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(54) BATTERY-POWERED STAND-ALONE
MOTOR UNIT*F16F 15/08* (2006.01)*H01M 50/209* (2021.01)(71) Applicant: MILWAUKEE ELECTRIC TOOL
CORPORATION, Brookfield, WI (US)*H02K 7/116* (2006.01)*H02K 11/33* (2016.01)*H02K 21/16* (2006.01)(72) Inventors: Connor P. Sprague, Milwaukee, WI
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WI (US)

(21) Appl. No.: 19/187,507

(52) U.S. Cl.

CPC *H02K 11/0094* (2013.01); *H01M 50/209*
(2021.01); *H02K 7/116* (2013.01); *H02K
11/33* (2016.01); *H02K 21/16* (2013.01); *E01C
19/402* (2013.01); *F16F 15/04* (2013.01);
F16F 15/08 (2013.01); *H01M 2220/30*
(2013.01)

(22) Filed: Apr. 23, 2025

ABSTRACT**Related U.S. Application Data**

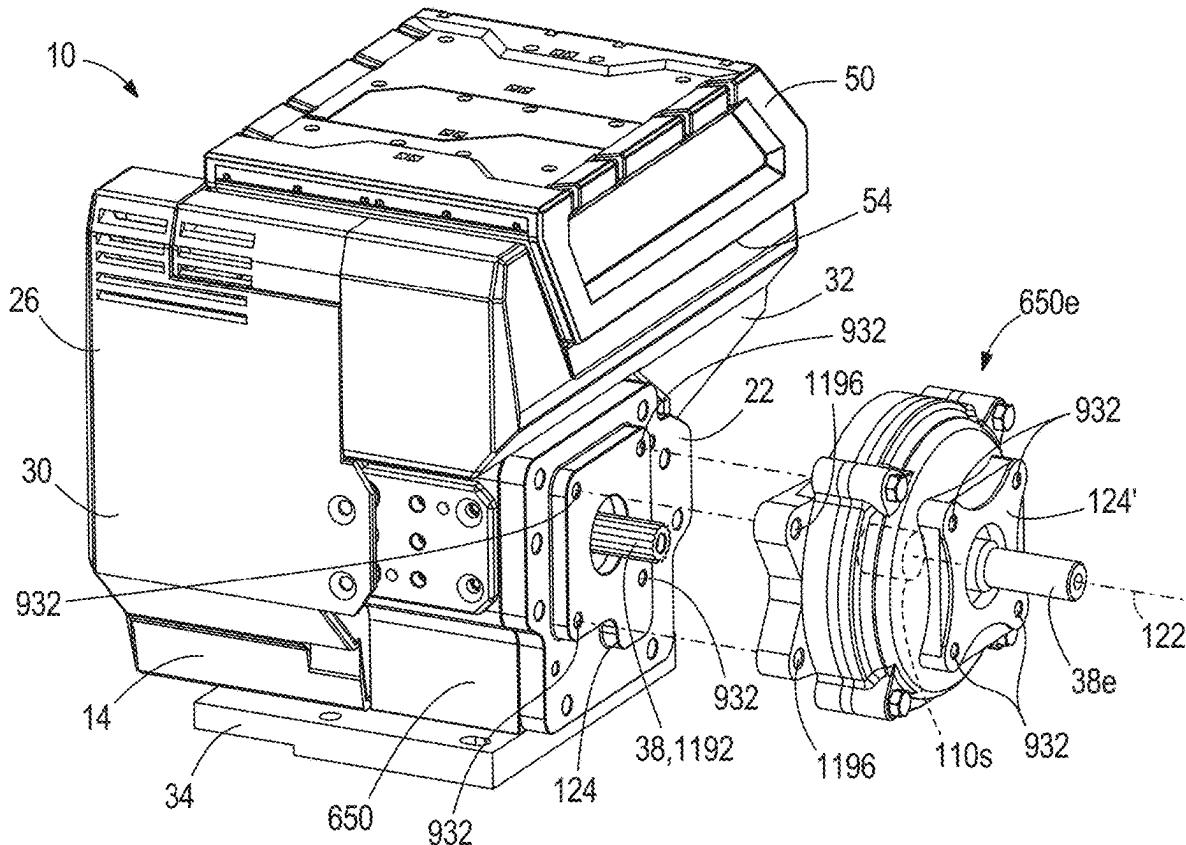
- (63) Continuation of application No. 18/133,017, filed on Apr. 11, 2023, now Pat. No. 12,294,249, which is a continuation of application No. 17/092,917, filed on Nov. 9, 2020, now Pat. No. 11,658,546.
- (60) Provisional application No. 62/952,566, filed on Dec. 23, 2019, provisional application No. 62/932,703, filed on Nov. 8, 2019.

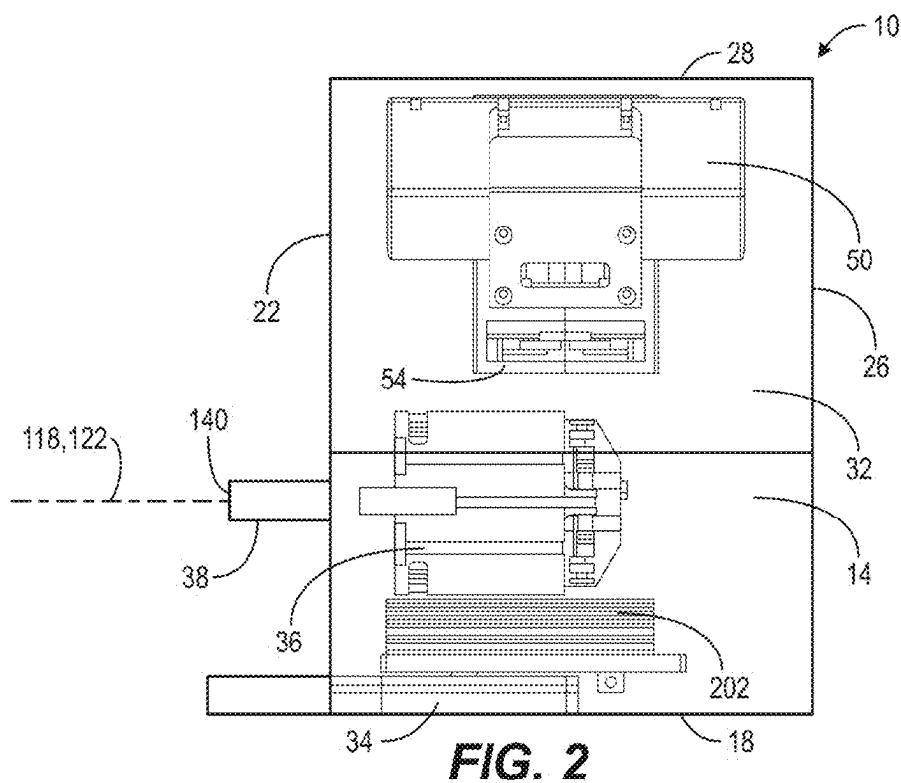
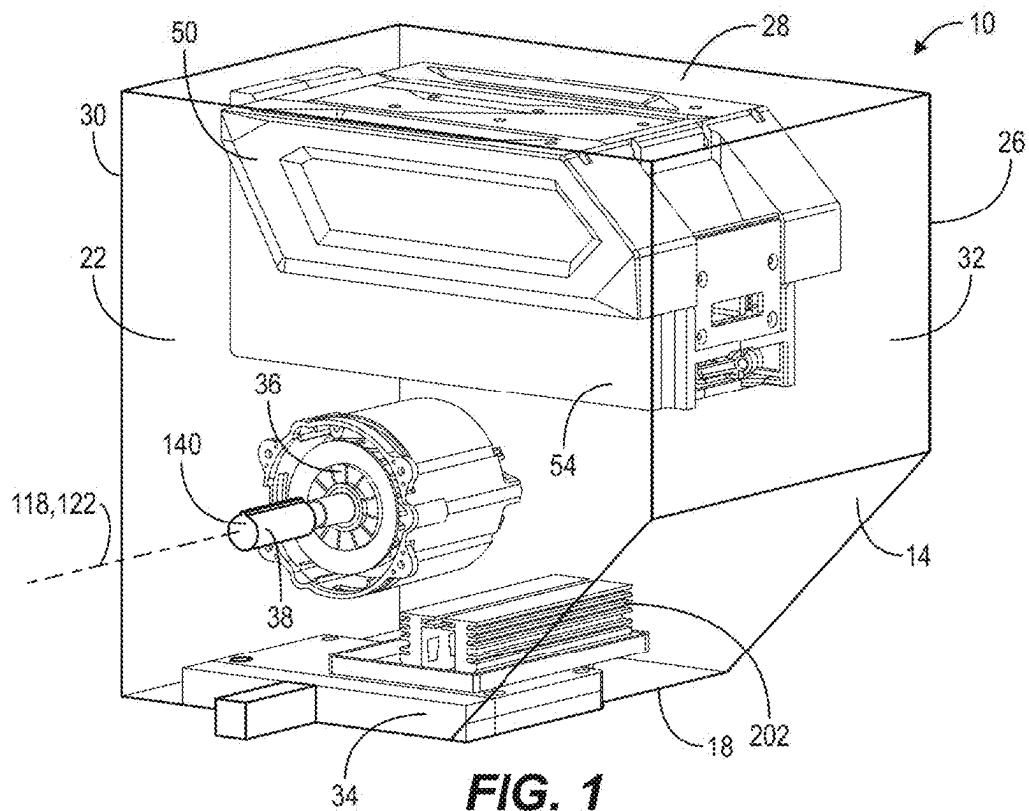
Publication Classification

(51) Int. Cl.

H02K 11/00 (2016.01)
E01C 19/40 (2006.01)
F16F 15/04 (2006.01)

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.





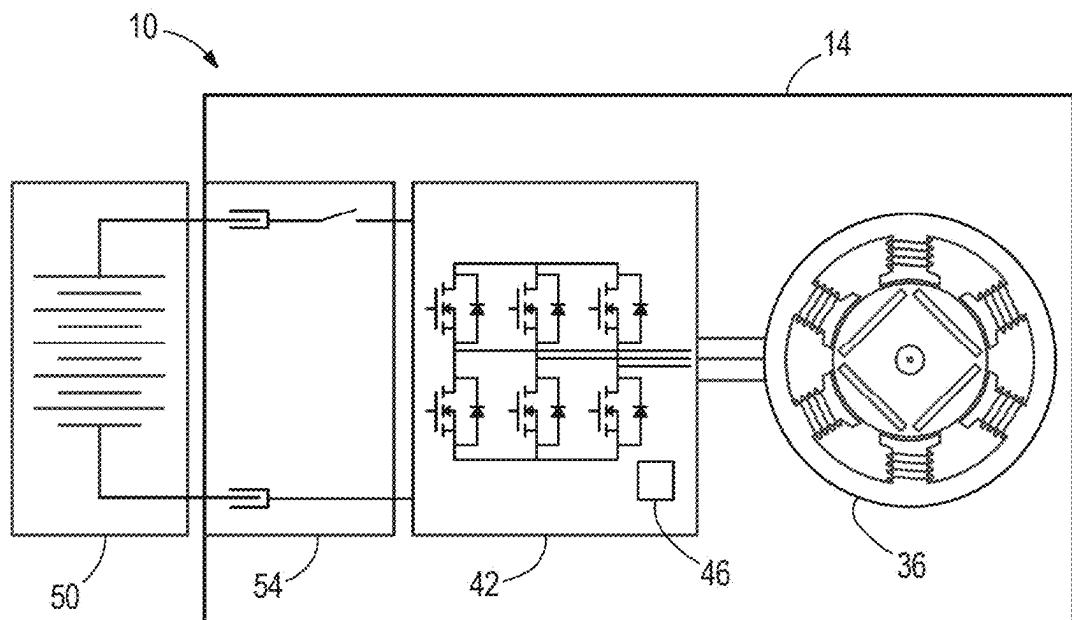


FIG. 3

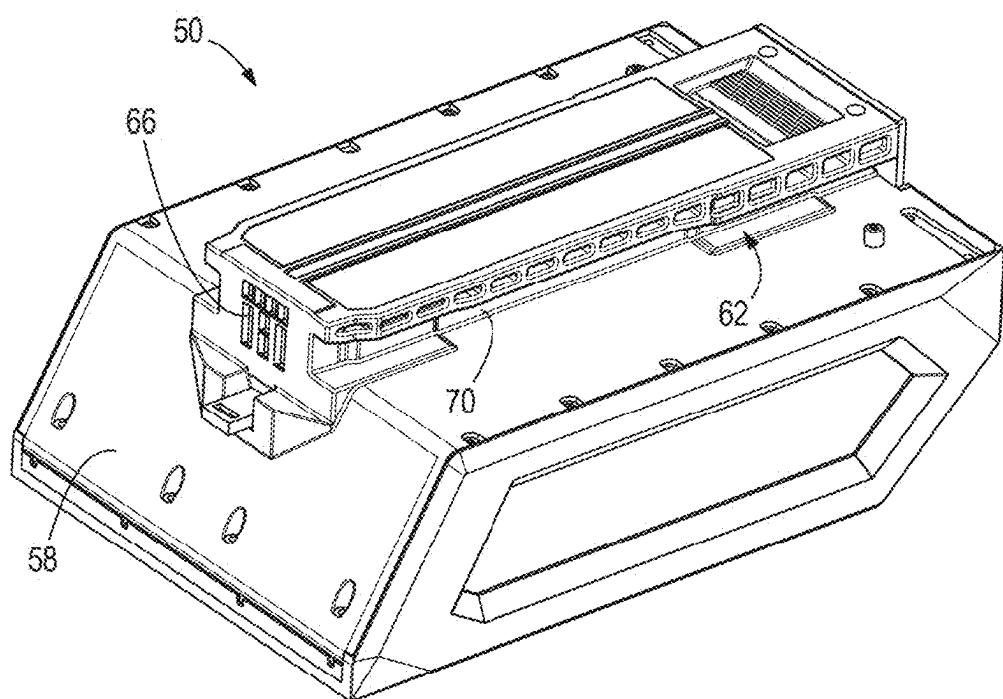


FIG. 4

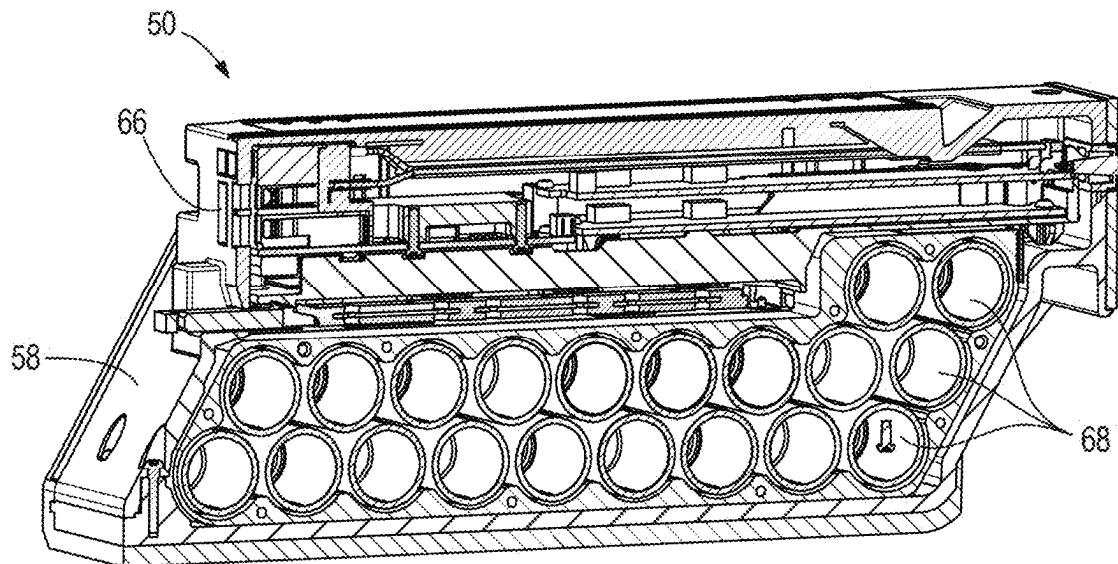


FIG. 5

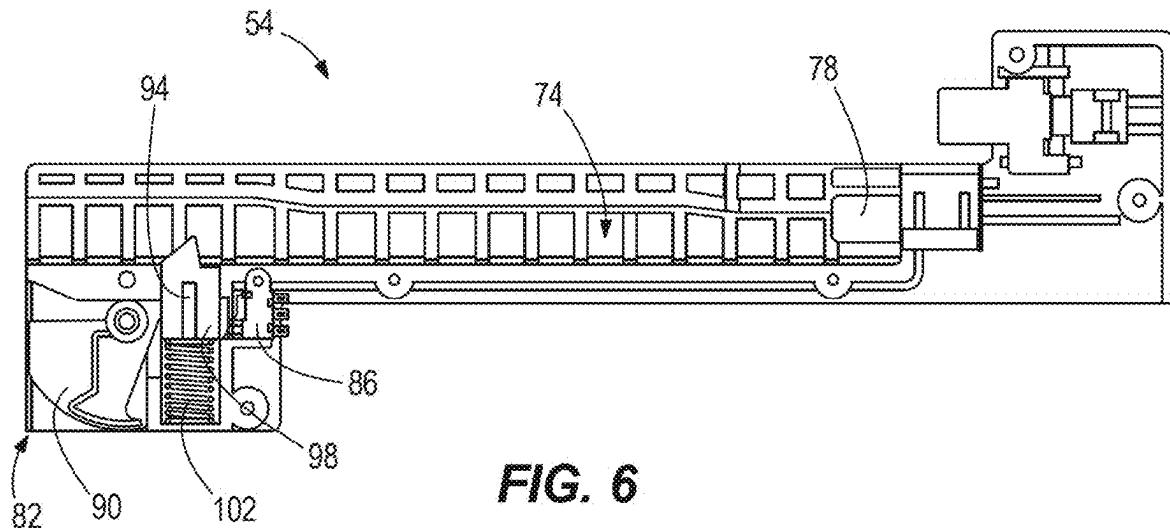


FIG. 6

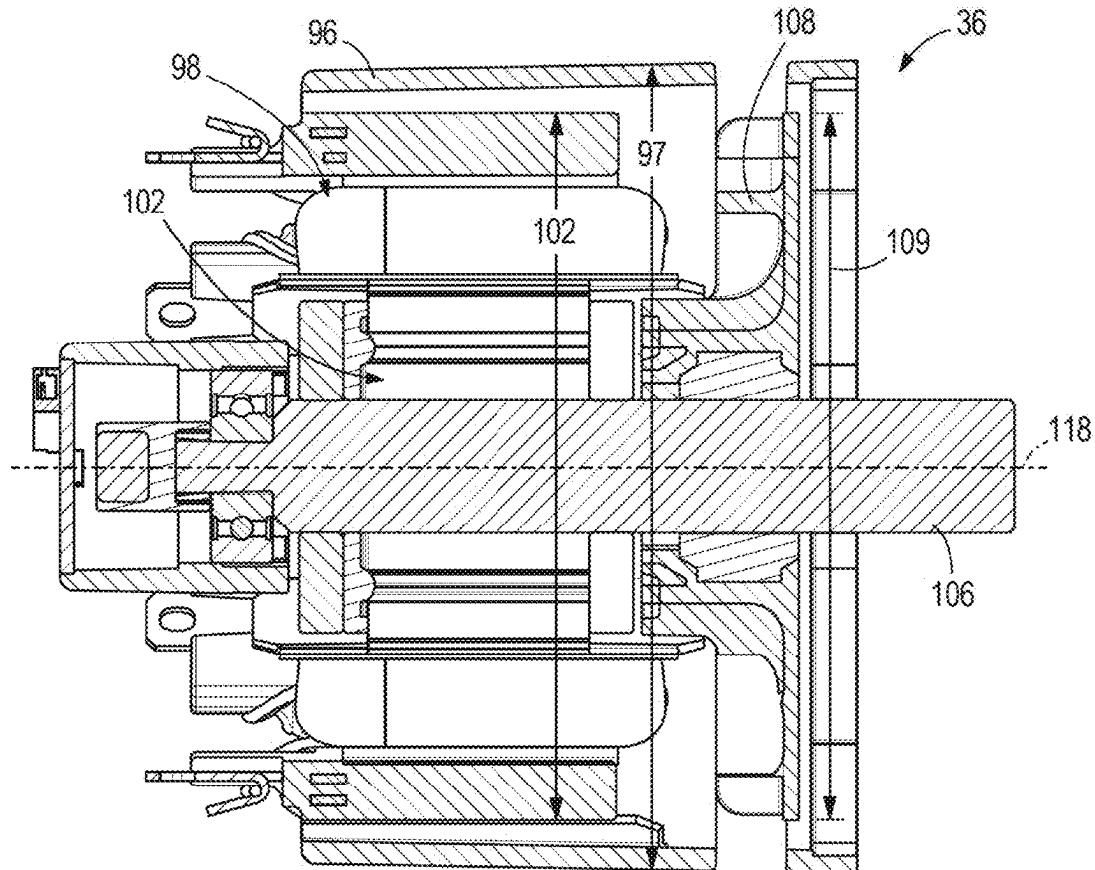


FIG. 7

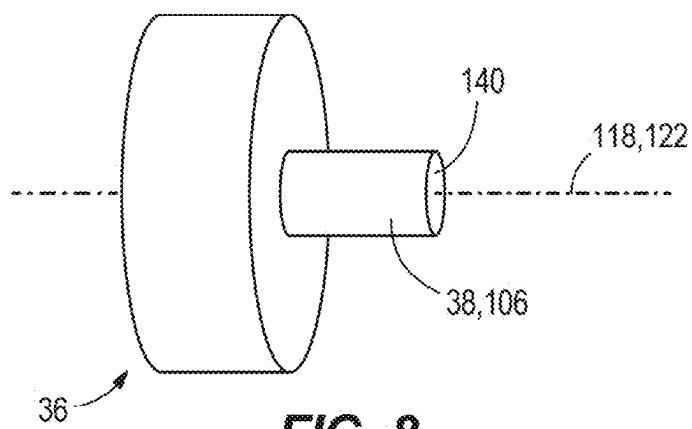
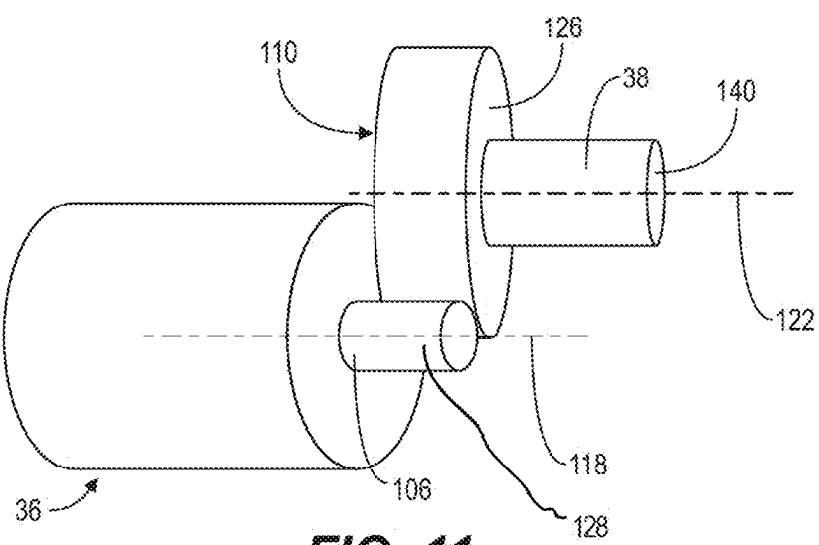
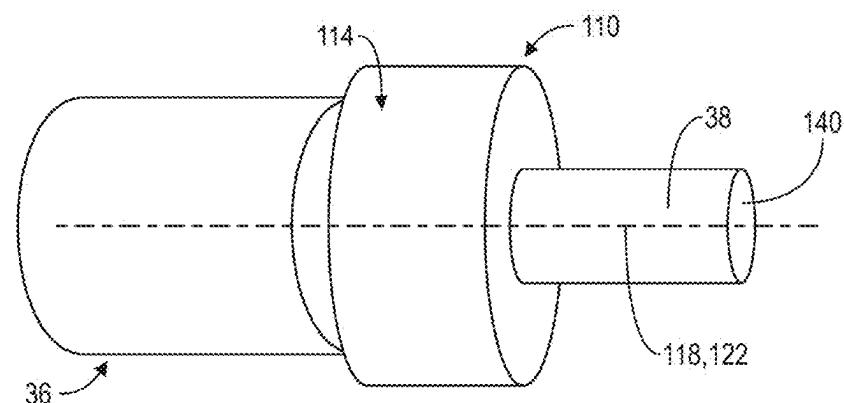
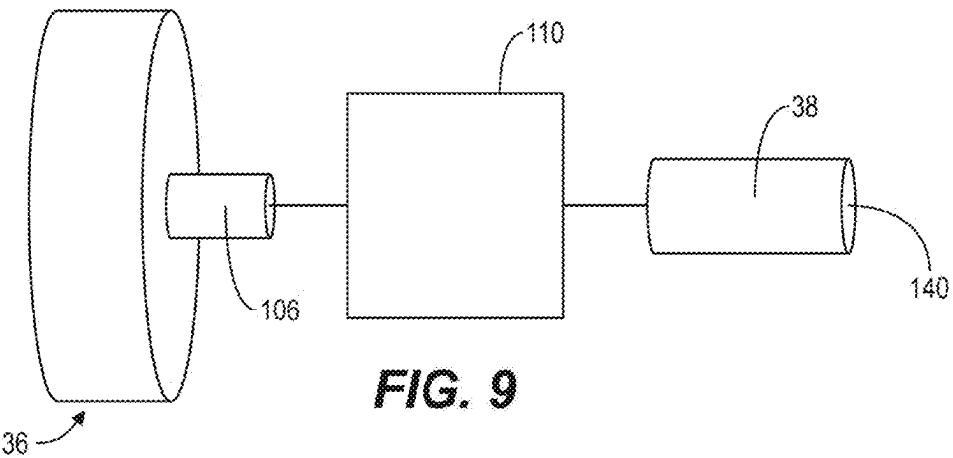
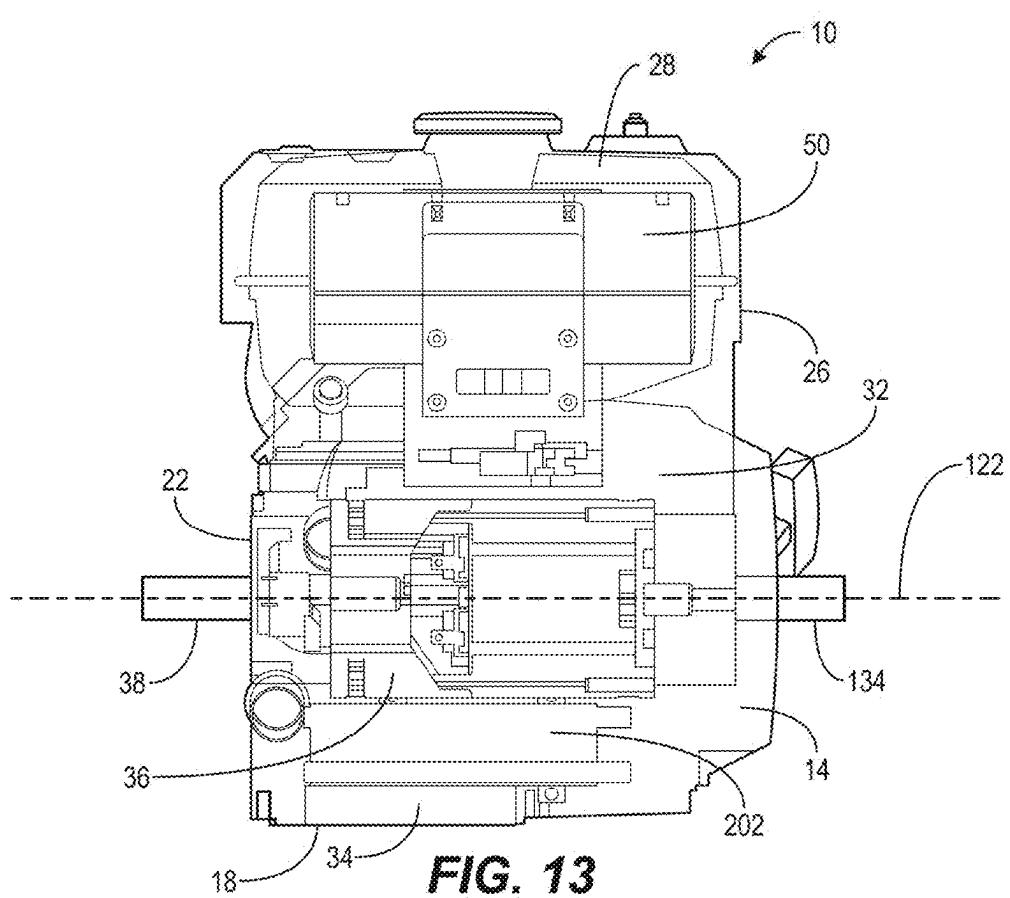
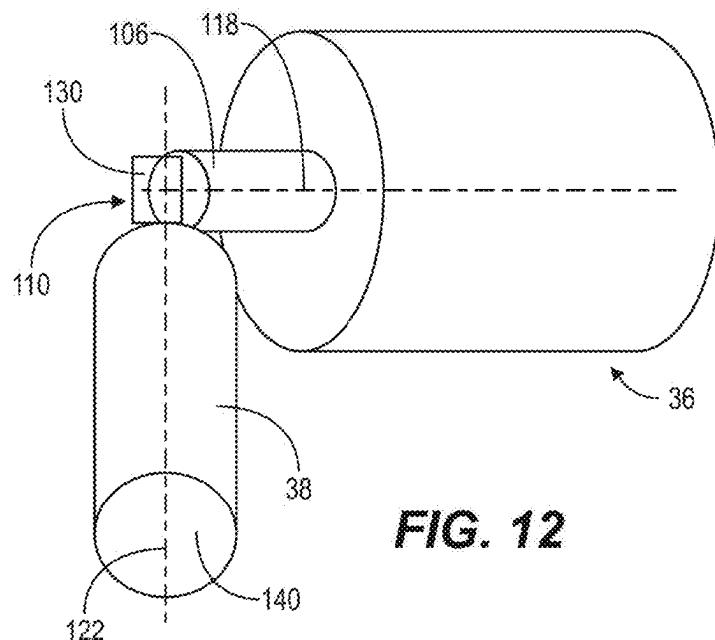


FIG. 8





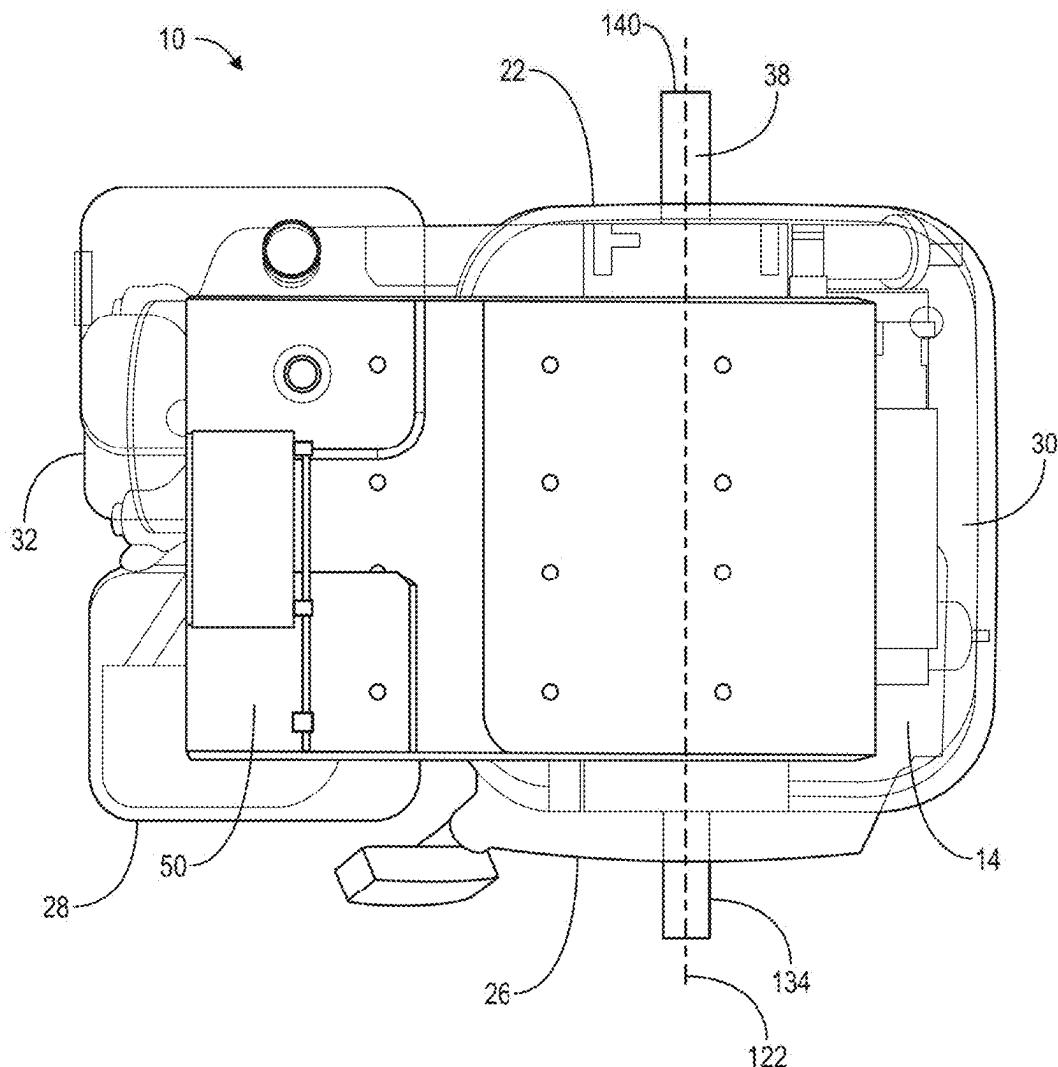
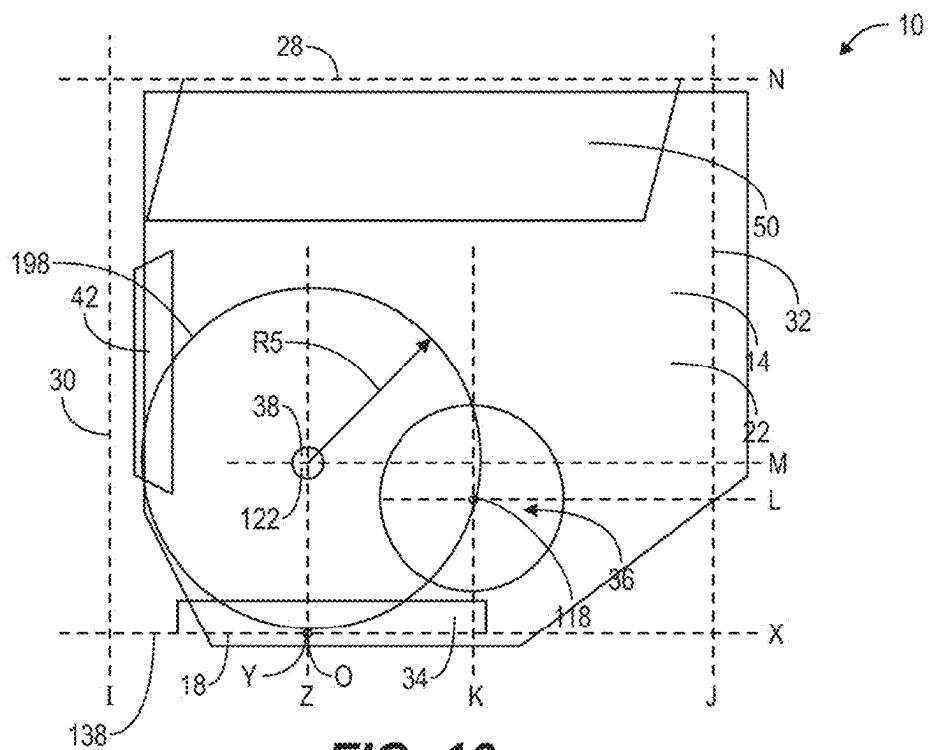
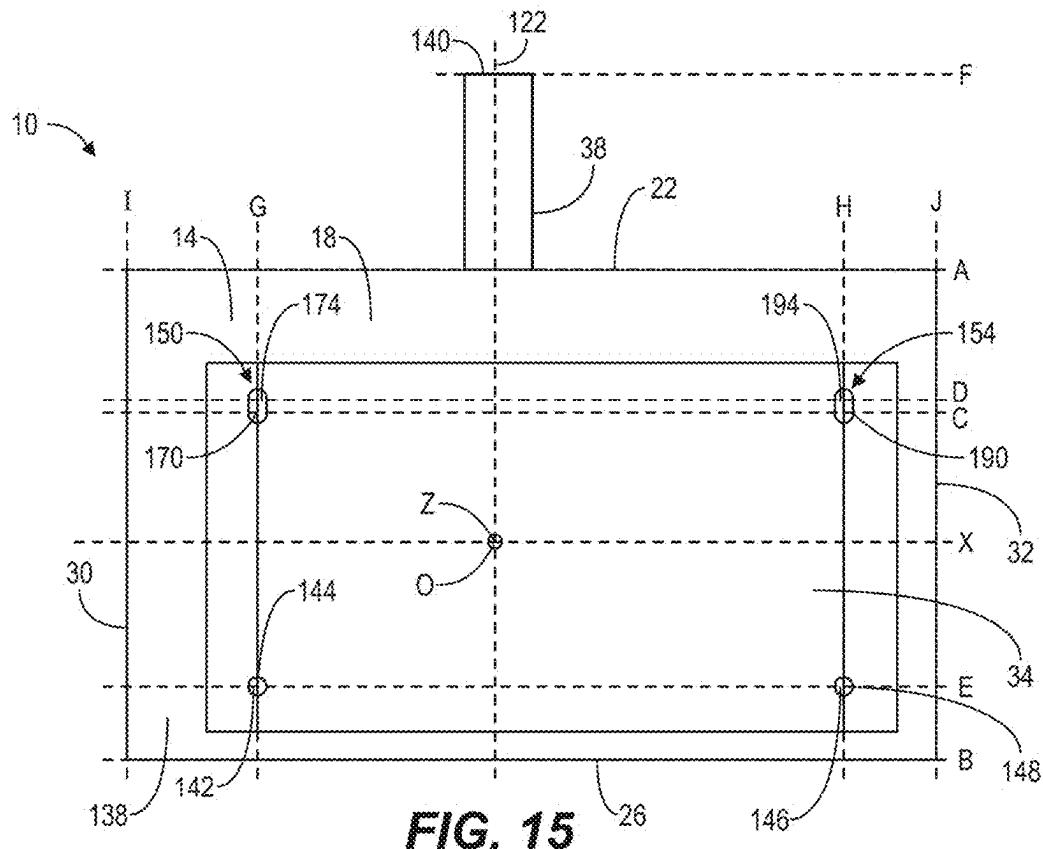


FIG. 14



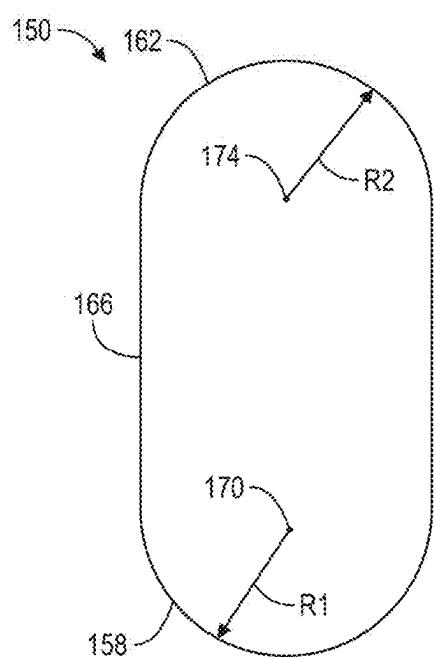


FIG. 17

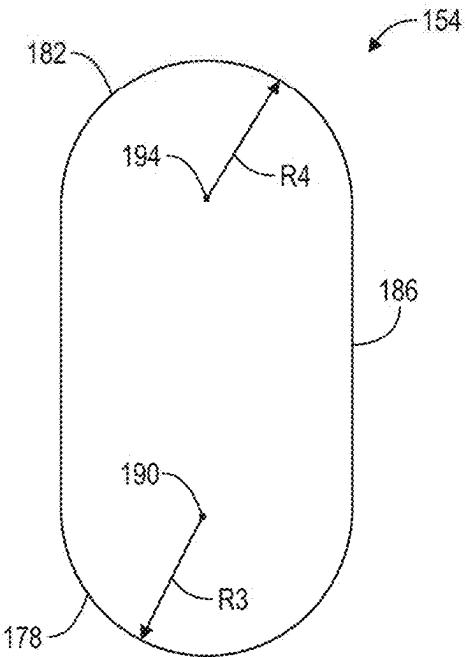


FIG. 18

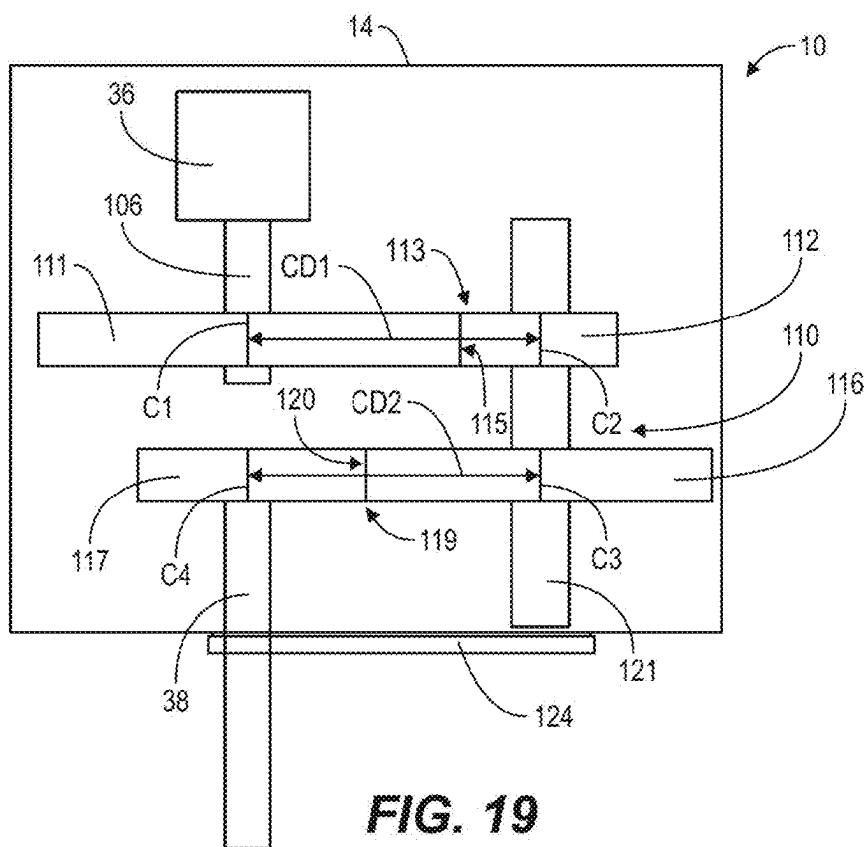


FIG. 19

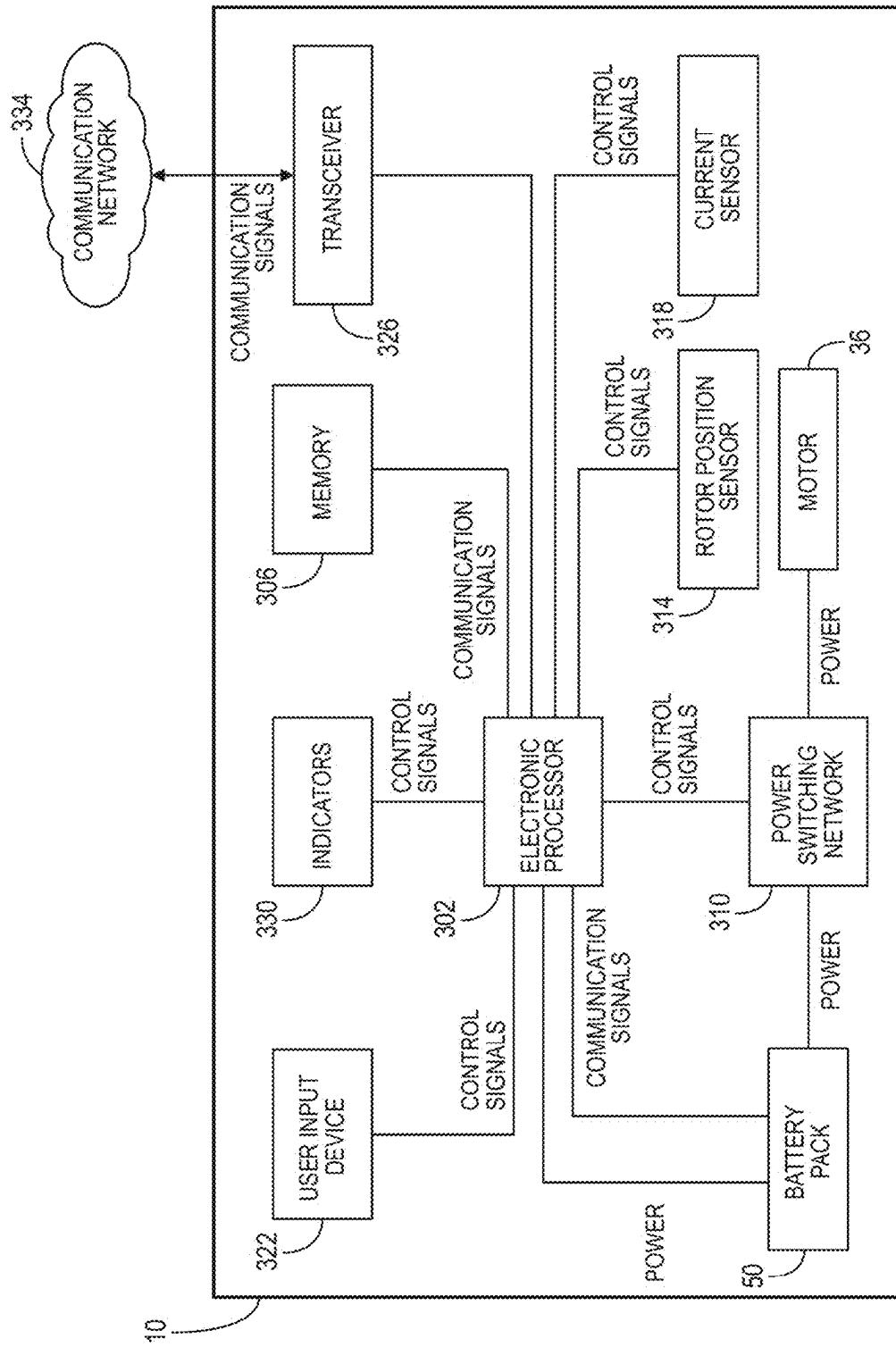


FIG. 20

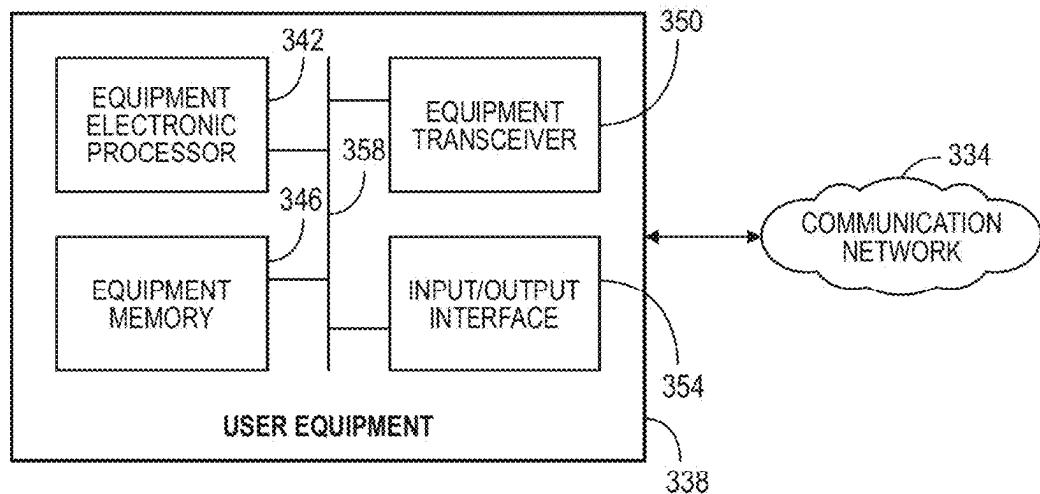


FIG. 21

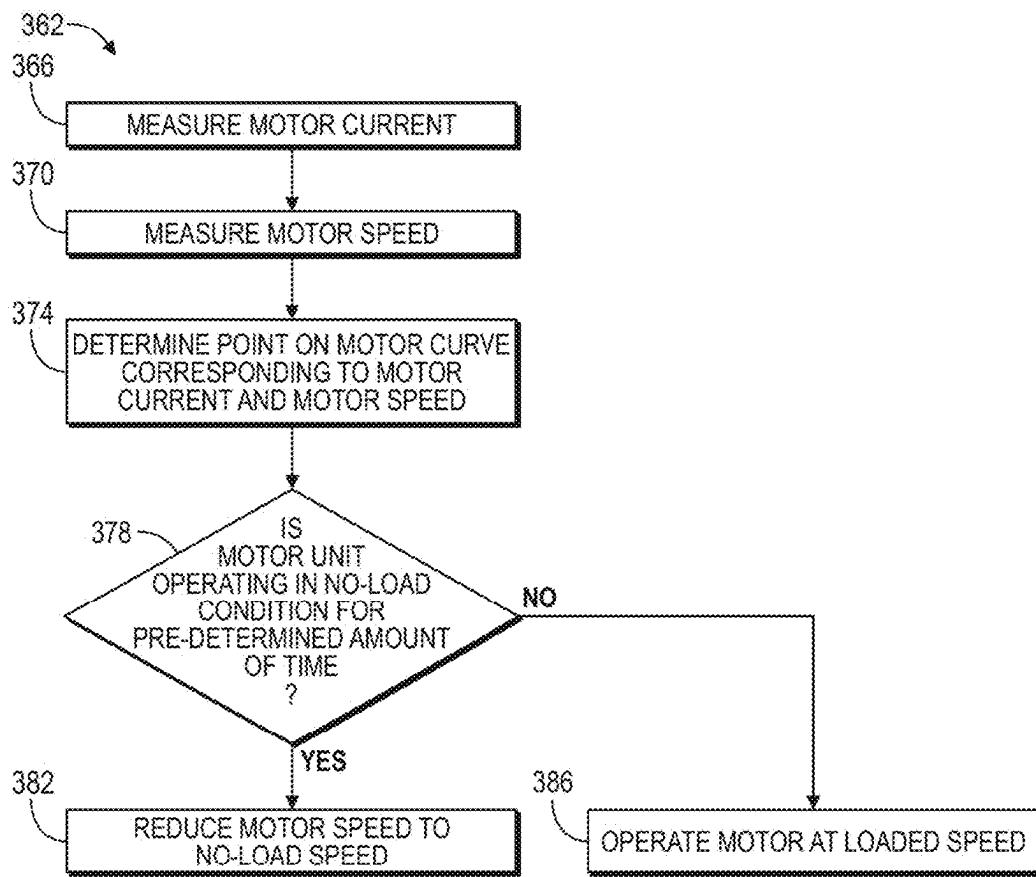


FIG. 22

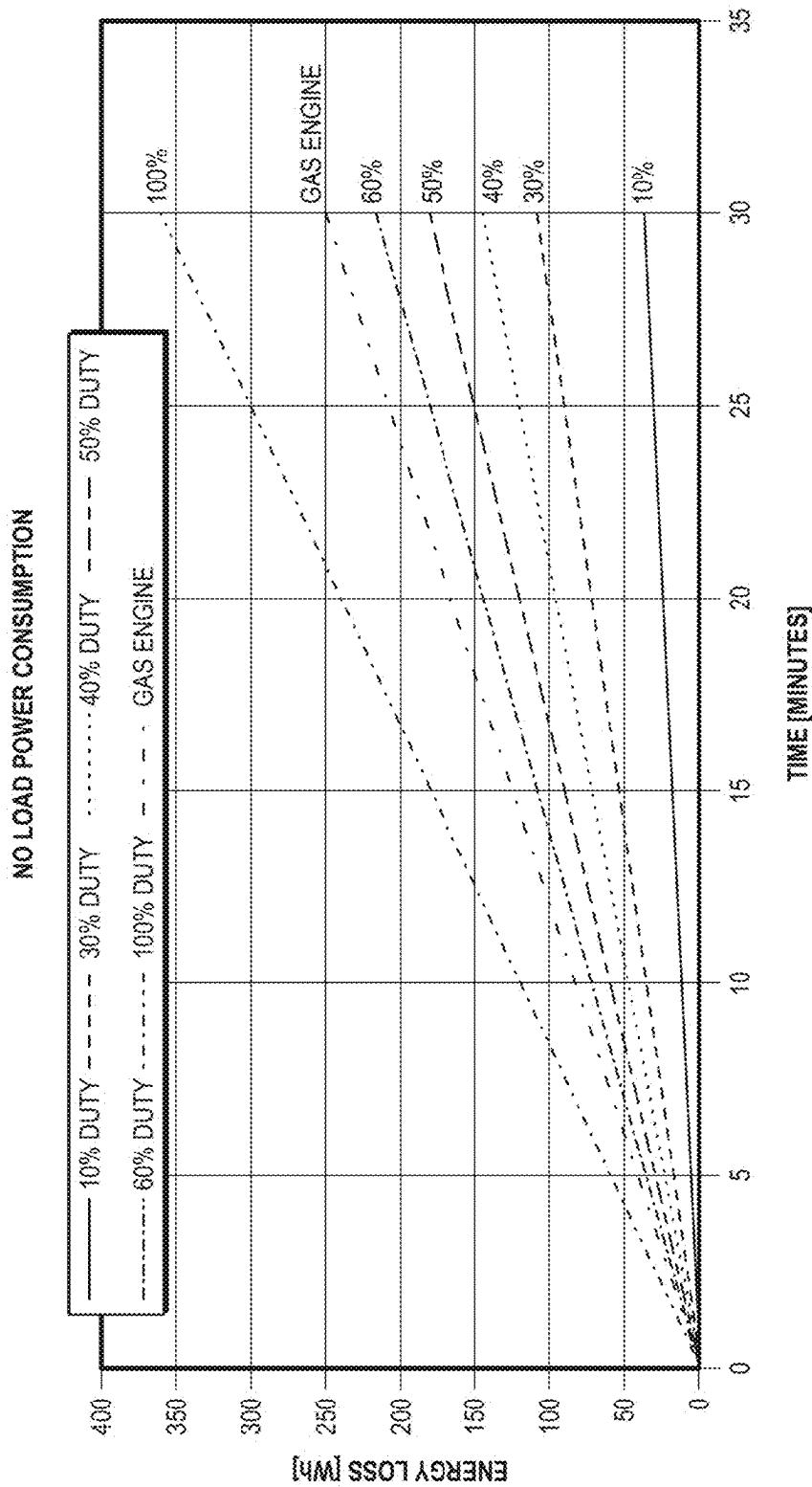


FIG. 23

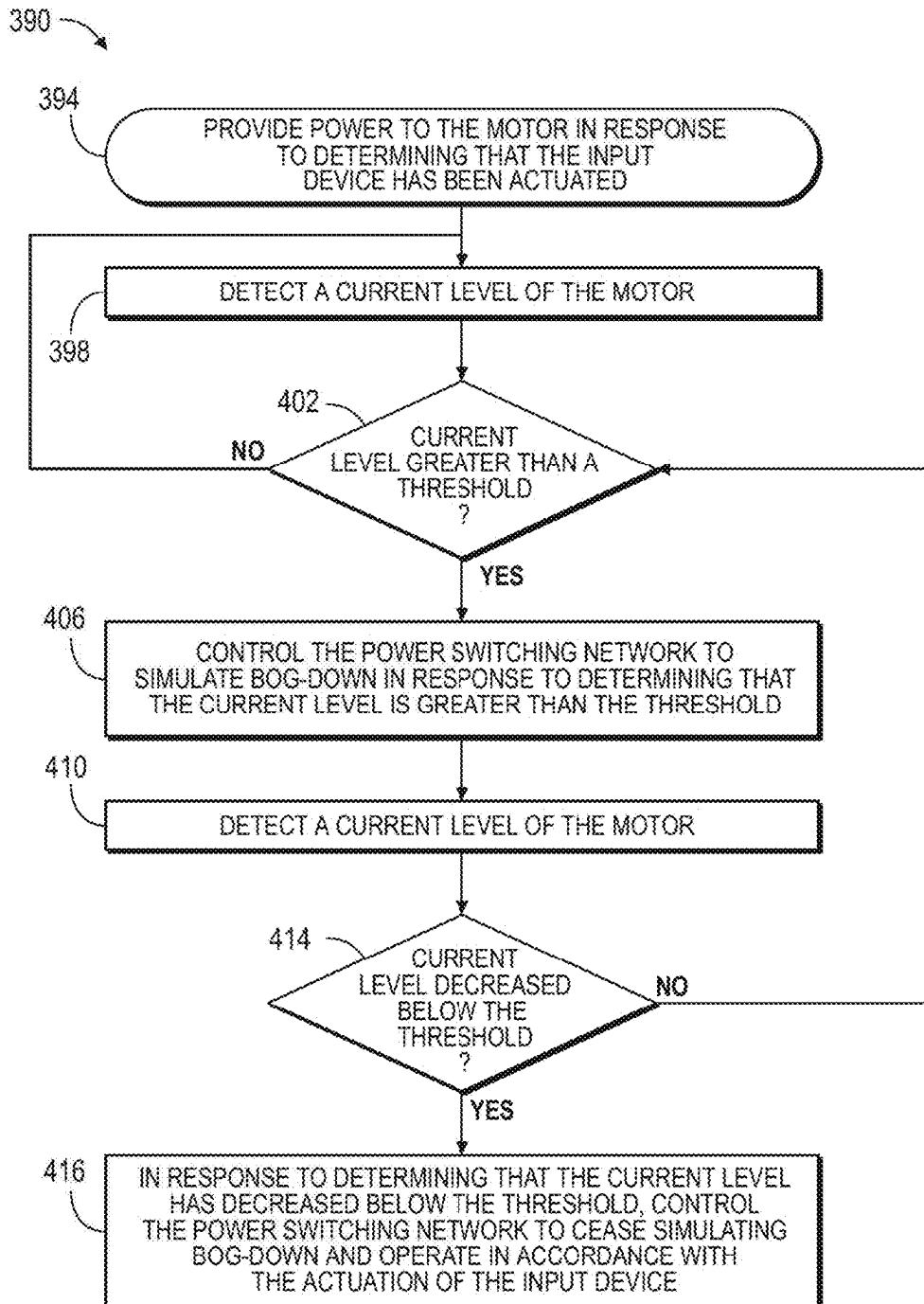
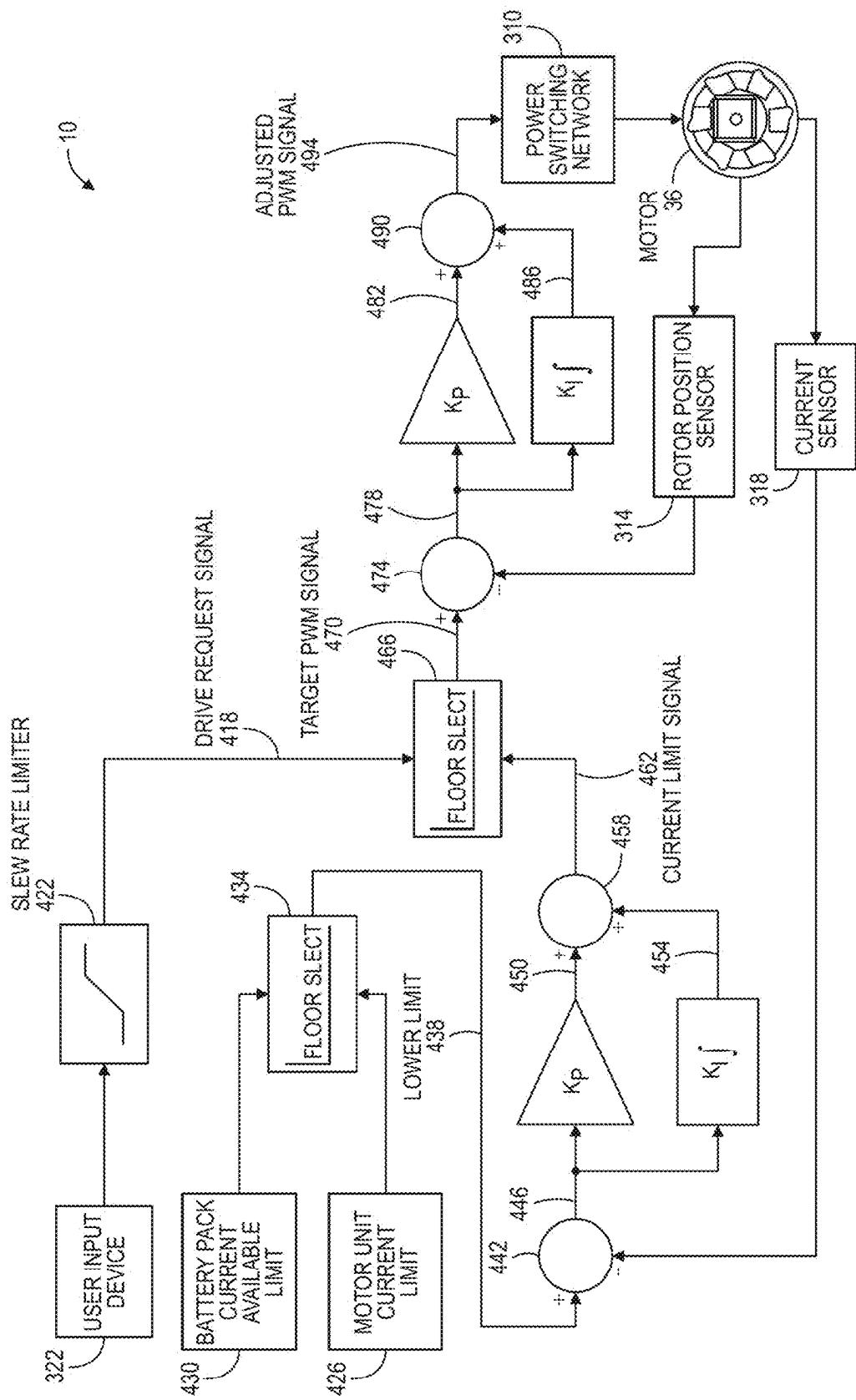
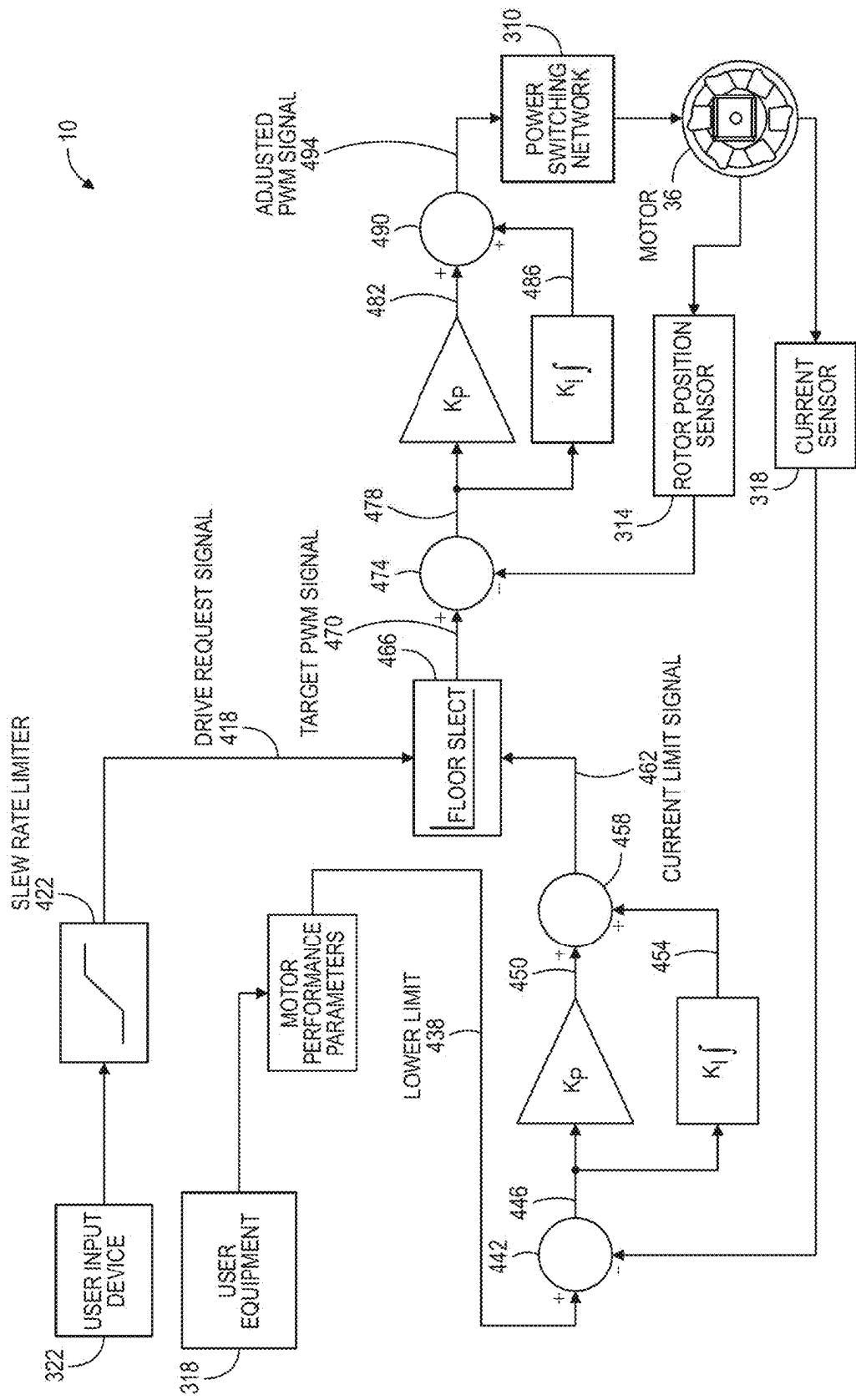


FIG. 24


FIG. 25


FIG. 26

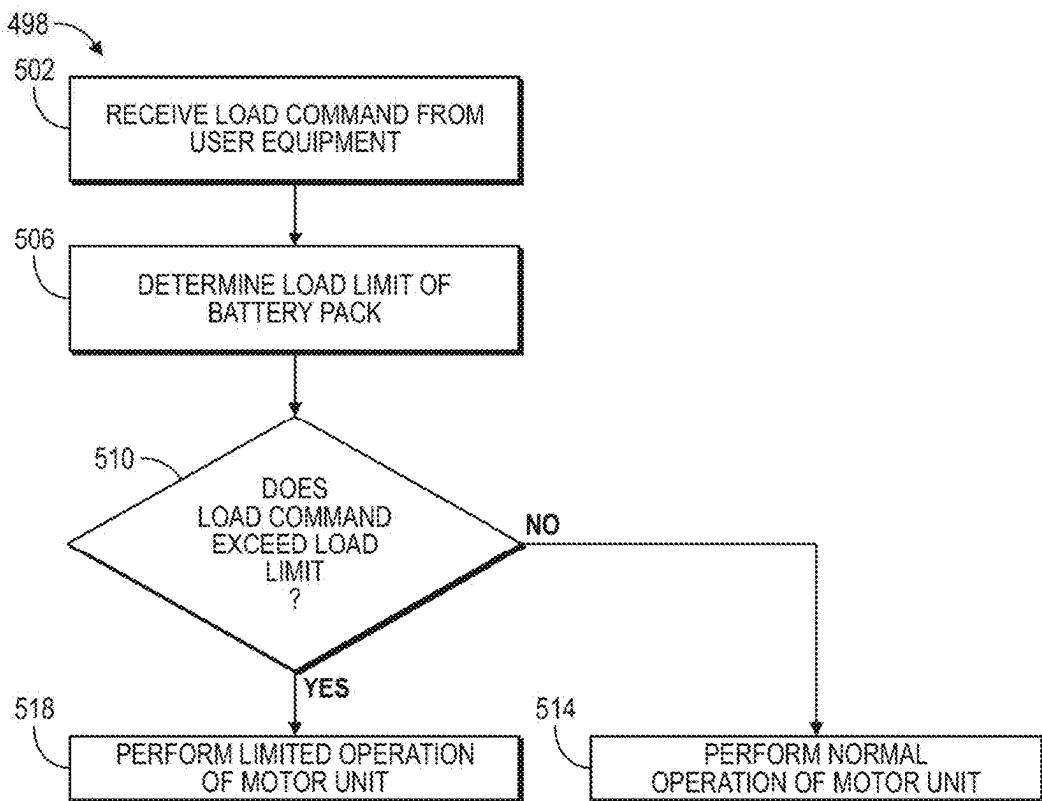


FIG. 27

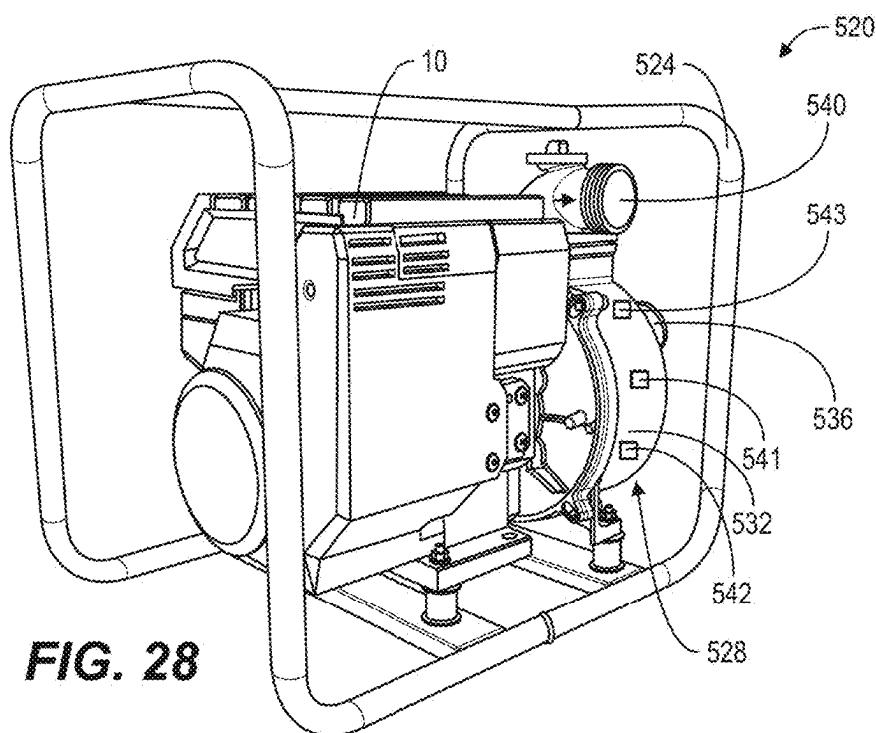


FIG. 28

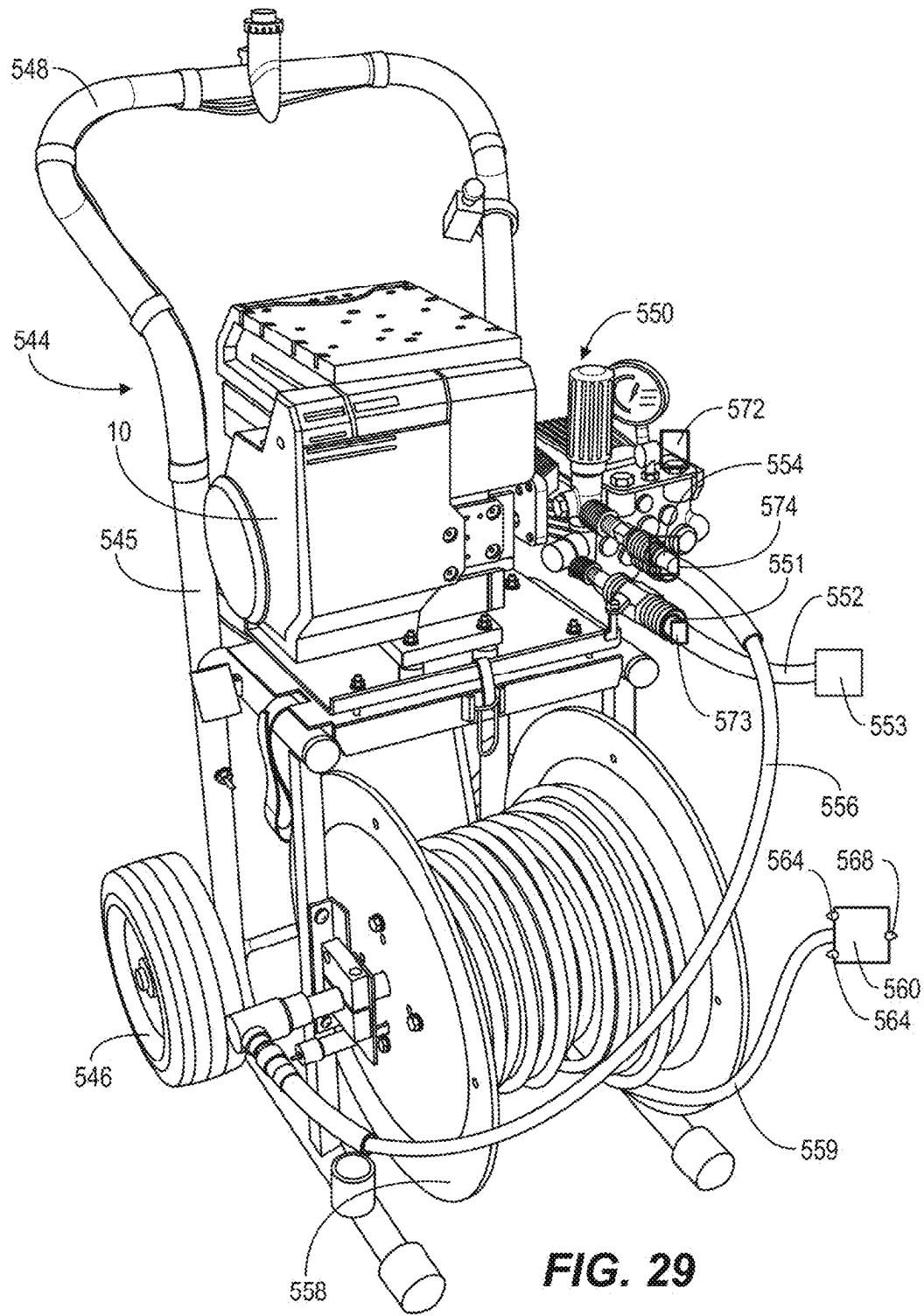


FIG. 29

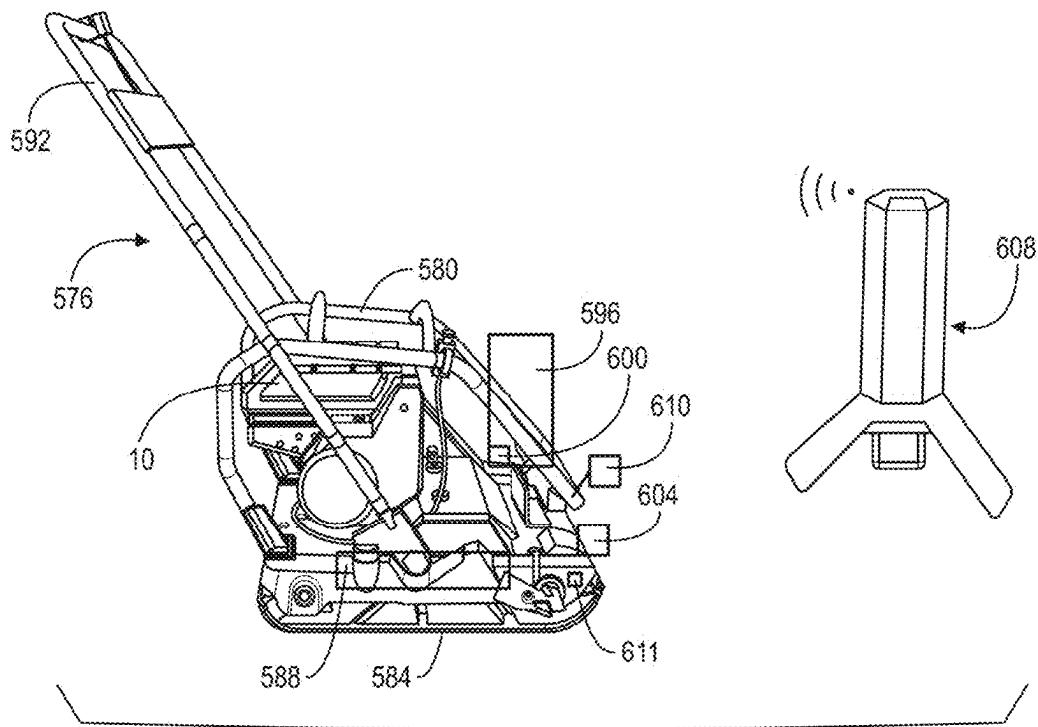


FIG. 30

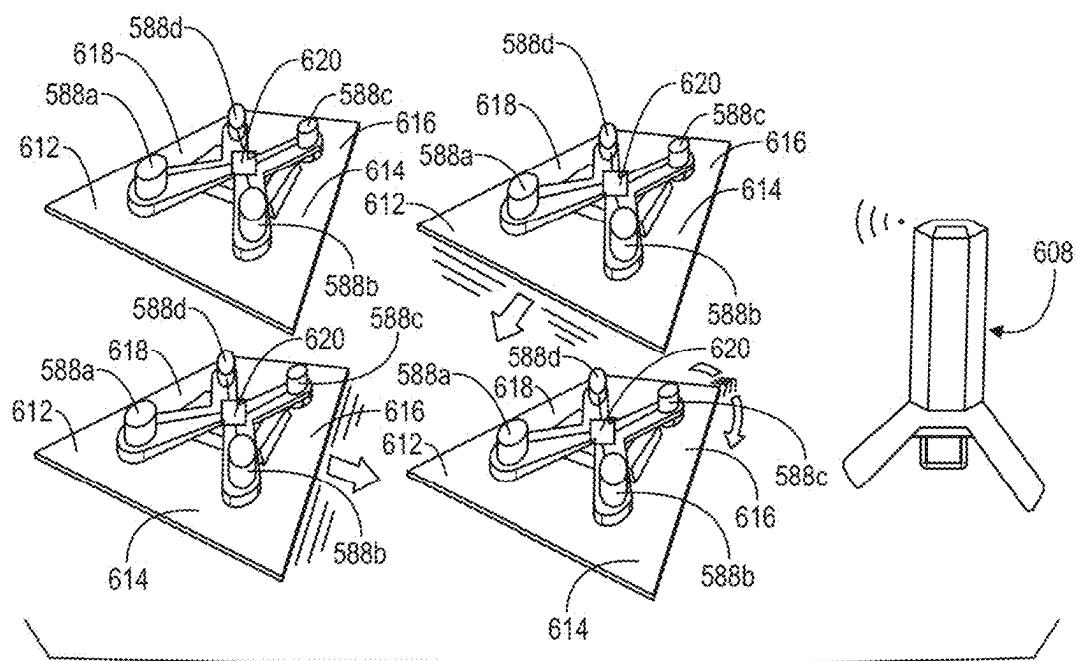


FIG. 31

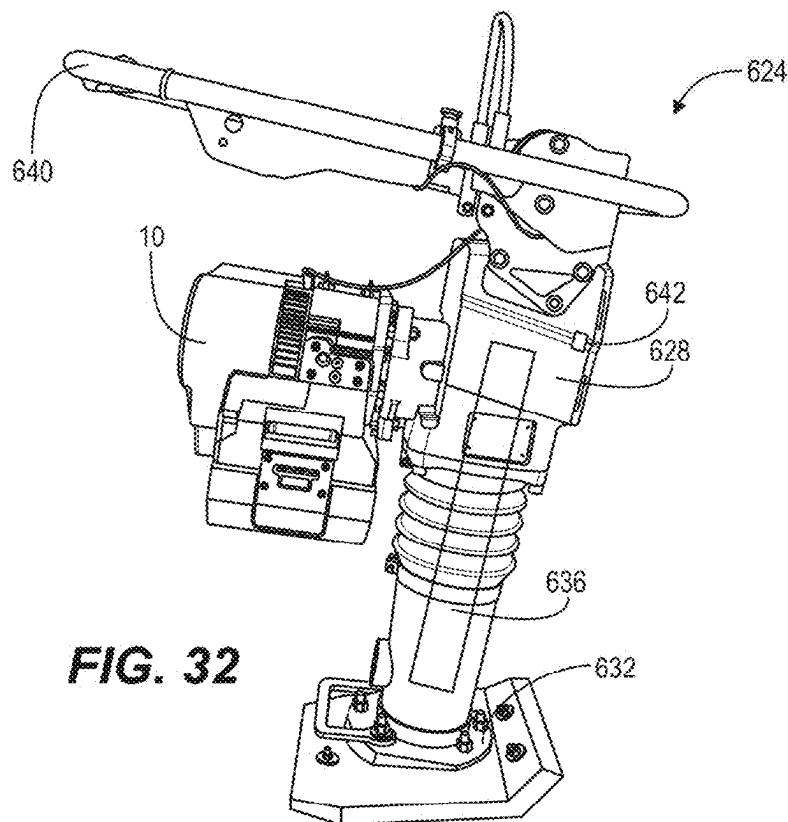


FIG. 32

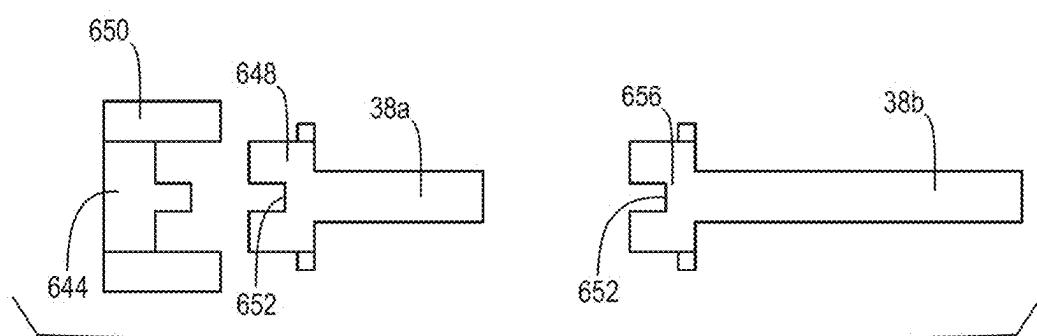


FIG. 33

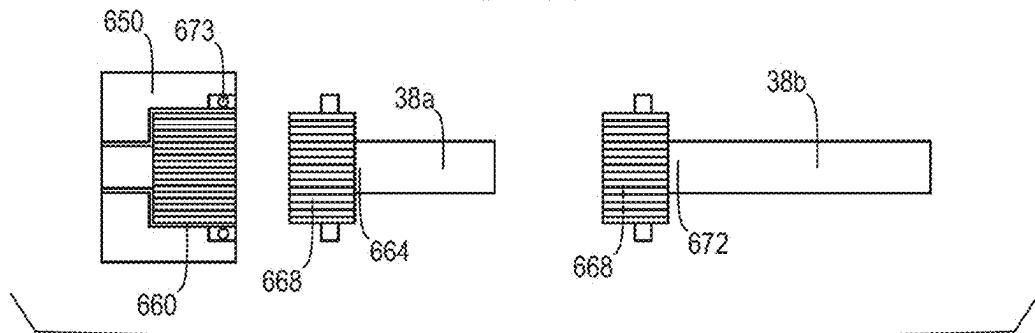


FIG. 34

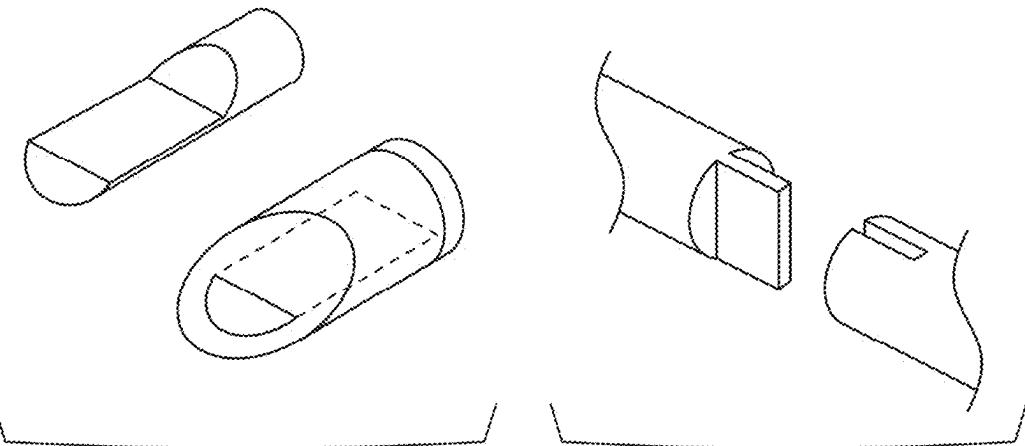


FIG. 35

FIG. 36

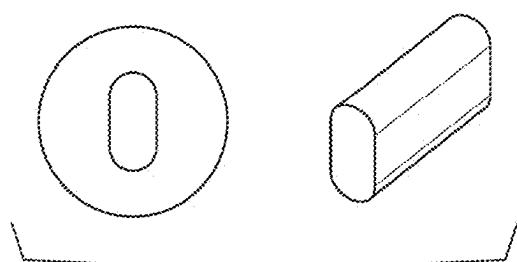


FIG. 37

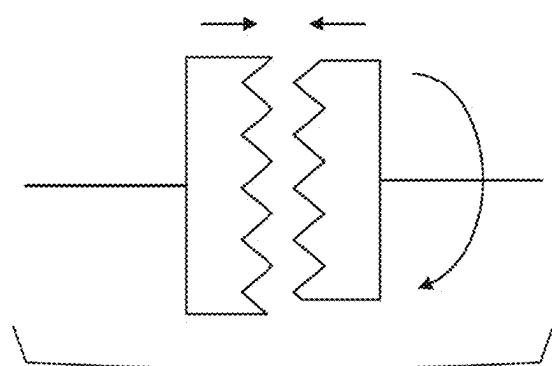


FIG. 38

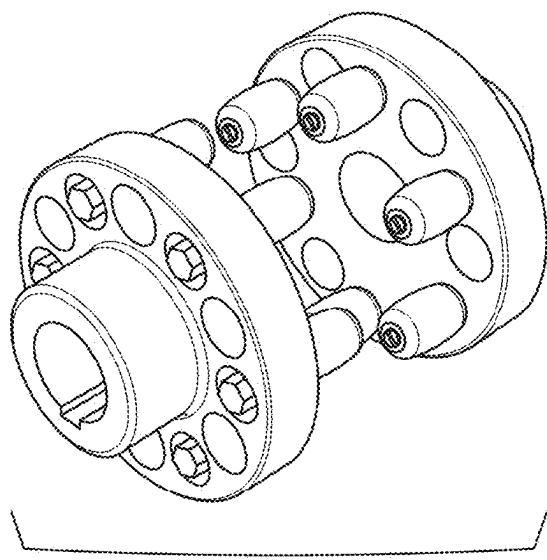


FIG. 39

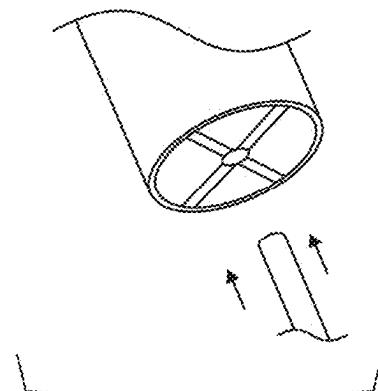


FIG. 40

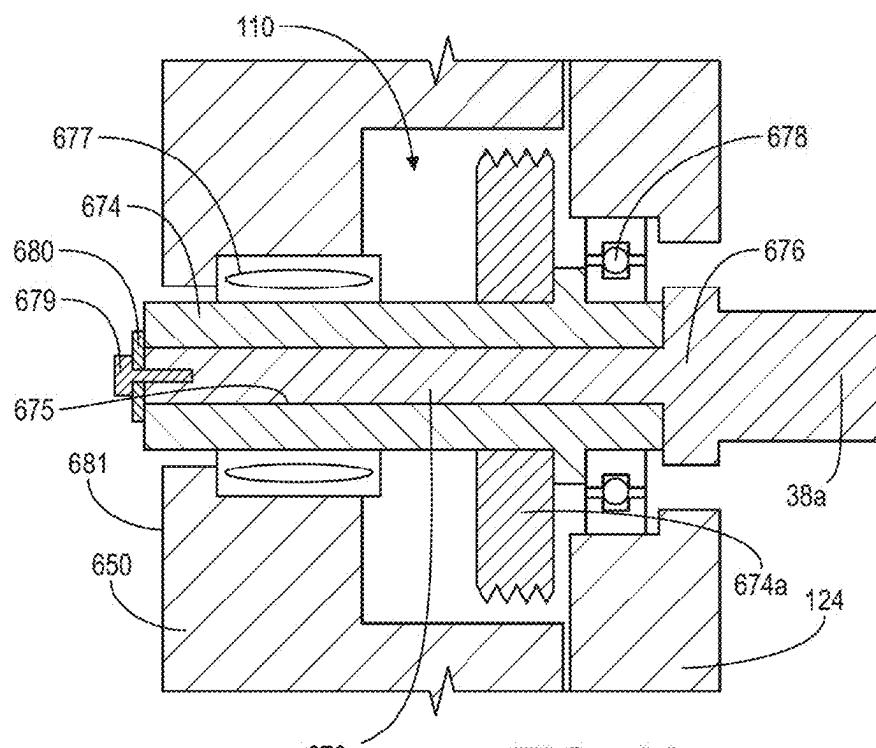


FIG. 41

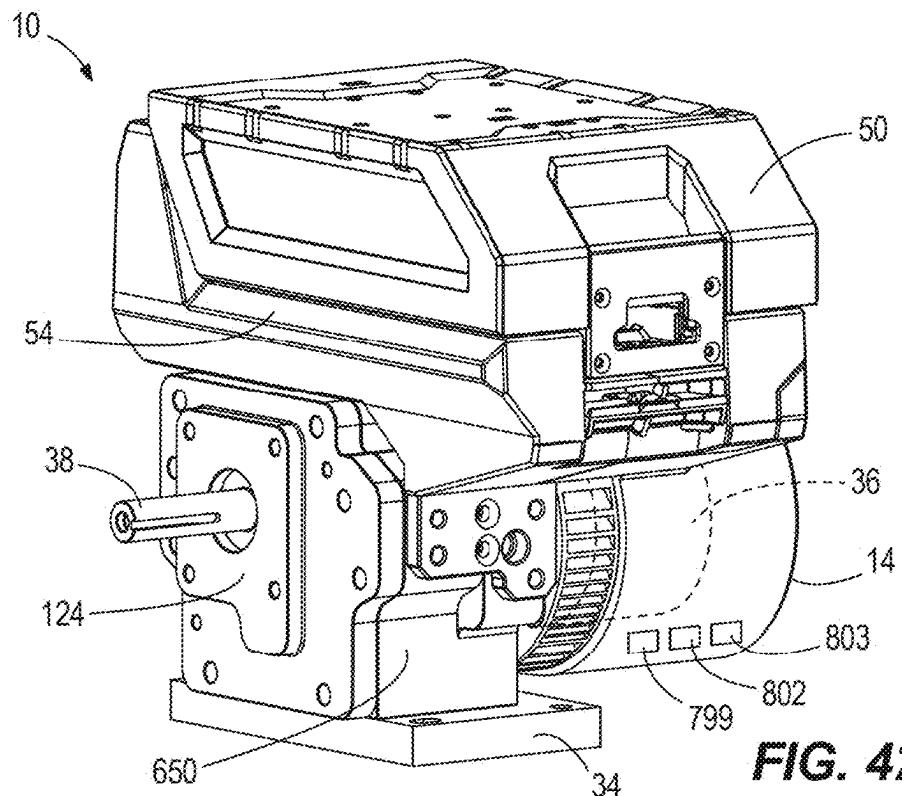


FIG. 42

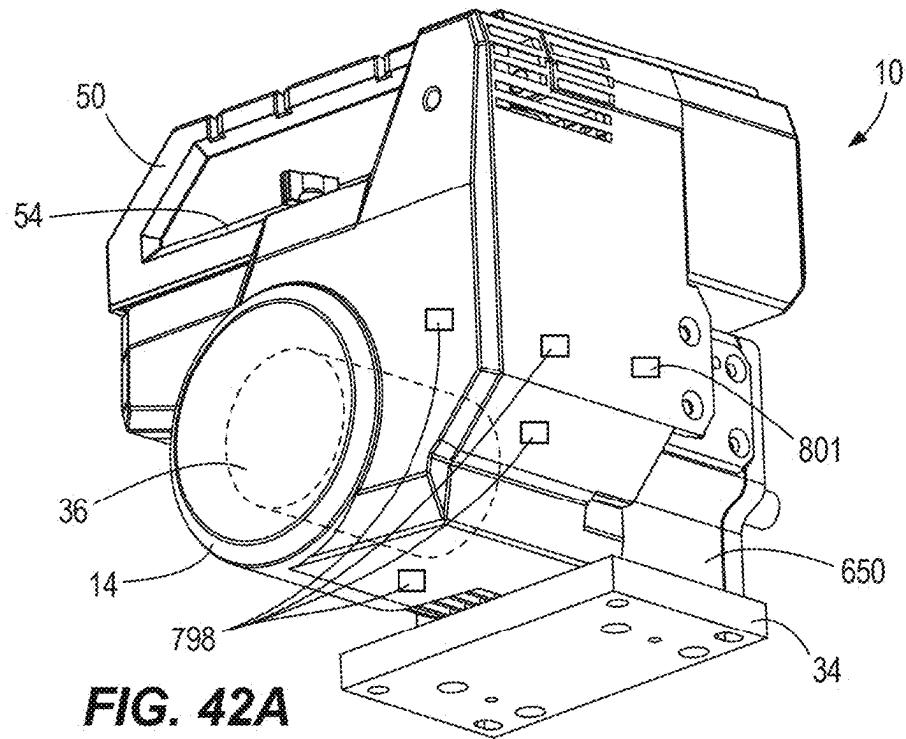


FIG. 42A

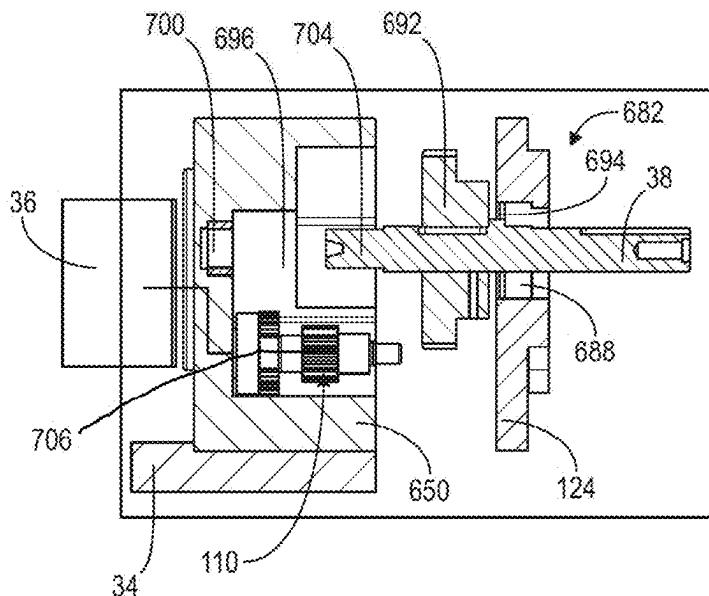


FIG. 43

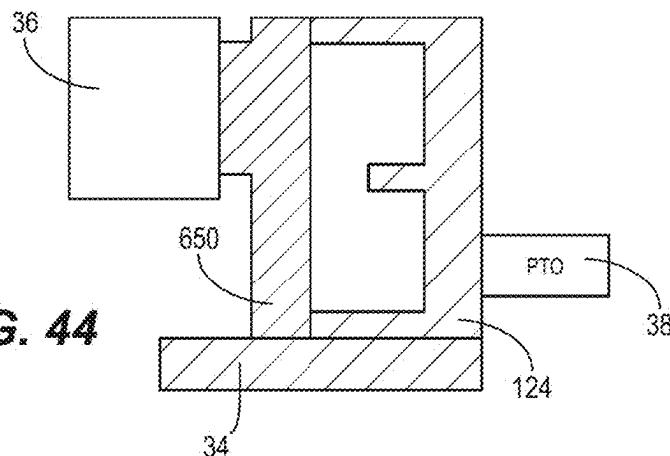


FIG. 44

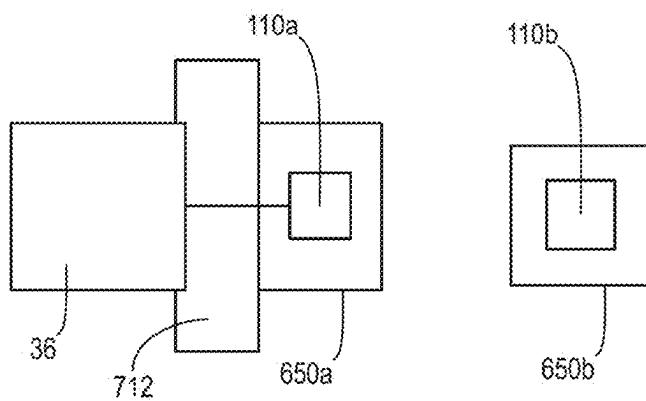
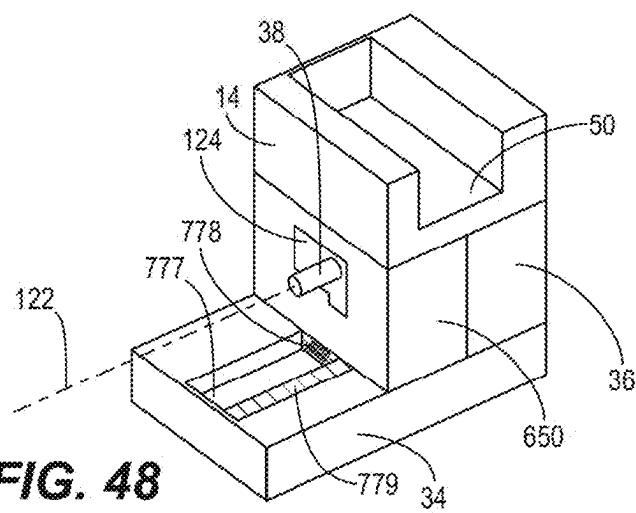
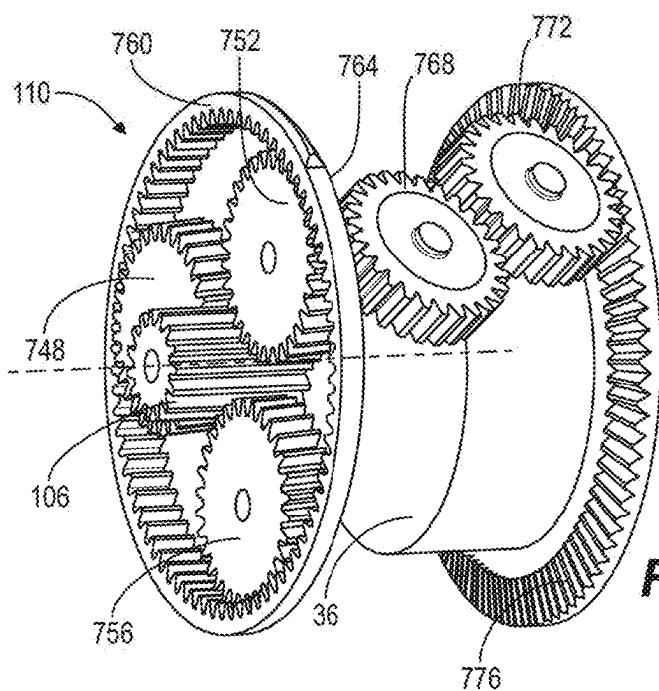
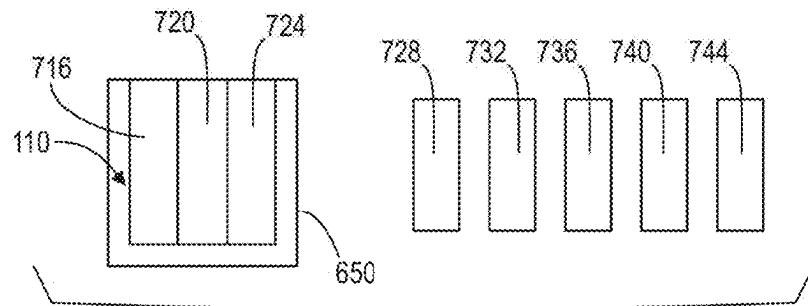
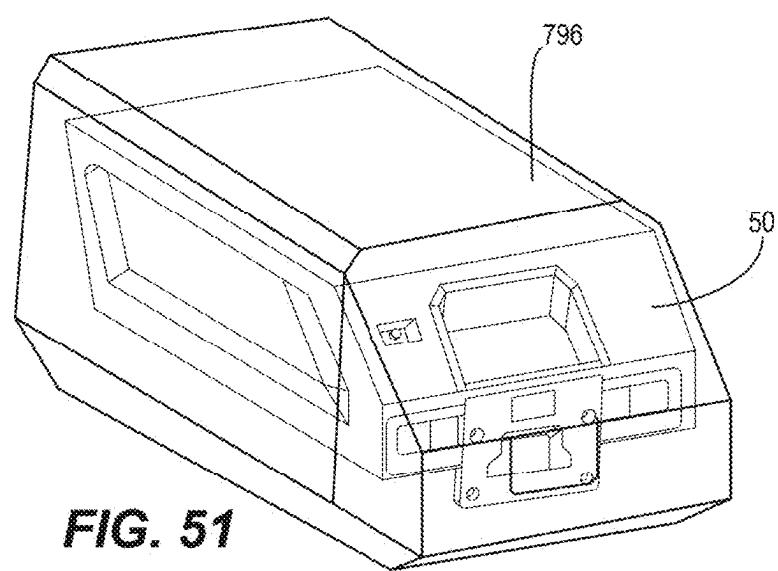
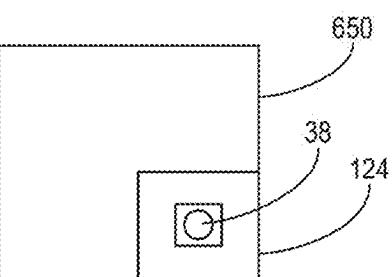
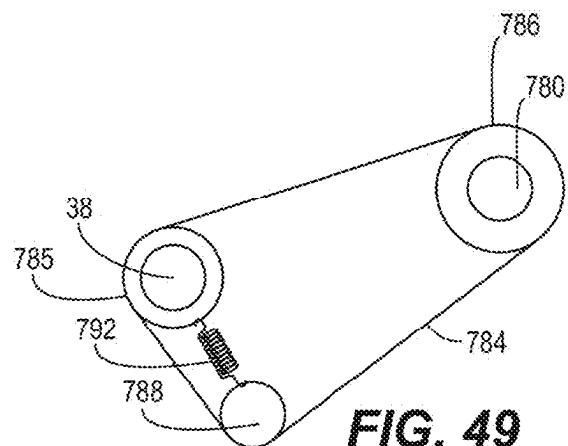


FIG. 45





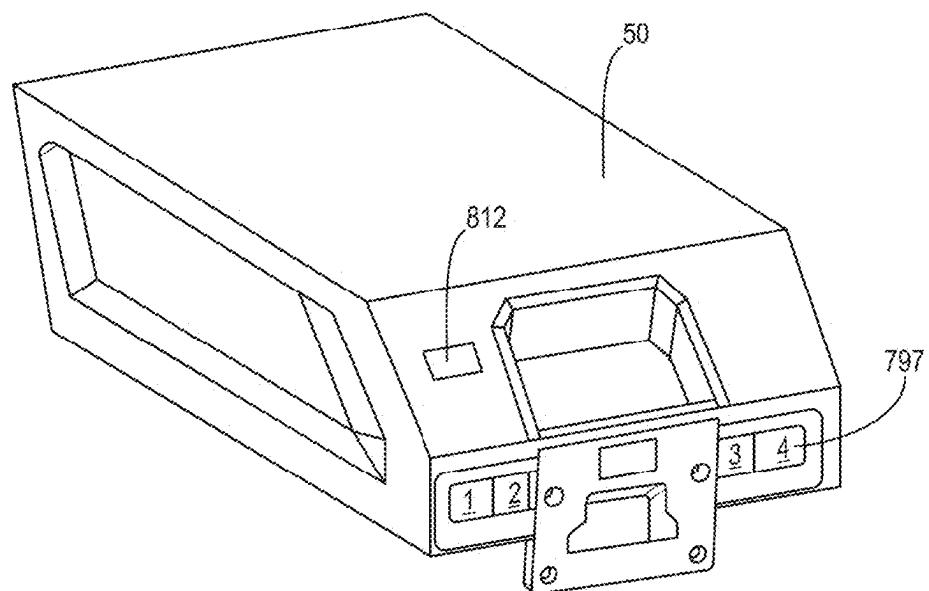


FIG. 52

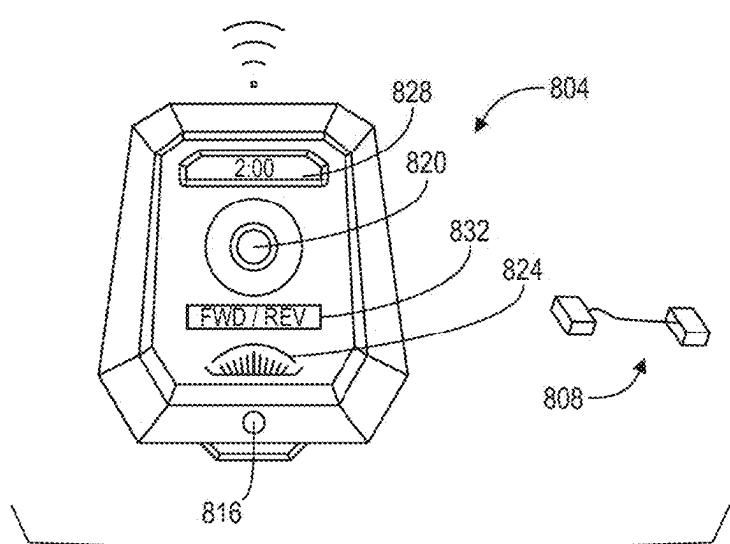


FIG. 53

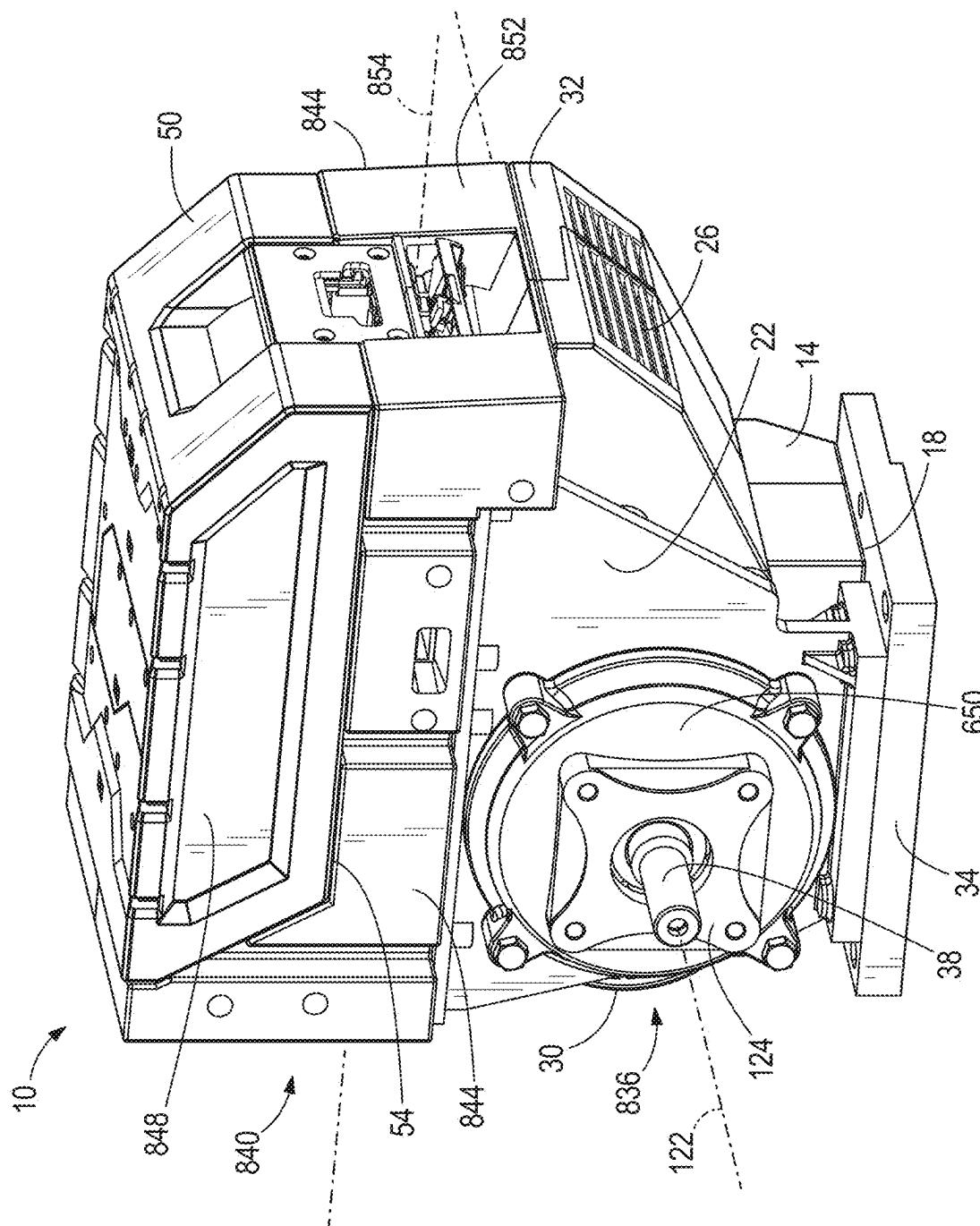


FIG. 54

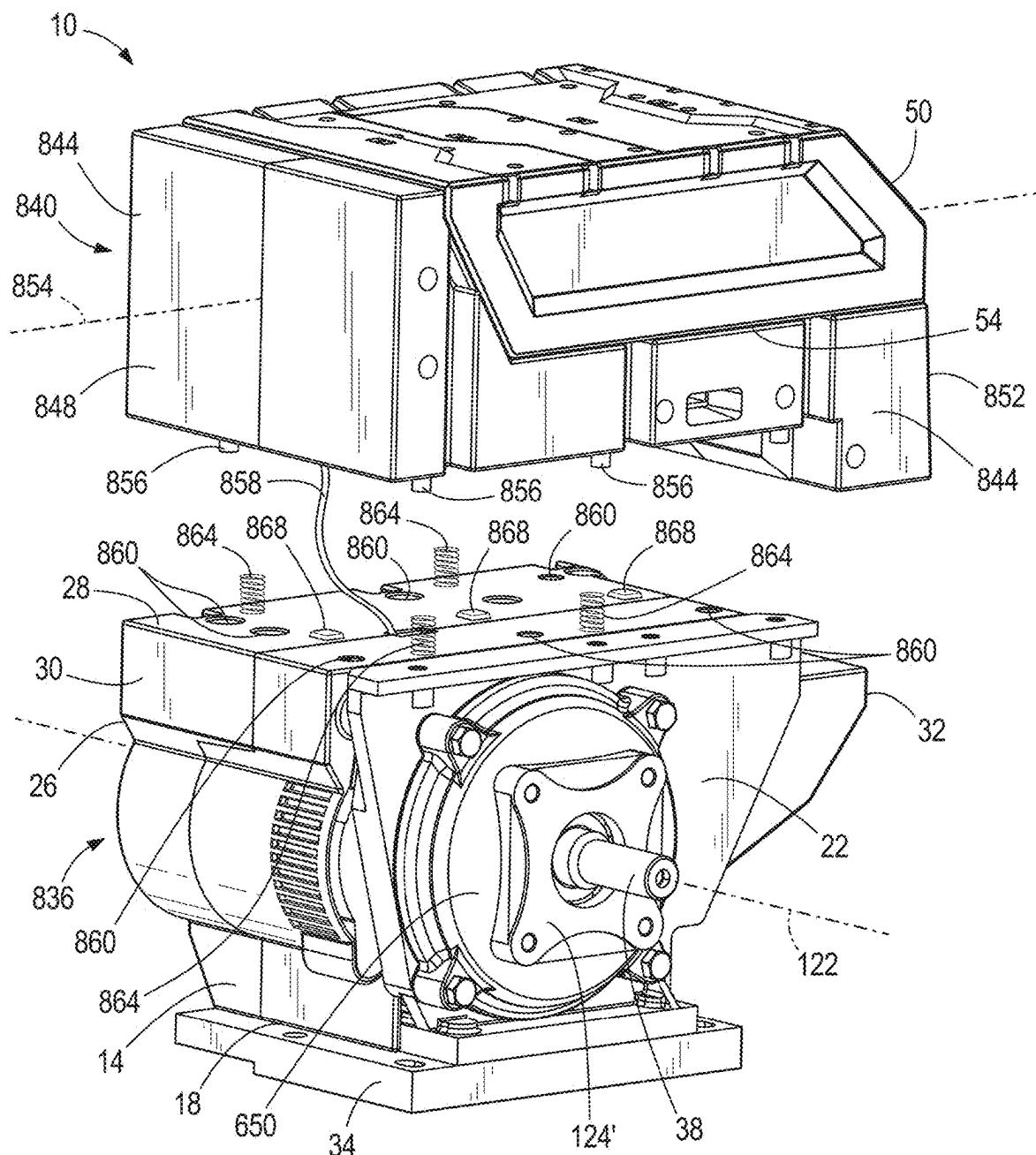


FIG. 55

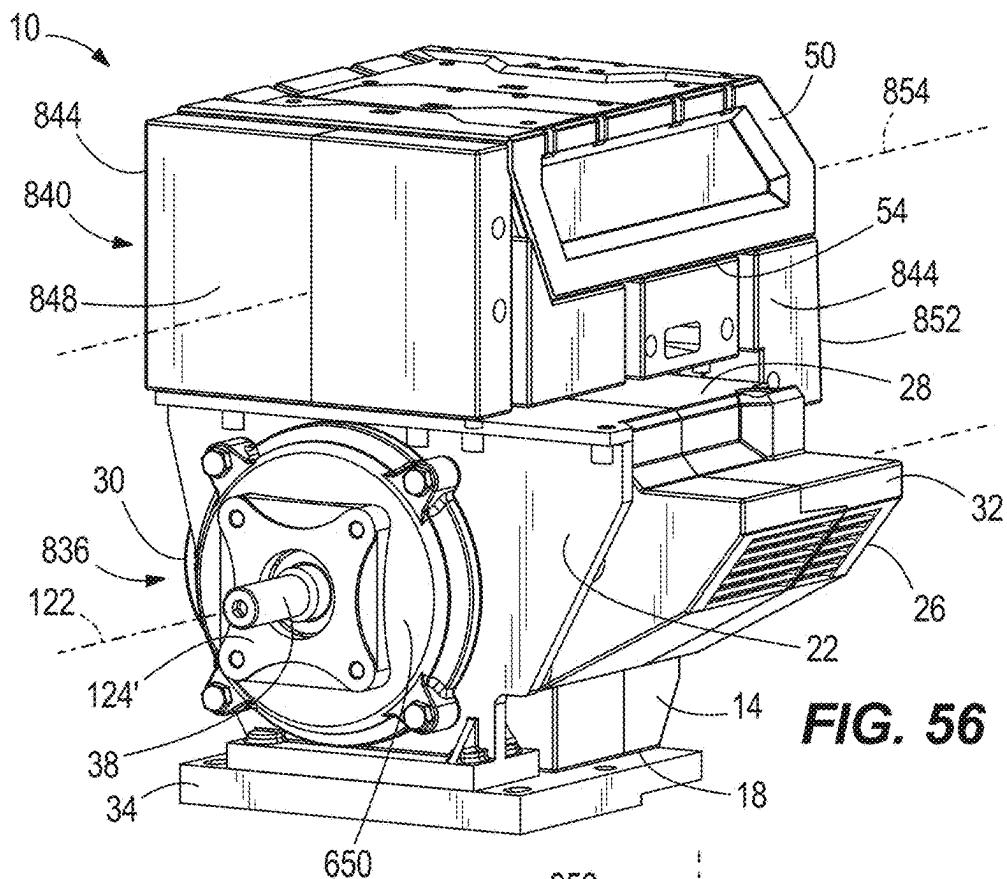


FIG. 56

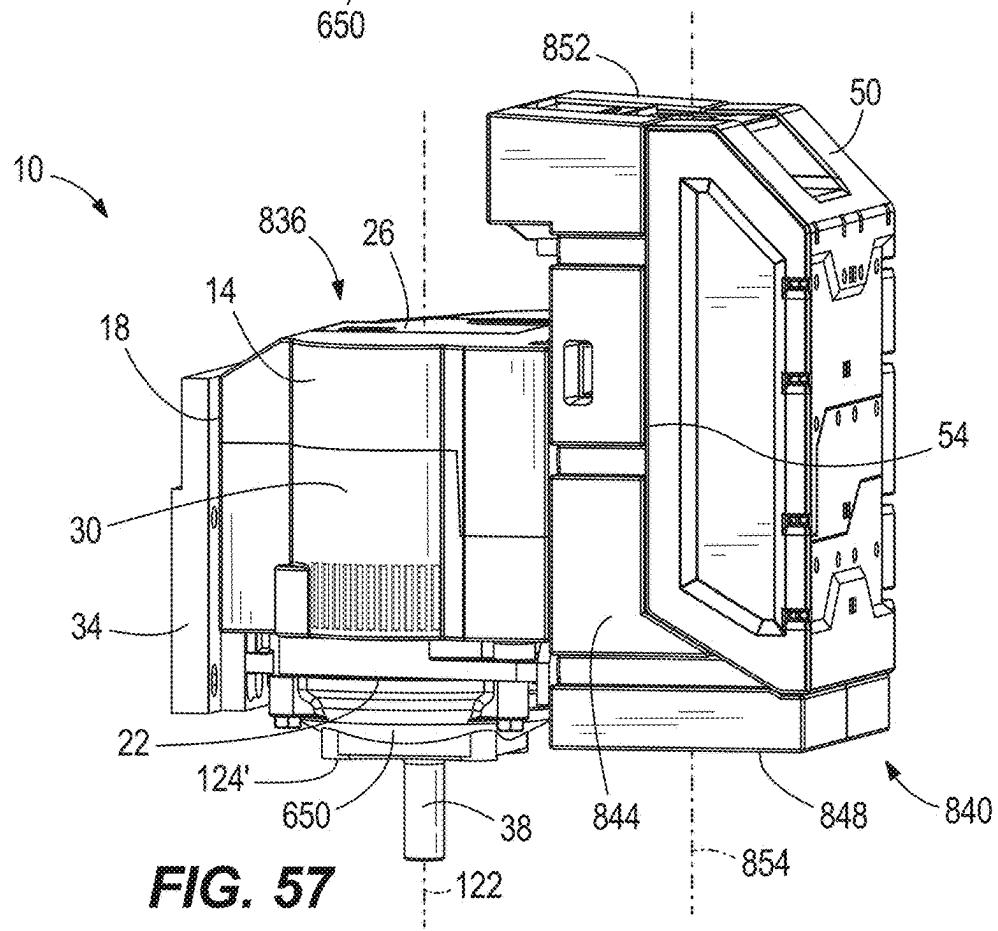


FIG. 57

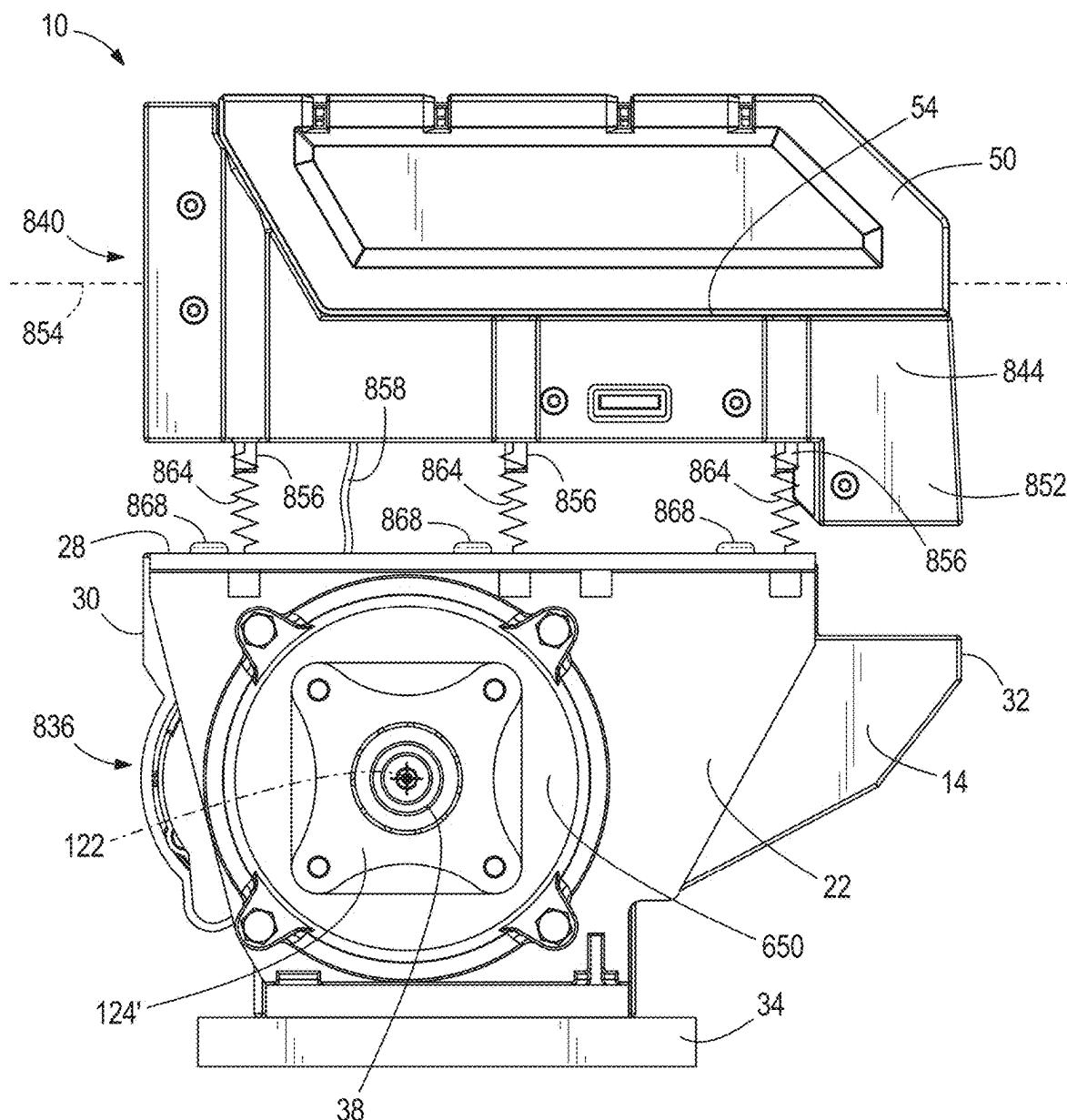


FIG. 58

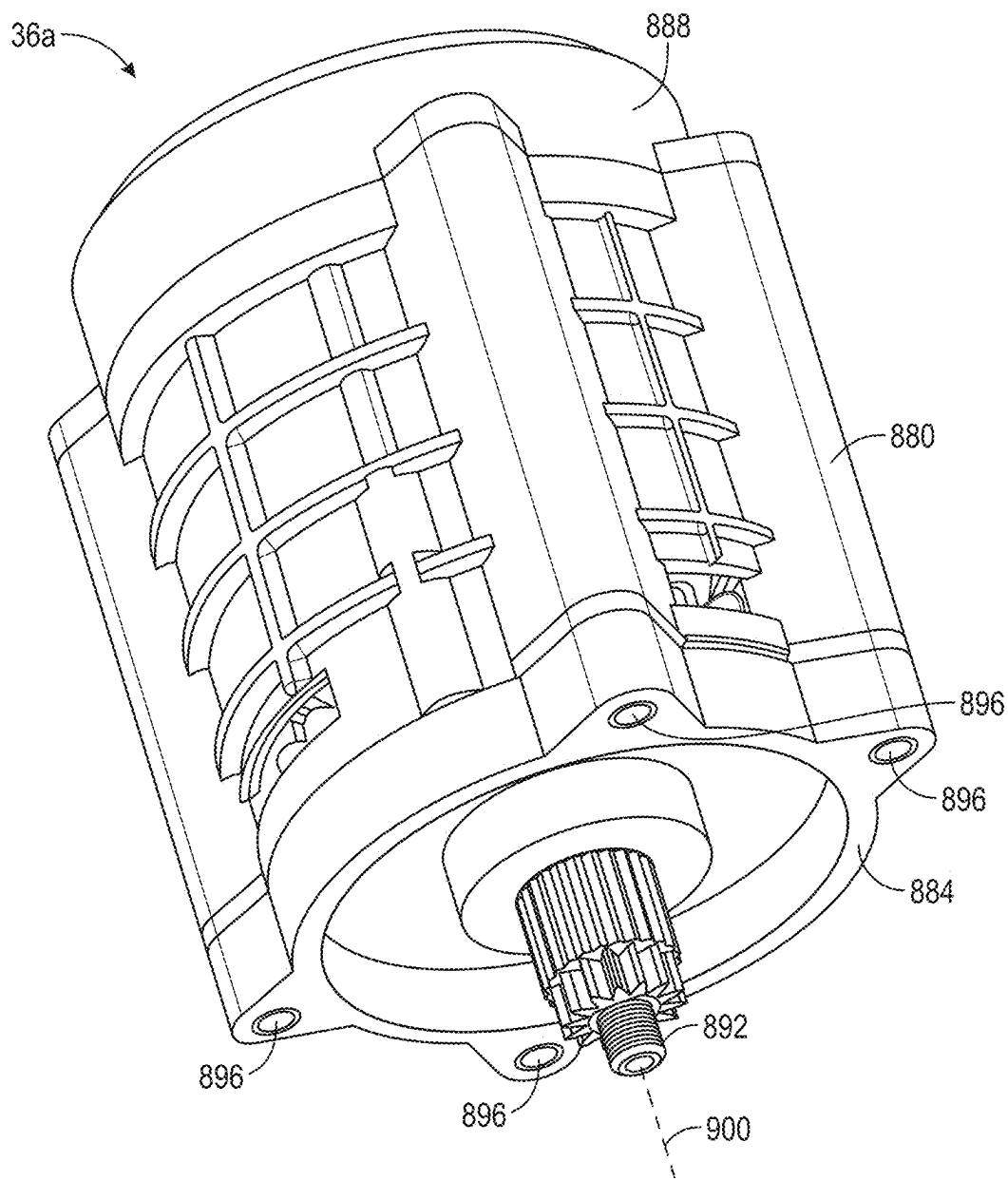
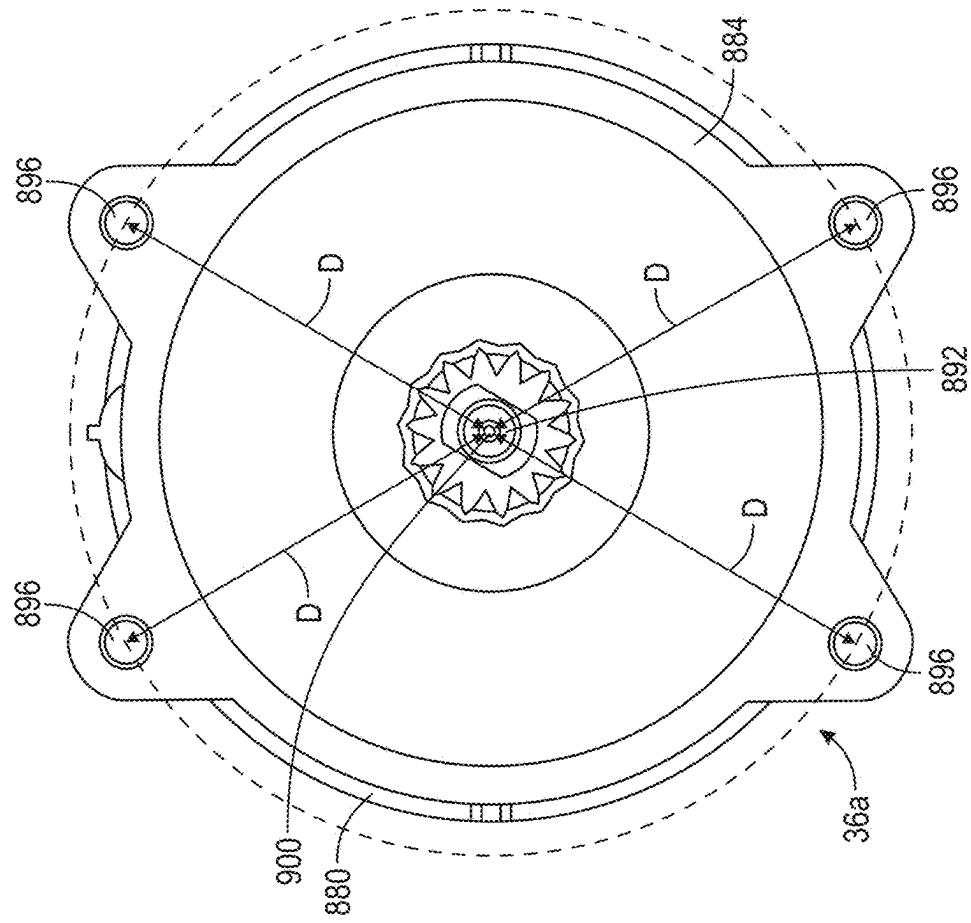
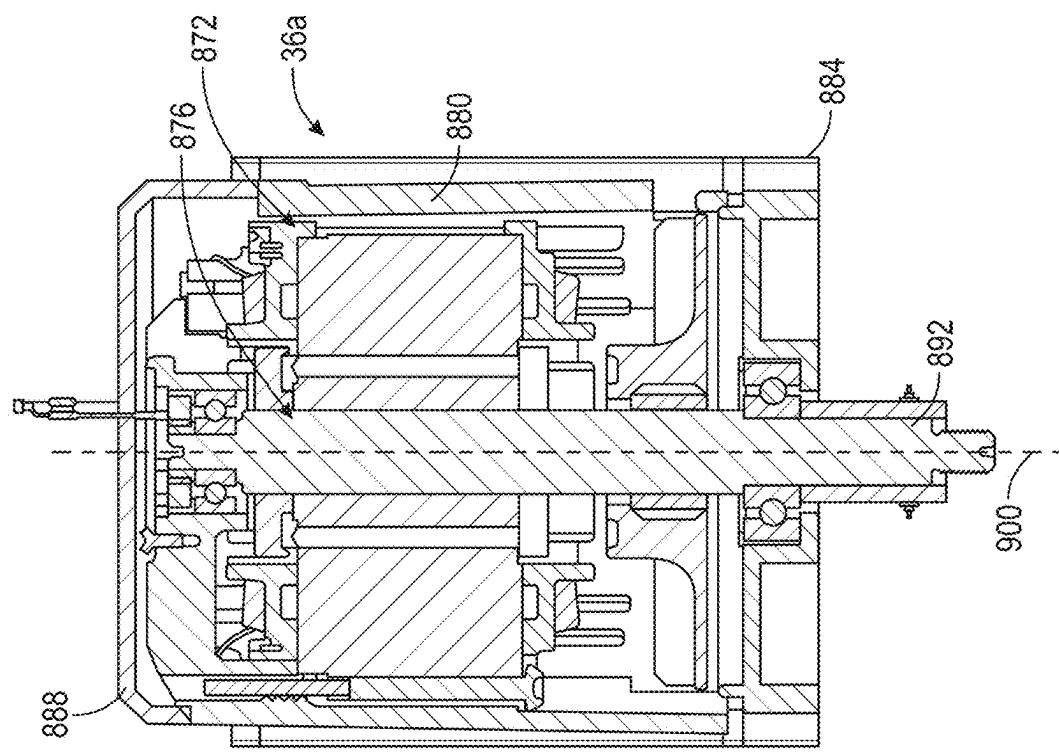
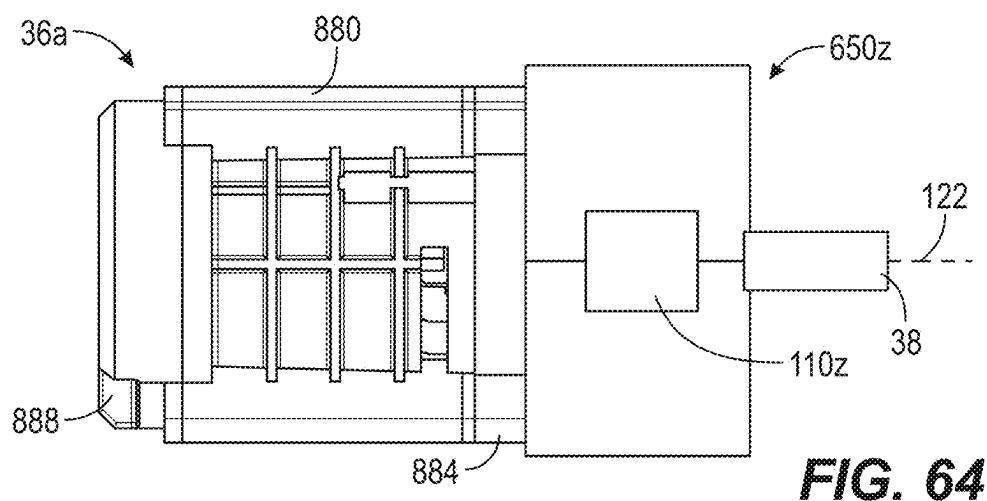
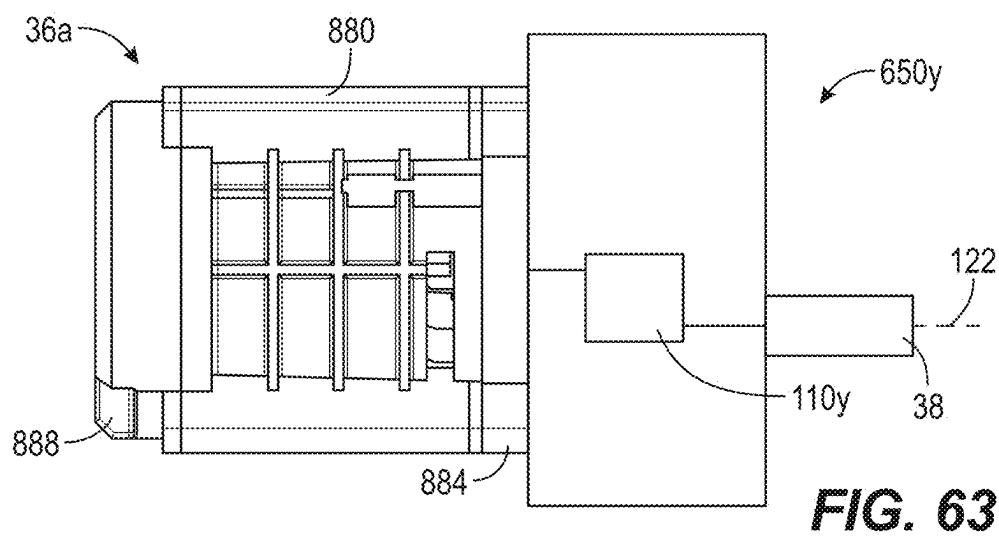
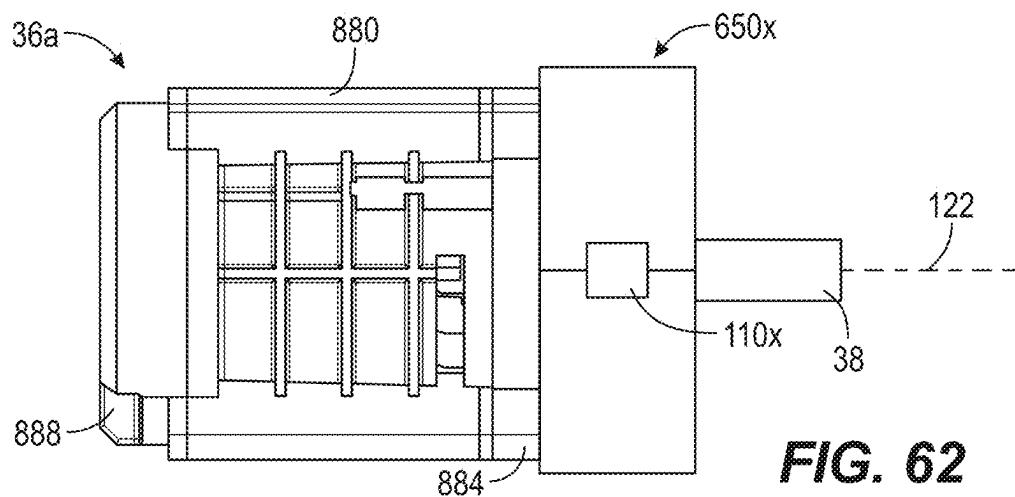


FIG. 59





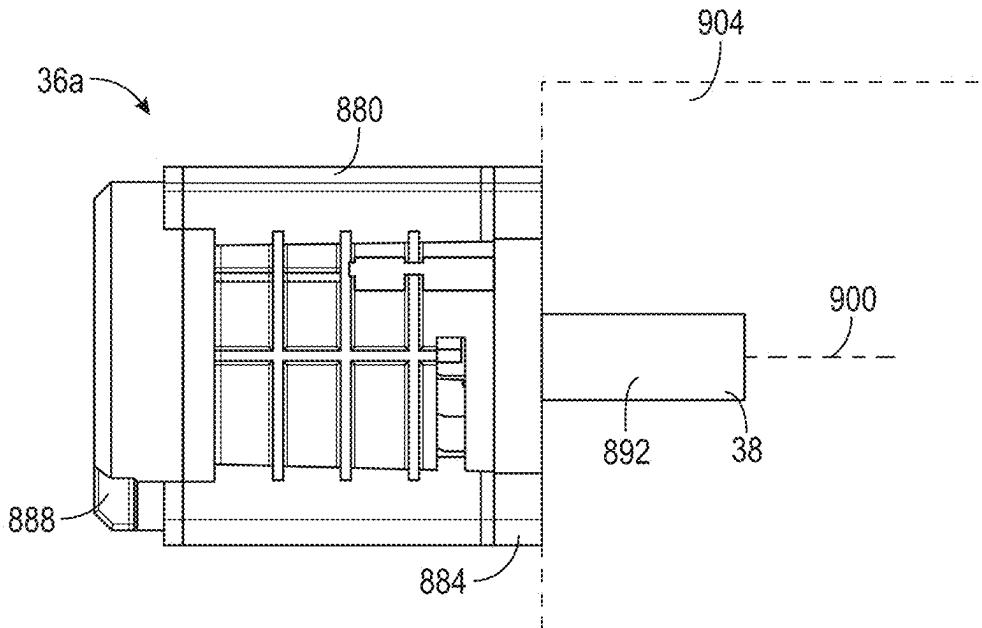


FIG. 65

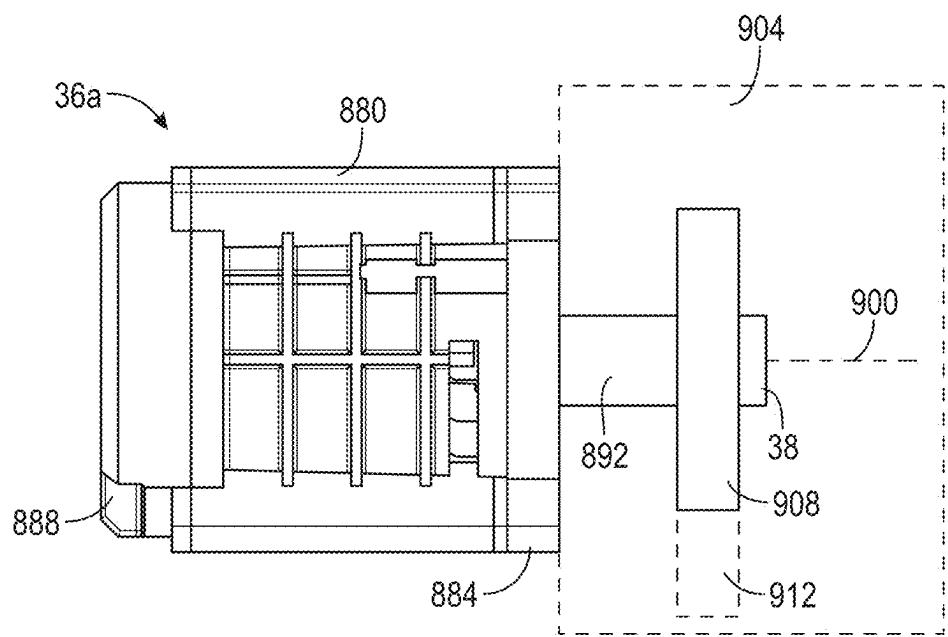


FIG. 66

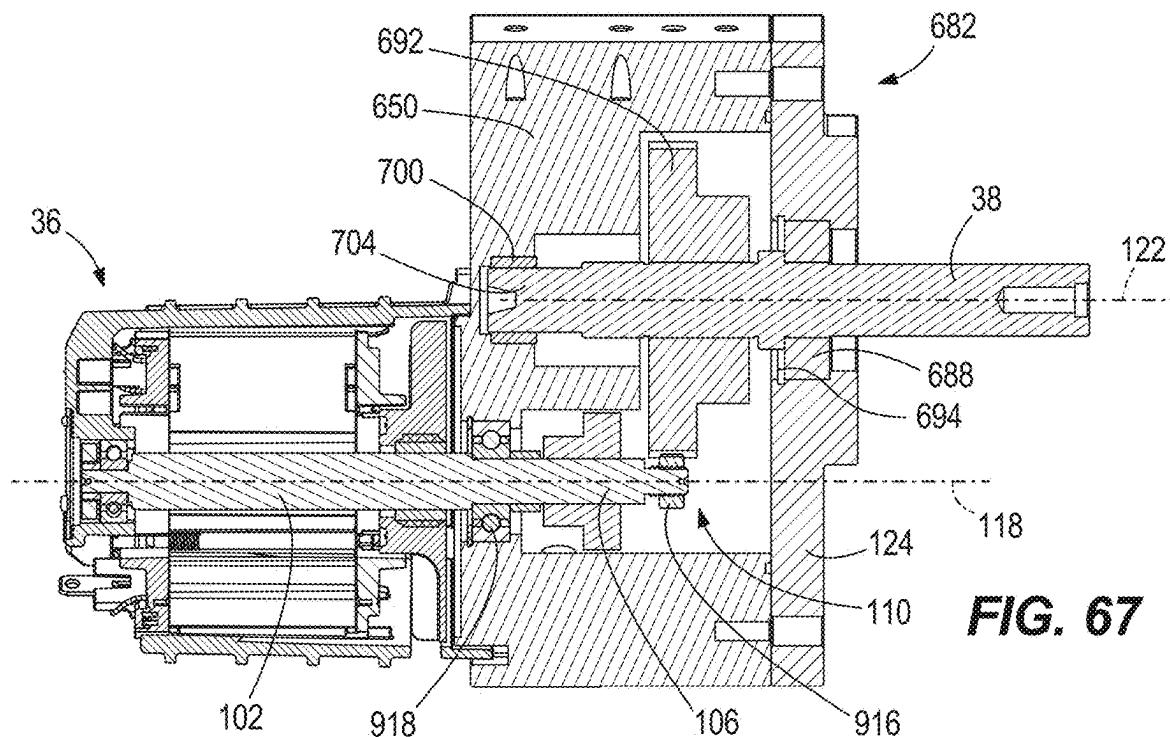


FIG. 67

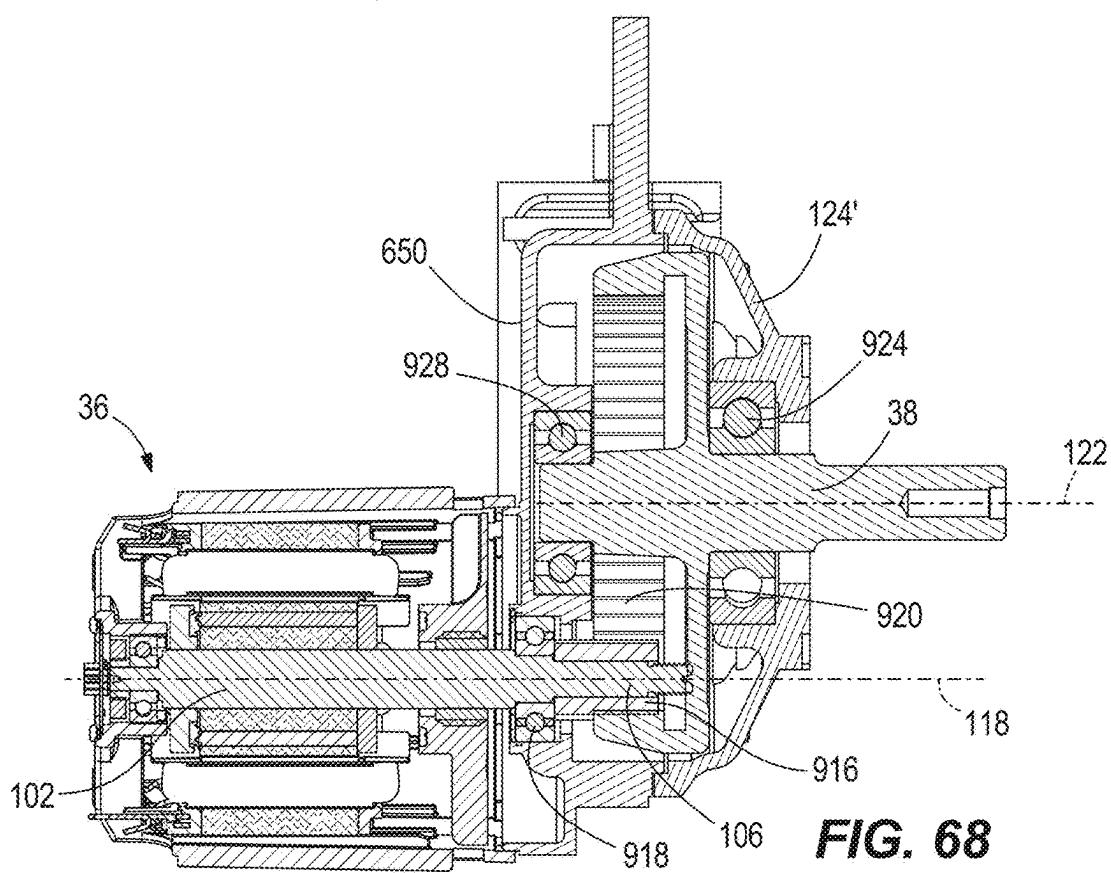


FIG. 68

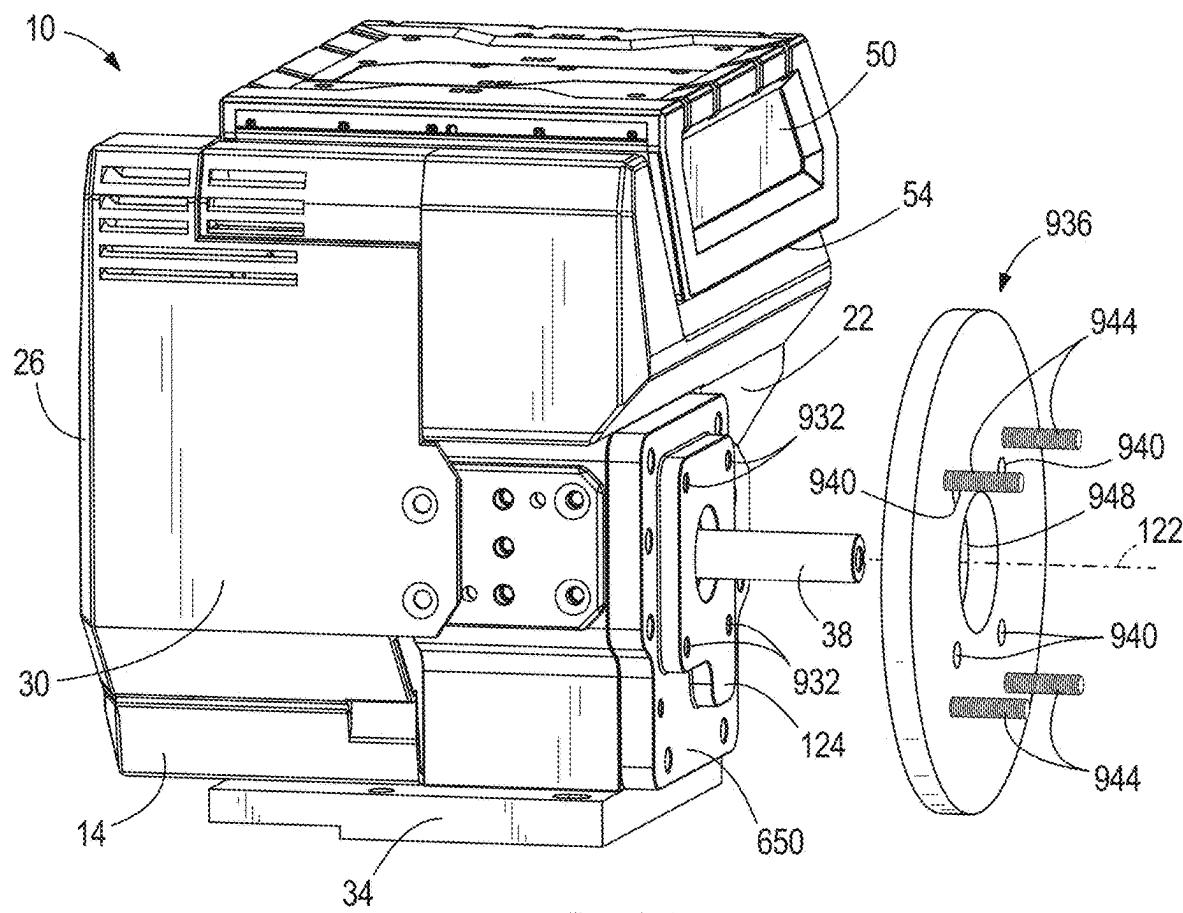


FIG. 69

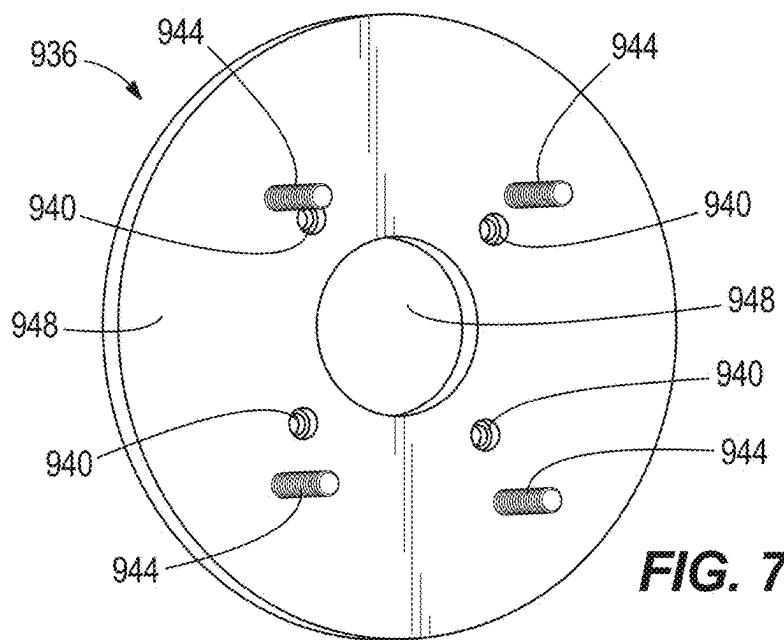


FIG. 70

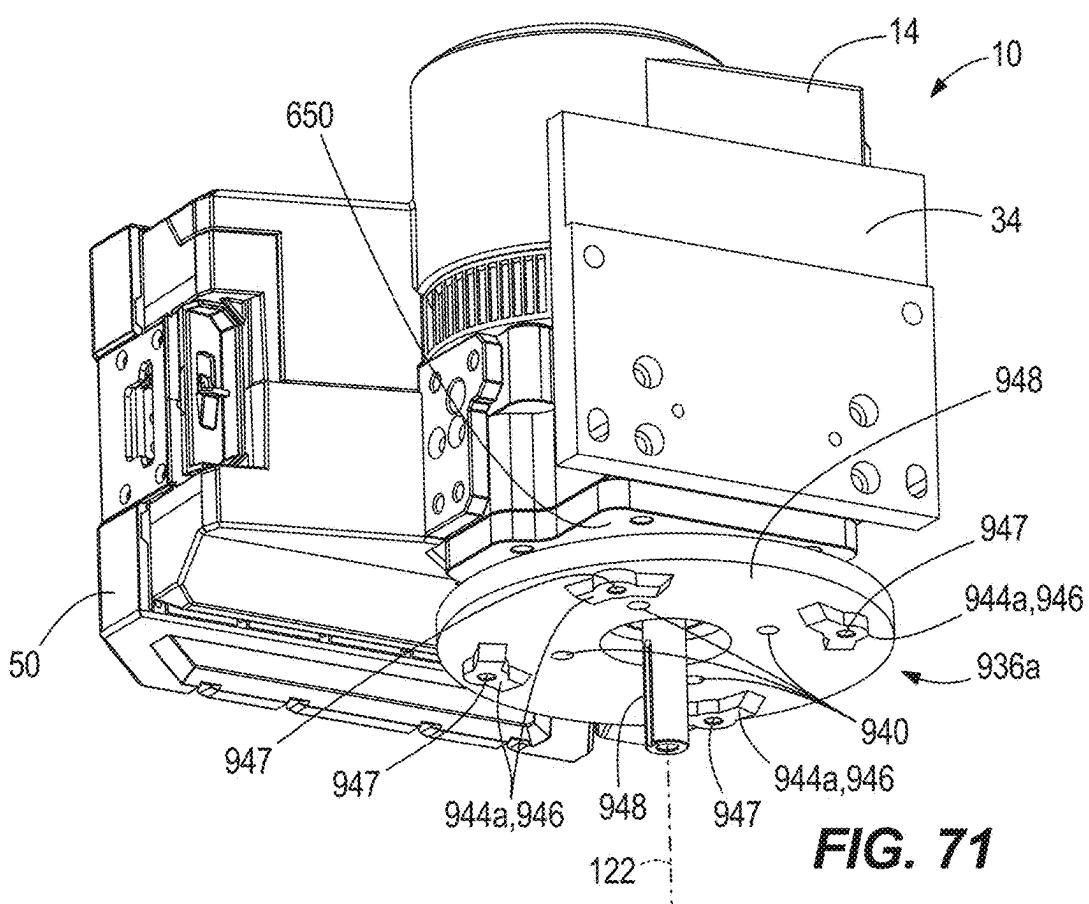


FIG. 71

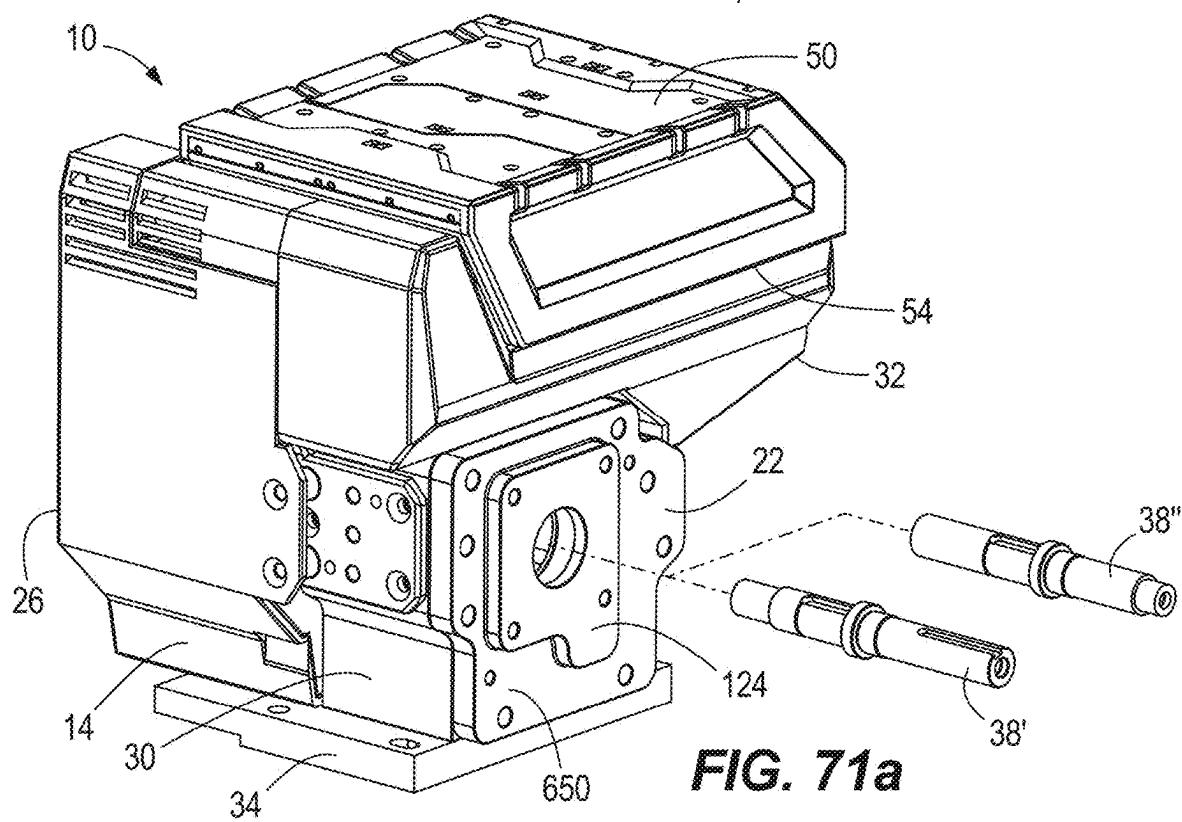


FIG. 71a

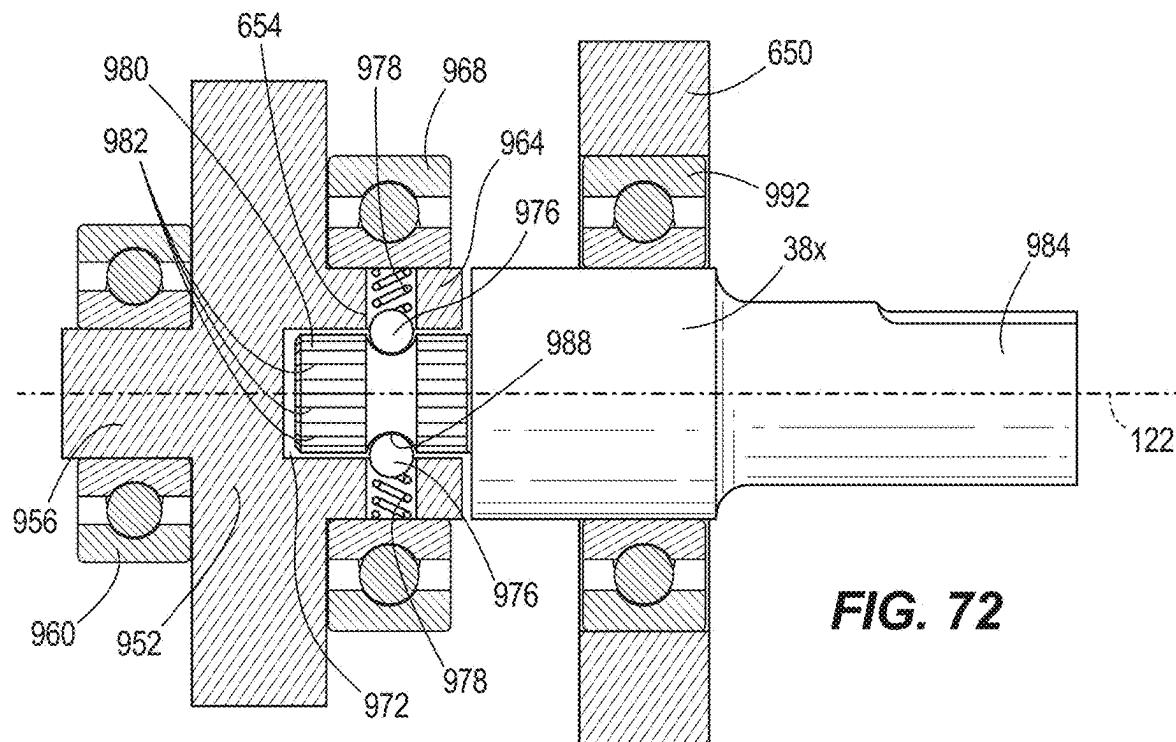


FIG. 72

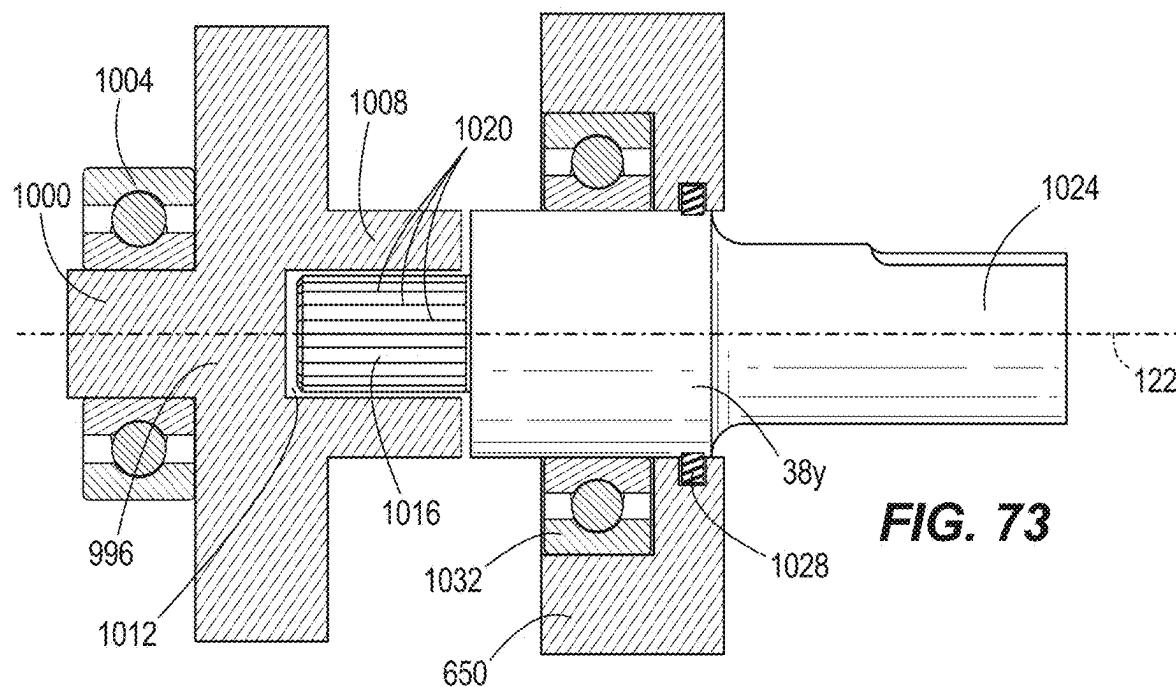
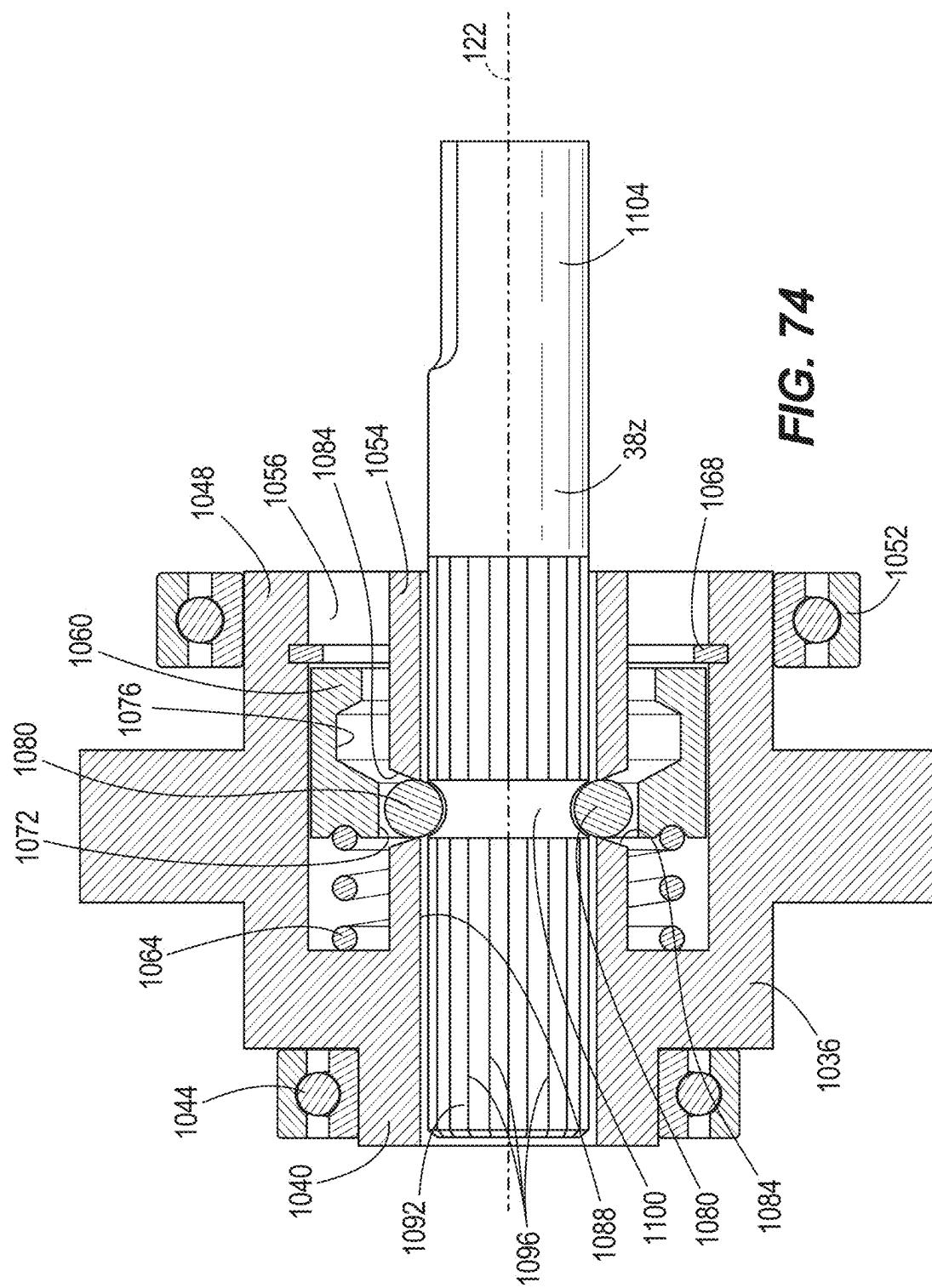
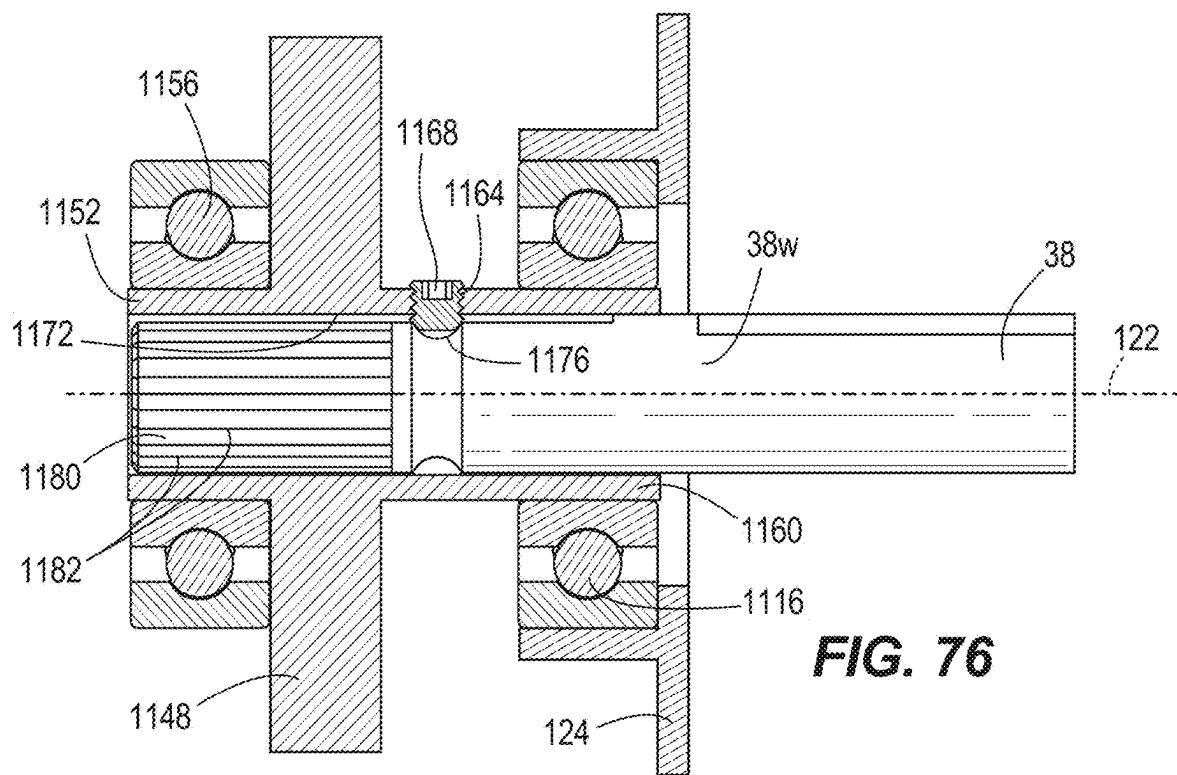
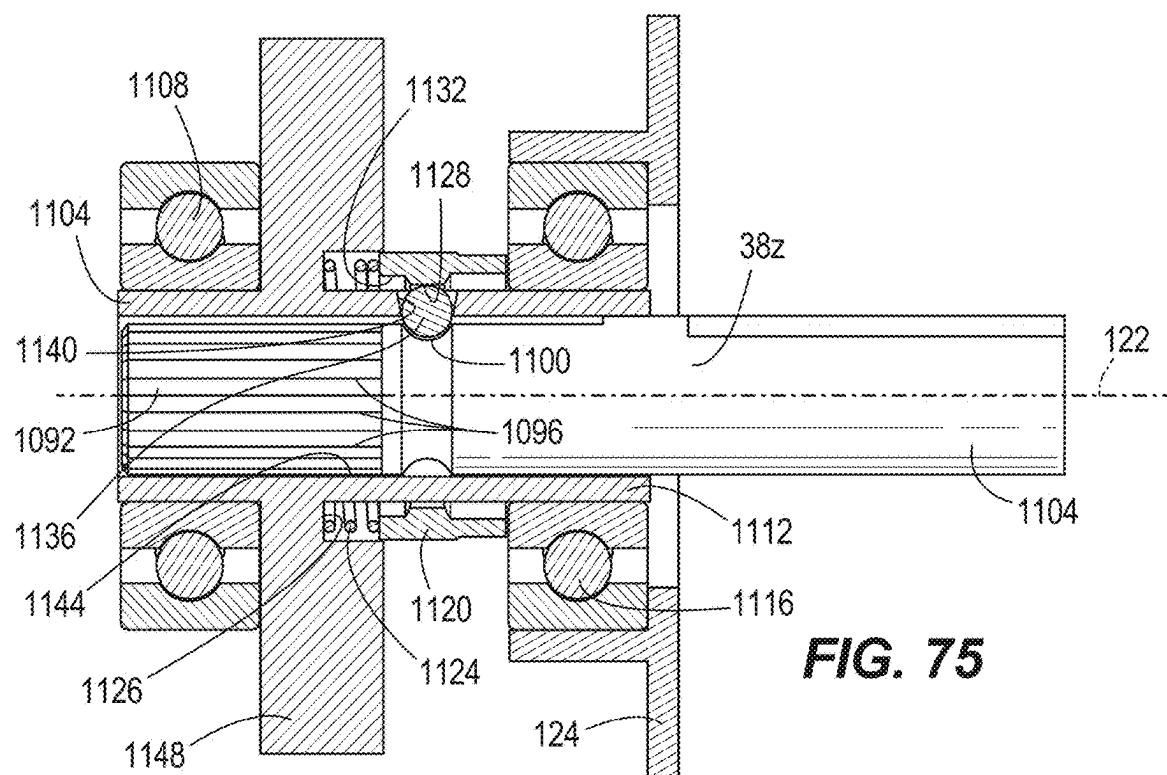
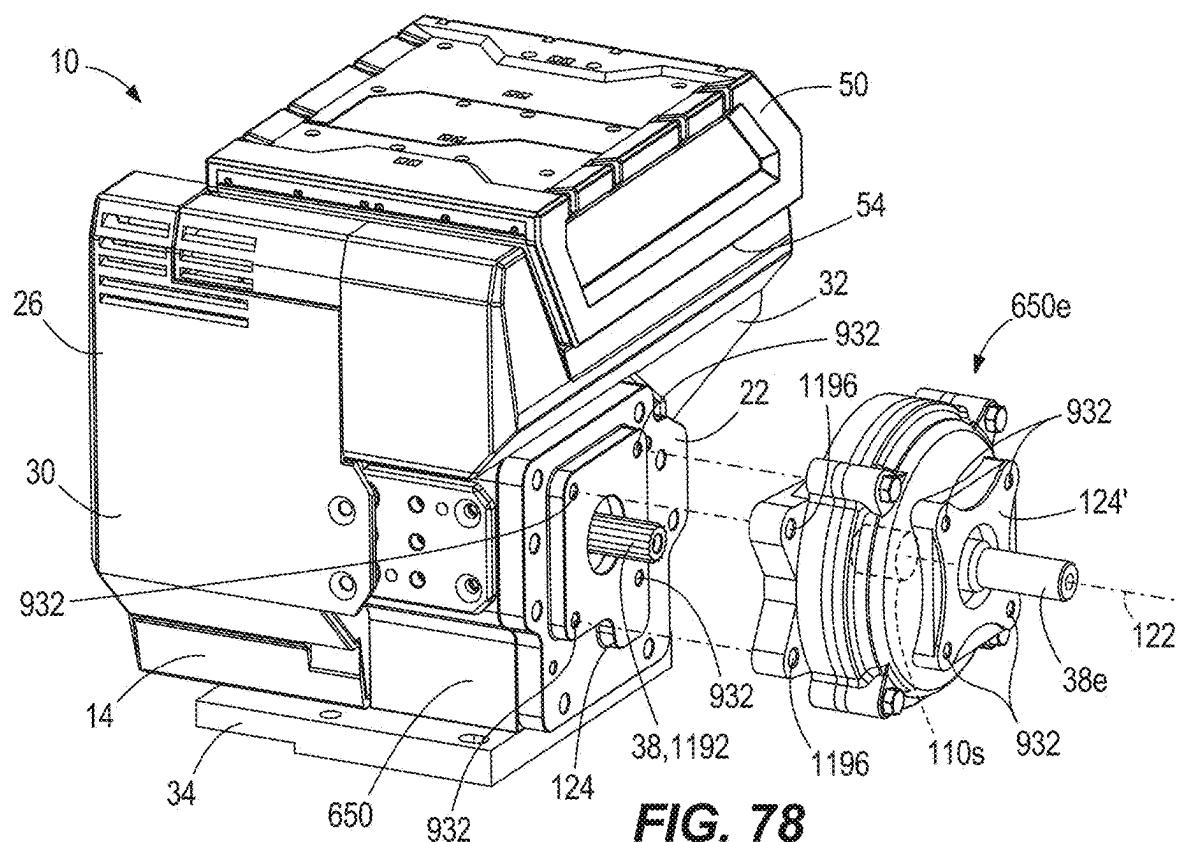
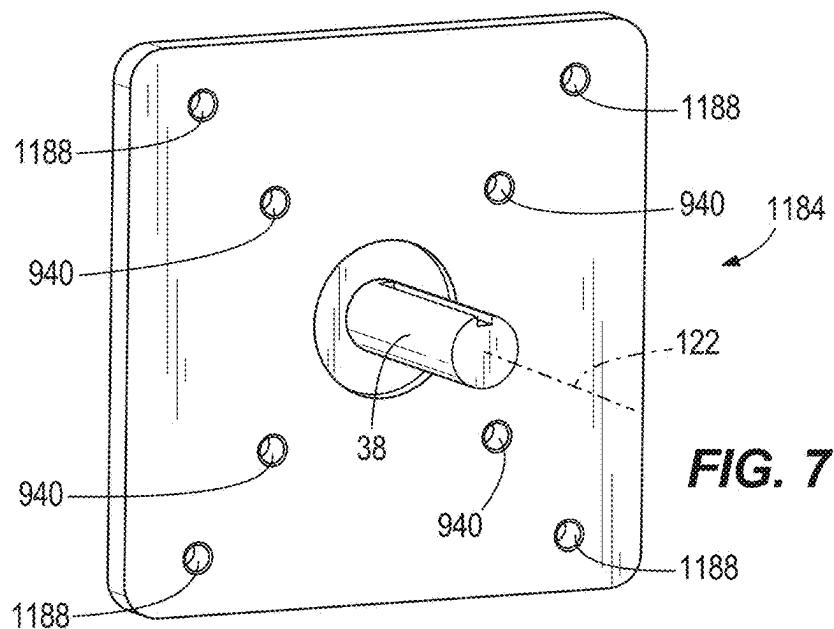


FIG. 73







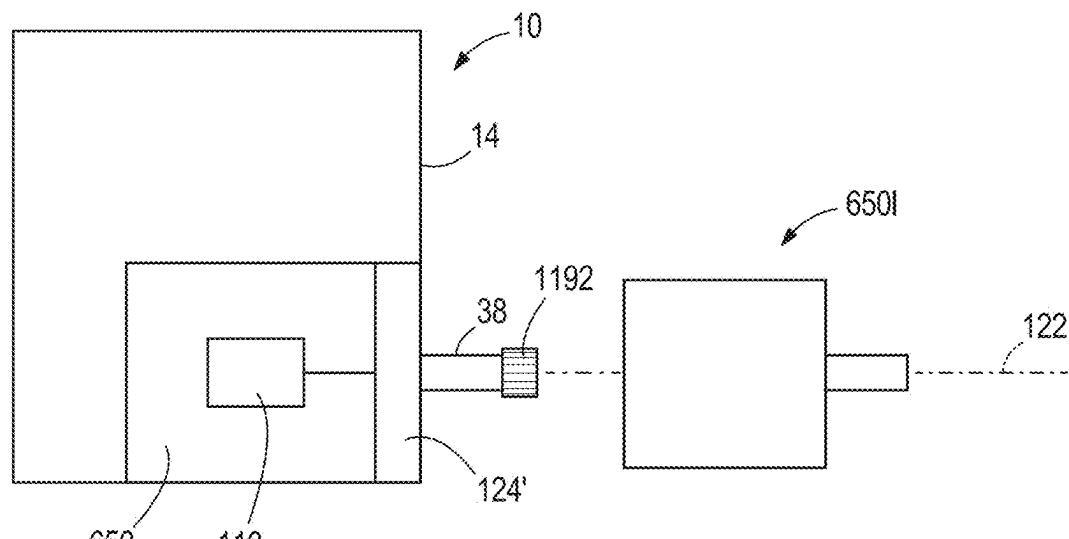


FIG. 79

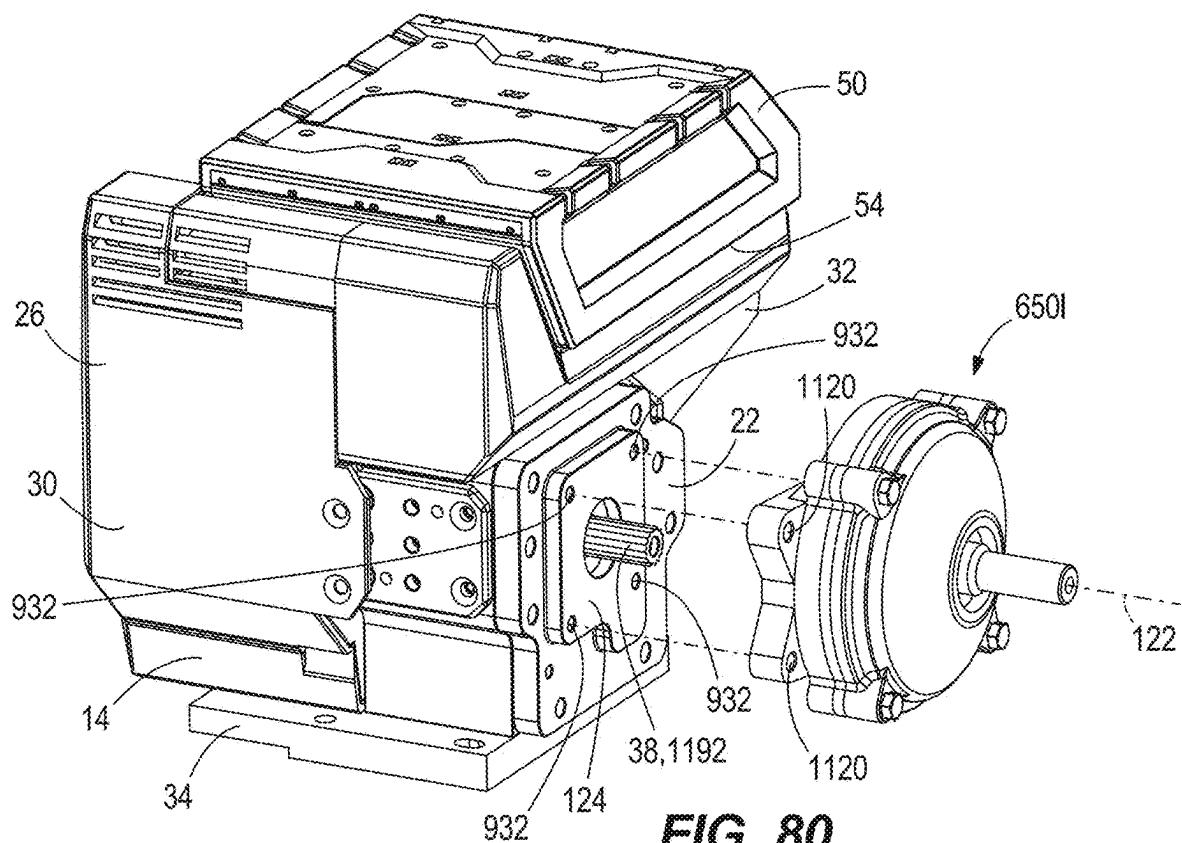


FIG. 80

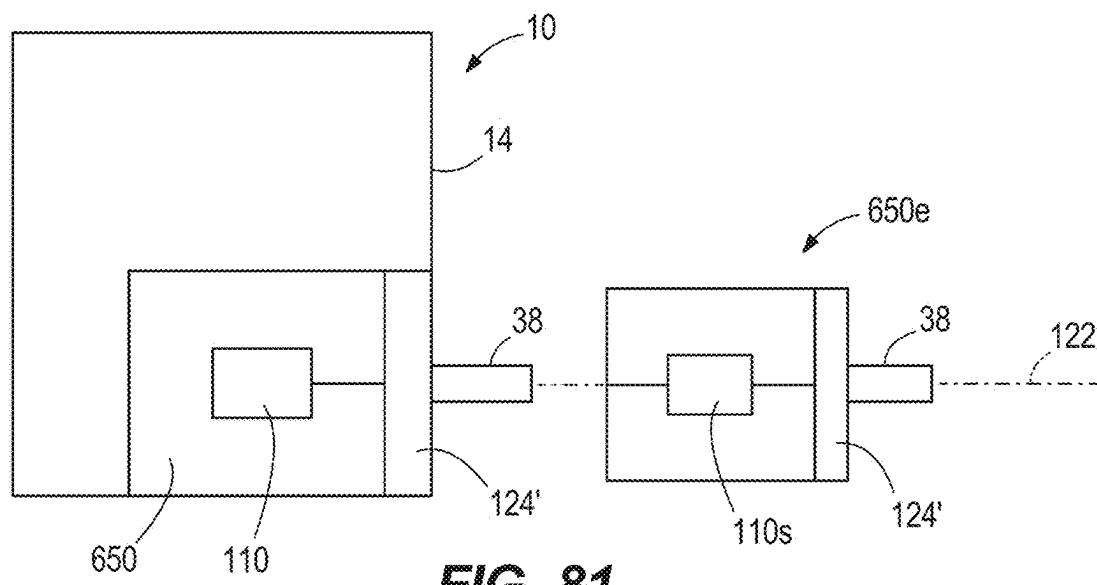


FIG. 81

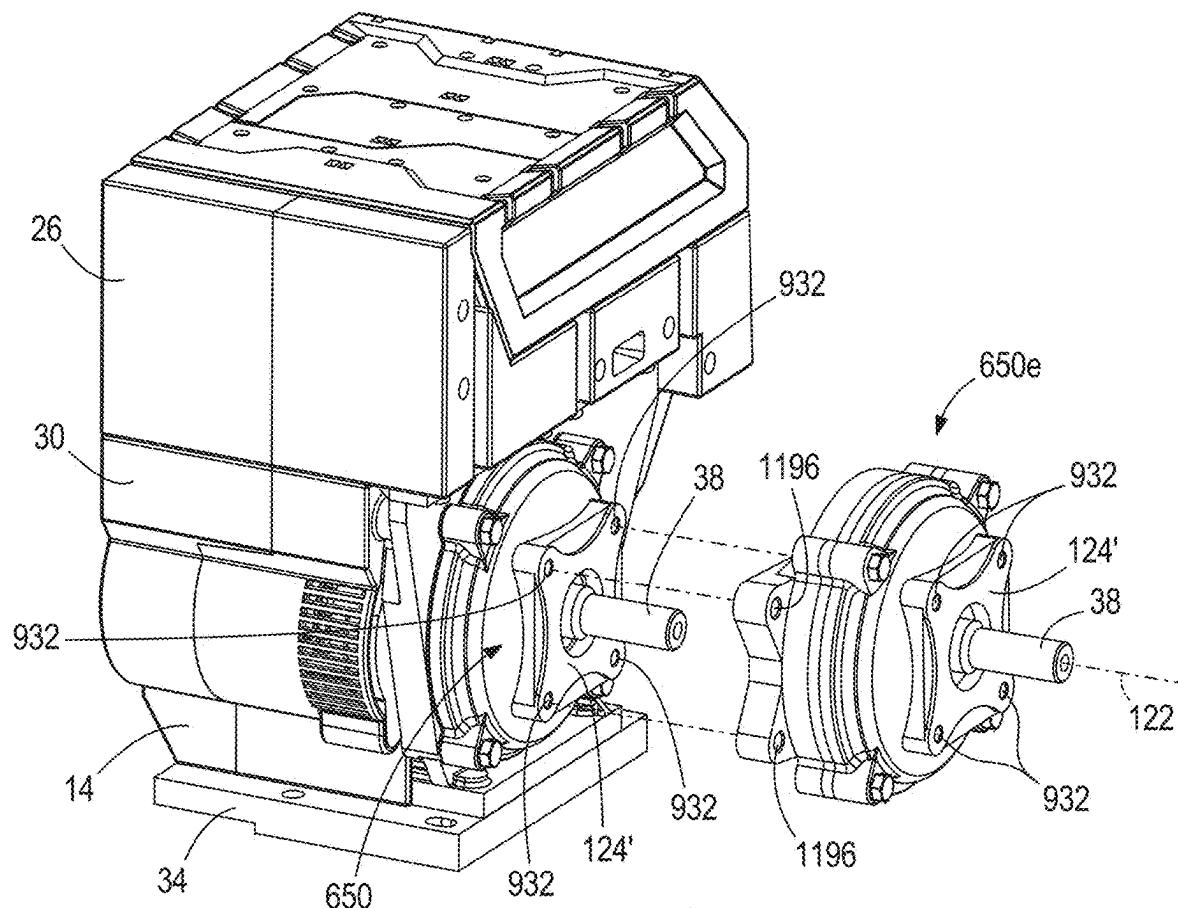
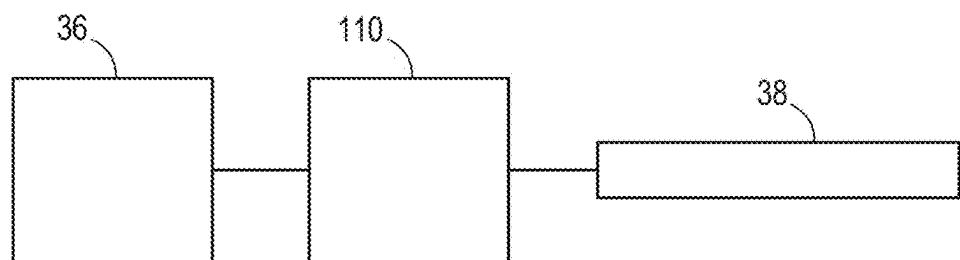
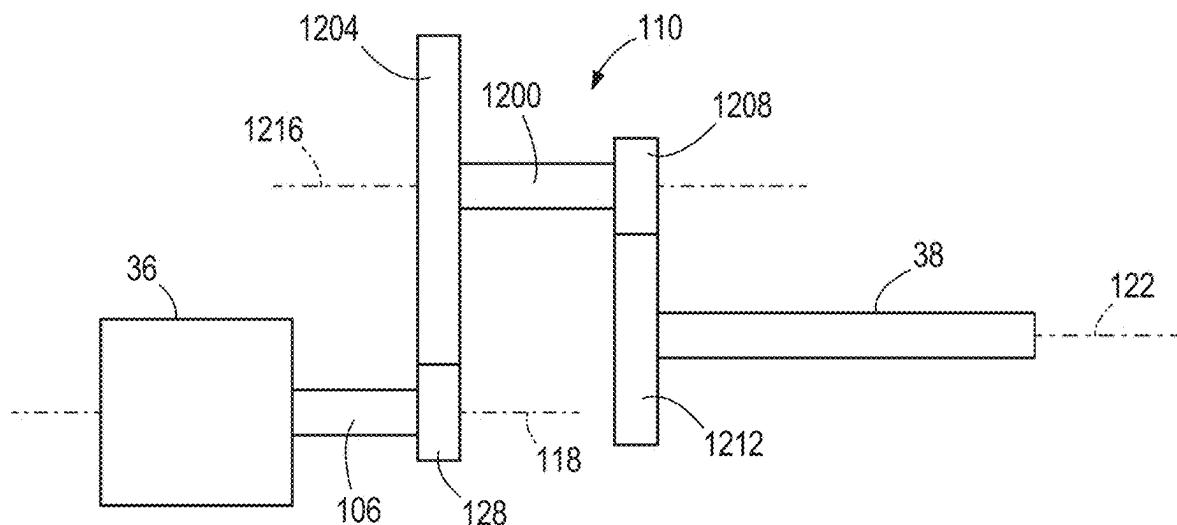


FIG. 82



BATTERY-POWERED STAND-ALONE MOTOR UNIT

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.

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. 42a 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. 71a 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 mm³. In some embodiments, the control electronics 42 has a weight of up to about 830 g. FIGS. 42 and 42a 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 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 mm³. 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 **C1** 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 **C2**, **C3** 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 **C4**. A first center distance **CD1** is defined between the rotational centers **C1** and **C2** of the first and second gears **111**, **112**. A second center distance **CD2** is defined between the rotational centers **C3** and **C4** of the third and fourth gears **116**, **117**. In the illustrated embodiment, the first center distance **CD1** is

equal to the second center distance CD2. However, in other embodiments, the first center distance CD1 may be different than the second center distance CD2.

[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 CD1 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 CD2 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 R1, a second semi-circular portion 162 having a radius R2, 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 R1 is defined and the second semi-circular portion 162 has a center 174 from which radius R2 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 R3, a second semi-circular portion 182 having a radius R4, 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 R3 is defined and the second semi-circular portion 182 has a center 194 from which radius R4 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, R1, R2, R3, and R4 are all equal, but in other embodiments, one or more of the radii R1, R2, R3, R4 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 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

TABLE 1-continued

	Distance from X-axis	Distance from Y-axis
Center 170 of first semi-circular portion 158 of first slot 150	C	G
Center 174 of second semi-circular portion 162 of first slot 150	D	G
Center 190 of first semi-circular portion 178 of second slot 154	C	H
Center 194 of second semi-circular portion 182 of second slot 154	D	H
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 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 R5 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 R5 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 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 R5, in millimeters, for each embodiment:

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

TABLE 4-continued

	K	L	M	N	I	J	R5
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 5

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

[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 6

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

[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 executes 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 unit 10. 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 **390** 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 tactiley, 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 to 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 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 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 (Amperes)	46	43
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 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 com-

pacted 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 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 588a, 588b, 588c, 588d, 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 588a, 588b, 588c, 588d, 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 588a, 588b, 588c, 588d 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 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 38a 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 38b 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 38a 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 38b 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 674a and an elongate bore 675 for receiving a stem 676a of a first male shaft subassembly 676 having the first power take-off shaft 38a. 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 676a of the first male shaft subassembly 676 while securing a washer 680 between the fastener 679 and the stem 676a 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 38b 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 650a with a first gear train 110a 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 110a when the first gearbox 650a is attached to the adapter plate 712. A second gearbox 650b with a second gear train 110b that has a different reduction ratio than the first gear train 110a 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 650a, 650b. In some embodiments, the first and second gearboxes 650a, 650b 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 110a, 110b, each of the additional gearboxes being attachable to the adapter plate 712.

[0224] Instead of swappable gearboxes 650a, 650b 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. 42a, 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. 42a) 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, jettie 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 is 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 **36a** for the motor unit **10** that is different than the motor **36**. The motor **36a** 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 **36a** 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** defin-

ing 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 **650x** (FIG. 62), **650y** (FIG. 63), and **650z** (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 **650x, 650y, 650z** 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 **650x, 650y, 650z** 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 **36a**, 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 **36a** is coupled to the gearbox **650**, but not the housing **14**. In some embodiments, the motor **36a** 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 **650x, 650y, 650z** and the gearboxes **650x, 650y, 650z** respectively include different gear trains **110x, 110y, 110z** for transferring torque from the output shaft **892** to the power take-off shaft **38**. For instance, the gear train **110x** may be a planetary gear train, the gear train **110y** may be a 2-stage gear train, and the gear train **110z** 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 **36a** to the power take-off shaft **38** the operator wants to achieve, the operator can couple one of the gearboxes **650x, 650y, 650z** to the adapter plate **884** of the motor **36a**.

[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 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 SAE 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 936a of FIG. 71 has mounting elements 944a 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 944a 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. 71a, 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 38x 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 38x 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 38x 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 38x 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 38x is axially locked with respect to the final drive gear 952. When the power-take off shaft 38x is secured in the final drive gear 952, the power take-off shaft 38x 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 38x 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 38x.

[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 38y 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 38y 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 38y includes a snap ring 1028, or clip, configured to axially retain the power take-off shaft 38y 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 38y 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 1066 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 38z 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 38z 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 38z 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 38z 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 38z is inserted, the ball detents 1080 are pushed by the power take-off shaft 38z radially outward into the circumferential recess 1076 of the collar 1060. Once the power take-off shaft 38z 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 groove 1100 of the power take-off shaft 38z, thus axially locking the power take-off shaft 38z with respect to the final drive gear 1036. If the power take-off shaft 38z 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 38z cannot be moved axially.

[0270] To remove the power take-off shaft 38z 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 38z is then pulled from the passage 1088. As the power take-off shaft 38z moves out of the passage 1088, the detents 1080 are pushed by the power take-off shaft 38z 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 38z.

[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 1116 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 38z 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 38z 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 38z 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 38z 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 38z, thus axially locking the power take-off shaft 38z with respect to the final drive gear 1100. If the power take-off shaft 38z 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 38z cannot be moved axially.

[0274] To remove the power take-off shaft 38z 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 38z from the passage 1144. As the power take-off shaft 38z is pulled from the passage 1144, the detents 1136 are pushed by the power take-off shaft 38z 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 38z.

[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 38w, an operator inserts the power take-off shaft 38w into the passage 1172 until a circumferential groove 1176 in the shaft 38w 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 38w, such that the power take-off shaft 38w is axially coupled to the final drive gear 1148. Also, because the power take-off shaft 38w has a splined portion 1180 having splines 1182 that mates with a corresponding splined portion in the passage 1172, the power take-off shaft 38w 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 38w 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 38w, 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 38w. 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 38w. In other embodiments, instead of a circumferential groove 1176, the power take-off shaft 38w 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, 936a, and interchangeable power take-off shafts 38, such as the power take-off shaft 38a, 38b, 38w, 38x, 38y, 38z 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.

	Example 1	Example 2	Example 3	Example 4	Example 5
Third hole pattern of adapter plate 1104	SEA J609 Flange A	SEA J609 Flange A	SEA J609 Flange A	SEA J609 Flange B	SEA J609 Flange C
Type of power take-off shaft 38 for adapter plate 1104	SAE J609 Extension 3	SAE J609 Extension 5	SAE J609 Extension 7	SAE J609 Extension 3	SAE J609 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 650e 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 650e. The external gearbox 650e 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 650e has a power take-off shaft 38e 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 110s of external gearbox 650e. Thus, the external gear box 650e 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 650e 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 650e. The external gearbox 650e 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 650e 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 650e 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 650e. Thus, an operator or OEM could use the external gearbox 650e 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 650e 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 110s of external gearbox 650e.

[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.

What is claimed is:

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 from the second faceplate.

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