaft section **660** to which a first male shaft subassembly **664** can mount within the gearbox **650** of the motor unit **10**. The first male shaft subassembly **664** includes the first power take-off shaft **38***a* configured to drive the first tool and a male shaft section **668** that mates with the female shaft section **660**. In the embodiment of FIG. **34**, a second male shaft subassembly **672** is provided with the male shaft section **668** and the second power take-off shaft **38***b* configured to drive the second tool. Thus, the first and second male shaft subassemblies **664**, **672** may be conveniently swapped in and out of mating relationship with the female shaft section **660** to allow an operator to quickly and conveniently adapt the motor unit **10** to drive different first and second tools. In contrast, a typical gas engine does not permit such quick or convenient replacement of the power take-off shaft. In some embodiments, the male shaft section **668** mates with the female shaft section **660** via a splined connection. In the embodiment illustrated in FIG. **34**, the first and second male shaft subassemblies **664**, **672** are axially retained to the gearbox **650** via a retaining ring **673** on the gearbox **650**.
[0217] In some embodiments, the female socket **652** mates with the male shaft section **644**, and the male shaft section **668** mates with the female shaft section **660**, via any of the following connection methods: spline-fit (FIG. **34**), keyed, half-circle shaft w/female bore (FIG. **35**), tongue & groove

(FIG. **36**), double "D" (FIG. **37**), face ratchet bolted together, Morse taper, internal/external thread, pinned together, flats and set screws, tapered shafts, or serrated connections (FIG. **38**).

[0218] In some embodiments, different types of power take-off shaft subassemblies **38** may couple to the gear train **110** using a quick-connect structure similar to any of the following applications: modular drill, pneumatic quick connect, socket set-style, ball-detent hex coupling, drill chuck, pins filling gaps around shaft, hole saw arbor. In some embodiments, different types of power take-off shaft subassemblies **38** may couple to the gear train **110** using one of the following coupling structures: Spring coupling, c-clamp style, love joy style, plates w/male/female pegs (FIG. **39**), or female collar with radial fasteners (FIG. **40**).

[0219] In another embodiment shown in FIG. **41**, the geartrain **110** includes a female shaft section **674** with a gear **674***a* and an elongate bore **675** for receiving a stem **676***a* of a first male shaft subassembly **676** having the first power take-off shaft **38***a*. The female shaft section **674** is rotatably supported in the gearbox **650** by first and second bearings **677**, **678**. Once received in the elongate bore **675**, the first male shaft subassembly **676** is axially secured to the female shaft section **674** via a fastener **679** inserted into the stem **676***a* of the first male shaft subassembly **676***a* while securing a washer **680** between the fastener **679** and the stem **676***a* of the first male shaft subassembly **676**. Thus, unlike the embodiments of FIGS. **33** and **34**, the embodiment of FIG. **41** requires the operator to access a side **681** of the gearbox **650** opposite the faceplate **124** to access the fastener **679**. In the embodiment of FIG. **41**, a second male shaft subassembly having the second power take-off shaft **38***b* can be inserted in lieu of the first male shaft subassembly **676** to allow an operator to conveniently adapt the motor unit **10** to drive different first and second tools. In contrast, a typical gas engine does not permit such quick or convenient replacement of the power take-off shaft.

[0220] In an embodiment shown in FIG. **43**, a shaft subassembly **682** may be removably coupled to the gearbox **650**. Specifically, the shaft subassembly **682** includes the faceplate **124**, the power take-off shaft **38** rotatably supported by a first bearing **688** in the faceplate **124**, and a first gear **692** arranged on and coupled for rotation with the power take-off shaft **38**. In some embodiments, the power take-off shaft **38** is axially constrained with respect to the faceplate **124** with a retaining ring **694**. The shaft subassembly **682** is removably received in a recess **696** of the gearbox **650**. The recess **696** includes a second bearing **700** for rotatably supporting an end **704** of the power take-off shaft **38** within the recess **696** when the shaft subassembly **682** is received in the recess **696** and coupled to the gearbox **650**.

[0221] Also, when the shaft subassembly **682** is received in the recess **696** and coupled to the gearbox **650**, the first gear **692** is engaged with an upstream gear **706** of the gear train **110**, the faceplate **124** covers the gear train **110** and the first gear **692** is the final drive gear of the gear train **110**, such that the gear train **110** can drive the power take-off shaft **38** using a first overall reduction ratio. When the shaft subassembly **682** is removed from the gearbox **650**, the first gear **692** can be replaced with a second gear, and the upstream gear **706** of the gear train **110** that engages with the first gear **692** can be changed as well. Using the second gear with the shaft subassembly **682** and a different gear as the upstream gear results in a second overall reduction ratio of the gear train **110**. The second overall reduction ratio is different than the first overall reduction ratio, such that an operator can reconfigure the shaft subassembly **682** for driving different tools by swapping between the first gear **692** and the second gear. Also, when the shaft subassembly **682** is removed from the gearbox **650**, at least a portion of the gear train **110** is exposed, thus enabling an operator to replace, repair, or access certain gears within the gear train **110**, such as the upstream gear **706**. In other embodiments, instead of just the first gear **692**, the entire shaft subassembly **682** can be changed out for a different subassembly to change the reduction ratio.

[0222] As shown in FIG. **43**, the motor **36** mounts to a portion of the gearbox **650** that has a generally C-shaped cross-section, and the faceplate **124** is part of a shaft subassembly **682** including the power take-off shaft **38**, with the faceplate **124** being generally planar. In an alternative embodiment shown in FIG. **44**, the geometries are swapped from those of the embodiment of FIG. **43**. Specifically, the motor **36** mounts to a portion of the gearbox **650** having a generally planar cross-section and the faceplate **124** has a generally reverse-C-shaped cross-section.

[0223] As shown in FIG. **45**, in some embodiments, a first gearbox **650***a* with a first gear train **110***a* is removably attachable to an adapter plate **712** adjacent the motor **36** in the housing **14**, such that the output shaft **106** of the motor **36** can drive the first gear train **110***a* when the first gearbox **650***a* is attached to the adapter plate **712**. A second gearbox **650***b* with a second gear train **110***b* that has a different reduction ratio than the first gear train **110***a* is also removably attachable to the adapter plate **712**. Thus, depending on what tool an operator wishes to drive with the motor unit **10**, an operator can select either the first or second gearboxes **650***a*, **650***b*. In some embodiments, the first and second gearboxes **650***a*, **650***b* can attach to the adapter plate **712** via a bayonet connection. In some embodiments, there are a plurality of additional gearboxes respectively having different gear trains than the first and second gear trains **110***a*, **110***b*, each of the additional gearboxes being attachable to the adapter plate **712**.

[0224] Instead of swappable gearboxes **650***a*, **650***b* as in the embodiment of FIG. **45**, and instead of embodiments of FIGS. **19** and **43** that allow an operator to change or replace individual gears, in some embodiments the gear train **110** in the gearbox **650** includes a transmission allowing an operator to shift gear sets to change the reduction ratio. In some embodiments, the gear train **110** in the gearbox **650** has a predetermined number of stages that can be arranged in different combinations to produce different outputs. For example, as shown in FIG. **46**, the gearbox **650** might include three slots **716**, **720**, **724** for accepting cartridge-style gear stages **728**, **732**, **736**, **740**, **744** (e.g., planetary stages). Thus, depending on the output that an operator desires from the gear train **110**, the operator can selectively insert three of the five stages **728**, **732**, **736**, **740**, **744** into the three slots **716**, **720**, **724** in a particular order depending on which tool the operator wishes the motor unit **10** to drive.

[0225] As shown in FIG. **47**, in some embodiments, the motor **36** is enveloped within the gear train **110** in the gearbox **650**. Specifically, the output shaft **106** of the motor **36** acts as a sun gear with three planetary gears **748**, **752**, **756** between the output shaft **106** and a ring gear **760** that includes a first face gear **764**. First and second spur gear **768**, **772** are arranged between the first face gear **764** and a second face gear **776**.

[0226] As shown in FIG. **48**, in some embodiments, the flange **34** is configured to translate all or part of the housing **14** and gearbox **650** with respect to the flange **34** to provide freedom for varying geometries of the power take-off shaft **38**. For instance, the flange **34** may include a groove **777** for receipt of a tongue **778** of the housing or gearbox **650** to permit lateral translation. In some embodiments, a locking mechanism **779** may be included to lock the housing **14** at a particular position with respect to the flange **34**. The lateral translation of housing **14** with respect to flange **34** permits an operator to slide the housing **14** in a direction away from the tool to which the motor unit **10** is mounted, then service or remove the power take-off shaft **38**, without having to decouple the flange **34** from the tool. In some embodiments, the housing **14** can translate with respect to the flange **34** in a direction parallel to, perpendicular to, or both parallel and perpendicular to the rotational axis **122** of the power take-off shaft **38**.

[0227] As shown in FIG. **49**, in some embodiments, the power take-off shaft **38** is coupled to an input shaft **780** of a tool via an endless drive member **784** (e.g., a belt or chain) that is coupled to first and second pulleys **785**, **786** that are respectively arranged on the power take-off shaft **38** and input shaft **780**. In the embodiment of FIG. **49**, the motor unit **10** also includes a tensioner **788** with a spring **792** to adjust the tension of the endless drive member **784**. In some embodiments, the first pulley **785** can be arranged on the input shaft **780** and the second pulley **786** can be arranged on the power take-off shaft **38** to produce a different gear reduction ratio.

[0228] As shown in FIG. **50**, in some embodiments, the gearbox **650** is sectioned to have a quartile faceplate **124** that allows for access to only the power take-off shaft **38**.

[0229] As shown in FIG. **51**, in some embodiments, the battery **50** can be stored within a cover **796** to protect the electronics from the ingress of water or moisture. In some embodiments, the cover **796** is a hard case cover **796**. As shown in FIG. **52**, in some embodiments, the battery **50** includes a system lock out apparatus, such as a keypad **797** or a key, which can be utilized to prevent unauthorized individuals from accessing the battery **50**, for example, in a scenario in which the battery **50** has been rented along with the motor unit **10**.
[0230] Because the control electronics **42** of the motor unit **10** don't require intake of ambient air for combustion or exhaust of noxious gases, the control electronics **42** can be fully sealed within a fully sealed waterproof compartment within housing **14**. As shown in FIG. **42***a*, in some embodiments, the housing **14** includes doors **798** that can open and close at various locations on the housing **14** to allow an operator to quickly reconfigure where the air intake and exhaust ports are located for cooling of the motor **36**. In some embodiments, the motor unit **10** can operate using AC power from a remote power source, or DC power via the battery **50**. Additionally, the motor unit **10** may include an AC power output **799**, as a passthrough or inverted to AC power, for connection with an AC power cord of a power tool. In some embodiments, the housing **14** includes inlets **801** (FIG. **42***a*) for pressurized air for cleaning or to supplement a cooling airflow.
[0231] In some embodiments, the motor unit **10** can be mated with a new tool (e.g. one of the pump system **520**, jetter **544**, compactor **576**, or rammer **624**) and the memory **306** can be reprogrammed to optimize the motor unit **10** for operation with the new tool. In some embodiments, the electronic processor **302** automatically recognizes which type of new tool the motor unit **10** has been mated with, and governs operation of the motor unit **10** accordingly. In some embodiments, the electronic processor **302** can automatically detect with which tool the motor unit **10** has been mated via Radio Frequency Identification (RFID) communication with the new tool. In another embodiment, the tool may be detected with a resistor inserted into a plug connected to the electronic processor **302**. For example, a resistor between 10K and 20K ohms would indicate to the electronic processor **302** that the motor unit **10** system was connected to a power trowel or other tool.
[0232] In yet another embodiment, the tool may be detected with a multi-position switch (e.g., a 10-position rotary switch). Each position on the switch would correspond with a different type of tool system.
[0233] In yet another embodiment, the tool may be detected with a user interface on the motor unit **10** in which a user selects, from a pre-programmed list, the make and model of tool to which the motor unit **10** is attached. The motor unit **10** would then apply the appropriate system controls for the tool.
[0234] In some embodiments, the memory **306** is reprogrammable via either BLUETOOTH or Wi-Fi communication protocols. In some embodiments, the electronic processor **302** has control modes for different uses of the same tool. The control modes may be preset or user-programmable, and may be programmed remotely via BLUETOOTH or Wi-Fi. In some embodiments, the electronic processor **302** utilizes master/slave tool-to-tool communication and coordination, such that the motor unit **10** can exert unidirectional control over a tool, or an operator can use a smartphone application to exert unidirectional control over the motor unit **10**.
[0235] In some embodiments, the operator or original equipment manufacturer (OEM) is allowed limited access to control the speed of the motor unit **10** through the electronic processor **302** via, e.g., a controller area network (CAN)-like interface. In some embodiments, the electronic processor **302** is capable of a wider range of speed selection with a single gear set in the gear train **110** than a gasoline engine. For example, the control electronics **42** are configured to drive the motor **36** at less than 2,000 RPM, which is lower than any speed a gasoline engine is capable of, which permits the associated tool to have a greater overall runtime over a full discharge of the battery **50**, than a gasoline engine. Additionally the control electronics **42** are configured to drive the motor at more than 3,600 RPM, which is higher than any speed a gasoline engine is capable of, and with the

capability to deliver more torque. The wider range of speeds of motor **36** offers greater efficiency and capability than a gasoline engine. In some embodiments, the operator could have access to control the current drawn by the motor **36** in addition to the speed.

[0236] In some embodiments, the electronic processor **302** is configured to log and report data. For example, the electronic processor **302** is configured to provide wired or wireless diagnostics for monitoring and reading the status of the motor unit **10**. For example, the electronic processor **302** can monitor and log motor unit **10** runtime for example, in a rental scenario. In some embodiments, the motor **36** and the electronic processor **302** use regenerative braking to charge the battery **50**. In some embodiments, the motor unit **10** includes a DC output **803** for lights or accessories (FIG. **42**). In some embodiments, the electronic processor **302** can detect anomalies or malfunctions of the motor unit **10** via voltage, current, motion, speed, and/or thermocouples. In some embodiments, the electronic processor **302** can detect unintended use of or stoppage of the motor unit **10**. If the tool driven by the motor unit **10** (e.g. one of the pump system **520**, jetter **544**, compactor **576**, or rammer **624**) is not running with the intended characteristics or is not being used correctly or safely, the electronic processor **302** can detect the anomaly and deactivate the motor unit **10**. For example, the motor unit **10** can include one or more accelerometers to sense if the motor unit **10** and tool is in the intended orientation. And, if the electronic processor **302** determines that the motor unit **10** is not in the intended orientation (i.e. the tool has fallen over), the electronic processor **302** can deactivate the motor unit **10**.

[0237] In some embodiments, the motor unit **10** includes accessible sensor ports **802** (FIG. **42**) to electrically connect with user-selected sensors for use with the piece of power equipment, such as accelerometers, gyroscopes, GPS units, or real time clocks, allowing an operator to customize the variables to be sensed and detected by the electronic processor **302**. In some embodiments, the electronic processor **302** can indicate the status of the battery **50**, such as when the battery is running low, to an operator via visual, audio, or tactile notifications. In some embodiments, the electronic processor **302** can operate an auxiliary motor that is separate from the motor **36** to drive an auxiliary device such as a winch. The auxiliary motor may be internal or external to the motor unit **10**.

[0238] In some embodiments, the motor unit **10** can include digital controls on a customizable user interface, such as a touch display or a combination of knobs and buttons. In contrast, an analog gasoline engine does not include such digital controls. In some embodiments, the user interface for the motor unit **10** can be modular, wired, or wireless and can be attachable to the motor unit **10** or be hand held. In some embodiments, the motor unit **10** can be controlled with a remote control **804** that includes status indicators for certain characteristics of the motor unit **10**, such as charge of the battery **50** and the temperature, as shown in FIG. **53**. In some embodiments, the motor unit **10** can provide status indications with a remote, programmable device. In some embodiments, the remote control **804** can include a USB cord **808** that plugs into a USB port **812** on the battery **50** (FIG. **52**), or a USB port elsewhere on the motor unit **10**, such that the remote control **804** can be charged by the battery **50**. In some embodiments the remote control **804** can be charged wirelessly from the battery **50**. The remote control **804** can include a variety of controls, such as: [0239] a button **816** to turn the motor unit **10** on or off; [0240] a joystick **820** to steer the tool (e.g., the compactor **576**); [0241] a dial **824** to adjust the flow rate of the tool (e.g. the pump system **520** or jetter **544**); [0242] a timer **828** for a delayed start or stop of the tool; and [0243] a switch **832** to select forward or reverse directions of the power take-off shaft **38**.

[0244] The remote control **804** can also control the operating pressure of the tool (e.g. the pump system **520** or jetter **544**), or other operating characteristics of the tool.

[0245] In an embodiment shown in FIGS. **54-58**, the housing **14** of the motor unit **10** is split into a base **836** having the first, second, third, fourth, fifth, and sixth sides, **18**, **22**, **26**, **28**, **30**, **32**, and a battery module **840** that is removably coupled to the base **836**. As explained in further detail below (with ref to FIGS. **78-82**), the motor unit **10** of FIGS. **54-58** has a different faceplate **124′** than the faceplate **124**. The battery module **840** includes the battery receptacle **54** for receiving the battery pack **50**, as described above. The battery module **840** also includes a pair of opposed side walls **844**, a rear wall **848**, and a front wall **852** opposite the rear wall **848**. The side walls **844** are longer than the rear and front walls **848**, **852**, such that the battery module **844** defines a battery module axis **854** that is parallel to the side walls **844**. The battery pack **50** is removable from the battery receptacle **54** by sliding the battery pack **50** in a direction away from the rear wall **848** in a direction parallel to or coaxial with the battery module axis **854**.

[0246] The battery module **840** also includes a plurality of coupling members, such as fasteners **856** (FIGS. **55** and **58**), configured to mate with a plurality of receiving elements, such as bores **860** on the fourth side **28** of the base **836**, such that the battery module **840** can be secured to the fourth side **28** of base **836**. The bores **860** are arranged on the fourth side **28** such that the battery module **840** is configured to be coupled to the base **836** in a first position (FIG. **54**) or a second position (FIGS. **56** and **57**). Thus, in some embodiments, there may be twice as many bores **860** as fasteners **856**, to facilitate the two different positions of the battery module **840** with respect to the base **836**. In some embodiments, there is at least one fastener **856** that is received in a different bore **860** when the battery module **840** is coupled to the base **836** in the first position than when the battery module **840** coupled to the base **836** in the second position. In some embodiments, one of the base **836** and the battery module **840** may include, e.g., an extended wire harness **858** (FIG. **58**) to facilitate the electrical connection between the second terminal **78** of the battery receptacle **54**, which is in the battery module **840**, and the control electronics **42**, which are in the base **836**.

[0247] In the first position of the battery module **840** shown in FIG. **54**, the side walls **844** of the battery module **840** are parallel to the second and third sides **22**, **26** of the base **836**, the battery module axis **854** is perpendicular to the rotational axis **122** of the power take-off shaft **38**, the rear and front walls **848**, **852** of the battery module **840** are perpendicular to the second side and third sides **22**, **26** of the base **836**, and the battery module **840** is removable in a direction away from the fifth side **30** of the base **836**. In the second position of the battery module shown in FIGS. **56** and **57**, the side walls **844** of the battery module **840** are perpendicular to the second and third sides **22**, **26** of the base **836**, the battery module axis **854** is parallel to the rotational axis **122** of the power take-off shaft **38**, the rear and front walls **848**, **852** of the battery module **840** are parallel to the second and third sides **22**, **26** of the base **836**, and the battery module **840** is removable in a direction away from the second side **22** of the base **836**.

[0248] Thus, when the operator or original equipment manufacturer (OEM) wants the motor unit **10** in an arrangement in which the battery pack **50** needs to be removable in the space above the sixth side **32** of the base **836**, or there needs to be free space above the power take-off shaft **38** and second side **22** of the base **836**, the operator or OEM can elect to couple the battery module **840** to the base **836** in the first position shown in FIG. **54**. Thus, the first position of the battery module **840** may be useful in, e.g., high vibration applications, horizontal power take-off shaft **38** applications (FIG. **54**), or vertical power take-off shaft **38** applications.

[0249] Alternatively, when the operator or OEM wants the motor unit **10** in an arrangement in which the battery pack **50** needs to be removable in a space above the third side **26** of the base **836**, or there needs to be free space above the fifth and sixth sides **30**, **32** of the base **836**, the operator or OEM can elect to couple the battery module **840** to the base **836** in the second position shown in FIGS. **56** and **57**. Thus, the second position of the battery module **840** may be useful in, e.g., high vibration applications, horizontal power take-off shaft **38** applications (FIG. **56**), or vertical power take-off shaft **38** applications (FIG. **57**).

[0250] As shown in FIGS. **55** and **58**, in some embodiments, the base **836** includes a plurality of vibration damping members, such as springs **864** and/or elastomeric spacers **868**, that inhibit vibration transferred from the base **836** to the battery module **840** during operation of the motor unit **10**. Thus, vibration transferred to the battery pack **50** is inhibited, increasing the lifespan of the battery pack **50**, the battery receptacle **54**, and the base **836**.

[0251] FIGS. **59-66** illustrate a motor **36***a* for the motor unit **10** that is different than the motor **36**. The motor **36***a* includes a stator **872**, a rotor **876** rotatable relative to the stator **872**, and a housing **880** in which the rotor **876** and stator **872** are arranged. The motor **36***a* also includes an adapter plate **884** coupled to the housing **880** and a back cover **888** coupled to the housing **880**. The housing **880** is sized to accommodate the specific diameter of the rotor **876**. In some embodiments, the rotor **876** has a diameter ranging from 70 mm to 120 mm.

[0252] An output shaft **892** of the rotor **876** protrudes from the adapter plate **884**. As shown in FIGS. **59** and **60**, the adapter plate **884** includes first plurality of holes **896** defining a first hole pattern. As shown in FIG. **60**, each of the holes **896** is the same distance D away from a rotational axis **900** defined by the output shaft **892**. A variety of different gearboxes **650***x* (FIG. **62**), **650***y* (FIG. **63**), and **650***z* (FIG. **64**) each have a second plurality of holes defining a second hole pattern that is identical to the first hole pattern defined by the first plurality of holes **896**. Thus, when at least two holes of the second hole pattern of one of the gearboxes **650***x*, **650***y*, **650***z* are aligned with at least two of the first plurality of holes **896**, the selected gearbox **650** may be coupled to the adapter plate **884** by, e.g., inserting fasteners through the aligned holes in the first and second hole patterns. In some embodiments, the fasteners may extend through the back cover **888**, the housing **880**, the adapter plate **884**, and the selected gearbox **650**. When one of the gearboxes **650***x*, **650***y*, **650***z* is coupled to the adapter plate **884**, the output shaft **892** extends into the selected gearbox **650**. In some embodiments, in addition to being coupled to the adapter plate **884** of the motor **36***a*, the selected gearbox **650** is also coupled to the housing **14** of the motor unit **10**. In some embodiments, the selected gearbox **650** is not coupled to the housing **14** of the motor unit **10**. In some embodiments, the gearbox **650** is coupled to the housing **14** and the motor **36***a* is coupled to the gearbox **650**, but not the housing **14**. In some embodiments, the motor **36***a* is coupled to the housing **14**, as well as the gearbox **650**.

[0253] A power take-off shaft **38** extends from each of the gearboxes **650***x*, **650***y*, **650***z* and the gearboxes **650***x*, **650***y*, **650***z* respectively include different gear trains **110***x*, **110***y*, **110***z* for transferring torque from the output shaft **892** to the power take-off shaft **38**. For instance, the gear train **110***x* may be a planetary gear train, the gear train **110***y* may be a 2-stage gear train, and the gear train **110***z* may be a transmission. Thus, depending on the piece of power equipment the operator wants to use with the motor unit **10**, and the type of speed reduction from the motor **36***a* to the power take-off shaft **38** the operator wants to achieve, the operator can couple one of the gearboxes **650***x*, **650***y*, **650***z* to the adapter plate **884** of the motor **36***a*.

[0254] In some embodiments, the first hole pattern defined by the first holes **896** is identical to a second hole pattern on the piece of power equipment **904** itself. Thus, when the at least two holes of the second hole pattern of the power equipment **904** are aligned with at least two holes of the first hole pattern defined by the plurality of holes **896**, the power equipment **904** may be coupled to the adapter plate **884** by, e.g., inserting the fasteners **900** through aligned holes in the first and second hole patterns. Thus, the output shaft **892** drives the power equipment **904** directly (FIG. **65**) or via a pulley **908** (FIG. **66**) used to drive a belt **912**.

[0255] FIG. **67** illustrates an embodiment similar to the embodiment shown in FIG. **43**, with the following difference explained below. Specifically, the first gear **692** is meshingly engaged with and driven by a pinion **916** on the output shaft **106** of the motor **36** when the shaft subassembly **682** is coupled to the gearbox **650**. The motor **36** is coupled to the gearbox **650** and the output shaft **106** is supported by a bearing **918** in the gearbox **650**.

[0256] In an embodiment shown in FIG. **68**, an internal ring gear **920** is coupled to or integrally formed on the power take-off shaft **38**, which is supported by a first bearing **924** in the removable faceplate **124** and a second bearing **928** in the gearbox **650**. The internal ring gear **920** is meshingly engaged with and driven by the pinion **916** on the output shaft **106** of the motor **36**, and the motor **36** is coupled to the gearbox **650**. Thus, the removable faceplate **124** may be removed to swap out the internal ring gear **920** for other gears. For instance, in other embodiments, instead of the internal ring gear **920**, the gear train **110** could include single or multiple stage spur (FIGS. **11** and **47**) or helical gear sets, single or multistage planetary gearset planetary gears (FIGS. **10**, **46**, **47**, and **62**), hydraulic coupling, or a belt/chain drive (FIGS. **49** and **66**). In the embodiments illustrated in FIGS. **67** and **68**, the rotational axis **118** of the output shaft **106** is parallel to the rotational axis **122** of the power take-off shaft **38**. However, in other embodiments, the rotational axis **118** of the output shaft **106** is coaxial with the inline with the rotational axis **122** of the power take-off shaft **38**. In still other embodiments, the rotational axis **118** of the output shaft **106** is perpendicular to the rotational axis **122** of the power take-off shaft **38**. In still other embodiments, the rotational axis **118** of the output shaft **106** forms an oblique angle with respect to the rotational axis **122** of the power take-off shaft **38** with the use of bevel gears or worm gears.

[0257] As discussed in many embodiments above, the motor unit **10** includes a gear train **110** to lower the rotational speed output by the power take-off shaft **38**, as compared with the rotational speed of the motor **36**. Generally, DC brushless motors, such as the motor **36**, operate most efficiently at high speeds, ranging between 15,000 and 30,000 RPM. However, the desired output speed of the power take-off shaft **38** is generally in a range of 2,000-3,600 RPM, which is roughly equivalent to the speed of a power take-off shaft of a 150-250 cc class V small combustion engine that the motor unit **10** is intended to replace.

[0258] In some embodiments, other electric motors could be used, such as outer rotor motors, AC induction motors, or brushed motors. In some embodiments, the gear train **110** could include internal ring gear(s) (e.g. FIG. **68**), planetary gears (FIGS. **10**, **46**, **47**, and **62**), belts and/or chains (FIGS. **49** and **66**), bevel gears (FIG. **12**), helical or spur gears (FIGS. **11** and **47**) or even viscous fluid coupling.

[0259] In addition to using a gear train **110** to provide a reduced rotational speed to the power take-off shaft **38**, motor speed control can be used to reduce the rotational speed of the motor **36**, and thus the power take-off shaft **38**. Because the exact gear reduction ratio of the gear train **110** is known, the electronic processor **302** of the motor unit **10** can accurately control the speed of the motor **36** to achieve the desired speed of the power take-off shaft **38**. Also, as shown in the embodiments of FIGS. **8**, **65**, and **66**, the output shaft **106** is also the power take-off shaft **38**, such that the motor **36** directly drives the power take-off shaft **38** without any intermediate gear train. Thus, in the embodiments of FIGS. **8**, **65** and **66**, the rotational speed of the motor **36** is the same as the rotational speed of the power take-off shaft **38**. In some embodiments, the gear train **110** may be configured to increase the rotational speed of the power take-off shaft **38** to a value greater than the rotational speed of the motor **36**. “Gearing up” may be useful in, e.g., applications in which the piece of power equipment is a vacuum cleaner being driven by the power take-off shaft **38**.

[0260] In an embodiment shown in FIGS. **69-71**, the faceplate **124** includes a first plurality of holes **932** defining a first hole pattern. In other embodiments, the faceplate **124** is omitted and the first plurality of holes **932** defining the first hole pattern can be on the second side **22** of the housing **14** or the gearbox **650**. An adapter plate **936** includes a second plurality of holes **940** defining a second hole pattern that is identical to the first hole pattern, such that when the second holes **940** are aligned with the first holes **932**, the adapter plate **936** is configured to be coupled to the faceplate **124**.

[0261] In some embodiments, the first and second hole patterns are the hole patterns shown in the Flange A mounting pattern from the SA E International Surface Vehicle Recommended Practice Manual, J609, section (R) “Mounting Flanges and Power Take-Off Shafts for Small Engines”, issued May 1958 and revised July 2003 (“the SAE J609”), which is incorporated herein by reference. Thus, the adapter plate **936** is not needed when the motor unit **10** is to be used with a piece of power equipment utilizing the SAE J609 Flange A mounting pattern, because the first plurality of holes **932** defining the SAE J609 Flange A mounting pattern can be used to mount the piece of power equipment directly to the faceplate **124**. In other embodiments, the first plurality of holes **932** could define other mounting patterns besides the SAE J609 Flange A mounting pattern, such as the SAE J609 Flange Patterns B, C, D, E or F mounting patterns.

[0262] The adapter plate **936** also includes a first set of mounting elements **944** configured to align with a second set of mounting elements on a piece of power equipment, such that the adapter plate **936** can be coupled to the piece of power equipment. The adapter plate **936** of FIGS. **69** and **70** has mounting elements **944** that are dowel pins configured to align with a second set of mounting elements on, for example, a rammer. However, a different adapter plate **936***a* of FIG. **71** has mounting elements **944***a* that are protrusions **946** with holes **947** configured to align with a second set of mounting elements on, for example, a lawn mower, log splitter, or earth auger, in a vertical power take-off shaft **38** mounting arrangement. The mounting elements **944***a* could have a pattern of holes as laid out in the SAE J609 Flange Patterns B, C, D, E or F mounting patterns.

[0263] In other embodiments, the mounting elements **944** may include studs or fasteners. In some embodiment, the studs could be threaded. The adapter plate **936** also includes a through bore **948** for passage of the power take-off shaft **38**. In some embodiments, the adapter plate **936** includes a piloting member configured to pilot the adapter plate **936** onto the piece of power equipment, such that first set of mounting elements **944** of the adapter plate **936** are forced to align with the second set of mounting elements on the piece of power equipment. In some embodiments, the second holes **940** are recessed mounting holes so that fasteners can be arranged sub-flush on equipment side **948** of the adapter plate **936** to allow the adapter plate **936** to sit flat on the power equipment to which it is mounted.

[0264] As shown in FIG. **71***a*, the motor unit **10** can be provided to an OEM without a power take-off shaft **38** assembled. The OEM could then select an appropriate power take-off shaft **38′**, **38″** for the application needed and assemble the selected power take-off shaft **38** to the motor unit **10**. In some embodiments, the faceplate **124** of the gearbox **650** would need to be removed to assemble the different power take-off shafts **38′**, **38″**.

[0265] When swapping out different power take-off shafts **38**, a variety of different methods can be used to axially retain the power take off shaft **38**, as shown in FIGS. **72-76**. In FIG. **72**, a final drive gear **952** of the gear train **110** has a journal **956** rotatably supported by a first bearing **960**, a shaft carrier **964** rotatably supported by a second bearing **968**, a recess **972** in the shaft carrier **964**, and a plurality of ball detents **976** biased into the recess **972** by, e.g., springs **978**. A power take-off shaft **38***x* shown in FIG. **72** includes a splined portion **980** having splines **982** configured to be received in the recess **972**, and a driving end **984** configured to drive the piece of power equipment. The splined portion **980** includes a circumferential recess **988**.

[0266] When the splined portion **980** of the power-take off shaft **38***x* is inserted into the recess **972** of the final drive gear **952**, the splines **982** engage with corresponding splines of the recess **972**, such that the power-take off shaft **38***x* is coupled for rotation with the final drive gear **952**. In other embodiments, instead of a splined portion **980** with splines **982**, the power take-off shaft **38***x* could include a D-shape, hex shape, or other key and keyway mating connection with the recess **972** to enable co-rotation with the drive gear **952**. Also, when the splined portion **980** is received into the recess **972**, the ball detents **976** are biased into the circumferential recess **988**, such that the power take-off shaft **38***x* is axially locked with respect to the final drive gear **952**. When the power-take off shaft **38***x* is secured in the final drive gear **952**, the power take-off shaft **38***x* is rotatably supported with respect to the gearbox **650** (illustrated), faceplate **124**, or adapter plate **936** by a third bearing **992**. The power take-off shaft **38***x* can be removed by the operator pulling on the driving end **984** to overcome the biasing force of the detents **976** and move them out of the circumferential recess **988**. Then the operator can insert a different power take-off shaft that also has the splined portion **980** with the circumferential recess **988**, but has a different driving end configured to drive a different piece of power equipment than the power take-off shaft **38***x*.

[0267] In another embodiment shown in FIG. **73**, a final drive gear **996** of the gear train **110** has a journal **1000** rotatably supported by a first bearing **1004**, a shaft carrier **1008**, and a recess **1012** in the shaft carrier **1008**. A power take-off shaft **38***y* shown in FIG. **74** includes a splined portion **1016** having splines **1020** configured to be received in the recess **1012**, and a driving end **1024** configured to drive the piece of power equipment. In other embodiments, instead of a splined portion **1016** with splines **1020**, the power take-off shaft **38***y* could include a D-shape, hex shape, or other key and keyway mating connection with the recess **1012** to enable co-rotation with the drive gear **996**. The power take-off shaft **38***y* includes a snap ring **1028**, or clip, configured to axially retain the power take-off shaft **38***y* to one of the gear box **650**, faceplate **124**, or adapter plate **936**, depending on how the motor unit **10** is configured for that particular application. The power take-off shaft **38***y* is rotatably supported with respect to the snap ring **1028** by a second bearing **1032**.

[0268] In another embodiment shown in FIG. **74**, a final drive gear **1036** of the gear train **110** has a first journal **1040** supported by a first bearing **1044**, a second journal **1048** supported by a second bearing **1052**, a shaft carrier **1054**, and a circumferential recess **1056** between the shaft carrier **1054** and the second journal **1048**. A quick release collar **1060** is arranged in the recess **1056** and is biased away from the first journal **1040** by a compression spring **1064**, but is prevented from being biased out of the recess **1056** by a retaining clip **1068** set in the recess **1056**. The collar **1060** includes a circumferential lip **1072** and circumferential recess **1076** adjacent the circumferential lip **1072**. A plurality of ball detents **1080** are set in a plurality of radial bores **1084** extending through the shaft carrier **1054**. The collar **1060** is biased by the spring **1064** to a first position (FIG. **74**), in which the circumferential lip **1072** is axially aligned with the ball detents **1080**, such that the detents **1080** are forced into a passage **1088** in the shaft carrier **1054**. The collar **1060** is moveable from the first position to a second position, in which the circumferential recess **1076** is axially aligned with the ball detents **1080**. A power take-off shaft **38***z* includes a splined portion **1092** with splines **1096** and a circumferential groove **1100**, and a driving end **1104** configured to drive the piece of power equipment.

[0269] In operation of the embodiment shown in FIG. **74**, the collar **1060** is moved to the second position by the operator and the splined portion **1092** of the power take-off shaft **38***z* is inserted into the passage **1088** of the shaft carrier **1054**, such that splines **1096** of the splined portion **1092** mate with corresponding splines in the passage **1088**, thus coupling the power take-off shaft **38***z* for rotation with the final drive gear **1036**. In other embodiments, instead of a splined portion **1092** with splines **1096**, the power take-off shaft **38***z* could include a D-shape, hex shape, or other key and keyway mating connection with the passage **1088** to enable co-rotation with the drive gear **1036**. As the power take-off shaft **38***z* is inserted, the ball detents **1080** are pushed by the power take-off shaft **38***z* radially outward into the circumferential recess **1076** of the collar **1060**. Once the power take-off shaft **38***z* has been inserted, the collar **1060** is released and biased back to the first position by the spring **1064**, causing the detents **1080** to be pushed by the circumferential lip **1072** of the collar **1060** to a radially inward position in which they are arranged in the circumferential grove **1100** of the power take-off shaft **38***z*, thus axially locking the power take-off shaft **38***z* with respect to the final drive gear **1036**. If the power take-off shaft **38***z* is attempted to be removed from the passage **1088** before moving the collar **1060** to the second position, the circumferential lip **1072** prevents the detents **1080** from moving radially outward, and thus the power take-off shaft **38***z* cannot be moved axially.

[0270] To remove the power take-off shaft **38***z* from the final drive gear **1036**, the collar **1060** is first moved to the second position by the operator and the power take-off shaft **38***z* is then pulled from the passage **1088**. As the power take-off shaft **38***z* moves out of the passage **1088**, the detents **1080** are pushed by the power take-off shaft **38***z* radially outward into the circumferential recess **1076** of the collar **1060**. Then the operator can insert a different power take-off shaft that also has the splined portion **1092** with the circumferential recess **1100**, but has a different driving end configured to drive a different piece of power equipment than the power take-off shaft **38***z*.

[0271] In another embodiment shown in FIG. **75**, a final drive gear **1100** of the gear train **110** has a first journal **1104** supported by a first bearing **1108**, a shaft carrier **1112** supported by a second bearing **116** arranged in the faceplate **124** of the gear box **650**. A quick release collar **1120** is arranged around the shaft carrier **1112** and is biased away from the first journal **1104** by a compression spring **1124** seated in a recess **1126** in the final drive gear **1100**. The release collar **1120** abuts against the second bearing **1116** when the faceplate **124** is coupled to the gearcase **650**.

[0272] The collar **1120** includes a circumferential lip **1128** and circumferential recess **1132** adjacent the circumferential lip **1128**. A plurality of ball detents **1136** are set in a plurality of bores **1140** extending through the shaft carrier **1112**. As noted above, when the faceplate **124** is coupled to the gearbox **650**, the collar **1120** is biased by the spring **1124** to a first position, in which the collar **1120** abuts the second bearing **1116**, such that the circumferential lip **1128** is axially aligned with the ball detents **1136**, and the detents **1136** are thus forced by the circumferential lip **1128** into a passage **1144** in the shaft carrier **1112**. When the faceplate **124**, and thus the second bearing **1116**, is removed from the gearbox **650**, the collar **1120** is moveable from the first position to a second position, in which the circumferential recess **1132** is axially aligned with the ball detents **1136**.

[0273] In operation of the embodiment shown in FIG. **75**, the faceplate **124** is not yet coupled to the gearbox and the collar **1120** is thus in the second position. The splined portion **1092** of the power take-off shaft **38***z* is inserted into the passage **1144** of the shaft carrier **1112**, such that splines **1096** of the splined portion **1092** mate with corresponding splines in the passage **1144**, thus coupling the power take-off shaft **38***z* for rotation with the final drive gear **1100**. In other embodiments, instead of a splined portion **1092** with splines **1096**, the power take-off shaft **38***z* could include a D-shape, hex shape, or other key and keyway mating connection with the passage **1144** to enable co-rotation with the drive gear **1100**. Once the power take-off shaft **38***z* has been inserted, the faceplate **124** is coupled to the gearbox **650**, thus causing the collar **1120** to be moved from the second position to the first position, causing the detents **1136** to be pushed by the circumferential lip **1128** of the collar **1120** to a radially inward position in which they are arranged in the circumferential recess **1100** of the power take-off shaft **38***z*, thus axially locking the power take-off shaft **38***z* with respect to the final drive gear **1100**. If the power take-off shaft **38***z* is attempted to be removed from the passage **1144** before moving the collar **1120** to the second position, the circumferential lip **1128** prevents the detents **1136** from moving radially outward, and thus the power take-off shaft **38***z* cannot be moved axially.

[0274] To remove the power take-off shaft **38***z* from the final drive gear **1100**, the faceplate **124**, and thus the second bearing **1116**, is removed from the gearbox **650**. As the faceplate **124** is removed, the collar **1120** is biased by the spring **1124** from the first position to the second position, in which the circumferential recess **1132** is axially aligned with the ball detents **1136**. The operator then pulls the power take-off shaft **38***z* from the passage **1144**. As the power take-off shaft **38***z* is pulled from the passage **1144**, the detents **1136** are pushed by the power take-off shaft **38***z* radially outward into the circumferential recess **1132** of the collar **1120**. Then the operator can insert a different power take-off shaft **38** that also has the splined portion **1092** with the circumferential recess **1100**, but has a different driving end configured to drive a different piece of power equipment than the power take-off shaft **38***z*.

[0275] In another embodiment shown in FIG. **76**, a final drive gear **1148** of the gear train **110** has a first journal **1152** supported by a first bearing **1156** and a shaft carrier **1160** supported by a second bearing **1116** arranged in the faceplate **124** of the gear box **650**. The shaft carrier **1160** includes a threaded bore **1164** for a set screw **1168** that is radially moveable into or out of a passage **1172** in the shaft carrier **1160**. To install a power take-off shaft **38***w*, an operator inserts the power take-off shat **38***w* into the passage **1172** until a circumferential groove **1176** in the shaft **38***w* is axially and circumferentially aligned with the bore **1164** of the shaft carrier **1160**. The operator then screws the set screw **1168** radially inward to engage the circumferential recess **1176** of the power take-off shaft **38***w*, such that the power take-off shaft **38***w* is axially coupled to the final drive gear **1148**. Also, because the power take-off shaft **38***w* has a splined portion **1180** having splines **1182** that mates with a corresponding splined portion in the passage **1172**, the power take-off shaft **38***w* is coupled for rotation with the final drive gear **1148**. In other embodiments, instead of a splined portion **1180** with splines **1182**, the power take-off shaft **38***z* could include a D-shape, hex shape, or other key and keyway mating connection with the passage **1172** to enable co-rotation with the drive gear **148**.

[0276] In order to remove the power take-off shaft **38***w*, the operator simply unscrews the set screw **1168** until it is out of the circumferential groove **1176** and passage **1172**, and then removes the power take-off shaft **38***w*. Then the operator can insert a different power take-off shaft **38** that also has the splined portion **1180** with the circumferential groove **1176**, but has a different driving end configured to drive a different piece of power equipment than the power take-off shaft **38***w*. In other embodiments, instead of a circumferential groove **1176**, the power take-off shaft **38***w* could include a radial bore to receive the set screw **1168**, thus enabling both axial retention and co-rotation with the drive gear **1148**.

[0277] Thus, with interchangeable adapter plates **936**, **936***a*, and interchange power take-off shafts **38**, such as the power take-off shaft **38***a*, **38***b*, **38***w*, **38***x*, **38***y*, **38***z* and their corresponding mounting arrangements described above and shown in FIGS. **33**, **34** and **72-76**, the motor unit **10** can be customized to mate with and drive a variety of different pieces of power equipment. Indeed, the power take-off shaft **38** could have the dimensions of any of the power take-off shaft Extensions for horizontal crankshaft engines defined in the SAE J609, such as the dimensions of Extensions 1, 2, 3, 4, 4a, 4b, 6, 6a, 6b, or 8.

[0278] In another embodiment shown in FIG. **77**, like the embodiment of FIGS. **69-71**, the faceplate **124** includes the first plurality of holes **932** defining a first hole pattern. However, unlike the embodiment of FIGS. **69-71**, instead of a through bore **948**, the embodiment of FIG. **77** includes an adapter plate **1184** having a rotatable power take-off shaft **38**. Depending on the desired application, the power take-off shaft **38** could have the dimensions of any of the extensions defined in the SAE J609, such as extensions 1, 2, 3, 4, 4a, 4b, 6, 6a, 6b, or 8.

[0279] Like the adapter plate **936** of FIGS. **69-71**, the adapter plate **1184** includes the second plurality of holes **940** defining the second hole pattern that is identical to the first hole pattern, such that when the second holes **940** are aligned with first holes **932** of the faceplate **124**, the adapter plate **1104** is configured to be coupled to the faceplate **124**.

[0280] The adapter plate **1104** also includes a third plurality of holes **1188** defining a third hole pattern that is different than the first and second hole patterns and identical to a fourth hole pattern on a certain piece of power equipment. Thus, after the adapter plate **1104** has been coupled to the faceplate **124**, the adapter plate **1104** is configured to be coupled to the piece of power equipment when the third hole pattern is aligned with the fourth hole pattern. When the adapter plate **1104** is coupled to both the faceplate **124** and the piece of power equipment, the power take-off shaft **38** is configured to receive torque from the motor **36** via the geartrain **110** to thereby drive the piece of power equipment. In some embodiments, the third hole pattern could be one of the SAE J609 Flange Patterns B, C, D, E or F mounting hole patterns.

[0281] Unlike the adapter plate **936**, the adapter plate **1184** does not require an operator to swap out power take-off shafts **38**, because the power take-off shaft **38** is included as part of the adapter plate **1184**. Thus, different adapter plates **1184** can be created with different combinations of third hole patterns and power take-off shafts **38** directed to certain types of equipment. Some examples are listed in the table below. However, the combinations and permutations of the adapter plate **1184** are not limited to these examples, and the adapter plate **1184** can have its third hole pattern and power take-off shaft **38** modified to mate with any application.

TABLE-US-00011 Example 1 Example 2 Example 3 Example 4 Example 5 Third hole pattern of adapter SEA J609 SEA J609 SEA J609 SEA J609 SEA J609 plate 1104 Flange A Flange A Flange A Flange B Flange C Type of power take-off shaft SAE J609 SAE J609 SAE J609 SAE J609 SAE J609 38 for adapter plate 1104 Extension 3 Extension 5 Extension 7 Extension 3 Extension 7

[0282] In an embodiment of the motor unit **10** shown in FIG. **78**, the motor unit **10** includes the gearbox **650** with the faceplate **124**, and the power take-off shaft **38** with a pinion **1192**. An external gearbox **650***e* is coupled to the faceplate **124** via the first plurality of holes **932** defining a first hole pattern, which match a corresponding pattern of holes **1196** on the external gearbox **650***e*. The external gearbox **650***e* has a faceplate **124′** that also has the first plurality of holes **932** defining the first hole pattern, such that the faceplate **124′** can couple to the piece of power equipment by aligning the first hole pattern with an identical hole pattern on the piece of power equipment. The external gearbox **650***e* has a power take-off shaft **38***e* that receives torque via the motor **36**, the gear train **110** of the gearbox **650**, the power take-off shaft **38** with pinion **1192**, and a second gear train **110***s* of external gearbox **650***e*. Thus, the external gear box **650***e* can be coupled to the faceplate **124** and used to achieve additional gear reduction that would not be achievable with the gearbox **650** alone.

[0283] In an embodiment of the motor unit **10** shown in FIGS. **79** and **80**, the first plurality of holes **932** of the face plate **124** has a SAE J609 Flange A mounting hole pattern. Thus, the motor unit **10** is ready, without alteration, to be coupled to a legacy gearbox **6501** of a piece of power equipment that has a corresponding pattern of holes **1120** that align with the first plurality of holes **932**. Thus, the legacy gearbox **6501** could be easily installed to the motor unit **10** and/or serviced.

[0284] In an embodiment shown in FIGS. **81** and **82**, the motor unit **10** includes the gearbox with a faceplate **124′**, and the power take-off shaft **38** having a keyway shaft, such as the J609 Extension 3 shaft. The external gearbox **650***e* is coupled to the faceplate **124′** via the first plurality of holes **932** defining a first hole pattern, which match the corresponding pattern of holes **1196** on the external gearbox **650***e*. The external gearbox **650***e* has the same faceplate **124′** as the faceplate **124′** of the gearbox **650**, and thus the same first plurality of holes **932**. Thus, the external gear box **650***e* can be coupled to the faceplate **124**, and then to the piece of power equipment by aligning the first plurality of holes **932** of the gearbox **650** with the piece of power equipment. The external gear box **650***e* can thus be used to achieve additional gear reduction that would not be achievable with the gearbox **650** alone. The faceplate **124′** also has the same power take-off shaft **38** as the power take-off shaft **38** of the motor unit **10**, such that these parts would be easy to swap between the gearbox **650** and external gearbox **650***e*. Thus, an operator or OEM could use the external gearbox **650***e* to achieve a mechanical reduction, but still have the option to swap the power take-off shaft **38** to be the J609 Extension 5 shaft, and to replace faceplate **124′** to utilize a new J609 flange mounting pattern. Also, the power take-off shaft **38** of the external gearbox **650***e* thus receives torque via the motor **36**, the gear train **110** of the gearbox **650**, the power take-off shaft **38** of the motor unit **10**, and the second gear train **110***s* of external gearbox **650***e*.

[0285] FIG. **83** schematically illustrates another embodiment of the gear train **110** for transferring torque from the motor **36** to the power take-off shaft **38**. Specifically, the gear train **110** includes an intermediate shaft **1200** having a first spur gear **1204** engaged with the motor pinion **128** on the output shaft **106**, and a second spur gear **1208** engaged with a third spur gear **1212** on the power take-off shaft **38**. The intermediate shaft **1200** defines an intermediate axis **1216** that is parallel to both the rotational axis **118** of the output shaft **106** and the rotational axis **122** of the power take-off shaft **38**. Thus, in the multi-stage spur gear embodiment of FIG. **83**, torque is transferred from the output shaft **106** to the intermediate shaft **1200** and then to the power take-off shaft **38**, via the first, second, and third spur gears **1204**, **1208**, **1212**. The multi-stage spur gear arrangement of the gear train **110** permits the individual gears **1204**, **1208**, **1212** to have smaller diameters than, for example, the gears in the single stage spur gear train arrangement of FIG. **11**. Also, in some embodiments, the first, second, and third spur gears **1204**, **1208**, **1212** are removable and replaceable with different gears to allow the operator to achieve different gear reduction ratios.

[0286] FIG. **84** schematically illustrates several other embodiments of the gear train **110** for transferring torque from the motor **36** to the power take-off shaft **38**.

[0287] In a first embodiment of FIG. **84**, the gear train **110** includes a multi-speed transmission capable of shifting one or more gears to change the reduction ratio of the gear train **110**, and thus the rotational output speed of the power take-off shaft **38**, without changing the speed of the motor **36**. The motor **36** typically operates at a high speed so when the output shaft **106** speed is reduced, the motor **36** may not be capable of producing adequate power across the entire operating range of a gas engine. For example, if the motor **36** was geared to provide the full-speed, wide open throttle (WOT) performance of a small gas engine, it would be difficult for the power take-off shaft **38** to also match the torque performance of that gas engine at lower speeds. An additional gearset (or sets) with a multi-speed transmission extends the total output speed and torque range to the power take-off shaft **38**. Thus, the arrangement of FIG. **84** enable the motor unit **10** to achieve a wider range of speeds for the power take-off shaft **38**.

[0288] In a second embodiment of FIG. **84**, the gear train **110** includes a planetary gear set. A planetary gear set allows a compact design envelope to achieve a desired gear reduction ratio, as compared with a single stage spur gear (FIG. **11**) or multi-stage spur gear (FIG. **83**) arrangement. Smaller gears could be produced using less material and cheaper manufacturing methods (e.g.: powder metallurgy versus CNC machining).

[0289] In a third embodiment of FIG. **84**, the gear train **110** includes a continuously variable transmission ("CVT"). In some embodiments, the CVT is an electronically controlled CVT ("eCVT"). Using a CVT or eCVT in the motor unit **10** provides OEMs and users flexibility when choosing different gear ratios, and/or a program could be used to determine the correct output speed for a particular application.

[0290] Various features of the invention are set forth in the following claims.

Claims

1. A stand-alone motor unit for use with a piece of power equipment, the motor unit comprising: a housing; an electric motor arranged in the housing; a battery pack to provide power to the electric motor; a first plurality of holes in a side of the housing, the first plurality of holes defining a first hole pattern; a first power take-off shaft extending from the side of the housing; a gearbox including a first gear train configured to transfer torque from the motor to the first power take-off shaft; and an external gearbox including a second gear train configured to receive torque from the first power take-off shaft, a second plurality of holes defining a second hole pattern that is identical to the first hole pattern, such that the external gearbox is configured to be coupled to the side of the housing when the first hole pattern is aligned with the second hole pattern, a second power take-off shaft receiving torque from the second gear train, and a third plurality of holes defining a third hole pattern that is identical to a fourth hole pattern on the piece of power equipment, such that the piece of power equipment is configured to be coupled to the external gearbox when the third hole pattern is aligned with the fourth hole pattern, wherein when the external gearbox is coupled to the side of the housing and the piece of power equipment, the second power take-off shaft is configured to receive torque from the motor via the first gear train, first power take-off shaft, and second gear train.

2. The stand-alone motor unit of claim 1, wherein the third hole pattern is identical to the first hole pattern.

3. The stand-alone motor unit of claim 1, wherein the first hole pattern is an SAE J609 Flange A mounting pattern.

4. The stand-alone motor unit of claim 1, wherein the first power take-off shaft includes a keyway shaft.

5. The stand-alone motor unit of claim 4, wherein the first power take-off shaft includes a J609 Extension 3 shaft.

6. The stand-alone motor unit of claim 1, wherein the second power take-off shaft is the same as the first power take-off shaft.

7. The stand-alone motor unit of claim 1, wherein the housing includes a first faceplate on which the first plurality of holes is arranged.

8. The stand-alone motor unit of claim 7, wherein the external gearbox includes a second faceplate on which the third plurality of holes is arranged.

9. The stand-alone motor unit of claim 8, wherein the second faceplate is the same as the first faceplate.

10. A stand-alone motor unit for use with a piece of power equipment, the motor unit comprising: a housing; an electric motor arranged in the housing; a battery pack to provide power to the electric motor; a first plurality of holes in a side of the housing, the first plurality of holes defining a first hole pattern; a first power take-off shaft extending from the side of the housing; and an external gearbox including a gear train configured to receive torque from the first power take-off shaft, a second plurality of holes defining a second hole pattern that is identical to the first hole pattern, such that the external gearbox is configured to be coupled to the side of the housing when the first hole pattern is aligned with the second hole pattern, a second power take-off shaft receiving torque from the gear train, and a third plurality of holes defining a third hole pattern that is identical to a fourth hole pattern on the piece of power equipment, such that the piece of power equipment is configured to be coupled to the external gearbox when the third hole pattern is aligned with the fourth hole pattern, wherein when the external gearbox is coupled to the side of the housing and the piece of power equipment, the second power take-off shaft is configured to receive torque from the motor via the first power take-off shaft and the gear train.

11. The stand-alone motor unit of claim 10, wherein the gear train includes a planetary gear set.

12. The stand-alone motor unit of claim 10, wherein the gear train includes a continuously variable transmission.

13. The stand-alone motor unit of claim 10, wherein the gear train includes an intermediate shaft that is parallel to the first and second power take-off shafts.

14. The stand-alone motor unit of claim 13, wherein the intermediate shaft supports a first spur gear that is coupled to the first power take-off shaft and a second spur gear that is coupled to the second power take-off shaft.

15. The stand-alone motor unit of claim 10, wherein the third hole pattern is identical to the first hole pattern.

16. The stand-alone motor unit of claim 10, wherein the second power take-off shaft is the same as the first power take-off shaft.

17. A stand-alone motor unit for use with a piece of power equipment, the motor unit comprising: a housing; an electric motor arranged in the housing; a battery pack to provide power to the electric motor; a first plurality of holes in a side of the housing, the first plurality of holes defining a first hole pattern; a gearbox including a first gear train configured to transfer torque from the motor; and an external gearbox including a second gear train configured to receive torque from the first gear train, a second plurality of holes defining a second hole pattern that is identical to the first hole pattern, such that the external gearbox is configured to be coupled to the side of the housing when the first hole pattern is aligned with the second hole pattern, a power take-off shaft receiving torque from the second gear train, and a third plurality of holes defining a third hole pattern that is identical to a fourth hole pattern on the piece of power equipment, such that the piece of power equipment is configured to be coupled to the external gearbox when the third hole pattern is aligned with the fourth hole pattern, wherein when the external gearbox is coupled to the side of the housing and the piece of power equipment, the power take-off shaft is configured to receive torque from the motor via the first gear train and the second gear train.

18. The stand-alone motor unit of claim 17, wherein the housing includes a first faceplate on which the first plurality of holes is arranged.

19. The stand-alone motor unit of claim 18, wherein the external gearbox includes a second faceplate on which the third plurality of holes is arranged.

20. The stand-alone motor unit of claim 19, wherein the power take-off shaft extends form the second faceplate.