



## (51) International Patent Classification:

*B60K 6/00* (2006.01)      *B60K 6/26* (2007.10)  
*B60K 6/24* (2007.10)      *B60K 6/50* (2007.10)

## (21) International Application Number:

PCT/US2015/065874

## (22) International Filing Date:

15 December 2015 (15.12.2015)

## (25) Filing Language:

English

## (26) Publication Language:

English

## (30) Priority Data:

62/091,710 15 December 2014 (15.12.2014) US

(71) Applicant: GENERAL ELECTRIC COMPANY  
[US/US]; 1 River Road, Schenectady, NY 12345 (US).(72) Inventors: FAMA, Anthony, Paul; 2901 East Lake Road,  
Lawrence Park, PA 16531-0001 (US). PLUMMER,  
Jeremy, Clayton; 402 Shingle Oak Lane, Prospect, PA  
16052 (US). BROWN, Timothy, Warren; 2901 East Lake  
Road, Building 42-415, Erie, PA 16531 (US). BISHAR,  
James, Samuel; 2901 East Lake Road, Erie, PA 16531  
(US). BAJPAI, Abhinav, Ramnath; 2901 East Lake  
Road, Lawrence Park, PA 16531-0001 (US).(74) Agents: KRAMER, John, A. et al.; General Electric Com-  
pany, Global Patent Operation, 3135 Easton Turnpike,  
Fairfield, CT 06828 (US).(81) Designated States (*unless otherwise indicated, for every  
kind of national protection available*): AE, AG, AL, AM,  
AO, AT, AU, AZ, BA, BB, BG, BH, BN, BR, BW, BY,  
BZ, CA, CH, CL, CN, CO, CR, CU, CZ, DE, DK, DM,  
DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT,  
HN, HR, HU, ID, IL, IN, IR, IS, JP, KE, KG, KN, KP, KR,  
KZ, LA, LC, LK, LR, LS, LU, LY, MA, MD, ME, MG,  
MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM,  
PA, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW, SA, SC,  
SD, SE, SG, SK, SL, SM, ST, SV, SY, TH, TJ, TM, TN,  
TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.(84) Designated States (*unless otherwise indicated, for every  
kind of regional protection available*): ARIPO (BW, GH,  
GM, KE, LR, LS, MW, MZ, NA, RW, SD, SL, ST, SZ,  
TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, RU,  
TJ, TM), European (AL, AT, BE, BG, CH, CY, CZ, DE,  
DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU,  
LV, MC, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK,  
SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ,  
GW, KM, ML, MR, NE, SN, TD, TG).

## Published:

— with international search report (Art. 21(3))

## (54) Title: SYSTEM AND METHOD FOR VEHICLE SYSTEM CONTROL

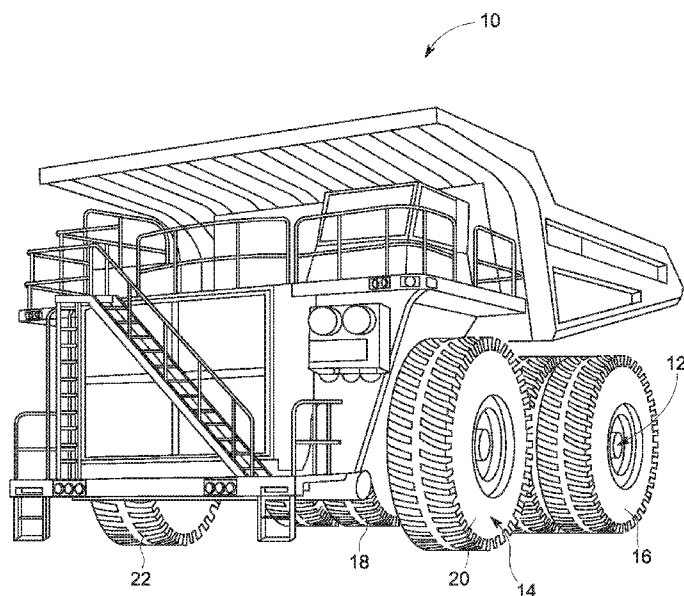


FIG. 1

(57) Abstract: A system includes a drive system (e.g., a vehicle drive system) and a controller. The drive system includes a motor and/or engine and a rotational component (e.g., gear or bearing) that is rotated during operation of the drive system. The controller is configured to receive operational information of the drive system and to determine an estimated lifespan of the rotational component based at least in part on torque, speed, and time information associated with the rotational component. The controller is further configured to control the drive system or another vehicle system based on the estimated lifespan. For example, for a bearing, the controller may be configured to track time of operation in different speed ranges and/or torque ranges, for determining a corrected speed and/or a corrected force, respectively, that is used for determining the estimated lifespan.

## SYSTEM AND METHOD FOR VEHICLE SYSTEM CONTROL

### CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This application claims priority to U.S. Provisional Application No. 62/091,710 filed December 15, 2014, which is incorporated by reference herein in its entirety.

### FIELD OF THE INVENTION

[0002] Embodiments of the invention relate generally to the vehicles and other engine- and/or motor-powered systems. Other embodiments relate to vehicle system control.

### BACKGROUND OF THE INVENTION

[0003] Many machines include a drive system for transmitting power mechanically to perform various tasks. For example, an off-highway vehicle (OHV), such as a mining vehicle used to haul heavy payloads excavated from a mine, typically includes a drive system for moving the vehicle along a route and/or for lifting or otherwise processing a load. Additionally, mobile machines and stationary machines often include drive systems for performing various other tasks including, but not limited to, driving pumps, compressors, electric generators, and the like.

[0004] In transmitting power to perform such tasks, the components of a drive system experience loads that tend to fatigue such components. Over time, these loads may decrease the strength of the components, which may eventually lead to component failure due to the accumulated fatigue experienced in transmitting power. In order to prevent the failure of drive system components and, more specifically, rotating components such as bearings and gears, vehicles are typically taken out of service for overhaul at predetermined intervals, at which time many rotating components of the drive system may be serviced and/or replaced. Conventionally, however, overhaul intervals are generalized and are based solely on engine hours, without regard to the forces and speeds seen by each component during actual operation.

### BRIEF DESCRIPTION OF THE INVENTION

[0005] In an embodiment, a system (e.g., a system for controlling a vehicle or other powered system) includes at least one controller and a drive system. The drive system

includes a motor and/or engine for driving a load, and at least one rotational component, which refers to a component (e.g., a gear or bearing) that is rotated during operation of the drive system. The controller is configured to receive operational information of the drive system in operation and to determine an estimated lifespan of the rotational component based at least in part on torque information, speed information, and time information associated with the rotational component. (The information may be included in the operational information, or the controller may be configured to determine/calculate the information based on the received operational information.) The controller is also configured to control the drive system and/or another system (e.g., another vehicle system) based at least in part on the estimated lifespan.

[0006] In an embodiment, a system (e.g., a vehicle control system) includes a controller and a vehicle drive system. The vehicle drive system includes a wheel, a transmission, and a motor; the motor is configured to drive the transmission for rotating the wheel. The drive system also includes a gear and/or a bearing that is rotated during operation of the drive system. The controller is configured to receive operational information of the drive system and to determine an estimated lifespan of the gear or bearing based at least in part on torque and speed information associated with the gear or bearing and time information of how long the drive system is operated (e.g., time of how long the gear or bearing is rotated). The controller is also configured to control the drive system or another vehicle system based at least in part on the estimated lifespan.

[0007] In an embodiment, a method (e.g., a method of controlling a vehicle or other powered system) includes, with at least one controller, receiving speed information and/or torque information of a motor of a drive system of the vehicle or other powered system. The method further includes determining an estimated lifespan for at least one rotational component of the drive system in dependence upon the speed information and/or the torque information, and controlling a system of the vehicle (or other powered system) based on the determined estimated lifespan.

[0008] In embodiments, the time, torque, and speed information are applied to a transfer function, for a given type or set of characteristics of the rotational component, which results in a determined equivalent damage (wear) of the rotational component. For example, time of operation and/or total revolutions of the rotational component may be “bucketized,” that is, grouped into distinct speed and/or torque ranges, for the controller to determine corrected/normalized speeds and/or forces, which are used as a basis for determining the equivalent damage. The damage is then used to determine the estimated lifespan.

## BRIEF DESCRIPTION OF THE DRAWINGS

[0009] The present invention will be better understood from reading the following description of non-limiting embodiments, with reference to the attached drawings, wherein below:

[0010] FIG. 1 is a perspective view of an embodiment of a vehicle.

[0011] FIG. 2 is a schematic diagram of an embodiment of a vehicle control system.

[0012] FIGS. 3A, 3B, and 3C are schematic diagrams of embodiments of a drive system.

[0013] FIG. 4 is a schematic diagram of an embodiment of a control system.

[0014] FIG. 5 is a flowchart illustrating an embodiment of a method for vehicle control.

[0015] FIG. 6 is a flowchart illustrating an embodiment of a method for vehicle control.

## DETAILED DESCRIPTION OF THE INVENTION

[0016] Reference will be made below in detail to exemplary embodiments of the invention, examples of which are illustrated in the accompanying drawings. Wherever possible, the same reference numerals used throughout the drawings refer to the same or like parts. While embodiments of the invention are described and illustrated in connection with OHVs and other vehicles, other embodiments are applicable to powered systems (machines having engines and/or motors for driving a load) more generally.

[0017] As used herein, “drive system” refers to all components of a powered system that mechanically contribute to driving of a load, e.g., pistons, shafts, drive arms, transmissions (including gears), and structure that supports such components (e.g., bearings, bushings, and so on). In the case of a vehicle, for example, drive system components are those that contribute to movement of the vehicle (e.g., vehicle propulsion, and/or movement of vehicle work members for performing tasks, such as scoops, buckets, lifts, and dump beds), including, but not limited to, the engine, transmission, drive shaft, differential, axles and wheels, and intervening components for interconnecting the same. As used herein, “rotational component” means a component of the drive system of a vehicle or other powered system that rotates (turns about an axis) during operation of the drive system, including, but not limited to, bearings, gears, shafts, and the like.

[0018] Embodiments of the invention relate to methods and systems for controlling powered systems (e.g., vehicles), which involve predicting/estimating overhaul intervals (lifespans) for drive system rotational components. For example, in an embodiment, a method includes, with at least one controller (e.g., a controller that is part of a vehicle control unit), receiving a speed feedback (referring generally to speed information) and a torque feedback (referring generally to torque information) from a drive system, e.g., relating to electric motor speed and/or torque. The method further includes the controller determining an estimated lifespan of a rotational component of the drive system in dependence upon the speed feedback and the torque feedback.

[0019] FIGS. 1 and 2 illustrate aspects of a vehicle 10 in which embodiments of systems and methods of the invention may be implemented. The vehicle 10, as illustrated, is a haul truck specifically engineered for use in high production mining and heavy-duty construction environments, and includes a set of drive wheels 12 coupled to a diesel-electric drive system 100 that provides motive power to the haul truck 10. (The haul truck 10 is illustrative of vehicles and other powered systems generally, although in embodiments, a system and/or method of the invention is implemented on a haul truck specifically.) As shown therein, the drive wheels 12 are the rear wheels of the vehicle, which include a left rear wheel 16 and a right rear wheel 18. The vehicle 10 also includes a set of front wheels 14 including, at least, a left front wheel 20 and a right front wheel 22.

[0020] With reference to the drive system 100 as shown in FIG. 2, each drive wheel 16, 18 is driven by a three-phase alternating-current (AC) induction wheel motor 102, 104. Electrical power is supplied by a diesel engine 106 that is configured to drive a three-phase AC generator 108, both of which are housed within the haul truck 10. In other embodiments, other types of engines may be utilized. The AC output of the alternator 108 is fed into one or more rectifiers 110, which convert the AC output to direct current (DC). The DC output of the rectifier(s) 110 is in turn fed into a set of first and second inverters 112, 114, e.g., there may be one inverter per motor. The first inverter 112 supplies three-phase, variable frequency AC power to wheel motor 102. Similarly, the second inverter 114 supplies three-phase AC power to wheel motor 104.

[0021] As further shown in FIG. 2, the drive system 100 includes a drive system control unit 116 coupled to the inverters 112, 114, which, among other tasks, determines and sends a desired torque request signal to the inverters 112, 114. The torque request signal is processed by the control unit for the inverters 112, 114 to drive the motors 102, 104 to the desired torque output magnitude, and in the desired rotational direction corresponding to the

intended direction of vehicle movement, for vehicle propulsion. The control unit is also configured to control the motors 102, 104 to provide retarding tractive effort to the rear wheels to slow or stop the vehicle 10. That is, in a propel mode of operation electrical power is fed to the motors to turn the wheels to move the vehicle, and in a retard mode of operation, each motor is switched to act as a generator, thereby providing resistance to wheel movement to slow the vehicle. Electricity generated by the motors is stored in one or more batteries, dissipated (e.g., using a heater-like resistor grid), and/or used to power other onboard systems. In an embodiment, the control unit 116 includes one or more controllers (e.g., micro-controllers or processors) operating according to a set of stored instructions to provide for system control, as discussed in detail herein.

[0022] FIGS. 3A, 3B, and 3C illustrate, more generally, other embodiments of drive systems 100. For example, in FIG. 3A a drive system includes an engine 106, a motor 118, and a transmission 120. (Each may also include a control unit 116.) The engine is configured to provide electrical power to the motor (e.g., as in FIG. 2), which is configured to drive the transmission for moving a load 122, e.g., a wheel. The transmission 120 includes mechanical equipment to interface the motor with the load, for transferring energy from the motor to the load. For example, the transmission 120 may include one or more rotational components 124, such as shafts 126, gears 128, and/or bearings 130. In FIG. 3B, the drive system includes a motor, but no engine, e.g., the motor is supplied with electrical power from an on-board battery or a catenary, third rail, or other off-board supply. In FIG. 3C, the drive system includes an engine but no motor, e.g., the engine drives a drive shaft, which is mechanically interfaced with the transmission for moving the wheel or other load.

[0023] As an example, U.S. Patent No. 8,714,661, issued May 6, 2014 and incorporated by reference herein in its entirety, shows a wheel motor in more detail, including a transmission with rotational components such as gears and bearings.

[0024] The control unit 116 includes one or more controllers that are configured (e.g., by way of stored control software) to control the torque output magnitude of the motor or motors 102, 104, 118 to actuate a load 122, e.g., in the case of a vehicle, to propel or retard the vehicle. As examples, U.S. Patent No. 8,988,016, issued March 24, 2015, and U.S. Patent No. 9,209,736, issued December 8, 2015, both incorporated by reference herein in their entireties, disclose motor control units that control, and provide operational information about, motor torque and speed.

[0025] In embodiments, the control unit 116 (or another controller) is configured to predict or estimate overhaul intervals for rotational components of the drive system 100. In

particular, the control unit is configured to obtain on-board torque and speed information, and to use this information, as applied to a transfer function (for example), to determine an equivalent damage that can be applied to any component whose life is limited by cyclical stresses. The control unit is configured to then use the calculated damage to determine profile severity and predict an overhaul interval for each rotating component, and/or to estimate component useful lifespan. This information (e.g., determined estimated lifespan) is used to control a system, e.g., the control unit may be configured to use the information as a basis for controlling the vehicle or other powered system for movement or other operation, or as a basis for controlling a storage device to store the information, or as a basis for controlling a communication device to communicate the information to a remote location.

[0026] With reference to FIG. 4, in an embodiment, a system 132 (e.g., a system for controlling a vehicle or other powered system) includes at least one controller 134 and a drive system 100. The drive system may be configured as described in regards to any of FIGS. 2-3C, e.g., it includes a motor and/or engine for driving a load, and at least one rotational component. The controller 134 is configured to receive operational information 136 of the drive system in operation and to determine an estimated lifespan of the rotational component(s) based at least in part on torque information, speed information, and time information associated with the rotational component. The controller is also configured to generate control signals 138 to control the drive system and/or another system 140 (e.g., another vehicle system) based at least in part on the determined estimated lifespan. For example, if an estimated operational time until failure (e.g., determined based in part on the estimated lifespan less how long the component has been in operation) of a component is relatively short (such as less than a remaining time until the next scheduled maintenance operation), then the controller may be configured to control the powered system to a different duty cycle that results in a lower degree of wear/damage of the component over time than if the powered system was not controlled to the different duty cycle. Alternatively or additionally, as mentioned, the controller may be configured to generate control signals to control a memory unit for storing information about the estimated lifespan, and/or to generate control signals to control a communication device for communicating information about the estimated lifespan to a remote location (e.g., off board a vehicle) or otherwise.

[0027] The torque information, speed information, and/or time information may be included in the operational information, or the controller may be configured to determine/calculate the information based on the received operational information or otherwise. (For example, time lengths of operation may be determined using an internal

clock of the controller and/or an external clock, referenced to received signals that are indicative of the drive system being in operation.) Torque and/or speed information may be generated by sensors that are operably coupled to the drive system (e.g., speed sensors associated with a motor or engine), or torque and/or speed information may be received from a vehicle traction control system as described in the aforementioned U.S. Patent Nos. 8,988,016 and 9,209,736. Such a traction control system may be implemented in a separate controller/control unit, or it may be part of the controller 134. That is, a controller 134 may include a sub-system for vehicle traction control, e.g., which provides motor torque and speed information (motor speed and torque are controlled to designated levels responsive to throttle commands), and also a sub-system for system control based on estimated rotational component lifespans.

[0028] Alternatively or additionally, the controller 134 may be configured to determine speed and/or torque information (associated with a rotational component) based on motor power (voltage and current applied to a motor), according to the relationship

$$(1) \quad T = \frac{Pw \cdot 9.554}{n}$$

where T is torque in newton meters (N\*m), Pw is power in watts, and n is speed in rpm. (In non-SI units of torque in foot-pounds (ft-lbf) and power in horsepower, the conversion factor would be 5252 instead of 9.554.) That is, motor power is a function of the voltage and current provided to the motor, and it is possible to determine torque at a given speed based on the equation above. Also, since torque is (generally speaking) a force acting at a distance, in embodiments, forces for determining equivalent damage may be based on the calculated or provided torque in relation to a geometry of the rotational component, transmission, and/or otherwise of the drive system. That is, forces applied to a rotational component are based on torque and a geometry of the transmission/drive system.

[0029] FIGS. 4 and 5 illustrate an embodiment of a method 200 that may be carried out by a controller 134 to determine estimated lifespans (and thereby recommended overhaul intervals) for bearings of a drive system. At step 202, utilizing a bucket sort algorithm, speed information is measured/received and grouped into distinct speed buckets 142 having predefined speed ranges 144. That is, the controller is configured to determine, based on time and speed information (included and/or derived from the operational information 136 or otherwise), plural time lengths t1, t2, t3, t4, etc. that the bearing rotates within plural

respective distinct speed ranges 144, namely,  $0 - x$  rpm where  $x > 0$ ;  $x - y$  rpm where  $y > x$ ;  $y - z$  rpm where  $z > y$ ;  $z - a$  rpm where  $a > z$ , and so on. In an embodiment, the controller may be configured to group bearing rotation into eight speed buckets/distinct speed ranges, including a first bucket for measured speeds of less than 500 rpm, a second bucket for measured speeds between 500 rpm and 1000 rpm, a third bucket for measured speeds between 1000 rpm and 1500 rpm, a fourth bucket for measured speeds between 1500 rpm and 2000 rpm, a fifth bucket for measured speeds between 2000 rpm and 2500 rpm, a sixth bucket for measured speeds between 2500 rpm and 3000 rpm, a seventh bucket for measured speeds between 3000 rpm and 3500 rpm, and an eighth bucket for measured speeds in excess of 3500 rpm. In an embodiment, more or fewer buckets may be utilized and the range of speeds defining each bucket may vary from the above-indicated ranges. (The number of speed ranges, and the speeds defining each range, may be based on the type of component and/or the maximum possible speed of the component during drive system operation.)

[0030] At step 204, using the relationship between total time and the time spent within each speed range, the controller 134 develops/determines a corrected speed for the bearing (e.g., a corrected speed may be developed for each bearing of the system 100). In an embodiment, corrected speed is calculated by taking a specific speed range (e.g., each speed bucket) and multiplying it by the proportion of time spent within that speed range.

[0031] Once the corrected speed is determined, corrected force or torque may be calculated for each rotational component. To determine the corrected torque values, the motor torque information is measured/received and grouped into distinct torque buckets 146 having predefined torque ranges, at step 206. In embodiments, the torque information may be grouped into two sets of buckets/distinct ranges, namely, a set of propel torque buckets 148, for propulsion force, and a set of at least one retard torque bucket 150, for retarding force. More specifically, in embodiments, the controller is configured to determine plural time lengths  $t_5$ ,  $t_6$ ,  $t_7$ , etc. that the component operates in respective distinct torque ranges 146, namely,  $0 - b$  N\*m (or ft-lbf or the like) where  $b > 0$ ;  $b - c$  N\*m (or ft-lbf or the like) where  $c > b$ , etc. The torque information may be grouped into ranges within a propel mode of operation 148, wherein the motor operates to drive a transmission to drive a load (e.g., wheel), and into one or more ranges within a retard mode of operation 150, wherein the motor/drive system is switched for the load (e.g., wheel) to drive the motor through the transmission (e.g., for vehicle slowing or stopping). In one embodiment, there are plural distinct torque ranges within the propel mode of operation, but only one range within the retard mode of operation, that is, all time of operation within the retard mode is considered

equivalent, torque- and/or force-wise. In one embodiment, there are two torque ranges within the propel mode, with the first being 0 to 3000 ft-lbf (0 to ~4060 N\*m) and the second being > 3000 ft-lbf.

**[0032]** At step 208, the torque ranges 146 are paired with drive geometries/configurations to develop/determine a respective equivalent reaction force for each torque range. That is, for each torque range, there is an equivalent reaction force, which is a function of drive system geometry, torque, and time length of operation. The particular drive system configuration for each vehicle or other powered system will determine the total number of reaction forces required. As used herein, “equivalent reaction force” means the force required to oppose the torque transmitted through the drive system 100 and/or the weight on the system (essentially, a reaction to the load applied to the system). Once all equivalent reaction forces are developed, they are normalized at step 210 for use in bearing life calculations. In an embodiment, the equivalent reaction force for each torque bucket/range may be normalized using either advanced or basic bearing life calculations, as known in the art.

**[0033]** At step 212, using the relationship between total time (of operation of the component) and the time spent at each equivalent reaction force, the controller 134 develops a corrected torque/force for the bearing or other component. In particular, the controller 134 utilizes the relationship between total time (in both propel and retard modes) and the time spent at each equivalent reaction force to develop a corrected force/torque for each bearing of the system.

**[0034]** In an embodiment, lifespan is then calculated for each bearing, at step 214, based on the corrected speed and the corrected torque/force. For example, a formula that may be utilized for basic bearing life calculation is:

$$(2) \quad L_{10} = L = \left[ \frac{C}{P} \right]^p, \text{ where:}$$

$L_{10}$  = Basic life rating, in millions of revolutions

$C$  = Dynamic Load Rating (lb)(characteristic of the component, provided by the manufacturer)

$P$  = Equivalent Dynamic Load (lb)(from torque feedback/information)

$p$  = Life Exponent (3 for ball bearings, 10/3 for roller bearings)

[0035] Finally, at step 216, the controller 134 determines the percentage of life remaining (or “damage”) for each bearing by using the life calculated at step 214 and the total run time of operation of the bearing.

[0036] In an embodiment, the controller 134 is configured to similarly determine an estimated lifespan (and thereby an estimated or recommended overhaul interval) for drive system gearing. For example, FIG. 6 illustrates an embodiment of a method 300 carried out by the controller 134 to determine estimated drive system gear lifespans.

[0037] At step 302, utilizing a bucket sort algorithm, the motor torque feedback/information is measured/received and grouped into torque buckets having predefined distinct torque ranges. In certain embodiments, the measured torque may be grouped into two sets of buckets/ranges, namely, a set of propel torque buckets, for propulsion force, and a set of retard torque buckets, for retarding force. At step 304, the propel and retard torque feedbacks are paired with drive geometries and configurations to develop equivalent reaction forces for each torque bucket. As discussed above, the particular drive system configuration for each vehicle or other powered system will determine the total number of reaction forces required.

[0038] Each equivalent force is then developed into an equivalent stress experienced for each gear in the drive system, at step 306. In an embodiment, equivalent stress is determined utilizing a number of factors including, but not limited to, load distribution, load sharing, and misalignment. More specifically, force is a function of gear geometry (e.g., number of teeth, diameter) and torque, and stress is a function of the force applied over an area, e.g., of a gear tooth. In an embodiment, all speed-dependent factors may use the maximum rotational speed at torque based on the capability of the drive system if the real-time speed is unknown.

[0039] Using the equivalent stress developed for each gear, the number of cycles until failure (both in bending and pitting failure modes) at every stress is then determined based on the S-N curve for each gear, at step 308. (For a given material of a gear, the S-N curve is a relationship of stress and number of cycles/revolutions, indicating the number of cycles at a given stress before the material enters a failure mode.) At step 310, the controller 134 then compares the number of cycles to failure determined for each gear to the actual number of revolutions of the gear in operation to calculate a “damage”/wear for each bucket. Miner’s Rule may then applied for each individual gear, at step 312, to sum the damage and determine the life depleted (and/or percentage of life remaining).

[0040] In embodiments, instead of grouping torque information into distinct ranges, it is possible for the controller to be configured to calculate instantaneous damage/wear of a gear based on the torque experienced at a given speed for a given time of operation, and to sum the calculated damages to determine an estimated lifespan.

[0041] As will be readily appreciated, embodiments of the invention allow for the more effective prediction of overhaul schedules, which allows each vehicle (or other powered system) to be assessed on an individual level. In particular, overhaul intervals no longer need to be generalized and based solely on engine operating hours. As a result, operators of vehicles can get the most use out of vehicle rotating components, which translates to a greater mean time before overhauls. This, in turn, leads to reduced maintenance costs. Moreover, the on-board overhaul prediction tool of the present invention allows vehicle operators to better understand profile severity and better prepare for overhauls, which reduces vehicle downtime and excess inventory. As will be readily appreciated, the system and method for overhaul prediction described above may be applied to independent rotating components or collectively as a drive system. In particular, the system and method may be utilized to determine overhaul intervals for individual components, or an overhaul interval for servicing the drive system, as a whole.

[0042] While the present invention has been heretofore described as being configured to determine the percentage of life remaining for rotating components of a vehicle drive system or other drive system based on sensed/received speed and torque values, and to therefore predict an optimum overhaul interval for such components, the present invention is not so limited in this regard. In particular, in other embodiments, the controller 134 may also be configured to develop a calculated damage and, thus, estimate the life remaining in various components based on temperature feedback captured by the drive system control software. For example, for components limited by thermal cycles, the output of a thermal model may be utilized to determine the number of cycles endured, and then a similar process to that described above may be utilized to determine the life depleted (or percentage of life remaining) for such components. Accordingly, the overhaul prediction tool embodied in the controller 134 may therefore be utilized to estimate component life or to log wear based on factors such as thermal cycling. As will be readily appreciated, this can assist in evaluating actual usage in the field as well as assist in reliability investigations for components such as IGBTs or other power transistors.

[0043] In an embodiment, a system includes a drive system and at least one controller. The drive system comprises at least one of a motor or an engine, the drive system

configured to drive a load, and at least one rotational component that is rotated during operation of the drive system. The at least one controller is operably coupled with the drive system. The at least one controller is configured to receive operational information of the drive system in operation and to determine an estimated lifespan of the rotational component based at least in part on torque information associated with the rotational component, speed information associated with the rotational component, and time information of how long the drive system is operated. (At least one of one or more of the torque information, the speed information, or the time information is included as part of the operational information or the at least one controller is configured to determine one or more of the torque information, the speed information, or the time information from the operational information.) The at least one controller is further configured to control at least one of the drive system or a second system associated with the drive system based at least in part on the estimated lifespan.

**[0044]** In an embodiment, the rotational component comprises a bearing, and the at least one controller is configured to determine, based on the time information and the speed information, plural time lengths that the bearing rotates within plural respective distinct speed ranges, and to determine a corrected speed based on the time lengths and a total time of bearing operation. The at least one controller is also configured to determine the estimated lifespan based in part on the corrected speed that is determined.

**[0045]** In an embodiment, the rotational component comprises a bearing, and the at least one controller is configured to determine, based on the time information and the torque information, plural time lengths of bearing operation within plural respective distinct torque ranges, each torque range having a respective equivalent reaction force, and to determine a corrected force based on the time lengths and a total time of bearing operation. The at least one controller is also configured to determine the estimated lifespan based in part on the corrected force that is determined. The torque ranges may include at least first and second, distinct torque ranges within a propel mode of operation of the drive system during which the drive system is configured to drive the load, and a distinct torque range within a retard mode of operation of the drive system during which the drive system is configured to be driven by the load.

**[0046]** In an embodiment, the drive system is a vehicle drive system of a vehicle, the vehicle drive system including the motor and the load including a wheel of the vehicle that the motor is configured to drive, and the rotational component comprises a bearing associated with the motor. The at least one controller is configured to determine, based on the time information and the speed information, plural first time lengths that the bearing rotates within

plural respective distinct speed ranges, and to determine a corrected speed based on the first time lengths and a total time of bearing operation. The at least one controller is configured to determine, based on the time information and the torque information, plural second time lengths of bearing operation within plural respective distinct torque ranges, each torque range having a respective equivalent reaction force, and to determine a corrected force based on the second time lengths and the total time of bearing operation, wherein the torque ranges include at least first and second, distinct torque ranges within a propel mode of operation of the drive system during which the motor is configured to drive the wheel, and a third torque range within a retard mode of operation of the drive system during which the motor is configured to be driven by the wheel. The at least one controller is configured to determine the estimated lifespan based in part on the corrected speed and the corrected force that are determined.

[0047] In an embodiment, the at least one controller is configured to control the second system based at least in part on the estimated lifespan, the second system being located on board the vehicle and comprising at least one of a memory unit configured to store information of the estimated lifespan, a communication unit configured to transmit the information of the estimated lifespan off board the vehicle, or an electronic display configured to display the information of the estimated lifespan to an operator.

[0048] In an embodiment, the at least one controller is configured to control the vehicle drive system for travel of the vehicle along a route based at least in part on the estimated lifespan.

[0049] In an embodiment, the at least one controller is configured to determine a percentage of life remaining of the at least one rotational component based on the estimated lifespan and a total operating time of the at least one rotational component, and to control the at least one of the drive system or the second system based on the percentage of life remaining that is determined.

[0050] In an embodiment, the rotational component comprises a gear, the at least one controller is configured to determine an equivalent damage of the gear based on a speed of rotation of the gear, a torque associated with the speed of rotation, and a length of time at which the gear rotates at the speed of rotation, and the at least one controller is configured to determine the estimated lifespan based in part on the equivalent damage.

[0051] In an embodiment, the rotational component comprises a gear, the at least one controller is configured to determine, based on the time information, the torque information, and the speed information, a respective number of revolutions of the gear in each of plural distinct torque ranges, wherein a respective number of cycles to failure is associated with

each of the torque ranges, and the at least one controller is configured to determine, for each of the torque ranges, a respective damage equivalent based on a comparison of the number of cycles to failure with the number of revolutions of the gear in the torque range, and to determine the estimated lifespan based on a summation of the damage equivalents that are determined for the torque ranges.

[0052] In an embodiment, the number of cycles to failure for each torque range is based on a respective equivalent stress associated with the torque range and an S-N curve of the gear, the equivalent stress based on an equivalent reaction force associated with the torque range and a geometry of at least one of the gear or the drive system.

[0053] In an embodiment, the torque ranges include at least first and second, distinct torque ranges within a propel mode of operation of the drive system during which the drive system is configured to drive the load, and a third torque range within a retard mode of operation of the drive system during which the drive system is configured to be driven by the load.

[0054] In an embodiment, the drive system is a vehicle drive system of a vehicle, the vehicle drive system including the motor and a transmission and the load including a wheel of the vehicle, the motor configured to drive the transmission for rotating the wheel, and the rotational component comprises a gear of the transmission. The at least one controller is configured to determine, based on the time information, the torque information, and the speed information, a respective number of revolutions of the gear in each of plural distinct torque ranges, wherein a respective number of cycles to failure is associated with each of the torque ranges, wherein the torque ranges include at least first and second, distinct torque ranges within a propel mode of operation of the drive system during which the motor is configured to drive the wheel through the transmission, and a third torque range within a retard mode of operation of the drive system during which the motor is configured to be driven by the wheel through the transmission. The at least one controller is configured to determine, for each of the torque ranges, a respective damage equivalent based on a comparison of the number of cycles to failure with the number of revolutions of the gear in the torque range, and to determine the estimated lifespan based on a summation of the damage equivalents that are determined for the torque ranges.

[0055] In an embodiment, the number of cycles to failure for each torque range is based on a respective equivalent stress associated with the torque range and an S-N curve of the gear, the equivalent stress based on an equivalent reaction force associated with the torque range and a geometry of at least one of the gear or the drive system.

[0056] In an embodiment, a system includes a vehicle drive system comprising a wheel, a transmission, and a motor, wherein the motor is configured to drive the transmission for rotating the wheel, the drive system including at least one of a gear or a bearing that is rotated during operation of the drive system, and at least one controller operably coupled with the drive system. The at least one controller is configured to receive operational information of the drive system in operation and to determine an estimated lifespan of the at least one of the gear or the bearing based at least in part on torque information and speed information associated with the at least one of the gear or the bearing and time information of how long the drive system is operated, wherein at least one of one or more of the torque information, the speed information, or the time information is included as part of the operational information or the at least one controller is configured to determine one or more of the torque information, the speed information, or the time information from the operational information. The at least one controller is further configured to control at least one of the drive system or a second vehicle system based at least in part on the estimated lifespan.

[0057] In an embodiment, the at least one controller is configured to determine, based on one or more of the time information, the torque information, or the speed information, a respective time of operation of the gear or bearing in each of plural distinct torque ranges, wherein the torque ranges include at least first and second, distinct torque ranges within a propel mode of operation of the drive system during which the motor is configured to drive the wheel with the transmission, and a third torque range within a retard mode of operation of the drive system during which the motor is configured to be driven by the wheel with the transmission, wherein plural equivalent reaction forces are respectively associated with the torque ranges. The at least one controller is configured to determine the estimated lifespan based at least in part on the times of operation of the gear or bearing in the torque ranges, the equivalent reaction forces, and a total time of operation of the gear or bearing.

[0058] In an embodiment, a method of predicting an overhaul interval for at least one rotating component of a vehicle includes the steps of, at a control unit, receiving a speed feedback from a motor of the vehicle, at the control unit, receiving a torque feedback from the motor of the vehicle, and determining an estimated life for the at least one rotating component in dependence upon the speed feedback and the torque feedback.

[0059] In an embodiment, the step of determining an estimated life includes determining a corrected speed for the at least one rotating component and determining a corrected torque for the at least one rotating component.

[0060] In an embodiment, the step of determining the corrected speed includes grouping the speed feedback into a plurality of distinct speed buckets, each of the buckets being defined by a predetermined speed range, and multiplying each speed range by a proportion of time spent within each speed range.

[0061] In an embodiment, the step of determining the corrected torque includes grouping the torque feedback into a plurality of distinct torque buckets, each of the buckets being defined by a predetermined torque range, and developing an equivalent reaction force for each torque bucket. In an embodiment, the plurality of torque buckets may include at least one propel torque bucket for propulsion force and at least one retard torque bucket for retarding force.

[0062] In an embodiment, the method may also include the step of determining a percentage of life remaining for the at least one rotating component in dependence upon the determined estimated life and a total operating time for the at least one rotating component.

[0063] In an embodiment, the at least one rotating component is a bearing of a drive system of the vehicle. In an embodiment, the bearing may form a part of a transmission of the vehicle.

[0064] In another embodiment, a method of predicting an overhaul interval for at least one rotating component of a vehicle is provided. The method includes the steps of, at the control unit, receiving a torque feedback from a motor of the vehicle, and determining an estimated life for the at least one rotating component in dependence upon the torque feedback.

[0065] In an embodiment, the method may also include the steps of grouping the torque feedback into a plurality of distinct torque buckets, each of the buckets being defined by a predetermined torque range, developing an equivalent reaction force for each torque bucket, and developing an equivalent stress for each equivalent reaction force. In an embodiment, the equivalent stress is determined in dependence upon at least one of load distribution, load sharing and misalignment.

[0066] In an embodiment, the method may also include the step of calculating a number of cycles to failure for the rotating component.

[0067] In an embodiment, the rotating component is a gear and the number of cycles to failure for the gear is calculated using an S-N curve for the gear.

[0068] In an embodiment, the method may also include the step of comparing the number of cycles to failure to an actual number of revolutions determined by the control unit, and determining a percentage of life remaining for the gear.

[0069] In yet another embodiment, a system is provided. The system includes a drive system including a motor, at least one wheel driven by the motor, and at least one rotating component, and a control unit in communication with the motor. The control unit is configured to control the motor to provide a rotational output to the at least one wheel. In addition, the control unit is configured to predict an overhaul interval for the at least one rotating component in dependence upon at least one operating parameter of the drive system.

[0070] In an embodiment, the at least one operating parameter includes a speed feedback and a torque feedback received by the control unit from the motor.

[0071] In an embodiment, the control unit is configured to determine an estimated life for the at least one rotating component in dependence upon the speed feedback and the torque feedback.

[0072] In an embodiment, the control unit is configured to determine the estimated life by calculating a corrected speed for the at least one rotating component and calculating a corrected torque for the at least one rotating component.

[0073] In an embodiment, calculating the corrected speed includes grouping the speed feedback into a plurality of distinct speed buckets, each of the speed buckets being defined by a predetermined speed range, and multiplying each speed range by a proportion of time spent within each speed range.

[0074] In an embodiment, calculating the corrected torque includes grouping the torque feedback into a plurality of distinct torque buckets, each of the torque buckets being defined by a predetermined torque range, and developing an equivalent reaction force for each torque bucket.

[0075] In an embodiment, the plurality of torque buckets may include at least one propel torque bucket for propulsion force and at least one retard torque bucket for retarding force.

[0076] In an embodiment, the control unit is configured to determine a percentage of life remaining for the at least one rotating component in dependence upon the estimated life and a total operating time for the at least one rotating component.

[0077] In an embodiment, the at least one rotating component is a bearing of the drive system of a vehicle. In an embodiment, the bearing forms a part of a transmission of the vehicle.

[0078] It is to be understood that the above description is intended to be illustrative, and not restrictive. For example, the above-described embodiments (and/or aspects thereof) may be used in combination with each other. In addition, many modifications may be made

to adapt a particular situation or material to the teachings of the invention without departing from its scope. While the dimensions and types of materials described herein are intended to define the parameters of the invention, they are by no means limiting and are exemplary embodiments. Many other embodiments will be apparent to those of skill in the art upon reviewing the above description. The terms “including” and “in which” are used as the plain-English equivalents of the respective terms “comprising” and “wherein.” Moreover, the terms “first,” “second,” “third,” “upper,” “lower,” “bottom,” “top,” etc. are used merely as labels, and are not intended to impose numerical or positional requirements on their objects.

[0079] This written description uses examples to disclose several embodiments of the invention, including the best mode, and also to enable one of ordinary skill in the art to practice the embodiments of invention, including making and using any devices or systems and performing any incorporated methods.

[0080] As used herein, an element or step recited in the singular and proceeded with the word “a” or “an” should be understood as not excluding plural of the elements or steps, unless such exclusion is explicitly stated. Furthermore, references to “one embodiment” of the present invention are not intended to be interpreted as excluding the existence of additional embodiments that also incorporate the recited features. Moreover, unless explicitly stated to the contrary, embodiments “comprising,” “including,” or “having” an element or a plurality of elements having a particular property may include additional such elements not having that property.

[0081] Since certain changes may be made in the embodiments described herein without departing from the spirit and scope of the invention herein involved, it is intended that all of the subject matter of the above description or shown in the accompanying drawings shall be interpreted merely as examples illustrating the inventive concept herein and shall not be construed as limiting the invention.

What is claimed is:

1. A system comprising:
  - a drive system comprising at least one of a motor or an engine, the drive system configured to drive a load, and at least one rotational component that is rotated during operation of the drive system; and
  - at least one controller operably coupled with the drive system,
  - wherein the at least one controller is configured to receive operational information of the drive system in operation and to determine an estimated lifespan of the rotational component based at least in part on torque information associated with the rotational component, speed information associated with the rotational component, and time information of how long the drive system is operated, wherein at least one of one or more of the torque information, the speed information, or the time information is included as part of the operational information or the at least one controller is configured to determine one or more of the torque information, the speed information, or the time information from the operational information, and
  - wherein the at least one controller is further configured to control at least one of the drive system or a second system associated with the drive system based at least in part on the estimated lifespan.
2. The system of claim 1, wherein:
  - the rotational component comprises a bearing;
  - the at least one controller is configured to determine, based on the time information and the speed information, plural time lengths that the bearing rotates within plural respective distinct speed ranges, and to determine a corrected speed based on the time lengths and a total time of bearing operation; and
  - the at least one controller is configured to determine the estimated lifespan based in part on the corrected speed that is determined.
3. The system of claim 1, wherein:
  - the rotational component comprises a bearing;
  - the at least one controller is configured to determine, based on the time information and the torque information, plural time lengths of bearing operation within plural respective distinct torque ranges, each torque range having a respective equivalent reaction force, and to

determine a corrected force based on the time lengths and a total time of bearing operation;  
and

the at least one controller is configured to determine the estimated lifespan based in part on the corrected force that is determined.

4. The system of claim 3, wherein the torque ranges include at least first and second, distinct torque ranges within a propel mode of operation of the drive system during which the drive system is configured to drive the load, and a distinct torque range within a retard mode of operation of the drive system during which the drive system is configured to be driven by the load.

5. The system of claim 1, wherein:

the drive system is a vehicle drive system of a vehicle, the vehicle drive system including the motor and the load including a wheel of the vehicle that the motor is configured to drive, and the rotational component comprises a bearing associated with the motor;

the at least one controller is configured to determine, based on the time information and the speed information, plural first time lengths that the bearing rotates within plural respective distinct speed ranges, and to determine a corrected speed based on the first time lengths and a total time of bearing operation;

the at least one controller is configured to determine, based on the time information and the torque information, plural second time lengths of bearing operation within plural respective distinct torque ranges, each torque range having a respective equivalent reaction force, and to determine a corrected force based on the second time lengths and the total time of bearing operation, wherein the torque ranges include at least first and second, distinct torque ranges within a propel mode of operation of the drive system during which the motor is configured to drive the wheel, and a third torque range within a retard mode of operation of the drive system during which the motor is configured to be driven by the wheel; and

the at least one controller is configured to determine the estimated lifespan based in part on the corrected speed and the corrected force that are determined.

6. The system of claim 5, wherein the at least one controller is configured to control the second system based at least in part on the estimated lifespan, the second system being located on board the vehicle and comprising at least one of a memory unit configured to store information of the estimated lifespan, a communication unit configured to transmit the

information of the estimated lifespan off board the vehicle, or an electronic display configured to display the information of the estimated lifespan to an operator.

7. The system of claim 5, wherein the at least one controller is configured to control the vehicle drive system for travel of the vehicle along a route based at least in part on the estimated lifespan.

8. The system of claim 1, wherein the at least one controller is configured to determine a percentage of life remaining of the at least one rotational component based on the estimated lifespan and a total operating time of the at least one rotational component, and to control the at least one of the drive system or the second system based on the percentage of life remaining that is determined.

9. The system of claim 1, wherein:  
the rotational component comprises a gear;  
the at least one controller is configured to determine an equivalent damage of the gear based on a speed of rotation of the gear, a torque associated with the speed of rotation, and a length of time at which the gear rotates at the speed of rotation; and  
the at least one controller is configured to determine the estimated lifespan based in part on the equivalent damage.

10. The system of claim 1, wherein:  
the rotational component comprises a gear;  
the at least one controller is configured to determine, based on the time information, the torque information, and the speed information, a respective number of revolutions of the gear in each of plural distinct torque ranges, wherein a respective number of cycles to failure is associated with each of the torque ranges; and  
the at least one controller is configured to determine, for each of the torque ranges, a respective damage equivalent based on a comparison of the number of cycles to failure with the number of revolutions of the gear in the torque range, and to determine the estimated lifespan based on a summation of the damage equivalents that are determined for the torque ranges.

11. The system of claim 10, wherein the number of cycles to failure for each torque range is based on a respective equivalent stress associated with the torque range and an S-N curve of the gear, the equivalent stress based on an equivalent reaction force associated with the torque range and a geometry of at least one of the gear or the drive system.

12. The system of claim 10, wherein the torque ranges include at least first and second, distinct torque ranges within a propel mode of operation of the drive system during which the drive system is configured to drive the load, and a third torque range within a retard mode of operation of the drive system during which the drive system is configured to be driven by the load.

13. The system of claim 10, wherein:

the drive system is a vehicle drive system of a vehicle, the vehicle drive system including the motor and a transmission and the load including a wheel of the vehicle, the motor configured to drive the transmission for rotating the wheel, and the rotational component comprises a gear of the transmission;

the at least one controller is configured to determine, based on the time information, the torque information, and the speed information, a respective number of revolutions of the gear in each of plural distinct torque ranges, wherein a respective number of cycles to failure is associated with each of the torque ranges, wherein the torque ranges include at least first and second, distinct torque ranges within a propel mode of operation of the drive system during which the motor is configured to drive the wheel through the transmission, and a third torque range within a retard mode of operation of the drive system during which the motor is configured to be driven by the wheel through the transmission; and

the at least one controller is configured to determine, for each of the torque ranges, a respective damage equivalent based on a comparison of the number of cycles to failure with the number of revolutions of the gear in the torque range, and to determine the estimated lifespan based on a summation of the damage equivalents that are determined for the torque ranges.

14. The system of claim 13, wherein the number of cycles to failure for each torque range is based on a respective equivalent stress associated with the torque range and an S-N curve of the gear, the equivalent stress based on an equivalent reaction force associated with the torque range and a geometry of at least one of the gear or the drive system.

15. A system comprising:

a vehicle drive system comprising a wheel, a transmission, and a motor, wherein the motor is configured to drive the transmission for rotating the wheel, the drive system including at least one of a gear or a bearing that is rotated during operation of the drive system; and

at least one controller operably coupled with the drive system,

wherein the at least one controller is configured to receive operational information of the drive system in operation and to determine an estimated lifespan of the at least one of the gear or the bearing based at least in part on torque information and speed information associated with the at least one of the gear or the bearing and time information of how long the drive system is operated, wherein at least one of one or more of the torque information, the speed information, or the time information is included as part of the operational information or the at least one controller is configured to determine one or more of the torque information, the speed information, or the time information from the operational information, and

wherein the at least one controller is further configured to control at least one of the drive system or a second vehicle system based at least in part on the estimated lifespan.

16. The system of claim 15, wherein the at least one controller is configured to determine, based on one or more of the time information, the torque information, or the speed information, a respective time of operation of the gear or bearing in each of plural distinct torque ranges, wherein the torque ranges include at least first and second, distinct torque ranges within a propel mode of operation of the drive system during which the motor is configured to drive the wheel with the transmission, and a third torque range within a retard mode of operation of the drive system during which the motor is configured to be driven by the wheel with the transmission, wherein plural equivalent reaction forces are respectively associated with the torque ranges; and

the at least one controller is configured to determine the estimated lifespan based at least in part on the times of operation of the gear or bearing in the torque ranges, the equivalent reaction forces, and a total time of operation of the gear or bearing.

17. A method of controlling a vehicle, comprising:

with at least one controller, receiving speed information of a motor of a drive system of the vehicle;

with the at least one controller, receiving torque information of the motor;

with the at least one controller, determining an estimated lifespan for at least one rotational component of the drive system in dependence upon the speed information and the torque information;

with the at least one controller, controlling a system of the vehicle based on the estimated lifespan that is determined.

18. The method of claim 17, wherein the step of determining the estimated lifespan includes determining a corrected speed for the at least one rotational component and determining a corrected torque for the at least one rotational component.

19. The method of claim 18, wherein the step of determining the corrected speed includes grouping the speed information into a plurality of distinct speed buckets, each of the buckets being defined by a respective predetermined speed range, and multiplying each speed range by a respective proportion of time spent by the rotational component within each speed range.

20. The method of claim 19, wherein the step of determining the corrected torque includes grouping the torque information into a plurality of distinct torque buckets, each of the buckets being defined by a respective predetermined torque range, and developing a respective equivalent reaction force for each torque bucket.

21. The method of claim 20, wherein the plurality of torque buckets include at least one propel torque bucket for propulsion force and at least one retard torque bucket for retarding force.

22. The method of claim 20, further comprising determining a percentage of life remaining for the at least one rotational component in dependence upon the determined estimated lifespan and a total operating time for the at least one rotational component.

23. The method of claim 22, wherein the at least one rotational component comprises a bearing of the drive system.

24. A method of controlling a vehicle, comprising:

with at least one controller, receiving torque information from a drive system of the vehicle;

with the at least one controller, determining an estimated lifespan of at least one rotational component of the drive system in dependence upon the torque information; and

with the at least one controller, controlling a system of the vehicle based on the estimated lifespan that is determined.

25. The method of claim 24, further comprising:

grouping the torque information into a plurality of distinct torque buckets, each of the torque buckets being defined by a respective predetermined torque range;

developing a respective equivalent reaction force for each torque bucket; and

developing a respective equivalent stress for each equivalent reaction force.

26. The method of claim 25, wherein the equivalent stress is determined in dependence upon at least one of load distribution, load sharing, or misalignment of the rotational component.

27. The method of claim 25, further comprising calculating a number of cycles to failure for the rotational component.

28. The method of claim 27, wherein:

the at least one rotational component comprises a gear; and

the number of cycles to failure for the gear is calculated using an S-N curve for the gear.

29. The method of claim 28, further comprising:

comparing the number of cycles to failure to an actual number of revolutions determined by the at least one controller; and

determining a percentage of life remaining for the gear, wherein the system of the vehicle is controller based on the percentage of life remaining that is determined.

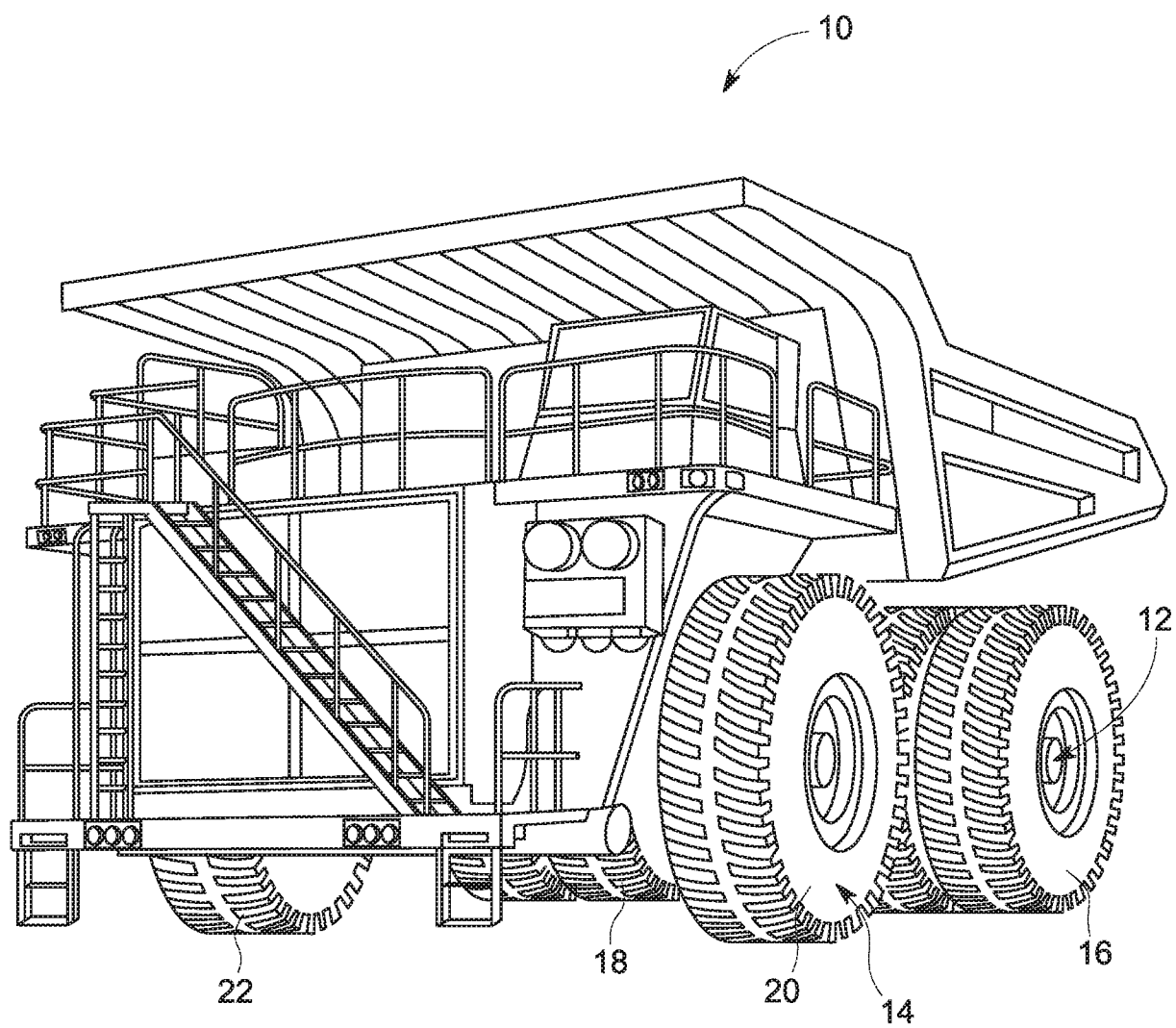


FIG. 1

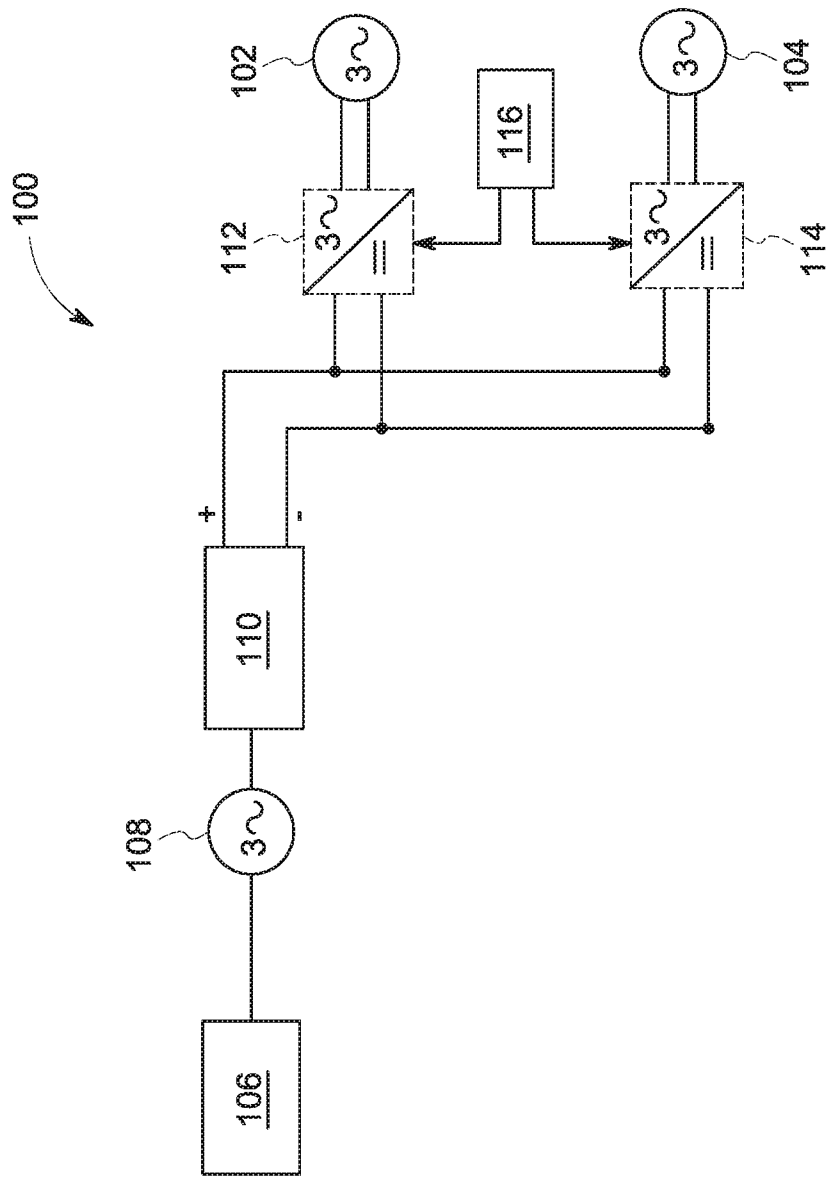


FIG. 2

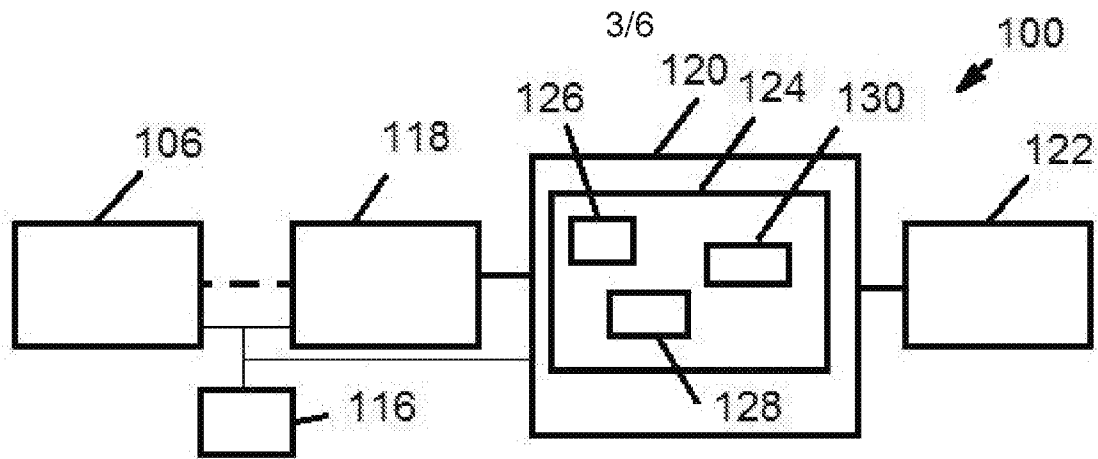


FIG. 3A

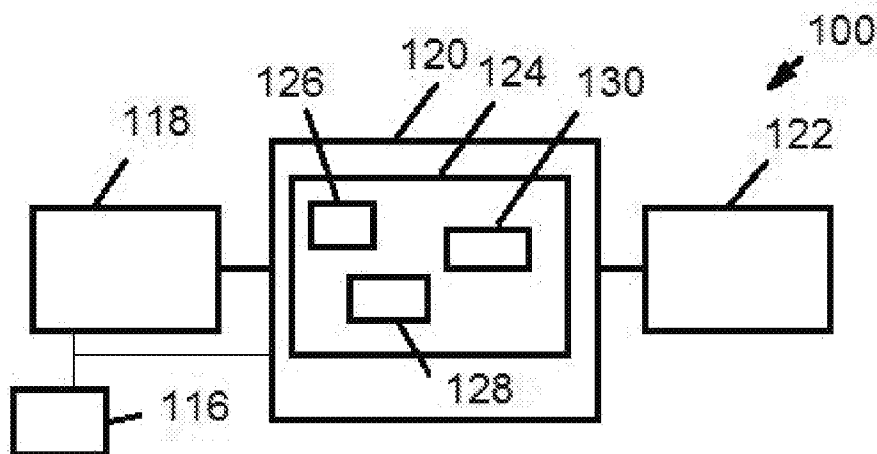


FIG. 3B

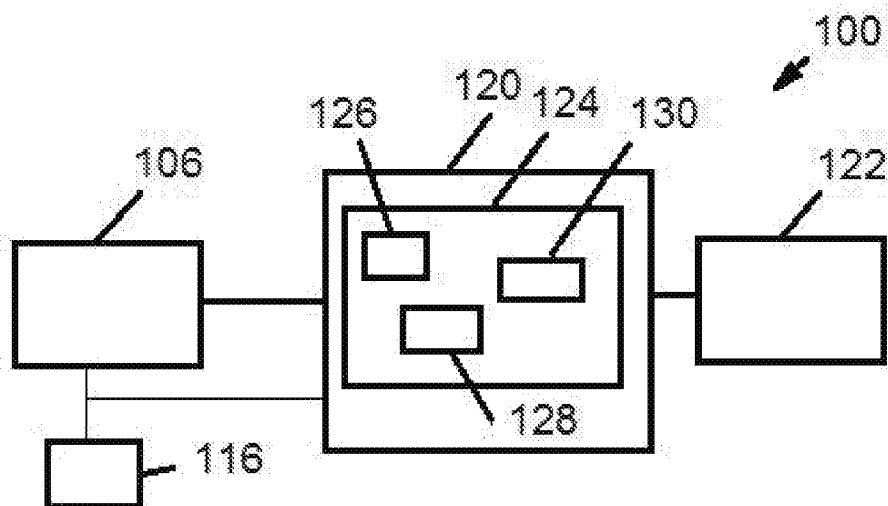


FIG. 3C

4/6

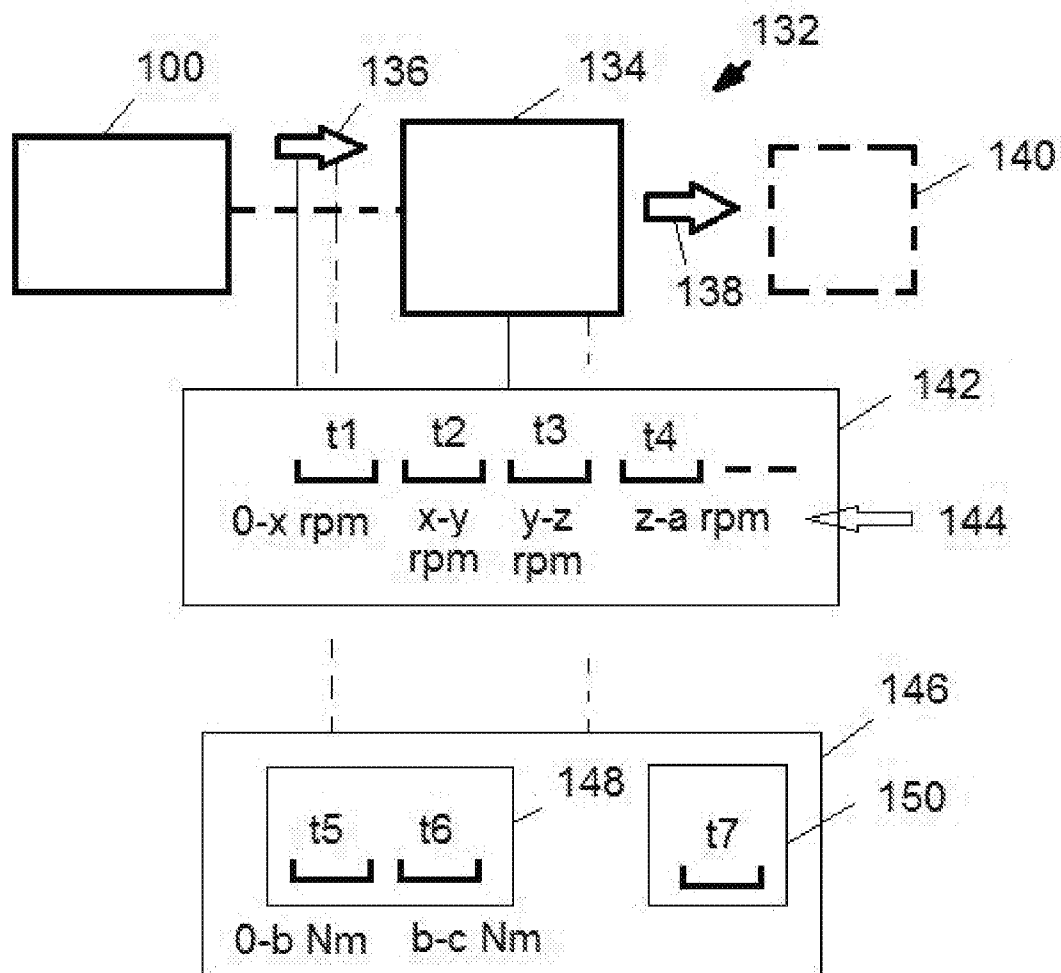


FIG. 4

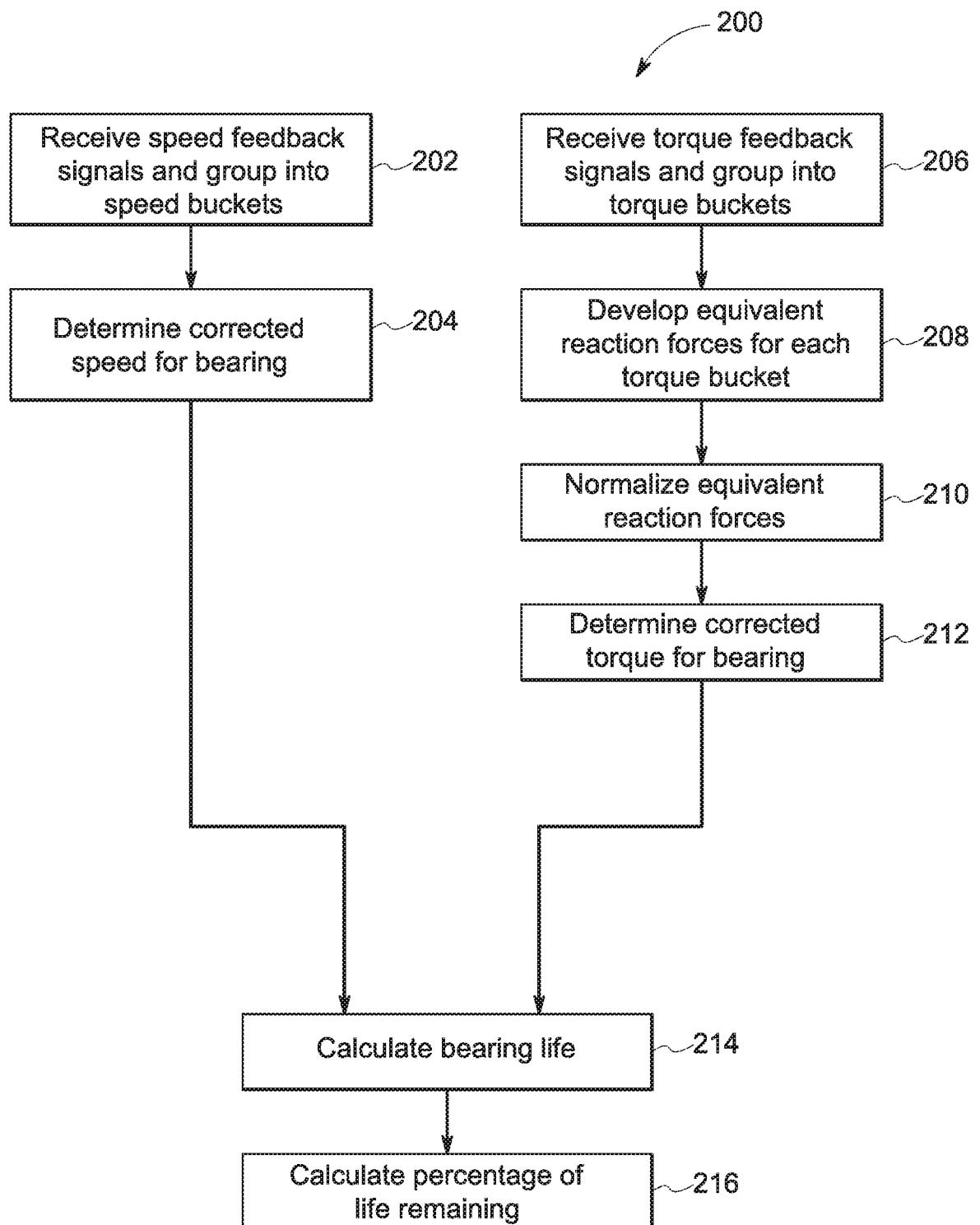


FIG. 5

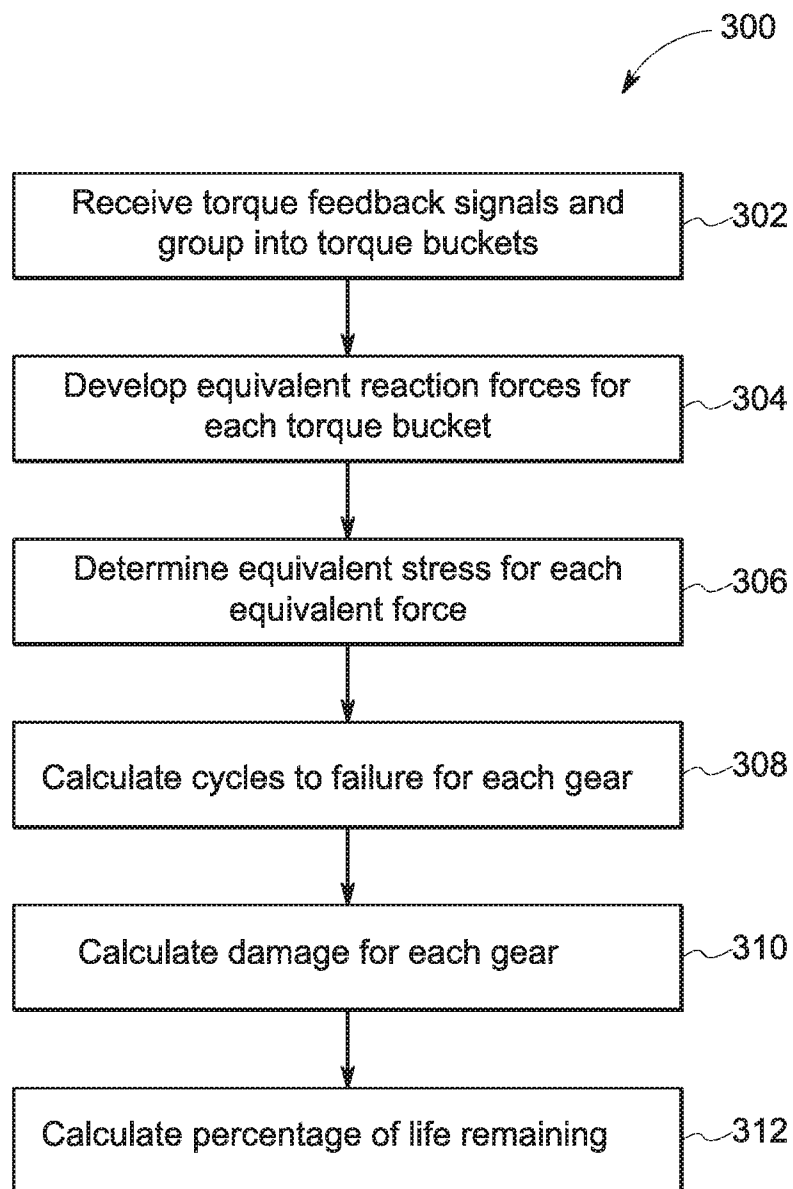


FIG. 6

## INTERNATIONAL SEARCH REPORT

International application No.  
**PCT/US2015/065874****A. CLASSIFICATION OF SUBJECT MATTER****B60K 6/00(2006.01)i, B60K 6/24(2007.10)i, B60K 6/26(2007.10)i, B60K 6/50(2007.10)i**

According to International Patent Classification (IPC) or to both national classification and IPC

**B. FIELDS SEARCHED**

Minimum documentation searched (classification system followed by classification symbols)

B60K 6/00; B60W 10/08; G07C 3/00; G07C 5/00; G06F 17/60; G01M 13/02; B60S 5/00; G01P 3/44; G06Q 10/00; G01M 13/04; B60K 6/24; B60K 6/26; B60K 6/50

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Korean utility models and applications for utility models

Japanese utility models and applications for utility models

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

eKOMPASS(KIPO internal) &amp; keywords: engine, motor, gear, bearing, lifespan, failure, fatigue, drive, vehicle

**C. DOCUMENTS CONSIDERED TO BE RELEVANT**

| Category* | Citation of document, with indication, where appropriate, of the relevant passages | Relevant to claim No.       |
|-----------|------------------------------------------------------------------------------------|-----------------------------|
| Y         | US 2013-0013138 A1 (LU et al.) 10 January 2013                                     | 1, 8, 15, 17, 24            |
| A         | paragraphs [0155]–[0170] and figures 20A–21.                                       | 2–7, 9–14, 16, 18–23, 25–29 |
| Y         | US 2014-0046614 A1 (PETTERSSON et al.) 13 February 2014                            | 1, 8, 15, 17, 24            |
| A         | see paragraphs [0050]–[0060], claim 17 and figure 1.                               |                             |
| A         | US 2009-0099886 A1 (GREINER et al.) 16 April 2009                                  | 1–29                        |
| A         | See paragraphs [0013]–[0049] and figures 1, 2.                                     |                             |
| A         | EP 1508880 A2 (BATTENFELD EXTRUSIONSTECHNIK G.M.B.H.) 23 February 2005             | 1–29                        |
| A         | See paragraphs [0001]–[0016].                                                      |                             |
| A         | JP 2002-092137 A (NIPPON MITSUBISHI OIL CORP.) 29 March 2002                       | 1–29                        |
| A         | See abstract and figure 1.                                                         |                             |



Further documents are listed in the continuation of Box C.



See patent family annex.

\* Special categories of cited documents:

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier application or patent but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&amp;" document member of the same patent family

Date of the actual completion of the international search

29 March 2016 (29.03.2016)

Date of mailing of the international search report

**29 March 2016 (29.03.2016)**

Name and mailing address of the ISA/KR

International Application Division

Korean Intellectual Property Office

189 Cheongsa-ro, Seo-gu, Daejeon, 35208, Republic of Korea



Facsimile No. +82-42-481-8578

Authorized officer

PARK, Tae Wook

Telephone No. +82-42-481-3405



**INTERNATIONAL SEARCH REPORT**

Information on patent family members

International application No.

**PCT/US2015/065874**

| Patent document<br>cited in search report | Publication<br>date | Patent family<br>member(s)                                                                                                                                                                                     | Publication<br>date                                                                                                                                    |
|-------------------------------------------|---------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------|
| US 2013-0013138 A1                        | 10/01/2013          | AU 2012-279419 B2<br>CN 103648827 A<br>EP 2729323 A1<br>US 2013-0013231 A1<br>US 9050894 B2<br>WO 2013-006311 A1<br>WO 2013-006742 A1                                                                          | 28/05/2015<br>19/03/2014<br>14/05/2014<br>10/01/2013<br>09/06/2015<br>10/01/2013<br>10/01/2013                                                         |
| US 2014-0046614 A1                        | 13/02/2014          | AU 2012-228479 B2<br>CA 2827009 A1<br>CN 103430004 A<br>EP 2498076 A1<br>EP 2684018 A1<br>EP 2684018 B1<br>JP 05826866 B2<br>JP 2014-515096 A<br>KR 10-1478078 B1<br>KR 10-2013-0133040 A<br>WO 2012-123351 A1 | 28/08/2014<br>20/09/2012<br>04/12/2013<br>12/09/2012<br>15/01/2014<br>26/11/2014<br>02/12/2015<br>26/06/2014<br>31/12/2014<br>05/12/2013<br>20/09/2012 |
| US 2009-0099886 A1                        | 16/04/2009          | CA 2701225 A1<br>CN 101821779 A<br>CN 101821779 B<br>JP 05276110 B2<br>JP 2011-501264 A<br>WO 2009-048624 A1                                                                                                   | 16/04/2009<br>01/09/2010<br>11/09/2013<br>28/08/2013<br>06/01/2011<br>16/04/2009                                                                       |
| EP 1508880 A2                             | 23/02/2005          | EP 1508880 A3                                                                                                                                                                                                  | 23/11/2005                                                                                                                                             |
| JP 2002-092137 A                          | 29/03/2002          | None                                                                                                                                                                                                           |                                                                                                                                                        |