HIGH PRESSURE HYDRAULIC FORMING PRESS

Filed Dec. 18, 1963 5 Sheets-Sheet 1

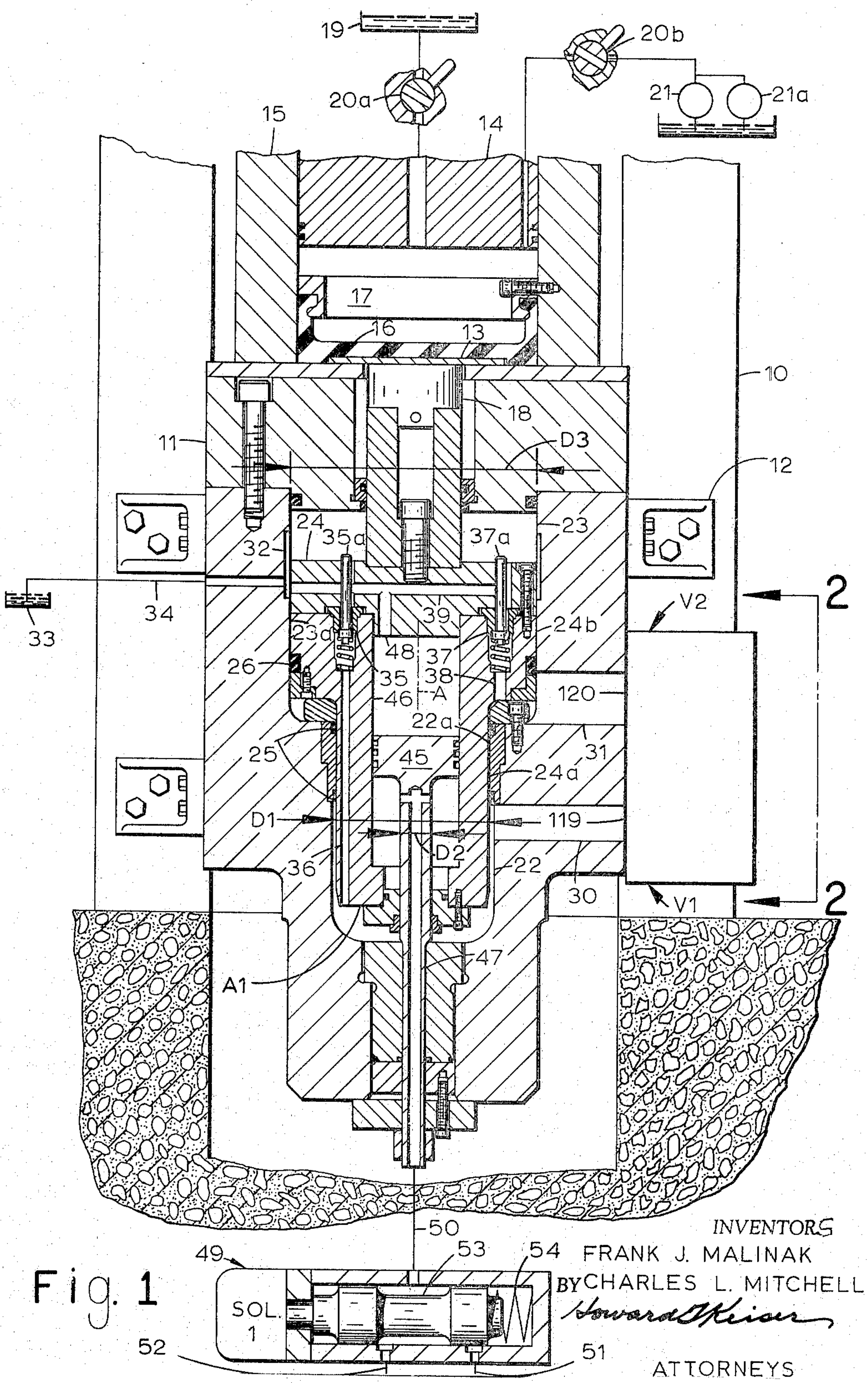

Fig. 1

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HIGH PRESSURE HYDRAULIC FORMING PRESS

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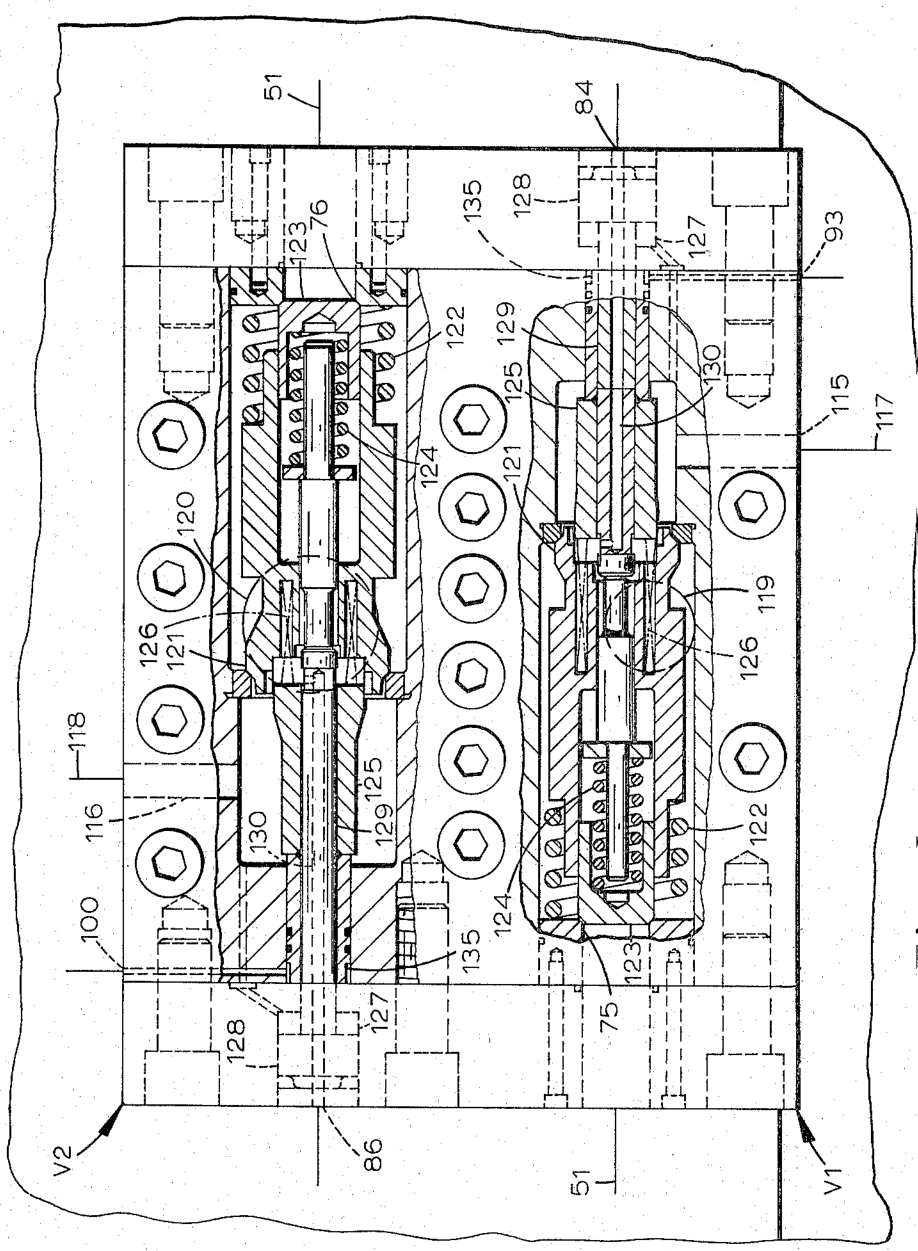

Fig. 2

HIGH PRESSURE HYDRAULIC FORMING PRESS

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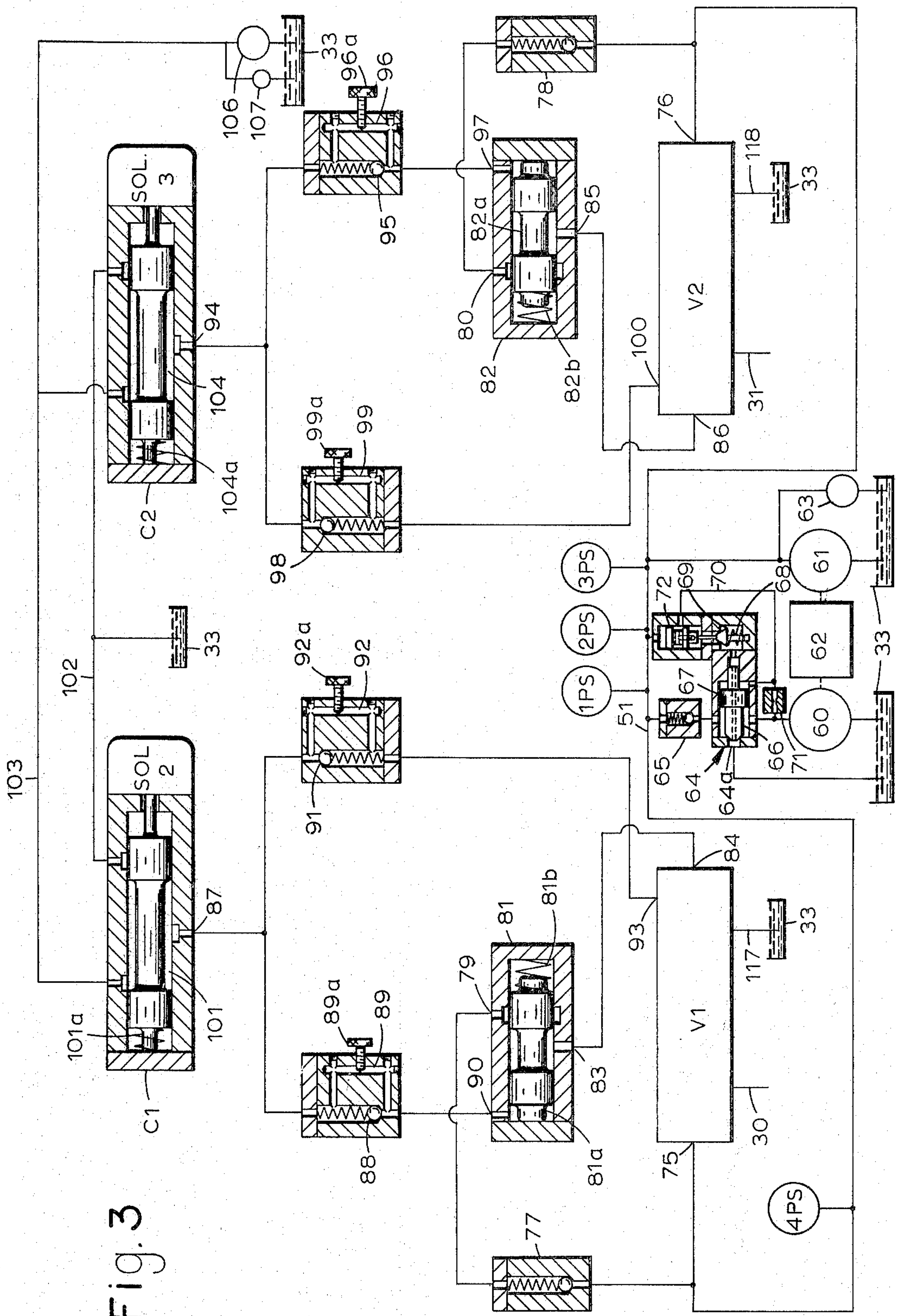


Fig. 3

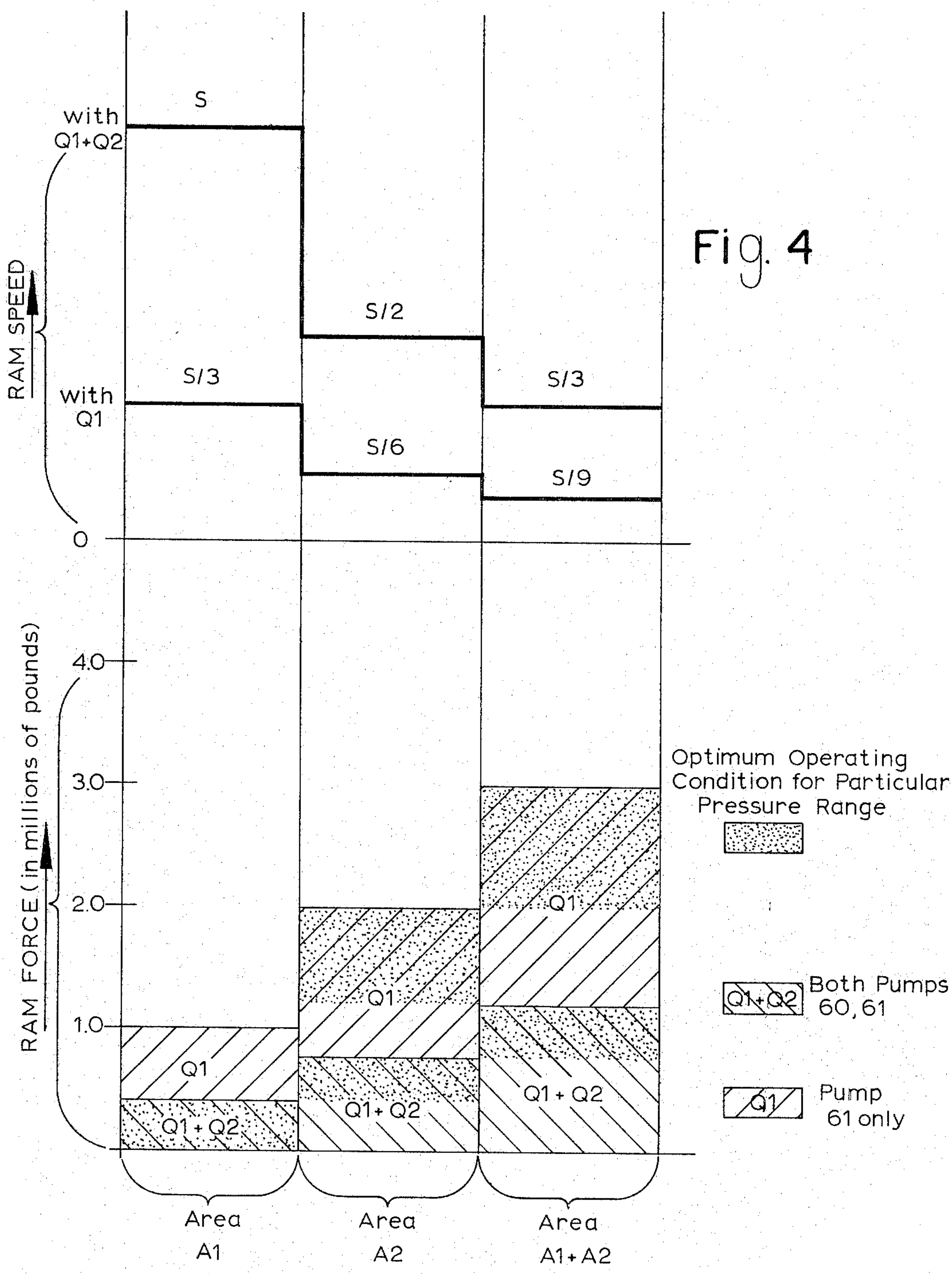
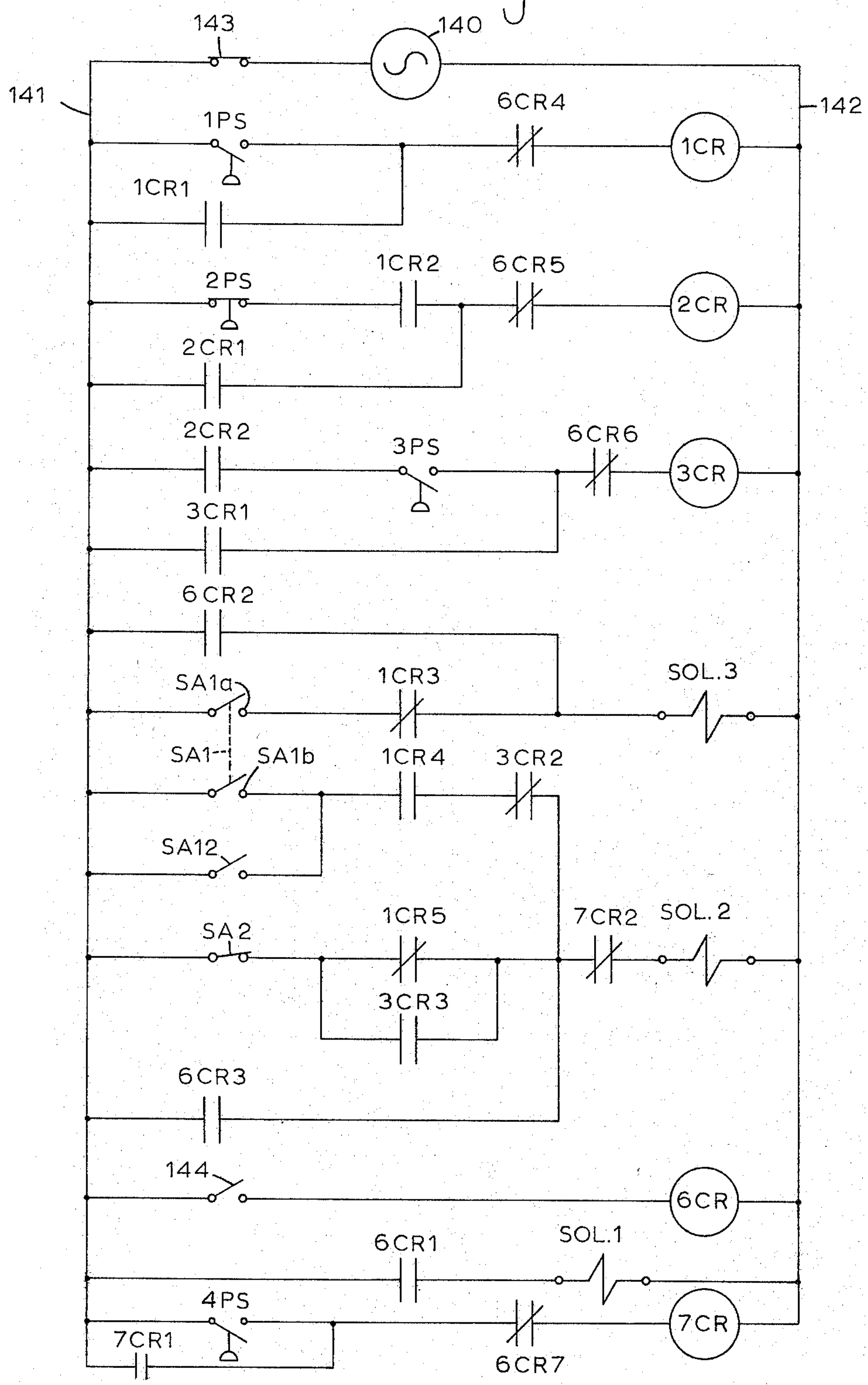

S
with
Q1+Q2
RAM SPEED
S/2
S/3
with
Q1
S/6
S/3
S/9
0
4.0
3.0
2.0
1.0
RAM FORCE (in millions of pounds)
Q1
Q1 + Q2
Q1
Q1+ Q2
Q1
Q1 + Q2
Area
A1
Area
A2
Area
A1+A2
Optimum Operating
Condition for Particular
Pressure Range
Q1+Q2 Both Pumps
60, 61
Q1 Pump
61 only

Fig. 4

Fig. 5


143
140
141
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1PS
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1CR
1CR1
1CR2
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6CR6
3PS
3CR
3CR1
6CR2
SA1a
1CR3
SOL.3
SA1
SA1b
1CR4
3CR2
SA12
SA2
1CR5
7CR2
SOL.2
3CR3
6CR3
144
6CR
6CR1
SOL.1
4PS
7CR
7CR1
6CR7

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HIGH PRESSURE HYDRAULIC FORMING PRESS

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Filed Dec. 18, 1963, Ser. No. 331,531
5 Claims. (Cl. 72—453)

The present invention relates to a hydraulic press.

In a hydraulic press where a ram is provided to exert a force on a workpiece, the magnitude of the force exerted by the ram is equal to the area of the ram pistons which are exposed to hydraulic fluid times the magnitude of the pressure of the hydraulic fluid acting on the ram pistons. The magnitude of the pressure of the hydraulic fluid acting on the ram pistons is determined by the magnitude of the resistance to ram movement produced in the formation of the workpiece. The resistance to ram movement is contributed in part by the resistance of the workpiece to deformation and in part by a backing force as, for example, the fluid pressure force in a diaphragm enclosed fluid pressure chamber behind the workpiece blank. The greater the area of the ram pistons exposed to hydraulic fluid of any given pressure, the greater the force exerted by the ram. But the greater the area of the ram pistons exposed to pressure fluid, the greater the rate of fluid flow to the pistons required to maintain a given speed of the ram. Or, stated another way, the greater the area of the ram pistons exposed to fluid pressure, the slower the ram speed for any given rate of pressure fluid flow to the ram pistons.

With a variable delivery pump supplying fluid to ram pistons of a given area, the speed of the ram can be adjusted by changing the volumetric output of the pump. Or, with a variable delivery pump, the area of the ram pistons can, for example, be increased to increase the force applied by the ram, and the volumetric output of the pump can be increased to maintain the speed of the ram constant despite the change in area of the ram pistons. While variable delivery pumps have been used in hydraulic presses with relatively low pressure systems (with a maximum pressure of, say, 5000 pounds per square inch), satisfactory variable delivery pumps are not commercially available at practical cost for high pressure hydraulic press systems (with pressures of, say, 10,000 pounds per square inch). Thus, in a high pressure system, it is necessary to use a constant volume pump.

It is conventional in a hydraulic press to have several ram pistons which can be selectively and sequentially connected to a constant volume source of fluid under pressure. With this conventional arrangement, and with a constant volume pump, any change in operating condition of the press to increase the ram piston area for increasing the force applied to the work inevitably results in a reduction in speed of the ram.

In the present invention, a hydraulic press is provided in which the area of the ram pistons exposed to fluid pressure can be changed and in which a plurality of constant volume pumps are utilized, either singly or in combination, to provide an increased number of operating conditions for the press. For each value of force which must be exerted, there is a particular operating condition (that is, a particular pump or combination of pumps operating on a particular ram piston area or combination of ram piston areas) which will produce the fastest ram speed possible, and, as the force requirement changes during a forming operation, different operating conditions will be required to produce the fastest ram speed possible (which operating conditions will be referred to herein as optimum operating conditions) during different portions of the forming cycle. Surprisingly, unlike conventional

presses, it is sometimes advantageous, when the force requirements increase, to shift to a smaller piston area than the area used for smaller force requirements. In the preferred form of the invention, controls are provided with which the initial operating condition can be selected and which automatically effect changes of operating condition during the forming cycle so that, at any instant during the forming cycle, the press will be in the optimum operating condition.

It is important, once a forming operation on a workpiece has begun, to keep the ram moving, even if there is a shift of piston areas, to maintain a smooth finish on a workpiece. If the ram stops before the forming operation is completed, an irregularity will appear on the workpiece. In the preferred form of the present invention illustrated herein, sequentially controlled valves are provided for switching from one ram piston area to another in a manner eliminating the possibility of the ram stopping.

It is therefore one object of the present invention to provide an improved hydraulic press with an increased number of different operating conditions for obtaining maximum speed and efficiency of the press with a given power input. It is another object of the present invention to provide an improved hydraulic press which automatically changes operating conditions during the forming cycle as the force requirements of the press change to maintain the press in the optimum operating condition for maximum ram speed. It is still another object of the present invention to provide a hydraulic press in which the initial operating condition can be selected and which thereafter automatically changes operating conditions to maintain the press in the optimum operating condition for maximum ram speed. It is yet another object of the present invention to provide, in a hydraulic press, improved mechanism for switching from one ram area to another without stopping the ram.

Other objects and advantages of the present invention should be readily apparent by reference to the following specification, considered in conjunction with the accompanying drawings forming a part thereof, and it is to be understood that any modifications may be made in the exact structural details there shown and described, within the scope of the appended claims, without departing from or exceeding the spirit of the invention.

In the drawings:

FIG. 1 is a fragmentary elevational view, partly in cross-section, showing the press of the present invention;

FIG. 2 is a view taken on the line 2—2 of FIG. 1, with parts broken away for clarity;

FIG. 3 is a hydraulic diagram of the portion of the hydraulic system for controlling the operation of the press ram;

FIG. 4 is a chart showing different operating conditions for the hydraulic press (with the relative speed of the ram shown for the different operating conditions and with the optimum operating condition of the press indicated for different force requirements); and

FIG. 5 is an electrical diagram for the electrical system controlling the operation of the press ram.

There is shown in FIG. 1 a hydraulic press having an upstanding frame 10. A bed member 11, connected to the frame by brackets 12, supports a workpiece blank 13 for a forming operation thereon. A head member 14, connected to the frame 10 above the bed, slidably receives a sleeve 15. The sleeve 15, which carries a flexible diaphragm 16 in its lower end, is lowered on the head member 14 (by motors mounted on the frame, not shown) to lower the diaphragm into engagement with the workpiece blank 13 for forming. Hydraulic fluid flows from a fluid reservoir 19 (fixed on head member 14), when valve 20*a* is open, to the chamber 17 defined by the head member 14, sleeve 15, and diaphragm 16 as the sleeve 15 is lowered on the head member before the forming operation begins. After the diaphragm 16 is engaged with the workpiece blank, valve 20*a* is closed. Thereafter, valve 20*b* is operated selectively to supply additional fluid to chamber 17 by a high pressure pump 21 (having relief valve 21*a* and rated at, for example, 10,000 pounds per square inch) to raise the pressure in chamber 17 to, say, 5000 pounds per square inch. Thereafter, a ram 18 is raised to form the workpiece. As the ram 18 rises, chamber 17 decreases in size which raises the pressure in chamber 17. The increase in pressure in chamber 17 may be magnified during forming by supplying additional fluid through valve 20*b*, or may be modified during forming by releasing a limited amount of fluid through valve 20*a*. After the forming operation, the sleeve 15 is raised (with valve 20*a* open to return fluid to the reservoir) for removal of the finished workpiece.

The bed member 11 defines two connecting chambers, or cylinders, 22 and 23, lying in end-to-end relationship and having a common central axis A which is also the central axis of the ram 18. An actuating member, or actuator, 24 is received in the cylinders and is connected at its upper end to the ram 18. The actuating member 24 may be considered as comprising two pistons, a lower piston 24*a* slidably received in the lower cylinder 22 and in sealing engagement (by virtue of annular seals 25) with cylinder wall 22*a* and an upper piston 24*b* slidably received in the upper cylinder 23 and in sealing engagement (by virtue of annular seal 26) with cylinder wall 23*a*.

A passage 30 through the bed member 11 defines a hydraulic line in continuous communication with the lower end of piston 24*a* and a passage 31 through the bed member 11 defines a hydraulic line in continuous communication with the lower end of piston 24*b*. An anular groove 32 in the upper end of cylinder 23 is in continuous communication with sump 33 through line 34 extending through bed member 11.

The ram 18 is raised by the application of fluid under pressure through line 30 to the lower end of cylinder 22 to act on the lower end of piston 24*a* and/or by the application of fluid under pressure through line 31 to the lower end of cylinder 23 to act on the lower end of piston 24*b*. Two safety valves are provided in the actuating member 24 to stop the actuating member when it reaches its upper limit of travel. One normally closed safety valve 35 is connected by hydraulic fluid passage 36 to the lower end of cylinder 22 and the other normally closed safety valve 37 is connected by hydraulic fluid passage 38 to the lower end of cylinder 23. Both valves are opened by engagement of the valve rods 35*a* and 37*a* with the upper end wall of cylinder 23 to open passages 36 and 38 to the sump through passage 39, groove 32, and line 34.

The ram 18 is lowered by means of a stationary piston 45 received in a cylinder 46 in the actuating member 24 and connected by a piston rod 47 to the lower end of base member 11. The cylinder 46 above piston 45 is continuously connected to the sump 33 through line 48, line 39, groove 32, and line 34. The cylinder 46 below piston 45 is connected to a valve 49 by a hydraulic fluid line 50 extending through piston rod 47. Valve 49 is connected to a pressure line 51 and a return line 52. When solenoid SOL1 of the valve is energized and the valve plunger 53 is to the right of the position shown in FIG. 1, line 50 is connected to pressure line 51 (and disconnected from return line 52), putting pressure in chamber 46 below the stationary piston 45 to lower the actuating member 24 and ram 18. Solenoid SOL1 is deenergized whenever fluid pressure is introduced to either cylinder 22 (through line 30) or cylinder 23 (through line 31). With SOL1 deenergized, spring 54 shifts valve plunger 53 to the left (as shown in FIG. 1), connecting line 50 to return line 52 (and disconnecting line 50 from line 51) to relieve the pressure in cylinder 46 below piston 45 so that the actuating member 24 and ram 18 can be raised.

With the particular construction shown, the effective area A1 of the ram actuator 24 exposed to the pressure in cylinder 22 (or, more specifically, the effective area A1 of piston 24*a* exposed to pressure in cylinder 22) is equal to $\pi(D1)^2/4-\pi(D2)^2/4$ where D1 is the diameter of piston 24*a* and D2 is the diameter of piston rod 47. The effective area A2 of the ram actuator 24 exposed to the pressure in cylinder 23 (or, more specifically, the effective area A2 of piston 24*b* exposed to pressure in cylinder 23) is equal to $\pi(D3)^2/4-\pi(D1)^2/4$ where D3 is the diameter of piston 24*b*.

In forming workpieces from blanks 13, the most suitable pressure to apply to chamber 17 will depend on several factors including the shape of the workpiece and the thickness of the workpiece blank. In fact, for most forming operations, the most satisfactory results can be obtained when the pressure in chamber 17 increases as the shape of the workpiece changes during the elevation of ram 18. In any forming operation, the flexible diaphragm pressing down on ram 18 because of the pressure in chamber 17 defines a resistance to upward movement of the ram 18, and an upward force must be applied to the ram sufficiently great to overcome this resistance and maintain the upward movement of the ram 18. Since, for many workpieces, the pressure in chamber 17 increases during the forming operation, the resistance to upward movement of the ram will increase during the forming operation.

It is usually desirable, particularly when forming a large quantity of parts, to form the workpiece in the shortest possible time, and this requires the highest speed of the ram obtainable with the power available, as long as this speed does not exceed the maximum permissable forming speed of the metal being drawn. With a machine constructed with a source of power of practical size, the utilization of the full power available will not result in a ram speed exceeding the maximum permissable forming speed of the metal in the usual forming operation.

With a hydraulic press having a ram actuating member operated by a motor driven pump, the power output of the motor is proportional to the product of the rate of flow Q of hydraulic fluid from the pump and the pressure P of the hydraulic fluid. The pressure of the hydraulic fluid required to move the ram is determined by the resistance to ram movement and the effective area of the ram piston, or pistons, exposed to the hydraulic fluid. It is known to provide more than one ram piston so that different effective piston areas can be utilized by supplying hydraulic fluid selectively to one or more of the pistons. Thus, for example, if three different effective piston areas are available, the ram can be operated at three different speeds with a constant volume pump since, with a given rate of flow from the pump, the speed of the ram will be inversely proportional to the ram piston area exposed to the hydraulic fluid. With this arrangement, the rate of flow Q from the pump will be the same under all conditions of operation and the pressure P of the fluid will vary, for any given effective piston area, as the resistance to ram movement varies.

In the hydraulic press disclosed herein, more operating conditions of the press are made possible by the use of two constant volume pumps, and means are provided to change the operating condition of the press to maintain the press in the operating condition providing the greatest ram speed possible. This results in automatically achieving the fastest forming cycle possible.

As shown in FIG. 3, two constant volume pumps 60, 61 are provided. Pump 60 is a low pressure, high volume pump rated at, for example, a maximum pressure of 4000 pounds per square inch with a constant flow Q1 of 20 gallons per minute. The pump 61 is a high pressure, low volume pump rated at, for example, a maximum pressure of 10,000 pounds per square inch with a constant flow Q2 of 10 gallons per minute. Both pumps 60, 61 are driven by a power source 62 which may be a single electric motor, or a bank of motors, but, in either event, the full capacity of the power source is available to either or both pumps as required.

The high pressure pump 61 takes fluid from sump 33 and delivers it under pressure to pressure line 51. A safety relief valve 63 is set to open at 10,000 pounds per square inch to return fluid to the sump, thereby preventing a pressure in excess of 10,000 pounds per square inch from developing in line 51. The low pressure pump 60 is connected to pressure line 51 through an unloading valve 64 and a check valve 65. The unloading valve 64 remains closed, so that the full output of pump 60 is delivered to line 51, until the pressure in line 51 reaches 4000 pounds per square inch, at which time the unloading valve opens to dump the output of pump 60 to the sump at atmospheric pressure. The unloading valve, which is a commercially available valve, has a plunger 66 with a piston 67 thereon. When the pressure in line 51 is below 4000 pounds per square inch, the spring 68 holds poppet valve 69 close, and the valve plunger 66 is in the position shown. At this time fluid flows from the output side of the pump 60 through the unloading valve and check valve 65 to line 51, but no fluid flows through the branch line 70, which contains the restriction 71, so the pressures on both sides of the piston 67 are equal. The area of piston 67 exposed to pressure in line 70 is slightly larger than the area of the piston 67 exposed to the output pressure of pump 60, so the plunger 66 is held to the left, as shown, blocking the discharge port 64*a* connected to the sump. When the pressure in line 51 reaches 4000 pounds per square inch, the plunger 72, one end of which is exposed to line 51, overcomes the force of spring 68 to open poppet valve 69 and initiate flow in line 70 (which flow passes through plunger 72, past poppet valve 69, through plunger 66 and port 64*a* to the sump). With flow in line 70 occurring through restriction 71, the pressure behind piston 67 drops, and the plunger 66 shifts to the right, opening a passage through port 64*a* from the output side of the pump 60 to the sump. The check valve 65 prevents the loss of fluid to the sump from line 51 when the unloading valve 64 is open.

The pressure line 51 is connected to the inlet ports 75 and 76, respectively, or two valves V1 and V2, and is also connected through check valves 77 and 78 to the inlet ports 79 and 80, respectively, of operating valves 81 and 82. The outlet port 83 is connected to an operating port 84 of valve V1 and the outlet port 85 of valve 82 is connected to an operating port 86 of valve V2.

The outlet port 87 of a control valve C1 is connected, through check valve 88 and a restricted passage 89 bypassing the check valve, to the control port 90 of valve 81, and is connected, through check valve 91 and a restricted passage 92 bypassing the check valve, to a conditioning port 93 of valve V1. The outlet port 94 of a control valve C2 is connected, through check valve 95 and a restricted passage 96 bypassing the check valve, to the control port 97 of valve 82, and is connected, through check valve 98 and a restricted passage 99 bypassing the check valve, to a conditioning port 100 of valve V2. Control valve C1 has a solenoid SOL2 which, when energized, shifts valve plunger 101 to the left (as shown in FIG. 3) to connect a pilot pressure line 103 to outlet port 87. When solenoid SOL2 is deenergized, valve plunger 101 is shifted to the right by spring 101*a* to connect outlet port 87 to a return line 102. Control valve C2 has a solenoid SOL3 which, when energized, shifts valve plunger 104 to the left (as shown in FIG. 3) to connect pilot pressure line 103 to outlet port 94. When solenoid SOL3 is deenergized, valve plunger 104 is shifted to the right by spring 104*a* to connet outlet port 94 to return line 102. A pilot pressure pump 106, having a relief valve 107, supplies fluid from sump 33 to pilot presure line 103 at a relatively low pressure of, say, 500 pounds per square inch.

Valves V1 and V2 each have discharge ports, 115 and 116, respectively (see FIG. 2) connected by lines 117 and 118, respectively, to sump 33. Valve V1 has a cylinder port 119 connected to line 30 through which fluid to and from chamber 22 flows, and valve V2 has a cylinder port 120 connected to line 31 through which fluid to and from chamber 23 flows. The valves V1, V2 are similar, and each has a central valve member 121 (biased by spring 122) which, when in the position shown, blocks the cylinder port (119, 120) from the discharge port (116, 117). Slidably received in valve member 121 is another valve member 123 (biased by spring 124) which, when in the position shown, blocks the inlet ports (75, 76) connected to the main pressure line 51. Each valve has a sleeve 125 slidably received therein which is biased away from valve member 121 by a spring 126 received therebetween. Each valve has a cylinder 127 with one end connected to the operating port (84, 86) and the other end connected to the discharge port (115, 116). A piston 128 in cylinder 127 is connected to a rod 129 (slidably received in sleeve 125) which, when piston 127 is shifted to the inner end of cylinder 127 in response to pressure at the operating port, abuts against valve member 123 and holds the inlet ports (75, 76) closed. The rod has a passage 130 therethrough which connects the operating port (84, 86) to the discharge port (115, 116) when the sleeve 125 is retracted from valve member 121 as shown.

The control valves C1, C2 are either both energized simultaneously to block the flow of pressure fluid to both cylinders 22 or 23, or one is energized and the other deenergized to block flow to one cylinder, or both are deenergized to permit flow to both cylinders. When the solenoids SOL2 and SOL3 are energized, pilot pressure is present at ports 90 and 97 of operating valves 81 and 82. Thus operating ports 84 and 86 of valves V1 and V2 will be connected to the main pressure line 51 through the operating valves 81, 82. Since the pistons 128 in valves V1, V2 are larger than the area of valve members 123 exposed to pressure in line 51, the valve members 123 are forced by rods 129 to close ports 75, 76 in response to main line pressure at ports 84, 86. At the same time, pilot pressure at ports 93, 100 is communicated to chambers 135 at the outer end of sleeves 125 to hold the sleeves 125 in abutting engagement with valve members 121 and valve members 121 will be held off their seats to connect the cylinder ports 119, 120 to the discharge ports 115, 116.

Solenoid SOL2 of control valve C1 is deenergized to produce flow of pressure fluid to cylinder 22. When the solenoid is deenergized, pilot pressure is removed from port 90 of valve 81 and port 93 of valve V1 and these ports are connected to return line 102. As pilot pressure is removed immediately from port 90, the valve member 81*a* of valve 81 is shifted by spring 81*b* to the position shown in FIG. 3 to cut off the supply of main pressure fluid to port 84 of valve V1. Thereafter (because decay of pressure at port 93 of valve V1 is delayed by restriction 92*a* in line 92) sleeve 125 of valve V1 retracts to the position shown in FIG. 2, allowing valve member 121 to close. This opens passage 130 of valve V1 to discharge port 115 and hence connects port 84 to return line 117. Thus rod 129 retracts and the force of pressure in line 51 opens valve member 123.

When it is desired to change the application of fluid under pressure from area A1 to area A2, solenoid SOL2 of control valve C1 is energized and solenoid SOL3 of control valve C2 is deenergized simultaneously. It is important that, during this change of area, the ram continue moving since stopping of the ram will result in an irregularity in the surface of the workpiece being formed. Pilot pressure line 103 is connected to port 87 of control valve C1 when solenoid SOL2 is energized, and pilot pressure is immediately placed on port 93 of valve V1. Simultaneously, port 94 of control valve C2 is connected to return line **102** and pilot pressure is immediately removed from control port **97** of valve **82** to permit valve member **82a** to shift to the right under the bias of spring **82b** and block the supply of main line pressure fluid from port **86** of valve V2. Thereafter (because increase of pressure at control port **90** of valve **81** is slowed by restriction **89a** in passage **89**), pressure from main line **51** is placed on port **84** of valve V1. However, the restriction produced by needle valve **89a** in line **89** is greater than the restriction produced by needle valve **99a** in line **99**, and pressure is therefore relieved from port **100** of valve V2 after pressure appears at port **93** of valve V1 and after main line pressure is blocked from port **86** of valve V2 but before main line pressure appears at inlet port **84** of valve V1. Consequently, the sequence of events is that first, sleeve **125** of valve V1 is advanced into abutting engagement with valve member **121** but valve member **121** remains closed because the pressure on the opposite side of the valve member **121** (equal to the pressure in chamber **22**) holds it closed. At the same time, port **85** of control valve **82** is blocked to block main line pressure from port **86** of valve V2, but rod **129** of valve V2 will not retract until port **86** of valve V2 is connected to discharge. Next, the pressure at port **100** decays, allowing sleeve **125** of valve V2 to retract because of spring **126**, thereby opening port **86** to exhaust, closing valve member **121**, and permitting valve member **123** of valve V2 to open under the force of pressure in line **51**. Thus, at this time, fluid under pressure is supplied both to area A1 and to area A2 so that the upward movement of actuator **24** continues. Finally, when pressure builds up at control port **90** of valve **81** and valve member **81a** is shifted to the right, pressure is introduced to port **84** of valve V1 to close port **75**. With port **75** closed, the upward movement of actuator **24** lowers the pressure in cylinder **22**, permitting valve member **121** of valve V1 to open and connecting chamber **22** to exhaust through line **30**, past valve member **121** to discharge port **115**. It should be noted that the restriction defined by needle valve **96a** in line **96** is greater than the restriction defined by needle valve **92a** in line **92** so that a switch from area A2 to A1 can be effected in the same manner as the switch from area A1 to A2.

For purposes of explanation of the operation of the present invention, let it be assumed that the effective area A1 of piston **24a** exposed to pressure in cylinder **22** is 100 square inches, and that the effective area A2 of piston **24b** exposed to pressure in cylinder **23** is 200 square inches. Assume also that pump **60** produces a constant volume of 20 gallons per minute flow Q2 and is rated at a maximum pressure of 4000 pounds per square inch (so unloading valve **64** is set to operate at 4000 pounds per square inch pressure). Assume that pump **61** produces a constant volume flow Q1 of 10 gallons per minute and has a rated maximum pressure of 10,000 pounds per square inch.

With these parameters, and up to 4000 pounds per square inch pressure, the combined flow Q1 plus Q2 of both pumps can be supplied to area A1 only (to produce, at 4000 pounds per square inch pressure, a force of 400,000 pounds); or can be supplied to area A2 only (to produce, at 4000 pounds per square inch pressure, a force of 800,000 pounds); or can be supplied to areas A1 and A2 simultaneously (to produce, at 4000 pounds per square inch pressure, a force of 1,200,000 pounds). It will be noted, however that a given flow (as, for example 30 gallons per minute) to area A1 will produce a faster ram speed than the same flow to a larger area. With the parameters used for illustrative purposes, and a flow of 30 gallons per minute, the ram speed S when area A1 is used will be 69.3 inches per minute, which is twice the ram speed when area A2 is used and three times the ram speed when areas A1 and A2 are used simultaneously. It will be noted that the power utilized, when area A1 alone is used, to produce a ram force of 400,000 pounds and a ram speed S (which may, for illustrative purposes, be considered as the maximum power available), is the same as the power utilized to produce, when area A2 is used alone, a ram force of 800,000 pounds and a ram speed $S/2$, or to produce, when areas A1 and A2 are used simultaneously, a ram force of 1,200,000 and a ram speed of $S/3$.

At pressures over 4000 pounds per square inch, pump **60** is unloaded to the sump at atmospheric pressure, and flow available to the system is limited to the output of pump **61**, which is 10 gallons per minute, and indicated as Q1. Consequently the speed of the ram, when any given area, or combination of areas, is used will be one third the speed thereof when the flow was 30 gallons per minute. However, since higher pressure can be used (up to 10,000 pounds per square inch) higher forces can be realized. Specifically, when area A1 is used alone, the ram can exert a force of 1,000,000 pounds at 10,000 pounds per square inch; when area A2 is used alone, the ram can exert a force of 2,000,000 pounds at 10,000 pounds per square inch; and when areas A1 and A2 are used simultaneously, the ram can exert a force of 3,000,000 pounds at 10,000 pounds per square inch. The power used at maximum pressure (10,00 pounds per square inch) in each of these three operating conditions is the same but is less than the power consumed at maximum pressure (4000 pounds per square inch) when both pumps are operating.

When a single constant volume pump is used in conjunction with a plurality of ram piston areas, and the maximum speed of the ram is desired, the operation will begin with the smallest area possible to obtain the required force. As the force requirements increase during the operation, the areas used must progressively increase, and the speed of the ram consequently decreases. With the use of two constant volume pumps, however, and a plurality of areas, it is not always necessary to shift to a larger area (and lower speed) when the force increases. Unexpectedly, it is sometimes possible to shift to a smaller area and operate at a greater speed than if the area had remained unchanged.

This is illustrated in FIG. 4 in which two operating conditions (both pumps operating at or under 4000 pounds per square inch, or pump **61** operating alone over 4000 pounds per square inch) are shown for area A1 alone, area A2 alone, and for areas A1 and A2 together. FIG. 4 shows that under 4000 pounds per square inch, the highest speed S is obtainable with the use of both pumps operating only on area A1. A change of operating condition however, is necessary during the operation if the force required rises above 400,000 pounds. Either pump **60** must be unloaded, to permit higher pressure, or, if the pressure is to be held under 4000 pounds per square inch to retain the use of pump **60**, the area must be changed from A1 to A2. The first alternative would reduce the speed of the ram from S to $S/3$; the second alternative reduces the speed of the ram to only $S/2$ and hence is preferred. The optimum operating condition for each force range is dotted in FIG. 4 to indicate the area or combination of areas used, and the pump or combination of pumps used, to obtain maximum possible ram speed.

It will be noted that between 800,000 pounds and 1,200,000 pounds, the area $A1+A2$, with both pumps operating is preferred and, at 1,200,000 pounds force output, the maximum power is being used. Since no larger area is available, the low pressure pump must be unloaded. Surprisingly, however, a smaller area A2 should be used between 1,200,000 pounds of force and 2,000,000 pounds of force since, with this smaller area, a higher speed of $S/6$ is obtainable as compared to the maximum speed of $S/9$ if the combined areas A1, A2 are used.

Although five optimum operating conditions are shown in FIG. 4, each for a different pressure range, it is rare that more than three operating conditions are necessary for the formation of a particular workpiece. In virtually all forming operations, the pressure requirements increase during the forming operation. Controls are provided automatically to effect two shifts of operating condition in response to the force requirement, each shift changing from the optimum operating condition in one force range to the optimum operating condition for the next higher force range when the force reaches the maximum value of the lower force range. The press can be set to begin the forming operation in any of the three operating condtions which are optimum for the three lower force ranges, and will automatically shift, during the forming cycle, progressively to the two optimum operating conditions for the next two successively larger force ranges.

As shown in FIG. 3, four pressure switches 1PS, 2PS, 3PS, and 4PS are connected to main pressure line 51. To illustrate particular operating cycles, assume that pressure switches 1PS and 3PS are normally open switches that close when the pressure in line 51 rises to 4000 pounds per square inch; that pressure switch 2PS is a normally closed switch that opens when the pressure in line 51 rises to 3500 pounds per square inch; and that pressure switch 4PS is a normally open switch that closes when the pressure in line 51 reaches 10,000 pounds per square inch. As shown in FIG. 5, a source 140 of electrical energy is connected across lines 141 and 142 when switch 143 is closed. A relay 6CR, connected across lines 141 and 142, is energized, to close normally open contacts 6CR1, 6CR2, and 6CR3 and to open normally closed contacts 6CR4, 6CR5, 6CR6 and 6CR7, only when switch 144 is closed. Relay 1CR, which is connected in series between lines 141, 142 with pressure switch 1PS and the normally closed contacts 6CR4 of relay 6CR, will be energized, if switch 144 is open, when the pressure in line 51 reaches a pressure of 4000 pounds per square inch. Normally open contacts 1CR1 of relay 1CR are connected across pressure switch 1PS to seal in relay 1CR until contacts 6CR4 open when switch 144 is closed. Relay 2CR is connected across lines 141, 142 in series with pressure switch 2PS, normally open contacts 1CR2 of relay 1CR, and normally closed contacts 6CR5 of relay 6CR. Assuming switch 144 is open, relay 2CR will be initially energized only after relay 1CR has been energized and when the pressure in line 51 is below 3500 pounds per square inch. Normally open contacts 2CR1 of relay 2CR are connected across switch 2PS and contacts 1CR2 to seal in relay 2CR until switch 144 is closed. Relay 3CR is connected across lines 141, 142 in series with pressure switch 3PS, normally open contacts 2CR2 of relay 2CR, and normally closed contacts 6CR6 of relay 6CR. Assuming switch 144 is open, relay 3CR will be energized only after relay 2CR has been energized and when the pressure in line 51 reaches 4000 pounds per square inch. Normally open contacts 3CR1 of relay 3CR are connected across contacts 2CR2 and switch 3PS to seal in relay 3CR until switch 144 is closed. Relay 7CR is connected across lines 141, 142 in series with pressure switch 4PS and the contacts 6CR7 of relay 6CR. With switch 144 open, relay 7CR is energized when the pressure in line 51 reaches 10,000 pounds per square inch. Normally open contacts 7CR1 of relay 7CR are connected across switch 4PS to seal in relay 7CR until switch 144 is closed.

Suppose a workpiece blank 13 is to be formed under a steadily increasing pressure during forming from an initial pressure in chamber 17 of a magnitude to exert a force of 500,000 pounds resisting elevation of ram 18 to a final pressure in chamber 17 of a magnitude to exert a force of 1,500,000 pounds against ram 18. Reference to FIG. 4 will show that the initial operating condition of the press entails the use of both pumps 60, 61 in conjunction with ram piston area A2. At an initial forming force of 500,000 pounds and an effective area A2

of 200 square inches, the initial pressure in main pressure line 51 will be 2500 pounds per square inch. When the force requirement reaches 800,000 pounds (and the pressure in line 51 reaches 4000 pounds per square inch), FIG. 4 shows that pressure should be applied to area A1 as well as to area A2. With 300 square inches of effective piston area instead of 200 square inches, the pressure in line 51 will drop to approximately 2667 pounds per square inch when the switch is made but will thereafter rise until the force requirement is 1,200,000 pounds and the pressure in line 51 is again 4000 pounds per square inch. At a force requirement of 1,200,000 pounds, FIG. 4 shows that pressure should be removed from area A1 and that low pressure pump 60 should be unloaded. When this change of operating condition is made, the effective ram piston area will be 200 square inches and the pressure in line 51 will be 6000 pounds per square inch at the force requirement of 1,200,000. Thereafter, the pressure in line 51 will rise to a final value, at the force requirement of 1,500,000 pounds, of 7500 pounds per square inch.

The operator selects the proper initial area, to place the press in the proper initial operating condition, and, thereafter, the press will automatically change operating conditions at the proper time during the forming cycle. To initially select the area A2, the operator closes switch SA2 and leaves switches SA1 and SA12 open. Switch 144 is also opened. Solenoid SOL2, which is connected between lines 141 and 142 in series with normally closed contacts 7CR2 of relay 7CR, can be energized, when the switch SA2 is closed, through either the normally closed contacts 1CR5 of relay 1CR or the normally open contacts 3CR3 of relay 3CR. Solenoid SOL2 is also connected across lines 141, 142 in series with normally open contacts 6CR3 of relay 6CR so that solenoid SOL2 will be energized whenever switch 144 is closed. :An alternate current path for the energization of solenoid SOL 2 through either the contacts SA1b of switch SA1 or the contacts of switch SA12 and normally open contacts 1CR4 of relay 1CR and normally closed contacts 3CR2 of relay 3CR, will not be effective during a forming cycle which begins with area A2 since both switches SA1 and SA12 will be open. Solenoid SOL3 is connected across lines 141, 142 through contacts SA1*a* of switch SA1 and normally closed contacts 1CR3 of relay 1CR, but will not be energized through this current path when the forming cycle begins with area A2 because switch SA1 will be left open. However, normally open contacts 6CR2 are connected across the contacts SA1a and ICR3 so that solenoid SOL3 will be energized when switch 144 is closed.

With switches 143 and SA2 closed, and switches SA1, SA12, and 144 open, solenoid SOL2 will be energized at the beginning of the forming cycle to block line 51 from area A1 and solenoid SOL3 will be deenergized to connect pressure line 51 to area A2. With an initial pressure in line 51 of 2500 pounds per square inch, pressure switches 1PS, 3PS, and 4PS, will be open, and relays 1CR, 3CR, and 7CR will therefore be deenergized. Pressure switch 2PS will be closed but contacts 1CR2 of relay 1CR will be open so relay 2CR will also be deenergized. When the force requirement reaches 800,000 pounds and the pressure in line 51 is therefore at 4000 pounds per square inch, pressure switches 1PS and 3PS close, and relay 1CR is energized. Relay 2CR, and consequently relay 3CR, are not energized at this time because pressure switch 2PS opened at 3500 pounds per square inch.

When relay 1CR is energized, solenoid SOL2 is deenergized and area A1 is opened to pressure line 51 to increase the effective ram piston area to 300 square inches. This drops the pressure in line 51 to below 3500 pounds per square inch, and relay 2CR is energized. As the pressure in line 51 drops as a result of the change in operating condition, switch 3PS opens so that relay 3CR is not energized at this time. However, as the force requirement increases, the pressure in line **51** rises and, when the force reaches 1,200,000 pounds and the pressure in line **51** reaches 4000 pounds per square inch, switch **3**PS closes to energize relay **3**CR. Thus, at this time, solenoid SOL**2** is again energized to block area A**1** from pressure line **51**.

At this change of operating condition, the pressure in line **51** jumps to 6000 pounds per square inch and continues to rise until the completion of the forming cycle. When the workpiece is completely formed, switch **144** is closed to energize relay **6**CR so that both solenoids SOL**2** and SOL**3** are energized at that time, blocking both areas A**1** and A**2** from line **51**. At the same time, relays **1**CR, **2**CR, and **3**CR are deenergized to condition the circuit for another forming operation. Energization of relay **6**CR energizes solenoid SOL**1** to lower the ram for removal of the workpiece.

If, for example, the force requirements of a forming cycle start at an initial force of 250,000 pounds and rise to a final force of 1,000,000 pounds, initially switch SA**1** is closed and switches **144**, SA**2** and SA**12** are left open so that initially solenoid SOL**3** is energized to block area A**2** from the pressure line **51** and the forming cycle begins with only area A**1** effective. When the pressure in line **51** first reaches 4000 pounds per square inch (at a force of 400,000 pounds) and relay **1**CR is energized to open contacts **1**CR**3** and close contacts **1**CR**4**, solenoid SOL**3** is deenergized (to open area A**2** to line **51**) and solenoid SOL**2** is energized (to close area A**1** from line **51**). This drops the pressure in line **51**, and when, subsequently, the pressure again rises to 4000 pounds per square inch to energize relay **3**CR, contacts **3**CR**2** are opened to deenergize solenoid SOL**2** and again open area A**1** to line **51**.

If a forming cycle is to require, for example, an initial force of 1,000,000 pounds which rises to a final force of 3,000,000 pounds, switch SA**12** is initially closed and switches SA**1** and SA**2** are left open. Thus neither solenoid SOL**2** nor solenoid SOL**3** are energized and both area A**1** and area A**2** are exposed to pressure line **51**. When the pressure in line **51** first reaches 4000 pounds per square inch (at a force of 1,200,000 pounds) and relay **1**CR is energized to close contacts **1**CR**4**, solenoid SOL**2** is energized to close area A**1** from line **51**. At the same time, low pressure pump **60** unloads. At this change of operating condition, the pressure in line **51** immediately jumps to 6000 pounds per square inch, and then increases to 10,000 pounds per square inch, at a force requirement of 2,000,000 pounds. At a pressure of 10,000 pounds per square inch in pressure line **51**, pressure switch **4**PS closes to energize relay **7**CR. Contacts **7**CR**2** open, deenergizing solenoid SOL**2** and opening area A**1** to pressure line **51**. Although the pressure in line **51** immediately drops to approximately 6667 pounds per square inch, solenoid SOL**2** remains deenergized until the forming operation is completed and switch **144** is thereafter closed.

What we claim is:

1. In a hydraulic press

(a) a bed,

(b) a ram,

(c) a pair of cylinders in end-to-end relation inside the bed,

(d) an actuator connected to the ram, said actuator defining two pistons received respectively in said cylinders and having different effective areas,

(e) a pressure line,

(f) a pair of constant volume pumps connected to the pressure line, said pair consisting of a low pressure pump and a high pressure pump,

(g) means responsive to pressure in the pressure line to disconnect the low pressure pump from the pressure line at a predetermined pressure,

(h) means selectively to connect one or the other or both of said cylinders to the pressure line,

(i) and means sequentially to change the cylinders connected to the pressure line in response to the magnitude of the pressure in the pressure line.

2. In a hydraulic press for forming a workpiece blank,

(a) a bed,

(b) a ram to engage one side of the workpiece blank during forming,

(c) a fluid pressure chamber having a diaphragm therein to engage the other side of the workpiece blank during forming, the pressure in said chamber changing during the forming operation to change the resistance to ram movement,

(d) a pair of cylinders in end-to-end relation inside the bed,

(e) an actuator connected to the ram, said actuator defining two pistons received respectively in said cylinders and having different effective areas,

(f) a pressure line,

(g) a pair of constant volume pumps connected to the pressure line, said pair consisting of a low pressure pump and a high pressure pump,

(h) an unloading valve to disconnect the low pressure pump from the pressure line at a predetermined pressure.

(i) means selectively to connect one or both cylinders to the pressure line to produce the maximum ram speed against the initial resistance to ram movement,

(j) and means sequentially to connect or disconnect cylinders to the pressure line during the forming operation to maintain maximum ram speed at any given amount of resistance to ram movement.

3. In a hydraulic press for forming a workpiece blank,

(a) a bed,

(b) a ram to engage one side of the workpiece blank during forming,

(c) a pair of cylinders in end-to-end relation inside the bed,

(d) an actuator connected to the ram, said actuator defining two pistons received respectively in said cylinders and having different effective areas,

(e) a fluid pressure chamber having a diaphragm therein to engage the other side of the workpiece blank during forming, the pressure in said chamber increasing during the forming operation to increase the resistance to ram movement,

(f) a pressure line,

(g) a pair of constant volume pumps connected to the pressure line, said pair consisting of a low pressure pump and a high pressure pump,

(h) means selectively to connect one or both cylinders to the pressure line to produce the maximum ram speed against the initial resistance to ram movement, the pressure in the pressure line increasing as the resistance to ram movement increases,

(i) means sequentially to connect or disconnect cylinders to the pressure line during the forming operation in response to pressure in the pressure line to maintain maximum ram speed at any given amount of resistance to ram movement,

(j) and means to disconnect the low pressure pump whenever the pressure in the pressure line rises above a predetermined value.

4. In a hydraulic press,

(a) a ram,

(b) a pair of cylinders in end-to-end relation,

(c) a pair of coaxial pistons received, respectively, in said cylinders and connected to the ram,

(d) a pressure line connected to the cylinders,

(e) a pair of constant volume pumps connected to the pressure line to provide alternate rates of flow thereto,

(f) a pair of valves connected, respectively, between the pressure line and the cylinders,

(g) and control means responsive to pressure in said pressure line for sequential operation of said valves to connect one of said cylinders to the pressure line before disconnecting the other cylinder from the pressure line in changing from said other cylinder to said one cylinder during forming.

5. In a hydraulic press for forming a workpiece blank,
(a) a bed,
(b) a ram to engage one side of the workpiece blank during forming,
(c) a pair of cylinders in end-to-end relation inside the bed,
(d) an actuator connected to the ram, said actuator defining two pistons received respectively in said cylinders and having different effective areas,
(e) a fluid pressure chamber having a diaphragm therein to engage the other side of the workpiece blank during forming, the pressure in said chamber increasing during the forming operation to increase the resistance to ram movement,
(f) a pressure line,
(g) a pair of constant volume pumps connected to the pressure line, said pair consisting of a low pressure pump and a high pressure pump,

(h) a pair of valves connected, respectively, between the pressure line and the cylinders,
(i) and control means responsive to pressure in said pressure line for sequential operation of said valves to connect one of said cylinders to the pressure line before disconnecting the other cylinder from the pressure line in changing from said other cylinder to said one cylinder during forming.

References Cited by the Examiner

UNITED STATES PATENTS

1,955,278	4/1934	Ferris et al.	100—269
1,982,711	12/1934	Vickers	100—269
2,220,798	11/1940	Dinzl	100—269
2,313,623	3/1943	Bungay	100—269
2,937,606	5/1960	Paulton	72—63
2,938,451	5/1960	Seltzer	100—269
3,168,033	2/1965	Hansen	100—269

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