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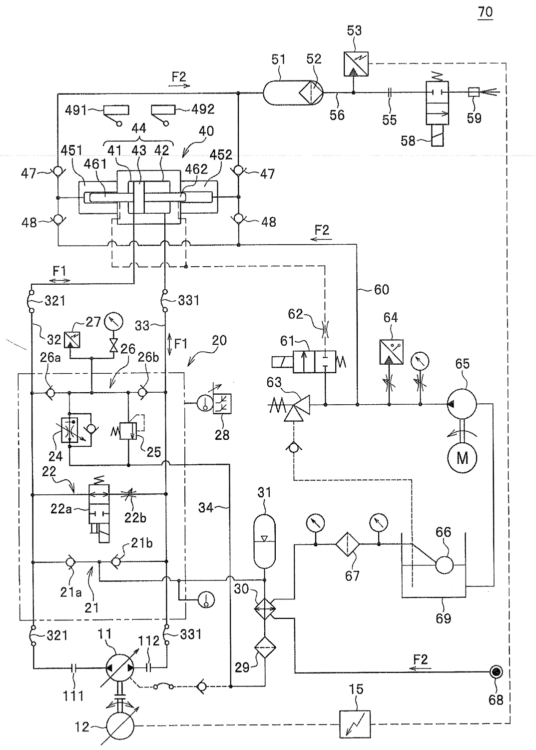
(54) **ULTRA-HIGH PRESSURE GENERATOR**

(57) An ultra-high pressure generator (70) includes: an intensifier (40) that discharges pressurized fluid (F2) and has a double-acting drive cylinder (44) formed to have a first chamber (41) and a second chamber (42) which are delimited by a piston (43) driven by a working medium (F1), high pressure cylinders (451,452) which discharge the pressurized fluid (F2), and plungers (461,462) which reciprocate with the piston (43) in the high pressure cylinders (461,462); a closed-circuit working medium pump (11) having a first port (111) and a second port (112) as suction/discharge ports for the working medium (F1) ; a drive source (12) that drives the closed-circuit working medium pump (11) ; a first working medium channel (32) that communicates the first chamber (41) with the first port (111) ; and a second working medium channel (33) that communicates the second chamber (42) with the second port (112), wherein the closed-circuit working medium pump (11) sucks/discharges the working medium (F1) from/to the first and second chambers (41,42) respectively via the first and second ports (111,112) to drive the intensifier (40).

FIG. 1



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Description

[0001] This application claims the benefit of priority to Japanese Patent Application No. 2014-190725, filed on September 19, 2014.

BACKGROUND OF THE INVENTION

Field of the Invention

[0002] The present invention relates to an ultra-high pressure generator obtaining ultra-high pressure output by plungers which are reciprocatively driven by hydraulic pressure or the like.

Description of the Related Arts

[0003] An ultra-high pressure pump that discharges a jet of high pressure fluid has been known to have the following configuration (see FIG. 1 in Japanese Patent Application Publication number S63-39799). An open-circuit hydraulic pump (working medium pump) 1 is connected, at a discharging side, to low pressure cylinder chambers C1 and C2 in an intensifier 2 via a two-way control valve (directional control valve) 3. When the directional control valve 3 is at the position VI, hydraulic oil (working medium) boosted by the hydraulic pump 1 is supplied to the cylinder chamber C1 and the working medium in the cylinder chamber C2 is returned to a tank 25. At this time, the piston P in the intensifier 2 is moved toward the right direction in FIG. 1. When the piston P in the intensifier 2 reaches the right end, the directional control valve 3 is switched to the position V2. The pressurized working medium is supplied to the cylinder chamber C2 and the working medium in the cylinder chamber C1 is returned to the tank 25. At this time, the piston P in the intensifier 2 is moved toward the left direction in FIG. 1. When the piston P in the intensifier 2 reaches the left end, the directional control valve 3 is switched to the position V1. The pressure of the pressurized fluid is pressurized by a factor of an intensify ratio in the pressure of the working medium. The pressure of the pressurized fluid is controlled by the relief valve 27 controlling the pressure of the working medium.

SUMMARY OF THE INVENTION

[0004] The aforementioned high pressure generator with the open-circuit hydraulic pump and the directional control valve has the following problem.

[0005] In a cutting application by water jet, the high pressure generator discharges the pressurized fluid continuously. At the time of discharging the jet from the high pressure generator, the hydraulic pressure generator is driven to have high pressure loss in the directional control valve. When the discharge of the fluid under high pressure is stopped, a double-acting drive cylinder is stopped, which makes the pressure loss of the hydraulic oil as the fluid under low pressure become zero. The amount of the pressure loss in the directional control valve appears as a temporary abnormal rise of hydraulic pressure of the hydraulic oil. The temporary abnormal rise of hydraulic pressure of the hydraulic oil affects the discharge pressure of the fluid under high pressure according to the intensify ratio of the intensifier. Here, the intensify ratio is a pressure ratio between the pressure of the pressurized fluid under high pressure and the pressure of the hydraulic oil under low pressure, and is normally set as several tens of times. That is, when the continuous discharge of the fluid under high pressure is stopped, the pressure rises temporarily by the pressure amount of several tens of times of the pressure loss in the directional control valve. Therefore, when the continuous discharge is stopped, the pressure rises excessively.

[0006] In the cutting application by water jet, pulsation in a high pressure circuit occurs when the double-acting intensifier switches directions. If the directional control valve is increased in size with the aim of reducing the pressure loss thereof, responsiveness of the directional control valve deteriorates. At the stroke ends of the intensifier, the pressurized fluid is not supplied from a pressure process in the cylinder to a downstream side of a check valve. Then, the pressurized fluid is not supplied till a travel direction in the intensifier is switched, causing the pressure to drop. This pressure drop is determined by the switching time of the travel direction in the intensifier, the volume of an accumulator and the discharge amount. If the responsiveness of the working fluid deteriorates, a pressure waveform of the pressurized fluid is disturbed. The jet of the pressurized fluid, that is, the flow rate of the water jet depends on the pressure. Therefore, the deterioration of responsiveness in the working fluid circuit causes quality of the jet water to degrade.

[0007] In the high pressure generator including a double-acting intensifier driven by the open-circuit hydraulic pump, the directional control valve for the hydraulic pressure generator is mandatory. However, the pressure loss in the directional control valve causes mechanical efficiency to drop.

[0008] The present invention is intended to provide an ultra-high pressure generator that reduces fluctuations in a pressure waveform of pressurized fluid and enhances mechanical efficiency.

[0009] In view of the problem above, the invention provides an ultra-high pressure generator including: an intensifier that discharges pressurized fluid and includes a double-acting drive cylinder formed to have a first chamber and a second chamber which are delimited by a piston that is driven by a working medium, a high pressure cylinder that discharges the pressurized fluid, and a plunger that reciprocates with the piston in the high pressure cylinder; a closed-circuit working medium pump that has a first port and a second port as suction/discharge ports for the working medium, and sucks/discharges the working medium from/to the first chamber and the second chamber respectively via the first port and the second port to drive the intensifier; a drive source that drives the closed-circuit working medium pump; a first working medium channel that communicates the first chamber with the first port; and a second working medium channel that communicates the second chamber with the second port.

[0010] According to the configuration of the ultra-high pressure generator, the closed-circuit working medium pump is used to suck the working medium from a pressurized side in the intensifier, pressurize it, and to return it to a pressing side in the intensifier, which does not require a directional control valve that controls flow directions of the working medium to be supplied to the first or second chamber. Therefore, the problem can be addressed that pressure of the high pressure fluid or the pressurized fluid increases abnormally at the time of stopping discharge due to the pressure loss in the directional control valve.

[0011] That is, according to at least preferred embodiments of the present invention, in a case where the pressurized fluid is discharged continuously, when the flow direction of the closed-circuit working medium pump is reversed, the pressure in either one of the first and second chambers becomes approximately 0 MPa, and the other one is pressurized immediately. Further, since the pressure of the working medium becomes zero temporarily when the travel direction of the piston in the double-acting drive cylinder is switched, the pressure does not increase abnormally at the time of switching the travel direction. With these effects, a stable pressure waveform can be obtained which has little pressure fluctuations of the high pressure fluid.

[0012] Still further, according to the ultra-high pressure generator having the configuration above, since the working medium filled in the double-acting drive cylinder of the intensifier is directly driven by the closed-circuit working medium pump, high response speed of the intensifier can be achieved. Thus, the pressure waveform of the pressurized fluid can be stable.

[0013] Therefore, a stable jet can be obtained when a water jet is discharged by an ultra-high pressure generator in accordance with embodiments of the present invention.

[0014] The working medium is filled in the first or second chamber of the double-acting drive cylinder. When the direction of the intensifier is switched, either one of the first and second chambers which has been pressurized is changed to a supply side, and the other one that has been a supply side is pressurized. In at least preferred embodiments, at the time of switching the directions of the intensifier, a bidirectionally rotatable drive source is reversely rotated against inertial force of the closed-circuit pressurizing device to suck the working fluid from a supplying chamber. At this time, since the pressurized fluid that has been pressurized in the high pressure cylinder is expanded based on compression rate of the pressurized fluid to push back the piston, a load on the drive system can be reduced.

[0015] In embodiments of the present invention, the closed-circuit working medium pump is preferably a fixed-displacement swash plate axial pump and the drive source is preferably a bidirectionally rotatable drive source.

[0016] According to the ultra-high pressure generator having the configuration above, reliability of the closed-circuit working medium pump is improved.

[0017] In certain embodiments in accordance with the present invention, the closed-circuit working medium pump may be a variable-displacement swash plate axial pump that can reverse a tilt angle between positive and negative directions. With such a configuration, a unidirectionally rotatable drive source can be applied as a drive source.

[0018] In embodiments of the present invention, the drive source can preferably be a servo motor, and the ultra-high pressure generator can comprise a pressure detector that detects pressure of the pressurized fluid discharged from the intensifier and a controller that controls the number of rotations of the servo motor in response to the pressure detected by the pressure detector.

[0019] According to the ultra-high pressure generator having the configuration above, the flow rate and the pressure of the closed-circuit working medium pump is controlled in response to the pressure of the pressurized fluid detected by the pressure detector. Since proper pressure of the working medium can be generated by the closed-circuit working medium pump when the ultra-high pressure generator is driven, the pressure waveform of the pressurized fluid is stabilized.

[0020] According to the configuration above, since the ultra-high pressure generator in accordance with such embodiments of the present invention does not need to include a relief circuit for regulating the pressure of the working medium, the thermal loss of the relief circuit does not exist, thereby increasing the mechanical efficiency. Further, since the thermal loss of the relief circuit does not need to be recovered, the amount of cooling water can be significantly reduced.

[0021] In a case where the ultra-high pressure generator is used as a continuous discharge high pressure generator, when the discharge of the pressurized fluid is stopped, the servo motor continues to rotate so that the closed-circuit working medium pump keeps the pressure.

[0022] The ultra-high pressure generator in accordance with embodiments of the present invention preferably includes a storage tank in which the pressurized fluid is stored, a supply port through which the pressurized fluid is supplied to the storage tank, and a heat exchanger that cools the working medium, wherein the pressurized fluid supplied through the supply port is supplied to the storage tank via the heat exchanger.

[0023] According to the configuration as described above, since a cooling medium that cools the working medium is reused as the pressurized fluid, the amount of the pressurized fluid needed for the ultra-high pressure generator can be reduced.

[0024] Thus, the ultra-high pressure generator according to at least preferred embodiments of the present invention can reduce the fluctuations in the pressure waveform of the pressurized fluid and can improve the mechanical efficiency.

BRIEF DESCRIPTION OF THE DRAWINGS

[0025] Embodiments of the invention will now be described, by way of example only, with reference to the accompanying drawings, in which:

FIG. 1 is a diagram showing a hydraulic pressure circuit of an ultra-high pressure generator according to an embodiment of the present invention; and
FIG. 2 is a chart showing a pressure waveform of fluid under high pressure in the ultra-high pressure generator according to the illustrated embodiment of the present invention.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

[0026] Referring to FIG. 1, an ultra-high pressure generator 70 in an embodiment of the present invention will be described. A working medium F1 is hydraulic oil and pressurized fluid F2 is water, in the ultra-high pressure generator 70. The ultra-high pressure generator 70 is preferably used for water jet cutting in which ultra-high pressure water is discharged continuously.

[0027] The ultra-high pressure generator 70 of the present embodiment is a device that continuously discharges the pressurized fluid F2 under ultra-high pressure. The ultra-high pressure generator 70 includes: an intensifier 40 having a double-acting drive cylinder 44 formed to have a first chamber 41 and a second chamber 42 which are delimited by a piston 43 driven by the working medium F1, and plungers 461, 462 which reciprocate with the piston 43 in high pressure cylinders 451, 452 respectively; a closed-circuit working medium pump 11 having a first port 111 and a second port 112 as suction/discharge ports; a bidirectionally rotatable drive source 12 that drives the closed-circuit working medium pump 11; a first working medium channel 32 that communicates the first chamber 41 with the first port 111; and a second working medium channel 33 that communicates the second chamber 42 with the second port 112.

[0028] The closed-circuit working medium pump 11 is a fixed-displacement swash plate axial pump and a drive source thereof is constituted with a servo motor as a bidirectionally rotatable drive source 12.

[0029] The ultra-high pressure generator 70 further includes a pressure detector 53 that measures the pressure of the pressurized fluid F2 discharged from the intensifier 40 and a controller 15 that controls the number of rotations of the bidirectionally rotatable drive source 12 in response to the pressure detected by the pressure detector 53.

[0030] The ultra-high pressure generator 70 includes a supply port 68 through which the pressurized fluid F2 is supplied, a heat exchanger 30 that cools the working medium F1 and a storage tank 69 in which the pressurized fluid F2 is stored. The pressurized fluid F2 supplied from the supply port 68 flows through the heat exchanger 30 into the storage tank 69.

[0031] The intensify ratio is determined to be ratio of the cross-sectional area of the piston 43 to cross-sectional areas of the high pressure cylinders 451, 452. The pressure of the pressurized fluid F2 is pressurized by a factor of the intensify ratio based on the pressure of the working medium F1. The boost pressure is set to be several tens of times. The plungers 461, 462 in the intensifier 40 are caused to reciprocate from side to side by the double-acting drive cylinder 44 in the high pressure cylinders 451, 452. A pair of suction valve 48 and discharge valve 47 is arranged at the ends of the high pressure cylinders 451, 452, respectively. When the working medium F1 flows into the first chamber 41, the piston 43 in the double-acting drive cylinder 44 moves toward the right direction in FIG. 1. At this time, the pressurized fluid F2 flows into the high pressure cylinder 451 through the suction valve 48. Besides, the pressurized fluid F2 is discharged from the high pressure cylinder 452 through the discharge valve 47. When the piston 43 moves toward the right direction (right side) in FIG. 1 to reach around the right end, a right end detector 492 detects the piston 43 to switch a travel direction of the piston 43 toward the left direction in FIG. 1. When the piston 43 is moved toward the left direction (left side) in FIG. 1, the double-acting drive cylinder 44 acts reversely as described above. Likewise, a left end detector 491 detects that the piston 43 has reached around the left end. The reciprocation of the double-acting drive cylinder 44 allows the pressurized fluid F2 to be discharged continuously.

[0032] It is noted that detectors such as proximity switches, limit switches may be used as the left end detector 491 and right end detector 492. When the proximity switches are used, respective detectors 491, 492 can be installed in the intensifier 40, resulting in a simple structure.

[0033] It is also noted that the suction valves 48 and discharge valves 47 are check valves, but a directional flow regulation valve may be used in place of the pair of check valves. In addition, if a one-shot ultra-high pressure generator is used which is not the continuous discharge type, the discharge valves 47 is unnecessary.

[0034] The closed-circuit working medium pump 11 is a fixed-displacement swash plate axial pump. The first port 111 is directly connected to the first chamber 41 via the first working medium channel 32, and the second port 112 is directly connected to the second chamber 42 via the second working medium channel 33. That is, when the piston 43 in the intensifier 40 moves toward the right side, the closed-circuit working medium pump 11 pressurizes the working medium F1 in the second chamber 42 to predetermined pressure to feed to the first chamber

41. When the piston 43 in the intensifier 40 moves toward the left side, the closed-circuit working medium pump 11 feeds the working medium F1 in the first chamber 41 to the second chamber 42 reversely. The closed-circuit working medium pump 11 controls the pressure and the flow rate of the working medium F1 by controlling the number of rotations thereof. The bidirectionally rotatable drive source 12 as a servo motor can control the number of rotations as desired to maintain a rotation angle such that the output shaft thereof does not rotate. Further, the closed-circuit working medium pump 11 can control the pressure and the flow rate of the working medium F1 by the use of combination of the fixed-displacement swash plate axial pump and the bidirectionally rotatable servo motor, and can set the flowing rate of the working medium F1 to zero while maintaining the pressure of the working medium F1. Still further, reliability of the ultra-high pressure generator is enhanced by the use of the fixed-displacement swash plate axial pump.

[0035] It is noted that a variable-displacement axial plunger pump that can reverse a tilt angle from positive to negative or vice versa and a unidirectionally rotatable drive source can be used in place of the combination of the closed-circuit working medium pump 11 and the bidirectionally rotatable drive source 12. The variable-displacement axial plunger pump capable of reversing a tilt angle can switch a suction side and a discharge side of two ports by reversing the tilt angle, and can be used as the closed-circuit working medium pump.

[0036] A circuit for the working medium F1 is arranged in a valve block 20 as shown below. The valve block 20 is connected to the intensifier 40 and is connected to the closed-circuit working medium pump 11 with rubber hoses 321, 321, 331, 331 as pipes, respectively. Connecting respective components with the rubber hoses 321, 321, 331, 331 allows for absorbing vibrations that may occur at respective components to improve assemblability and maintainability as well as durability of the ultra-high pressure generator 70.

[0037] The valve block 20 includes a temperature detector 28 that detects temperature of the working medium. When the temperature of the working medium F1 increases abnormally, the temperature detector 28 gives a warning. The temperature detector 28 is attached to the valve block 20 not to contact the working medium F1 directly, and then it is hard for the temperature detector 28 to suffer damage due to the pressure fluctuations of the working medium F1 or the like.

[0038] It is noted that the temperature detector 28 can be connected to a supply circuit 21 or a selection circuit 26 when a problem such as breakdown does not need to be considered.

[0039] The first working medium channel 32 is connected to the second working medium channel 33 with the selection circuit 26 inclusive of a pair of check valves 26a, 26b. The check valves 26a, 26b are installed to have the working medium channels 32, 33 as upstream sides. A pressure detector 27 that detects the pressure of the working medium F1 is arranged in the selection circuit 26. The selection circuit 26 allows the pressure detector 27 to detect the pressure of either one of the first working medium channel 32 and the second working medium channel 33 which has higher pressure. Thus, the structure for detecting the pressure can be formed simply. The pressure detector 27 can inform abnormality when the pressure of the working medium F1 is out of a normal range.

[0040] The first working medium channel 32 is connected to the second working medium channel 33 with the supply circuit 21 that includes a pair of check valves 21a, 21b having the working medium channels 32, 33 as downstream sides. The supply circuit 21 communicates the check valves 21a, 21b with a working medium tank 31. The working medium tank 31 is applied with internal pressure. The working medium F1 as hydraulic oil is incompressible fluid, but is slightly compressed by pressurization. One of the first chamber 41 and second chamber 42 in the intensifier 40, which is at a supply side, is set to have pressure around zero MPa normally, and the other is set to have setting pressure. The total amount of the working medium F1 accumulated in the system is changed depending on the volume of the working medium F1 presented in either one of the first chamber 41 and second chamber 42, which is at a compression cycle side, and the pipes. The supply circuit 21 functions to regulate the total amount of the working medium F1. The working medium tank 31 only needs to have the function to regulate the total amount of the working medium F1, and therefore can be reduced in size. The working medium tank 31 is equivalent to a thin-walled gas accumulator to have a radiation function for the working medium F1.

[0041] A pressure equalization circuit 22 including an electromagnetic valve 22a and a throttle valve 22b for driving the intensifier 40 connects the first working medium channel 32 with the second working medium channel 33. The electromagnetic valve 22a shuts off the pressure equalization circuit 22 before the closed-circuit working medium pump 11 starts operation, and opens the pressure equalization circuit 22 when the closed-circuit working medium pump 11 stops operation. When the pressure equalization circuit 22 is open, the pressure of the first working medium channel 32 and the pressure of the second working medium channel 33 become identical and the intensifier stops operation. Since the electromagnetic valve 22a is normally open, the electromagnetic valve 22a opens the pressure equalization circuit 22 to function as a safety circuit when the power supply is stopped at emergency. The throttle valve 22b prevents the hydraulic device from receiving impact pressure to be damaged due to abrupt pressure change when the pressure equalization circuit 22 opens. Further, if the total amount of the working medium F1 in the system is large, the pressure of the working medium F1 may fluctuate due to switching of the electromagnetic valve 22a. However, since the total amount of the working medium F1 in the present embodiment is small, large pressure fluctuations do not occur, and then the throttle valve 22b is not necessarily required.

[0042] It is noted that, if some other device is arranged to secure safety, the pressure equalization circuit 22 is not necessarily required.

[0043] A recovery circuit 34 communicates the selection circuit 26 with the working medium tank 31. In the recovery circuit 34, a safety valve 25 is connected in parallel with a flow regulation valve 24, and a filter 29 and a heat exchanger 30 are connected with these elements in series. If control in the servo system of the closed-circuit working medium pump 11 runs away, the safety valve 25 functions to maintain the pressure of the working medium F1 less than or equal to a setting value. This function of the safety valve 25 prevents the pressure of the ultra-high pressure generator 70 from increasing abruptly. The flow regulation valve 24 controls the amount of the highly pressurized working medium F1 that is recovered from the selection circuit 26 to the working medium tank 31 via the recovery circuit 34. As mentioned above, the working medium tank 31 regulates the amount of the working medium F1 in the system according to the reciprocation of the piston 43 in the intensifier 40. The recovery circuit 34 functions to supply the necessary working medium F1 to the working medium tank 31. When recovered into the working medium tank 31, the working medium F1 is filtered by the filter 29 and cooled by the heat exchanger 30. As mentioned above, according to the switching of the travel directions of the piston 43 in the intensifier 40, the working medium F1 is supplied from the working medium tank 31 via the supply circuit 21 and is returned from the selection circuit 26 to the working medium tank 31. Thus, a constant amount of the working medium F1 flows in the circuits via the working medium tank 31 according to the operation of the intensifier 40. Therefore, the working medium F1 is always cooled by the heat exchanger 30 and the temperature thereof is kept constant.

[0044] The working medium F1 recovered via the recovery circuit 34 is a leak of the working medium F1 boosted by the closed-circuit working medium pump 11. Since the flow regulation valve 24 is arranged in the recovery circuit 34 for the leak that deteriorates the mechanical efficiency, the leak amount can be regulated properly to prevent the mechanical efficiency from being deteriorated excessively.

[0045] In addition, the flow regulation valve 24 is arranged in the recovery circuit 34, allowing for setting the flow rate of the working medium F1 flowing into the heat exchanger 30 to a predetermined amount. In the ultra-high pressure generator 70, a cooling medium of the heat exchanger 30 is the pressurized fluid F2. Since all the pressurized fluid F2 is flown through the heat exchanger 30, heat quantity recovered by the heat exchanger 30 may become too large. However, by throttling the flow rate of the working medium F1 having higher temperature which is flowed through the heat exchanger 30, the recovered heat quantity can be controlled.

[0046] It is noted, in a case where some other safety measure is taken against the abnormal pressure increase, the safety valve 25 may be eliminated. In a case where the heat quantity generated in the system is small and the working medium F1 can be cooled sufficiently by outside air, the heat exchanger 30 is unnecessary.

[0047] In a case where the leak amount from the working medium pump 11 can offset the supply amount of the working medium from the working medium tank 31, the flow regulation valve 24 and the pipe connecting the flow regulation valve 24 can be eliminated. If the safety valve 25 and the flow regulation valve 24 can be eliminated, the recovery circuit 34 is unnecessary. In this case, all the working medium to be supplied can be offset by the leak from the working medium pump 11.

[0048] The pressurized fluid F2 is supplied from the supply port 68 for the pressurized fluid F2, passes through the heat exchanger 30, is filtered by the filter 67, and then, is stored in the storage tank 69. The pressurized fluid F2 is supplied into the storage tank 69 by the use of a ball tap 66, and when the liquid surface in the storage tank 69 reaches an upper limit, the supply of the pressurized fluid F2 is stopped.

[0049] It is noted that positions of the filter 67 and the heat exchanger 30 are exchangeable.

[0050] A vortex pump 65 sucks the pressurized fluid F2 from the bottom of the storage tank 69 to supply the pressurized fluid F2 to suction valves 48, 48 in the intensifier 40 through a supply channel 60.

[0051] A safety valve 63 is arranged in the supply channel 60. The safety valve 63 has advantageous effects of deterring the discharge port of the vortex pump 65 from being closed completely when discharging of the pressurized fluid F2 is stopped to prevent breakdown of the vortex pump 65. Further, if the suction valve 48 leaks, the pressurized fluid F2 under ultra-high pressure flows into the supply channel 60. The safety valve 63 has functions to prevent the breakdown of the device at the time of this kind of emergency.

[0052] In the supply channel 60, an electromagnetic valve 61 is arranged to supply cooling water for packing. When the electromagnetic valve 61 is opened, the cooling water for packing flows through the throttle valve 62 to packing members (not shown) that seal between the high pressure cylinders 451, 452 and the plungers 461, 462 to cool the packing members. A pressure switch 64 for detecting supply pressure is arranged in the supply channel 60. The pressure switch 64 monitors whether the supply pressure of the pressurized fluid F2 exceeds cracking pressure of the suction valves 48, 48 so that the pressurized fluid F2 is supplied to the intensifier 40.

[0053] It is noted that the pressure switch 64 can be replaced by a pressure detector.

[0054] The discharge valves 47, 47 are in communication with a discharge port 55 via an accumulator 51 through a discharge pipe 56. A filter 52 is arranged in the accumulator 51. Since the filter 52 is arranged in the accumulator 51, the filter 52 receives ultra-high pressure from inside and outside thereof. A filter for a normal pressure level can be used as the filter 52.

[0055] The pressurized fluid F2 under ultra-high pressure discharged from the discharge port 55 is ejected from a nozzle 59 via an on-off valve 58. The pressure detector 53 that detects the pressure of the pressurized fluid F2 under ultra-high pressure is connected to the discharge pipe 56.

[0056] The controller 15 controls the pressure and the flow rate of the closed-circuit working medium pump 11, and the travel direction in the intensifier 40 according to the position of the piston 43 in the intensifier 40 and the pressure of the pressurized fluid F2 that is detected by the pressure detector 53. Pressure feedback is calculated based on the degree of pressure increase. The modern control having high robustness such as the adaptive control can be properly used for the pressure control.

[0057] FIG. 2 shows a pressure waveform W1 of the pressurized fluid F2 generated by the ultra-high pressure generator 70 configured as described above. In FIG. 2, the horizontal axis indicates elapsed time and the vertical axis indicates pressure. The pressure and the flow rate of the closed-circuit working medium pump 11 is regulated based on actual discharge pressure to determine the speed of the plungers 461, 462 properly, which forms the pressure waveform W1 of the pressurized fluid F2 as an approximately straight line at a setting pressure P. The pressure is temporarily decreased at constant time intervals in synchronization with switching the travel directions of the piston 43.

[0058] During the continuous discharge being stopped, the closed-circuit working medium pump 11 stops rotating, and this rotation status is maintained by the bidirectionally rotatable drive source 12. Thus, the working medium F1 in the closed-circuit working medium pump 11 does not flow at the pressuring side. Since the working medium F1 does not flow, the pressure loss in the first and second working medium channels 32, 33 disappears and the pressure of working medium F1 slightly increases. Since the pressure of the pressurized fluid F2 that is pressurized under ultra-high pressure becomes larger than the pressure of the working medium F1 by the factor of the intensify ratio, the pressure of the pressurized fluid F2 increases (ΔP) by the factor of the intensify ratio relative to pressure increase of the working medium F1. The number of rotations of the closed-circuit working medium pump 11 is controlled by the pressure feedback, thereby minimizing the ΔP. When the continuous discharge is resumed, the pressure of the pressurized fluid F2 turns back to stable pressure again at around the setting pressure.

[0059] In an ultra-high pressure generator that generates pressure level of 600 MPa, an intensify ratio of around 30 times is necessary. The higher the pressure becomes, the greater the intensify ratio is necessary, and, the greater the intensify ratio becomes, the greater the rate of the pressure increase becomes when the discharge is stopped. Further, in a case where the pressure is extremely high, the ultra-high pressure fluid generates high internal stress in the pressure pipes. The pressure causes vibration, which greatly limits a material, thickness and inner surface finishing of the pressure pipes. The pressure increase and pressure vibration of the ultra-high pressure fluid give excessive stress on the ultra-high pressure generator and the pressure pipe system.

[0060] The pipe fittings such as pipes, valves, hoses, joints and the like used in the ultra-high pressure pipes receive excessive internalstress. According to the ultra-high pressure generator 70 of the present embodiment, the pressure vibration is reduced greatly, allowing for longer service life of the pipe fittings. Therefore, the ultra-high pressure generator 70 is suitably adapted to an ultra-high pressure generator that generates especially high pressure.

[0061] The ultra-high pressure generator 70 of the present embodiment controls the closed-circuit working medium pump 11 according to the pressure detected by the pressure detector 53, thereby keeping the discharge pressure stably at around the setting pressure P. The discharge pressure is stable at a constant value, which stabilizes the flow rate and the flow volume of the jet of the pressurized fluid F2 ejected from the nozzle 59. Further, the pressure waveform is stabilized, allowing the volume of the accumulator 51 to be reduced. The accumulator 51 is a pressure vessel to have high internal stress generated inside thereof. The internal stress increases in proportion to the square of the internal diameter of the accumulator. In addition, energy accumulated in the accumulator is in proportion to the internal volume. Therefore, the ultra-high pressure generator that generates ultra high pressure over 600 MPa has a very difficult technical problem in producing an accumulator with large volume. The ultra-high pressure generator 70 has a stable pressure waveform, allowing the accumulator volume to be reduced, and can suitably be adapted to an ultra-high pressure generator that generates especially high pressure.

[0062] Since the ultra-high pressure generator 70 includes the plungers 461, 462 and the high pressure cylinders 451, 452 on both sides of the double-acting drive cylinder 44, the pressure of the pressurized fluid F2 acts upon the piston 43 via the plungers 461, 462 when the travel direction of the piston 43 is switched, where the pressure of the pressurized fluid F2 is ultra-high pressure in the high pressure cylinders 451, 452 which has been in a compression cycle until right before the switching. At this time, the pressurized fluid F2 in the high pressure cylinders 451, 452 is expanded based on the expansion rate thereof. Further, since the working medium F1 is slightly compressed, the compressed working medium F1 is expanded at the time of switching. With these actions, when the travel direction of the piston 43 in the intensifier 40 is switched, the working medium F1 that has been pressurized until right before the switching flows into the closed-circuit working medium pump 11.

Although a large stress is applied to the closed-circuit working medium pump 11 and the bidirectionally rotatable drive source 12 when the rotational direction is switched, the stress applied to the closed-circuit working medium pump 11 at this time can be reduced by the actions described above.

[0063] Since the ultra-high pressure generator 70 does not include the relief valve 27 and the directional control valve 3 (see FIG. 1 in Japanese Patent Application Publication number S63-39799) in the related art, the mechanical efficiency thereof is improved. The improvement of the mechanical efficiency reduces waste heat generated from the ultra-high pressure generator 70. Therefore, the amount of cooling water for cooling the working medium F1 can be reduced greatly. Since the necessary amount of cooling water is small, the ultra-high pressure generator 70 can match the discharge amount of the pressurized fluid F2 with the amount of cooling water and can temporarily use the supplied pressurized fluid F2 as the cooling water. Still further, since the flow rate of the necessary pressurized fluid F2 is small, the storage tank 69 can be reduced in size.

[0064] The mechanical efficiency of the ultra-high pressure generator 70 is substantially improved, which allows the mechanical components constituting the device to be reduced in size as well as the configuration to be simplified. Thus, the machine can be downsized as a whole.

[0065] The ultra-high pressure generator 70 according to an embodiment of the present invention is described above, but the configuration of the present invention is not limited to the one described above. For example, the bidirectionally rotatable drive source 12 is not limited to a servo motor, but may be a source that can control torque and the number of rotations, and can keep the rotation.

[0066] Further, an electromagnetic pressure relief valve can be arranged in the recovery circuit 34 in place of the pressure equalization circuit 22, the electromagnetic valve 22a, the throttle valve 22b, the flow regulation valve 24 and the safety valve 25. In this case, when the intensifier 40 is stopped operation, the electromagnetic pressure relief valve is opened to reduce the pressure in the working medium channels 32, 33. When the intensifier 40 resumes operation, the electromagnetic pressure relief valve is closed.

[0067] The ultra-high pressure generator 70 according to the illustrated embodiment of the present invention can be applied to a pressure/fatigue breakdown testing device, a hydroforming device, not limited to a water jet application.

Claims

1. An ultra-high pressure generator (70) comprising:

    an intensifier (40) that discharges pressurized fluid (F2) and includes a double-acting drive cylinder (44) formed to have a first chamber (41) and a second chamber (42) which are delimited by a piston (43) driven by a working medium (F1), a high pressure cylinder (451,452) that discharges the pressurized fluid (F2), and a plunger (461,462) that reciprocates with the piston (43) in the high pressure cylinder (451,452);
    a closed-circuit working medium pump (11) that has a first port (111) and a second port (112) as suction/discharge ports for the working medium (F1), and sucks/discharges the working medium from/to the first chamber (41) and the second chamber (42) respectively via the first port (111) and the second port (112) to drive the intensifier (40);
    a drive source (12) that drives the closed-circuit working medium pump (11);
    a first working medium channel (32) that communicates the first chamber (41) with the first port (111); and
    a second working medium channel (33) that communicates the second chamber (42) with the second port (112).

2. The ultra-high pressure generator (70) according to claim 1, wherein the closed-circuit working medium pump (111) is a fixed-displacement swash plate axial pump and the drive source (12) is a bidirectionally rotatable drive source.

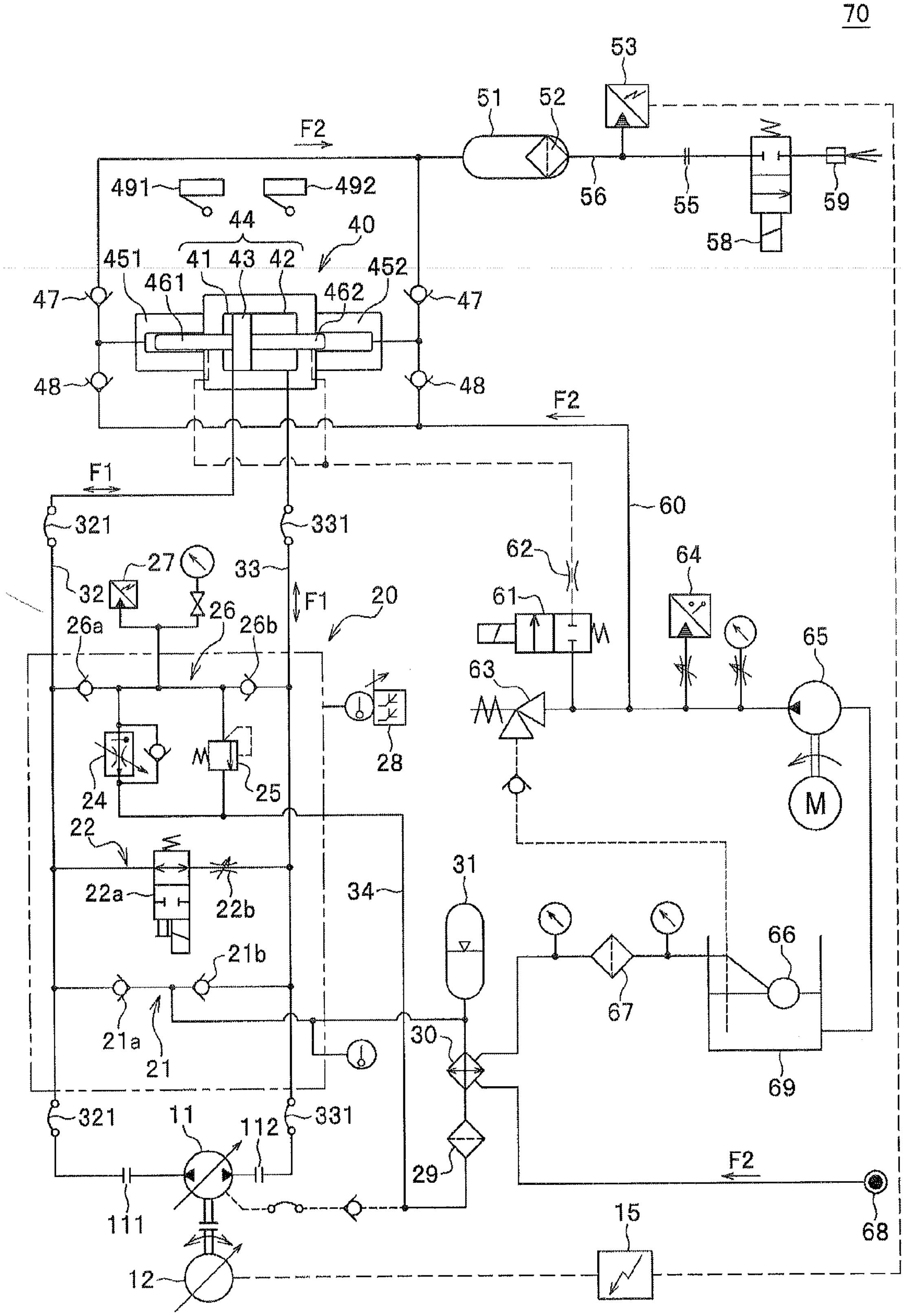
3. The ultra-high pressure generator (70) according to claim 1, wherein the closed-circuit working medium pump (11) is a variable-displacement swash plate axial pump that can reverse a tilt angle between positive and negative directions.

4. The ultra-high pressure generator (70) according to any of claims 1 to 3, wherein the drive source (12) is a servo motor, and the ultra-high pressure generator (70) further comprises:

    a pressure detector (53) that detects pressure of the pressurized fluid (F2) discharged from the intensifier (40); and a controller (15) that controls the number of rotations of the servo motor in response to the pressure detected by the pressure detector (53).

5. The ultra-high pressure generator (70) according to any of claims 1 to 4, wherein the ultra-high pressure generator (70) further comprises: a storage tank (69) in which the pressurized fluid (F2) is stored; a supply port (68) through which the pressurized fluid is supplied to the storage tank (69); and a heat exchanger (30) that cools the working medium (F1), and wherein the pressurized fluid (F2) supplied through the supply port (68) is supplied to the storage tank (69) via the heat exchanger (30).

FIG. 1



70
53
51
52
F2
491
492
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55
59
44
40
58
451
41
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42
452
461
462
47
47
48
48
F2
F1
60
321
331
62
27
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64
32
F1
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26a
26
26b
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31
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22a
22b
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F2
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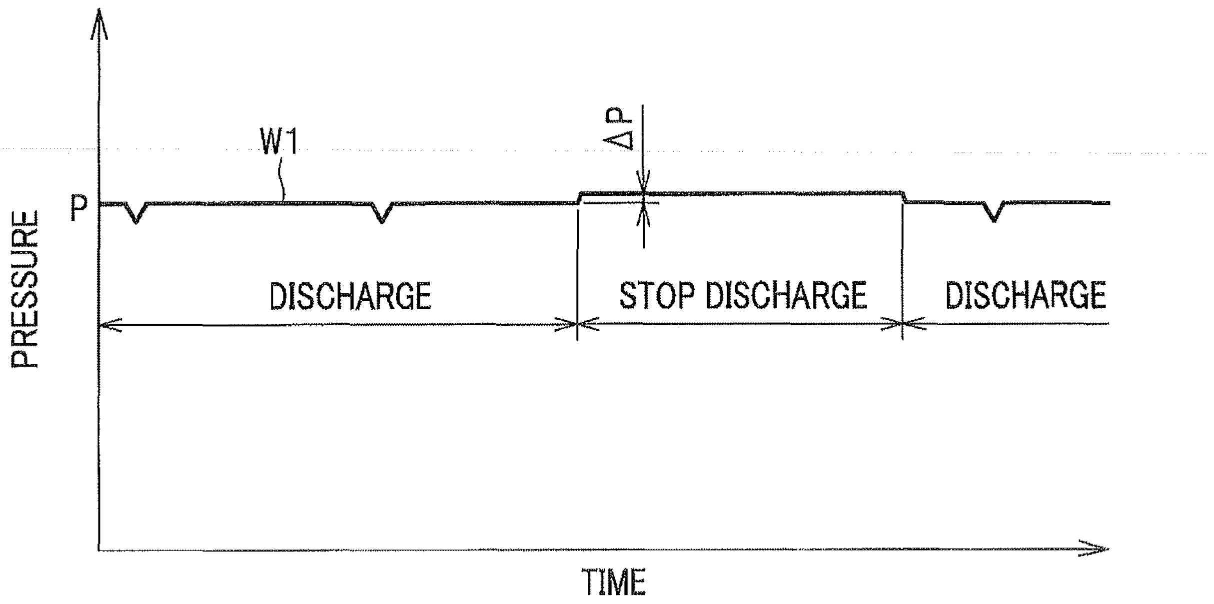
111
68
15
12

FIG. 2



REFERENCES CITED IN THE DESCRIPTION

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