



US 20160265520A1

(19) **United States**(12) **Patent Application Publication**
SKINNER, JR. et al.(10) **Pub. No.: US 2016/0265520 A1**(43) **Pub. Date: Sep. 15, 2016**(54) **ELECTRONIC CONTROL FOR A ROTARY FLUID DEVICE**(71) Applicant: **EATON CORPORATION**, Cleveland, OH (US)(72) Inventors: **Jeffrey David SKINNER, JR.**, Madison, MS (US); **Joshua Aaron SMITH**, Ridgeland, MS (US)(21) Appl. No.: **15/033,324**(22) PCT Filed: **Oct. 29, 2014**(86) PCT No.: **PCT/US2014/062973**

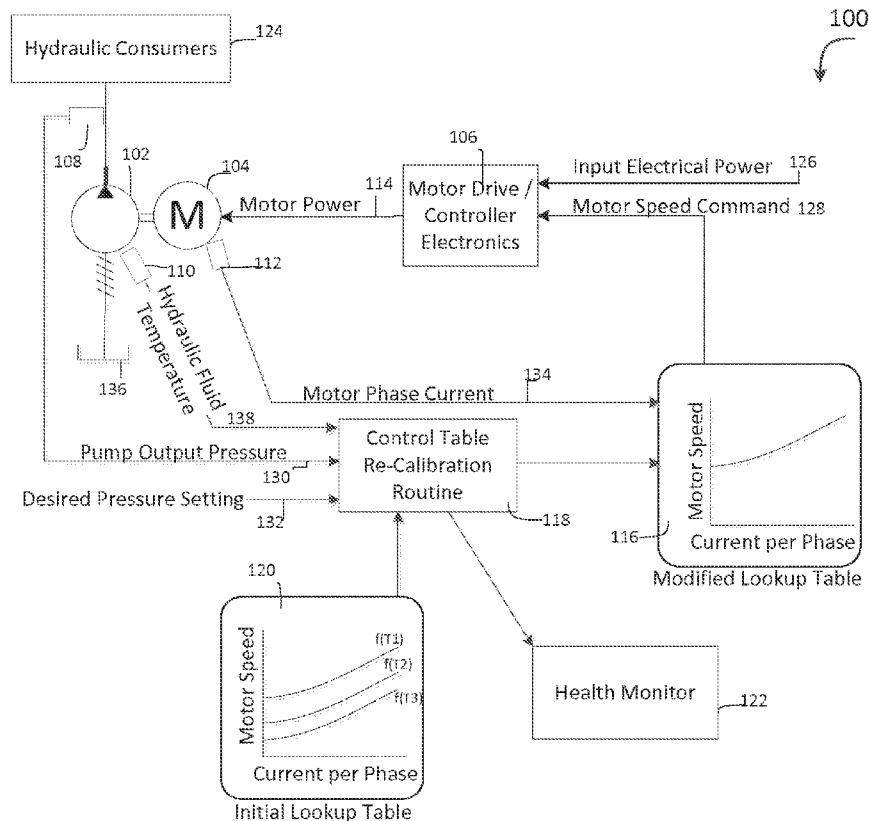
§ 371 (c)(1),

(2) Date: **Apr. 29, 2016****Related U.S. Application Data**

(60) Provisional application No. 61/896,683, filed on Oct. 29, 2013.

Publication Classification(51) **Int. Cl.**
F04B 17/03 (2006.01)
F04B 49/08 (2006.01)
F04B 23/06 (2006.01)(52) **U.S. Cl.**CPC **F04B 17/03** (2013.01); **F04B 23/06** (2013.01); **F04B 49/08** (2013.01)(57) **ABSTRACT**

A fluid system is provided including a fluid pump having an output and an electric motor coupled to the fluid pump. The electric motor is adapted to operate the fluid pump in response to an electrical signal. A controller adapted to communicate the electrical signal to the electric motor, the controller including an initial lookup table having initial performance data related to the fluid pump and the electric motor. The initial performance data from the initial lookup table and sensed performance data applied to a modifiable lookup table are used by the controller to set aspects of the electrical signal communicated to the electric motor to achieve a desired system pressure generated by the fluid pump. A pressure sensor in communication with the output that is adapted to communicate a sensed system pressure to the controller, the controller being adapted to update the modifiable lookup table based on a difference between the desired system pressure and the sensed system pressure to minimize variation between the sensed system pressure and the desired system pressure.



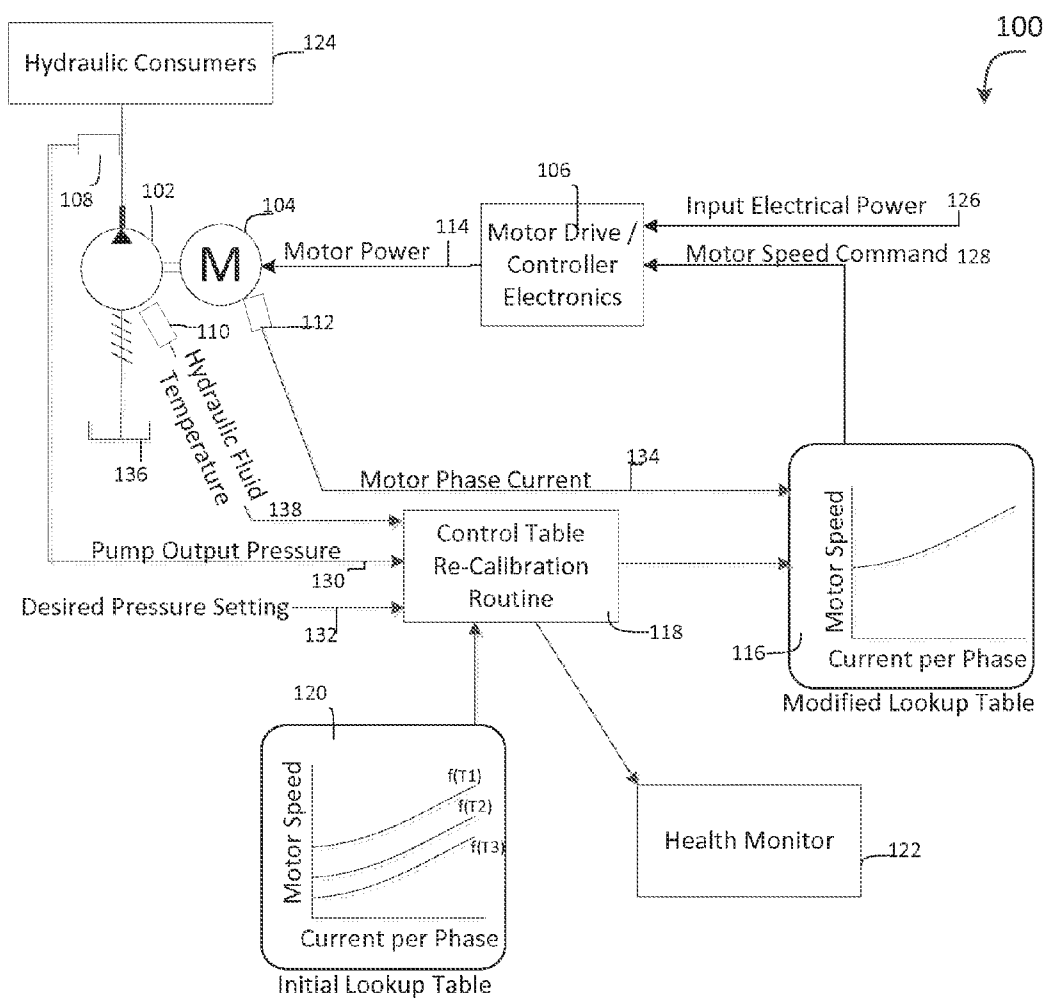


FIG. 1

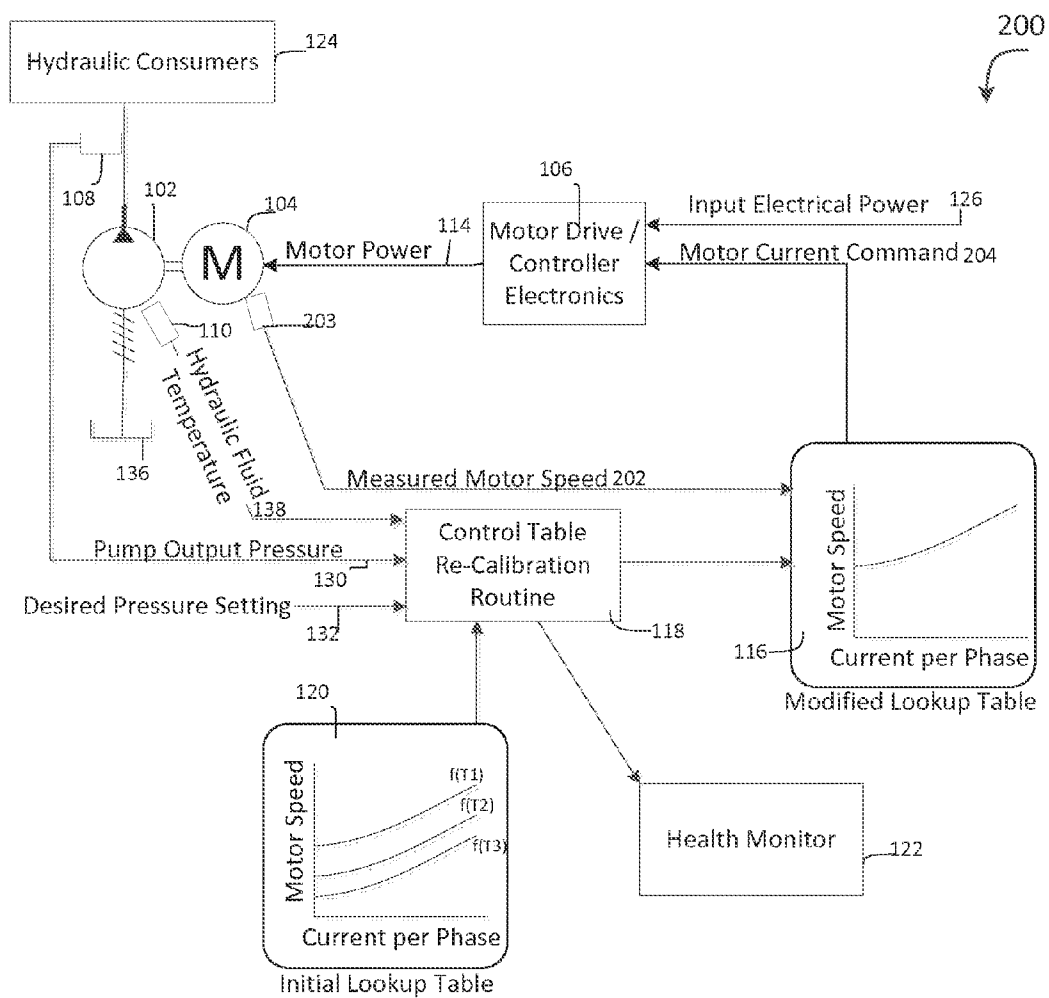


FIG. 2

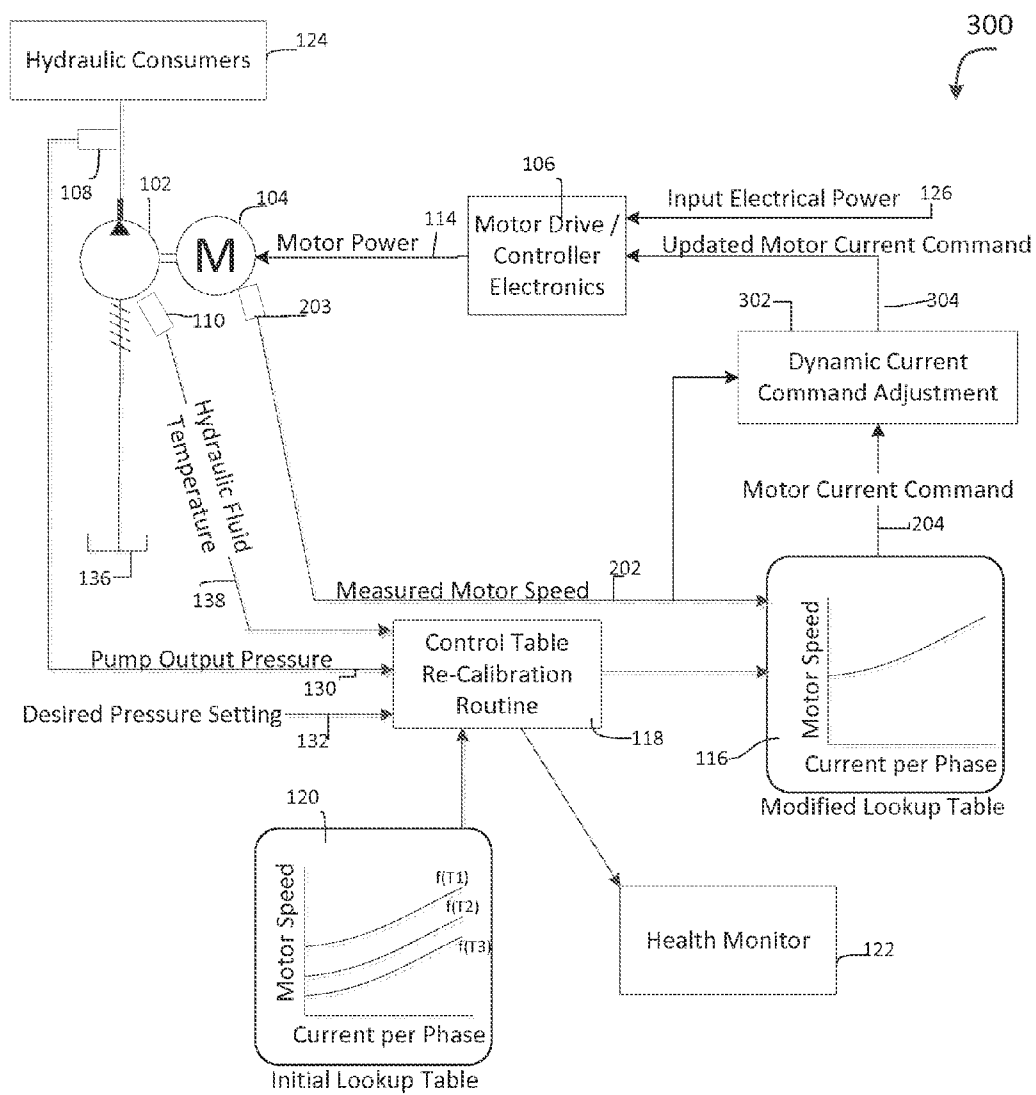


FIG. 3

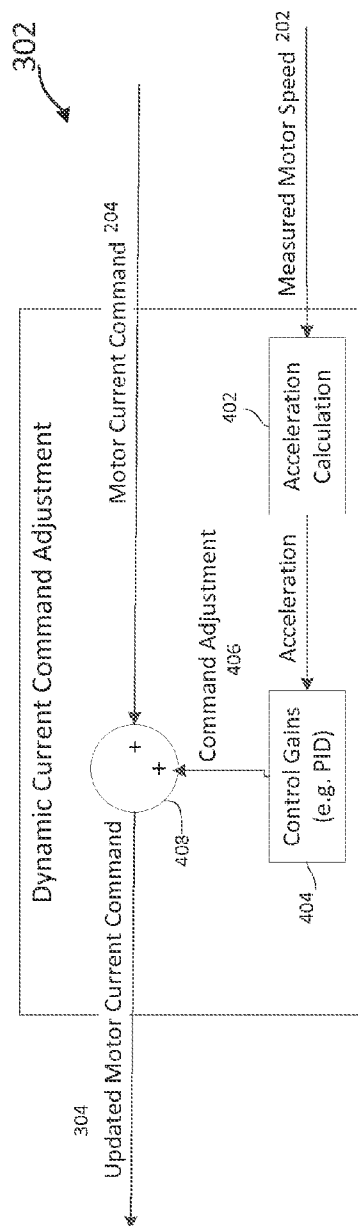


FIG. 4

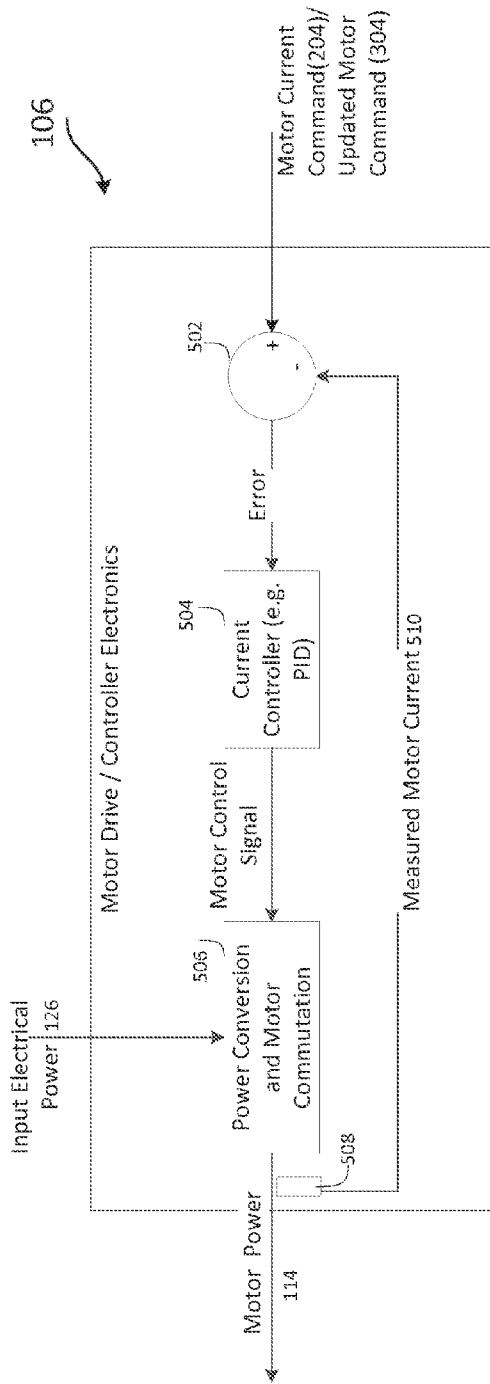


FIG. 5

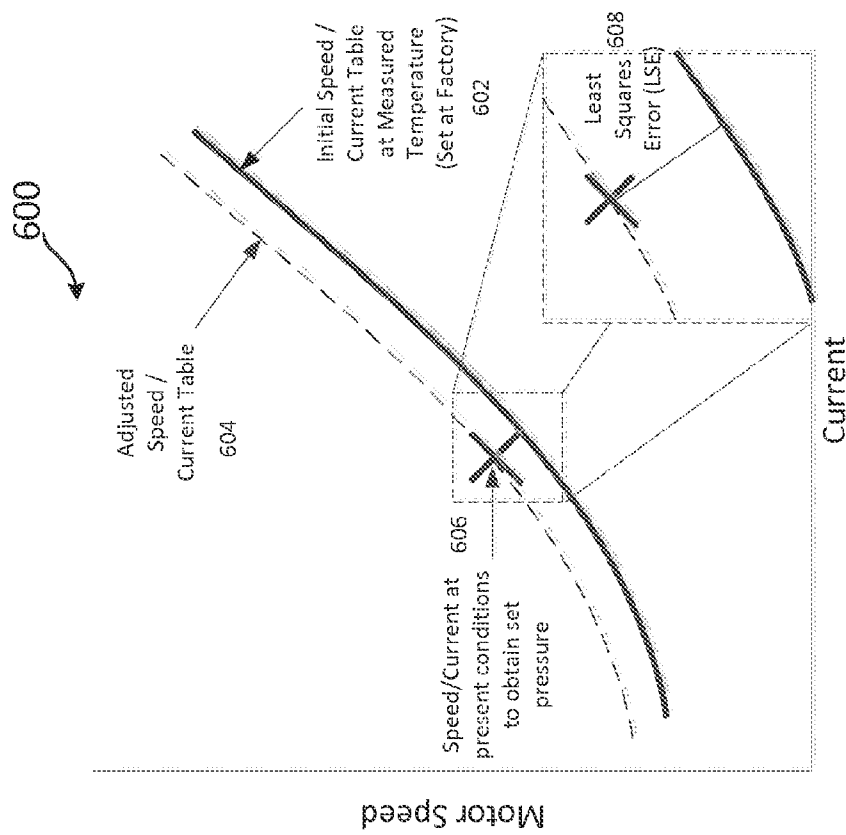


FIG. 6

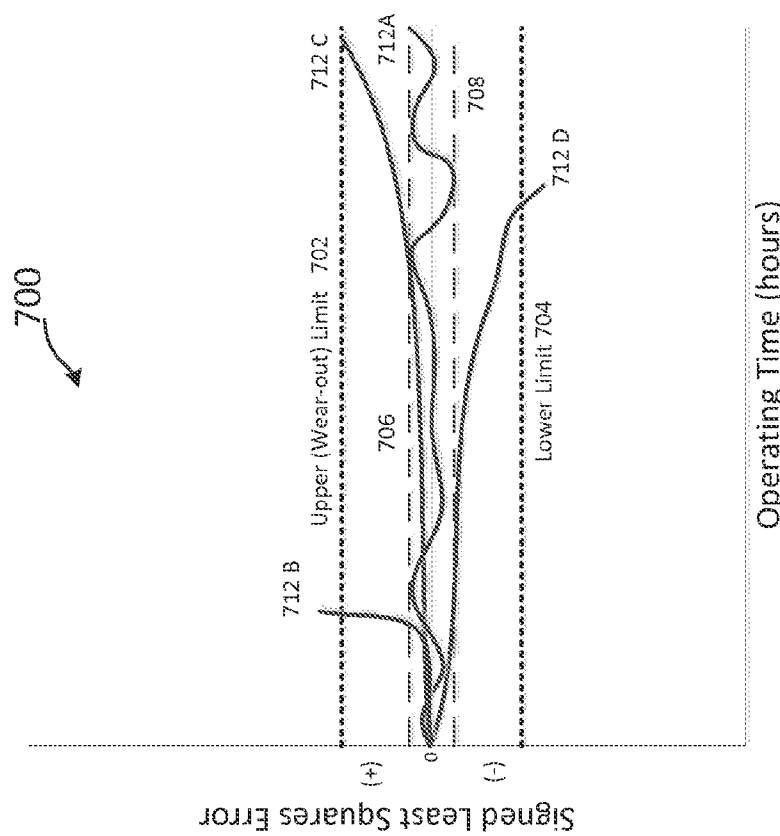


FIG. 7

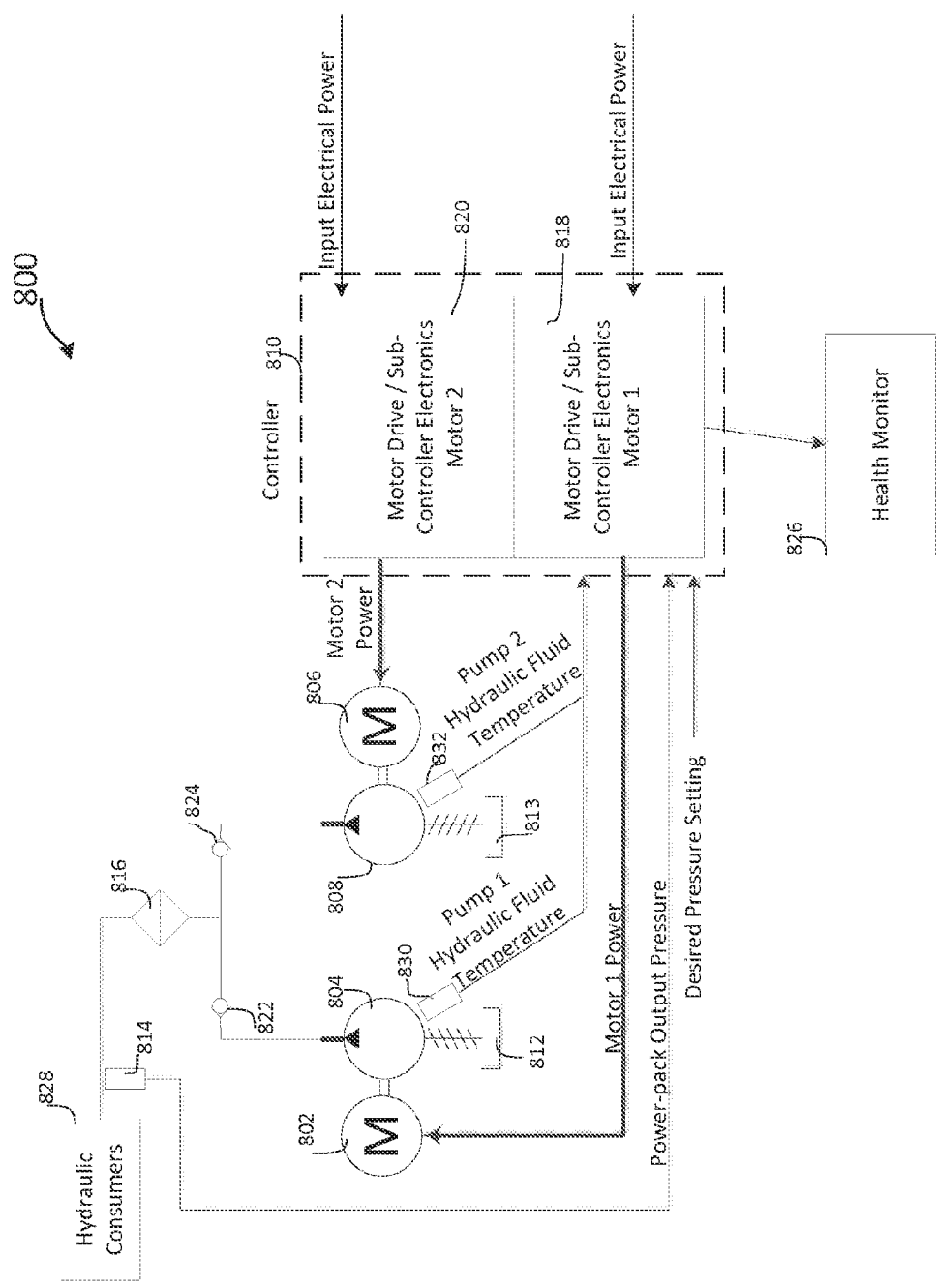
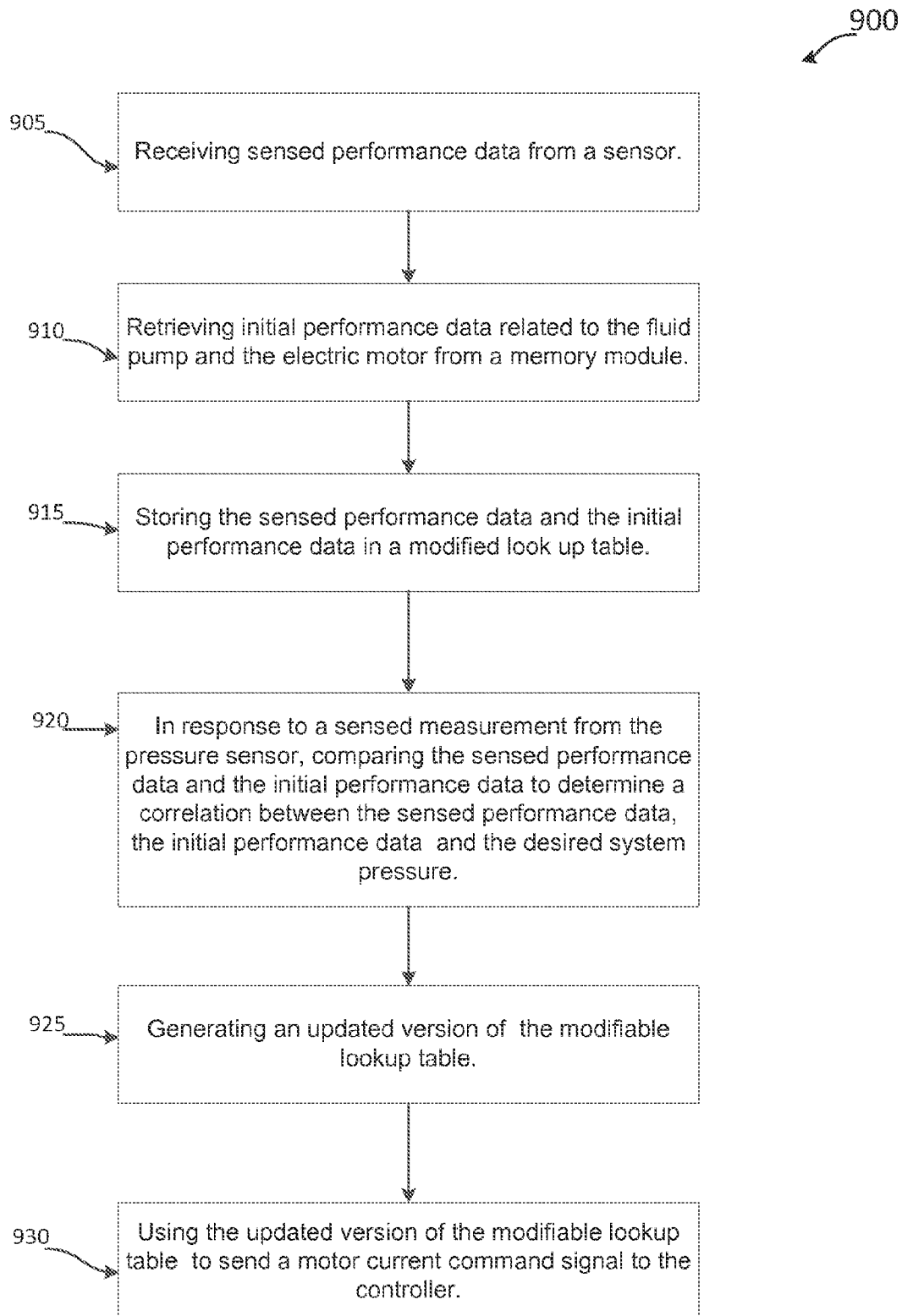


FIG. 8

**FIG. 9**

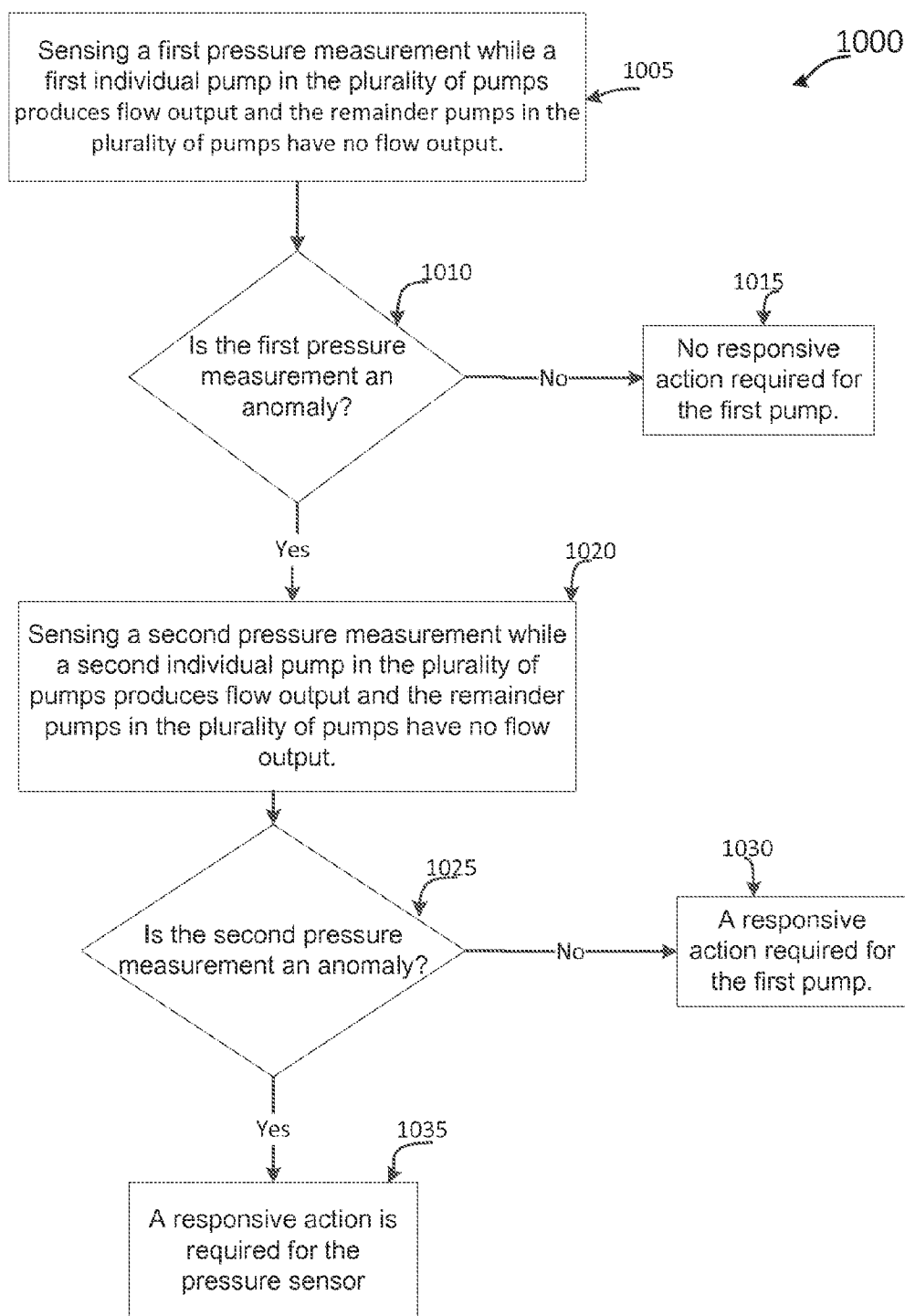


FIG. 10

ELECTRONIC CONTROL FOR A ROTARY FLUID DEVICE

CROSS-REFERENCE TO RELATED APPLICATION(S)

[0001] This application is being filed on Oct. 29, 2014, as a PCT International Patent application and claims priority to U.S. Patent Application Ser. No. 61/896,683 filed on Oct. 29, 2013, the disclosure of which is incorporated herein by reference in its entirety.

BACKGROUND

[0002] An electronic controlled rotary fluid device according to the present disclosure improves robustness of the device identified in U.S. Patent Publication Number 2010/0021313 for systems in which the variation in performance due to external factors such as fluid temperature is to be reduced.

SUMMARY

[0003] Some or all of the above needs and/or problems may be addressed by certain examples of the disclosure. Certain examples of the disclosure can include systems and methods for controlling a rotary fluid device. A control methodology can be applied to single motor-pump configurations and multiple motor-pump configurations. In addition, the single and multiple motor-pump configurations may only require a single pressure sensor for an entire power pack system. The single pressure sensor can be integrated into a control loop to periodically provide pressure data used to reduce variation in the performance of the system. Accordingly, the sensed pressure data may initiate an updating step causing a recalculation to the parameters used to control the fluid device system.

[0004] Other facets of the control methodology can be implemented by a controller that allows for the system to further refine current commands sent to a motor by using a dynamic current command update. In an example, the dynamic current command update can be applied to maintain steady state operation, when a flow demand or system pressure may cause the fluid device system to operate in a transient state. In controlling the system, the periodic sampling of the pressure sensor of system can be used to determine if an update to the operating parameters should be made. For example, when the desired system pressure and the sensed system pressure exceed a predetermined threshold, the operating parameters may be updated to minimize the difference between the current and desired system pressure. In the proceeding system operations, updates may serve as the system parameters. However, the control methodology also possesses fail safe mechanisms, wherein when certain operating parameters exceed predetermined thresholds the system may revert back to initial factory settings.

[0005] In other examples, the controller uses updated operating parameters to perform control operations on multi-motor pump systems. For example, the controller can maintain and update a lookup table for each motor-pump configuration in the system. In the process of maintaining the lookup tables, the controller can recalibrate the lookup table for each configuration. When the system output flow is sensed by the pressure sensor and the flow can be isolated to a single motor-pump configuration, the recalibrations can be completed. The controller can also be configured to determine the operation of the pressure sensor by comparing the operation of the

sensor by alternating the active motor-pump configuration. In another example, the controller can be configured to statistically differentiate the current operation from the initial operation of the system using the system operating parameters to determine the useful life of system components. In addition, the statistical calculations may be used to predict component failure. Further, the controller can operate the system in a power savings mode, wherein various configurations and alternating activity of multi-motor-pumps can be used to maximize the useful life of the motor-pumps, while maintaining a requested system flow output and pressure. The power saving mode may be applied in controller examples where the controller is configured with sub-controllers that control an individual motor-pump and communicate with each other.

BRIEF DESCRIPTION OF THE DRAWINGS

[0006] FIG. 1 is a schematic view of a hydraulic system having a rotary fluid device and control methodology according to an example of the disclosure.

[0007] FIG. 2 is a schematic view of a hydraulic system having a rotary fluid device and control methodology according to another example of the disclosure.

[0008] FIG. 3 is a schematic view of a hydraulic system having a rotary fluid device and control methodology according to another example of the disclosure utilizing a dynamic current command adjustment.

[0009] FIG. 4 is a block diagram illustrating a dynamic current command adjustment.

[0010] FIG. 5 is a block diagram illustrating a motor drive controller command.

[0011] FIG. 6 is a lookup table according to an example of the disclosure.

[0012] FIG. 7 is a chart illustrating health trending of a rotary fluid device.

[0013] FIG. 8 is a block diagram for illustrating an example method for controlling a fluid system with a plurality of pumps according to an example of the disclosure.

[0014] FIG. 9 is a flowchart for illustrating an example method recalibrating the modifiable lookup table for a fluid pump according to an example of the disclosure.

[0015] FIG. 10 is a flowchart for illustrating an example method for determining the fluid pump operation in a plurality of pumps and pressure sensor operation according to an example of the disclosure.

DETAILED DESCRIPTION

[0016] Reference will now be made in detail to the exemplary aspects of the present disclosure that are illustrated in the accompanying drawings. Wherever possible, the same reference numbers will be used throughout the drawings to refer to the same or like structure.

[0017] An aspect of the present disclosure relates to a fluid system that has a fluid pump having an output, an electric motor that operates the fluid pump in response to an electrical signal, a pressure sensor, and a controller. The controller communicates the electrical signal derived from a modifiable lookup table. The pressure sensor communicates with the controller and the controller updates the modifiable lookup table based on a difference between the desired system pressure and the sensed system pressure to minimize variation between the sensed system pressure and the desired system pressure.

[0018] Another aspect of the present disclosure relates to the fluid system also including a temperature sensor for sensing a hydraulic fluid temperature of hydraulic fluid passing through the fluid pump. The controller also includes a plurality of initial lookup tables and plurality of modifiable lookup tables corresponding to different hydraulic fluid temperatures. Based on the hydraulic fluid temperature sensed by the temperature sensor, the controller selects an appropriate modifiable lookup table from the plurality of updatable lookup tables.

[0019] Another aspect of the present disclosure relates to the controller in the fluid system being configured to monitor the sensed motor speed over time and determine whether an acceleration condition exists. The controller is also configured to modify the electrical signal sent to power the motor when the acceleration condition exists.

[0020] Another aspect of the present disclosure relates to the controller in the fluid system being configured to perform a recalibration routine to update the modifiable table. The recalibration steps may comprise receiving sensed performance data from a sensor; retrieving initial performance data related to the fluid pump and the electric motor from a memory module; storing the sensed performance data and the initial performance data in a modified lookup table; in response to a sensed measurement from the pressure sensor, comparing the sensed performance data and the initial performance data to determine a correlation between the sensed performance data, the initial performance data and the desired system pressure; generating an updated version of the modifiable lookup table; using the updated version of the modifiable lookup table to send a motor current command signal to the controller.

[0021] Another aspect of the present disclosure relates to a fluid system that has a plurality of fluid pumps, each pump coupled to a motor. The fluid system includes a junction location for combining fluid output flow from the fluid pumps, and wherein a pressure sensor is positioned at or downstream of the junction location. In another example, each motor is controlled by a sub-controller.

[0022] Another aspect of the present disclosure relates to the controller in the fluid system being configured to determine pressure sensor functionality in multi-motor-pump configurations. The steps to determine pressure sensor functionality may comprise sensing a first pressure measurement while first individual pump in the plurality of pumps produces an output flow and the remainder pumps in the plurality of pumps do not produce a flow output; determining whether the first pressure measurement is an anomaly based on a predetermined threshold for system pressure; in response to determining that the first pressure measurement is an anomaly, sensing a second pressure measurement wherein the second pressure measurement is based on alternating the first individual pump to a no flow output state and producing the flow output from a second individual pump from the remainder pumps; and determining whether the second pressure measurement is an anomaly based on the predetermined threshold for system pressure.

[0023] Referring now to the drawings, FIG. 1 illustrates a hydraulic system having a rotary fluid device and a methodology for control of a rotary fluid device system **100**, such as a motor **104** and pump **102**, in which the indirect pressure control using motor current and lookup tables is supplemented using a pressure sensor **108**. In an example, the rotary fluid device described herein is a positive displacement pump

102 (e.g., inline piston, radial piston, gear, etc.) that is driven by a variable speed electric motor **104**. A low pressure side of the pump **102** can be in fluid communication with a reservoir **136**. While not expressly described within this disclosure, the principles described herein may also be applied to a centrifugal type pump driven by a variable speed motor to achieve a desired pressure flow characteristic. A current sensor **112** used for a lookup table **116** based control can be installed anywhere that steady state current can be detected including on the input cables of the motor drive (e.g., 3Phase 400 Hz 115 VAC), after the transformer and rectification in a controller **106** (135 VDC, not illustrated), or in the power cables between the motor drive and the motor (PWM phase current). In generating the modified lookup table **116**, the controller receives a motor phase current **134** from the current sensor **112**.

[0024] The controller **106** further includes a plurality of outputs including a voltage output, a phase current output, and a phase angle output. In the subject example, each of the plurality of outputs is in electrical communication with the electric motor **104**.

[0025] The controller **106** further includes a circuit having a microprocessor and a storage media. In an example, the microprocessor may be a field programmable gate array (FPGA). The FPGA is a semiconductor device having programmable logic components, such as logic gates (e.g., AND, OR, NOT, XOR, etc.) or more complex combinational functions (e.g., decoders, mathematical functions, etc.), and programmable interconnects, which allow the logic blocks to be interconnected. In an example, the FPGA can be programmed to provide voltage and current to the electric motor **104** of the rotary fluid device system **100** such that the rotary fluid device system **100** responds in accordance with desired performance characteristics (e.g., constant horsepower, pressure compensation, constant speed, constant pressure, etc.). In another example, the storage media can be volatile memory (e.g., RAM), non-volatile memory (e.g., ROM, flash memory, etc.), or a combination of the two. The storage media includes program code for the FPGA, an initial lookup table **120** and a modified (dynamic) lookup table **116**.

[0026] Motor speed command **128** is based on a modifiable lookup table **116**, which consolidates the pump and motor characteristics (e.g., torsional, volumetric, and electrical efficiency) into a single curve of steady state motor speed versus current that results in the desired pressure **132** versus flow at the output of the pump **102**. This approach may be modified to use a family of curves for external factors, which may have a strong influence on the motor-pump performance. Fluid temperature **138** is an example of one such variable illustrated in FIG. 1. A temperature transducer **110** installed in a flow stream of the pump **102** can be used to adjust the speed versus current curve to ensure a more consistent output pressure from the system **100**.

[0027] The fast speed response required by typical hydraulic consumers **124** will be satisfied by the internal motor speed control loop based on the lookup tables (**120** and **116**) as described in U.S. Patent Publication Number 2010/0021313. Unlike U.S. Patent Publication Number 2010/0021313, the adjustments to the control tables described herein can be applied to the steady state performance—an adjustment/recalibration control should not respond to transient conditions including pressure changes during flow transients. This is achieved by requiring persistence in the operating condition (e.g., greater than about 0.5 seconds) prior to invoking the

control and monitoring logic described. In referring to FIG. 2, there can be another example where the input to update the modifiable lookup table 116 can be a measured motor speed 202 sensed by a speed sensor 203 and the output sent to the controller 106 can be a motor current command 204.

[0028] One technical effect of certain examples of the disclosure is that the control methodology adjusts the motor-pump steady state operating characteristics, which can be considered a slow control loop that adjusts the pump performance at a very slow rate (e.g., less than about 1 Hz). By adding a pressure sensor 108 between the pump outlet port 102 and the hydraulic consumers 124, the pump control lookup table 120 can be modified in order to minimize the variation in the outlet pressure. A pressure sensed 130 by the sensor 108 is compared with a desired set pressure 132 (e.g., 3000 psi) and the difference is added as an error signal to adjust the speed versus current modified lookup table 116 (possibly as an outer proportional-integral-derivative (PID) control, although other control schemes are possible).

[0029] In another example as depicted in FIG. 3, the fluid device system can include a dynamic current adjustment. The dynamic current adjustment 302 is a control element that can be used to further adjust the current command when the systems respond to conditions that may cause the system to operate in a transient state. As discussed later, the dynamic current adjustment 302 can use the inputs of the motor current command 204 and the measured motor speed 202 to generate an updated motor current command 304.

[0030] In referring to FIG. 4, the output from the modified table 116 is a motor current command 204, which is sent to the controller 106 that may adjust the speed of the motor 104 in order to maintain the desired attribute of the system 300, depicted in FIG. 3. As discussed earlier, the dynamic current adjustment is completed in element 302 as depicted in FIG. 4. In circumstances, such as increased flow demand, pressure drop or other cause to change the load placed on the motor 104, the motor 104 may respond by accelerating into a transient state. In order to return to steady state operation, the dynamic current command adjustment 302 may further modify the motor current command 204 generated from a recalibration routine 118. As shown in the example in FIG. 4, the motor current command 204 and measured motor speed 202 serve as inputs. In the adjustment routine, the controller 106 may calculate a motor acceleration 402 and determine whether the calculated acceleration exceeds a predetermined threshold. Based on the calculated acceleration, a control gain 404 may be applied to generate a command adjustment 406. In one example, the command adjustment 406 may be an output of a proportional derivative integral (PID) control function. In other examples, the adjustment factor may be an output of a function generated from various combinations of proportional, derivative, and integral controller functions. The dynamic current command adjustment routine 302 may then perform a function operation at a summing point 408 to combine the command adjustment 406 with the motor current command 204 to produce an updated motor current command 304.

[0031] Referring to FIG. 5, the controller takes the feedback from the system operation to determine the electrical power 114 sent to a motor 104. In an example, the controller 106 takes the motor current command 204 and the measured motor current 510, sensed from a current sensor 508 and determines the difference between the two inputs at a summation point 502. The error indicates the difference between

current supplied to power the motor and the current that the system requires to maintain a desired attribute. In another example, the error signal resultant from the summation point can be minimized. The controller 106 may apply a PID controlling function 504 to the error signal to generate a motor control signal. In other examples, the motor control signal may be an output of a function generated from various combinations of proportional, derivative and integral controller functions. In a power conversion process 506, input electrical power 126 is combined with aspects of the generated motor control signal that may include adjustments to: current, frequency, voltage, or phase angle. The resulting output can be the motor power 114 sent to power the motor. In another example, when the system uses a dynamic current adjustment from FIG. 4, the updated motor command 304 may be used as an input to the controller 106, instead of the motor current command 204.

[0032] FIG. 6 illustrates an exemplary modified lookup table data 600 to be stored in a memory device, such as re-writable memory, and used for the motor control. In an example, the initial lookup table 120 is stored in read-only-memory (ROM) and is used for health monitoring and reversion as described later in this disclosure. Since the pressure sensor 108 is being used only to adjust the modified lookup table 116 within the motor controls and is not within the speed control loop, a low frequency (e.g., <1 Hz) loop rate can be used. In addition, direct communication between the pressure sensor 108 and the controller 106 is not required to prevent latency. Instead, for configurations where the motor controller (drive) 106 is remote from the motor 104 and pump 102, the pressure sensor 108 signal can be discretized and communicated over a standard communication serial bus at relatively slow sampling rates. This method of updating modifiable lookup table 116 based on sensed output pressure allows for on the fly re-calibration of the motor-pump system as required by variations due to internal and external influences (e.g., temperature, wear-out, etc.) and does not require prior knowledge of all of these effects before designing the controller 106 hardware/software.

[0033] Referring to FIG. 6, a least squares error 608 for each operating point 606 as compared to the factory set lookup table curves 602 can be used to measure the change in motor-pump performance over time. For instance, as mechanical wear-out of the pump 102 occurs, the pump internal leakage and internal friction may increase causing a drift in the motor current required to maintain the pump pressure at the set point 606. This drift can be measured using a least squares calculation of the error 608 between the adjusted operating condition to maintain steady state 604 and initial curves 602 programmed into read-only memory when the motor-pump was assembled at the factory. For example, the value of the least squares error 608 can be plotted over time, as shown in FIG. 7. By trending this over time, the health of the motor 104 and pump 102 can be determined in addition to trending the degradation in pump performance to predict the onset of failure before it occurs (predictive health monitoring 122).

[0034] In FIG. 7, it is assumed that the least squares error is "signed" indicating whether the present motor operation is above (positive) or below (negative) the initial lookup table performance. Typical pump wear out would result in a gradual increase in motor current required to maintain a given pump pressure. This is illustrated as curve 712C—the slope of the curve over time could easily be used to predict when the

performance variation will cross a predetermined threshold **702** at which point the motor-pump would need to be replaced. Curve **712A** illustrates typical random error that should be expected with normal operation (note, the error varies both above and below the initial curves). It may be desirable to add inner thresholds, where one inner threshold is positive **706** and another is negative **708** (indicated as inner dashed lines) within which no adjustment to the motor data table would be required. Curve **712B** illustrates a sudden shift in motor-pump performance, which may be the result of a total pump failure or loss of the pressure sensor. Curve **712D** illustrates a gradual drift, which would make the motor-pump appear to be more efficient. This would likely indicate calibration drift in the pressure sensor (**108**) or temperature sensor **110**. A lower threshold **704** may be used to indicate required replacement of the motor-pump assembly or testing of the sensors.

[0035] Any detected faults or prediction of faults to occur will be communicated outside of the control system through an appropriate interface, such as an aircraft user interface. These communications can be used by a system controller or maintenance computer to direct action (e.g., maintenance activity or reconfiguration of the aircraft system).

[0036] The motor-pump control described herein is robust as described above and fail safe. In the event of pressure sensor failure (e.g., detectable by a time history similar to curve **712B** but differentiated from normal transient flow response by persistence greater than about 0.5 seconds for instance), the motor **104** and pump **102** will continue operating with the data table as constructed just prior to loss of the signal. If the error is too great (exceeds a pre-determined threshold **702**), the motor **104** and pump **102** will revert to the initial lookup table coded in read-only memory at the factory. In this condition the motor **104** and pump **102** would operate at a lower operating pressure, but would still be available to power the hydraulic consumers **124**.

[0037] If a temperature sensor signal is lost (broken cable for instance), the pressure sensor **108** will continue to update the lookup table **116** to control the motor-pump device to the set pressure.

[0038] If performance of the motor **104** and pump **102** degrades to a point where the steady state current exceeds the limit allowed by the electrical power distribution system, the motor-pump control **106** can be set to reduce the set pressure to continue operation. Trending, as described above, can be used to determine the maximum duration of safe operation within an operating threshold based on the maximum current allowed and the minimum pressure required.

[0039] Referring to FIG. **8**, an example is described in which additional controls may be added to a hydraulic power pack system **800** that includes at least two motors (**802**, **806**) and two pumps (**804**, **808**) providing hydraulic flow. Each pump is in fluid communication with a fluid reservoir (**812**, **813**). The configuration illustrated obviates multiple pressure sensors in each power pack system **800**. Where the example illustrated in FIG. **1** uses one pressure sensor **108** per motor **104** and pump (**102**), the example in FIG. **8** uses only one pressure sensor **814** per power pack system **800**. In the example, the illustrated pressure sensor **814** has been placed on the down-stream side of the output filter **816**. This allows for adjustment of the motor-pump control to maintain a constant pressure at the hydraulic consumers **828** as the pressure drop across the filter **816** varies over time and with varying fluid temperature and flow rates. In another example, pressure

sensors **814** may be installed before the filter **816** or in systems in which no pressure filter **816** is installed.

[0040] Referring still to FIG. **8**, the hydraulic system **800** is shown in which two electric motors (**802**, **806**) and two pumps (**804**, **808**) may also include check valves (**822**, **824**). The check valves (**822**, **824**) are included at the outlet of each pump to allow flow only in one direction, protecting against back flow across the hydraulic pumps that may occur. In another example, a controller **810** can be configured to operate multiple sub-controllers. In FIG. **8**, sub-controller **1** (**818**) and sub-controller **2** (**820**) may each individually operate a respective motor-pump configuration. For example sub-controller **1** (**818**) controls the operation of motor **1** (**802**) and pump **1** (**804**). Similarly, sub-controller **2** (**820**) controls operation of motor **2** (**806**) and pump **2** (**808**). However, these controllers may be installed in a single enclosure as illustrated schematically. In another example, adjustment to a modifiable lookup table **116** can also be impacted based on the temperature of the hydraulic fluid in the pumps received from the temperature sensors (**830**, **832**).

[0041] In order to distinguish each motor-pump performance from the others for the purpose of calibrating the modifiable lookup table **116** as described in the example of FIGS. **1-8**, the following examples are considered.

[0042] In one example, during conditions where there is no requirement for all of the parallel motor-pumps to remain powered simultaneously (e.g., steady cruise in an aircraft hydraulic system), the power packs can be individually powered and calibrated (e.g., only one motor-pump is powered at a time) using the common pressure sensor **814** illustrated in FIG. **8** after the power pack output filter **816**.

[0043] In another example, during conditions where a total flow rate demanded by the hydraulic consumers **828** is less than the maximum flow capacity of a single pump, the remaining pumps can be commanded to operate at reduced pressure (e.g., 1500 psi). In this case, the pump(s) set to operate at lower pressure will have their output flow blocked by the outlet check valve (**822**, **824**) and will not contribute to the system flow. The pump operating at full pressure may be calibrated using the methodology described above in reference to FIGS. **1-7** to adjust the speed versus measured current lookup table **116** to maintain system pressure. The remaining pumps can then be sequenced individually to full pressure (while all others are set to low pressure) using the single pressure sensor **814** to calibrate the modifiable lookup table **116**. This method can be used for calibration any time the power-pack system **800** is operational and the calibration mode can be aborted immediately if a system flow demand is detected by reduced power pack output pressure in combination with the full pressure pump operating at or near its maximum speed or above a predetermined threshold (25% speed for instance). Health monitoring **826** and prognostics described above may also be used to monitor the performance of the individual motor-pumps over time.

[0044] Similar to the calibration mode described above, it is possible to reduce the power consumed by a dual motor-pump power pack by reducing the pressure of one of the pumps to a low pressure setting (e.g., 1500 psi), the alternate pump will maintain the required system pressure (e.g., 3000 psi) and hold the reduced pressure pump check valve closed. If a high flow demand is detected by a low pressure in combination with the primary pump reaching maximum speed or a speed above a predetermined threshold (e.g., 90% speed), the lower

pressure pump will immediately exit power savings mode and provide supplemental flow to the system at the rated system pressure (e.g., 3000 psi).

[0045] It may be desirable to add a communication link between the motor-pump sub-controllers (818, 820) to reduce the individual motor-pump power/energy extraction, to minimize wear and tear and/or to minimize the audible noise generated by the power pack system 800. For example, if a dual motor-pump power pack is used and it is determined that one of the motor-pumps will operate in the low pressure power savings mode for most of the system life, an additional monitoring and control function may be used to track the motor-pump usage (e.g., time at torque/speed for the individual motors) and balance the power savings mode between the two units. One such method is to always opt to operate the motor-pump with the highest damage ratio (calculated as integral of input electrical power over the operating time) in power savings mode. This will balance the wear and tear between the two motor-pumps (802, 804, 806, 808) and maximize system life.

[0046] A communication linkage between sub-controller 1 (818) and sub controller 2 (820) may also be used to prevent the individual motor-pumps from operating at maximum speed (or minimize the time operating at or near maximum speed) by balancing the loads between the two motors (802, 806). For example, if a large hydraulic consumer 828 flow is demanded, the typical control will cause one motor-pump to ramp-up to near full speed while the other, potentially in a lower pressure power savings mode, will continue to operate at a near zero speed. Alternatively, a system monitoring and control function may be used to command the two pumps (804, 808) to equal speeds, whereby each pump will output half of the system flow demand by operating at one-half its rated speed. This has the advantage of reducing the typical wear and tear on the otherwise high speed motor-pump as well as reducing the audible noise levels. To balance the power savings with the reduced speed objective, a speed threshold may be used on the primary pump to determine when the second pump should be powered to supplement the system flow. For example, the second motor-pump may be commanded out of low pressure power savings mode if the primary motor-pump speed exceeds 25% of its rated value.

[0047] Additionally, temperature sensors (830, 832) on the motor-pumps can be used by a monitoring and control function to adjust which motor-pump is providing system flow based on the individual motor temperatures. This can potentially be used to permit safe operation of the power pack if the usage, duty cycle, or failure of one of the motor-pumps causes one of the motor-pumps to overheat. In this case, the overheating motor-pump will be commanded into a lower power state (or off depending on the severity of the overheat condition) and the other (in a dual motor-pump arrangement) will be commanded into full pressure mode.

[0048] FIG. 9 is a flowchart for illustrating an example method for recalibrating 118 a modifiable lookup 116 table according to an example of the disclosure. The method 900 can be implemented by systems 200 in FIG. 2. The operations described and shown in the method 900 of FIG. 9 may be carried out or performed in any suitable order as desired in various examples of the disclosure. Additionally, in certain examples, at least a portion of the operations may be carried out in parallel. The method 900 can start in Block 905; the method can include receiving sensed performance data from a sensor. In Block 910, the method can include retrieving

initial performance data related to the fluid pump and the electric motor from a memory module. In Block 915, the method can include storing the sensed performance data and the initial performance data in a modified lookup table. In Block 920, the method can include in response to a sensed measurement from the pressure sensor, comparing the sensed performance data and the initial performance data to determine a correlation between the sensed performance data, the initial performance data and the desired system pressure. In Block 925, the method can include generating an updated version of the modifiable lookup table. In certain examples, the update to the modified lookup table will only occur when deviations between the desired and the sensed pressure exceed a predetermined threshold. In Block 930, the method can include using the updated version of the modifiable lookup table to send a motor current command signal to the controller.

[0049] FIG. 10 is a flowchart for illustrating an example method for determining an operating functionality of the pressure sensor. The method 1000 can be implemented using a multi pump system, such as 800 in FIG. 8. The operations described and shown in the method 1000 of FIG. 10 may be carried out or performed in any suitable order as desired in various examples of the disclosure. The method can start in Block 1005, the method can include sensing a first pressure measurement while a first individual pump in the plurality of pumps produces flow output and the remainder pumps in the plurality of pumps have no flow output. In an example, the first individual pump can be the only pump that is powered to produce flow for the system, while the remaining pumps in the system are unpowered. In another example, the first individual pump can operate at the desired pressure of the system and the remaining pumps in this system are powered but operated a lower pressure such that the flow from the remaining pumps is inhibited by check valves. Block 1005 is followed by Decision Block 1010. At Decision Block 1010, a determination is made whether the first system pressure from the pressure sensor is an anomaly. An anomaly can be a predefined variation from a threshold. If it is determined that the first pressure measurement is an anomaly, then the YES branch is followed and the method 1000 continues to Block 1020. At Block 1020, a second pressure measurement is sensed, while a second individual pump in the plurality of pumps produces the output flow and the first individual pump is no longer producing flow. Referring back to Decision Block 1010, if it is determined that the first pressure measurement is not at anomaly, then the NO branch is followed and the method 1000 continues to Block 1015 where no responsive action is required for the first pump.

[0050] Method 1000 proceeds to Decision Block 1025 from Block 1020 and a determination is made whether the second pressure measurement is an anomaly. If it is determined that the second sensed pressure is an anomaly, then the YES branch is followed and the method continues to block 1035. At Block 1035, a responsive action may be required to address the pressure sensor. Referring back to Decision Block 1025, if it is determined that the second pressure measurement is not an anomaly, then the NO branch is followed and the method 1000 continues to Block 1030 where a responsive action may be required for the first pump. In addition, method 1000 can be applied to a fluid device system where there are more than two pumps, where active pump operational status can be rotated through each pump in the plurality to determine

the operational efficiency of each pump, as well as determine the operation of the pressure sensor.

[0051] Accordingly, blocks of the block diagrams and flow diagrams support combinations of means for performing the specified functions, combinations of elements or steps for performing the specified functions and program instruction means for performing the specified functions. It will also be understood that each block of the block diagrams and flow diagrams, and combinations of blocks in the block diagrams and flow diagrams, can be implemented by special purpose, hardware-based computer systems that perform the specified functions, elements or steps, or combinations of special purpose hardware and computer instructions.

[0052] While the disclosure has been described in connection with what is presently considered to be the most practical of various examples, it is to be understood that the disclosure is not to be limited to the disclosed examples, but on the contrary, is intended to cover various modifications and equivalent arrangements included within the spirit and scope of the appended claims.

[0053] Various modifications and alterations of this disclosure will become apparent to those skilled in the art without departing from the scope and spirit of this disclosure, and it should be understood that the scope of this disclosure is not to be unduly limited to the illustrative examples set forth herein.

What is claimed is:

1. A fluid system comprising:
 - a fluid pump having an output;
 - an electric motor coupled to the fluid pump, the electric motor being adapted to operate the fluid pump in response to an electrical signal;
 - a controller adapted to communicate the electrical signal to the electric motor, the controller including an initial lookup table having initial performance data related to the fluid pump and the electric motor, wherein the initial performance data from the initial lookup table and sensed performance data applied to a modifiable lookup table are used by the controller to set aspects of the electrical signal communicated to the electric motor to achieve a desired system pressure generated by the fluid pump; and
 - a pressure sensor in communication with the output that is adapted to communicate a sensed system pressure to the controller, the controller being adapted to update the modifiable lookup table based on a difference between the desired system pressure and the sensed system pressure to minimize variation between the sensed system pressure and the desired system pressure.
2. The fluid system of claim 1, wherein the initial lookup table establishes a relationship between motor current, motor speed, and the desired system pressure.
3. The fluid system of claim 1, further comprising a motor speed sensor for communicating a sensed motor speed to the controller, wherein the electrical signal includes a motor current command, and wherein the controller determines a value of the motor current command for achieving the desired system pressure.
4. The fluid system of claim 1, further comprising a temperature sensor for sensing a hydraulic fluid temperature of hydraulic fluid passing through the fluid pump, wherein the controller includes a plurality of initial lookup tables and plurality of modifiable lookup tables corresponding to different hydraulic fluid temperatures, and wherein the controller selects an appropriate modifiable lookup table from the plu-

ality of updatable lookup tables based on the hydraulic fluid temperature sensed by the temperature sensor.

5. The fluid system of claim 4, wherein the controller is configured to monitor the sensed motor speed over time to determine whether an acceleration condition exists, and wherein the controller is configured to modify the motor current command when the acceleration condition exists.

6. The fluid system of claim 5, wherein the controller adjusts a magnitude of the motor current command based on a calculation to maintain the desired system pressure when the acceleration condition is detected.

7. The fluid system of claim 1, further comprising a current sensor for sensing a sensed current provided to the motor, wherein the controller is configured to compare the sensed current with a desired current corresponding to a value of the motor current command, wherein the comparison between the sensed current and the desired current results in a motor control signal, and wherein the controller modifies the motor control signal to compensate for variations between the sensed current and the desired current.

8. The fluid system of claim 1, wherein initial data corresponding to the initial lookup table is stored in a memory module of the controller.

9. The fluid system of claim 1, wherein a recalibration routine is used to update the modifiable lookup table based on the sensed system pressure sensed while the fluid system is operating at steady state.

10. The fluid system of claim 1, wherein the controller is configured to perform a recalibration routine to update the modifiable table, wherein the recalibration routine comprises:

- receiving sensed performance data from a sensor;
- retrieving initial performance data related to the fluid pump and the electric motor from the initial lookup table;
- storing the sensed performance data and the initial performance data in the modified lookup table;
- in response to a sensed measurement from the pressure sensor, comparing the sensed performance data and the initial performance data to determine a correlation between the sensed performance data, the initial performance data and the desired system pressure;
- generating an updated version of the modifiable lookup table; and
- using the updated version of the modifiable lookup table to send a motor current command signal to the controller.

11. The fluid system of claim 10, wherein determining a correlation between the sensed performance data, the initial performance data, and the desired system pressure comprises calculating a least squares error of an operating point between sensed performance data and the initial performance data.

12. The fluid system of claim 11, wherein generating an updated version of the modifiable lookup table is based on maintaining the desired system pressure.

13. The fluid system of claim 12, wherein generating an updated version of the modifiable lookup table further comprises reducing the least squares error of the operating point between the sensed performance data and the initial performance data.

14. The fluid system of claim 11, wherein the controller is further configured to determine remaining life of a component of the fluid system, wherein determining the remaining life comprises comparing the correlation between the sensed performance data and the initial performance data to at least one threshold over a time period.

15. The fluid system of claim **1**, wherein the fluid pump is one of a plurality of fluid pumps, wherein each one of the plurality of fluid pumps is coupled to a motor, wherein the fluid system includes a junction location for combining fluid output flow from the fluid pumps, and wherein the pressure sensor is positioned at or downstream of the junction location and wherein each motor is controlled by the controller.

16. The fluid system of claim **15**, wherein the controller is further configured with a plurality sub-controllers to individually control each electric motor and wherein the controller establishes a communication link between the plurality of sub-controllers.

17. The fluid system of claim **15**, wherein check valves are positioned between each pump in the plurality of pumps and the junction location.

18. The fluid system of claim **15**, wherein the controller operates an individual pump or a combination of fluid pumps depending upon a demand placed on the fluid system.

19. The fluid system of claim **17**, wherein the fluid pump is one of a plurality of fluid pumps incorporated into a power pack controlled by the controller, wherein the power pack includes a power pack outlet that receives a total flow provided by the fluid pumps.

20. The fluid system of claim **19**, wherein check valves are provided between the fluid pumps and the power pack outlet, wherein the total flow passes through a power pack outlet filter, and wherein the pressure sensor is positioned downstream from the power pack outlet filter.

21. The fluid system of claim **15**, wherein the controller is configured to recalibrate the modifiable lookup table of an individual pump in the plurality of pumps, wherein the individual pump is powered during the fluid system operation with remaining pumps in the plurality of pumps unpowered.

22. The fluid system of claim **21**, wherein the controller is configured to recalibrate the modifiable lookup table of the individual pump in the plurality of pumps, wherein the individual pump that is powered is alternated.

23. The fluid system of claim **20**, wherein the controller is configured to recalibrate the modifiable lookup table of the individual pump in the plurality of pumps, wherein the individual pump in the plurality of pumps is operated at a desired system pressure and remaining pumps in the plurality of pumps are operated at a pressure lower than the desired system pressure, wherein output of the remaining pumps is blocked by the attached check valves.

24. The fluid system of claim **23**, wherein the controller is configured to recalibrate the modifiable lookup table of the individual pump in the plurality of pumps, wherein the individual pump that operates at the desired system pressure is alternated.

25. The fluid system of claim **10**, wherein the controller is configured to monitor the correlation, wherein when the correlation exceeds the threshold, a responsive action is triggered, wherein the responsive action comprises the fluid system reverting to operate based on initial performance data from an initial lookup table.

26. The fluid system of claim **15**, wherein the controller is configured to determine the pressure sensor functionality, wherein determine the pressure sensor functionality comprises:

sensing a first pressure measurement while a first individual pump in the plurality of pumps is producing an output flow and remainder pumps in the plurality of pumps are not producing a flow output;

determining whether the first pressure measurement is an anomaly based on a predetermined threshold for system pressure;

in response to determining that the first pressure measurement is an anomaly, sensing a second pressure measurement wherein the second pressure measurement is based on alternating the first individual pump to a no flow output state and producing the flow output from a second individual pump from the remainder pumps; and

determining whether the second pressure measurement is an anomaly based on the predetermined threshold for system pressure.

27. The fluid system of claim **26**, wherein the controller is configured to determine the pressure sensor functionality, wherein determine the pressure sensor functionality further comprises, in response to determining that the second pressure measurement is an anomaly, performing a responsive action on the pressure sensor.

28. The fluid system of claim **26**, wherein the controller is configured to determine the pressure sensor functionality, wherein determine the pressure sensor functionality further comprises, in response to determining that the second pressure measurement is not an anomaly, performing a responsive action on the first individual pump.

29. The fluid system of claim **4**, wherein determine whether an acceleration condition exists comprises sensing at least one of: a change flow demand in the system and a decrease in pressure in the system.

30. The fluid system of claim **1**, wherein the controller samples the measured pressure from the pressure sensor at a rate greater than 1 hertz.

31. The fluid system of claim **1**, wherein the aspects of the electrical signal are voltage, phase current, phase angle, or combinations thereof.

32. The fluid system of claim **1**, wherein the electric motor is a brushless DC motor and the fluid pump is an axial piston type pump.

33. The fluid system of claim **1**, wherein the fluid pump is a fixed displacement pump.

34. The fluid system in claim **1**, wherein the electric motor is a brushless DC motor and the fluid pump is a radial piston type pump.

35. A fluid system comprising:

a fluid pump having an output;

an electric motor coupled to the fluid pump, the electric motor being adapted to operate the fluid pump in response to an electrical signal;

a controller adapted to communicate the electrical signal to the electric motor, the controller including a lookup table having performance data related to the fluid pump and the electric motor, wherein the performance data from the lookup table is used by the controller to set aspects of the electrical signal communicated to the electric motor to achieve a desired system pressure generated by the fluid pump; and

a pressure sensor in communication with the output that is adapted to communicate a sensed system pressure to the controller, the controller being adapted to update the lookup table based on a difference between the desired system pressure and the sensed system pressure to minimize variation between the sensed system pressure and the desired system pressure.

36. The fluid system of claim **35**, wherein the lookup table establishes a relationship between motor current, motor speed, and the desired system pressure.

37. The fluid system of claim **36**, further comprising a motor speed sensor for communicating a sensed motor speed to the controller, wherein the electrical signal includes a motor current command, and wherein the controller determines a value of the motor current command for achieving the desired system pressure from the lookup table based on the sensed motor speed.

38. The fluid system of claim **35**, wherein the lookup table is updated based on sensed system pressure sensed while the fluid system is operating at steady state and the lookup table is not updated based on sensed system pressure sensed while system is operating in a transitory state.

39. A fluid system comprising:

a fluid pump having an output;

an electric motor coupled to the fluid pump, the electric motor being adapted to operate the pump in response to an electrical signal;

a controller adapted to communicate the electrical signal to the electric motor, the controller including a lookup table having performance data related to the fluid pump and the electric motor, wherein the performance data from the lookup table is used by the controller to set

aspects of the electrical signal communicated to the electric motor in order to achieve a desired attribute of the fluid pump; and

a pressure sensor in communication with the output is adapted to communicate a sensed pressure to the controller, the controller adapted to create a modified lookup table to minimize variation in the output.

40. A fluid system comprising:

at least two fluid pumps, each pump having an output;

an electric motor coupled to each fluid pump, the electric motor being adapted to operate the pump in response to an electrical signal;

at least one controller adapted to communicate the electrical signal to the electric motor, the controller including a lookup table having performance data related to the fluid pumps and the electric motors, wherein the performance data from the lookup table is used by the controller to set aspects of the electrical signal communicated to each electric motor in order to achieve a desired attribute of the fluid pumps; and

a pressure sensor in communication with the outputs is adapted to communicate a sensed pressure to the controller, the controller adapted to create a modified lookup table to minimize variation in the outputs.

* * * * *