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(54) **MOVABLE-BLADE OPERATION SYSTEM FOR HYDRAULIC MACHINE**

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(57) **ABSTRACT**

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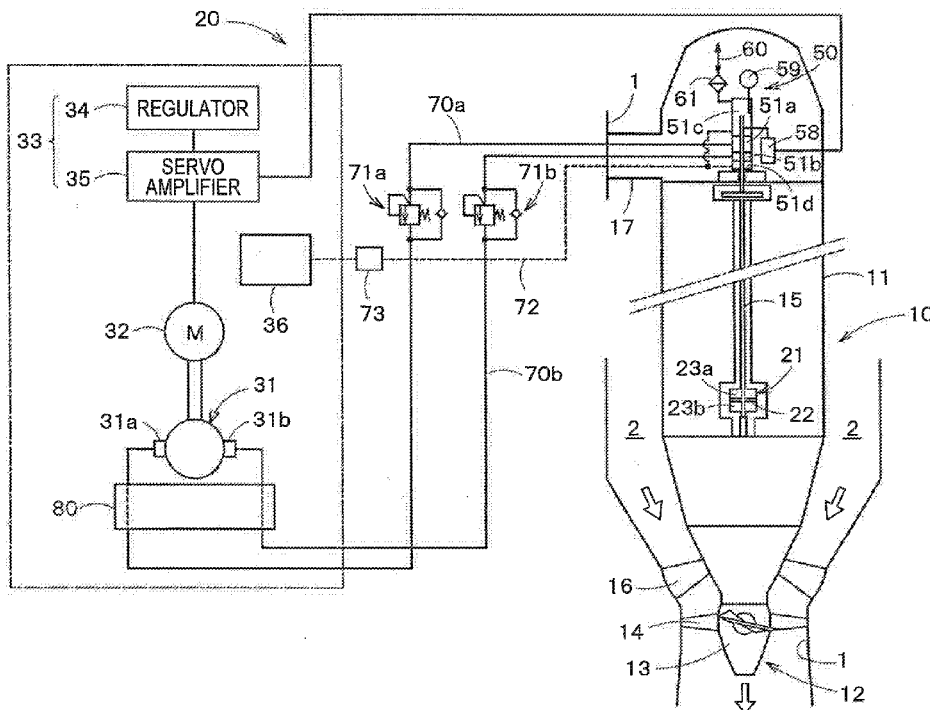
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A movable-blade operation system for a hydraulic machine according to an embodiment includes an oil hydraulic cylinder installed within a rotational shaft, a bidirectional pump, a pump drive motor, a control unit, and an oil head installed in the hydraulic machine. The bidirectional pump selectively feeds pressurized hydraulic oil to one of a first cylinder chamber and a second cylinder chamber. The oil head couples the rotational shaft rotatably, and the hydraulic oil fed from the bidirectional pump to the first cylinder chamber and the second cylinder chamber flows through the oil head. The bidirectional pump, the pump drive motor, and the control unit are installed outside the hydraulic machine.



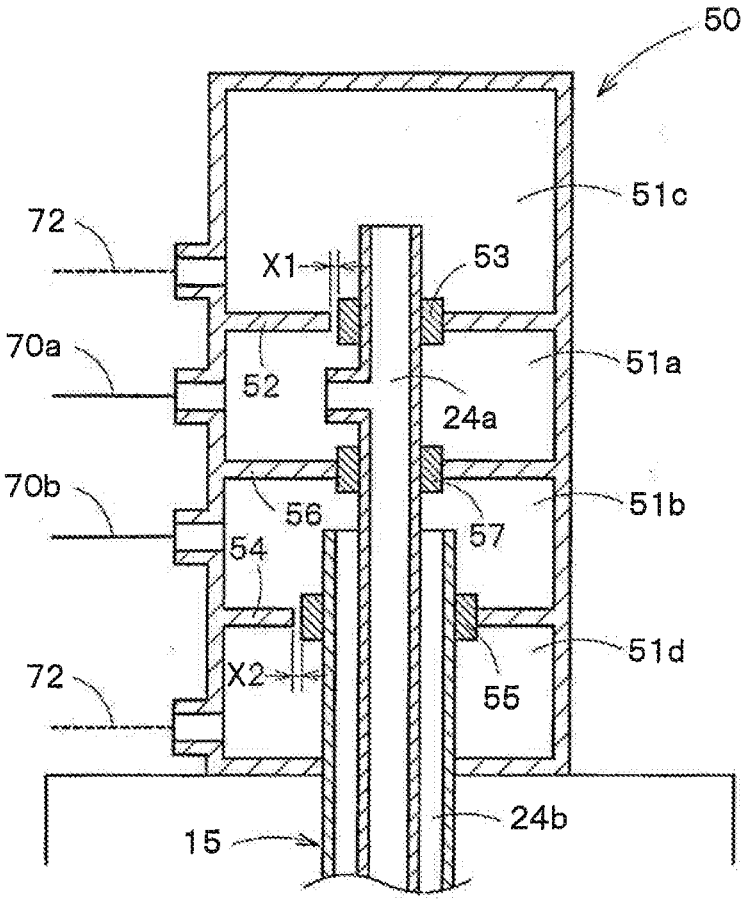


FIG. 2

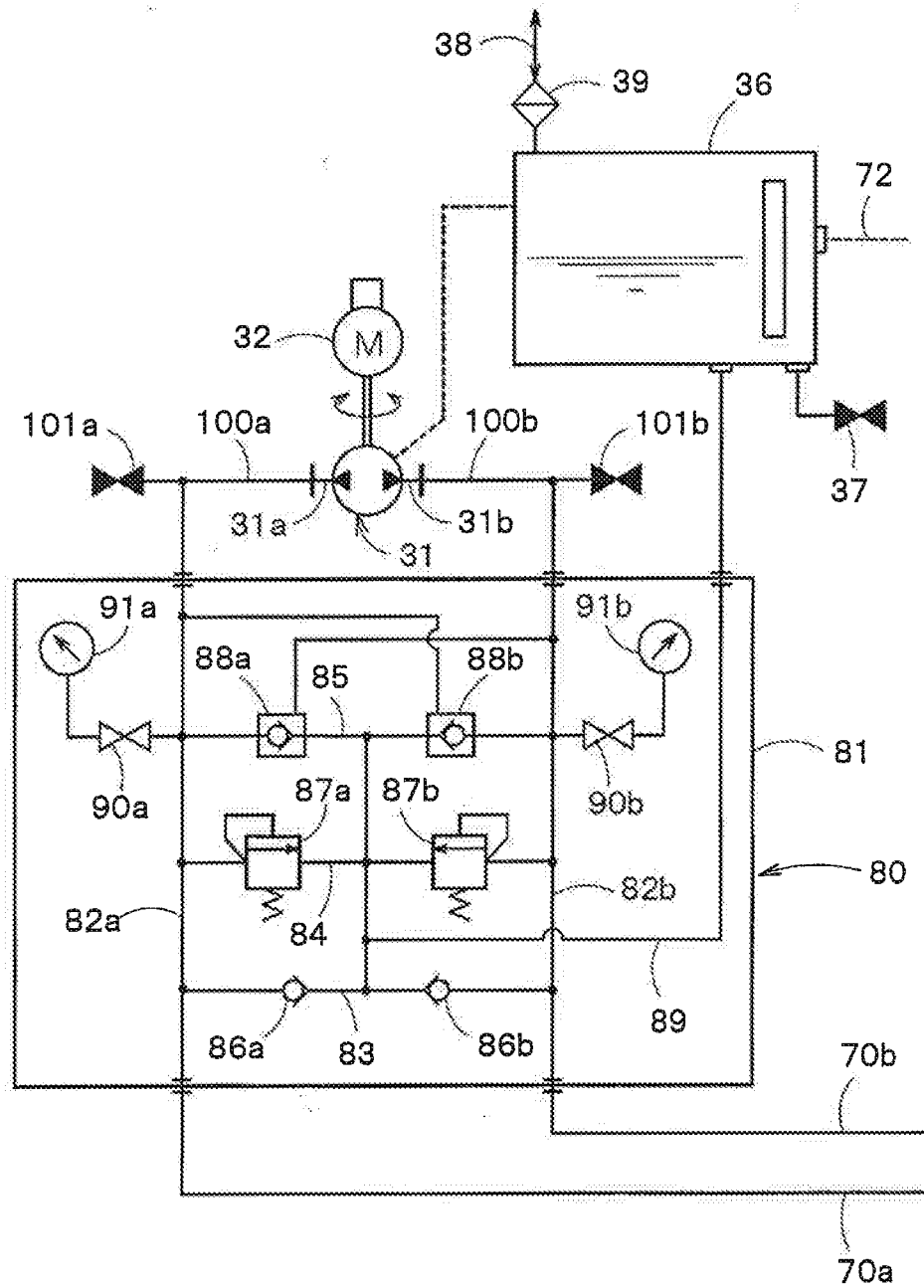


FIG. 3

MOVABLE-BLADE OPERATION SYSTEM FOR HYDRAULIC MACHINE

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This application is based upon and claims the benefit of priority from Japanese Patent Application No. 2017-060094 filed on Mar. 24, 2017; the entire contents of which are incorporated herein by reference.

[0002] Embodiments of the present invention relate to a movable-blade operation system for a hydraulic machine.

BACKGROUND

[0003] A hydraulic machine includes runner vanes that experience a water current force to drive the rotation of an electric generator. The runner vanes in the hydraulic machine such as a bulb turbine or a Kaplan turbine have adjustable opening. To adjust the runner vane opening, a movable-blade operation system is installed. The movable-blade operation system may also be used to adjust the opening of guide vanes installed for regulating a water current flowing into the runner.

[0004] Known examples of the movable-blade operation system include a movable-blade operation system with a pressure oil tank and a compressor. In the movable-blade operation system, the compressor increases the pressure of the hydraulic oil contained in the pressure oil tank. The pressurized hydraulic oil in the pressure oil tank is fed to an oil hydraulic cylinder to adjust the opening of the movable blades. Components such as the pressure oil tank and the compressor are installed outside the main body of the hydraulic machine (e.g., the bulb of a bulb turbine).

[0005] However, such a movable-blade operation system with a pressure oil tank uses a larger amount of hydraulic oil. Thus, if an oil leakage should happen, a large amount of leakage oil would adversely affect the environment.

[0006] As a technique to offset the difficulty, for a small or medium capacity hydraulic machine, an electric-servo movable-blade operation apparatus is known that includes an electric servomotor as an actuator. This operation apparatus may use a smaller amount of hydraulic oil, and even if an oil leakage should happen, its amount may be reduced. The operation apparatus may thus be environment-friendly.

[0007] However, in the electric-servo movable-blade operation apparatus, the electric servomotor and each movable blade are connected via a ball screw, which is a special part. Thus, the replacement of a ball screw following a failure or a similar event takes a long time.

[0008] To overcome the difficulty, electric-servo movable-blade operation apparatuses for guide vanes have been replaced with direct-pressurizing movable-blade operation systems that include general-purpose components. A direct-pressurizing movable-blade operation system directly feeds hydraulic oil pressurized by a pump or other mechanism to an oil hydraulic cylinder without using the pressure oil tank described above. This system may thus use a smaller amount of hydraulic oil.

[0009] However, the oil hydraulic cylinder (oil hydraulic servomotor) for runner vanes is installed within a rotational shaft that rotates together with the runner. Thus, if a direct-pressurizing movable-blade operation system for runner vanes is used, a runner vane controller including a pump for feeding pressurized hydraulic oil to the oil hydraulic cylinder

of other mechanism is installed within the main body of the hydraulic machine and near the rotational shaft.

[0010] Thus, in order to modify a movable-blade operation system with a pressure oil tank of other mechanism as described above into a direct-pressurizing movable-blade operation system, a runner vane controller is installed within the main body of the hydraulic machine, and the main body of the hydraulic machine is substantially remodeled. This modification of the movable-blade operation system may involve a heavy workload and a long working time.

BRIEF DESCRIPTION OF THE DRAWINGS

[0011] FIG. 1 illustrates the whole configuration of a movable-blade operation system for a hydraulic machine according to one embodiment.

[0012] FIG. 2 is an enlarged schematic view illustrating the structure of an oil head illustrated in FIG. 1.

[0013] FIG. 3 is a detailed view illustrating the configuration of a runner vane controller in FIG. 1.

DETAILED DESCRIPTION

[0014] A movable-blade operation system for a hydraulic machine according to an embodiment adjusts the opening of movable blades that rotate together with a rotational shaft of the hydraulic machine. The movable-blade operation system includes an oil hydraulic cylinder in the rotational shaft, a bidirectional pump, a pump drive motor for driving the bidirectional pump, a control unit for controlling the pump drive motor, and an oil head in the hydraulic machine. The oil hydraulic cylinder includes a piston connected to the movable blades, and a first cylinder chamber and a second cylinder chamber defined by the piston. The bidirectional pump selectively feeds pressurized hydraulic oil to one of the first cylinder chamber and the second cylinder chamber. The oil head, to which the rotational shaft is rotatably connected, allows the passage of the hydraulic oil to be fed from the bidirectional pump to the first cylinder chamber and the second cylinder chamber. The bidirectional pump, the pump drive motor, and the control unit are installed outside the hydraulic machine.

[0015] The movable-blade operation system for the hydraulic machine according to one embodiment of the present invention will now be described with reference to the drawings. In this example, the hydraulic machine is a bulb turbine.

[0016] A bulb turbine 10 will now be described first with reference to FIG. 1.

[0017] The bulb turbine 10 is installed in a water flow channel through which water flows from an upper reservoir (not shown). The water flow channel is defined by a channel wall 1 formed as a civil engineering structure. In the present embodiment, the channel wall 1 extends in a perpendicular direction, and the bulb turbine 10 illustrated in FIG. 1 is a vertical shaft bulb turbine.

[0018] The bulb turbine 10 includes a bulb 11 (main body of the hydraulic machine) and a rotatable runner 12 installed at the downstream end of the bulb 11. The runner 12 includes a runner hub 13 and multiple runner vanes 14 (movable blades) retained on the runner hub 13. The runner vanes 14 are turnable about the runner hub 13, and the opening of the runner vanes 14 is adjustable. The bulb 11 contains an electric generator (not shown), which is connected with the runner hub 13 via a rotational shaft 15. With this structure,

when the runner vanes **14** receive a water current, the runner vanes **14**, the runner hub **13**, and the rotational shaft **15** rotate together with each other. The resulting rotational drive force allows the electric generator to generate electric power. Running water that has exited the runner **12** flows into a lower reservoir (or a tailrace) (not shown).

[0019] The bulb **11** and the channel wall **1** of the bulb turbine **10** have a flow channel **2** between them. In the flow channel **2**, water that has entered the runner **12** flows. The flow channel **2** includes multiple guide vanes **16** (guide blades) upstream of the runner **12**. The guide vanes **16** can adjust the amount of a water current flowing into the runner **12**. The guide vanes **16** are turnable about the bulb **11**, and the opening of the guide vanes **16** is adjustable.

[0020] An access port **17** is formed upstream of the guide vanes **16**. The access port **17** extends from the bulb **11** to the channel wall **1** and allows an internal inspection of the bulb **11** in the bulb turbine **10**. The access port **17** also functions as a support for the bulb **11** together with other members (not shown).

[0021] A movable-blade operation system **20** for the hydraulic machine according to the present embodiment adjusts the opening of the runner vanes **14** as described above. The movable-blade operation system **20** will now be described.

[0022] As illustrated in FIG. 1, the movable-blade operation system **20** includes an oil hydraulic cylinder **21** (runner vane servomotor) installed within the rotational shaft **15**, a runner vane controller **30** for controlling the oil hydraulic cylinder **21**, and an oil head **50**. In the present embodiment, the runner vane controller **30** includes a bidirectional pump **31**, an AC servomotor **32**, and a control unit **33**, which are described later, and is located outside the bulb **11** of the bulb turbine **10**. For example, the runner vane controller **30** is suitably located in the building of a hydroelectric power plant including the bulb turbine **10**.

[0023] The oil hydraulic cylinder **21** includes a piston **22** connected to the runner vanes **14**, and a first cylinder chamber **23a** and a second cylinder chamber **23b** defined by the piston **22**. The piston **22** is connected to the runner vanes **14** via a runner vane operation mechanism (not shown) including an operation rod. In the present embodiment, the oil hydraulic cylinder **21** is installed within the rotational shaft **15** and near the runner **12**. This arrangement allows the runner vane operation mechanism to be simplified in structure, offering advantages in mechanical strength.

[0024] The first cylinder chamber **23a** and the second cylinder chamber **23b** are filled with hydraulic oil fed from the bidirectional pump **31** of the runner vane controller **30**. When the pressure of the hydraulic oil contained in the first cylinder chamber **23a** exceeds the pressure of the hydraulic oil contained in the second cylinder chamber **23b**, the runner vanes **14** turn in a first direction (e.g., the opening direction). When the pressure of the hydraulic oil contained in the second cylinder chamber **23b** exceeds the pressure of the hydraulic oil contained in the first cylinder chamber **23a**, the runner vanes **14** turn in a second direction opposite to the first direction (e.g., the closing direction).

[0025] As illustrated in FIG. 2, the rotational shaft **15** of the bulb turbine **10** includes a first internal channel **24a** communicating with the first cylinder chamber **23a** and a second internal channel **24b** communicating with the second cylinder chamber **23b**. In the present embodiment, the first internal channel **24a** extends along the central axis of

rotation of the rotational shaft **15**, whereas the second internal channel **24b** is cylindrical and formed concentrically around the first internal channel **24a**.

[0026] As illustrated in FIG. 1, the runner vane controller **30** includes the bidirectional pump **31** for selectively feeding pressurized hydraulic oil to one of the first cylinder chamber **23a** and the second cylinder chamber **23b**, the AC servomotor **32** (pump drive motor) for driving the bidirectional pump **31**, and the control unit **33** for controlling the AC servomotor **32**. The bidirectional pump **31** includes a first port **31a** and a second port **31b**, and draws hydraulic oil in via one of the first port **31a** and the second port **31b**, and discharges the hydraulic oil via the other.

[0027] The control unit **33** includes a regulator **34** (control command unit) for issuing a rotational speed command value to the AC servomotor **32**, and a servo amplifier **35** (amplifier) for supplying the AC servomotor **32** with the power corresponding to the rotational speed command value issued from the regulator **34**. When the servo amplifier **35** supplies the AC servomotor **32** with the power corresponding to the rotational speed command value, the AC servomotor **32** drives the bidirectional pump **31** in a forward direction or a reverse direction to feed pressurized hydraulic oil from the bidirectional pump **31** to one of the first cylinder chamber **23a** and the second cylinder chamber **23b**.

[0028] The runner vane controller **30** further includes a sump tank **36** storing hydraulic oil to be fed to the first cylinder chamber **23a** and the second cylinder chamber **23b**, and an oil pressure regulator **80**, which are installed outside the bulb **11** of the bulb turbine **10**. When an insufficient amount of hydraulic oil is fed to the first cylinder chamber **23a** or the second cylinder chamber **23b**, the hydraulic oil stored in the sump tank **36** is supplied to a first pipe **70a** or a second pipe **70b** described later. As illustrated in FIG. 3, the sump tank **36** has an exhaust valve **37** that allows the hydraulic oil in the sump tank **36** to be discharged. The sump tank **36** also has a vent **38** that allows the pressure in the sump tank **36** to be maintained at atmospheric pressure. The vent **38** has a filter **39**. The oil pressure regulator **80** will be described in detail later.

[0029] As illustrated in FIG. 1, the bulb **11** of the bulb turbine **10** contains the oil head **50**. In FIG. 1, the oil head **50** is placed at the upstream end of the bulb **11**. The rotational shaft **15** is rotatably coupled to the oil head **50**, which allows the passage of the hydraulic oil to be fed from the bidirectional pump **31** to the first cylinder chamber **23a** and the second cylinder chamber **23b**.

[0030] As illustrated in FIGS. 1 and 2, the oil head **50** includes a first head chamber **51a** that connects the first port **31a** of the bidirectional pump **31** and the first cylinder chamber **23a**, and a second head chamber **51b** that connects the second port **31b** of the bidirectional pump **31** and the second cylinder chamber **23b**. More specifically, the first head chamber **51a** connects the first pipe **70a** (described later) and the first internal channel **24a**, whereas the second head chamber **51b** connects the second pipe **70b** (described later) and the second internal channel **24b**.

[0031] The first head chamber **51a** and the second head chamber **51b** are adjacent to each other along the axis of the rotational shaft **15** (in vertical directions in FIG. 2). The first head chamber **51a** is adjacent to a third head chamber **51c**, whereas the second head chamber **51b** is adjacent to a fourth head chamber **51d**. In the present embodiment, the fourth head chamber **51d**, the second head chamber **51b**, the first

head chamber **51a**, and the third head chamber **51c** are arranged in this order in a direction away from the oil hydraulic cylinder **21**.

[0032] As illustrated in FIG. 2, the first head chamber **51a** and the third head chamber **51c** are separated by a first divider **52**. The rotational shaft **15** extends through the first divider **52**. The first divider **52** and the rotational shaft **15** have a first seal **53** between them. The first seal **53** and the first divider **52** have a gap **X1** between them. This structure allows the hydraulic oil contained in the first head chamber **51a** to partially flow into the third head chamber **51c**. Note that the gap **X1** is just wide enough to allow an effective increase in the pressure of the hydraulic oil contained in the first cylinder chamber **23a**. The gap **X1** is opened not in whole circumference of the first seal **53**, but is partially formed in the circumference. The first seal **53** is supported by the first divider **52**.

[0033] The second head chamber **51b** and the fourth head chamber **51d** are separated by a second divider **54**. The rotational shaft **15** extends through the second divider **54**. The second divider **54** and the rotational shaft **15** have a second seal **55** between them. Any gap through which hydraulic oil is made to flow, like the gap **X1**, is not formed between the second seal **55** and the second divider **54**. That is, hydraulic oil is prevented from traveling between the second head chamber **51b** and the fourth head chamber **51d**. However, hydraulic oil in the second head chamber **51b** flows into the fourth head chamber **51d** via a minute gap, and is stored in the fourth head chamber **51d**. The fourth head chamber **51d** includes a barrier **62** that prevents the hydraulic oil in the fourth head chamber **51d** from flowing into the bulb **11**.

[0034] The second head chamber **51b** is connected with a head line **X2** that communicates with the third head chamber **51c**, and the hydraulic oil contained in the second head chamber **51b** partially flows into the third head chamber **51c**. This structure can prevent the depletion of the hydraulic oil contained in the third head chamber **51c**, and allows a bearing (not shown) within the third head chamber **51c** for rotatably supporting the rotational shaft **15** to be immersed in the hydraulic oil. The structure can also prevent air taken via a vent **60** described later from entering the first head chamber **51a** or the like. The head line **X2** has a flow channel cross-sectional area just enough to allow an effective increase in the pressure of the hydraulic oil contained in the second cylinder chamber **23b**.

[0035] The first head chamber **51a** and the second head chamber **51b** are separated by a third divider **56**. The rotational shaft **15** extends through the third divider **56**. The third divider **56** and the rotational shaft **15** have a third seal **57** between them. Any gap through which hydraulic oil is made to flow, like the gap **X1** or the head line **X2**, is not formed between the third seal **57** and the third divider **56**. That is, hydraulic oil is prevented from traveling between the first head chamber **51a** and the second head chamber **51b**.

[0036] As illustrated in FIG. 1, the oil head **50** includes an opening position detector **58** for detecting the opening position of the runner vanes **14**. The opening position detection value for the runner vanes **14** detected by the opening position detector **58** is transmitted to the regulator **34** described above. The regulator **34** calculates the difference between the opening position detection value for the runner vanes **14** transmitted from the opening position

detector **58**, and an opening position command value into which an opening command value for the runner vanes **14** transmitted from a control apparatus (not shown) is converted. The calculated difference is transmitted to the servo amplifier **35**. The servo amplifier **35** determines whether the difference is greater than a predetermined value. The servo amplifier **35** has a changeover function for increasing the rotational speed of the AC servomotor **32** upon determining that the difference is greater than the predetermined value.

[0037] The oil head **50** also includes an oil level detector **59** for detecting the oil level of the hydraulic oil contained in the third head chamber **51c**. If the value of the oil level detected by the oil level detector **59** is smaller than a predetermined value, the first pipe **70a** or the second pipe **70b** described later is suitably supplied with hydraulic oil from the sump tank **36**. This prevents a lowered oil level from causing air in the third head chamber **51c** to enter the first pipe **70a**. The oil head **50** also has the vent **60** that connects the inside of the third head chamber **51c** and the atmosphere, and thus the internal pressure of the third head chamber **51c** is maintained at atmospheric pressure. The vent **60** has a filter **61**.

[0038] The bidirectional pump **31** and the oil head **50** are coupled by the first pipe **70a** and the second pipe **70b**. The first pipe **70a** connects the first port **31a** of the bidirectional pump **31** and the first head chamber **51a** of the oil head **50**. More specifically, the first pipe **70a** extends from the first head chamber **51a** of the oil head **50** included in the bulb **11** in a direction away from the bulb **11**, and communicates with the first port **31a** of the bidirectional pump **31**.

[0039] Similarly, the second pipe **70b** connects the second port **31b** of the bidirectional pump **31** and the second head chamber **51b** of the oil head **50**. More specifically, the second pipe **70b** extends from the second head chamber **51b** of the oil head **50** included in the bulb **11** in a direction away from the bulb **11**, and communicates with the second port **31b** of the bidirectional pump **31**. In this manner, the first port **31a** of the bidirectional pump **31** communicates with the first cylinder chamber **23a** via the first head chamber **51a**, whereas the second port **31b** communicates with the second cylinder chamber **23b** via the second head chamber **51b**.

[0040] The first pipe **70a** and the second pipe **70b** may also extend through the access port **17** described above. This arrangement enables the first pipe **70a** and the second pipe **70b** to avoid being exposed to a water current, and allows the pipes **70a**, **70b** to be simplified in structure, offering advantages in mechanical strength. Each of the first pipe **70a** and the second pipe **70b** may be formed of multiple pipes connected to each other.

[0041] As illustrated in FIG. 1, the first pipe **70a** has a first counterbalance valve **71a**. The first counterbalance valve **71a** prevents a pressure drop of the hydraulic oil contained in the first head chamber **51a** of the oil head **50**. More specifically, although the first counterbalance valve **71a** permits the flow of hydraulic oil from the first port **31a** of the bidirectional pump **31** to the first head chamber **51a**, the first counterbalance valve **71a** prevents the flow of hydraulic oil from the first head chamber **51a** to the first port **31a**. Thus, upon a pressure drop of the hydraulic oil contained in the first head chamber **51a**, hydraulic oil flows from the bidirectional pump **31** to the first head chamber **51a** to increase the pressure. This mechanism maintains the pressure of the hydraulic oil contained in the first head chamber **51a** at a

certain level or higher. In contrast, when the pressure of the hydraulic oil contained in the first head chamber 51a rises to a predetermined value or greater, the first counterbalance valve 71a permits the flow of hydraulic oil from the first head chamber 51a to the bidirectional pump 31. In the present embodiment, the first counterbalance valve 71a and a second counterbalance valve 71b are installed outside the bulb 11 of the bulb turbine 10 as well as outside the runner vane controller 30.

[0042] Similarly, the second pipe 70b has the second counterbalance valve 71b. The second counterbalance valve 71b has the same function as the first counterbalance valve 71a, and a detailed description thereof is omitted herein.

[0043] As illustrated in FIG. 1, the sump tank 36 and the oil head 50 are coupled by a recovery pipe 72. The recovery pipe 72 extends from the third head chamber 51c and the fourth head chamber 51d of the oil head 50 included in the bulb 11 in a direction away from the bulb 11, and communicates with the sump tank 36. The recovery pipe 72 recovers the hydraulic oil contained in the third head chamber 51c and the hydraulic oil contained in the fourth head chamber 51d and returns them to the sump tank 36. The recovery pipe 72 may extend through the access port 17 like the first pipe 70a and the second pipe 70b.

[0044] The sump tank 36 is coupled to a circulation pipe 73 for circulating the stored hydraulic oil. The circulation pipe 73 includes a circulation pump 74 and a hot-line oil purifier 75. The hot-line oil purifier 75 purifies the hydraulic oil passing through the circulation pipe 73. In FIG. 3, the circulation pipe 73 is omitted for visual clarity.

[0045] The oil pressure regulator 80 of the runner vane controller 30 will now be described in detail with reference to FIG. 3.

[0046] The oil pressure regulator 80 regulates the pressure of the hydraulic oil in the system in the side of the first pipe 70a and the pressure of the hydraulic oil in the system in the side of the second pipe 70b. More specifically, during the operation of the movable-blade operation system 20, the amount of the hydraulic oil contained in the system in the side of the first pipe 70a decreases, and the amount of the hydraulic oil contained in the system in the side of the second pipe 70b also decreases. A decrease in the oil amount causes a pressure drop of the hydraulic oil. To address this, the runner vane controller 30 in the present embodiment includes the oil pressure regulator 80.

[0047] As illustrated in FIG. 3, the oil pressure regulator 80 includes a housing 81, and a first main line 82a and a second main line 82b provided in the housing 81.

[0048] The first main line 82a connects the first pipe 70a and the first port 31a of the bidirectional pump 31, whereas the second main line 82b connects the second pipe 70b and the second port 31b of the bidirectional pump 31. The first main line 82a and the second main line 82b are connected by a first bypass line 83, a second bypass line 84, and a third bypass line 85. The first bypass line 83 includes a first check valve 86a and a second check valve 86b. The second bypass line 84 includes a first relief valve 87a and a second relief valve 87b. The third bypass line 85 includes a first pilot check valve 88a and a second pilot check valve 88b.

[0049] The first bypass line 83, the second bypass line 84, and the third bypass line 85 communicate with a supply line 89 extending from the sump tank 36. The supply line 89 feeds hydraulic oil supplied from the sump tank 36 to the first bypass line 83 between the first check valve 86a and the

second check valve 86b, to the second bypass line 84 between the first relief valve 87a and the second relief valve 87b, and to the third bypass line 85 between the first pilot check valve 88a and the second pilot check valve 88b.

[0050] The first check valve 86a prevents the flow of hydraulic oil from the first main line 82a to the sump tank 36, and permits the flow of hydraulic oil from the sump tank 36 to the first main line 82a. Thus, when the pressure of the hydraulic oil contained in the first main line 82a falls below the pressure of the hydraulic oil contained in the sump tank 36 (or atmospheric pressure), hydraulic oil is supplied from the sump tank 36 to the first main line 82a. Similarly, when the pressure of the hydraulic oil contained in the second main line 82b falls below the pressure of the hydraulic oil contained in the sump tank 36, the second check valve 86b allows hydraulic oil to be supplied from the sump tank 36 to the second main line 82b.

[0051] When the pressure of the hydraulic oil contained in the first main line 82a rises to a predetermined value or higher, the first relief valve 87a described above permits the flow of hydraulic oil from the first main line 82a to the sump tank 36. This mechanism prevents the pressure of the hydraulic oil contained in the first main line 82a from becoming excessively high. Similarly, when the pressure of the hydraulic oil contained in the second main line 82b rises to a predetermined value or higher, the second relief valve 87b described above permits the flow of hydraulic oil from the second main line 82b to the sump tank 36. This mechanism prevents the pressure of the hydraulic oil contained in the second main line 82b from becoming excessively high.

[0052] The first pilot check valve 88a and the second pilot check valve 88b described above permit the flow of hydraulic oil in the third bypass line 85 depending on the pressure ratio between the pressure of the hydraulic oil contained in the first main line 82a and the pressure of the hydraulic oil contained in the second main line 82b. More specifically, the first pilot check valve 88a normally prevents the flow of hydraulic oil from the first main line 82a to the sump tank 36. However, when the internal pressure of the second main line 82b increases and the ratio of the pressure in the second main line 82b to the pressure in the first main line 82a rises, the first pilot check valve 88a permits the flow of hydraulic oil from the first main line 82a to the sump tank 36. The first pilot check valve 88a also permits the flow of hydraulic oil from the second main line 82b to the first main line 82a. The first pilot check valve 88a also has the same function as the first check valve 86a described above.

[0053] Similarly, the second pilot check valve 88b normally prevents the flow of hydraulic oil from the second main line 82b to the sump tank 36. However, when the internal pressure of the first main line 82a increases and the ratio of the pressure in the first main line 82a to the pressure in the second main line 82b rises, the second pilot check valve 88b permits the flow of hydraulic oil from the second main line 82b to the sump tank 36. The second pilot check valve 88b also permits the flow of hydraulic oil from the first main line 82a to the second main line 82b. The second pilot check valve 88b also has the same function as the second check valve 86b described above.

[0054] The first main line 82a is coupled to a pressure gauge 91a via a stop valve 90a. The pressure gauge 91a indicates the pressure of the hydraulic oil contained in the first main line 82a. Similarly, the second main line 82b is coupled to a pressure gauge 91b via a stop valve 90b. The

pressure gauge **91b** indicates the pressure of the hydraulic oil contained in the second main line **82b**.

[0055] The first main line **82a** and the first port **31a** of the bidirectional pump **31** are connected by a first communication line **100a**. The first communication line **100a** includes an exhaust valve **101a** that allows the discharge of the hydraulic oil contained in the system in the side of the first pipe **70a**. Similarly, the second main line **82b** and the second port **31b** of the bidirectional pump **31** are connected by a second communication line **100b**. The second communication line **100b** includes an exhaust valve **101b** that allows the discharge of the hydraulic oil contained in the system in the side of the second pipe **70b**.

[0056] The functional effects of the present embodiment with the described structure will now be described.

[0057] When the runner vanes **14** are turned in the first direction, the regulator **34** issues a rotational speed command value to the servo amplifier **35**, and the power corresponding to the rotational speed command value is supplied from the servo amplifier **35** to the AC servomotor **32**. In response, the AC servomotor **32** drives the bidirectional pump **31** to draw hydraulic oil in via the second port **31b** of the bidirectional pump **31** and discharge the hydraulic oil via the first port **31a**. As a result, the pressurized hydraulic oil leaves the bidirectional pump **31** via the first port **31a**, flows through the first main line **82a**, the first pipe **70a**, the first head chamber **51a**, and the first internal channel **24a**, and reaches the first cylinder chamber **23a** of the oil hydraulic cylinder **21**. That is, the supply of the pressurized hydraulic oil increases the pressure of the hydraulic oil contained in the first cylinder chamber **23a**. The increased pressure of the hydraulic oil drives the piston **22** to turn the runner vanes **14** in the first direction via the runner vane operation mechanism (not shown), and the runner vanes **14** are adjusted to a desired opening position.

[0058] During an increase in the pressure of the hydraulic oil contained in the first head chamber **51a**, the opening position detector **58** detects the opening position of the runner vanes **14**, and the opening position detection value for the runner vanes **14** is transmitted to the regulator **34**. The regulator **34** calculates the difference between the opening position detection value and an opening position command value into which an opening command value for the runner vanes **14** transmitted from the control apparatus (not shown) is converted. When the servo amplifier **35** determines that the difference calculated by the regulator **34** is greater than a predetermined value, the servo amplifier **35** uses the changeover function to increase the rotational speed of the AC servomotor **32**. This enables an increase in the hydraulic oil discharging power of the bidirectional pump **31**. The increased discharging power can raise the pressure applied to the oil hydraulic cylinder **21** from the hydraulic oil, resulting in an increased speed of the runner vanes **14** turning in the first direction.

[0059] During this process, the hydraulic oil contained in the first head chamber **51a** partially flows into the third head chamber **51c**. The hydraulic oil that has entered the third head chamber **51c** is recovered through the recovery pipe **72** and returned to the sump tank **36**. The hydraulic oil returned to the sump tank **36** is, as described later, supplied to the system in the side of the first pipe **70a** or the system in the side of the second pipe **70b** as appropriate. This mechanism allows hydraulic oil to be circulated within the movable-

blade operation system **20**, and thus the deterioration of the hydraulic oil can be slowed down.

[0060] When the runner vanes **14** are turned in the second direction, the regulator **34** issues a rotational speed command value to the servo amplifier **35**, and the power corresponding to the rotational speed command value is supplied from the servo amplifier **35** to the AC servomotor **32**. In response, the AC servomotor **32** drives the bidirectional pump **31** to draw hydraulic oil in via the first port **31a** of the bidirectional pump **31** and discharge the hydraulic oil via the second port **31b**. As a result, the pressurized hydraulic oil leaves the bidirectional pump **31** via the second port **31b**, flows through the second main line **82b**, the second pipe **70b**, the second head chamber **51b**, and the second internal channel **24b**, and reaches the second cylinder chamber **23b** of the oil hydraulic cylinder **21**. That is, the supply of the pressurized hydraulic oil increases the pressure of the hydraulic oil contained in the second cylinder chamber **23b**. The increased pressure of the hydraulic oil drives the piston **22** to turn the runner vanes **14** in the second direction opposite to the first direction, and the runner vanes **14** are adjusted to a desired opening position.

[0061] During an increase in the pressure of the hydraulic oil contained in the second head chamber **51b**, the opening position detector **58** detects the opening position of the runner vanes **14**, and the opening position detection value for the runner vanes **14** is transmitted to the regulator **34**. The regulator **34** calculates the difference between the opening position detection value and an opening position command value into which an opening command value for the runner vanes **14** transmitted from the control apparatus (not shown) is converted. When the servo amplifier **35** determines that the difference calculated by the regulator **34** is greater than a predetermined value, the servo amplifier **35** uses the changeover function to increase the rotational speed of the AC servomotor **32**. This enables an increase in the hydraulic oil discharging power of the bidirectional pump **31**. The increased discharging power can raise the pressure applied to the oil hydraulic cylinder **21** from hydraulic oil, resulting in an increased speed of the runner vanes **14** turning in the second direction.

[0062] During this process, the hydraulic oil contained in the second head chamber **51b** partially flows into the fourth head chamber **51d**. The hydraulic oil that has entered the fourth head chamber **51d** is recovered through the recovery pipe **72** and returned to the sump tank **36**. The hydraulic oil returned to the sump tank **36** is, as described later, supplied to the system in the side of the first pipe **70a** or the system in the side of the second pipe **70b** as appropriate. This mechanism allows hydraulic oil to be circulated within the movable-blade operation system **20**, and thus the deterioration of the hydraulic oil can be slowed down.

[0063] During the operation of the movable-blade operation system **20**, when the pressure of the hydraulic oil contained in the first head chamber **51a** of the oil head **50** decreases, the first counterbalance valve **71a** permits the flow of hydraulic oil from the first port **31a** of the bidirectional pump **31** to the first head chamber **51a**. This enables the pressure of the hydraulic oil contained in the first head chamber **51a** to be increased and maintained at a certain level or higher, and prevents the entry of air, which may compromise the operability, into the first head chamber **51a**, the first pipe **70a** communicating with the first head chamber **51a**, and the first internal channel **24a**.

[0064] When the pressure of the hydraulic oil contained in the second head chamber **51b** of the oil head **50** decreases, the second counterbalance valve **71b** permits the flow of hydraulic oil from the second port **31b** of the bidirectional pump **31** to the second head chamber **51b**. This enables the pressure of the hydraulic oil contained in the second head chamber **51b** to be increased and maintained at a certain level or higher, and prevents the entry of air, which may compromise the operability, into the second head chamber **51b**, the second pipe **70b** communicating with the second head chamber **51b**, and the second internal channel **24b**.

[0065] The hydraulic oil stored in the sump tank **36** is partially drawn into the circulation pipe **73** and circulated by the circulation pump **74**. During the circulation, the hydraulic oil is purified by the hot-line oil purifier **75**. This process enables the hydraulic oil stored in the sump tank **36** to be purified, and prevents hydraulic oil contamination, which may compromise the operability. In addition, the position of the hot-line oil purifier **75**, which is not in the first pipe **70a** or the second pipe **70b** but in the circulation pipe **73**, can prevent any malfunction in the hot-line oil purifier **75** from interfering with the operation of the oil hydraulic cylinder **21**.

[0066] The functional effects of the oil pressure regulator **80** will now be described.

[0067] For example, when the ratio of the pressure of the hydraulic oil contained in the second main line **82b** to the pressure of the hydraulic oil contained in the first main line **82a** is high, the first pilot check valve **88a** permits the flow of hydraulic oil from the first main line **82a** to the sump tank **36**. As a result, the hydraulic oil contained in the first main line **82a** flows into the sump tank **36** to prevent an abnormal increase in the pressure of the hydraulic oil contained in the first main line **82a**. More specifically, in the case where the system in the side of the first pipe **70a** has a capacity larger than the capacity of the system in the side of the second pipe **70b**, when hydraulic oil is drawn in via the first port **31a** of the bidirectional pump **31** and discharged via the second port **31b**, the piston **22** of the oil hydraulic cylinder **21** may stop unless the hydraulic oil corresponding to the capacity difference between the capacity of the system in the side of the first pipe **70a** and the capacity of the system in the side of the second pipe **70b** is fed to the sump tank **36**. As a result, the pressure of the hydraulic oil contained in the first main line **82a** may increase abnormally. In the case where the system in the side of the first pipe **70a** has a capacity larger than the capacity of the system in the side of the second pipe **70b**, the first pilot check valve **88a** serves as a flow channel for feeding the hydraulic oil corresponding to the capacity difference between the capacity of the system in the side of the first pipe **70a** and the capacity of the system in the side of the second pipe **70b** to the sump tank **36** in order not to stop the piston **22**. Additionally, the operation of the piston **22** can effectively prevent a pressure rise in the hydraulic oil contained in the first main line **82a**.

[0068] In contrast, when the ratio of the pressure of the hydraulic oil contained in the first main line **82a** to the pressure of the hydraulic oil contained in the second main line **82b** is high, the second pilot check valve **88b** permits the flow of hydraulic oil from the second main line **82b** to the sump tank **36**. As a result, the hydraulic oil contained in the second main line **82b** flows into the sump tank **36** to prevent an abnormal increase in the pressure of the hydraulic oil contained in the second main line **82b**. More specifically, in

the case where the system in the side of the second pipe **70b** has a capacity larger than the capacity of the system in the side of the first pipe **70a**, when hydraulic oil is drawn in via the second port **31b** of the bidirectional pump **31** and discharged via the first port **31a**, the piston **22** of the oil hydraulic cylinder **21** may stop unless the hydraulic oil corresponding to the capacity difference between the capacity of the system in the side of the second pipe **70b** and the capacity of the system in the side of the first pipe **70a** is fed to the sump tank **36**. As a result, the pressure of the hydraulic oil contained in the second main line **82b** may increase abnormally. In the case where the system in the side of the second pipe **70b** has a capacity larger than the capacity of the system in the side of the first pipe **70a**, the second pilot check valve **88b** serves as a flow channel for feeding the hydraulic oil corresponding to the capacity difference between the capacity of the system in the side of the second pipe **70b** and the capacity of the system in the side of the first pipe **70a** to the sump tank **36** in order not to stop the piston **22**. Additionally, the operation of the piston **22** can effectively prevent a pressure rise in the hydraulic oil contained in the second main line **82b**.

[0069] In this manner, the oil pressure regulator **80** can regulate the pressure of the hydraulic oil contained in the first main line **82a** and the pressure of the hydraulic oil contained in the second main line **82b**.

[0070] When the pressure of the hydraulic oil contained in the first main line **82a** of the oil pressure regulator **80** falls below atmospheric pressure, hydraulic oil stored in the sump tank **36** is fed through the supply line **89** to the first bypass line **83**. The fed hydraulic oil passes through the first check valve **86a** and reaches the first main line **82a**. In this manner, the first main line **82a** can be supplied with the hydraulic oil to prevent the pressure of the hydraulic oil contained in the first main line **82a** from falling below atmospheric pressure. The hydraulic oil from the sump tank **36** may also be fed through the supply line **89** to the third bypass line **85**. The fed hydraulic oil may pass through the first pilot check valve **88a** and reach the first main line **82a**.

[0071] Similarly, when the pressure of the hydraulic oil contained in the second main line **82b** of the oil pressure regulator **80** falls below atmospheric pressure, hydraulic oil stored in the sump tank **36** is fed through the supply line **89** to the first bypass line **83**. The fed hydraulic oil passes through the second check valve **86b** and reaches the second main line **82b**. In this manner, the second main line **82b** can be supplied with the hydraulic oil to prevent the pressure of the hydraulic oil contained in the second main line **82b** from falling below atmospheric pressure. The hydraulic oil from the sump tank **36** may also be fed through the supply line **89** to the third bypass line **85**. The fed hydraulic oil may pass through the second pilot check valve **88b** and reach the second main line **82b**.

[0072] According to the present embodiment, the bidirectional pump **31** can directly feed pressurized hydraulic oil to the oil hydraulic cylinder **21** without using an existing pressure oil tank. This allows the movable-blade operation system **20** to reduce the amount of hydraulic oil usage. With this system, even if an oil leakage should happen, its amount can be reduced. The system can thus have a reduced environmental impact. Furthermore, the bidirectional pump **31** according to the present embodiment, which directly feeds pressurized hydraulic oil to the oil hydraulic cylinder **21**, can drive the oil hydraulic cylinder **21** with power consumption

lower than the way of pressurizing the hydraulic oil stored in the pressure oil tank. Thus, the movable-blade operation system 20 can consume lower energy, contributing to improved energy conservation.

[0073] According to the present embodiment, the oil hydraulic cylinder 21 and the oil head 50 are installed within the bulb 11 of the bulb turbine 10, whereas the runner vane controller 30 including the bidirectional pump 31, the AC servomotor 32, and the control unit 33 is installed outside the bulb 11 of the bulb turbine 10. Thus, if an existing movable-blade operation system including a pressure oil tank, a compressor, and other components outside a bulb turbine 10 is modified into the movable-blade operation system 20 according to the present embodiment, the pressure oil tank, the compressor, and the other components may be replaced with the runner vane controller 30 according to the present embodiment. In this case, the bulb 11 of the bulb turbine 10 may not be remodeled. Thus, the existing movable-blade operation system can be easily modified into the movable-blade operation system 20, which can reduce the amount of hydraulic oil usage.

[0074] According to the present embodiment, as described above, the runner vane controller 30 including the bidirectional pump 31, the AC servomotor 32, and the control unit 33 is installed outside the bulb 11 of the bulb turbine 10. This allows the runner vane controller 30 to be operated and inspected not inside the bulb 11 but outside the bulb 11, resulting in an improvement in workability.

[0075] In the embodiment described above, the first counterbalance valve 71a and the second counterbalance valve 71b are installed outside the runner vane controller 30. However, this is not restrictive. The first counterbalance valve 71a and the second counterbalance valve 71b may be incorporated in the runner vane controller 30.

[0076] In the present embodiment described above, the circulation pipe 73 coupled with the sump tank 36 includes the hot-line oil purifier 75. However, this is not restrictive. The hot-line oil purifier 75 may be installed in the recovery pipe 72. In this case, the recovery pipe 72 suitably includes a pump (not shown) that draws hydraulic oil in from the third head chamber 51c and the fourth head chamber 51d of the oil head 50. This pump is preferably driven depending on the oil level of the hydraulic oil contained in the third head chamber 51c, detected by the oil level detector 59. For example, the pump is preferably driven if the detected oil level is higher than a predetermined upper limit, and stopped if the detected oil level is lower than a predetermined lower limit.

[0077] The embodiment described above allows an existing movable-blade operation system to be easily modified.

[0078] While certain embodiments have been described, these embodiments have been presented by way of example only, and are not intended to limit the scope of the inventions. Indeed, the novel embodiments described herein may be embodied in a variety of other forms; furthermore, various omissions, substitutions and changes in the form of the embodiments described herein may be made without departing from the spirit of the inventions. The accompanying claims and their equivalents are intended to cover such forms or modifications as would fall within the scope and spirit of the inventions.

[0079] In the embodiment described above, although the hydraulic machine is a vertical shaft bulb turbine, this is not restrictive. The movable-blade operation system is appli-

cable to a horizontal shaft bulb turbine as well as to a hydraulic machine other than a bulb turbine, such as a Kaplan turbine.

1. A movable-blade operation system for a hydraulic machine, for adjusting opening of movable blades that rotate together with a rotational shaft of the hydraulic machine, the system comprising:

an oil hydraulic cylinder installed within the rotational shaft, the oil hydraulic cylinder including a piston coupled to the movable blades, and including a first cylinder chamber and a second cylinder chamber that are defined by the piston;

a bidirectional pump configured to selectively feed pressurized hydraulic oil to one of the first cylinder chamber and the second cylinder chamber;

a pump drive motor configured to drive the bidirectional pump;

a control unit configured to control the pump drive motor; and

an oil head installed in the hydraulic machine and coupling the rotational shaft rotatably, the hydraulic oil to be fed from the bidirectional pump to the first cylinder chamber and the second cylinder chamber flowing through the oil head,

wherein the bidirectional pump, the pump drive motor, and the control unit are installed outside the hydraulic machine.

2. The movable-blade operation system according to claim 1, wherein

the bidirectional pump and the oil head are coupled by a first pipe communicating with the first cylinder chamber and by a second pipe communicating with the second cylinder chamber.

3. The movable-blade operation system according to claim 2, wherein

the first pipe and the second pipe extend through an access port allowing an internal inspection of the hydraulic machine.

4. The movable-blade operation system according to claim 2, wherein

the first pipe includes a first counterbalance valve, and the second pipe includes a second counterbalance valve.

5. The movable-blade operation system according to claim 1, wherein

the control unit includes a control command unit configured to issue a rotational speed command value for the pump drive motor, and an amplifier configured to supply the pump drive motor with power corresponding to the rotational speed command value issued from the control command unit, and

the amplifier includes a changeover function for increasing a rotational speed of the pump drive motor when a difference between an opening position detection value for the movable blades and an opening position command value for the movable blades is greater than a predetermined value.

6. The movable-blade operation system according to claim 1, further comprising

a sump tank installed outside the hydraulic machine and configured to store hydraulic oil to be fed to the first cylinder chamber and the second cylinder chamber, and a recovery pipe coupling the sump tank and the oil head, wherein the recovery pipe returns a part of hydraulic oil in the oil head to the sump tank.

7. The movable-blade operation system according to claim 6, further comprising
a hot-line oil purifier configured to purify hydraulic oil.

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