

How a Discharge Relief Valve Controls Pressure

Relief valves are used in most pumping systems to prevent excessive pressures caused by changes in the conditions under which the system is operating. There are many different kinds of relief valves and they function in different ways depending on the type of pump, the characteristics of the pump driver (engine or motor, etc.), and the operating conditions. This discussion is restricted to pilot-operated valves used with centrifugal pumps driven by internal combustion engines, feeding one or more discharge lines, any or all of which may be shut off without the prior knowledge of the pump operator—in other words, to relief valves used on fire department pumbers.

To understand the function of a relief valve, one must first understand the basic principles of the centrifugal pump and the internal combustion engine.

A centrifugal pump develops pressure in the fluid being pumped by imparting kinetic (moving) energy to the fluid by means of the rotation of the impeller(s). The fluid (water) enters the impeller near its center and is whirled by the impeller vanes, thus developing centrifugal force which urges the water outward into the discharge manifold. At a given rpm, the pressure at a given flow rate is always the same. As the flow rate is increased the pressure decreases, but the power required increases. Note that if the pump capacity is *decreased*, the power is also *decreased* (providing that the rpm is constant), and the pressure is *increased*. When we say that the “power” is decreased, at constant rpm, what we really mean is that the torque requirement is decreased; power is equal to torque multiplied by rpm.

In the above discussion, the term “pressure” means *net pump pressure*, or the difference between discharge pressure and intake pressure. When a pump is operating from draft or a booster tank, the intake pressure is usually negative (partial vacuum), but it will be near zero, and will not change appreciably with a change in flow rate. When the pump is operating from a hydrant or in relay, however, the intake pressure ordinarily is at least 10 psig, and it can vary appreciably with a change in flow.

An internal combustion engine develops torque and power by burning fuel in its cylinders; the pressure of the gases formed by the combustion pushes the pistons down and turns the crankshaft. The torque developed

depends on the amount of fuel burned during each cycle, and the power depends on the torque and speed. At a given throttle setting, therefore, the engine will develop a certain torque. (The torque changes somewhat with speed due to the effect of speed on the fuel/air mixture, the way it is fed into the combustion chamber, and the way combustion takes place; however, for the purpose of this discussion, we can ignore the effect of speed on torque.)

The relief valve is merely a piston in a cylinder; one end of the piston normally closes a passageway between pump discharge and pump intake. The other end of the piston is subject to water pressure, with this pressure regulated (modulated) automatically by a pilot valve. Thus, one end (the smaller in area) is subject to pump discharge pressure, and the other to a pressure which is modulated by the pilot valve.

The pilot valve incorporates a stem which moves to open a passageway in response to changes in pump discharge pressure. It is “set” at any desired value (usually between 90 and 300 psig, as required by NFPA Standard) by the operator who adjusts the compression in a coil spring which opposes the load caused by discharge pressure acting on a diaphragm or piston. At any discharge pressure below the setting, the pilot valve will be closed; at any pressure higher than the setting, the pilot valve will be open.

Water enters the pilot valve at pump discharge pressure. An orifice permits water to flow to a line leading to the relief valve. This line also is connected to pump intake, but when the pilot valve is closed, this connection is blocked, and there is no flow through the orifice; hence, the pressure on the relief valve piston is equal to the pump discharge pressure. When the pilot valve opens and permits water to flow to pump intake, the friction loss due to flow through the orifice decreases the pressure on the relief valve piston and permits the relief valve to open, thus bypassing water from pump discharge through the relief valve and its associated piping back to pump intake.

In order to keep the discharge pressure the same when the flow through the discharge valves is decreased, the load on the engine must be regulated so that engine speed will not increase and cause a rise in net pump pressure.

When operating from draft or from a booster tank, it is necessary only that the relief valve bypass the same flow that is shut off, so that the torque load on the engine will be kept the same; the rpm then will stay the same, so will the net pump pressure, and as the intake pressure won't rise significantly, neither will the discharge pressure. In this case, as long as the flow that must be bypassed can flow through the relief valve without causing more friction loss than the net pump pressure, the relief valve will maintain the discharge pressure at the setting of the pilot valve. The larger the relief valve and the higher the net pump pressure, the more water can be bypassed before the friction loss gets too high. The relief valve does not open fully until the maximum flow is being bypassed; at lesser flows the pilot valve modulates the pressure on the relief valve piston so that it opens just far enough so that the friction loss through the relief valve and piping is equal to the net pump pressure.

When operating from a hydrant connected to a high capacity water distribution system, the intake pressure may be quite high, but it won't change significantly when the flow rate changes. Usually the net pump pressure won't be as high as when operating from draft, so less flow can be bypassed without causing friction loss through the valve system equal to the net pump pressure.

With a intake pressure of 50 psig, the minimum discharge pressure which the relief valve will hold with a given reduction inflow is 50 psi higher than when operating at draft. As an example, if a relief valve will hold 90 psig discharge pressure when operating at draft, with a 750 gpm reduction in flow, then it will hold only a discharge pressure of 140 psig or higher when operating with 50 psig intake pressure with the same reduction in flow. It will not hold 90 psig under these conditions because the friction loss through the relief valve will be more than the net pump pressure of 40 psi. Instead, the flow will be reduced, the engine will speed up due to decreased torque load, and the net pump pressure will be increased. The system will stabilize when the flow through the relief valve and any discharge lines still open, and the net pump pressure (equal to the friction loss through the relief valve and piping) causes a torque load equal to the torque transmitted to the pump by the engine.

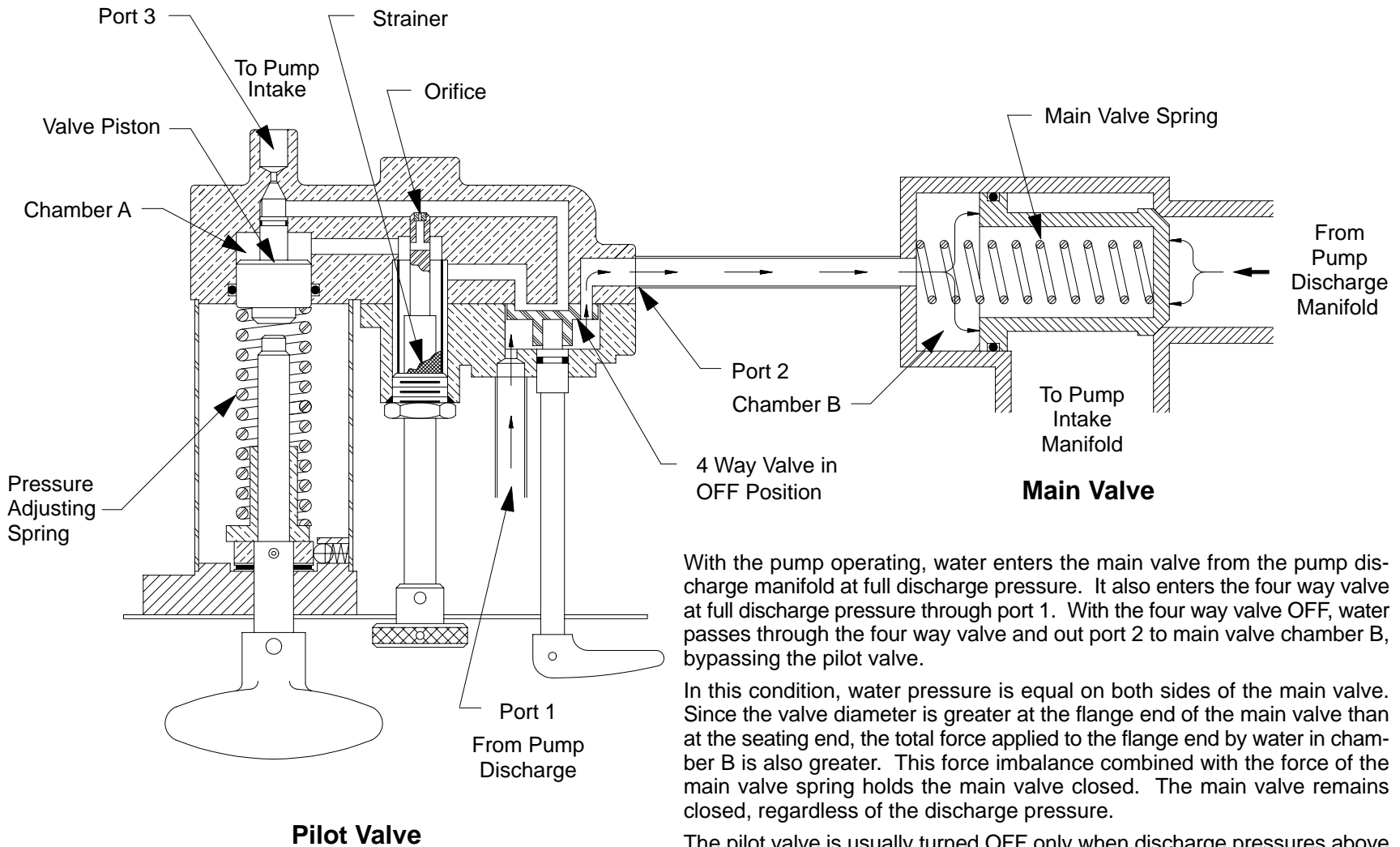
When operating in relay, or from a hydrant at which the residual pressure will vary appreciably with different flow rates, the problem becomes more severe. When the flow through the pump discharge valves is reduced, then flow through the hydrant is also reduced and the residual pressure at the hydrant is increased. Consequently, the intake pressure at the pump is also increased. In order to hold the discharge pressure, then, the net pump pressure must be reduced. The only way this can be accomplished is to increase the flow through the pump. This will tend to decrease the net pressure even if the rpm is not reduced, but it will also increase the torque load on the engine and thus reduce the rpm and likewise the net pressure.

If the reduction in flow through the discharge valves is relatively small (one line shut down), the increase in intake pressure won't be very high, and if the net pressure was high enough originally, the relief valve can bypass a sufficient flow to increase the load on the engine, slow it down, and decrease the net pressure by an amount equal to the increase in intake pressure and hold the discharge pressure constant. But if, for instance, with a discharge pressure of 120 psig and a intake pressure of 20 psig, 750 gpm is shut off and the intake pressure increases to 50 psig, the net pressure must be reduced from 100 psi to 70 psi. To do this, the relief valve would have to bypass considerably more than 750 gpm with a friction loss of 70 psi. This would take a large valve, as probably at least 1000 gpm would have to be bypassed at 70 psi friction loss.

Under almost all operating conditions, a relief valve does a completely satisfactory job of controlling discharge pressure. The following general rule should be remembered: **The higher the net pump pressure, the greater the reduction in flow can be without increasing the discharge pressure.** This means that:

1. When operating from a hydrant or in relay, when the intake pressure is 10 psig or more, a relief valve will not control the discharge pressure with as great a reduction in flow as when operating from draft.
2. If the intake pressure can vary appreciably, a relief valve will control the discharge pressure with only a moderate reduction in flow.

Discharge Relief Valve Operation – OFF Position

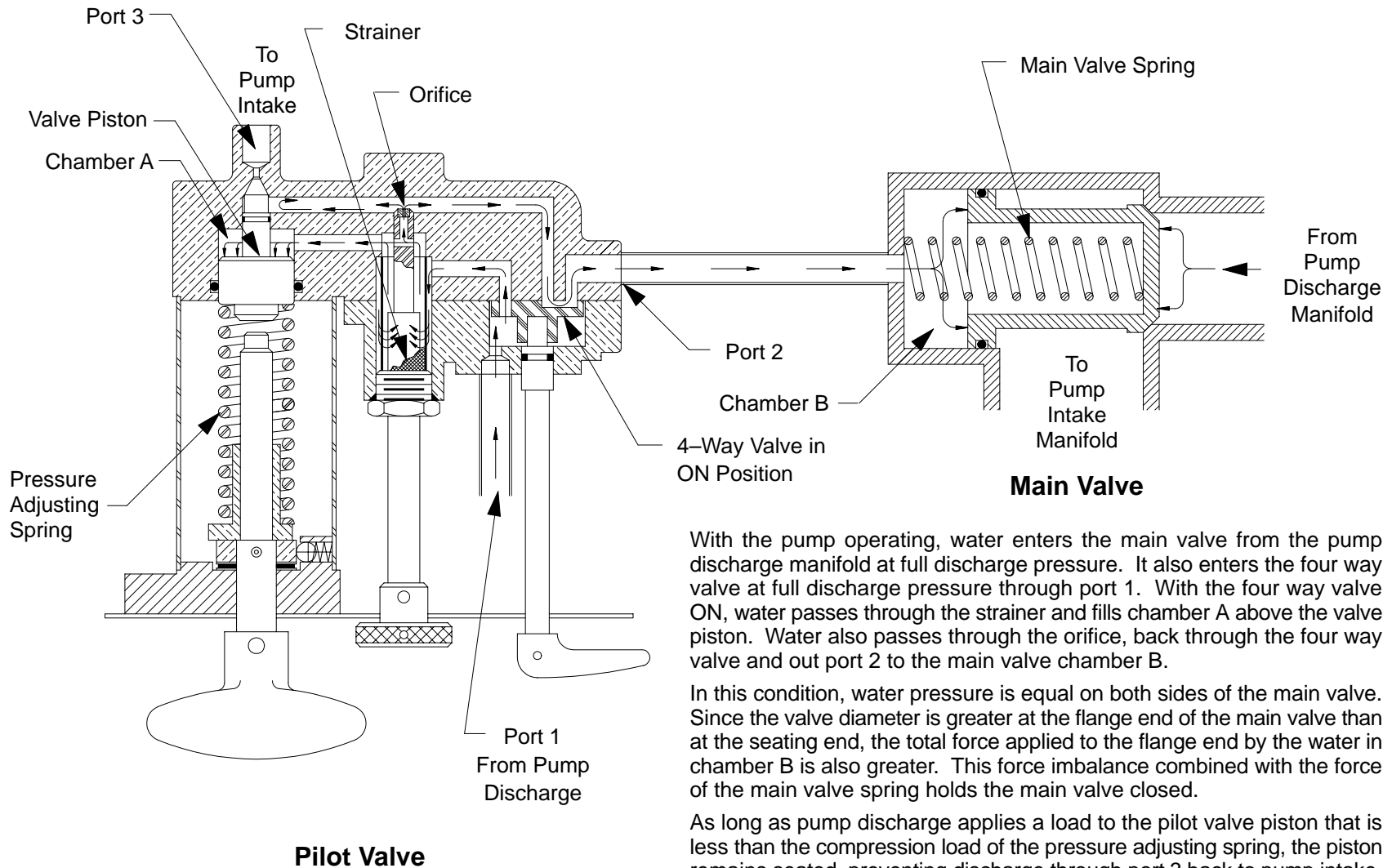


With the pump operating, water enters the main valve from the pump discharge manifold at full discharge pressure. It also enters the four way valve at full discharge pressure through port 1. With the four way valve OFF, water passes through the four way valve and out port 2 to main valve chamber B, bypassing the pilot valve.

In this condition, water pressure is equal on both sides of the main valve. Since the valve diameter is greater at the flange end of the main valve than at the seating end, the total force applied to the flange end by water in chamber B is also greater. This force imbalance combined with the force of the main valve spring holds the main valve closed. The main valve remains closed, regardless of the discharge pressure.

The pilot valve is usually turned OFF only when discharge pressures above 300 psi are required, or if higher pressures are desired without the necessity of disturbing the pilot valve setting.

Discharge Relief Valve Operation – On Position (Main Valve Closed)

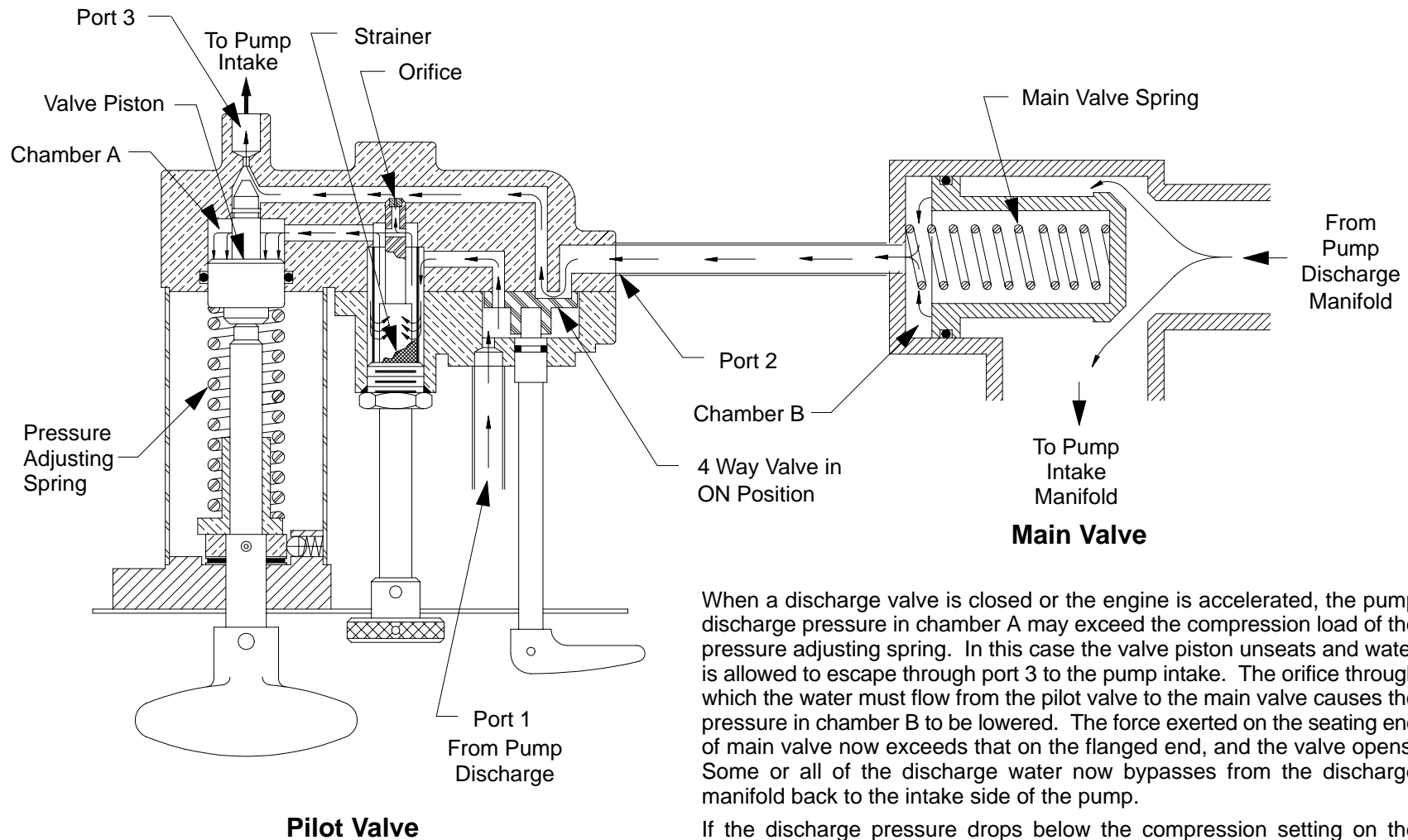


With the pump operating, water enters the main valve from the pump discharge manifold at full discharge pressure. It also enters the four way valve at full discharge pressure through port 1. With the four way valve ON, water passes through the strainer and fills chamber A above the valve piston. Water also passes through the orifice, back through the four way valve and out port 2 to the main valve chamber B.

In this condition, water pressure is equal on both sides of the main valve. Since the valve diameter is greater at the flange end of the main valve than at the seating end, the total force applied to the flange end by the water in chamber B is also greater. This force imbalance combined with the force of the main valve spring holds the main valve closed.

As long as pump discharge applies a load to the pilot valve piston that is less than the compression load of the pressure adjusting spring, the piston remains seated, preventing discharge through port 3 back to pump intake.

Discharge Relief Valve Operation – On Position (Main Valve Open)



When a discharge valve is closed or the engine is accelerated, the pump discharge pressure in chamber A may exceed the compression load of the pressure adjusting spring. In this case the valve piston unseats and water is allowed to escape through port 3 to the pump intake. The orifice through which the water must flow from the pilot valve to the main valve causes the pressure in chamber B to be lowered. The force exerted on the seating end of main valve now exceeds that on the flanged end, and the valve opens. Some or all of the discharge water now bypasses from the discharge manifold back to the intake side of the pump.

If the discharge pressure drops below the compression setting on the pressure adjusting spring, the valve piston will reseat and stop flow through port 3 allowing pressure to build up in chamber B and reclose the main valve. Usually the pressure drops to a level where the pressure in chamber B increases enough to balance discharge pressure acting on the opposite end of the main valve, so the main valve is neither fully open nor fully closed.

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