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TWO-IN-ONE GEAR AND BEARING CURRENT SENSING AND REDUCTION VIA CURRENT CHOKE

Abstract

A vehicle, system and method of operating the vehicle. The system includes a motor, a choke and a processor. The motor includes a rotor shaft and a bearing between the rotor shaft and the motor, wherein a bearing current flows through the bearing and along the rotor shaft between the motor and a gearbox of the vehicle and wherein the motor is run at a selected motor speed and selected motor torque. The choke is disposed at the rotor shaft between the motor and the gearbox. The choke includes a winding, wherein the bearing current passes through the choke to induce a sensing current through the winding. The processor is configured to determine the bearing current from the sensing current and transmit a signal to notify a user when the bearing current is greater than a selected damage threshold.

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Background/Summary

INTRODUCTION

[0001] The subject disclosure relates to diagnosing internal motor currents and, in particular, to a system and method of detecting damage to bearings of a motor based on a bearing current of the motor.

[0002] An electric motor is used to operate an electric vehicle. When operated with a given range of motor torque or motor speed, internal currents can be induced in the motor which can cause damage. In, particular a current can flow through a bearing that allows a rotor shaft to rotate with respect to a frame of the motor. This bearing current can cause damage to the bearing over time, thereby inhibiting operation of the motor. Accordingly, it is desirable to provide a method for diagnosing a damage to a bearing of the motor due to bearing current.

SUMMARY

[0003] In one exemplary embodiment, a method of operating a vehicle is disclosed. A motor of the vehicle is run at a selected motor speed and a selected motor torque to generate a bearing current that flows through a bearing of the motor and along a rotor shaft between the motor and a gearbox of the vehicle. A sensing current is measured, the sensing current being induced through a winding at a choke in response to flow of the bearing current through the choke. The bearing current is determined from the sensing current. A signal is transmitted to notify a user when the bearing current is greater than a selected damage threshold.

[0004] In addition to one or more of the features described herein, measuring the sensing current further includes measuring the sensing current via an ammeter coupled to the winding.

[0005] In addition to one or more of the features described herein, measuring the sensing current further includes measuring a voltage across a resistor that connects ends of the winding and determining the sensing current from the voltage and a resistance of the resistor.

[0006] In addition to one or more of the features described herein. measuring the sensing current further comprises measuring a voltage across ends of the winding and integrating the voltage over a time duration to determine the sensing current.

[0007] In addition to one or more of the features described herein, the choke is disposed at the rotor shaft between the motor and the gearbox.

[0008] In addition to one or more of the features described herein, the method further includes measuring an inverter common mode current at an inverter and determining a common mode current at the motor based on the inverter common mode current, wherein the inverter common mode current is measured via one of an inverter choke through which a positive DC power line of the inverter and a negative DC power line of the inverter passes and an inverter choke through which at least one of an AC output line of the inverter passes.

[0009] In addition to one or more of the features described herein, the method further includes at least one of changing an oil of a drive unit in response to the signal and replacing the bearing in response to the signal.

[0010] In another exemplary embodiment, a system for operating a vehicle is disclosed. The system includes a motor, a choke and a processor. The motor includes a rotor shaft and a bearing between the rotor shaft and the motor, wherein a bearing current flows through the bearing and along the rotor shaft between the motor and a gearbox of the vehicle and wherein the motor is run at a selected motor speed and selected motor torque. The choke includes a winding, wherein the bearing current passes through the choke to induce a sensing current through the winding. The processor is configured to determine the bearing current from the sensing current and transmit a signal to notify

a user when the bearing current is greater than a selected damage threshold.
[0011] In addition to one or more of the features described herein, the system further includes an ammeter coupled to the winding to measure the sensing current.
[0012] In addition to one or more of the features described herein, the system further includes a resistor that connects ends of the winding and a voltmeter for measuring a voltage induced across the resistor by the sensing current, wherein the processor determines the sensing current from the voltage and a resistance of the resistor.
[0013] In addition to one or more of the features described herein, the system further includes a voltmeter across ends of the winding for measuring a voltage and an integrating circuit configured to integrate the voltage over a time duration to determine the sensing current.
[0014] In addition to one or more of the features described herein, wherein the choke is disposed at the rotor shaft between the motor and the gearbox.
[0015] In addition to one or more of the features described herein, the system further includes one of an inverter choke through which a positive DC power line of an inverter and a negative DC power line of the inverter passes and an inverter choke through which at least one of an AC output line of the inverter passes, wherein the processor is configured to measure an inverter common mode current at the inverter choke and determine a common mode current at the motor based on the inverter common mode current.
[0016] In addition to one or more of the features described herein, the system further includes at least one of changing an oil of a drive unit in response to the signal and replacing the bearing in response to the signal.
[0017] In another exemplary embodiment, a vehicle is disclosed. The vehicle includes a motor, a choke and a processor. The motor includes a rotor shaft and a bearing between the rotor shaft and the motor, wherein a bearing current flows through the bearing and along the rotor shaft between the motor and a gearbox of the vehicle and wherein the motor is run at a selected motor speed and selected motor torque. The choke includes a winding, wherein the bearing current passes through the choke to induce a sensing current through the winding. The processor is configured to determine the bearing current from the sensing current and transmit a signal to notify a user when the bearing current is greater than a selected damage threshold.
[0018] In addition to one or more of the features described herein, the vehicle further includes an ammeter coupled to the winding to measure the sensing current.
[0019] In addition to one or more of the features described herein, the vehicle further includes a resistor that connects ends of the winding and a voltmeter for measuring a voltage induced across the resistor by the sensing current, wherein the processor determines the sensing current from the voltage and a resistance of the resistor.
[0020] In addition to one or more of the features described herein, the vehicle further includes a voltmeter across ends of the winding for measuring a voltage and an integrating circuit configured to integrate the voltage over a time duration to determine the sensing current.
[0021] In addition to one or more of the features described herein, the choke is disposed at the rotor shaft between the motor and the gearbox.
[0022] In addition to one or more of the features described herein, the vehicle further includes one of an inverter choke through which a positive DC power line of an inverter and a negative DC power line of the inverter passes and an inverter choke through which at least one of an AC output line of the inverter passes, wherein the processor is configured to measure an inverter common mode current at the inverter choke and determines a common mode current at the motor based on the inverter common mode current.
[0023] The above features and advantages, and other features and advantages of the disclosure are readily apparent from the following detailed description when taken in connection with the accompanying drawings.

Description

BRIEF DESCRIPTION OF THE DRAWINGS

[0024] Other features, advantages and details appear, by way of example only, in the following detailed description, the detailed description referring to the drawings in which:

[0025] FIG. **1** shows a vehicle in accordance with an illustrative embodiment;

[0026] FIG. **2** show a side cross-sectional view of a motor of the vehicle, in an embodiment;

[0027] FIG. **3** shows a perspective view of a choke in an embodiment;

[0028] FIG. **4** shows a perspective view of the choke in a second embodiment;

[0029] FIG. **5** shows a perspective view of the choke in a third embodiment;

[0030] FIG. **6** shows graphs of electrical parameters of the motor over time;

[0031] FIG. **7** shows a plot of bearing current in an illustrative embodiment;

[0032] FIG. **8** shows a flowchart of a method of using current measurements to diagnose and repair or maintain the motor;

[0033] FIG. **9** shows a flowchart of a method of using sensing current measurements to diagnose and repair or maintain the motor including multiple sensors;

[0034] FIG. **10** shows a drive assembly including the motor and gearbox, in an illustrative embodiment;

[0035] FIG. **11** shows a view of the circuitry of the inverter, in an embodiment;

[0036] FIG. **12** shows a perspective view of the current sensor of the inverter, in an embodiment; and

[0037] FIG. **13** shows a perspective view of the current sensor, in another embodiment.

DETAILED DESCRIPTION

[0038] The following description is merely exemplary in nature and is not intended to limit the present disclosure, its application or uses. It should be understood that throughout the drawings, corresponding reference numerals indicate like or corresponding parts and features.

[0039] In accordance with an exemplary embodiment, FIG. **1** shows an embodiment of a vehicle **10**, which includes a vehicle body **12** defining, at least in part, an occupant compartment **14**. The vehicle body **12** also supports various vehicle subsystems including a propulsion system **16**, and other subsystems to support functions of the propulsion system **16** and other vehicle components, such as a braking subsystem, a suspension system, a steering subsystem, and others.

[0040] The vehicle **10** may be an electrically powered vehicle (EV), a hybrid vehicle or any other vehicle. In an embodiment, the vehicle **10** is an electric vehicle that includes multiple motors and/or drive systems. Any number of drive units may be included, such as one or more drive units for applying torque to front wheels (not shown) and/or to rear wheels (not shown). The drive units are controllable to operate the vehicle **10** in various operating modes, such as a normal mode, a high-performance mode (in which additional torque is applied), all-wheel drive ("AWD"), front-wheel drive ("FWD"), rear-wheel drive ("RWD") and others.

[0041] For example, the propulsion system **16** is a multi-drive system that includes a front drive unit **20** for driving front wheels, and rear drive units for driving rear wheels. The front drive unit **20** includes a front electric motor **22** and a front inverter **24** (e.g., front power inverter module or FPIM), as well as other components such as a cooling system. A left rear drive unit **30**L includes a left rear electric motor **32**L and a left rear inverter **34**L. A right rear drive unit **30**R includes a right rear electric motor **32**R and a right rear inverter **34**R. The front inverter **24**, left rear inverter **34**L and right rear inverter **34**R (e.g., power inverter units or PIMs) each convert direct current (DC) power from a high voltage (HV) battery system **40** to poly-phase (e.g., two-phase, three-phase, six-phase, etc.) alternating current (AC) power to drive the front electric motor **22** the left rear electric motor **32**L and the right rear electric motor **32**R.

[0042] As shown in FIG. **1**, the drive systems feature separate electric motors. However, embodiments are not so limited. For example, instead of separate motors, multiple drives can be provided by a single machine that has multiple sets of windings that are physically independent.

[0043] As also shown in FIG. **1**, the drive systems are configured such that the front electric motor **22** drives the front wheels (not shown), and the left rear electric motor **32**L and right rear electric motor **32**R drive the rear wheels (not shown). However, embodiments are not so limited, as there may be any number of drive systems and/or motors at various locations (e.g., a motor driving each wheel, twin motors per axle, etc.). In addition, embodiments are not limited to a dual drive system, as embodiments can be used with a vehicle having any number of motors and/or power inverters.

[0044] In the propulsion system **16**, the front drive unit **20**, left rear drive unit **30**L and right rear drive unit **30**R are electrically connected to a battery system **40**. The battery system **40** may also be electrically connected to other electrical components (also referred to as "electrical loads"), such as vehicle electronics (e.g., via an auxiliary power module or APM **42**), heaters, cooling systems and others. The battery system **40** may be configured as a rechargeable energy storage system (RESS).

[0045] In an embodiment, the battery system **40** includes a plurality of separate battery assemblies, in which each battery assembly can be independently charged and can be used to independently supply power to a drive system or systems. For example, the battery system **40** includes a first battery assembly such as a first battery pack **44** connected to the front inverter **24**, and a second battery pack **46**. The first battery pack **44** includes a plurality of battery modules **48**, and the second battery pack **46** includes a plurality of battery modules **50**. Each of the first plurality of battery modules **48** and the second plurality of battery modules **50** includes a number of individual cells (not shown). In various embodiments, one or more of the battery packs can include a MODACS (Multiple Output Dynamically Adjustable Capacity) battery.

[0046] Each of the front electric motor **22** and the left rear electric motor **32**L and right rear electric motor **32**R is a three-phase motor having three phase motor windings. However, embodiments described herein are not so limited. For example, the motors may be any poly-phase machines supplied by poly-phase inverters, and the drive units can be realized using a single machine having independent sets of windings.

[0047] The battery system **40** and/or the propulsion system **16** includes a switching system having various switching devices for controlling operation of the first battery pack **44** and second battery pack **46**, and selectively connecting the first battery pack **44** and second battery pack **46** to the front drive unit **20**, left rear drive unit **30**L and right rear drive unit **30**R. The switching devices may also be operated to selectively connect the first battery pack **44** and the second battery pack **46** to a charging system. The charging system can be used to charge the first battery pack **44** and the second battery pack **46**, and/or to supply power from the first battery pack **44** and/or the second battery pack **46** to charge another energy storage system (e.g., vehicle-to-vehicle (V2V) and/or vehicle-to-everything (V2X) charging). The charging system includes one or more charging modules. For example, a first onboard charging module (OBCM) **52** is electrically connected to a charge port **54** for charging to and from an AC system or device, such as a utility AC power supply. A second OBCM **53** may be included for DC charging (e.g., DC fast charging or DCFC).

[0048] In an embodiment, the switching system includes a first switching device **60** that selectively connects to the first battery pack **44** to the front inverter **24**, left rear inverter **34**L and right rear inverter **34**R, and a second switching device **62** that selectively connects the second battery pack **46** to the front inverter **24**, left rear inverter **34**L and right rear inverter **34**R. The switching system also includes a third switching device **64** (also referred to as a "battery switching device") for selectively connecting the first battery pack **44** to the second battery pack **46** in series.

[0049] Any of various controllers can be used to control functions of the battery system **40**, the switching system and the drive units. A controller includes any suitable processing device or unit and may use an existing controller such as a drive system controller, an RESS controller, and/or controllers in the drive system. For example, a controller **65** may be included for controlling switching and drive control operations as discussed herein.

[0050] The controller may include processing circuitry that may include an application specific integrated circuit (ASIC), an electronic circuit, a processor (shared, dedicated, or group) and memory that executes one or more software or firmware programs, a combinational logic circuit, and/or other suitable components that provide the described functionality. The controller may include a non-transitory computer-readable medium that stores instructions which, when processed by one or more processors of the controller, implement a method of determining a voltage to be applied at an inverter of the electric vehicle, according to one or more embodiments detailed herein.

[0051] The vehicle **10** also includes a computer system **55** that includes one or more processing devices **56** and a user interface **58**. The computer system **55** may communicate with the charging system controller, for example, to provide commands thereto in response to a user input. The various processing devices, modules and units may communicate with one another via a communication device or system, such as a controller area network (CAN) or transmission control protocol (TCP) bus.

[0052] As illustrated herein, the vehicle **10** is an electric vehicle. In an alternative embodiment, the vehicle **10** can be an internal combustion engine vehicle, a hybrid vehicle, etc.

[0053] FIG. **2** show a side cross-sectional view **200** of a motor **202** of the vehicle, in an embodiment. The motor **202** includes a frame **204** that forms an enclosed space including a stator **206** and a rotor **208** therein. The rotor **208** rotates about a longitudinal axis **205** of the motor **202** with respect to the stator **206** and is connected to a rotor shaft **210**. The rotor shaft **210** passes out of the motor **202** through an aperture **212** in the frame **204** and into a gearbox **214**, thereby transferring torque from the motor to the gear box.

[0054] The motor **202** further includes one or more bearing housings for reducing friction between the rotor shaft **210** and the frame **204** during rotation of the rotor **208**. A first bearing housing **216** is disposed between the rotor shaft **210** and the frame **204** on a first side of the rotor **208** near the aperture **212**. A second bearing housing **218** is disposed between the rotor shaft **210** and the frame **204** at a second side of the rotor **208** opposite the first side. The first bearing housing **216** includes a first set of bearings **220** that reduce friction between the rotor shaft and the frame at the first side and the second bearing housing **218** includes a second set of bearings **222** that reduce friction between the rotor shaft and the frame at the second side. The gearbox **214** can include a third bearing housing **224** having a third set of bearings **226** for reducing friction between the rotor shaft **210** and a frame of the gearbox.

[0055] An inverter **228** provides a three-phase current to the motor **202** to produce rotation of the rotor **208**. An electrical current is sent through the stator **206** to generate a magnetic field. The rotor **208** responds to the magnetic field by rotating with respect to the stator **206**. Incidental currents are induced when the motor **202** is operated or run with a given range of motor torque and motor speed. These incidental currents include a circulating bearing current **230** (CBC), an electrical discharge machining bearing current (EDM BC **232**), first gear current **234** and a second gear current **236**. The circulating bearing current **230** (CBC) circulates through the rotor **208**, the rotor shaft **210**, the first set of bearings **220**, the frame **204** and second set of bearings **222**. The EDM BC **232** is similar to the circulating bearing current **230** and includes a discharge current between the stator **206** and the rotor **208**. The first gear current **234** is discharged from the stator **206** into the frame **204**, through the first set of bearings **220** and into the rotor shaft **210**, where it passes from the motor **202** to the gearbox **214**. The second gear current **236** is discharged from the stator **206** to the rotor **208** and then passes through the rotor shaft **210** from the motor **202** to the gearbox **214**.

[0056] The rotor shaft **210** includes various chokes for suppressing the incidental currents. A first internal choke **240** is located along the rotor shaft **210** between the rotor **208** and the first bearing housing **216**. A second internal choke **242** is located along the rotor shaft **210** between the rotor **208** and the second bearing housing **218**. In alternative embodiments, only one of the chokes or a combination of two chokes is present. In other embodiments, the rotor shaft **210** can include more

than three chokes.
[0057] The circulating bearing current **230**, EDM BC **232**, and the second gear current **236** pass through the first internal choke **240**, while the circulating bearing current and EDM BC **232** pass through the second internal choke **242**. The first internal choke **240** and second internal choke **242** reduces these currents, as discussed herein. An external choke **244** is located along the rotor shaft between the motor **202** and the gearbox **214**. The first gear current **234** and the second gear current **236** pass through the external choke **244**, which is used to reduce these currents.
[0058] FIG. **3** shows a perspective view of a choke **300** in an embodiment. The choke **300** includes a magnetic material in the shape of a ring **302** that encircles a shaft **304**, such as the rotor shaft **210**. A primary current **306** passes along the shaft **304** through the ring **302**. The primary current **306** (I.sub.P) can be an alternating current which generates a magnetic field **308** in the ring **302**. The magnetic field **308** creates a magnetic flux in the magnetic material of the ring **302**. A change of the magnetic flux due to change in the magnetic field dissipates heat due to hysteresis losses.
[0059] A winding **310** is looped around the ring **302** to allow the choke **300** to be used as a current sensor. The winding **310** is connected by an electrical circuit to a measurement device **312**. For illustrative purposes, the measurement device **312** is shown in FIG. **3** as an ammeter. The magnetic field **308** in the ring **302** induces a sensing current **314** through the winding **310** and the measurement device **312** measures the sensing current.
[0060] Referring back to FIG. **2**, the first internal choke **240**, the second internal choke **242** and the external choke **244** are shown with wires that allow them to be used as current sensors.
[0061] FIG. **4** shows a perspective view **400** of the choke **300** in a second embodiment. The voltmeter **402** serves as the measurement device and is attached to the winding **310**. A resistor **404** having a known resistance R connects across two ends of the winding **310** (i.e., a first end having current which has not entered the winding of the choke and a second end having current that has exited the winding). The voltmeter **402** measures a voltage across the resistor **404** induced by the sensing current I.sub.s. The sensing current I.sub.s can then be determined by Ohm's law: I.sub.s=V/R.
[0062] FIG. **5** shows a perspective view **500** of the choke **300** in a third embodiment. The voltmeter **402** serves as the measurement device and is connected across the two ends of the winding **310**. The voltage measured at the voltmeter **402** is sent to an integrator or integrating circuit **502** which integrates the voltage to determine the sensing current, as shown in Eq. (1):
[00001] $I_s = k\int v\,dt \quad \text{Eq. (1)}$
where v is the measured voltage and k is a conversion constant.
[0063] FIG. **6** shows graphs **600** of electrical parameters of the motor over time. A first graph **602** shows a common mode voltage **604** supplied to the stator **206** from the inverter **228**. A second graph **606** shows a shaft voltage **608** induced along the rotor shaft **210** in response to the common mode voltage **604**. A third graph **610** shows a bearing current **612** passing through the bearings (e.g., first set of bearings **220**) of the motor **202** in response to the shaft voltage **608**. The bearing current **612** can be detected by the current sensors (e.g., the sensor of the first internal choke **240**).
[0064] The common mode voltage **604** is a pulse width modulated (PWM) voltage. The common mode voltage **604** transitions from one voltage level to another voltage level during a PWM event **616**. The rapid change in voltage during the time duration of a PWM event **616** induces the shaft voltage **608** shown in the second graph **606**. The shaft voltage **608** in turn induces the bearing current **612** shown in the third graph **610**. The bearing current **612** reaches a peak value **614** at the end of the PWM event **616**, after which the bearing current dissipates with transitory fluctuations.
[0065] FIG. **7** shows a plot **700** of bearing current in an illustrative embodiment. The plot includes curve **702** represents the bearing current during a switching cycle of the inverter. The curve **702** begins at the beginning of a switching period (Tsw) and ends at the end of the switching period. A method can be used to identify the global maximum **704** of the bearing current. A delay time

(T.sub.delay) is selected after the beginning of the switching period and a value of the bearing current is measured at the selected delay time. The delay time is then increased and a new bearing current is measured at the new delay time. The larger value of the bearing current is retained. This can be repeated until a global maximum **704** of the bearing current (peak bearing current) is identified.
[0066] FIG. **8** shows a flowchart **800** of a method of using current measurements to diagnose and repair or maintain the motor. In box **802**, the motor is operated at a torque and speed at which a circulating bearing current is present. A delay T.sub.PWM_ADC between a PWM event and an ADC trigger is set to zero. In box **804**, an ADC trigger is commanded (in response to a PWM event) to measure the bearing current I.sub.bearing. In box **806**, the measured bearing current I.sub.bearing is set to its magnitude (i.e., set I.sub.bearing equal to the absolute value of I.sub.bearing).
[0067] In box **808**, the bearing current I.sub.bearing is compared to previous maximum peak value of the bearing current (I.sub.bearing,peak). If the bearing current is greater than previous maximum peak value, the method proceeds to box **8108**.
[0068] In box **810**, the maximum peak value is updated to the measured bearing current. In box **812**, a total delay time is compared to the switch time Tsw. If the delay time is greater than the switch time, the method proceeds to box **816**. Otherwise, the method proceeds to box **814**. In box **814**, the delay time T.sub.PWM_ADC between the PWM event and ADC trigger is increased by a selected amount, such as a few nanoseconds. From box **814**, the method returns to box **804**. The loop including box **804**, box **806**, box, **808**, box **810** and box **812** thereby adjusts the delay time T.sub.PWM_ADC to a value at which the peak value of the bearing current is less than the previous maximum peak values.
[0069] Returning to box **808**, if the measured bearing current is less than or equal to the maximum of the previous peak values, the method proceeds to box **816**. In box **816**, the peak value of the bearing current (I.sub.bearing,peak) is obtained. In box **818**, the peak value of the bearing current I.sub.bearing,peak is compared to a damage threshold I.sub.bearing,damage. The damage threshold is a determined threshold indicative of damage being done to the bearings, for example, through electrical discharge. If the peak bearing current I.sub.bearng,peak is greater than the damage threshold I.sub.bearing,damage, the method proceeds to box **820**. Otherwise, the method returns to box **802**.
[0070] In box **820**, a first warning signal is transmitted to a display to warn an operator of possible damage to the bearings. The display can be a monitor or a display at a dashboard of the vehicle, for example. In particular, the first signal informs the user of the need to change the oil of the drive unit or motor. Old oil is generally more conductive than new oil and can therefore increase the magnitude of the bearing current. Changing out the old oil for new oil therefore reduces the oil conductivity and the magnitude of the bearing current. Once the oil is changed, the peak bearing current I.sub.bearing,peak is measured again.
[0071] In box **822**, the peak bearing current I.sub.bearing,peak measured in box **820** is once again compared to the damage threshold. If the peak bearing current is still greater than the damage threshold, the method proceeds to box **824**. Otherwise, the method returns to box **802**. In box **824**, a second warning signal is transmitted to the display to notify the operator who identifies and replaces the damaged bearings of the motor.
[0072] FIG. **9** shows a flowchart **900** of a method of using sensing current measurements to diagnose and repair or maintain the motor including multiple sensors. The flowchart **900** includes boxes **802-818** of the flowchart **800** shown in FIG. **8**. From box **814**, the method proceeds to box **902**. In box **902**, multiple current sensors are used to measure bearing currents. Each current sensor measures current through an associated bearing. If the current through a specified percentage of the bearings or through a specified number of the bearings exceeds a threshold or current limit, the method proceeds to box **904**. In box **904**, the oil is changed at the drive unit or motor. Returning to

box **902**, if the current through more than 90% of the bearings exceeds the threshold or current limit, the method proceeds to box **906**. In box **906**, the damaged bearings are identified and replaced.

[0073] FIG. **10** shows a drive assembly **1000** including the motor **202** and gearbox **214**, in an illustrative embodiment. The motor **202** is coupled to the gearbox **214** via the rotor shaft **210**. The rotor shaft **210** is attached to a frame of the gearbox **214** via a first bearing housing **1002** including bearings B**1**. A first gear **1004** (G**1**) couples the rotor shaft **210** to a transmission shaft **1006**. The transmission shaft **1006** is held in place in the gearbox **214** at a first contact location **1008** at one end of the transmission shaft and a second contact location **1010** at an opposite end of the transmission shaft. A second bearing housing **1012** including bearings B**2** is disposed at the first contact location **1008** to reduce friction between the transmission shaft **1006** and a frame of the gearbox **214**. Similarly, a third bearing housing **1014** including bearings B**3** is disposed at the second contact location **1010** to reduce friction between the transmission shaft **1006** and the frame of the gearbox **214**. A first current sensor CS**1** **1015** is located on the rotor shaft **210** between the motor **202** and the gearbox **214**. A second current sensor CS**2** **1016** is located on the transmission shaft **1006** between the gear G**1** and the first contact location **1008**. A third current sensor CS**3** **1018** is located on the transmission shaft **1006** between the gear G**1** and the second contact location **1010**.

[0074] The first current sensor CS**1** **1015** measures a current I.sub.CS1 through the rotor shaft **210**. The second current sensor CS**2** **1016** measures a current I.sub.cs2 through the transmission shaft **1006** between the gear G**1** and the first contact location **1008**. The third current sensor CS**3** measures a current I.sub.CS3 through the transmission shaft **1006** between the gear G**1** and the second contact location **1010**. These measured currents can be used to determine currents at other locations within the gearbox **214** at which no current sensors are located. Exemplary locations include the bearings B**1**, bearings B**2** bearings B**3** and gear G**1**, as shown by Eqs. (2)-(5):

[00002] $I_{B1} = I_{CS1} - (I_{CS2} - I_{CS3}) \quad \text{Eq.}(2) \quad I_{G1} = I_{CS2} + I_{CS3} \quad \text{Eq.}(3)$

$I_{B2} = I_{CS2} \quad \text{Eq.}(4) \quad I_{B3} = I_{CS3} \quad \text{Eq.}(5)$

where I.sub.B1 is the current through the bearings B**1** of the gearbox, I.sub.B2 is the current through the bearings B**2**, I.sub.G1 is the current through the gear G**1** and I.sub.B3 is the current through the bearings B**3**.

[0075] FIG. **11** shows a view **1100** of the circuitry of the inverter **228**, in an embodiment. The inverter **228** includes a positive DC power line **1102** and a negative DC power line **1104** for providing power to the motor. An inverter choke serves as a current sensor CS**1**. The positive DC power line **1102** and the negative DC power line **1104** pass through the current sensor CS**1** to induce a sensing current and suppress the common mode current. The current sensor CS**1** measures an inverter common mode current (“inverter current”) through at least one of the positive DC power line **1102** and the negative DC power line **1104**. The current sensor CS**1** allows a direct measurement of a common mode current (CMC) in the motor **202**.

[0076] FIG. **11** also shows AC output lines **1110**, **1112**, and **1114** of the inverter **228**. In various embodiments, an AC current sensor **1116** can be disposed around the AC output lines **1110**, **1112**, and **1114** for measuring the inverter common mode current.

[0077] FIG. **12** shows a perspective view **1200** of the current sensor CS**1** in an embodiment. The positive DC power line **1102** and the negative DC power line **1104** pass through the current sensor CS**1**. A winding **1202** is wrapped around a magnetic ring to form the current sensor CS**1**. A resistor **1204** having a known resistance R connects across two ends of the winding **1202**. A voltmeter **1206** measures a voltage across the resistor **1204** resulting from a current I.sub.s induced in the winding **1202**. The current I.sub.s can then be determined by Ohm's law: I.sub.s=V/R. The current through the positive DC power line **1102** and the negative DC power line **1104** can be determined from the current I.sub.s. It is to be understood that more than two power lines can pass through the current sensor CS**1**, in various embodiments.

[0078] FIG. **13** shows a perspective view **1300** of the current sensor CS**1** in another embodiment. The voltmeter **1206** is connected across two ends of the winding **1202**. The voltage measured at the voltmeter **1206** is sent to an integrator or integrator circuit **1302** which integrates the voltage to determine the sensing current, as discussed herein with respect to Eq. (1). Similar to FIG. **12**, it is to be understood that more than two power lines can pass through the current sensor CS**1**, in various embodiments.

[0079] The terms “a” and “an” do not denote a limitation of quantity, but rather denote the presence of at least one of the referenced item. The term “or” means “and/or” unless clearly indicated otherwise by context. Reference throughout the specification to “an aspect”, means that a particular element (e.g., feature, structure, step, or characteristic) described in connection with the aspect is included in at least one aspect described herein, and may or may not be present in other aspects. In addition, it is to be understood that the described elements may be combined in any suitable manner in the various aspects.

[0080] When an element such as a layer, film, region, or substrate is referred to as being “on” another element, it can be directly on the other element or intervening elements may also be present. In contrast, when an element is referred to as being “directly on” another element, there are no intervening elements present.

[0081] Unless specified to the contrary herein, all test standards are the most recent standard in effect as of the filing date of this application, or, if priority is claimed, the filing date of the earliest priority application in which the test standard appears.

[0082] Unless defined otherwise, technical and scientific terms used herein have the same meaning as is commonly understood by one of skill in the art to which this disclosure belongs.

[0083] While the above disclosure has been described with reference to exemplary embodiments, it will be understood by those skilled in the art that various changes may be made and equivalents may be substituted for elements thereof without departing from its scope. In addition, many modifications may be made to adapt a particular situation or material to the teachings of the disclosure without departing from the essential scope thereof. Therefore, it is intended that the present disclosure not be limited to the particular embodiments disclosed, but will include all embodiments falling within the scope thereof.

Claims

1. A method of operating a vehicle, comprising: running a motor of the vehicle at a selected motor speed and a selected motor torque to generate a bearing current that flows through a bearing of the motor and along a rotor shaft between the motor and a gearbox of the vehicle measuring a sensing current induced through a winding at a choke in response to flow of the bearing current through the choke; determining the bearing current from the sensing current; and transmitting a signal to notify a user when the bearing current is greater than a selected damage threshold.

2. The method of claim 1, wherein measuring the sensing current further comprises measuring the sensing current via an ammeter coupled to the winding.

3. The method of claim 1, wherein measuring the sensing current further comprises measuring a voltage across a resistor that connects ends of the winding and determining the sensing current from the voltage and a resistance of the resistor.

4. The method of claim 1, wherein measuring the sensing current further comprises measuring a voltage across ends of the winding and integrating the voltage over a time duration to determine the sensing current.

5. The method of claim 1, wherein the choke is disposed at the rotor shaft between the motor and the gearbox.

6. The method of claim 1, further comprising measuring an inverter common mode current at an

inverter and determining a common mode current at the motor based on the inverter common mode current, wherein the inverter common mode current is measured via one of: (i) an inverter choke through which a positive DC power line of the inverter and a negative DC power line of the inverter passes; and (ii) an inverter choke through which at least one of an AC output line of the inverter passes.
7. The method of claim 1, further comprising at least one of: (i) changing an oil of a drive unit in response to the signal; and (ii) replacing the bearing in response to the signal.
8. A system for operating a vehicle, comprising: a motor of the vehicle, the motor including a rotor shaft and a bearing between the rotor shaft and the motor, wherein a bearing current flows through the bearing and along the rotor shaft between the motor and a gearbox of the vehicle and wherein the motor is run at a selected motor speed and selected motor torque; a choke including a winding, wherein the bearing current passes through the choke to induce a sensing current through the winding; and a processor configured to determine the bearing current from the sensing current and transmit a signal to notify a user when the bearing current is greater than a selected damage threshold.
9. The system of claim 8, further comprising an ammeter coupled to the winding to measure the sensing current.
10. The system of claim 8, further comprising a resistor that connects ends of the winding and a voltmeter for measuring a voltage induced across the resistor by the sensing current, wherein the processor determines the sensing current from the voltage and a resistance of the resistor.
11. The system of claim 8, further comprising a voltmeter across ends of the winding for measuring a voltage and an integrating circuit configured to integrate the voltage over a time duration to determine the sensing current.
12. The system of claim 8, wherein the choke is disposed at the rotor shaft between the motor and the gearbox.
13. The system of claim 8, further comprising one of: (i) an inverter choke through which a positive DC power line of an inverter and a negative DC power line of the inverter passes; and (ii) an inverter choke through which at least one of an AC output line of the inverter passes, wherein the processor is configured to measure an inverter common mode current at the inverter choke and determine a common mode current at the motor based on the inverter common mode current.
14. The system of claim 8, further comprising at least one of: (i) changing an oil of a drive unit in response to the signal; and (ii) replacing the bearing in response to the signal.
15. A vehicle, comprising: a motor including a rotor shaft and a bearing between the rotor shaft and the motor, wherein a bearing current flows through the bearing and along the rotor shaft between the motor and a gearbox of the vehicle and wherein the motor is run at a selected motor speed and selected motor torque; a choke including a winding, wherein the bearing current passes through the choke to induce a sensing current through the winding; and a processor configured to determine the bearing current from the sensing current and transmit a signal to notify a user when the bearing current is greater than a selected damage threshold.
16. The vehicle of claim 15, further comprising an ammeter coupled to the winding to measure the sensing current.
17. The vehicle of claim 15, further comprising a resistor that connects ends of the winding and a voltmeter for measuring a voltage induced across the resistor by the sensing current, wherein the processor determines the sensing current from the voltage and a resistance of the resistor.
18. The vehicle of claim 15, further comprising a voltmeter across ends of the winding for measuring a voltage and an integrating circuit configured to integrate the voltage over a time duration to determine the sensing current.
19. The vehicle of claim 15, wherein the choke is disposed at the rotor shaft between the motor and the gearbox.
20. The vehicle of claim 15, further comprising one of: (i) an inverter choke through which a

positive DC power line of an inverter and a negative DC power line of the inverter passes; and (ii) an inverter choke through which at least one of an AC output line of the inverter passes, wherein the processor is configured to measure an inverter common mode current at the inverter choke and determines a common mode current at the motor based on the inverter common mode current.