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CONTROL SYSTEM FOR A FLUID MANAGEMENT SYSTEM

Abstract

A control system includes: a controller configured to: access an estimated torque and estimated speed of a motor mechanically coupled to an impeller of a centrifugal machine; access at least one set of pre-determined performance data values associated with a known speed of the impeller, where each set of pre-determined performance data values includes: a plurality of flowrate values and a plurality of performance metric values; determine an operating point of the centrifugal machine based on the estimated torque, the estimated speed, and the at least one set of pre-determined performance data values; compare the determined operating point to a best efficiency point (BEP) associated with the centrifugal machine; and determine whether to change the speed of the motor based on the comparison.

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Background/Summary

CROSS-REFERENCE TO RELATED APPLICATIONS [0001] This application is a divisional of U.S. patent application Ser. No. 17/380,531, filed Jul. 20, 2021 and titled CONTROL SYSTEM FOR A FLUID MANAGEMENT SYSTEM, which claims the benefit of U.S. Provisional Application No. 63/056,026, filed on Jul. 24, 2020 and titled CONTROL SYSTEM FOR A FLUID MANAGEMENT SYSTEM. Each of these applications is incorporated herein by reference in its entirety.

TECHNICAL FIELD
[0002] This disclosure relates to a control system for a fluid management system.
BACKGROUND
[0003] An electric motor converts electrical energy into mechanical energy that is provided to an impeller of a centrifugal machine. The centrifugal machine may be part of a fluid management system.
SUMMARY
[0004] In one aspect, a control system includes: a controller configured to: access an estimated torque and estimated speed of a motor mechanically coupled to an impeller of a centrifugal machine; access at least one set of pre-determined performance data values associated with a known speed of the impeller, where each set of pre-determined performance data values includes: a plurality of flowrate values and a plurality of performance metric values; determine an operating point of the centrifugal machine based on the estimated torque, the estimated speed, and the at least one set of pre-determined performance data values; compare the determined operating point to a best efficiency point (BEP) associated with the centrifugal machine; and determine whether to change the speed of the motor based on the comparison.
[0005] Implementations may include one or more of the following features. The controller may be configured to access a plurality of sets of pre-determined data values associated with the centrifugal machine, and, in these implementations, each one of the plurality of sets may be associated with a different known speed of the impeller, and the performance metric values may include head values and efficiency values. The controller may be further configured to compare the estimated speed of the motor to the known speed of the impeller; and if the estimated speed of the motor and the known speed are similar to within a speed threshold, the controller may determine a machine power characteristic based on the pre-determined head values and the pre-determined efficiency values; and if the estimated speed of the motor and the known speed are not similar to within the speed threshold, the controller may determine an updated set of head values, and an updated set of efficiency values; and the controller may determine the machine power characteristic based on the updated set of head values and the updated set of efficiency values. The controller also may be further configured to determine a power value on the machine power characteristic that corresponds to the estimated torque and to determine a flowrate operating point, the flowrate operating point being the flowrate value that corresponds to the determined power value. To determine the operating point of the centrifugal machine, the controller may be configured to determine an efficiency operating point and a head operating point based on the flowrate operating point. To compare the determined operating point to the best efficiency point (BEP), the controller may be configured to compare the determined efficiency operating point to the best efficiency point (BEP). If the controller changes the speed of the motor, after changing the speed of the motor, the

controller may be further configured to: to determine an updated set of head values at the flowrate values and an updated set of efficiency values at the flowrate values; and update the machine power characteristic based on the updated set of head values and the updated set of efficiency values.
[0006] The controller may change the speed of the motor to thereby change a flowrate of a fluid that is moved by the impeller, and the controller also may be further configured to determine the efficiency operating point again after changing the speed of the motor.
[0007] In another aspect, a control system for a pump system includes a controller configured to:
[0008] determine whether a current operating point of the pump system is in a bounded operating region, where the current operating point includes a current value of a flowrate of fluid moved by the pump system and a current value of a performance metric; and the bounded operating region is defined by a minimum value of the flowrate, a maximum value of the flowrate, a minimum value of the performance metric, and a maximum value of the performance metric; and if the current operating point is not in the bounded operating region, the controller is configured to adjust a parameter of a motor that is mechanically coupled to the pump system to thereby change the current operating point until the current operating point is in the bounded operating region.
[0009] Implementations may include one or more of the following features. The controller may be configured to compare the current value of the flowrate of the fluid moved by the pump system to a best efficiency point flowrate associated with the pump system before determining whether the current operating point is in the bounded operating region; if the the current flowrate is less than the best efficiency point flowrate, the controller may increase a speed of the motor before determining whether the current operating point is in the bounded operating region; and if the current flowrate is greater than the best efficiency point flowrate, the controller may decrease the speed of the motor before determining whether the current operating point is in the bounded operating region. The parameter of the motor may include the speed of the motor; and if the current operating point is not within the bounded operating region and the current flowrate is less than the best efficiency point flowrate, the controller may decrease the speed of the motor until the current operating point is in the bounded operating region; and if the current operating point is not within the bounded operating region and the current flowrate is greater than the best efficiency point flowrate, the controller may increases the speed of the motor until the current operating point is in the bounded operating region.
[0010] The control system may also be configured to determine whether the current value of the performance metric is acceptable. The performance metric may include an operating efficiency, and to determine whether the current value of the operating efficiency is acceptable, the controller may be configured to compare the current value of the operating efficiency to a best efficiency point. The current value of the operating efficiency may be considered to be acceptable if a difference between the current value of the operating efficiency and the best efficiency point is less than an efficiency threshold. The performance metric may be a flowrate or an operating head.
[0011] In some implementations, one or more of the minimum flowrate, the maximum flow rate, the minimum value of the performance metric, and the maximum value of the performance metric are set by an operator of the pump system.
[0012] In another aspect, a set point value for a flowrate of fluid moved by a centrifugal machine is accessed; a duration of a first time period and a duration of a second time period are determined based on the set point value for the flowrate and a best efficiency point flowrate for the centrifugal machine; the centrifugal machine is controlled to operate at the best efficiency point flowrate for the duration of the first time period; and the centrifugal machine is controlled to operate at zero flowrate for the duration of the second time period. The duration of the first time period and the duration of the second time period are such that the average flowrate of the fluid over the first and second time periods is the set point value of the flowrate.
[0013] Implementations may include one or more of the following features. The first time period may be immediately before the second time period. The set point value for the flowrate may be

received from an operator of the centrifugal machine. The centrifugal machine may be controlled by controlling a motor controlling apparatus that provides a motor power signal to a motor that is mechanically coupled to an impeller of the centrifugal machine.
[0014] Implementations of any of the techniques described herein may include an apparatus, a device, a controller, a control system, a fluid management system, and/or a method. The details of one or more implementations are set forth in the accompanying drawings and the description below. Other features will be apparent from the description and drawings, and from the claims.

Description

DRAWING DESCRIPTION
[0015] FIG. **1** is a block diagram of an example of a fluid management system.
[0016] FIG. **2** is a block diagram of an example of a centrifugal machine.
[0017] FIG. **3** is a block diagram of another example of a fluid management system.
[0018] FIGS. **4** and **5** are flowcharts of example processes.
[0019] FIG. **6** is an example of a P-Q curve.
[0020] FIG. **7** is an example of an efficiency curve.
[0021] FIG. **8** is an example of a performance characteristic curve for a centrifugal machine.
[0022] FIGS. **9** and **10** are flowcharts of other example processes.
[0023] FIGS. **11-14** are illustrations of other examples of performance characteristic curves for a centrifugal machine.
[0024] FIG. **15** is a flowchart of another example process.
[0025] FIG. **16** is an example of a plot of speed of an impeller as a function of time.
[0026] FIG. **17** is an example of a plot of flowrate of a centrifugal machine as a function of time.
DETAILED DESCRIPTION
[0027] Referring to FIG. **1**, a block diagram of a fluid management system **100** is shown. The fluid management system **100** may be, for example, a pumping system. The fluid management system **100** includes a centrifugal machine **120** that is used to move fluid in a process **170**. The process **170** may be, for example, an industrial, commercial process, or a residential process. The process **170** may be a chilling system; a heating, ventilation, and cooling (HVAC) system; a wastewater or waste fluid processing system; a chemical processing system; or a filtration system, just to name a few.
[0028] The fluid management system **100** includes a controller **150**. As discussed below, the controller **150** determines the operating point of the centrifugal machine **120** without relying on sensors (such as flow meters and pressure sensors). Moreover, the controller **150** determines the operating point using pre-determined performance data **151**, which is determined prior to the machine **120** being deployed into the system, and without performing a characterization of the centrifugal machine **120** after the centrifugal machine **120** has been deployed into the system **100**. The controller **150** also enables more efficient operation of the centrifugal machine **120**.
[0029] The centrifugal machine **120** is driven by a motor **140**. The motor **140** may be a direct current (DC) motor or an alternating current (AC) motor. For example, the motor **140** may be a brushless DC motor, a permanent magnet AC motor, or an AC induction motor, just to name a few. The motor **140** may be a single-phase motor or a multi-phase motor. Although FIG. **1** shows one motor, the fluid management system **100** may include more than one motor. The fluid management system **100** also includes a motor controlling apparatus **110**, which provides a motor power signal **141** to the motor **140**. The motor controlling apparatus **110** is any type of apparatus configured to drive the motor **140**. For example, the motor controlling apparatus **110** may be a variable frequency drive (VDF) or an adjustable speed drive (ASD).
[0030] The motor power signal **141** is an AC electrical signal that has a voltage (V) and current (i)

sufficient to drive the motor **140**. In implementations in which the motor **140** is a multi-phase motor, the motor power signal **141** is a multi-phase A C electrical signal. The motor **140** includes a stator **148** and a rotor **149**. The stator **148** includes one winding per phase. The rotor **149** rotates relative to the stator **148** in response to receiving the motor power signal **141**. The direction and speed of the rotor **149** are determined by the characteristics (amplitude, frequency, and/or phase) of the motor power signal **141**.

[0031] The centrifugal machine **120** is any type of centrifugal machine. For example, the centrifugal machine **120** may be a pump, a blower, or a compressor. Referring also to FIG. **2**, the centrifugal machine **120** includes a body **121**, an inlet **123** though which fluid flows into the body **121**, an outlet **124** through which fluid flows out of the body **121**, and an impeller **122**. The impeller **122** is coupled to the rotor **149** via a linkage **126**. The linkage **126** is any type of connection capable of transferring the mechanical energy generated by the motor **140** to the impeller **122**. For example, the linkage **126** may include a rod, gears, a shaft, or a combination of such devices. The rotation of the impeller **122** imparts rotational energy to the fluid in the body **121** and transports the fluid in the body **121** between the inlet **123** and the outlet **124**.

[0032] The centrifugal machine **120** is associated with performance metrics, including head (H) and efficiency. The efficiency of the centrifugal machine **120** is the relationship between the input horsepower (which is the input torque multiplied by the rotational speed of the impeller **122**) and the flowrate (Q). The head (H) of the machine **120** is the amount of pressure P required to achieve a given flowrate (Q) at the outlet **124**. The flowrate (Q) has units of volume over time, for example, cubic meters per second. The head (H) has units of pressure, for example, pounds per square inch or Pascals. The rotational speed or speed of the impeller **122** is expressed as rotations per unit of time. The relationship between head (H) and flowrate (Q) is referred to as the H-Q curve. The centrifugal machine **120** is also associated with a system head (Hsys), which is the opposition to the flow that is created by increasing the head (H). The system head (Hsys) accounts for the configuration and components used with the centrifugal machine **120** (such as piping or other types of transfer systems that convey fluid between the outlet **124** and the process **170**). The system head (Hsys) curve intersects the H-Q curve at the operation points of the centrifugal machine **120**.

[0033] The centrifugal machine **120** is associated with the pre-determined performance data **151**. The pre-determined performance data **151** is provided by the manufacturer of the centrifugal machine **120** and is collected before the centrifugal machine **120** is placed into service in the fluid management system **100**.

[0034] FIGS. **4**, **5**, **9**, **10**, and **15** show flow charts of processes for determining the operating point of the centrifugal machine **120** during use and/or controlling the operation of the centrifugal machine **120**. Prior to discussing these techniques, an overview of an example implementation of the motor controlling apparatus **110** and the controller **150** is discussed with respect to FIG. **3**.

[0035] FIG. **3** is a block diagram of a fluid management system **300** that includes a controller **350**. The controller **350** is an implementation of the controller **150** (FIG. **1**). The fluid management system **300** includes a motor controlling apparatus **310** that is coupled to the motor **140** via an electrical connection such as, for example, an electrical cable. The motor controlling apparatus **310** may be, for example, a variable speed drive (VSD), an adjustable speed drive (ASD), or a variable frequency drive (VFD). The motor controlling apparatus **310** provides a motor power signal **341** to the motor **140**. The motor **140** drives the centrifugal machine **120**.

[0036] The motor controlling apparatus **310** receives A C electrical power from an electrical power distribution network **301**, which may be, for example, a multi-phase electrical power grid that provides electricity to industrial, commercial, and/or residential customers. The A C electrical power distribution network **301** distributes A C electrical power that has a fundamental frequency of, for example, 50 or 60 Hertz (Hz). The distribution network **101** may have an operating three-phase line-to-line voltage of, for example, up to 690 volt (V) root mean square (RMS) for low voltage, and above 690V (for example, 10 kV) for medium or high voltage. The network **301** may include, for example, one or more transmission lines, distribution lines, power distribution or substation transformers, electrical cables, and/or any other mechanism for transmitting electricity.

[0037] The motor controlling apparatus **310** includes an electrical network **312** that receives A C electrical power **305** from the distribution network **301** at an input node **314**. The motor controlling apparatus **310** is enclosed in a housing or enclosure **311**. The housing **311** is a three-dimensional body made of a solid and rugged material that protects the electrical network **312**. The motor controlling apparatus **310** also includes an output node **309**. The motor **140** connects to the motor controlling apparatus **310** at the output node **309**.

[0038] The electrical network **312** generates the AC motor power signal **341** based on the A C electrical power **305** from the distribution network **301**. The electrical network **312** includes a converter **360** and an inverter **380**. The converter **360** includes an electrical network **362** configured to convert the A C electrical power **305** into direct current (DC) electrical power **313**. The converter **360** may be, for example, an active front end (AFE) or pulse width modulation (PWM) rectifier, or an 18-pulse rectifier. The electrical network **362** includes electronic components such as diodes arranged to form a rectifier or in any other configuration that allows the AC electrical power **305** to be converted into the DC electrical power **313**.

[0039] The inverter **380** includes an electrical network **382** configured to convert the DC electrical power **313** into the AC motor power signal **341**. The electrical network **382** may include power transistors or other controllable switching devices. For example, the electrical network **382** may include three half-bridge circuits that each include two switching elements (such as, for example, power transistors) connected in series. Each pair of switching elements receives a direct-current (DC) voltage from a DC power source (for example, a battery, DC power supply, or other source of DC power). In these implementations, the inverter **380** generates a three-phase pulse width modulated (PWM) signal by applying signals based on a command signal to each pair of switching elements. The characteristics (amplitude, frequency, and phase) of the three-phase PWM motor power signal **341** is determined by controlling the switching operations of the half-bridge circuits. The PWM technique may be implemented based on any type of control algorithm, such as, for example, a 6-step electronic commutation, various field oriented controls, a space vector PWM, or a sinusoidal PWM.

[0040] The controller **350** is coupled to the motor controlling apparatus **310** via a control link **377**. The control link **377** is any type of pathway that is capable of carrying data, information, and/or commands. For example, the control link **377** may be an electrical cable, copper traces on a printed circuit board, or a wireless data connection. The controller **350** includes an electronic processing module **352**, an electronic storage **354**, and an I/O interface **356**. In some implementations, the electronic processing module **352**, the electronic storage **354**, and the I/O interface **356** are implemented as a microcontroller. Moreover, although the controller **350** is shown as being outside of the housing **311**, the controller **350** may be enclosed in the housing **311**.

[0041] The electronic processing module **352** includes one or more electronic processors. The electronic processors of the module **352** may be any type of electronic processor, may be multiple types of processors, and may or may not include a general purpose central processing unit (CPU), a graphics processing unit (GPU), a microcontroller, a field-programmable gate array (FPGA), Complex Programmable Logic Device (CPLD), a digital signal processor (DSP), a microcontroller unit (MCU) and/or an application-specific integrated circuit (A SIC).

[0042] The electronic storage **354** is any type of electronic memory that is capable of storing data and instructions in the form of computer programs or software, and may include multiple types of memory. For example, the electronic storage **354** may include volatile and/or non-volatile components. The electronic storage **354** and the processing module **352** are coupled such that the processing module **352** is able to read data from and write data to the electronic storage **354**.

[0043] The processes **400**, **500**, **900**, **1000**, and **1500** may be implemented as a collection of instructions that are stored on the electronic storage **354** and executed by the electronic processing

module **352**. Additionally, the PWM technique or other control technique to drive the electronic network **382** of the inverter **380** may be implemented as a collection of executable instructions or computer software that is stored on the electronic storage **354**.
[0044] Furthermore, the pre-determined performance data **151** may be stored on the electronic storage **354**. The pre-determined performance data **151** includes N data values of the head (H), where N is any integer number that is greater than two, and each of the N data values corresponds to a flowrate at the outlet **124** for a particular rotational speed of the impeller **122**. For example, if N is 5, the pre-determined performance data **151** includes five (5) values of the head (H), with each of the five values of the head (H) being for a different flowrate at a particular rotational speed of the impeller **122**. The pre-determined performance data **151** also includes efficiency values for the machine **120**. The efficiency values provide a relationship between efficiency and flowrate. The efficiency values also include a best efficiency point (BEP), which is the greatest efficiency at which the machine **120** is capable of operating. The BEP may be expressed as a percentage between 0% and 100% or as a value between 0 and 1.
[0045] The pre-determined performance data **151** may include M sets of pre-determined data, with each of the M sets being associated with a different speed of the impeller **122** and where M is an integer value that is greater than 1. For example, the pre-determined performance data **151** may include N pairs of head (H), flowrate (Q) values at each of M different speeds of the impeller **122**. The M speeds that are part of the pre-determined performance data **151** are referred to as the M pre-determined impeller **122** speeds. Each of the M different speeds of the impeller **122** is associated with a BEP flowrate (Q_BEP). The BEP flowrate for a particular impeller **122** speed is the flowrate at which the centrifugal machine **120** is the most efficient. The BEP flowrate (Q_BEP) varies with impeller **122** speed.
[0046] The pre-determined performance data **151** may be stored as a collection of discrete values. For example, the pre-determined performance data **151** may be a collection of M sets of N pairs of data values in which each pair includes a value of a metric (for example, head (H) or efficiency) paired with an associated value of flowrate (Q). The pre-determined performance data **151** may be stored in a lookup table or a database. In some implementations, the pre-determined performance data **151** is alternatively or additionally stored in the form of an equation that relates one of the metrics (for example, head (H) or efficiency) to flowrate (Q).
[0047] The I/O interface **356** is any interface that allows a human operator, an external device, and/or an autonomous process to interact with the controller **350**. The I/O interface **356** may include, for example, audio input and/or output (such as speakers and/or a microphone), visual output (such as lights, light emitting diodes (LED)), serial or parallel port, a Universal Serial Bus (USB) connection, and/or any type of network interface, such as, for example, Ethernet. The I/O interface **356** also may allow communication without physical contact through, for example, an IEEE 802.11, Bluetooth, cellular, or a near-field communication (NFC) connection. The controller **350** may be, for example, operated, configured, modified, or updated through the I/O interface **356**.
[0048] In some implementations, the I/O interface **356** enables the controller **350** to communicate with a remote station **395**. The remote station **395** may be any type of station through which an operator is able to communicate with the controller **350** without making physical contact with the controller **350**. For example, the remote station **395** may be a computer-based work station, a smart phone, tablet, or a laptop computer that connects to the controller **350** via a services protocol, or a remote control that connects to the controller **350** via a radio-frequency signal.
[0049] FIG. **4** is a flowchart of a process **400**. The process **400** is an example of a process for determining the operating point of the centrifugal machine **120**. The process **400** may be performed by the controller **150** or the controller **350**. For example, machine-readable instructions to implement the process **400** may be stored on the electronic storage **374** and executed by the electronic processing module **372**. The process **400** is discussed with respect to the fluid management system **300**; however, the process **400** may be applied to other fluid management

systems.

[0050] Information related to the motor **140** is accessed (**410**). The accessed information includes a speed of the motor **140** (a rotational speed of the rotor **149**) and a torque produced by the motor **140** while the motor **140** is operational and is receiving the motor power signal **341**. The speed of the motor **140** and the torque produced by the motor **140** may be obtained in any manner known in the art.

[0051] In some implementations, the speed of the motor **140** and the torque produced by the motor **140** are estimated from the motor power signal **341** without using speed or torque sensors. For example, the speed of the motor **140** and the torque of the motor **140** may be estimated based on the value or amplitude of the voltage of the motor power signal **341**, the frequency of the voltage and/or current of the motor power signal **341**, the load value of the motor **140** (which may be sensed directly by a power sensor or approximated to be equal to the input power), and on the nameplate data associated with the motor **140**. The nameplate data includes a rated power, a rated speed, a rated frequency, and a rated voltage of the motor **140**. An example of such a technique for estimating the speed of the motor **140** and the torque of the motor 140 is provided in U.S. Pat. No. 8,203,298. The nameplate information and instructions for estimating the speed and torque may be stored on the electronic storage **354** and executed by the electronic processing module **352**.

[0052] In other examples, the estimated speed and torque are determined by a separate controller and provided to the controller **350** via the I/O interface **356**. In still other implementations, the operator of the fluid management system **300** may provide estimated values of the speed and torque of the motor **140** to the controller **350** via the I/O interface **356**. Furthermore, in some implementations, the torque and/or speed of the motor **140** is determined based on a prior estimated, entered, or known value of the torque and/or speed. For example, the motor **140** speed may be increased or decreased by a known constant amount compared to the prior speed.

[0053] In these implementations, the current speed of the motor **140** is determined by adding or subtracting the known amount from the prior speed value.

[0054] The pre-determined performance data **151** is accessed (**420**). The pre-determined performance data **151** may include, for example, five (5) values of the head (H) of the machine **120** for five corresponding flowrates (Q), and five values of the efficiency of the machine **120** for five corresponding flowrates (Q).

[0055] The operating point of the machine **120** is determined (**430**). The operating point is determined based on the measured or estimated speed and torque of the motor **140** from (**410**) and the accessed pre-determined performance data **151** from (**420**). The operating point determination does not rely on sensors associated with the machine **120**. For example, the operating point is determined without using a flowmeter or a pressure meter at the inlet **123** or the outlet **124**. Furthermore, in implementations in which no sensors are used to estimate the speed and torque of the motor **140**, the operating point is determined or estimated solely from the motor power signal **341** and information about the motor **140**. A detailed example of determining the operating point of the machine **120** is provided with respect to FIG. **5**.

[0056] FIG. **5** is a flow chart of a process **500**. The process **500** is another example of a process for determining an operating point of the centrifugal machine **120**. The process **500** may be performed by the controller **150** or the controller **350**. For example, machine-readable instructions to implement the process **500** may be stored on the electronic storage **374** and executed by the electronic processing module **372**. The process **500** is discussed with respect to the fluid management system **300**; however, the process **500** may be applied to other fluid management systems.

[0057] The estimated speed (rpm_est) and torque (P_est) of the motor **140** are available based on element (**410**) discussed above with respect to FIG. **4**. The speed (rpm_est) of the motor **140** is compared to the M pre-determined impeller **122** speeds (**510**). Specifically, the controller **350** determines whether or not the estimated speed of the motor **140** (rpm_est) corresponds to any of the M pre-determined impeller **122** speeds (**515**). For example, in some implementations, the linkage **126** is configured such that the speed of the rotor **149** is the same as the speed of the impeller **122**. In these implementations, the estimated speed (rpm_est) is compared to the M pre-determined impeller **122** speeds directly. For example, the estimated speed (rpm_est) may be subtracted from each of the M pre-determined impeller **122** speeds to determine whether the estimated speed (rpm_est) is the same as one of the M pre-determined impeller **122** speeds. In other implementations, the linkage **126** transfers mechanical energy of the rotor **149** to the impeller **122** in a more complex manner (for example, through a gear system), and the speed of the rotor **149** is not the same as the speed of the impeller **122**. In these implementations, the estimated speed (rpm_est) of the rotor **149** is first adjusted to account for the effects of the linkage **126**, and then the adjusted estimated speed is compared to the M pre-determined impeller **122** speeds to determine whether the estimated speed (rpm_est) corresponds to one of the M pre-determined impeller **122** speeds.

[0058] The scenario in which the estimated speed (rpm_est) corresponds to one of the M pre-determined impeller speeds is discussed first.

[0059] If the estimated speed (rpm_est) is the same as or within a threshold difference of the M pre-determined impeller **122** speeds, then the process **500** calculates a P-Q curve (**525**) using the values in the pre-determined performance data **151** that are associated with that pre-determined impeller **122** speed. The P-Q curve is power (P), for example, in units of watts, used by the machine **120** as a function of flowrate (Q). The P-Q curve may be determined using Equation 1:

[00001] $P_k = \frac{H_k Q_k \rho g}{\eta_k}, \quad \text{Equation(1)}$

[0060] where k is an integer indexing value that is between 1 and N, P is the power used by the centrifugal machine **120**, Q is the flowrate, H is the head (H) at the flowrate Q, p is the density of the fluid in the body **121**, g is the acceleration of gravity, and n is the efficiency of the machine **120**. The N values of Q and H in Equation 1 are from the pre-determined performance data **151** at the pre-determined impeller **122** speed that corresponds to the estimated motor speed (rpm_est). The pre-determined performance data **151** also includes efficiency as a function of flowrate, and the efficiency values that correspond to the flowrates Q used in Equation (1) are obtained from the pre-determined performance data **151**.

[0061] FIG. **6** shows an example of a determined P-Q curve **604**. The P-Q curve **604** is found by determining N values of P using Equation 1 and then determining a relationship between the N values of P and the N values of Q. The relationship may be found by any type of curve fitting or data fitting technique. In the example of FIG. **6**, the power (P) required by the centrifugal machine **120** increases linearly with the flowrate (Q).

[0062] The motor power used by the centrifugal machine **120** is located on the determined P-Q curve (**530**). The power provided by the motor **140** is related to the torque and speed of the motor according to Equation 2:

[00002] $\text{P\_motor} = \text{torque} * \text{speed}. \quad \text{Equation(2)}$

[0063] The estimated torque of the motor **140** (P_est) and the estimated speed of the motor **140** (rpm_est) are known from (**410**). Thus, the power provided to the centrifugal machine **120** (P_motor) can be determined from Equation 2. After determining (P_motor), the corresponding operating flowrate (Q_op) is determined from the P_Q curve. Referring again to FIG. **6**, Q_op is shown on the horizontal axis.

[0064] The operating point of the centrifugal machine **120** is determined (**535**). Because the estimated motor speed (rpm_est) was determined to correspond to one of the M pre-determined impeller **122** speeds, the pre-determined performance data **151** includes values of the head (H) and values of the efficiency of the centrifugal machined **120** as a function of flowrate (Q) for (rpm_est). Thus, the head (H) and efficiency of the centrifugal machine **120** at the current flowrate (Q_op) can be determined. The operating point may be head (H) and the corresponding flowrate (Q_op) and/or an efficiency value (n_op) and the corresponding flowrate (Q_op). FIG. **7** illustrates the determination of the operating efficiency (n_op) using an efficiency curve derived from efficiency data included in the pre-determined performance data **151**.

[0065] The controller **350** determines whether or not the operating efficiency (n_op) is acceptable (**545**). To determine whether the operating efficiency (n_op) is acceptable, the controller **350** compares the operating efficiency (n_op) to the best efficiency point (BEP) of the centrifugal machine **120**. For example, the operating efficiency (n_op) may be compared to the BEP by subtracting the operating efficiency (n_op) from the BEP, determining a ratio between the operating efficiency (n_op) and the BEP, or by determining a percentage difference between the operating efficiency (n_op) and the BEP and comparing the result to an efficiency threshold. The efficiency threshold may be, for example, a percentage such as 1%, 2%, or 5%, or a value such as 0.01, 0.02, or 0.05. The efficiency threshold value may be stored on the electronic storage **374**. The efficiency threshold value may be provided by the operator of the fluid management system **300**, for example, via the I/O interface **376** such that the threshold can be adjusted depending on the application.

[0066] If the result of the comparison to the BEP is less than the efficiency threshold value, then the operating efficiency (n_op) is sufficiently close to the BEP, and the operating efficiency (n_op) of the centrifugal machine **120** is acceptable. If the operating efficiency (n_op) is acceptable, the centrifugal machine **120** is operating efficiently, and the process **500** ends or returns to (**510**) to continue monitoring the centrifugal machine **120**.

[0067] If the operating efficiency (n_op) is not acceptable, the controller **350** changes the speed of the motor **140** (**550**) such that the operating efficiency of the centrifugal machine **120** is moved closer to the BEP. Changing the speed of the motor **140** changes the speed of the impeller **122** and the operating point of the centrifugal machine **120**. In other words, changing the speed of the motor **140** changes the operating efficiency (n_op). The controller **350** changes the speed of the motor **140** by controlling the inverter **380** to change the characteristics (amplitude, frequency, and/or phase) of the motor power signal **341**.

[0068] After the controller **350** adjusts the motor **140**, the new speed (rpm_new) and torque (torque_new) of the motor **140** are determined at (**410**). The data in the pre-determined performance data **151** is adjusted to account for the new speed (rpm_new) using affinity laws (**520**). The affinity laws are relationship between head (H), efficiency, and impeller **122** speed. The affinity laws are:

[00003] $Q = \frac{r}{r0} Q_0, \quad \text{Equation(3)} \quad H = \left(\frac{r}{r0}\right)^2 H_0, \quad \text{Equation(4)} \quad P = \left(\frac{r}{r0}\right)^2 P_0, \quad \text{Equation(5)}$

[0069] where the subscript **0** denotes initial values, Q is the flowrate, H is the head, r is the rotational speed at which the impeller **122** is driven, and P is the mechanical power provided to the centrifugal machine **120**. In this example, r**0** is (rpm_est), which is the speed of the motor **140** prior to adjustment, and r is the updated estimated speed (rpm_new) determined after controlling the inverter **380** to change the speed of the motor **140**. Equations 3 and 4 are used to determine an updated H-Q curve. The affinity laws assume that the efficiency of the centrifugal machine **120** remains the same even though the speed of the impeller **122** changes. Thus, the relationship between efficiency and flowrate (Q) that is included in the pre-determined performance data **151** is not updated.

[0070] An updated P-Q curve is determined (**525**). The P-Q curve may be determined using Equation 1, the updated H-Q curve determined using the affinity laws at (**520**), and the efficiency data in the pre-determined performance data **151**. Alternatively, Equation 5 may be used to update the P-Q curve that was determined in the previous performance of (**525**).

[0071] The process **500** then proceeds to (**530**) to locate the power used by the centrifugal machine **120** at the updated estimated speed (rpm_new). The power (P_new) provided by the motor **140** at the updated estimated speed (rpm_new) is determined based on Equation 2. After determining the power provided to the centrifugal machine **120** at the updated speed (P_new), the updated flowrate

(Q_updated) achieved by providing the power (P_new) at the updated estimated speed (rpm_new) is determined from the updated P_Q curve.

[0072] The operating point is again determined (**535**). To determine the operating point (accounting for the change in the speed of the impeller **122**), the head (H) value that is associated with the updated flowrate (Q_updated) is determined from the updated H-Q curve found using Equations (3) and (4). The efficiency at Q_updated is determined from the efficiency curve that is included in the pre-determined performance data **151** (**540**). The efficiency at Q_updated is assessed to determine whether it is acceptable (**545**). The controller **350** continues to perform (**520**)-(**545**) in this manner until the current operating efficiency (n_op) determined at (**540**) is acceptable, or until the process **500** is halted (for example, by an operator).

[0073] The above discussion relates to an example in which the initial motor speed estimate (rpm_est) corresponds with one of the M pre-determined speeds. Returning to the discussion of (**515**), if the initial estimate of the motor speed (rpm_est) does not correspond to any of the M pre-determined impeller **122** speeds, the process **500** advances from (**515**) to (**520**) before advancing to (**525**). The affinity laws are applied at (**520**) to the H and Q values in the pre-determined performance data **151**, and the P-Q curve is determined at (**525**) using the corrected data that results from the application of the affinity laws. The controller **350** continues to perform (**520**)-(**545**) until the operating efficiency (n_op) determined at (**540**) is acceptable, or until the process **500** is halted.

[0074] FIG. **8** is an illustration of performance characteristic curves for the centrifugal machine **120**. FIG. **8** includes three H-Q curves **801***a*, **801***b*, **801***c* (shown with a short dashed line style). Each of the curves **801***a*, **801***b*, **801***c* is an H-Q curve at a different speed of the impeller **122**. The curve **801***a* is for a greater speed than than the curve **801***b*, and the curve **801***b* is for a greater speed than the curve **801***c*. FIG. **8** also includes three efficiency curves **802***a*, **802***b*, **802***c* (shown with a long dash line style). Each curve **802***a*, **802***b*, **802***c* represents a particular efficiency as a function of flowrate (Q). The efficiency curves **802***a*, **802***b*, **802***c* are part of the pre-determined performance data **151**. In the example of FIG. **8**, the curve **802***b* is for the BEP, and the curves **802***a* and **802***c* are for lower efficiencies. For example, the curve **802***b* may represent a 70% efficiency as a function of flow rate (Q) and the curves **802***a* and **802***c* may each represent 60% efficiency as a function of flow rate (Q).

[0075] FIG. **8** also includes a system head (Hsys) curve **803** (shown with a solid line style). The system head (Hsys) curve **803** is the system head (Hsys) as a function of flow rate (Q). The system head (Hsys) curve is determined by perturbing the speed of the motor **140** (for example, at **550** of the process **500**) and then recalculating the operating point at (**535**). In the example shown in FIG. **8**, (**520**)-(**550**) was performed three times and three operating points **804***a*, **804***b*, **804***c* were determined. The operating points **804***a*, **804***b*, **804***c* are where the system head curve **803** intersects the H-Q curves **802***a*, **802***b*, **802***c*. The Hsys curve is determined by performing a curve fit of the determined operating points **804***a*, **804***b*, **804***c*. The best efficiency point flowrate (Q_BEP) for a particular impeller **122** speed is the flowrate of the point where the highest efficiency curve (**802***b* in this example) intersects the H-Q curve. The best efficiency point flowrates (Q_BEP) are labeled as **805***a*, **805***b*, **805***c*.

[0076] Examples related to Q_BEP are discussed further with respect to FIG. **9**. FIG. **9** is a flow chart of a process **900**. The process **900** is used to adjust the speed of the motor **140** to achieve more efficient operation of the centrifugal machine **120**. The process **900** may be performed by the controller **150** or the controller **350**. For example, machine-readable instructions to implement the process **900** may be stored on the electronic storage **374** and executed by the electronic processing module **372**. The process **900** is discussed with respect to the fluid management system **300**; however, the process **900** may be applied to other fluid management systems.

[0077] The process **900** includes (**545**), which is discussed above. If the efficiency determined at (**540**) is acceptable, the process **900** ends. If the efficiency determined at (**540**) is not acceptable, the controller **350** compares Q_op to Q_BEP. Q_op is the flowrate (Q) associated with the operating point determined in (**535**). Q_BEP is the flowrate that corresponds to the intersection between the highest efficiency curve and the H-Q curve for the speed of the impeller **122**. For example, and referring to FIG. **8**, if the H_Q curve **801***b* is the H-Q curve for the speed of the impeller **122**, the operating point is **804***b* (corresponding to Qop_b of FIG. **8**) and the BEP operating point is **805***b* (corresponding to QBEP_b of FIG. **8**).

[0078] When the centrifugal machine **120** is operating at its highest efficiency, Q_op equals Q_BEP. If Q_op is not equal to Q_BEP, the speed of the motor **140** is adjusted to move Q_op closer to or equal to Q_BEP, as discussed below.

[0079] At (**947**) Q_op is assessed to determine if Q_op is less than Q_BEP. If Q_op is less than Q_BEP, the controller **350** increases the speed of the motor **140** (**950_2**). If Q_op is less than Q_BEP, the centrifugal machine **120** is oversized, and increasing the flowrate (Q) will move the operating point closer to Q_BEP. The flowrate is thus increased by increasing the speed of the motor **140**.

[0080] If Q_op is greater than Q_BEP (such as in the example discussed with respect to FIG. **8**), the controller decreases the speed of the motor **140** (**950_1**). If the Q_op is greater than the Q_BEP, the centrifugal machine **120** is undersized, and reducing the flowrate (Q) will move the operating point closer to Q_BEP. The flowrate is thus decreased by decreasing the speed of the motor **140**.

[0081] The speed of the motor **140** may be decreased at (**950_1**) or increased at (**950_2**) by a pre-determined constant amount that is stored on the electronic storage **354**. The amount of increase and decrease may be the same. For example, the speed of the motor **140** may be decreased at (**950_1**) or increased at (**950_2**) by 5 revolutions per minute. In other implementations, the amount at which the speed of the motor **140** is increased or decreased depends on operating conditions. For example, the amount at which the speed of the motor **140** is increased or decreased may be a fixed percentage of the current estimated speed of the motor **140**.

[0082] After the speed of the motor **140** is decreased at (**950_1**) or increased at (**950_2**), the speed and torque of the motor **140** are estimated using (**410**). The operating point is again determined at (**960_1**) if the speed of the motor **140** was decreased at (**950_1**). The operating point is determined at (**960_2**) if the speed of the motor **140** was increased at (**950_2**). The elements (**960_1**) and (**960_2**) are the same and both implement elements (**520**)-(**540**) of the process **500** (FIG. **5**). The elements (**960_1**) and (**960_2**) are shown as separate elements in FIG. **9** but may be implemented as a single module, function, or collection of machine executable instructions that use an input command that specifies the amount of speed increase or speed reduction, and generate an output command that acts on the inverter **380** to adjust the motor **140** accordingly. The process **900** continues until the determined efficiency is deemed to be acceptable at (**545**).

[0083] FIG. **10** is a flow chart of a process **1000**. The process **1000** is used to bring the centrifugal machine **120** to peak efficiency within a bounded operating region. The bounded operating region may be user-defined and does not necessarily include the flowrate that is associated with the BEP (Q_BEP). The process **1000** may be performed by the controller **150** or the controller **350**. For example, machine-readable instructions to implement the process **1000** may be stored on the electronic storage **374** and executed by the electronic processing module **372**. The process **1000** is discussed with respect to the fluid management system **300**; however, the process **1000** may be applied to other fluid management systems.

[0084] The process **1000** includes some elements of the process **500** and **900**, which are discussed above. The current operating efficiency (n_op) of the centrifugal machine **120** is assessed for acceptability at (**545**). If the current operating efficiency (n_op) is not acceptable, the current operating flowrate (Q_op) is compared to the flowrate associated with the BEP (Q_BEP) at (**947**). The speed of the motor **140** is decreased at (**950_1**) or increased at (**950_2**) and the new operating point of the centrifugal machine **120** at the new speed of the motor **140** is determined at (**960_1**) or (**960_2**), respectively, as discussed with respect to FIG. **9**.

[0085] The example in which the current operating flowrate (Q_op) is less than Q_BEP is discussed first. The updated operating point determined at (**960_2**) includes a head (H) value and a corresponding flowrate (Q_op). FIG. **11** shows an example of an operating point with a head (H) value and a flowrate (Q_op). FIG. **11** also shows a bounded operating region **1190**, a system head (Hsys) curve **1103**, an H-Q curve **1101***b*, and a maximum efficiency curve **1102***b*. Q_BEP is the point at which the efficiency curve **1102***b* intersects the Hsys curve **1103**.

[0086] The bounded operating region **1190** is a region in H-Q space that is defined by a maximum head (H**2**), a minimum head (H**1**), a minimum flowrate (Q**1**), and a maximum flowrate (Q**2**). The bounded operating region **1190** includes H**1**, H**2**, Q**1**, and Q**2**, and all values of head (H) between H**1** and H**2**, and all values of flowrate (Q) between Q**1** and Q**2**. The bounded operating region **1190** may be defined based on pre-determined values of H**1**, H**2**, Q**1**, and Q**2** that are loaded onto the electronic storage **374** by the manufacturer. In some implementations, the operator of the controller **350** is able to enter user-defined values of H**1**, H**2**, Q**1**, and Q**2** through the I/O interface **376**. Thus, the bounded operating region **1190** may be user-defined and may thus be tailored to the end-user's application.

[0087] The process **1000** adjusts the speed of the motor **140** until the centrifugal machine **120** is at the most efficient operating point within the bounded operating region **1190**. The values of (Q_op) and head (H) found in (**960_2**) are compared to H**1**, H**2**, Q**1**, and Q**2** to determine if the current operating point is within the bounded operating region **1190** (**1065_2**). If head (H) is between H**1** and H**2** and Q_op is between Q**1** and Q**2**, the current operating point (Q_op) is in the bounded operating region **1190**. In the example of FIG. **11**, the current operating point (Q_op) is in the bounded operating region **1190**. The process **1000** returns to (**545**) to determine whether the current efficiency (n_op) is acceptable. The process **1000** continues until an acceptable efficiency within the operating region **1190** is found.

[0088] In the example discussed with respect to FIG. **11**, Q_BEP is within the bounded operating region **1190**. However, the bounded operating region does not necessarily include Q_BEP. FIG. **12** shows an example of another bounded operating region **1290** that does not include Q_BEP. In this example, the current operating point (Q_op) is initially less than Q_BEP, and the speed of the motor **140** is increased (**950_2**). After the speed of the motor **140** is increased, the speed and torque of the motor **140** are estimated using (**410**). The current operating point (Q_op and head (H)) are estimated at 960_2. The current operating point Q_op is compared to Q**1** and Q**2**, and the head (H) is compared to H**1** and H**2** to determine whether the current operating point is within the bounded operating region **1290**. In the example shown in FIG. **12**, the current operating point is within the bounded operating region **1290**. The process **1000** returns to (**545**) to compare the current flowrate (Q_op) to Q_BEP and continues to increase the speed of the motor **140** until the current operating point determined at (**960_2**) is determined to be outside of the bounded operating region **1290** at (**1065_2**). The speed of the motor **140** is then decreased (**1068**) and the current operating point is determined (**960_2**) until the current operating point is within the region of operation **1290**.

[0089] In this example, Q_BEP is not within the region of operation **1290**, thus, the speed of the motor **140** is adjusted until Q_op is equal to the flowrate associated with a point **1206**. The point **1206** is on the boundary of the bounded operating region **1290** and is on the side closest to the BEP. The point **1206** is considered within the bounded operating region **1290**, and the process **1000** returns to (**545**) and ends because Q_op is now the closest it can be to Q_BEP while also being within the region of operation **1290**.

[0090] An example in which the current operating flowrate (Q_op) is greater than Q_BEP is discussed next with respect to FIGS. **13** and **14**. In the example of FIG. **13**, the speed of the motor **140** is decreased (**950_1**) to bring the current operating point (Q_op) closer to Q_BEP. The speed and torque of the motor **140** are estimated (**410**), and the new operating point is estimated (**960_1**). If the new operating point is within the bounded operating region **1390** (such as in the example shown in FIG. **13**), the process **1000** returns to (**545**). The process **1000** continues in this manner until the current flowrate (Q_op) is acceptable.

[0091] FIG. **14** shows an example in which Q_BEP is outside of a bounded operating region **1490**. The speed of the motor **140** is decreased (**950_1**) and a new operating point is determined (**960_1**). The operating point not within the bounded operating region **1490** (**1065_1**), and speed of the motor **140** is increased (**1067**). Each time the speed of the motor **140** is increased at (**1067**), the operating point is estimated (**960_1**). The speed of the motor **140** is increased until the operating point flowrate (Q_op) is at a point **1406**, which is on the boundary of the bounded operating region **1490**. The point **1406** is the flowrate in the bounded operating region **1490** that is the closest to Q_BEP. The process **1000** ends because the most efficient flowrate within the bounded operating region **1490** has been determined.

[0092] Other implementations of the processes **500**, **900**, and **1000** are possible. For example, element (**545**) is discussed above as being an assessment of the efficiency of the centrifugal machine **120** at the current operation point. For example, in the examples above, a difference between the BEP and the current operating efficiency (n_op) is compared to a threshold value. If the absolute value of the difference is less than the threshold, then the current operating efficiency (n_op) is deemed to be acceptable.

[0093] However, other implementations of (**545**) may be used in any of the processes **500**, **900**, and **1000**. For example, in some implementations, (**545**) determines an absolute value of a difference between the current operating point flowrate (Qop) as determined at (**540**) and a pre-defined flowrate (Qset), and compares the difference to a threshold (th_Q). If the absolute value of the difference is less than the threshold (th_Q), then the current operating point flowrate is deemed to be acceptable. Implementing (**545**) in this manner allows the processes **500**, **900**, and/or **1000** to be used to adjust the centrifugal machine **120** to any set flowrate point (Qset). Moreover, in some implementations, the electronic storage **374** includes instructions to compare the user-supplied Qset value to information about the centrifugal machine **120** to ensure that the value of Q set is a value of the flowrate that is possible to achieve with the centrifugal machine **120**.

[0094] To provide another example, in some implementations, (**545**) determines an absolute value of a difference between the current operating head (H) as determined at (**540**) and a pre-defined or user-supplied head (H set) value, and compares the difference to a threshold (th_H). If the absolute value of the difference is less than the threshold (th_H), then the current operating head (H) is deemed to be acceptable. Implementing (**545**) in this manner allows the processes **500**, **900**, and/or **1000** to be used to adjust the centrifugal machine **120** to any head (H) value. Moreover, in some implementations, the electronic storage **374** includes instructions to compare the user-supplied Hset value to information about the centrifugal machine **120** to ensure that the value of H set is a value of the head (H) that is possible to achieve with the centrifugal machine **120**.

[0095] FIG. **15** is a flow chart of a process **1500**. The process **1500** is used to operate the centrifugal machine **120** with a varying speed and thus a varying value of a performance metric. The average value of the performance metric equals a user-requested value of that metric. FIG. **16** is a plot of the speed of the impeller **122** or the motor **140** as a function of time. FIG. **17** is a plot of flowrate (a performance metric) of the centrifugal machine **120** as a function of time.

[0096] FIGS. **16** and **17** have the same time scale. As shown in FIGS. **16** and **17**, the speed of the impeller **122** and the flowrate vary over time.

[0097] The process **1500** may be performed by the controller **150** or the controller **350**. For example, machine-readable instructions to implement the process **1500** may be stored on the electronic storage **374** and executed by the electronic processing module **372**. The process **1500** is discussed with respect to the fluid management system **300**; however, the process **1500** may be applied to other fluid management systems.

[0098] A set point value for a metric is accessed (**1510**). The set point value may be, for example, a flowrate value (Qset) that an end user enters into the controller **350** using the I/O interface **376**. The centrifugal machine **120** is controlled to operate in an on-off manner such that the machine **120** repeatedly alternates between an on state and an off state, and the average value of the metric over time is the set point value (Qset). The metric has a first value during a first time period and a second value during a second time period. When the machine **120** is operated in the on-off manner, the second value of the metric is 0 and the machine **120** is off during the second time period. Continuing the example in which the end user wishes to control the machine **120** to have an average flow rate of Qset and also wishes to control the machine **120** in the on-off manner, Equation (6) shows the relationship between Q**1**, t**2**, t**1**, and Qset:

[00004] $\text{Qset} = \frac{(Q1)t1}{t1+t2}$, Equation(6)

[0099] where t**1** is a first finite time period, t**2** is a second finite time period, and Q**1** is the flowrate during the on state in the first time period t**1**. For example, the value of Q**1** may be Q_BEP. By using Q_BEP as the value of Q**1**, the centrifugal machine **120** operates in an efficient manner when in the on state. The end user may specify values of t**1** or t**2**. In some implementations, the end user specifies a value of Q**1** other than Q_BEP.

[0100] The centrifugal machine **120** is controlled to operate at the first value of the metric during the first time period (**1520**). Continuing the above example and referring to FIGS. **16** and **17**, the centrifugal machine **120** is controlled such that the flowrate is Q**1** during the first time period t**1**. The centrifugal machine **120** may be controlled using the process **900**, where (**545**) is configured to assess whether the flowrate of the current estimated operating point is equal to Q**1**, and the process **900** adjusts the speed of the motor **140** until the flow rate of the operating point is Q**1**.

[0101] The centrifugal machine **120** is controlled to operate at the second value of the metric during the second time period (**1530**). Continuing the example above, the second value of the flowrate is 0 because the machine **120** is off during the second time period. In this example, the centrifugal machine **120** is controlled by turning the machine **120** off. In other examples, the second value of the metric is non-zero, and the machine **120** is controlled using, for example, the process **900** to operate the machine **120** at the second value of the metric in the manner discussed in (**520**).

[0102] These implementations and other implementations are within the scope of the claims.

Claims

1. A control system for a pump system, the control system comprising a controller configured to: determine whether a current operating point of the pump system is in a bounded operating region, wherein the current operating point comprises a current value of a flowrate of fluid moved by the pump system and a current value of a performance metric; and the bounded operating region is defined by a minimum value of the flowrate, a maximum value of the flowrate, a minimum value of the performance metric, and a maximum value of the performance metric; and if the current operating point is not in the bounded operating region, the controller is configured to adjust a parameter of a motor that is mechanically coupled to the pump system to thereby change the current operating point until the current operating point is in the bounded operating region.

2. The control system of claim 1, wherein the controller is configured to compare the current value of the flowrate of the fluid moved by the pump system to a best efficiency point flowrate associated with the pump system before determining whether the current operating point is in the bounded operating region; if the current value of the flowrate is less than the best efficiency point flowrate, the controller increases a speed of the motor before determining whether the current operating point is in the bounded operating region; and if the current value of the flowrate is greater than the best efficiency point flowrate, the controller decreases the speed of the motor before determining whether the current operating point is in the bounded operating region.

3. The control system of claim 2, wherein the parameter of the motor comprises the speed of the motor; and if the current operating point is not within the bounded operating region and the current value of the flowrate is less than the best efficiency point flowrate, the controller decreases the speed of the motor until the current operating point is in the bounded operating region; and if the current operating point is not within the bounded operating region and the current value of the flowrate is greater than the best efficiency point flowrate, the controller increases the speed of the motor until the current operating point is in the bounded operating region.

4. The control system of claim 1, wherein the control system is further configured to determine whether the current value of the performance metric is acceptable.

5. The control system of claim 4, wherein the performance metric comprises an operating efficiency, and to determine whether the current value of the operating efficiency is acceptable, the controller is configured to compare the current value of the operating efficiency to a best efficiency point.

6. The control system of claim 5, wherein the current value of the operating efficiency is acceptable if a difference between the current value of the operating efficiency and the best efficiency point is less than an efficiency threshold.

7. The control system of claim 4, wherein the performance metric comprises a flowrate or an operating head.

8. The control system of claim 7, wherein one or more of the minimum flowrate, the maximum flow rate, the minimum value of the performance metric, and the maximum value of the performance metric are set by an operator of the pump system.

9. The control system of claim 1, wherein the performance metric comprises an operating head, and the bounded operating region is defined by a maximum operating head, a minimum operating head, a minimum flowrate, and a maximum flowrate.

10. The control system of claim 1, wherein the parameter comprises a speed of the motor.

11. The control system of claim 1, wherein the control system is further configured to determine the current operating point of the pump system.

12. The control system of claim 11, wherein the control system is configured to determine the current operation point of the pump system based on an estimate of one or more of a speed and a torque of a motor that drives the pump system.

13. The control system of claim 12, wherein the estimate of one or more of the speed and the torque of the motor that drives the pump system does not rely on a sensor associated with the pump system or the motor.

14. The control system of claim 13, wherein the estimate of one or more of the speed and the torque of the motor is based on a property of a motor power signal provided to the motor.

15. A method of operating a centrifugal machine, the method comprising: accessing a set point value for a flowrate of fluid moved by the centrifugal machine; determining a duration of a first time period and a duration of a second time period based on the set point value for the flowrate and a best efficiency point flowrate for the centrifugal machine; controlling the centrifugal machine to operate at the best efficiency point flowrate for the duration of the first time period; and controlling the centrifugal machine to operate at a second flowrate for the duration of the second time period, wherein the duration of the first time period and the duration of the second time period are such that an average flowrate of the fluid over the first and second time periods is the set point value of the flowrate.

16. The method of claim 15, wherein the first time period is immediately before the second time period.

17. The method of claim 15, wherein the set point value for the flowrate is received from an operator of the centrifugal machine.

18. The method of claim 15, wherein controlling the centrifugal machine comprises controlling a motor controlling apparatus that provides a motor power signal to a motor that is mechanically coupled to an impeller of the centrifugal machine.

19. The method of claim 15, wherein the second flowrate is a zero flowrate.

20. A system comprising: a pump system comprising: a body comprising an inlet and an outlet; an impeller configured to transport fluid between the inlet and the outlet; and a motor coupled to the impeller; and a control system for the pump system, the control system comprising a controller configured to: determine whether a current operating point of the pump system is in a bounded operating region, wherein the current operating point comprises a current value of a flowrate of fluid moved by the pump system and a current value of a performance metric; and the bounded operating region is defined by a minimum value of the flowrate, a maximum value of the flowrate, a minimum value of the performance metric, and a maximum value of the performance metric; and if the current operating point is not in the bounded operating region, the controller is configured to adjust a parameter of a motor that is mechanically coupled to the pump system to thereby change the current operating point until the current operating point is in the bounded operating region.