

June 24, 1958

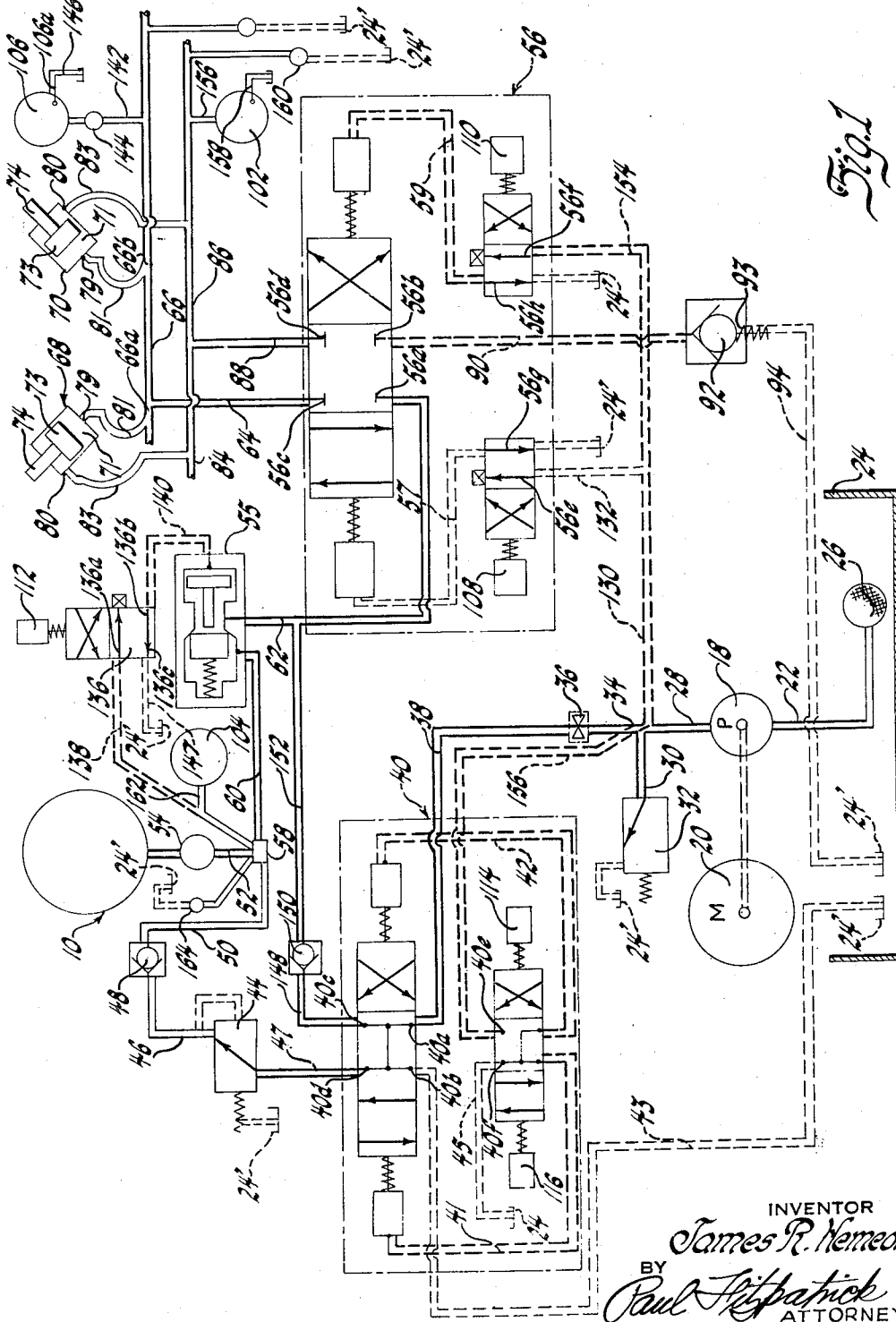
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2,839,895

HYDRAULIC DRIVING APPARATUS

Original Filed Aug. 29, 1952

5 Sheets-Sheet 1



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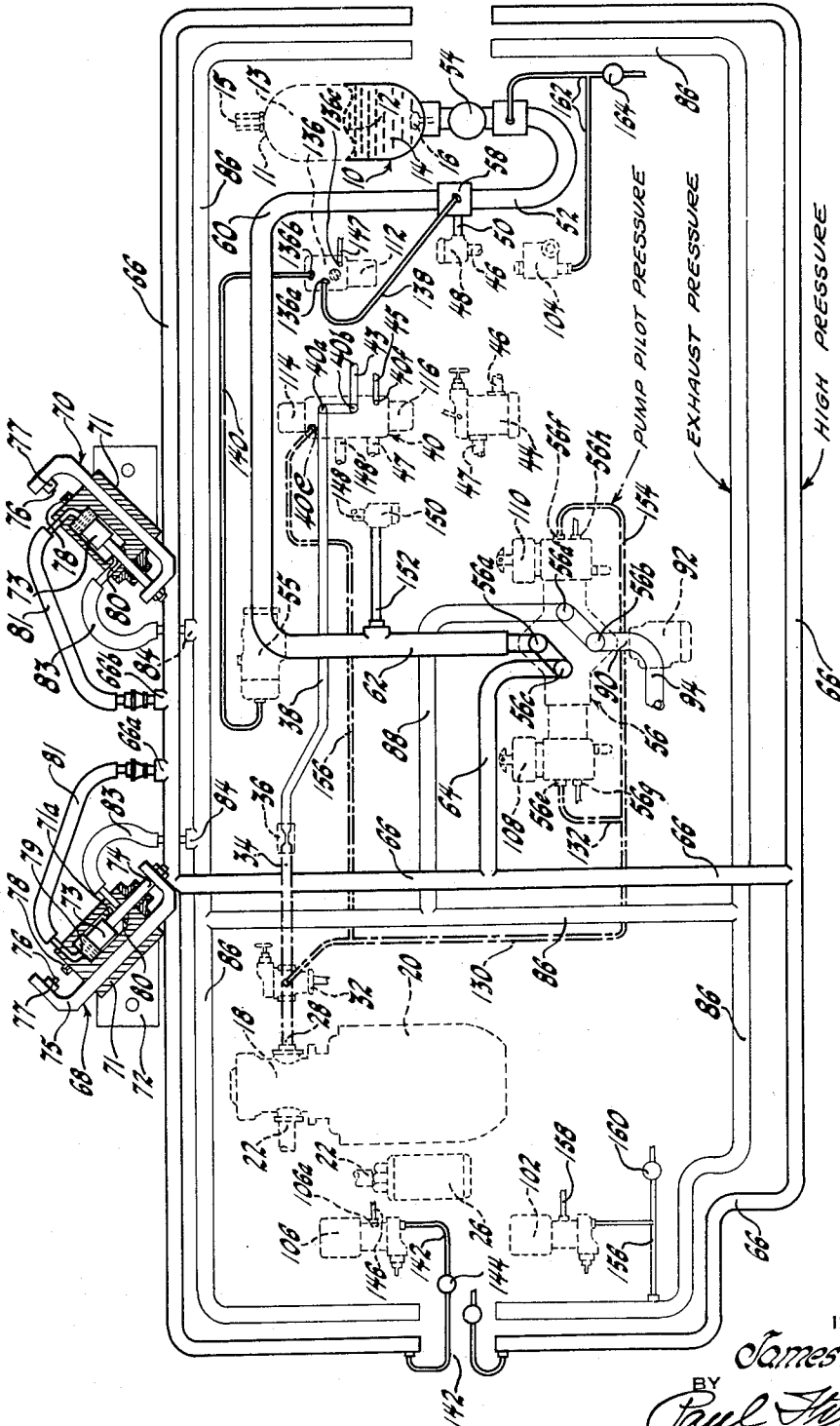


Fig. 2

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Original Filed Aug. 29, 1952

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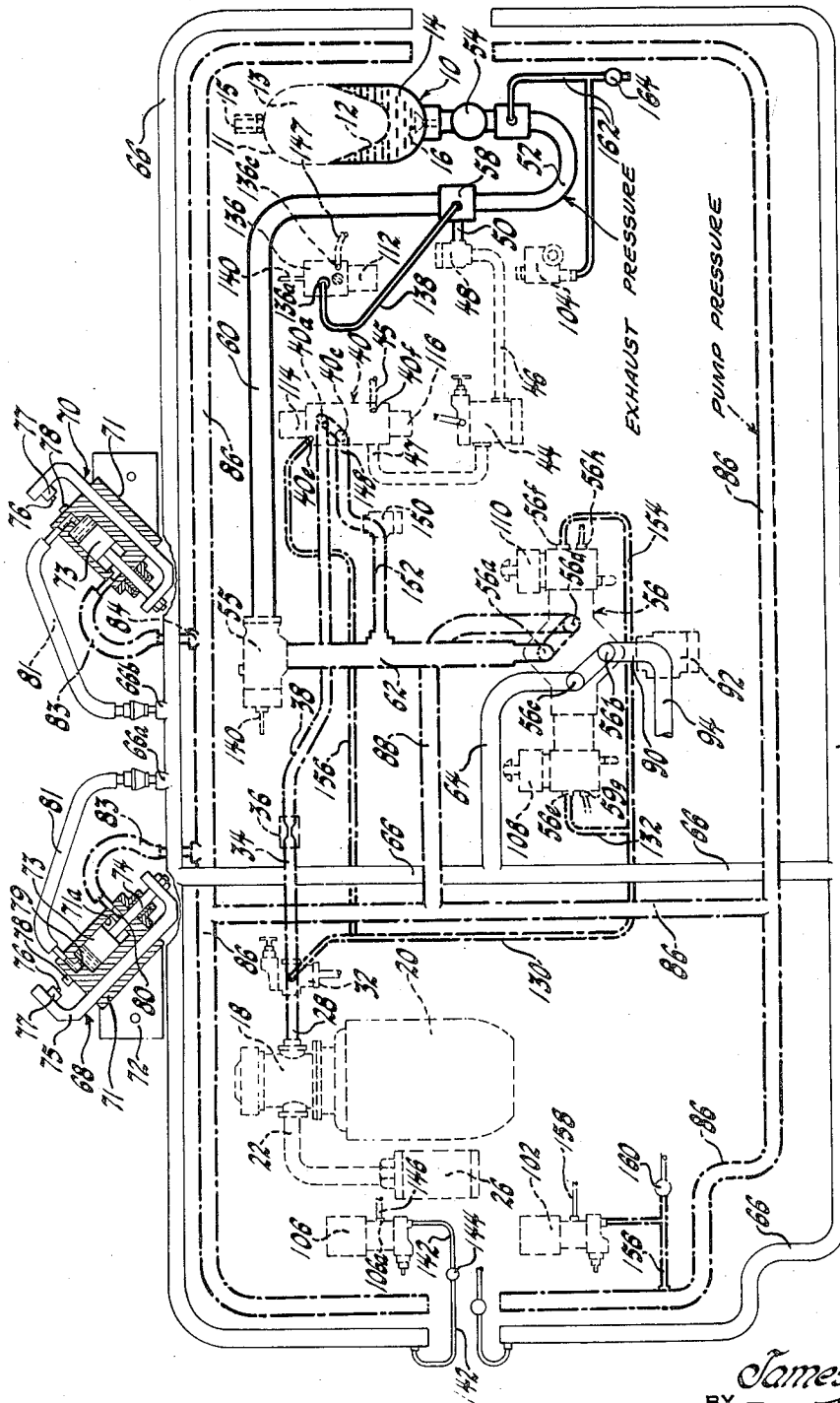


Fig. 3

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HYDRAULIC DRIVING APPARATUS

Original Filed Aug. 29, 1952

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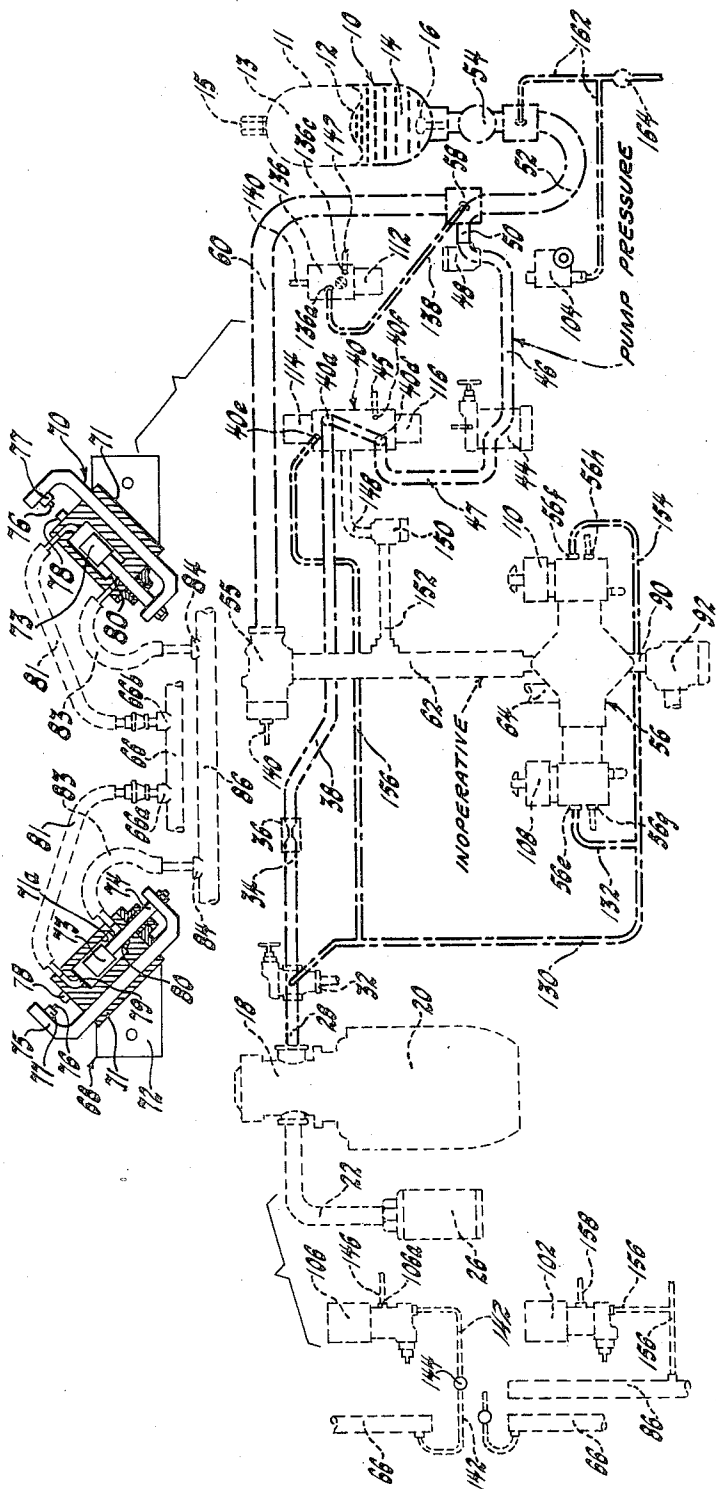


Fig. 4

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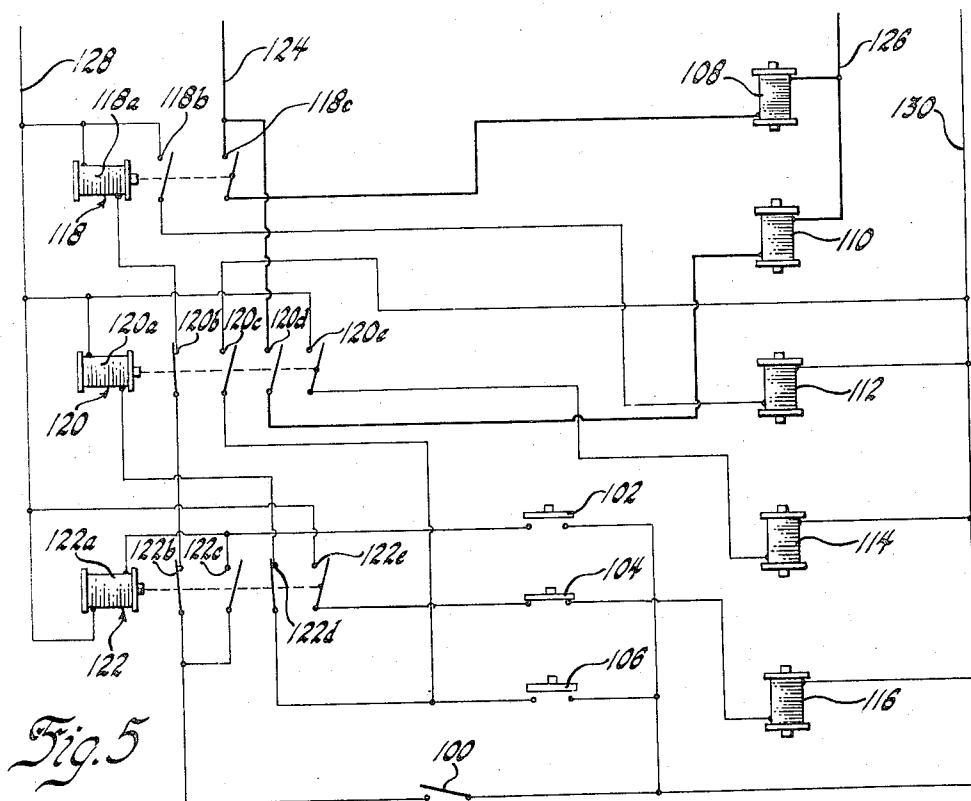
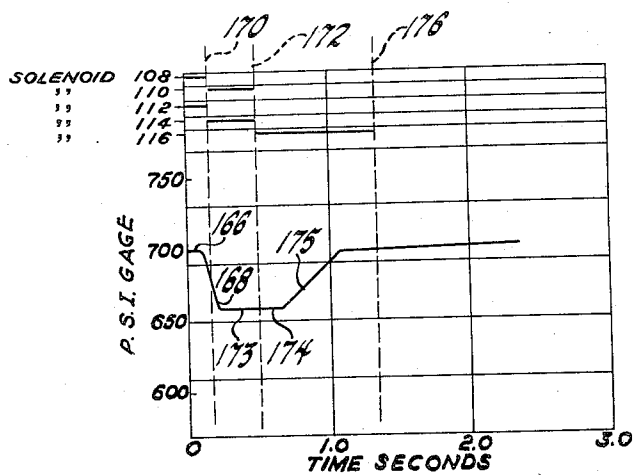
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HYDRAULIC DRIVING APPARATUS

Original Filed Aug. 29, 1952

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HYDRAULIC DRIVING APPARATUS

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Continuation of abandoned application Serial No. 307,019, August 29, 1952. This application May 8, 1956, Serial No. 583,476

8 Claims. (Cl. 60—51)

This invention relates to hydraulic driving apparatus, and more particularly to hydraulic driving apparatus wherein the hydraulic fluid is supplied to a load under the explosive force of an accumulator, so that the hydraulic fluid has a high impact force and a high level of kinetic energy.

In many manufacturing operations it is necessary to pierce holes in a workpiece, as for example a steel sheet or panel, and it is also often desirable to counterform these holes in order properly to seat the head of a screw. It has been the general practice to provide piercing apparatus wherein a hydraulically driven load, such as a piercing and counterforming tool, is driven by hydraulic fluid under the pressure of a pump. Even if a high volume pump is used the effect is to push the tool through the workpiece, and in consequence the quality of the pierce, and particularly the quality of the counterform operation is below that which is desired. The quality of the work is lowered when a plurality of piercing tools are driven by a single pump, as is desirable in quantity production, and even if the hydraulic pressure is increased the quality of the work is improved only very slightly because of the basic fact that pump pressure will merely push the tool through the workpiece.

The invention provides hydraulic piercing apparatus wherein a hydraulic accumulator is used to "explode" the tool into the workpiece with a high value of kinetic energy that will impact coin a sharp edged profile, particularly in the counterform operation. The term "accumulator" as used in the specification and claims is intended to cover any type of storage device wherein the hydraulic fluid or other force-transmitting means may be stored and suddenly released with an explosive action having a high value of kinetic energy.

The novel hydraulic piercing apparatus includes such an accumulator (which may be a conventional type of commercially obtainable hydraulic accumulator), a reservoir for hydraulic fluid, motor driven pump means for supplying the accumulator with hydraulic fluid from the reservoir under a predetermined pressure, hydraulic circuit means interconnecting the accumulator, pump and tool, and having valve means therein for directing the flow of hydraulic fluid, and control means which are automatically operable to control operation of the machine through a cycle comprising the steps of a work stroke wherein the pierce and counterform operation are done, a step in which the tools are retracted from the work pieces, and a final step in which the accumulator is recharged to the predetermined pressure in readiness for the next cycle of operation, which may be manually initiated.

During the pierce and counterform operation it is essential that the tool be driven under an explosive force with a high value of kinetic energy, and in order to insure proper accumulator action to provide this explosive force and high kinetic energy the valve means in the hydraulic circuit includes a check valve and a four-way directional control valve connected in series between the

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accumulator and the tool. The four-way directional control valve is shifted to provide the desired hydraulic path for the pierce stroke and the retract stroke, but if this valve alone were used leakage through the valve would reduce the accumulator efficiency, and therefore a check valve is installed in series with the four-way directional valve and the control means operates both valves simultaneously to open a clear passageway between the accumulator and the tool so that the hydraulic fluid reaches the tool under an explosive pressure.

The timing of the machine through the steps of the cycle is accomplished by pressure responsive switches, and the novel machine includes as one feature an arrangement whereby there is a delay in the operation of the switch which initiates the retract cycle. If this delay were not present the cycling of the machine would be upset because the accumulator action is of an explosive nature and the pressure build-up in the hydraulic circuit is extremely rapid when the check valve and four-way directional control valve are opened. In order to prevent the initiation of the retract step before the piercing step has been completed a restricted orifice or choke is provided in the inlet passage to the pressure responsive switch above mentioned so that, despite the rapid increase in pressure during the pierce stroke due to the rapid accumulator action, there is a delay in operating the pressure responsive switch so that said switch does not operate until some time after the pressure maximum is reached in the pressure manifold to which the switch is connected. By operating the switch at some time during the pierce stroke a further advantage is obtained in that the control valves start to shift before the completion of the pierce stroke, thereby preventing this valve shift time from delaying the initiation of the tool retracting step.

Inasmuch as the tools are retracted by hydraulic pressure against the bottom or rod end of the piston which drives the tool, the exhaust line leading from the rod end of the piston is filled with hydraulic fluid during operation of the machine. The explosive action of the accumulator results in a differential between the pressure and velocity factors in the exhaust portion of the hydraulic circuit so that the hydraulic fluid in the exhaust side overshoots, and there is a partial voiding of fluid from the exhaust portion of the hydraulic circuit. If this is allowed to occur there must be a delay in the tool retracting phase of the cycle while the pump fills the void in the exhaust tubing. The invention provides a novel means for controlling this differential between the pressure and velocity factors in the exhaust tubing and preventing overrunning of the fluid and partial voiding of the fluid from the exhaust line. In the apparatus illustrated this preventative means comprises a spring loaded valve in the exhaust line, the valve having the characteristics of high spring loading and rapid action such that it acts to permit exhaust fluid to flow back to the reservoir but prevents undesirable voiding of the exhaust line.

A machine constructed in accordance with the invention can perform a complete cycle in less than three seconds while utilizing a plurality of piercing tools, and the machine will provide an exceptionally high quality of pierce and counterform holes having sharply defined dimensions.

Other features and advantages of the invention will be apparent from the following description and from the drawings, in which:

Fig. 1 is a schematic representation of the hydraulic apparatus;

Fig. 2 is a fragmentary diagrammatic representation of the hydraulic apparatus, showing those parts which are operative during the pierce and counterform portion of the cycle;

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Fig. 3 is a fragmentary diagrammatic representation similar to Fig. 2, but showing those parts of the apparatus which are operative during the retract portion of the cycle;

Fig. 4 is a fragmentary diagrammatic representation similar to Fig. 2, but showing those parts of the apparatus which are operative during that portion of the cycle when the accumulator is recharged in preparation for the next automatic cycle of operation;

Fig. 5 is a circuit diagram of the electrical apparatus which controls the operation of the hydraulic apparatus; and

Fig. 6 is a timing chart showing a cycle of operation of the apparatus.

Referring now more particularly to the drawings, 10 is a hydraulic accumulator, and may comprise a 2½ gallon accumulator of conventional and commercially obtainable type comprising an outer shell 11 and an inner flexible bladder 12 which is filled with a gas 13 under pressure as, for example, nitrogen. The lower portion of the accumulator contains hydraulic fluid 14, such as hydraulic oil; and in the operation of the apparatus a clear passageway is suddenly opened from the accumulator to the piercing tool so that the gas 13 within the bladder 12 expands rapidly, or "explodes," to deliver the oil 14 from the accumulator to the piercing tool to drive the tool through a work stroke with substantially the full impact force of the pressure developed in said accumulator.

The accumulator 10 has valve means 15 through which the gas 13 may be introduced into the bladder 12 to provide a predetermined precharge gas pressure before operation of the apparatus commences. The oil or other fluid 14 may then be introduced under predetermined pressure into the bottom of the accumulator through a valve 16, the increasing volume of oil compressing the gas so that the bladder 12 assumes a position as shown in Figs. 2 and 4. Once the accumulator is charged in this manner it is ready for operation, and gas need not again be added until the pressure drops about ten percent due to leaks in the system. When the above mentioned hydraulic passageway to the piercing tool is suddenly opened the gas quickly expands or "explodes" so that the bladder 12 assumes the position shown in Fig. 3, the gas driving a portion of the oil through the hydraulic circuit to operate the piercing tool.

For most efficient operation of the accumulator it is necessary not only to control carefully the precharge pressure when the machine is set up and the pressures shown respectively in Figs. 2 and 3, but it is necessary also to take into consideration in determining the above pressures various factors such as gas temperature, oil temperature, ambient air temperature, the effect of air in solution in the hydraulic oil, the effect of leaks or other losses caused by instruments in the system, and the effect of internal leaks in the system. When these secondary factors are considered it is possible to predetermine the precharge pressure, the desired pressure under the conditions of Fig. 2 and the desired pressure under the conditions of Fig. 3 to provide for most efficient operation of the accumulator so that the force available during the work portion of the cycle is sufficient to meet the calculated demand of the piercing tool. If these secondary factors of accumulator operation are not considered, the accumulator will not provide the desired volume of oil under the desired pressure and will not provide the calculated force to operate the piercing tool properly. In one system in operation the two and one half gallon accumulator develops a pressure of the order of 700 pounds per square inch when it is in the condition of Fig. 2 (before the work stroke), and falls to a pressure of the order of 660 pounds as the work stroke is completed.

Of the above mentioned secondary factors affecting accumulator operation one of the most important, and

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one most frequently overlooked, is the gas temperature factor. Inasmuch as the nitrogen or other gas 13 cools rapidly when it expands rapidly, this factor must be taken into consideration both when the accumulator bladder 12 is precharged from a high pressure cylinder when the machine is being set up, and also during the steps of the automatic cycle when the nitrogen increases rapidly in volume with a consequent lowering in temperature so that the instantaneous pressures differ from those which may be calculated without reference to the temperature changes of the gas.

It will be understood that the optimum values of accumulator pressure and other factors controlling the quality of the operation performed by the machine may be determined approximately by calculation and adjusted by operating trials, or may be set arbitrarily and adjusted as a result of experience to obtain the best operating conditions. These optimum values will vary with the nature of the operation, the number of punches operated simultaneously, the piping layout, and other such factors apparent to those skilled in the art. An exemplary apparatus embodying the invention is described herein in detail.

In the apparatus illustrated, and referring particularly to Fig. 1, the accumulator 10 is supplied with oil 14 by means of a pump 18 driven by a motor 20. In one system which is in operation the pump is a commercially obtainable type having a capacity of 14 gallons per minute, and the motor is a commercially obtainable 5 horsepower electric motor. The capacities of the above described elements and the sizes of the hydraulic lines, valves, etc. given herein are set forth merely by way of example and as an aid in constructing an efficient machine of the type described, and these capacities and sizes in no way limit the invention.

The inlet side of the pump 18 is connected by 1¼" tubing 22 to an oil reservoir 24 having associated therewith an oil filter 26. In the drawings the return lines to the reservoir 24 are not shown in full in order to simplify the drawings, and in Fig. 1 these return lines are shown diagrammatically at 24'. In order to connect the pump 18 to the accumulator 10 the outlet side of the pump 18 is connected by means of ¾" lines 28 and 30 to a pump relief valve 32, and a ¾" line 34 is connected between the juncture of the lines 28 and 30 and a ¾" pilot pressure restrictor 36. The outlet side of this restrictor is connected by a ¾" line 38 to the inlet port 40a of a ¾" four-way solenoid controlled valve 40 having four main ports 40a, 40b, 40c and 40d, inlet and exhaust pilot ports 40e and 40f. Pilot lines 41 and 42 inside the valve body connect the pilot fluid to opposite sides of the valve, and an exhaust pilot line 45 returns to the reservoir 24. An exhaust line 43 leads from the exhaust port 40b to the reservoir 24 and a ¾" line 47 leads from the port 40d of the four-way valve 40 to a ¾" pressure reducing valve 44, and a ¾" line 46 leads from the outlet side of the valve 44 to a ¾" check valve 48. A ¾" line 50 connects the outlet side of the check valve 48 to a coupler 58 in a 1¼" line 52 which leads through a 1¼" needle valve 54 to the bottom of the accumulator 10.

The accumulator 10 is connected to the hydraulically driven load by a hydraulic circuit including a 1½" pilot operated check valve 55 and a 1¼" four-way valve 56 having four main ports 56a, 56b, 56c and 56d, inlet pilot ports 56e and 56f, and exhaust pilot ports 56g and 56h. Pilot lines 57 and 59 inside the valve body connect the pilot fluid to opposite sides of the valve. The 1¼" line 52 is connected to coupler 58, and a 1½" line 60 extends from the coupler 58 to the inlet side of the 1½" pilot operated check valve 55. The outlet side of this valve is connected by means of a 1½" line 62 to the inlet port 56a of the four-way valve 56, the port 56c of this valve being connected to a pressure manifold 66 by means of a 1¼" line 64. The pressure

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manifold 66 is provided with a plurality of take-off points through which oil under pressure may be delivered to the load, two such take-off points 66a and 66b being illustrated as connecting respectively with load elements 68 and 70. The hydraulically driven load means 68 and 70 comprise piercing tools which are shown diagrammatically in Fig. 1 and are shown in some detail in Figs. 2, 3 and 4. Inasmuch as each of these tools is similar to the other, only one will be described in detail, and it will be understood that the machine may include more than two such tools. Referring more particularly to Figs. 2, 3 and 4, the tool 68 comprises a cylinder body 71 adjustably secured on a mounting bracket 72. Within the cylinder body 71 is a cylinder chamber 71a having therein a piston 73 connected by means of a piston rod 74 to a yoke 75 which carries a piercing tool 76 mounted on a block 77, the face of said block being formed to provide a male counterform die cooperating with a female counterform die 78 carried on the cylinder block 71. At the pressure end of the cylinder chamber 71a is an inlet port 79 and at the exhaust end of the cylinder chamber is an exhaust port 80. The inlet or pressure port 79 is connected by means of a hose 81 to the take-off point 66a of the pressure manifold 66, and the exhaust port 80 is connected by means of a hose 83 to a coupling point 84 in an exhaust manifold 86, which is connected by a 1¼" line 88 with the port 56d in the 1¼" four-way valve 56, and an exhaust return to the reservoir 24 is completed by an exhaust line 90 which extends from the port 56b of said four-way valve to the inlet side of a specially constructed valve 92, which will be hereinafter described in more detail. A line 94 connects the exhaust side of the valve 92 to the reservoir 24.

The electrical control means for providing an automatic cycle for the hydraulic piercing apparatus is shown diagrammatically in Fig. 5, certain components of Fig. 5 also being shown in Figs. 1, 2, 3 and 4 in association with the hydraulic apparatus which they control.

Referring now to Fig. 5, the electrical apparatus includes a manually operated switch 100, three pressure operated switches 102, 104 and 106, five solenoids 108, 110, 112, 114 and 116, and three relays 118, 120 and 122 for controlling the operation of the solenoids. The solenoids 108 and 110 are operated from a relatively high voltage source, line wires 124 and 126 leading to this source, which may comprise a conventional commercial 140 volt source of voltage. Solenoids 112, 114 and 116 and the three relays 118, 120 and 122 are operated by a lower source of voltage, as for example 110 volts, and line wires 128 and 130 may lead to a conventional commercial 110 volt source. As shown in Fig. 5, the relay 118 comprises an operating coil 118a and two normally open switches 118b and 118c; the relay 120 comprises an operating coil 120a, a normally closed switch 120b and three normally open switches 120c, 120d and 120e; and the relay 122 comprises an operating coil 122a, a normally closed switch 122b, a normally open switch 122c, a second normally closed switch 122d and a second normally open switch 122e.

The operating coil 118a of the relay 118 is connected between the low voltage line wires 128 and 130 by means of a circuit which includes in series the coil 118a, the normally closed switch 120b, the normally closed switch 122b and the manually operated switch 100. The operating coil 120a of the relay 120 is connected between the line wires 128 and 130 by means of a circuit which includes in series said coil 120a, the normally closed switch 122d and the normally open pressure switch 106; and the operating coil 122a is connected between the line wires 128 and 130 by means of a circuit which includes said coil 122a and the normally open pressure switch 102.

The solenoid 108 is utilized on the piercing stroke of the cycle and is controlled by the relay 118, this solenoid

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being connected between the high voltage leads 124 and 126 by means of a circuit including the normally open switch 118c. The solenoid 110, which is utilized to retract the tools, is connected between the high voltage leads 124 and 126 by means of a circuit including the normally open relay switch 120d, so that the solenoid 110 is controlled by the relay 120. The solenoid 112 is used to control pilot pressure during the piercing stroke and is also controlled by the relay 118, said solenoid 112 being connected between the low voltage leads 128 and 130 by means of a circuit including the normally open relay switch 118b; the solenoid 114 is controlled by the relay 120 and is connected between the low voltage leads 128 and 130 by means of a circuit including the normally open relay switch 120e; and the solenoid 116 is controlled by the normally closed pressure switch 104 and by the relay 122, being connected between the low voltage leads 128 and 130 by means of a circuit including said pressure switch 104 and the normally open relay switch 122c. The normally open relay switch 122c is used to provide a holding circuit around the pressure switch 102.

Operation

In operation of the apparatus each cycle of operation is manually started, after which the apparatus will automatically and rapidly move through the steps of piercing and counterforming a hole, retracting the tools from the workpiece, and recharging the accumulator in readiness for the manual initiation of the next cycle of operation.

The piercing and counterforming step in the cycle is illustrated diagrammatically in Fig. 2, in which solid heavy lines are used to illustrate those portions of the hydraulic circuit subject to high pressure from the accumulator 10; solid light lines are used to illustrate those portions of the hydraulic circuit which are subject to exhaust pressure; and dashed and dotted lines are used to illustrate those portions of the circuit which are subject to pump pilot pressure.

Referring to Figs. 1, 2 and 5, before a cycle of operation is initiated the operator loads the workpieces (not shown) on to the tool die head and clamps the workpieces in place by means of a conventional type of starting handle or clamp arm (not shown). Preferably the apparatus is so designed that the last increment of movement of the clamp arm closes the manually operated starting switch 100 (Fig. 5). When switch 100 is closed relay 118 is energized, a circuit through the operating coil 118a of the relay being closed through the closed switches 120b, 122b and the closed manual switch 100. Energization of the relay 118 results in closure of relay switches 118b and 118c with consequent energization of solenoids 108 and 112.

As shown in Figs. 1 and 2, solenoid 108 is associated with the four-way valve 56, and this solenoid acts, when energized, to open the pilot port 56e so that oil under pump pilot pressure is directed against one end of the main spool of the valve 56 and shifts said spool to the right as the parts appear in Fig. 1. Pilot oil for this purpose is obtained by means of a pilot line 130 which is connected to the juncture of the oil lines 28 and 34, and pilot line 132 which connects with the pilot port 56e of the four-way valve 56. When the solenoid 108 is deenergized port 56e is blocked, but when said solenoid is energized this port connects with pilot line 57 (Fig. 1) which leads to one end of the main spool of the valve 56. Movement of the valve spool sets up a passage in the valve between the valve ports 56a and 56c. Simultaneously pilot pressure is available from the coupler 58 to a ¼" pilot valve 136 having pilot ports 136a, 136b and 136c. The pilot port 136a is connected to the coupler 58 by means of a pilot line 138; the pilot port 136b is connected to the 1½" pilot operated check valve by means of a pilot line 140; and the pilot port 136c is connected back to the reservoir 24 by means of a pilot exhaust line 147. With solenoid 112 energized the valve spool of

the valve 136 is moved to permit pilot pressure to flow from the coupling member 58 through the pilot lines 138 and 140 to the 1¼" pilot operated valve 55. This pilot pressure unseats the internal valve member of the pilot operated valve 55 and permits free flow of oil under pressure from the accumulator 10 to the 1¼" four-way valve 56. Since, as pointed out above there is free flow between the valve ports 56a and 56c of the four-way valve there is a clear path of movement for oil from the accumulator 10 to the cylinder end of the piston 73 in the piercing tool. This path extends from the accumulator through the valve 55, through the ports 56a and 56c of the valve 56 through the line 64 and manifold 66 and through the hose 81 and port 79 into the piston end of the cylinder chamber 71a. The piston and piston rod are actuated by the explosive force of the fluid from the accumulator and drive the male piercing tool 76 through the workpiece with plenty of kinetic energy remaining to impact the male counterform tool 77 into the workpiece and against the female contour die tool 78 to form a sharply defined hole and counterform.

During movement of piston 73, exhaust oil from the rod end of the piston travels out the exhaust port 80 and the connecting hose 83 to the exhaust manifold 86, from whence it is carried through the line 88 and ports 56d and 56b of the four-way valve 56 to the exhaust lines 90, 94 and back to the reservoir 24.

Because of the explosive force of the accumulator action the exhaust oil velocity is so high that, without preventive means, it would "overflow" and partially void the oil from the lower manifold and the exhaust tubing. If this were allowed to happen there would be a time lag before the tools could be retracted because the pump 18 would first have to fill the void in the manifold 86 and in the exhaust tubing before oil would be available to drive the piston 73 in a direction to retract the tools.

The invention includes a novel means to avoid this undesirable action. As shown in the drawings, there is a special valve 92 in the exhaust tubing 90, 94. This valve is a one-way valve having a valve closing spring so proportioned as to have a high loading or strength and fast action. Valve 92 is in some respects analogous to resistance valves used in hydraulic fluid systems to provide a predetermined pressure drop during flow in a hydraulic circuit and may be provided by modifying a commercial resistance valve to provide a closing spring of suitable strength. As will be understood, when the punch is operated at high velocity, the fluid below the piston 73 is driven out at high velocity and thus acquires a high velocity head. The valve 92 must permit the fluid to flow out at high velocity so that the rapid action of the cylinder can take place but must quickly stop the flow when the stroke of the piston is completed to prevent voiding in the return lines 83, 86, and 88. Since commercial resistance valves are provided in certain widely separated values of spring force, it would be an accident if one were suitable. I have provided a valve which controls the flow in a desired manner by properly adapting the strength of the valve closing spring. Because the necessary strength depends upon various factors such as the number of tools, the size of the cylinders, the speed of the stroke, and the dimensions of the return pipes, I have found no practicable way to calculate with sufficient accuracy the necessary strength of the spring 93. A suitable value can readily be determined, however, by experiment for any given installation. In the particular case under discussion, the spring exerts a closing force of 34 pounds on a valve of about 1" effective diameter. The proper values may be found by virtue of the fact that if the spring is too strong, the machine will chatter and hammer, and if it is too weak, the high velocity outflow will not be damped sufficiently quickly after the end of the piston stroke to prevent voiding. A valve spring which properly controls the differential between the pressure head and the velocity head of the outgoing oil, so

as to prevent voiding the system, may thus be readily determined by adjustment or experiment in a particular installation. Calculations may be helpful in determining the approximate range of values, but the best value so far as I am aware, can only be determined by operating trials of the system in view of the complicating factors and the approximate nature of calculations relating to hydraulic flows of a transient character.

Referring again to Figs. 1, 2 and 5, pressure operated switch 106 is connected to the pressure manifold 66 by means of a small diameter line 142 which incorporates a ¼" needle valve 144. This needle valve is opened partially, as for example by turning it one half turn off the bottom and then jamming the packing nut against vibration to hold the setting. This provides a choke orifice that will suppress the initial explosion pressure wave caused by the rapid, explosive accumulator action, and will prevent a premature firing of pressure switch 106, which is adjusted to operate at a pressure lower than the oil pressure in the manifold 66 at the peak of the accumulator action. This makes for an advanced action to cut total time taken for spool shift in the valves by initiating the electric function ahead of the actual hydraulic main flow as the accumulator "discharges." Pressure switch 106 is normally open and is closed by a predetermined pressure developed in the line 142. The outlet port of the pressure switch is connected by a line 146 back to the reservoir 24, the exhaust port 106a to which line 146 is connected having a small orifice to slow down the reset cycle and enable the contacts of the pressure switch to hold closed long enough to complete the circuit. A large orifice in this outlet port will permit the contacts to open too soon and will upset the cycling of the machine.

Referring to Fig. 5, closure of pressure switch 106 results in energization of relay 120 through the closed relay switch 122d and pressure switch 106. Energization of relay 120, with consequent movement of its switches 120b—120e to the position other than that shown in the drawing results in switch 120b being opened and switches 120c, d and e being closed. When switch 120b opens it deenergizes relay 118, so that solenoids 108 and 112 are also deenergized. When relay switch 120d closes it causes energization of solenoid 110 and when relay switch 120e closes it causes energization of solenoid 114. Closure of relay switch 120c establishes a holding circuit around the pressure switch 106.

When solenoid 112 is deenergized, valve 136, which is a spring offset valve, is spring returned with port 136a disconnected from ports 136b and 136c so that pilot pressure in the line 138 is ineffective to hold open the 1½" pilot operated check valve 55, and this latter valve is spring retracted to closed position, pressure from the accumulator 10 on the valve head aiding the spring to provide a fast, sealing closure of the line from the accumulator. The presence of the valve 55 in the line from the accumulator to the tools is an important feature of design because of the leakage present in four-way valves, as the valve 56. If the 1¼" pilot operated check valve 55 were not in the line between the accumulator and the four-way valve 56 there would be a loss of oil from the bottom of the accumulator depending upon the amount of leakage in the four-way valve 56.

While the tools could be retracted by making use of a further volume of oil from the accumulator 10, this action is not utilized in the present apparatus because the explosive force of the accumulator is not needed to retract the tools, and in addition, as a practical matter, commercially obtainable cylinders, as the cylinder 71, generally do not provide a cushion at the cylinder head end of the chamber. If cylinders are utilized having a cushioning means to absorb the explosive force of the piston 73, the accumulator may be used to retract the tools.

In the present machine the pump 18 is used to retract the tools relatively slowly as compared to the accumulator

action which is utilized on the pierce and counterform portion of the machine cycle. Fig. 3 will be used to describe the tool retracting portion of the cycle. In this figure dash and dot lines are used to indicate those portions of the hydraulic circuit which are connected to the pressure side of the pump 18, and solid heavy lines are used to indicate those portions of the hydraulic circuit which are connected to the exhaust side of the system. Solid light lines are used to represent those parts of the system which are operative during the pierce and counterform portion of the cycle. As pointed out above, at the end of the pierce and counterform portion of the cycle pressure switch 106 is energized, causing deenergization of relay 118 and of solenoids 108 and 112, so that valve 55 is closed and valve 56 is spring returned to its original position. Simultaneously solenoids 110 and 114 are energized. Solenoid 114 is associated with the $\frac{3}{4}$ " four-way valve 40, which is an open center-spring centered $\frac{3}{4}$ " four-way valve which, during the first portion of the operating cycle, has been positioned as shown in Fig. 2 with ports 40a and 40b connected, permitting oil in the line 38 delivered by the pump to be returned to the reservoir through exhaust line 43, so that in effect the pump 18 "free-wheels" except for the pilot pressure in the pilot lines. When solenoid 114 is energized the valve 40 is set up as shown in Fig. 3 with ports 40a and 40c connected, and pump pressure is now directed through the line 38, ports 40a—40c of valve 40, and a line 148 to the inlet side of a $\frac{3}{4}$ " check valve 150, the outlet side of which is connected by means of a $\frac{3}{4}$ " line 152 to the main oil line 62 at a point between valves 55 and 56. Since valve 55 is closed, the pump oil must flow to port 56a of the four-way valve 56. Pilot pressure is available to the port 56f of the valve 56 through pilot lines 130 and 154, and this same pilot pressure from the pressure side of the restrictor 36 is available to the pilot pressure port 40e of the valve 40 through a pilot line 156. When solenoid 110 is energized pilot pressure through the lines 154 and 59 (Fig. 1) shifts the main spool of the valve 56 to the left (as the parts appear in Figs. 1 and 3) so that port 56a is connected with port 56d and oil under pump pressure is directed through the valve 56 and through the oil line 88 to the exhaust manifold 86, from which the oil is conducted by the hose 83 and port 80 to the piston rod end of the cylinder chamber 71a.

The demand pressure in retracting the tools is low, being below 200 lbs. per square inch in the machine illustrated. At the completion of the retract stroke there is no more flow of oil through the line 64 and therefore there is an instantaneous pressure rise in the exhaust manifold 86. This increased pressure closes pressure switch 102, which is normally open, as shown in Fig. 5. When pressure switch 102 closes it causes energization of relay 122, with a consequent opening of relay switch 122d, which breaks the circuit to the relay coil 120 so that solenoids 110 and 114 are deenergized. Relay 122 establishes a self-holding circuit through switches 122c and 100. As shown in Fig. 3, pressure switch 102 is connected to the exhaust manifold 86 by means of a small line 156, a bleed line 158 extending from pressure switch 102 back to the reservoir 24.

A normally closed manifold drain valve 160 is provided for maintenance purposes.

During the tool retracting phase of the cycle, return oil from the piercing tool flows through the hose 81, pressure manifold 66, the line 64, valve 56 (through ports 56c and 56b) and lines 90 and 94 back to the reservoir. While the pressure and velocity heads are low as compared to the corresponding pressure and velocity values during the pierce phase of the cycle, there would be a partial voiding of the oil from the exhaust manifold if it were not for the presence of the spring loaded valve 92 described earlier.

As may be noted from a comparison of Figs. 2 and 3,

the bladder 12 in the accumulator 10 has expanded during the piercing phase of the cycle, and accumulator pressure now is low. Before the next cycle of operation, the accumulator must be recharged to the predetermined pressure required to produce the force necessary to provide a clean piercing and counterforming operation. This recharging phase of the cycle is shown in Fig. 4, wherein those portions of the hydraulic circuit shown in the dash-dot lines are subject to pump pressure, and those portions of the circuit shown in dashed lines are inoperative.

When pressure switch 102 closes on completion of the tool retracting phase of the cycle, relay 122 is energized so that its switches assume a position other than that shown in Fig. 5. With relay switch 122e closed, current flows through a circuit including said relay switch and including the normally closed pressure switch 104, so that solenoid 116 is energized. Energization of solenoid 116 changes the connections between the pilot valve ports of the valve 40 so that pilot pressure through the line 156 shifts the spool of the valve 40 to open a passage between valve ports 40a and 40d, so that now oil under pressure from the pump 18 flows through the line 38, through the valve 40 (ports 40a and 40d) and through the line 45 to the $\frac{3}{4}$ " pressure reducing valve 44, and thence through the line 46, the $\frac{3}{4}$ " check valve 48, and the lines 50 and 52 to the bottom of the accumulator. The increasing volume of oil in the accumulator compresses the gas in the bladder 12 so that pressure in the accumulator rises until the predetermined operating pressure is reached at which time normally closed pressure switch 104 is operated, this pressure switch being connected to the bottom side of the accumulator by a small line 162 and being set to open at the desired value of accumulator pressure. A small normally closed needle valve 164 is provided to drain the accumulator of oil when the gas precharge pressure in the accumulator is checked and the accumulator recharged with gas to the desired pressure.

When pressure switch 104 opens, solenoid 116 is deenergized as shown in Fig. 5. When solenoid 116 is released, valve 40 returns under internal spring pressure to its open center position wherein ports 40a and 40b are connected so that during the time the work is being unloaded from the die and a new workpiece is being mounted on the die the pump is "free wheeling" through the reservoir 24.

Relay 122 remains energized through manual switch 100 until this switch is opened in removing the workpiece, when the circuit is returned to its original condition with all relays deenergized, and with the energizing circuit for relay 118 through switches 120b and 122b set up to be closed by switch 100 when the next workpiece is clamped in position.

Fig. 6 shows the timing of a cycle of operation of a machine constructed in accordance with the invention and utilizing four piercing tools. If fewer piercing tools were used the cycle would be more rapid, and if more tools were used the cycle would be slower. The upper portion of the graph comprising Fig. 6 shows the energization time of the respective solenoids 108, 110, 112, 114 and 116, and the lower portion of the graph shows the pressures available and the timing of the machine cycle. When the manual switch 100 is closed solenoids 108 and 112 are briefly energized as earlier described. This causes a shift in the valve spools as above described, and this shift takes only a small fraction of a second as shown by the graph portion 166. After the valve spools shift to open a clear passage from the accumulator to the tools, the accumulator "explodes" and the accumulator pressure drops rapidly as shown by the graph portion 168. During this portion of the cycle pressure builds up in the manifold 66, and the broken vertical line 170, which is positioned approximately $\frac{2}{10}$ of a second after the cycle is initiated, shows the point of operation of pressure switch 106. As earlier described, this point of operation is in advance of the completion of the pierce phase of the cycle, as shown

by the point at which the line 170 crosses the line 168 while the accumulator pressure is still dropping. Closure of pressure switch 106 causes energization of solenoids 110 and 114, and these solenoids stay energized until the closure of pressure switch 102, which is indicated by the broken line 172. This occurs at the end of the retract phase of the cycle while the accumulator pressure is low as indicated by the graph portion 173, and closure of pressure switch 102 results in the deenergization of solenoids 110 and 114 and in the energization of solenoid 116 so that, after the valve spools have had time to shift into the proper position as earlier described and as shown by graph portion 174, the pump pressure is directed into the bottom of the accumulator and the pressure in the accumulator starts to rise as indicated by the graph portion designated as 175. When the pressure in the accumulator reaches a value which has been predetermined before the machine was put in operation (700 p. s. i. in the apparatus illustrated) pressure switch 104 opens as indicated by the broken vertical line 176.

With four pressure heads, it will be seen that the entire cycle of the machine takes place in less than 1½ seconds, so that the machine can operate much faster than the mechanical operations of loading and unloading the workpiece on the die head can be done.

This application is a continuation of my copending application entitled "Hydraulic Piercing Apparatus" filed August 29, 1952, as Serial No. 307,019, now abandoned.

While I have shown and described one embodiment of my invention, it is subject to many modifications. Changes, therefore, in the construction and arrangement may be made without departing from the spirit and scope of the invention as set forth in the appended claims.

I claim:

1. Hydraulic driving apparatus of the character described, including: a hydraulic accumulator; pump means for supplying said accumulator with hydraulic fluid under a predetermined pressure; hydraulically driven load means; hydraulic circuit means interconnecting said accumulator, pump means and load means; valve means in said circuit for directing the flow of hydraulic fluid therein, said valve means including a check valve and a directional control valve connected in series between said accumulator and load means; and control means having a portion operable to shift said directional valve and open said check valve concurrently to direct fluid from the accumulator to drive the load means in one direction with substantially the full impact force of the pressure developed in said accumulator and independently of said pump means, said control means having a portion operable to close said check valve and shift the directional valve to direct fluid to flow directly from said pump to drive said load means in another direction.

2. Hydraulic driving apparatus of the character described, including: a hydraulic accumulator; a reservoir; pump means for supplying said accumulator with hydraulic fluid from said reservoir under a predetermined pressure; hydraulically driven load means; hydraulic circuit means interconnecting said accumulator, pump means and load means; valve means in said circuit for directing the flow of hydraulic fluid therein, said valve means including a check valve and a directional control valve connected in series between said accumulator and load means; and control means having a portion operable to open said check valve and shift said directional valve concurrently to direct fluid from the accumulator to drive the load means in one direction with substantially the full impact force of the pressure developed in said accumulator and independently of said pump means, and said control means having a pressure actuated portion operable to close said check valve and shift said directional valve to direct fluid to flow directly from said pump means to drive said load means in the opposite direction.

3. Hydraulic driving apparatus of the character described, including: a hydraulic accumulator; pump means

for supplying said accumulator with hydraulic fluid under a predetermined pressure; hydraulically driven load means; hydraulic circuit means interconnecting said accumulator, pump means and load means; valve means in said circuit for directing the flow of hydraulic fluid therein, said valve means including a pilot operated check valve and a directional control valve connected in series between said accumulator and load means; a pilot valve; a pilot pressure hydraulic circuit connecting said pilot valve between said accumulator and said pilot operated check valve; and control means for operating said pilot valve to permit pilot pressure to open the pilot operated check valve, and for concurrently shifting said directional valve to direct fluid from the accumulator to the load means with substantially the full impact force of the pressure developed in said accumulator and independently of said pump means.

4. Hydraulic driving apparatus of the character described, including: a hydraulic accumulator; a reservoir; pump means for supplying said accumulator with hydraulic fluid from said reservoir under a predetermined pressure; hydraulically driven load means; hydraulic circuit means interconnecting said accumulator, pump means and load means; valve means in said circuit for directing the flow of hydraulic fluid therein; intake and exhaust manifolds connected between said load means and valve means; control means having a first portion operable to open the valve means in that part of the circuit between said accumulator and load means to direct fluid from the accumulator to drive the load means in one direction with substantially the full impact force of the pressure developed in said accumulator and independently of said pump means, a second portion responsive to fluid pressure in said intake manifold operable to shift the valve means to cause fluid flow directly from said pump to drive said load means in the opposite direction, and a third portion responsive to fluid pressure in said exhaust manifold operable to direct fluid from said pump to said accumulator to recharge the accumulator to said predetermined pressure; and means responsive to accumulator pressure for bypassing fluid from said pump to said reservoir when said predetermined pressure has been reached.

5. Hydraulic driving apparatus of the character described, including: a hydraulic accumulator; a reservoir; pump means for supplying said accumulator with hydraulic fluid from said reservoir under a predetermined pressure; hydraulically driven load means; hydraulic circuit means interconnecting said accumulator, pump means and load means; valve means in said circuit for directing the flow of hydraulic fluid therein; intake and exhaust manifolds connected between said load means and valve means; control means having a first portion operable to open the valve means in that part of the circuit between said accumulator and load means to direct fluid from the accumulator to drive the load means in one direction with substantially the full impact force of the pressure developed in said accumulator and independently of said pump means, a second portion responsive to fluid pressure in said intake manifold operable to shift the valve means to cause fluid flow directly from said pump to drive said load means in the opposite direction, and a third portion responsive to fluid pressure in said exhaust manifold operable to direct fluid from said pump to said accumulator to recharge the accumulator to said predetermined pressure; and means responsive to accumulator pressure for bypassing fluid from said pump to said reservoir when said predetermined pressure has been reached.

6. Hydraulic driving apparatus of the character described, including: a hydraulic accumulator; pump means for supplying said accumulator with hydraulic fluid under a predetermined pressure; hydraulically driven load means; hydraulic circuit means interconnecting said accumulator, pump means and load means; valve means in said circuit for directing the flow of hydraulic fluid therein; and control means having a first portion oper-

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able to open the valve means in that part of the circuit between said accumulator and load means to direct fluid from the accumulator to drive said load means in one direction with substantially the full impact force of the pressure developed in said accumulator and independently of said pump means, and a second portion operable to shift the valve means to cause fluid flow to drive the load means in the opposite direction, said second portion comprising a pressure responsive device having a restricted inlet passageway to cause a delay in the initiation of operation of said device.

7. Hydraulic driving apparatus of the character described, including: a hydraulic accumulator; a reservoir; motor driven pump means for supplying said accumulator with hydraulic fluid from said reservoir under a predetermined pressure; motor driven pump means for supplying said accumulator with hydraulic fluid from said reservoir under a predetermined pressure; hydraulically driven load means; hydraulic circuit means interconnecting said accumulator, pump means and load means; valve means in said circuit for directing the flow of hydraulic fluid therein, said valve means including a pilot operated check valve and a 4-way directional control valve connected in series between said accumulator and load means; a pilot valve; a pilot pressure hydraulic circuit connecting said pilot valve between said accumulator and said pilot operated check valve; intake and exhaust manifolds connected between said load means and the 4-way valve; and control means having a first portion operable to open said pilot valve to permit pilot pressure to open the pilot operated check valve and concurrently to shift said 4-way valve to direct fluid from the accumulator to drive said load means in one direction with substantially the full impact force of the pressure developed in said accumulator and independently of said pump means, a second portion responsive to fluid pressure in said intake manifold and operable to close the pilot valve for blocking operating pressure from the pilot operated valve, and to shift the 4-way valve to direct fluid flow directly from said pump to drive the load means in the opposite direction, said second portion comprising a pressure responsive switch connected between said intake

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manifold and said reservoir by hydraulic circuit means having a restricted orifice in the inlet to the switch to cause a delay in the initiation of operation of said switch, and a third control portion responsive to fluid pressure in said exhaust manifold and operable to direct fluid from the pump to the accumulator to recharge the accumulator to said predetermined pressure.

8. Hydraulic driving apparatus of the character described, including: a hydraulic accumulator; a reservoir; pump means for supplying said accumulator with hydraulic fluid from said reservoir under a predetermined pressure; hydraulically driven load means; hydraulic circuit means interconnecting said accumulator, pump means and load means; valve means in said circuit for directing the flow of hydraulic fluid therein, said valve means including a check valve and a directional control valve connected in series between said accumulator and load means; control means having a portion operable to open said check valve and shift said directional valve concurrently to direct fluid from the accumulator to said load means to drive the load means in one direction with substantially the full impact force of the pressure developed in said accumulator and independently of said pump means, and a pressure actuated portion operable to close said check valve and shift said directional valve to direct fluid from said pump to drive said load means in the opposite direction; an exhaust line for returning fluid from said load means through a portion of said valve means to said reservoir; and means in said exhaust line for controlling the differential between pressure and velocity of fluid return to prevent an overrun of fluid through said line with partial voiding of fluid therefrom.

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