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(54) **Electric motor driven lubrication supply system of a gas turbine and method**

(57) A system and method for controlling lubricant displacement from a lubrication system and a rotating machine includes supplying a gaseous fluid to the lubrication supply system to displace the lubricant. The gaseous fluid is preferentially directed through a first section of the lubrication supply system and to the rotating machine,

and is at least inhibited from flowing through a second section of the lubrication supply system. As a result, the gaseous fluid displaces the lubricant in the rotating machine and in the first section of the lubrication supply system, while the second section of the lubrication supply system remains at least substantially full of lubricant.

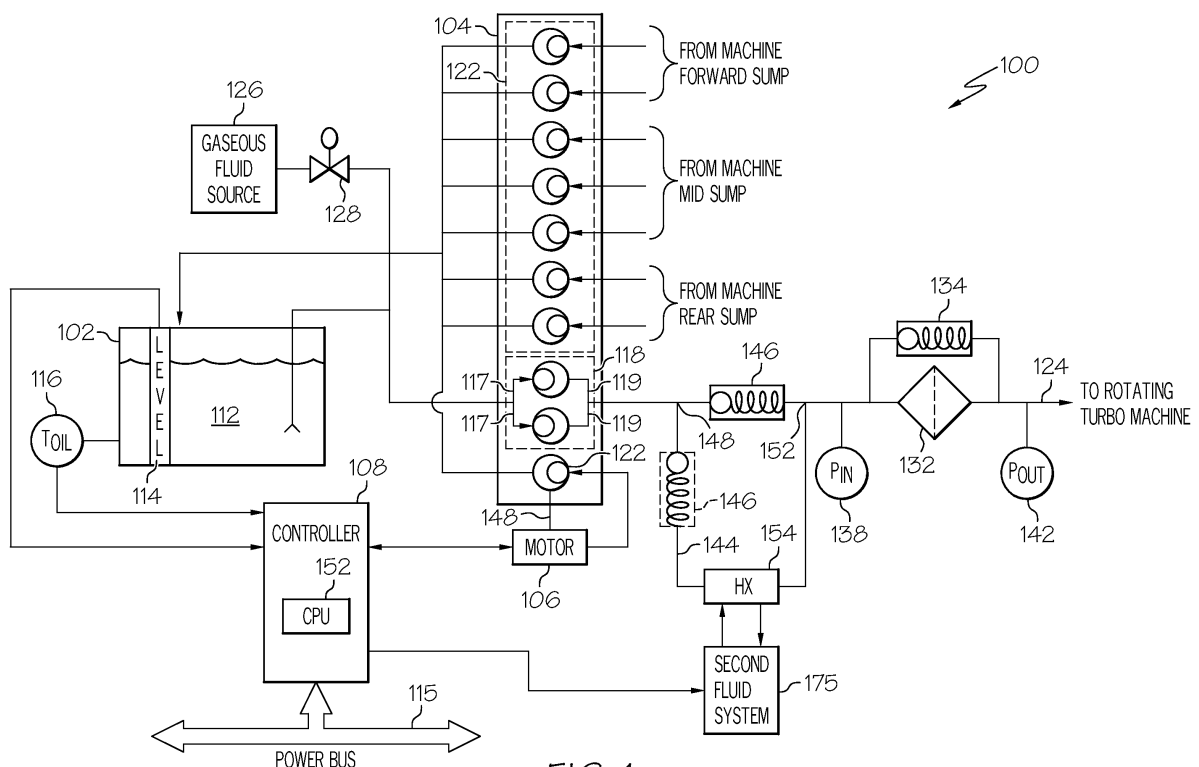


FIG. 1

Description

[0001] This invention was made with Government support under Contract No. N00019-02-C-3002, awarded by the U.S. Navy. The Government has certain rights in this invention.

TECHNICAL FIELD

[0002] The present invention relates to rotating machine lubrication and, more particularly, to a system and method for controlling lubricant removal from the rotating machine and the machine lubrication supply system during shutdown of the machine.

BACKGROUND

[0003] Many aircraft gas turbine engines are supplied with lubricant from a pump driven lubrication supply system. In particular, the lubrication supply pump, which may be part of a pump assembly having a plurality of supply pumps on a common, engine-driven or electric motor driven shaft, draws lubricant from a lubricant reservoir, and increases the pressure of the lubricant. The lubricant is then delivered, via an appropriate piping circuit, to the engine. The lubricant is directed, via appropriate flow circuits within the engine, to the various components that may need lubrication, and is collected in one or more recovery sumps in the engine. One or more of the pump assembly pumps then draws the lubricant that collects in the recovery sumps and returns the lubricant back to the reservoir.

[0004] When an aircraft gas turbine engine is shutdown, the lubricant is typically removed and returned to the reservoir to reduce the viscous drag due to residual lubricant on rolling and sliding lubricated surfaces during a subsequent startup. In many instances this is accomplished by actuating a valve that, when appropriately positioned, allows the supply pumps to draw air, rather than lubricant, into the system. The supply pumps direct the air into the supply system and engine, displacing the lubricant therefrom, and directing the displaced lubricant back to the lubricant reservoir.

[0005] Although the above-described systems and methods are generally safe, reliable, and robust, these systems and methods do suffer certain drawbacks. For example, during a subsequent cold engine and lubrication system startup, after the lubricant has been removed from the lubrication system and engine, the lubrication system and engine are first refilled with lubricant before lubricant pressure rises sufficiently to force lubricant into some engine components. Because lubricant is removed from the entire lubrication system during the engine shutdown sequence, the subsequent startup can use an undesired amount of power and take an undesired amount of time to raise lubricant pressure sufficiently high.

[0006] Hence, there is a need for lubricant supply system and method that can remove lubricant from a rotating

machine during shutdown of the machine and supply system, while decreasing the amount of power and time needed to raise lubricant pressure during a subsequent startup of the supply system and machine. The present invention addresses at least this need.

BRIEF SUMMARY

[0007] In one embodiment, and by way of example only, an aircraft lubrication supply system includes a motor, a pump, a fluid supply line, a fluid bypass line, and a controller. The motor is coupled to be selectively energized from a power bus and is operable, upon being energized, to rotate at a rotational speed and supply a drive force. The pump has at least a fluid inlet and a fluid outlet, is coupled to receive the drive force from the motor and is configured, in response thereto, to draw fluid into the fluid inlet from either a lubricant source or a gaseous fluid source, and to discharge the fluid via the fluid outlet. The fluid supply line is coupled to the fluid outlet and is configured to supply the fluid discharged from the fluid outlet to a rotating machine. The fluid bypass line has an inlet and an outlet. The fluid bypass line inlet is coupled to the fluid supply line at a first location, and the fluid bypass line outlet is coupled to the fluid supply line at a second location that is downstream of the first location. The bypass control valve is disposed between the fluid bypass line inlet and the fluid bypass line outlet, and is operable to control fluid flow at least through the fluid bypass line. The controller is configured to couple to the power bus and to receive a machine de-lube signal that indicates the rotating machine is being de-lubricated. The controller is operable, upon receipt of the machine de-lube signal, to controllably energize the motor from the power bus to thereby displace at least a substantial volume of lubricant in the fluid supply line and the rotating machine with fluid from the gaseous fluid source, and to cause the bypass control valve to move to a position that results in the fluid bypass line remaining at least substantially full of lubricant when the at least substantial volume of lubricant is displaced from the fluid supply line and the rotating machine.

[0008] In another exemplary embodiment, a method of removing lubricant from a lubrication supply system and a rotating machine supplied with lubricant by the lubrication supply system includes supplying a gaseous fluid to the lubrication supply system to displace the lubricant. The gaseous fluid is preferentially directed through a first section of the lubrication supply system and to the rotating machine, and is at least inhibited from flowing through a second section of the lubrication supply system. As a result, the gaseous fluid displaces the lubricant in the rotating machine and in the first section of the lubrication supply system, while the second section of the lubrication supply system remains at least substantially full of lubricant.

[0009] Other independent features and advantages of the preferred lubrication supply system and method will

become apparent from the following detailed description, taken in conjunction with the accompanying drawings which illustrate, by way of example, the principles of the invention.

BRIEF DESCRIPTION OF THE DRAWINGS

[0010] FIG. 1, which is the sole figure, is a schematic diagram of an aircraft lubrication supply system according to an exemplary embodiment of the present invention.

DETAILED DESCRIPTION OF A PREFERRED EMBODIMENT

[0011] The following detailed description is merely exemplary in nature and is not intended to limit the invention or its application and uses. Furthermore, there is no intention to be bound by any theory presented in the preceding background or the following detailed description. In this regard, although the system is depicted and described as supplying lubricant to a turbomachine, it will be appreciated that the invention is not so limited, and that the system and method described herein may be used to supply lubricant to any one of numerous airframe mounted rotating machines.

[0012] The following detailed description is merely exemplary in nature and is not intended to limit the invention or its application and uses. Furthermore, there is no intention to be bound by any theory presented in the preceding background or the following detailed description. In this regard, although the system is depicted and described as supplying lubricant to a turbomachine, it will be appreciated that the invention is not so limited, and that the system and method described herein may be used to supply lubricant to any one of numerous airframe mounted rotating machines.

[0013] With reference now to FIG. 1, a schematic diagram of an exemplary aircraft lubrication supply system 100 is depicted, and includes a reservoir 102, a pump assembly 104, a motor 106, and a controller 108. The reservoir 102 is used to store a supply of lubricant 112 such as, for example, oil or other suitable hydraulic fluid. A level sensor 114 and a temperature sensor 116 are installed within, or on, the reservoir 102. The level sensor 114 senses the level of lubricant in the reservoir 102 and supplies a level signal representative of the sensed level to the controller 108. The temperature sensor 116 senses the temperature of the lubricant in the reservoir 102 and supplies a temperature signal representative of the sensed temperature to the controller 108. It will be appreciated that the level sensor 114 and the temperature sensor 116 may be implemented using any one of numerous types of level and temperature sensors, respectively, that are known now or that may be developed in the future.

[0014] The pump assembly 104, at least in the depicted embodiment, includes a plurality of supply pumps 118 and a plurality of return pumps 122. The supply

pumps 118 each include a fluid inlet 117 and a fluid outlet 119. The supply pumps 118, when driven, draw fluid from one of two fluid sources, and discharge the fluid, at an increased pressure, into a fluid supply conduit 124. The fluid supply conduit 124, among other potential functions, supplies the lubricant to one or more rotating machines. Although one or more various types of machines could be supplied with the lubricant, in the depicted embodiment the lubricant is supplied to a rotating turbomachine. It will be appreciated that each of the pumps 118, 122 that comprise the pump assembly 104 could be implemented as any one of numerous types of centrifugal or positive displacement type pumps, but in the preferred embodiment each pump 118, 122 is implemented as a positive displacement pump.

[0015] The two fluid sources from which the supply pumps 118 may draw fluid include the reservoir 102 and a gaseous fluid source 126. The gaseous fluid source 126 may be configured as any one of numerous sources of gaseous fluid, but in the depicted embodiment it is configured as an air source. Preferably, the surrounding environment acts as a suitable air source. If not, however, a dedicated source of a suitable gas may be used. The specific source from whence the supply pumps 118 draw fluid may be controlled by, for example, a de-lube control valve 128. It will be appreciated that the de-lube control valve 128 may be implemented using any one of numerous types of valves to. In the depicted embodiment, however, the de-lube control valve 128 is implemented as a solenoid-operated valve.

[0016] As FIG. 1 also depicts, a lubricant filter 132 may also be disposed within the lubricant supply conduit 124. The lubricant filter 132 removes any particulate or other debris that may be present in lubricant before it is supplied to the rotating machine. A filter bypass valve 134, and appropriate bypass piping 136, are disposed in parallel with the lubricant filter 132. The bypass valve 134 is configured such that it is normally in a closed position, and moves to the open position when a predetermined differential pressure exists across it. Thus, if the lubricant filter 132 becomes clogged and generates a sufficiently high differential pressure, the bypass valve 134 will open to ensure a sufficient flow of lubricant to the rotating machine is maintained.

[0017] The lubricant supply conduit 132 also includes a pair of pressure sensors, a filter inlet pressure sensor 138 and a filter outlet pressure sensor 142. The pressure sensors 138, 142 are each operable to sense lubricant pressure and to supply a pressure signal representative of the sensed pressure to the controller 108. As the assigned nomenclature connotes, the filter inlet pressure sensor 138 senses lubricant pressure at the inlet to the lubricant filter 132, and the filter outlet pressure sensor 142 senses lubricant pressure at the outlet of the lubricant filter 132. It will be appreciated that the depicted configuration is merely exemplary of a particular embodiment, and that the system 100 could be implemented with more or less than this number of pressure sensors. For exam-

ple, the system 100 could be implemented with only the filter inlet pressure sensor 138 or only the filter outlet pressure sensor 142, with a plurality of filter inlet pressures sensors 138 and filter outlet pressure sensors 142, or with no pressure sensors.

[0018] The temperature of the lubricant that is supplied to the rotating machine is controlled, at least partially, via a fluid bypass line 144 and a bypass control valve 146. The fluid bypass line 144 includes an inlet 148 and an outlet 152. The fluid bypass line inlet 148 is coupled to the fluid supply line 124 at a first location, and the fluid bypass line outlet 152 is coupled to the fluid supply line 124 at a second location downstream of the first location. A heat exchanger 154 is disposed in the fluid bypass line 144. Fluid in the bypass line 144 and fluid from a second fluid system 175 flow into and through the heat exchanger 154. In the heat exchanger 154, heat is transferred between the two fluids. During normal system 100 operation, heat is typically transferred from the fluid (e.g., lubricant) in the fluid bypass line 144 to the fluid from the second fluid system 175, thereby cooling the fluid in the fluid bypass line 144. The cooled fluid then flows back into the fluid supply line 124. The amount of fluid (if any) that flows into and through the fluid bypass line 144 is controlled via the bypass control valve 146, embodiments of which will now be briefly described.

[0019] The bypass control valve 146 is disposed in the fluid supply line 124 between the fluid bypass line inlet 148 and the fluid bypass line outlet 152. The bypass control valve 146 is operable to control fluid flow at least through the fluid bypass line 144. More specifically, in the depicted embodiment, the bypass control valve 146 is movable between a closed position and an open position. When the bypass control valve 146 is in the closed position, all of the fluid discharged from the supply pumps 118 will flow into and through the fluid bypass line 144. Conversely, when the bypass control valve 146 is in the open position, most (if not all) of the fluid discharged from the supply pumps 118 will flow through the bypass control valve 146, and only a portion (if any) of the fluid will flow into and through the fluid bypass line 144.

[0020] From the above discussion, it may thus be appreciated that during normal system operations the bypass control valve 146 is preferably positioned to regulate the temperature of the lubricant supplied to the rotating machine. That is, if the lubricant discharged from the supply pumps 118 is below a predetermined temperature, then the bypass control valve 146 will be open and only a portion (if any) of the discharged lubricant discharged will flow into and through the fluid bypass line 144. If, however, the lubricant discharged from the supply pumps 118 reaches or exceeds a predetermined set temperature, then the bypass control valve 146 will close and all of the fluid discharged from the supply pumps 118 will flow into and through the fluid bypass line 144, and be cooled in the heat exchanger 154.

[0021] Before proceeding further it is noted that the bypass control valve 146 may be variously disposed and

variously configured. For example, and as is depicted in phantom in FIG. 1, rather than being disposed in the supply line 124, the bypass control valve 146 could be disposed in the fluid bypass line 144. Moreover, the bypass control valve 146 could be implemented using any one of numerous suitable devices, and be configured to move between the closed and open positions based on various sensed temperatures. For example, in the depicted embodiment the bypass control valve 146 is implemented using a thermally actuated valve, such as a eutectic-based actuator operated valve, that moves a valve element between the closed and open position based on the temperature of the actuator. With this type of valve, the actuator temperature varies with fluid temperature at the outlet of the bypass control valve 146 and, based on this temperature, controls the position of the valve element. In other embodiments, the fluid temperature at the inlet of the bypass control valve 146 could be used. In addition, a fluid temperature sensor could be included to sense fluid temperature at one or more locations in the fluid supply line 124 and the sensed temperature could be used to control an electric, hydraulic, or pneumatic actuator, or various other actuator types, to move the bypass control valve 146 between the closed and open positions.

[0022] No matter the specific configuration of the bypass control valve 146, it is noted that the lubricant that is ultimately supplied to the rotating machine flows to various components within the machine and is collected in one or more sumps in the rotating machine. The lubricant that is collected in the rotating machine sumps is then returned to the reservoir 102 for reuse. To do so, a plurality of the above-mentioned return pumps 122 draws used lubricant from the rotating machine sumps and discharges the used lubricant back into the reservoir 102 for reuse. It will be appreciated that the configuration of the pump assembly 104 described herein is merely exemplary, and that the pump assembly 104 could be implemented using any one of numerous other configurations. For example, the pump assembly 104 could be implemented with a single supply pump 118 and a single return pump 122, or with just one or more supply pumps 118. No matter how many supply or return pumps 118, 122 are used to implement the pump assembly 104, it is seen that each pump 118, 122 is mounted on a common pump assembly shaft 148 and is driven via a drive force supplied from the motor 106.

[0023] The motor 106 is selectively energized from a power bus 115 and, when energized, rotates at a speed controlled by the controller 108 to thereby supply the drive force to the pump assembly 104. In the depicted embodiment the motor 106 is directly coupled to the pump shaft 148 and thus rotates the pump shaft 148 (and thus the pumps 118, 122) at the motor speed. It will be appreciated, however, that the motor 106, if needed or desired, could be coupled to the pump shaft 148 via one or more gear assemblies, which could be configured to either step up or step down the motor speed. It will additionally be

appreciated that the motor 106 could be implemented as any one of numerous types of AC or DC motors, but in a particular preferred embodiment the motor 106 is implemented as a brushless DC motor.

[0024] As noted above, the motor 106 is selectively energized from the power bus 115 under the control of the controller 108. The controller 108 implements control logic via, for example, a central processing unit 152. The control logic that the controller 108 implements during operation of the rotating machine may differ from the control logic implemented during a shutdown sequence of the rotating machine. For example, during operation of the rotating machine the control logic may implement a predefined schedule of lubricant supply pressure as a function of various conditions. More specifically, the controller 108 may receive signals representative of various parameters. In response to these signals, the control logic in the controller 108 may determine the scheduled lubricant supply pressure based on these parameters, and control the motor 106 to rotate at least the supply pumps 118 at a speed that will supply lubricant from the reservoir 102 at the scheduled lubricant supply pressure. Conversely, during the shutdown sequence, the control logic may control the rotational speed of the motor 106 in accordance with a schedule that will displace at least a substantial volume of the lubricant in the rotating machine with air from the gaseous fluid source 126. Although the controller 108 is depicted using a single function block, it is noted that the controller 108 may be implemented as a single device or as two or more separate devices. For example, the controller 108 may implement the functions of both a motor controller and an engine (or other rotating machine) controller, or the controller 108 may be implemented separately, as a motor control unit and an engine control unit.

[0025] Regardless of the specific physical implementation of the controller 108, and regardless of the specific control logic that is implemented in the controller 108, when the shutdown sequence for the rotating machine is initiated, the system 100 is configured to de-lube the rotating machine. In the depicted embodiment, when the shutdown sequence is initiated, a valve control signal is additionally supplied to the de-lube control valve 128 that causes the de-lube control valve 128 to move to a position that fluidly communicates the supply pump inlets 117 with the gaseous fluid source 126. It will be appreciated that this valve control signal may be supplied from the controller 108 or from another device. Preferably, however, the valve control signal is supplied from the controller 108. When the shutdown sequence is initiated, a de-lube signal indicating that the rotating machine is being de-lubricated is additionally supplied to the controller 108. The de-lube signal may be generated within the controller 108 or it may be supplied to the controller 108 from another device.

[0026] No matter the specific source of the de-lube signal, the controller 108, in response to the de-lube signal, controllably energizes the motor 106 from the power bus

115. Because the supply pump inlets 117 are in fluid communication with the gaseous fluid source 126, air is discharged from the supply pumps 118 into the supply line 124. As alluded to above, the control logic implemented by the controller 108 during the shutdown sequence controls the rotational speed of the motor 106 in accordance with a schedule that will displace at least a substantial volume of the lubricant in the rotating machine with air from the gaseous fluid source 126.

[0027] In addition to the above, the controller 108 is also responsive to the de-lube signal to cause the bypass control valve 146 to move to a position that results in the fluid bypass line 144 remaining at least substantially full of lubricant when the lubricant is displaced from the fluid supply line 124 and the rotating machine. The manner in which the controller 108 implements this functionality may vary, but in the depicted embodiment the controller 108 supplies one or more signals that results in the bypass control valve 146 moving to the open position. With the bypass control valve 146 in the open position, the air being discharged by the pump will preferentially flow through the fluid supply line 124 and into and through the rotating machine, rather than through the fluid bypass line 144. This will result in the lubricant being displaced from the fluid supply line 124 and the rotating machine, yet the fluid bypass line 144 will remain full, or at least substantially full, of lubricant.

[0028] As was just noted, the controller 108 may cause the bypass control valve 146 to open in accordance with any one of numerous implementations. In one particular embodiment, the controller 108 supplies one or more signals that directly or indirectly results in an increased flow rate of the fluid from the second fluid system 175 through the heat exchanger 154. Because the flow rate of this fluid through the heat exchanger 154 increases, the amount of heat transfer from the lubricant to the fluid also increases, thereby cooling the lubricant in the fluid bypass line 144. The increase in flow rate of the fluid from the second fluid system 175 through the heat exchanger 154 is sufficient to maintain lubricant temperature at the outlet of the bypass control valve 146 at or below the temperature at which the bypass control valve 146 will open.

[0029] It will be appreciated that in other embodiments, such as when the bypass control valve 146 is disposed in the fluid bypass line 144, the controller 108 will supply one or more signals that directly or indirectly cause the bypass control valve 146 to remain closed. It will additionally be appreciated that for those embodiments in which the bypass control valve 146 is implemented with an electric, hydraulic, or pneumatic actuator, the controller could supply suitable signals directly to the actuator that appropriately position the bypass control valve 146 to either prevent or inhibit air flow through the fluid bypass line 144 during the de-lubrication portion of the machine shutdown sequence.

[0030] The above-described process results in a portion of the lubrication supply system 100 remaining full,

or at least substantially full, of lubricant following the shut-down of the rotating machine. Hence, the lubricant fill volume during a subsequent start sequence of the rotating machine will be reduced relative to a system that is fully purged of its lubricant, and the lubricant pressure in the system 100 will rise relatively quicker. As a result, the electrical power drawn by the motor 106 during the start sequence is significantly reduced relative to a system that was fully purged of its lubricant.

[0031] While the invention has been described with reference to a preferred embodiment, it will be understood by those skilled in the art that various changes may be made and equivalents may be substituted for elements thereof without departing from the scope of the invention. In addition, many modifications may be made to adapt to a particular situation or material to the teachings of the invention without departing from the essential scope thereof. Therefore, it is intended that the invention not be limited to the particular embodiment disclosed as the best mode contemplated for carrying out this invention, but that the invention will include all embodiments falling within the scope of the appended claims.

Claims

1. An aircraft lubrication supply system (100), comprising:

a motor (106) coupled to be selectively energized from a power bus (115) and operable, upon being energized, to rotate at a rotational speed and supply a drive force;

a pump (104) having at least a fluid inlet and a fluid outlet, the pump coupled to receive the drive force from the motor (106) and configured, in response thereto, to draw fluid into the fluid inlet from either a lubricant source (102) or a gaseous fluid source (126), and to discharge the fluid via the fluid outlet;

a fluid supply line (124) coupled to the fluid outlet and configured to supply the fluid discharged from the fluid outlet to a rotating machine;

a fluid bypass line (144) having an inlet and an outlet, the fluid bypass line (144) inlet coupled to the fluid supply line (124) at a first location, the fluid bypass line (144) outlet coupled to the fluid supply line (124) at a second location that is downstream of the first location;

a bypass control valve (146) disposed between the fluid bypass line (144) inlet and the fluid bypass line (144) outlet, the bypass control valve (146) operable to control fluid flow at least through the fluid bypass line (144); and

a controller (108) configured to couple to the power bus (115) and to receive a machine de-lube signal, the machine de-lube signal indicating that the rotating machine is being de-lubri-

cated, the controller (108) operable, upon receipt of the machine de-lube signal, to:

- (i) controllably energize the motor (106) from the power bus (115) to thereby displace at least a substantial volume of lubricant (112) in the fluid supply line (124) and the rotating machine with fluid from the gaseous fluid source (126), and
- (ii) cause the bypass control valve (146) to move to a position that results in the fluid bypass line (144) remaining at least substantially full of lubricant (112) when the at least substantial volume of lubricant (112) is displaced from the fluid supply line (124) and the rotating machine.

2. The system of Claim 1, wherein the bypass control valve (146) is disposed in the supply line (124) between the first location and the second location.

3. The system of Claim 1, wherein the bypass control valve (146) is disposed in the fluid bypass line between the bypass inlet and the fluid bypass line outlet.

4. The system of Claim 1, wherein the bypass control valve (146) is responsive to fluid temperature to thereby control fluid flow at least through the fluid bypass line (144).

5. The system of Claim 1, further comprising:

a heat exchanger (154) coupled to receive fluid flowing in the fluid bypass line (144) and a second fluid flowing in a second fluid system (175) at a flow rate, the heat exchanger (154) configured to allow heat transfer between the fluid flowing in the bypass line (144) and the second fluid.

6. The system of Claim 1, further comprising:

a de-lube control valve (128) in fluid communication with the pump fluid inlet, the de-lube control valve (128) movable between at least a first position, in which the pump fluid inlet is in fluid communication with the gaseous fluid source (126), and a second position, in which the pump fluid inlet is not in fluid communication with the gaseous fluid source (126).

7. A method of removing lubricant (112) from a lubrication supply system (100) and a rotating machine supplied with lubricant (112) by the lubrication supply system (100), the method comprising the steps of:

supplying a gaseous fluid to the lubrication sup-

ply system (100) to displace the lubricant (112);
preferentially directing the gaseous fluid through
a first section of the lubrication supply system
(100) and to the rotating machine, and at least
inhibiting the gaseous fluid from flowing through
a second section of the lubrication supply sys-
tem (100),
whereby the gaseous fluid displaces the lubri-
cant (112) in the rotating machine and in the first
section of the lubrication supply system (100),
and the second section of the lubrication supply
system (100) remains at least substantially full
of lubricant (112).

8. The method of Claim 7, wherein the lubrication supply system (100) includes a control valve that, based on its position, selectively at least inhibits fluid flow through the second section of the lubrication supply system (100), and wherein the method further comprises:

positioning the control valve to a position that at least inhibits fluid flow through the second section of the lubrication supply system (100).

9. The method of Claim 7, wherein:

the control valve is disposed in the first section of the lubrication supply system (100); and
the step of position the control valve comprises positioning the control valve to an open position.

10. The method of Claim 7, wherein
the control valve is disposed in the second section of the lubrication supply system (100); and
the step of position the control valve comprises positioning the control valve to a closed position.

