Aug. 10, 1965 M. L. WOLF 3,199,461

HYDRAULIC PUMP OR MOTOR

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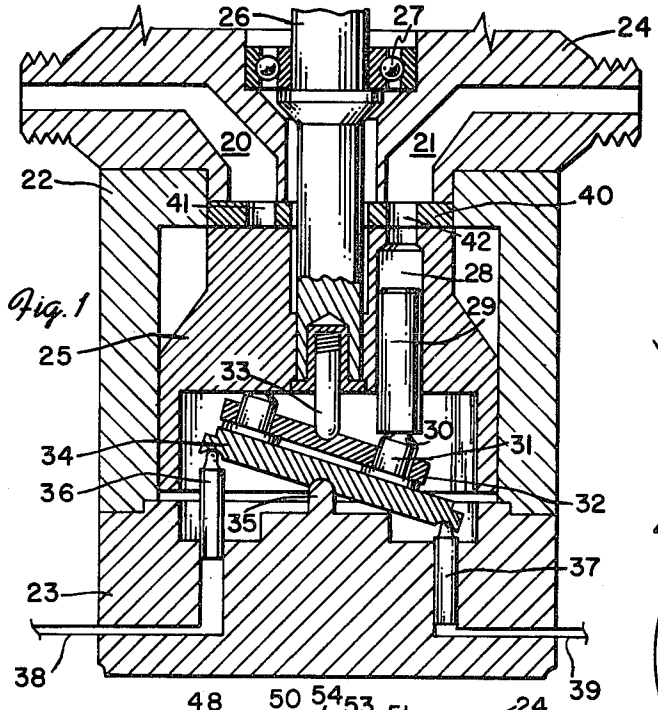


Fig. 1

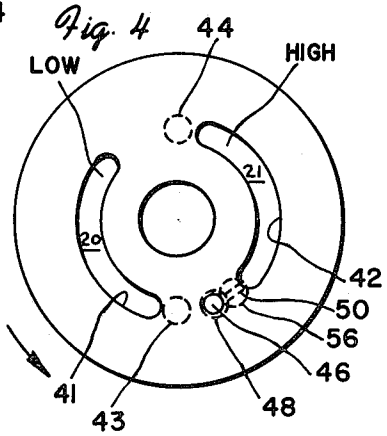


Fig. 4

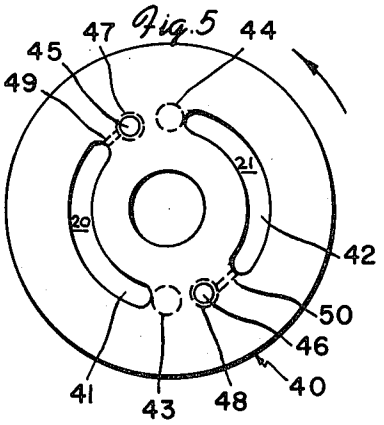


Fig. 5

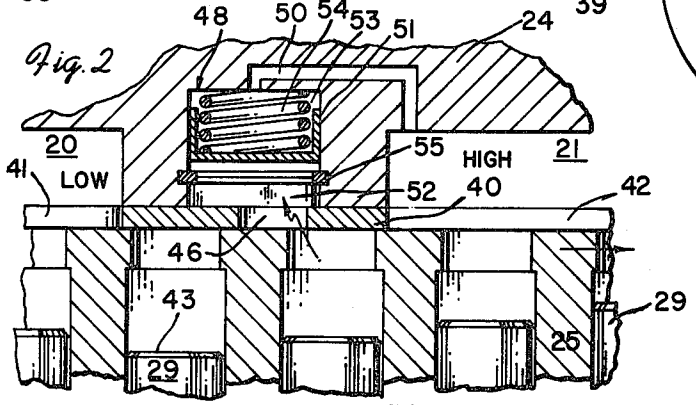


Fig. 2

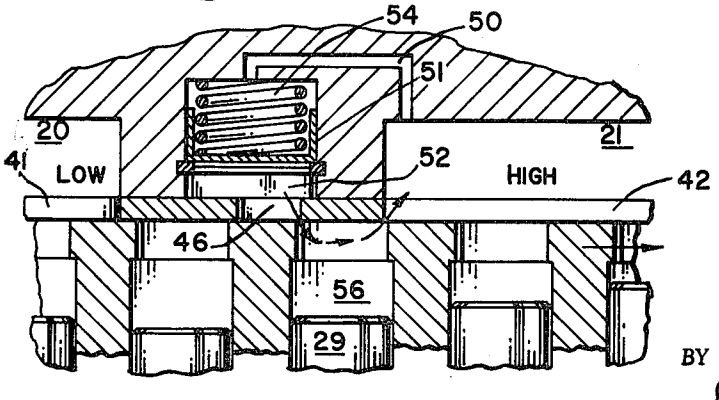


Fig. 3

INVENTOR.
MARVIN L. WOLF
BY Hubert Miller
ATTORNEY

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Fig. 6

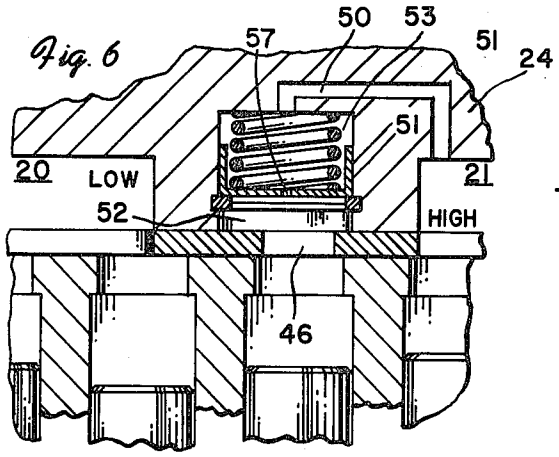


Fig. 7

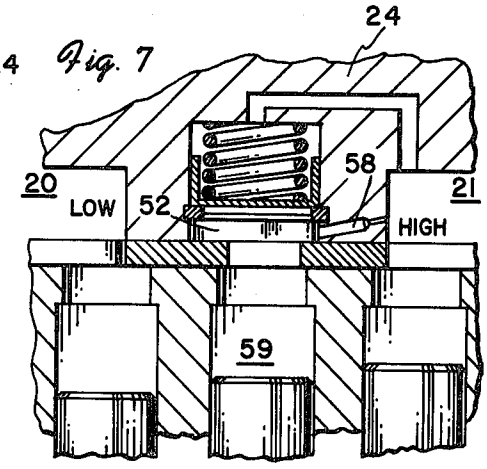


Fig. 8

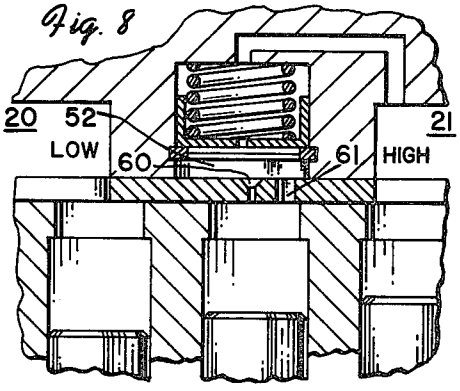
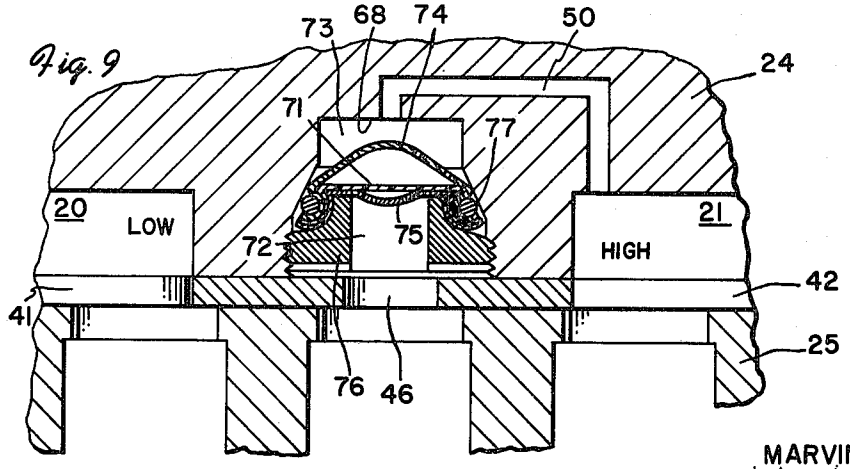


Fig. 9



INVENTOR.
MARVIN L. WOLF
BY Hubert Miller
ATTORNEY

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Fig. 10

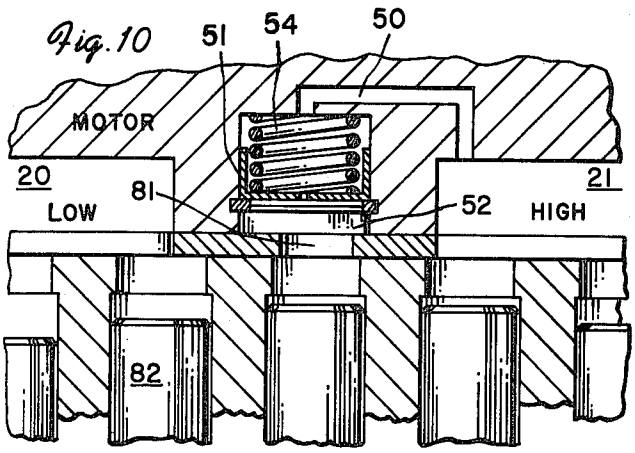


Fig. 11

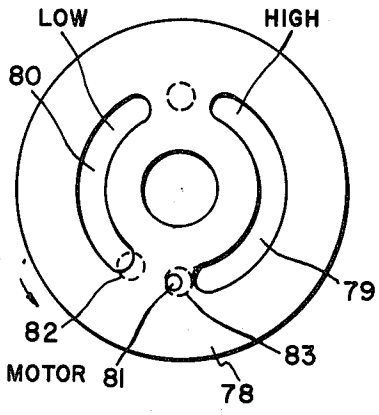
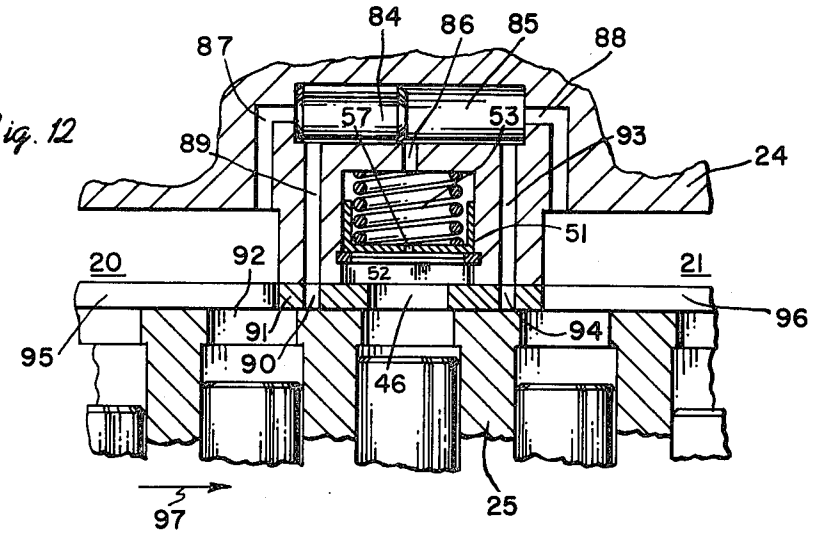


Fig. 12



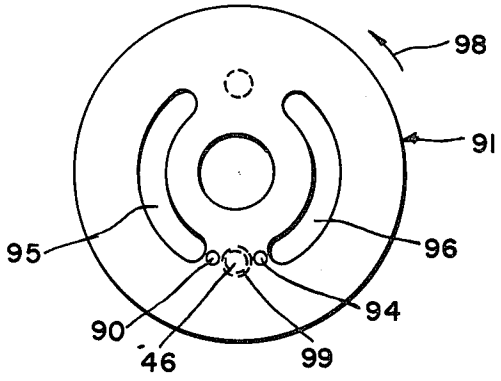


Fig. 13

INVENTOR.
MARVIN L. WOLF
BY Huber & Miller
ATTORNEY

Aug. 10, 1965 M. L. WOLF 3,199,461

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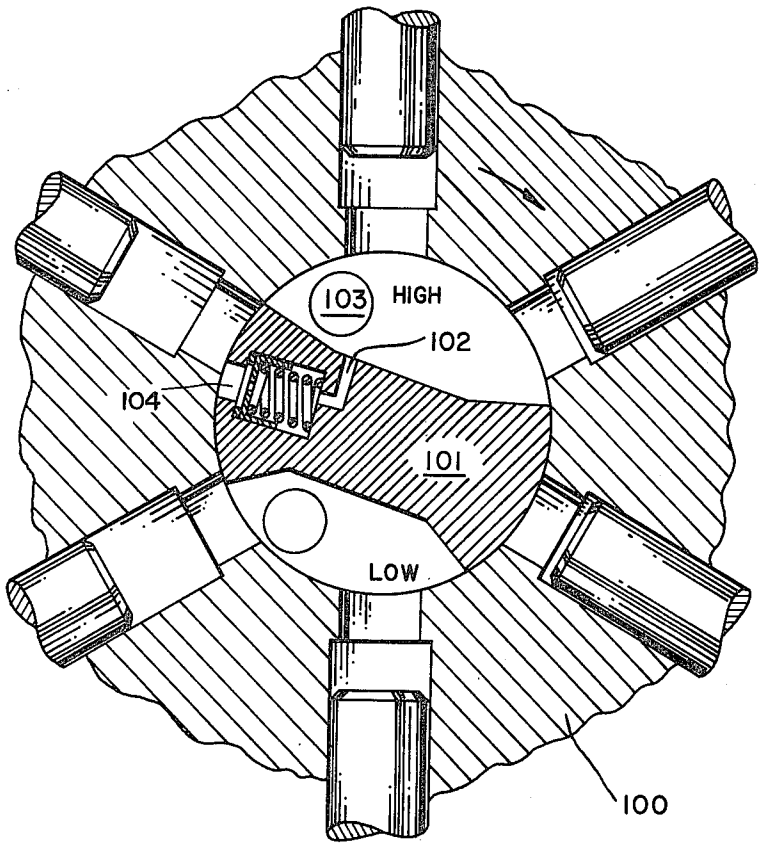


Fig. 14

INVENTOR.
MARVIN L. WOLF
BY Huber & Miller
ATTORNEY

United States Patent Office 3,199,461 Patented Aug. 10, 1965

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3,199,461

HYDRAULIC PUMP OR MOTOR

Marvin L. Wolf, Hutchinson, Kans., assignor to The Cessna Aircraft Company, Wichita, Kans., a corporation of Kansas

Filed May 27, 1963, Ser. No. 283,376
12 Claims. (Cl. 103—162)

This invention relates generally to fluid pressure energy translating devices which are capable of either generating and delivering or receiving and utilizing high fluid pressures.

More particularly this invention relates to multiple cylinder, reciprocating piston type, variable displacement pumps and motors, whether the cylinders are disposed parallel to the rotational axis of the cylinder block, or radially with respect to that axis of rotation.

In pumps and motors of the types mentioned above, movement of the cylinder block causes the open end of each piston chamber to successively register with a low pressure fluid port and with a high pressure fluid port in the body of the pump or motor. When a piston chamber containing fluid under a different pressure (either too high or too low) registers with a high pressure port in the body, a distinct and often violent shock or hammer occurs. Such shocks cause physical damage to pump elements, cause premature wear, cause objectionable operational noise, and reduce the volumetric efficiency of the pump or motor.

It is a prime object of this invention to provide a structure and means for eliminating such shocks during pump or motor operation, and which accomplishes shock elimination by either decreasing or increasing the fluid pressure in each piston chamber just prior to its actual registry with the high pressure port in the pump or motor body, to thus substantially equalize the pressures in the high pressure port and in each approaching piston chamber before they are in open communication.

Another object is to provide a shock eliminating structure of the type referred to above which accomplishes the referred to pressure equalization by either adding pressurized fluid to or receiving pressurized fluid from each piston chamber after it has broken communication with the low pressure port in the pump or motor body, and prior to its registry with the high pressure port therein.

An additional object of the invention is to provide an increase or decrease in pressure and fluid volume in each piston chamber of a variable volume hydraulic pump or motor, even though the piston stroke is set at minimum length.

A still further object of the invention is to provide a means for precisely controlling the rate and degree of pressure rise in each piston chamber of a variable piston stroke pump during the time the piston chamber is traveling from the low pressure port in the pump body to the high pressure port therein, regardless of the variation in the length of piston stroke, and regardless of the length of the land between the low and high pressure ports.

Another object is to provide a structure capable of substantially equalizing the pressures in a high pressure body port and an approaching piston chamber, prior to registry of the two, whether in a pump or a motor, and whether the pump or motor is operating in a clockwise or counterclockwise direction of rotation.

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Still another object is to provide a structure capable of incorporation into a multiple piston type hydraulic pump in which the pistons are reciprocated by contact with a movable cam, and in which the cam can be moved to reverse the phase of piston reciprocation to thereby reverse the direction of flow of fluid to and from the pump body, and in which the incorporated structure embodying this invention serves to equalize the pressures in the high pressure port and in each approaching piston chamber, prior to registry of the two, regardless of the direction of flow of fluid to and from the pump.

Further objects and advantages of the invention will be apparent when the following description is read in connection with the accompanying drawings, in which:

FIG. 1 is a central transverse sectional view through one type of multiple piston variable volume fluid pressure energy translating device embodying my invention;

FIG. 2 is a fragmentary flat pattern sectional view through the FIG. 1 device and shows a stationary portion of the body, and a portion of a rotating cylinder block, as well as the details of construction of one embodiment of my invention;

FIG. 3 is a view similar to FIG. 2 but shows the cylinder block in a different position with relation to the body section;

FIG. 4 is a top plan view of a ported valve plate for installation in a fluid pressure energy translating device which is incapable of reversing the direction of fluid flow therefrom;

FIG. 5 is a top plan view of a ported valve plate for a pump such as shown in FIG. 1, which is capable of reversing the direction of fluid flow therefrom by reversal of cam inclination;

FIGS. 6 and 7 are fragmentary flat pattern sectional views similar to FIGS. 2 and 3, and illustrate a variation in structural details which constitutes a second embodiment of the invention;

FIG. 8 is a view similar to FIGS. 6 and 7, and illustrates a valve plate which has a different porting arrangement than the valve plates in the other views;

FIG. 9 is a fragmentary flat pattern sectional view of a fluid pressure energy translating device which includes structure which constitutes a third embodiment of my invention;

FIG. 10 is a view similar to FIG. 9, and shows one embodiment of my invention incorporated in a uni-rotational fluid driven multi-piston motor;

FIG. 11 is a top plan view of a ported valve plate shown in the FIG. 10 motor;

FIG. 12 is a fragmentary flat pattern sectional view through a fluid pressure energy translating device of the multiple piston variable displacement type capable of being operated in either direction of rotor rotation, and either as a pump or as a motor, and embodying my invention in a fourth form;

FIG. 13 is a top plan view of a ported valve plate for the FIG. 12 device; and

FIG. 14 is a fragmentary transverse sectional through a fluid pressure energy translating device of the multiple piston variable displacement type embodying my invention, but which has its cylinders arranged radially with respect to the axis of rotation of the cylinder block.

FIG. 1 illustrates only one of many types of hydraulic energy translating devices in which my invention may be embodied. The FIG. 1 device is an axial piston type

hydraulic pump so designed that fluid pressurized therein can be selectively delivered from either of two ducts 20 or 21 in the pump body.

The pump body or housing includes a generally cylindrical, hollow intermediate section 22, an end or bottom section 23, and an end or head section 24.

A rotor in the form of a cylinder block 25 is journaled by body section 22, and is rigidly secured on a central drive shaft 26 which is journaled in bearing 27 in body section 24.

Cylinder block 25 is provided with a plurality of cylinder bores 28 disposed parallel to the rotational axis 26, and spaced concentrically around that axis. Each bore 28 is provided with a piston 29 which extends from the lower end of its bore and is connected by a conventional ball joint 30 to a shoe 31. The respective shoes are held in their proper relative positions, as the cylinder block is rotated, by a pressure plate 32, which centrally seats and is urged downward by a spring pressed plunger 33, mounted in a recess in the lower end of shaft 26.

The lower surfaces of shoes 31 are thus spring urged into positive slidable contact with the upper surface of a piston reciprocating cam plate 34. Plate 34 seats on and is tiltable in either direction about the cross sectionally semi-circular head of a transversely disposed fixed tongue 35, by means of controlled hydraulically or air pressure actuated cooperating pistons 36 and 37, mounted in bores in the end section 23, connected respectively with pressure ducts 38 and 39.

From FIG. 1, it will be seen that the upper end of cylinder block 25 is planar, and seats positively but slidably against the planar lower surface of a valve plate 40, having arcuate ports 41 and 42, which serve to control and time the flow of fluid between the piston chambers 28 and the ducts 20 and 21.

By forming the ports 41 and 42 in an integral part of head section 24, the valve plate, as a separate element, can be eliminated. Such separate plates are ordinarily provided, however, to permit plate replacement; to afford reversing of the direction of rotation of the rotor, if required; to afford conversion of the pump to a motor, etc. The relative locations of the ports 41 and 42, the distance between their respective adjacent ends, their relative lengths, etc., in relation to the reciprocation cycles of the respective pistons, together serve to time and govern the function of the device, as will be clearly understood by those familiar with this art.

It should also be understood that some pump and motor designs provide for the cylinder block to remain stationary, for the inclined cam plate to rotate with the driving or driven shaft, as the case may be, and for the valve plate to either rotate with the driving or driven shaft, or to be rotated or oscillated by separate but coordinated mechanism. My invention is capable of being embodied in all such designs.

Referring now to drawing FIGS. 2, 3 and 5, FIG. 5 illustrates the arrangement, size, spacing, etc., of the ports 41 and 42 in the valve plate 40, which ports communicate respectively with the ducts 20 and 21. This particular valve plate is designed to cause the fluid pressure energy translating device of FIG. 1 to function as a pump for taking in liquid under low or atmospheric pressure and for delivering that liquid under high pressure. The view of the valve plate is from its upper surface.

Valve plate 40 is indexed in the pump body so that as each piston reaches dead center at the end of its intake stroke the piston chamber for that piston has just broken its communication with the low pressure port 41, and is in the relative position indicated by the broken line circle 43, assuming that the cylinder block is rotating in the direction indicated by the arrows in FIGS. 2, 3, and 5, and that the inclination of cam plate 34 is as shown in FIG. 1. Similarly, as each piston reaches a dead

center position at the end of its fluid discharge stroke, the open end of the piston chamber is in the relative position indicated by the broken line circle 44, having just broken its communication with the adjacent end of high pressure port 42.

My invention includes the provision of additional ports 45 and 46 in valve plate 40, in the relative positions shown. It also includes correspondingly located pressure control chambers 47 and 48 in body section 24, communicating with ports 45 and 46 respectively, and through those ports with the piston chambers in the cylinder block 25, as they pass the respective ports.

The chambers 47 and 48 are in communication with the adjacent ducts 20 and 21 respectively by means of ducts 49 and 50 (FIG. 5). Each of the pressure control chambers 47 and 48 is divided by a movable barrier 51 (FIG. 2) into a pressure regulating compartment 52, and a pressure regulation assisting compartment 53.

In the FIG. 2 embodiment of the invention the barrier is in the form of a small skirted plunger which slidably seals against the wall surface of its cylindrical chamber 48, and which is normally urged by a coil spring 54 against a travel limiting stop 55.

Operation as a pump with single direction of rotation (FIGS. 1, 2 3, and 5)

When the FIG. 5 valve plate is installed in the FIG. 1 device, it can function only as a pump.

When shaft 26 and the attached cylinder block 25 are rotated, the pistons 29 are caused by inclined cam plate 34 to reciprocate, and the respective piston chambers register successively with the valve plate ports 41, 46, 42 and 45 (FIG. 5).

As each piston chamber is disconnected from the low pressure intake port 41 its piston has just reached the end of its suction stroke (dead center) and is in the relative position identified by the numeral 43 in FIGS. 2 and 5. As cylinder block movement continues the piston starts its compression stroke.

The degree of compression of the fluid in the piston chamber is a function of the stroke length movement of the piston between the time it starts its compression stroke and the instant the piston chamber first communicates with the high pressure discharge port 42. If the cam inclination angle is high, the piston stroke length is relatively long, and fluid compression is high.

During this travel of the piston chamber it communicates with pressure regulating chamber 52 (FIG. 2) through valve plate port 46. If the fluid pressure in the piston chamber becomes higher than the pressure existing in high pressure duct 21 (FIG. 2) then the pressure differential existing on opposite sides of barrier 51 forces that barrier slightly away from the piston and forces a minute quantity of fluid into pressure regulating compartment 52, thereby reducing the pressure in the piston chamber until it equals the pressure in duct 21 plus the slight force exerted by coil spring 54 on the barrier 51. The pressures in the piston chamber and in high pressure duct 21 are thus substantially equalized prior to initial registry of the piston chamber with the duct 21, and the undesirable and damaging effects of "shock" are eliminated.

As piston chamber movement continues until it is in the position indicated by numeral 56 in FIG. 3, the piston chamber opening bridges the land between valve plate ports 46 and 42. In this position the piston chamber is in communication with the pressure regulating compartment 52 and also with high pressure discharge duct 21. Excess fluid which may have entered compartment 52 during the pressure equalizing function is forced back out of compartment 52 into the high pressure duct 21 by the action of spring 54 on the barrier 51, and the barrier returns to its normal position, as in FIG. 3, ready to equalize the pressure in the next approaching piston chamber.

As piston chamber movement continues around the FIG. 5 valve plate, the piston completes its fluid discharge stroke and starts its suction stroke at position 44. The pressure on any high pressure fluid then trapped in the piston chamber is reduced by suction stroke movement of the piston during the time the piston chamber travels from position 44 to a point of its initial communication with low pressure port 41. The pressure regulating unit which communicates with port 45 is ineffective and unaffected during the last described portion of piston chamber movement. Since the pressure in the piston chamber is reduced substantially to the pressure in low pressure duct 20 prior to their initial communication, there is no shock due to differential pressures.

The piston chamber pressure regulating unit designated by numeral 47 in FIG. 5 is effective only when the piston actuating cam 34 (FIG. 1) is tilted in a direction opposite to that shown in FIG. 1. Reverse tilting of the cam causes a 180° change in piston cycling, and consequently reverses the direction of fluid flow from the pump. Duct 21 becomes a low pressure or intake port, and duct 20 becomes the high pressure discharge port. Pressure control unit 48 then becomes ineffective, and unit 47 assumes the pressure regulating function, as previously described. Such reversal of fluid flow from the pump is necessary when the pump is driving a fluid motor, and when it is desired to reverse the direction of rotation of the fluid motor.

If no reversal of fluid flow from the pump is required, or if the pump is not constructed so that its cam tilt direction can be reversed, then the valve plate of FIG. 4 can be used, and only one pressure control chamber 48 is required in the head 24.

FIGS. 6 and 7

If the service for which the pump is intended frequently requires extremely short piston strokes (cam inclination angle almost perpendicular to the rotational axis of the cylinder block) then the pressure rise in each piston chamber as it travels from position 43 in FIGS. 2 and 5 to position 56 in FIG. 3 is sometimes not sufficiently rapid to raise the piston chamber pressure to the pressure in the high pressure discharge duct 21 by the time the piston chamber initially communicates with that duct. To obviate this difficulty the modifications shown in either FIG. 6 or FIG. 7 may be used. The two are equivalent in function.

In the FIG. 6 pressure control unit a tiny orifice 57 is provided in barrier 51 to supply supplemental fluid to each piston chamber while it is in communication with the pressure regulating compartment 52. The orifice size is such as to prevent a rapid flow of fluid from duct 21 through duct 50 and through the orifice to the piston chamber. If the pressure in the piston chamber is not rising fast enough, due to short piston stroke, the flow of supplemental fluid through orifice 57 will cause an increase in the rate of pressure rise sufficient to cause the piston chamber pressure to be at or very near the pressure in the high pressure duct 21 at the time the piston initially communicates with that duct.

The FIG. 7 configuration functions in the manner just described above, and differs from the FIG. 6 configuration by the substitution of a small flow area orifice duct 58 for the orifice 57 in the barrier 51. Duct 58 permits the flow of a very limited quantity of supplemental fluid from high pressure duct 21 directly to pressure regulating chamber 52, and to the piston chamber 59 prior to its registry with duct 21 in body 24.

FIG. 8

A variation in valve parts porting only is shown in FIG. 8. Here a tiny flow orifice 60 and a relatively small diameter port 61, both in valve plate 40, are substituted for the single large diameter port 46 shown in FIGS. 2 to 7 inclusive. The purpose of this alternate porting is to provide a precise control over the rate of pressure rise in each piston chamber as it travels from low pressure duct 20 to high pressure duct 21, during the compression stroke of the piston.

Orifice 60, due to its small flow area, provides a finely metered flow of fluid in either direction between each piston and the pressure regulating compartment 52 during their registry, and before registry of the piston chamber with port 61. The flow through two such orifices, arranged in series, is well understood by those familiar with this art. By selection of proper orifice size, location, spacing and phasing or indexing with respect to the ducts 20 and 21, the fluid compression rate may be tailored to obtain almost any desired characteristic, regardless of the magnitude of piston stroke. Due to the minute quantity of supplemental fluid required in each piston chamber to provide the desired compression when the piston stroke is at or near zero, the size of orifice 60 is small enough that its action predominates only when piston stroke length is very small. At longer piston stroke the pressure control units previously described perform the compression controlling or equalizing function.

FIG. 9 embodiment

FIG. 9 illustrates a second embodiment of my overpressurization and underpressurization controlling invention. As in the first described embodiment it includes a pressure control chamber 68 located in the pump body 24, between the low pressure port 20 and the high pressure port 21. Chamber 68 is divided by a movable barrier 71 into pressure regulating compartment 72 and a pressure regulation assisting compartment 73. In the FIG. 9 embodiment the barrier 71 is molded in general hat section form from a liquid impervious neoprene or plastic material which has a strong tendency to return to its original molded configuration after being deformed, stretched or otherwise moved from its stable equilibrium position, in which it is shown in FIG. 9.

Barrier 71 is sandwiched between formed perforated sheet metal or screen wire stops 74 and 75 which serve to limit the movement of the central portion of barrier 71 due to pressure differential in chambers 72 and 73.

The diaphragm type barrier 71 and its two movement limiting stops are all formed with nesting skirts, as shown, which seat on the inner end of a threaded insert 76. A conventional neoprene O-ring 77 surrounds the assembled skirts and is compressed to seal against the wall of chamber 68 when insert 76 is threaded tightly into the threaded open end of that chamber.

Operation—FIG. 9 embodiment

The operation of this embdiment of the invention is almost the same as the operation of the FIG. 2 embodiment with the spring pressed plunger 51.

During the compression stroke of each piston, as the piston chamber travels from duct 20 to duct 21, the pressures in duct 21 and in the piston chamber are equalized before the piston first communicates with the duct 21, during communication of the piston chamber with the pressure regulating compartment 72. If the pressure in the communicating piston chamber is lower than the pressure in duct 21, then the higher pressure in assisting chamber 73 is translated, by barrier movement toward its stop 75, to the regulating compartment 72 and to the piston chamber. As the piston chamber moves on toward duct 21 it bridges the land in the valve plate between ports 46 and 42, and the barrier 75 returns to its position of stable equilibrium. Any fluid lost from compartment 72 during its pressure equalizing function is replaced during the time compartment 72 and duct 21 are in communication through the land bridging piston chamber opening.

Similarly if the pressure in the piston chamber is higher than the pressure in duct 21, the flexible barrier 71 is deflected toward its stop 74 until the pressures in the

piston chamber and in duct 21 are equalized. Excess fluid in regulating compartment 72 passes to duct 21 as the piston chamber opening bridges the valve plate land and affords momentary open communication between regulating compartment 72 and duct 21. Barrier 71 returns to its position of stable equilibrium, and is ready for its new pressure equalizing cycle.

It will be apparent that if supplemental fluid is desired it can be supplied by providing an orifice in the central portion of the barrier 71, such as described in connection with the modification shown in FIG. 6. The function and operation would be the same. Alternatively, the duct 58 shown in FIG. 7 could be used. Also the dual valve plate ports 60 and 61 (FIG. 8) could be substituted for the single large port 46, in connection with the FIG. 9 embodiment.

Adaptation to fluid driven motor

FIGS. 10 and 11 illustrate the invention as applied to a fluid driven motor, as distinguished from a pump. The pressure equalizing structure shown is the same as the structure illustrated in FIG. 2, but the FIG. 9 structure could be substituted. The primary difference is in the porting and indexing of the valve plate 78, as shown in FIG. 11.

In a counterclockwise rotating motor the high pressure port 79 becomes the inlet port, and low pressure port 80 becomes the discharge port. These ports, and the intermediate valve plate port 81 are of such length and are so arranged, and the valve plate is so indexed with respect to the stroke cycles of the pistons, that as each piston chamber reaches the position indicated by the broken line circle 82, the piston in that chamber is still traveling on its discharge or compression stroke.

As the piston chamber breaks its communication with low pressure port 80 and travels toward port 81 to the position 83 (FIG. 11), the piston in the chamber completes its compression stroke, compressing the fluid contained in the piston chamber at the time the chamber broke communication with the low pressure port 80. If too much or too little compression has occurred, communication of the piston chamber with the pressure regulating compartment 52, through port 81, serves to substantially equalize the pressures in the piston chamber and in high pressure duct 21 before the two actually communicate, as previously described. Shock is thus eliminated.

Adaptation of bi-rotational pump or motor (FIGS. 12 and 13)

FIGS. 12 and 13 illustrate one means for adapting the previously described pressure regulating structures of FIG. 2 or 9 to a fluid pump or motor which is capable of operating in either direction of rotation.

Referring to FIG. 12 the plunger type barrier 51 divides the pressure control chamber into the pressure regulating compartment 52 and the regulation assisting compartment 53, as previously described in connection with FIG. 2. The spring and stop arrangement are the same as for the FIG. 2 embodiment.

A floating piston 84 is reciprocable in a cylinder 85 formed in the body section 24. Intermediate its ends, cylinder 85 communicates with compartment 53 by means of a duct 86. At its opposite ends cylinder 85 communicates with body duct 20 through a duct 87, and with body duct 21 through a duct 88.

A duct 89 and a registering port 90 in the valve plate 91 afford communication between the successive piston chambers 92 and cylinder 85, near its left end. Similarly a duct 93 and a registering valve plate port 94 afford communication between the successive piston chambers and the cylinder 85, near its right end. Note that the ports 90 and 94 are sufficiently near the central port 46 to be bridged by the piston chamber openings as they travel in either direction of rotation. Note also that when the floating piston 84 is moved to the left hand end of its cylinder, ducts 87 and 89 are closed but duct 86 remains open. Similarly, when the piston 84 is moved to the right hand end of its cylinder, ducts 88 and 93 are closed, while duct 86 remains open. The piston 84 thus serves as a pressure differential actuated valve responsive to the pressure differences in body ducts 20 and 21.

Referring to FIG. 13, the valve plate 91 is provided with ports 95 and 96, which afford communication between the traveling piston chambers 92 in cylinder block 25 and the ducts 20 and 21, respectively, in body 24.

FIG. 12—Operation as bi-rotational motor

Assume that the FIG. 12 structure is embodied in a bi-rotational fluid driven motor; that ducts 20 and 21 are respectively low and high pressure ducts; and that the motor first operates in a counterclockwise direction, as indicated by arrows 97 and 98 in FIGS. 12 and 13. Due to the higher pressure in duct 21 the piston valve 84 will occupy the position shown in FIG. 12.

As each piston chamber opening is disconnected from low pressure duct 20, the piston in that chamber is still traveling axially on its compression or discharge stroke, and does not reach the end of its discharge stroke (dead center) until the piston chamber has reached the relative position indicated by the broken line circle 99 in FIG. 13. Hence fluid in the piston chamber is pre-compressed before the piston chamber reaches position 99. In this position the piston chamber is in communication only with pressure regulating chamber 52, and with cylinder 85 and duct 21 only through the tiny orifice 57 in barrier piston 51.

As the piston chamber travels from position 99 toward duct 21, the piston starts its power or intake stroke. During registry with pressure regulating compartment 52, the pressure in each successive piston chamber is raised by fluid pressure flow through orifice 57 and/or lowered by movement of barrier piston 51 to the pressure existing in duct 21 and duct 93 so that when the piston chamber makes its original registry with port 94 the pressures are substantially equal and shock is eliminated. A small amount of pressurized fluid will then enter the piston chamber through port 94 prior to the registry of the piston chamber and duct 21 for the majority of the piston's power stroke. Barrier piston 51 is returned to piston stop 55 by spring 53 during the time that the piston chamber bridges the space between ports 46 and 94.

If the rotational direction of the motor is to be reversed, then high pressure motive fluid must be introduced into duct 20, and duct 21 becomes a low pressure discharge duct. Piston valve 84 moves to the right hand end of its cylinder 85 and blocks ducts 88 and 93. Since the porting arrangement is symmetrical, the operation is the reverse of that just described above, the pressure in each piston chamber being equalized with the pressure in the high pressure duct 20 by registry with port 46 prior to actual registry of the piston chamber with port 90 and subsequently with duct 20.

FIG. 12—Operation as bi-rotational pump

The same structure (FIGS. 12 and 13) serves for a bi-rotational pump, it being necessary only to index the valve plate so that as each piston chamber is disconnected from the low pressure duct (20 or 21, depending on the direction of rotation of the cylinder block), the piston in the chamber has just completed its suction or intake stroke, and starts its compression stroke. As the piston chamber travels toward the high pressure duct it communicates successively with the pressure regulating chamber 52, and through ducts 88 and 93 with the high pressure duct 21, prior to actual direct communication with that duct. This prior communication substantially equalizes the pressure in each piston chamber and in the high pressure duct prior to their actual direct communication, thus eliminating hammer or shock due to pressure differences, as previously described.

FIG. 14—Radial piston pump or motor

FIG. 14 illustrates one manner in which either of those embodiments of the invention illustrated in FIG. 2 or 9 may be adapted for use in a pump or motor which has radially disposed cylinders in a cylinder block 100 which rotates about a stationary pintle 101. The pressure control chamber is located in the pintle, and is connected by a duct 102 with the high pressure duct 103. A port 104 is located to afford communication successively between the respective piston chambers and the pressure regulating compartment, as the cylinder block rotates.

Operation to substantially equalize the pressures in each piston chamber and in the high pressure duct prior to their actual direct communication is identical to the operation previously described in connection with the FIG. 2 and FIG. 9 embodiments.

Having described the invention with sufficient clarity to enable those familiar with this art to construct and use it, I claim:

1. In a multi-cylinder, reciprocating piston type fluid pressure energy translating device in which there is relative movement between a cylinder block and a fluid handling section which defines internal, spaced, low and high pressure ducts, and in which such relative movement successively brings open ends of the piston chambers in the cylinder block into alternate open communication with the low and the high pressure ducts in the fluid handling section, and in which piston reciprocation and the relative movement between the cylinder block and said fluid handling section is timed so that each piston travels on at least a portion of its compression stroke between the time its chamber breaks communication with said low pressure duct and the time its chamber begins direct communication with said high pressure duct,

structure for adjusting the pressure in each successive piston chamber to substantially equal the pressure in said high pressure duct between the time each piston chamber breaks communication with the low pressure duct and the time it starts communication with said high pressure duct, comprising:

a liquid filled pressure control chamber located between said low and high pressure ducts defined by the said fluid handling section;

a differential pressure movable barrier traversing said control chamber and continuously dividing it into

(a) a variable volume, piston chamber pressure regulating compartment, and

(b) a separate variable volume, pressure regulation assisting compartment,

said pressure regulating compartment having an open port located to openly communicate with the open end of each successive piston chamber between the time the piston chamber breaks communication with said low pressure duct and the time the piston chamber begins direct communication with said high pressure duct; and

duct means affording open communication between said high pressure duct and said pressure regulation assisting compartment,

whereby, during the time each piston chamber is in communication with said pressure regulating compartment, the liquid in both is subjected, through the movable barrier, to the pressure existing in said high pressure duct, and vice versa, and the pressure on the liquid in each successive piston chamber is thus adjusted, prior to the start of its communication with said high pressure duct, to substantially equal the pressure then existing in that duct.

2. The pressure regulating structure described in claim 1, and

means affording highly restricted but free liquid flow between said high pressure duct and said pressure regulating compartment independent of any simultaneous communication between the high pressure duct and the pressure regulating compartment through the successive individual piston chambers.

3. The pressure regulating structure described in claim 1 in which said pressure control chamber has a cylindrical wall, and said movable barrier is a floating plunger therein.

4. The structure described in claim 3, and

fixed means in said pressure control chamber limiting the movement of said floating plunger in both directions.

5. The structure described in claim 4, and

spring means urging said plunger in a direction toward said pressure regulating compartment.

6. The pressure regulating structure described in claim 1 in which said movable barrier is a flexible diaphragm movable in said pressure control chamber from a position of stable equilibrium; and

means sealing against liquid leakage between the peripheral edge of said diaphragm and the adjacent wall surface of said pressure control chamber.

7. The structure described in claim 6, and

fixed means disposed transversely in said control chamber on opposite sides of said diaphragm to limit its movement in either direction from its position of stable equilibrium.

8. In a multi-cylinder, reciprocating piston type fluid pressure energy translating device which includes a housing enclosing a rotatable cylinder block, and a cooperating fixed fluid handling section having internally open spaced low and high pressure ducts arranged to communicate alternately with open piston chambers in said cylinder block as the block rotates, and in which piston reciprocation and the rotational speed of the cylinder block is timed so that each piston travels on at least a portion of its compression stroke between the time its chamber breaks communication with said low pressure duct and the time its chamber begins direct communication with said high pressure duct,

structure for adjusting the pressure in each successive piston chamber to substantially equal the pressure in said high pressure duct between the time each piston chamber breaks communication with the low pressure duct and the time it starts direct communication with said high pressure duct, comprising:

a liquid filled pressure control chamber in said liquid handling section located between said spaced low and high pressure ducts;

a differential pressure movable barrier traversing said control chamber and continuously dividing it into

(a) a variable volume, piston chamber pressure regulating compartment, and

(b) a separate variable volume, pressure regulation assisting compartment,

said pressure regulating compartment having an open port located to openly communicate with the open end of each successive piston chamber between the time the piston chamber breaks communication with said low pressure duct and the time the piston chamber begins direct communication with said high pressure duct, the open port of said pressure regulating compartment being so spaced from said high pressure duct that the open end of each piston chamber momentarily communicates with both simultaneously as the relative movement cycle proceeds; and

duct means affording open communication between said high pressure duct and said pressure regulation assisting compartment,

whereby, during the time each piston chamber is in communication with said pressure regulating compartment, the liquid in both is subjected, through the movable barrier, to the pressure existing in said high pressure duct, and vice versa, and the pressure on the liquid in each successive piston chamber is thus adjusted, prior to the start of its communication with said high pressure duct, to substantially equal the

pressure then existing in that duct, and as each piston momentarily communicates with both the pressure regulating compartment and the high pressure duct, pressures in the pressure regulating compartment and in the pressure regulation assisting compartment are equalized, and said barrier returns to its normal position.

9. The structure described in claim 8, and

a fluid passage in the liquid handling section in communication with said high pressure duct and having an open end located between said pressure regulating compartment and said high pressure duct in a position to communicate with each piston chamber as it moves from the pressure regulating compartment to the high pressure duct, and so spaced from the pressure regulating compartment that each piston chamber, during its travel is simultaneously in communication with both the pressure regulating compartment and the open end of said fluid passage.

10. The structure described in claim 8, and

a ported valve plate located between the fixed liquid handling section and the cylinder block, and cooperating with both, and

ports in the valve plate controlling communication of the open ends of the respective piston chambers with

(a) said low pressure duct,

(b) said pressure regulating compartment,

(c) and said high pressure duct,

the ports controlling communication with the pressure regulating compartment being two in number, the first port being nearest the low pressure duct and being a liquid metering orifice of minute cross sectional area, and the second port being nearest the high pressure duct and being larger in cross sectional area, the said first and second ports being arranged in parallel and spaced sufficiently close together that the open end of each piston chamber can bridge the ports and communicate with the pressure regulating compartment through both ports simultaneously during travel from the low to the high pressure duct, as the cylinder block rotates.

11. In a multi-cylinder, reciprocating piston type, bi-rotational liquid pressure energy translating device which includes a housing enclosing a rotatable cylinder block which has a planar surface defining the open ends of a plurality of piston chambers, and a fixed liquid handling section which has a planar surface which slidably cooperates with the planar surface of the cylinder block, and which defines internally open ends of two spaced liquid handling ducts in said section, the said open ends of said ducts being arranged and located to communicate alternately with the open ends of the respective piston chambers as the cylinder block rotates in either rotational direction, and in which when the cylinder block rotation is clockwise the first of said ducts in the liquid handling section is a high pressure duct and the second of said ducts is a low pressure duct, and when cylinder block rotation is counterclockwise the second of said ducts is a high pressure duct, and the first duct is a low pressure duct, and in which device piston reciprocation and the rotational speed of the cylinder block is timed so that each piston travels on at least a portion of its compression stroke between the time its chamber breaks communication with the duct of low pressure and the time its chamber begins direct communication with the duct of high pressure, regardless of the rotational direction of said cylinder block,

structure for adjusting the pressure in each successive piston chamber to substantially equal the pressure in the duct of high pressure, regardless of the rotational direction of the cylinder block, between the time each piston chamber breaks communication with the low pressure duct and the time it starts communication with the high pressure duct, comprising:

a liquid filled pressure control chamber in the liquid handling section;

a differential pressure movable barrier traversing said control chamber and continuously dividing it into

(a) a variable volume, piston chamber pressure regulating compartment, and

(b) a separate variable volume, pressure regulation assisting compartment,

the pressure regulating compartment having an open port located in a position to communicate with the open end of each piston chamber during its travel between the two ducts in the liquid handling section;

a cylinder (85, FIG. 12) in said liquid handling section;

a pair of passages (87, 88) connecting the opposite ends of the cylinder respectively with the two ducts (20, 21) in the liquid handling section;

a pair of passages (89, 93) connected respectively with the opposite ends of said cylinder, each of said passages (89, 93) having an end open at the planar surface of said liquid handling section, the two open ends being located between a respective one of said ducts (20, 21) and the open end of said pressure regulating compartment in positions to communicate with the open ends of the piston chambers during their travel, the respective open ends of the two passages (89, 93) being located sufficiently near the opening (46) of the pressure regulating compartment that each piston chamber bridges the respective spaces between the opening (46) and the respective openings of the two passages (89, 93);

a fifth passage (86) connecting the central portion of said cylinder (85) and said pressure regulation assisting compartment; and

a floating plunger reciprocable in said cylinder constituting a valve responsive to the higher of the pressures in said ducts (20, 21), the length of the plunger being less than the distance between the respective ends of the cylinder and the respective remote edges of the said fifth passage opening,

whereby when one of the ducts (21) in the liquid handling section is the higher pressure duct, whether the device is operating as a pump or as a motor, the plunger (84) is forced by the higher pressure in the said duct (21) to the remote end of its cylinder, and blocks fluid flow through two of said passages (87, 89); and between the time each piston chamber travels from the lower pressure duct (20) to the higher pressure duct (21) the pressurized liquid therein is adjusted, through the movable barrier and the liquid on both sides thereof, to substantially equal the pressure existing in the higher pressure duct, prior to actual communication of the piston chamber with that duct;

and when the other of said ducts (20) is the higher pressure duct and the cylinder block is rotating in the opposite direction, whether the device is operating as a pump or as a motor, the plunger (84) is forced by the higher pressure to the opposite end of its cylinder and blocks flow through the other passages (88, 93), and pressure in each piston chamber is adjusted, while it is in communication with said pressure regulating compartment, to substantially equal the pressure in the higher pressure duct (20), prior to actual communication of the piston chamber with that duct.

12. The structure described in claim 1, and

a ported valve plate located between the fixed liquid handling section and the cylinder block, and cooperating with both, and

ports in the valve plate controlling communication of the open ends of the respective piston chambers with

(a) said low pressure duct,

(b) said pressure regulating compartment,

(c) and said high pressure duct,

the ports controlling communication with the pressure regulating compartment being two in number, the first port being nearest the low pressure duct and being a liquid metering orifice of minute cross sectional area, and the second port being nearest the high pressure duct and being larger in cross sectional area, the said first and second ports being arranged in parallel and spaced sufficiently close together that the open end of each piston chamber can bridge the ports and communicate with the pressure regulating compartment through both ports simultaneously during travel from the low to the high pressure duct, as the cylinder block rotates.

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LAURENCE V. EFNER, *Primary Examiner.*