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(19) **United States**(12) **Patent Application Publication**  
**Remboski et al.**(10) **Pub. No.: US 2019/0093757 A1**(43) **Pub. Date: Mar. 28, 2019**(54) **LUBRICANT SUPPORTED ELECTRIC MOTOR***H02K 7/116* (2006.01)*H02K 1/20* (2006.01)*H02K 5/20* (2006.01)(71) Applicant: **Neapco Intellectual Property Holdings, LLC**, Farmington Hills, MI (US)(52) **U.S. Cl.**CPC ..... *F16H 57/0476* (2013.01); *F16H 57/0441* (2013.01); *F16H 57/0413* (2013.01); *H02K 5/20* (2013.01); *H02K 7/1016* (2013.01); *H02K 7/116* (2013.01); *H02K 1/20* (2013.01); *H02K 9/19* (2013.01)(72) Inventors: **Donald Remboski**, Ann Arbor, MI (US); **Jacqueline Dedo**, Wolverine Lake, MI (US)(21) Appl. No.: **16/144,002**

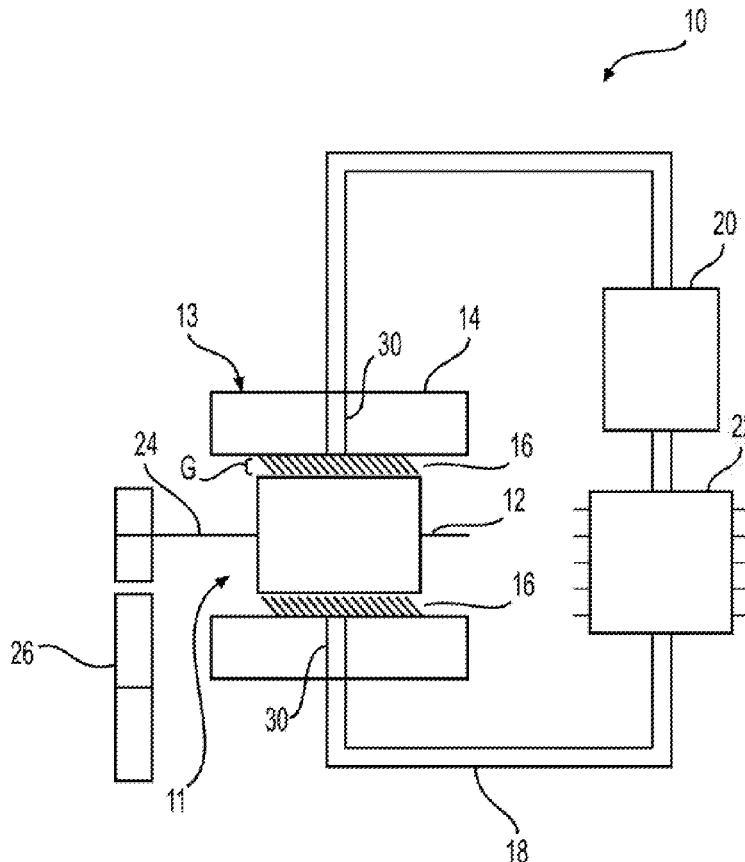
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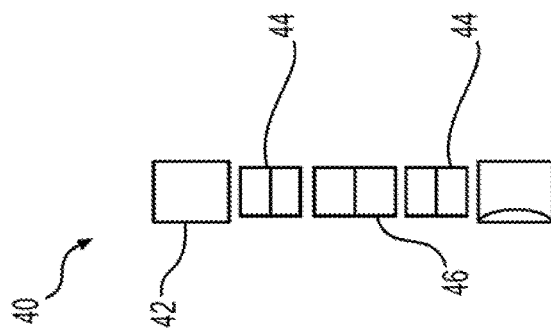
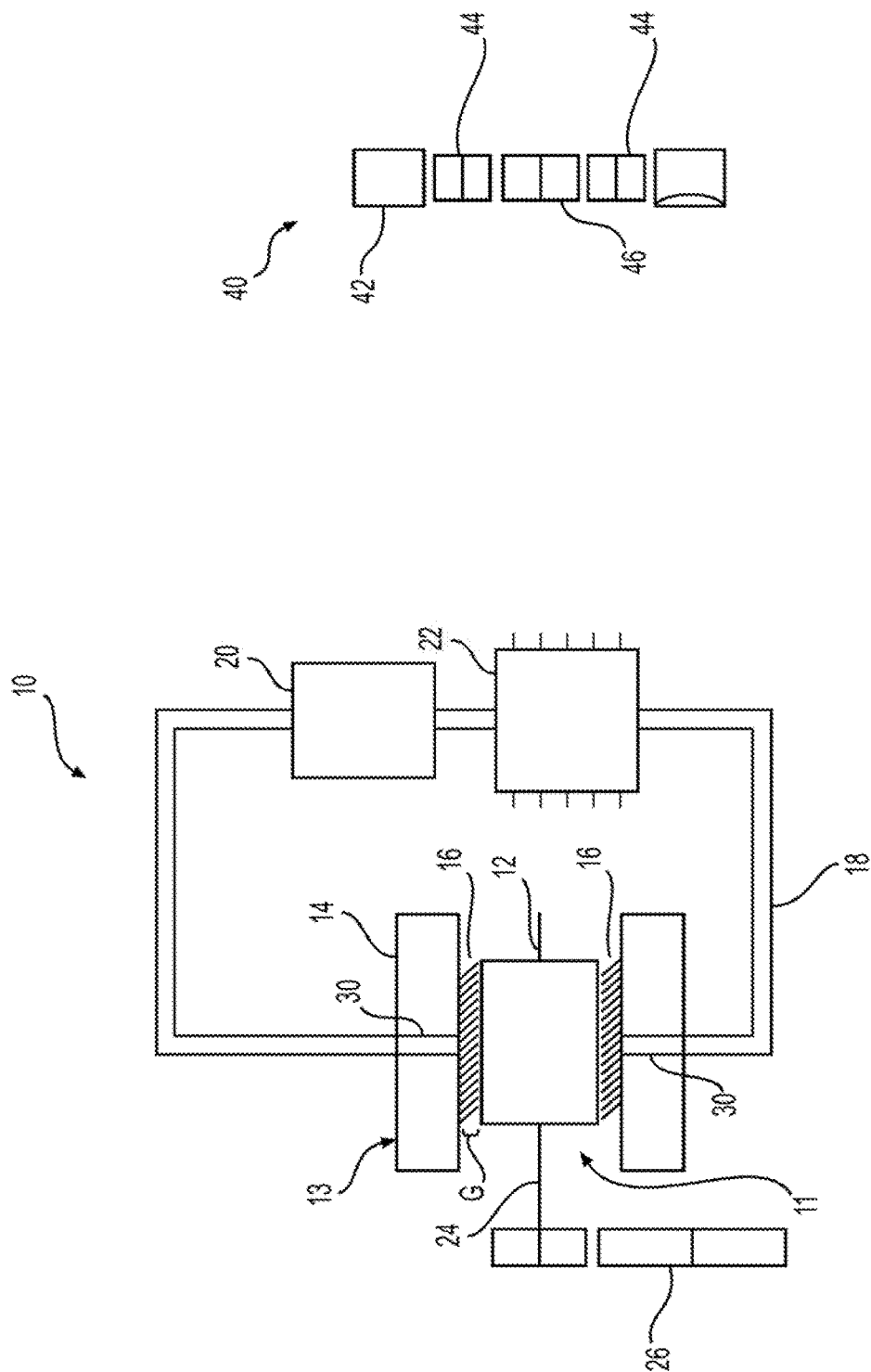
**ABSTRACT**(22) Filed: **Sep. 27, 2018****Related U.S. Application Data**

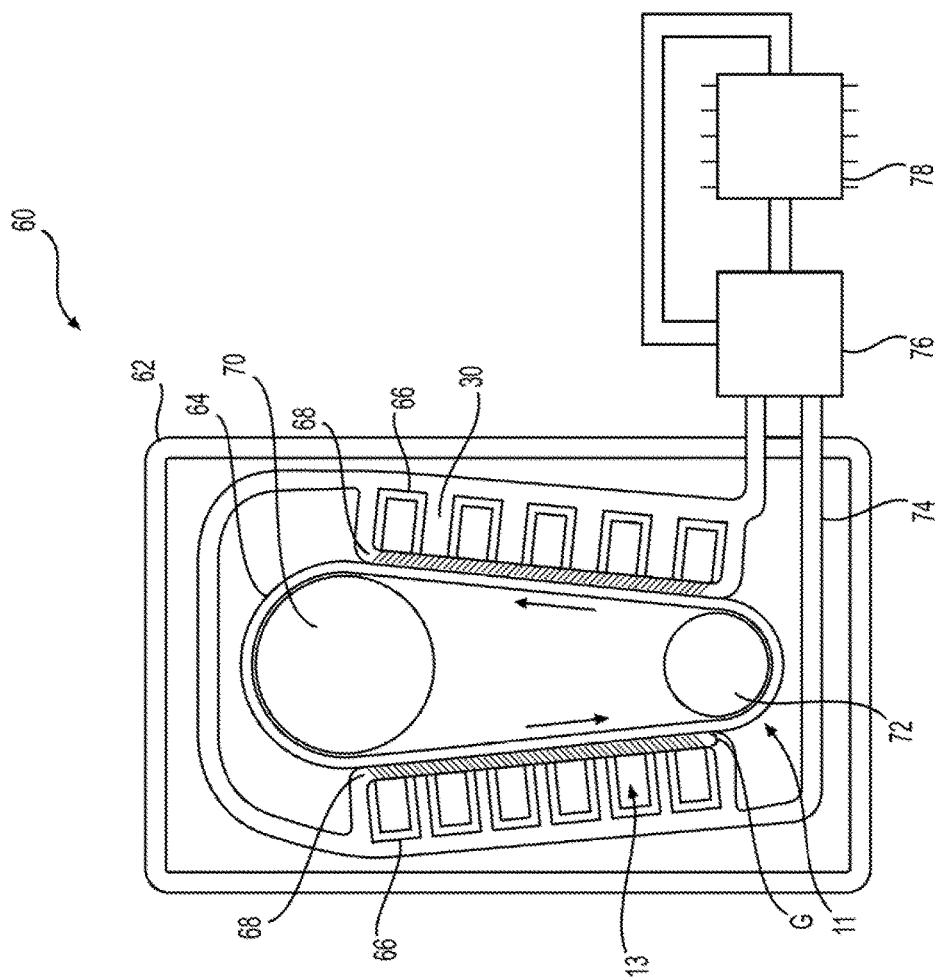
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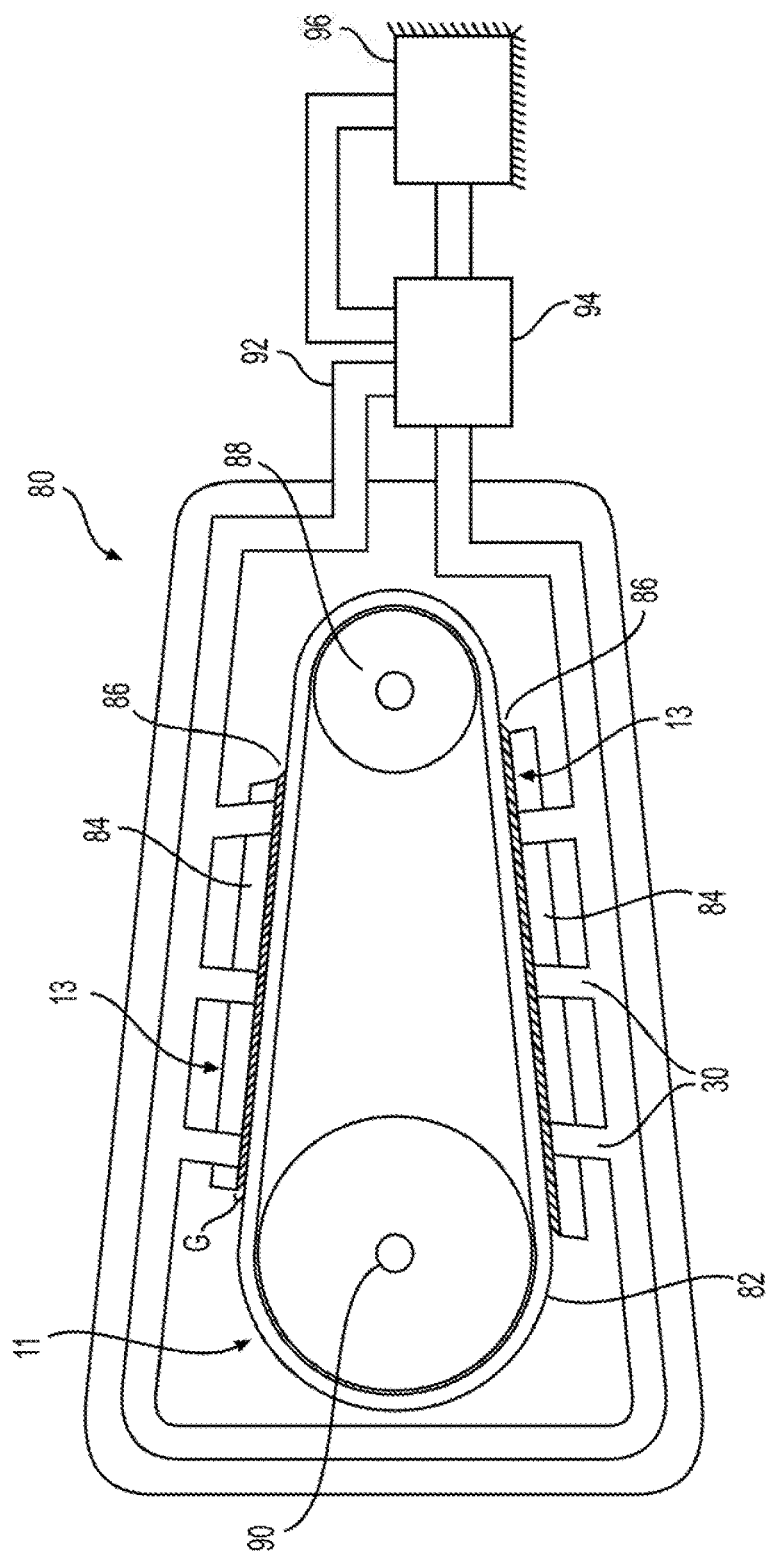
A lubricant supported electric motor includes a static member and a movable member movably disposed within the static member to define a gap therebetween. The static member may be configured as a stator and the movable member may be configured as a rotor. The movable member may also be configured to move relative to the static member. The static member and movable member are configured to exert an electromagnetic force therebetween and convert electrical energy into mechanical energy and move the movable member. A lubricant is disposed in the gap between the static member and the movable member to support the movable member relative to the static member.







**FIG. 3**



**FIG. 4**

## LUBRICANT SUPPORTED ELECTRIC MOTOR

### CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This application claims the benefit of U.S. provisional application No. 62/563,735, filed Sep. 27, 2017, which is hereby incorporated by reference as though fully set forth herein.

### FIELD OF THE DISCLOSURE

[0002] The present disclosure relates to electric motors. More particularly, the present disclosure relates to electric motors with lubricant support between a rotor and stator of the electric motor.

### BACKGROUND OF THE DISCLOSURE

[0003] This section of the written disclosure provides background information related to electric motors and is not necessarily prior art to the inventive concepts disclosed and claimed in this application.

[0004] Various drivelines in automotive, truck, and certain off-highway applications take power from a central prime mover and distribute the power to the wheels using mechanical devices, such as transmissions, transaxles, propeller shafts, and live axles. These configurations may work well when the prime mover may be bulky or heavy such as, for example, various internal combustion engines. More attention is being directed, however, toward environmental performance and issues relating to alternative energy sources, where the transportation industry is engaged in development of various electric vehicles as next-generation vehicle candidates.

[0005] Drive systems that may be used in electric vehicles include two types. The first type relates to a one-motor system in which a motor may be installed in the body of the vehicle and the power may be transmitted to both the left-side and right-side wheels via a differential device and drive shafts. The second type relates to an “on-wheel”, “near-wheel”, or “in-wheel” motor system in which one or more electric motors may be disposed proximate to, on, or within the vehicle wheels. With respect to such on-wheel motor systems, these systems may be configured without a differential, a drive shaft, or other driveline components necessary for performance of a one-motor system, as on-wheel motors and gear or other mechanical reducers may be installed directly on one or more of the wheels. The on-wheel configuration may significantly reduce layout restrictions imposed by driveline components and may greatly increase the degree of freedom in vehicle design. For example, it may be possible to maximize vehicle interior space and further improve vehicle driving performance through the independent traction control ability of each on-wheel motor. Efficiency may also be improved by minimizing energy loss incurred by driveline components, thereby providing a reduction in power consumption during operation and increasing vehicle range per charge. It should be understood that the electric motor described herein may be used in other fields and applications apart from transportation, such as, but not limited to, robotics or material handling.

[0006] Differentials, drive shafts, and other driveline components may work with electric motor prime movers, but the

on-wheel configuration may further provide the opportunity to distribute the prime mover function to each or some of the plurality of wheels of electric motor prime movers because of the small size and lighter weight of electric motors in comparison to internal combustion engines. This reduction and/or elimination of mechanical driveline components may result in a lighter-weight vehicle with more space for passengers and payload. However, on-wheel electric motors have a lack of mechanical robustness to survive the harsh on-wheel environment and lack efficiency in converting electric power to mechanical power.

[0007] Accordingly, one of the elements to providing an efficient electric motor may be to reduce the gap between the rotor and stator. For electric motors that may not be in a harsh environment, this may involve providing rotor and stator components with tight mechanical tolerances and a rotor spindle support system strong enough to keep the rotor from contacting the stator while the electric motor may be in operation. For electric motors in a harsh environment, such as an on-wheel motor subject to significant mechanical shock, the spindle support problem may be challenging due to the very high shock and vibration levels that may be experienced in the wheel end of a vehicle. Accordingly, there remains a need for an electric motor that can be used in an on-wheel configuration and is able to withstand the harsh environment encountered in that application and eliminates the axle shaft of the electric motor and replaces it with a supporting film of lubricant.

### SUMMARY OF THE DISCLOSURE

[0008] This section provides a general summary of the inventive concepts associated with this disclosure and is not intended to be interpreted as a complete and comprehensive listing of all of its aspects, objectives, features and advantages.

[0009] The present disclosure relates to an electric motor including a static member and a movable member moveably disposed within the static member to define a gap therebetween. A lubricant is disposed within the gap to provide a supporting film of lubricant between the static member and the movable member for improving the rigidity and reducing the size of the electric motor. The electric motor affords reductions in weight and packaging space of a vehicle drivetrain by configuring the electric motor in an on-wheel position to drive the vehicle, as one or more electric motors may be coupled to one or more wheels for use in various automotive, truck, or off-highway vehicles, or for use in other devices incorporating electric motors.

[0010] The static member may be configured as a stator and the movable member may be configured as a rotor such that the static member and movable member may be configured to exert an electromagnetic force therebetween and convert electrical energy into mechanical energy and move the movable member. The lubricant may be provided to the gap through the static member.

[0011] In an alternative embodiment, the static member is configured as a plurality of stator coils and the movable member is configured as a band and as a rotor. The moveable member may also be configured to move relative to the static member. The lubricant supported electric motor may include a lubricant disposed in a gap between the plurality of stator coils of the static member and the band of the movable

member to support the movable member relative to the static member. The lubricant may be provided to the gap through the static member.

**[0012]** In another alternative embodiment the static member is configured as a stator. The movable member is configured as a drive chain and as a rotor. The movable member may be configured to move relative to the static member.

**[0013]** The present disclosure includes articles of manufacture, systems, and processes that relate to a lubricant supported electric motor where the rotor of the electric motor is supported on the inside by pressurized lubricant, replacing the rotor axle, and on the outside, between the rotor and stator also by pressurized lubricant. By eliminating the rotor axle and replacing it with pressurized lubricant, the rotors can be increased to produce additional torque when compared to a non-lubricant supported electric motor. The generally incompressible lubricant provides a very rigid support mechanism for the rotor with respect to the stator in place of the rotor axle. As a result, the rotor output shaft may be a lightweight cantilever without the need for additional radial stiffness (such as provided by plain bearings in a non-lubricant supported motor) to absorb shock and vibration as well as reduced torsional stiffness for the output torque of the lubricant supported motor. Additionally, the lubricant provides a low-friction surface for the rotor and stator and provides for temperature regulation using a lubricant circulation system.

**[0014]** Further areas of applicability will become apparent from the description provided herein. The description and specific examples in this summary are intended for purposes of illustration only and are not intended to limit the scope of the present disclosure.

#### BRIEF DESCRIPTION OF THE DRAWINGS

**[0015]** The drawings described herein are for illustrative purposes only of selected aspects and not all possible implementations, and are not intended to limit the scope of the present disclosure.

**[0016]** FIG. 1 is a schematic plan view of a lubricant supported electric motor and a drive configuration, according to an aspect of the disclosure;

**[0017]** FIG. 2 is a schematic plan view of an exemplary drive configuration of a lubricant supported electric motor, according to an aspect of the disclosure;

**[0018]** FIG. 3 is a schematic plan view of a cam drive chain used for a starter/alternator configuration for use with a lubricant supported electric motor, according to an aspect of the disclosure; and

**[0019]** FIG. 4 is a schematic plan view of a linear drive integrated into a suspension trailer arm for a lubricant supported electric motor, according to an aspect of the disclosure.

#### DETAILED DESCRIPTION OF THE ENABLING EMBODIMENTS

**[0020]** Exemplary aspects will now be described more fully with reference to the accompanying drawings. In particular, a number of non-limiting aspects of vehicle driveline components with a wheel support with or without an end gear reduction unit integrated with a wheel end motor is provided so that this disclosure will be thorough and will fully convey the true and intended scope to those who are

skilled in the art. It will be apparent to those skilled in the art that specific details need not be employed, that example aspects may be embodied in many different forms and that neither should be construed to limit the scope of the disclosure. It should also be appreciated that the present disclosure can be utilized in connection with other types of vehicle components not described fully herein.

**[0021]** Referring to FIG. 1, a lubricant supported electric motor 10 is shown having a movable member 11 and a static member 13. The movable member 11 may be configured as a rotor 12 and the static member 13 may be configured as one or more stators 14. The rotor 12 may be configured to move (e.g., rotate) relative to the one or more stators 14. The rotor 12 and the stators 14 may be further configured to exert an electromagnetic force therebetween and to convert electrical energy into mechanical energy when energized that may cause the rotor 12 to move relative to the stators 14. A fluid lubricant 16 is disposed between the rotor 12 and the stators 14. It should be understood that the term "fluid" as used herein includes liquids, gases, plasmas, and plastic solids, or a combination thereof. The lubricant 16 may be configured as a pressurized film such that the lubricant 16 supports the rotor 12 relative to the stators 14. The lubricant 16 may be delivered to the rotor 12 and the stators 14 by a pressurized lubricant system 18. For example, at least one of the static member 11 and the movable member 13 defines at least one passage 30 to distribute lubricant 16 into the gap G between the static member 13 and the movable member 11.

**[0022]** The lubricant system 18 may be configured to provide lubricant 16 to one or more stators 14, for example. The lubricant system 18 may be connected to one or more passages 30 formed in the stators 14. The lubricant system 18 may include a pump 20 that may be configured to pressurize the lubricant 16. Additionally and alternatively, the lubricant supported motor 10 may include self-pumping elements using the rotor 12 and the stators 14 such that the movement of the rotor 12 relative to the stators 14 generates sufficient pressure to circulate the lubricant 16. According to an aspect, the lubricant 16 may be provided by adjacent devices, such as an internal combustion engine or a compressor.

**[0023]** According to an aspect, the lubricant system 18 may include the pump 20 and a heat exchanger 22. The heat exchanger 22 may be configured as a radiator or heat pump, for example. The heat exchanger 22 may remove heat from the lubricant 16 circulated through it by the lubricant system 18 and the pump 20. Additionally and alternatively, the temperature of the lubricant 16 may function in a heating capacity and/or may be heated to warm a cold lubricant supported electric motor 10 and/or to reduce the viscosity of the lubricant 16 in a cold environment, such as for an internal combustion engine or for climate control.

**[0024]** According to an aspect, the rotor 12 of the lubricant supported electric motor 10 may be supported on the inside by the pressurized lubricant 16, replacing a rotor axle (not shown), and on the outside, between the rotor 12 and stators 14 also by pressurized lubricant 16. By eliminating the rotor axle and replacing it with pressurized lubricant 16, the size of the rotor 12 may be increased to produce additional torque when compared to a non-lubricant supported electric motor. The generally incompressible lubricant 16 may provide a very rigid support mechanism for the rotor 12 with respect to the stators 14 in place of the rotor axle. As a result, the

rotor output shaft **24** may be configured as a lightweight cantilever without the need for additional radial stiffness (such as provided by plain bearings in a non-lubricant supported motor) to absorb shock and vibration as well as reduced torsional stiffness for the output torque of the lubricant supported motor. Additionally, the lubricant **16** may provide a low-friction surface for the rotor **12** and stators **14** and may provide for temperature regulation using the lubricant circulation system **18** that may include the pump **20** and the heat exchanger **22**.

[0025] Referring now to FIG. 2, in an alternative arrangement the rotor output shaft **24** of the lubricant supported motor **10** may be operably connected with a ring gear **42** surrounding a set of planetary gears **44** with a sun gear **46** disposed in the center.

[0026] According to an aspect, the rotor output shaft **24** may be directly connected to a wheel or with some speed reduction (e.g., gears), between the lubricant supported electric motor **10** and the wheel. The speed reducer may be configured with parallel axis gears **26** or with a planetary gear set/final drive **40** including but not limited to the ring gear **42**, planetary gears **44**, and sun gear **46**. Additionally and alternatively, the rotor output shaft **24** may permit shifting from one final drive ratio to another.

[0027] According to an aspect, the rotor **12** may be configured with an output shaft **24** that is operably connected to a final drive **40**. For example, the final drive **40** can include parallel axis gears **26**. The parallel axis gears **26** may be configured to transmit rotational energy to a wheel (not shown). The parallel axis gears **26** may provide one or more reduction ratios between the lubricant supported electric motor **10** and the wheel.

[0028] According to an aspect, in addition to supplying motive power in a wheel end, when configured with suitable windings in the stators **14**, the lubricant supported electric motor **10** may generate linear motion in the axial direction. This effect of “solenoid” linear motion may be used to actuate for example, friction brakes, operate a final drive ratio shift, or a combination thereof.

[0029] According to an aspect, various rotor **12** and stator **14** configurations may be used in the lubricant supported electric motor **10**. For example, the lubricant supported electric motor **10** may be configured as one of a radial flux motor and axial flux motor with magnetic circuits including permanent magnets, to use induction currents, to use magnetic reluctance, or to use a combination of permanent magnets and reluctance. Additionally and as alternatively shown in FIG. 3, the lubricant supported electric motor **20** may be configured as an integrated starter alternator drive **60** (ISAD) using a lubricant supported electric motor **10** in a linear motor configuration.

[0030] Referring now to FIG. 3, an ISAD **60** is shown disposed in an internal combustion engine (ICE) **62**. According to an aspect, a rotor belt **64** of the linear lubricant supported electric motor **11** may be configured as a timing belt or chain. The rotor **64** may be configured to rotate near a plurality of stators **66** disposed between a cam shaft **70** and a crankshaft **72** of the ICE **62**. Additionally and alternatively, the plurality of stators **66** may be disposed about the entire perimeter of the rotor belt **64**. According to an aspect, the plurality of stators **66** may be disposed about the interior of the rotor belt **64**. A lubricant **68** is disposed between the rotor belt **64** and the plurality of stators **66**. The lubricant **68** may be in the form of a pressurized film. The lubricant may be

pressurized by a pressurization system **74** including a pump **76** and delivered to a plurality of passages **30** disposed about the stators **66**. The pump **76** may be configured within the ICE **62** or outside of the ICE **62** to circulate the lubricant **68** to the rotor belt **64** and the plurality of stators **66**. Additionally and alternatively, the lubricant **68** may be pressurized by the ICE **62**, such as the lubrication system of the ICE **62**. The pressurization system **74** may include a heat exchanger **78** that is in fluid communication with the lubricant **68**. The heat exchanger **78** may be configured to remove heat from the lubricant **68**, for example. According to an aspect, the heat exchanger **78** may be configured to provide heat to the ISAD **60**, such as in a cold environment.

[0031] According to an aspect, the lubricant **68** may be pressurized by the rotational movement of the rotor belt **64** relative to the plurality of stators **66**. For example, the movable member **11** can be a rotor belt **64** and the static member **13** can be plurality of stators **66** may configured to generate suction that may distribute the lubricant **68** about the opposing surfaces of the rotor belt **64** and the plurality of stators **66** in the gap **G**. The suction may be sufficient to circulate the lubricant **68** to the heat exchanger **78** to remove heat from the lubricant **68**.

[0032] Referring now to FIG. 4, in an alternative arrangement, a wheel-end drivetrain (trailing-arm suspension) **80** is shown including a linear lubricant supported motor **11** configured as a linear motor. A movable member **11** can be a rotor chain **82** is configured as a drive chain and be positioned to interact with a static member **13** that can be configured as pair of stators **84**. The lubricant **86** may be provided between the rotor chain **82** and the pair of stators **84** via passages **30**. The rotor chain **82** may be configured to rotate about an idler pulley **88** and a wheel end spindle **90**. The idler pulley **88** and the wheel end spindle **90** are configured to maintain the rotor chain **82** in proximity to the stators **84** such that the film of the lubricant **86** supports the rotor chain **82** relative to the stators **84**. The lubricant **86** may be provided to the stators **84** by a lubrication system **92**. The lubrication system **92** may include a pump **94** which may be configured to circulate the lubricant **86** through the lubrication system **92**. A heat exchanger **96** may be configured with the lubrication system **92** to remove heat from the lubricant **86**. Additionally and alternatively, the lubricant **86** may be provided by another component connected to or in fluid communication with the wheel-end drivetrain **80**.

[0033] According to an aspect, the rotor chain **82** may be outfitted with suitable magnets or magnetic circuits to enable a set of stationary windings of the pair of stators **84** to exert a drive force on the rotor chain **82**.

[0034] According to an aspect, the wheel-end drivetrain **80** may be configured as a prime mover for a vehicle. For example, the wheel end drivetrain **80** may be integrated into a suspension trailing arm to provide tractive effort. This integration may have the advantage of reducing some of the prime mover mass as part of the un-sprung mass of the wheel-end drivetrain **80**. Additionally and alternatively, the wheel-end drivetrain **80** configuration may also offer packaging efficiencies due to the double use of the suspension trailing arm.

[0035] Obviously, many modifications and variations of the present disclosure are possible in light of the above teachings and may be practiced otherwise than as specifically described while within the scope of the appended claims. Individual elements or features of a particular aspect

are generally not limited to that particular aspect, but, where applicable, are interchangeable and may be used in a selected aspect, even if not specifically shown or described.

What is claimed is:

1. An electric motor comprising:
  - a static member configured as a stator;
  - a movable member configured as a rotor and moveable disposed within the stator to define a gap therebetween, the static member and movable member configured to exert an electromagnetic force therebetween and convert electrical energy into mechanical energy and move the movable member; and
  - a lubricant disposed in the gap between the static member and the movable member to support the movable member relative to the static member.
2. The electric motor of claim 1, wherein one of the stator or the rotor defines a passageway disposed in fluid communication with the gap for introducing the lubricant.
3. The electric motor of claim 2, wherein the stator defines the passageway.
4. The electric motor of claim 1, wherein the movable member is operably connected to a final drive device that is interconnected to a wheel of a vehicle.
5. The electric motor of claim 2, further comprising a pump disposed in fluid communication with the passageway for introducing the lubricant into the gap through the static member.
6. The electric motor of claim 1, further comprising at least one of a heat exchanger, a heat sink, and a radiator in fluid communication with the lubricant.
7. An electric motor comprising:
  - a static member configured as a plurality of stator coils;
  - a movable member, the movable member configured as a band and as a rotor and movably disposed within the stator to define a gap therebetween, the static member and movable member configured to exert an electromagnetic force therebetween and convert electrical energy into mechanical energy and move the movable member; and
  - a lubricant disposed in the gap between the plurality of stator coils of the static member and the band of the movable member to support the movable member relative to the static member.
8. The electric motor of claim 7, wherein one of the stator or the rotor defines a passageway disposed in fluid communication with the gap for introducing the lubricant.

9. The electric motor of claim 8, wherein the stator defines the passageway.

10. The electric motor of claim 7, wherein the movable member is operably connected to at least one of a crankshaft and a camshaft of an internal combustion engine.

11. The electric motor of claim 7, wherein the band is configured as at least one of a drive belt, a drive chain, a timing belt, and a timing chain of an internal combustion engine.

12. The electric motor of claim 7, further comprising a pump disposed in fluid communication with the passageway for introducing the lubricant into the gap.

13. The electric motor of claim 7, further comprising at least one of a heat exchanger, a heat sink, and a radiator in fluid communication with the lubricant.

14. An electric motor comprising:

a static member configured as a stator;

a movable member, the movable member configured as a drive chain and as a rotor and movably disposed within the stator to define a gap therebetween, the static member and movable member configured to exert an electromagnetic force therebetween and convert electrical energy into mechanical energy and move the movable member; and

a lubricant disposed in the gap between the plurality of stator coils of the static member and the band of the movable member to support the movable member relative to the static member.

15. The electric motor of claim 14, wherein one of the stator or the rotor defines a passageway disposed in fluid communication with the gap for introducing the lubricant.

16. The electric motor of claim 15, wherein the stator defines the passageway.

17. The electric motor of claim 14, wherein the movable member includes a connection to at least one of a wheel-end spindle and an idler gear of a trailing arm suspension of a vehicle.

18. The electric motor of claim 14, wherein the drive chain is configured as at least one of a drive belt and a drive chain of a trailing arm suspension of a vehicle.

19. The electric motor of claim 14, further comprising a pump disposed in fluid communication with the passageway for introducing the lubricant into the gap.

20. The electric motor of claim 14, further comprising at least one of a heat exchanger, a heat sink, and a radiator in fluid communication with the lubricant.

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