Experimental Investigation on Transient Response of Two Stage Pressure Relief Valve

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Abstract: Pressure control valves are used in fluid power systems to control the operation of the hydraulic system. The time response of a hydraulic system is the integrated result of the response times of all of the components used in the system. The ability to understand and manage the valve performance characteristics like transient response, pressure-flow are important in automation and heavy industrial processes. In this paper, part of experimental research work carrying out on the two stage pressure relief valve is presented.

Keywords: Cracking pressure, Pilot valve, Pressure override, Relief Valve, Two stages, Transient response.

1. Introduction

Considering safety and accuracy reasons, it is required to control pressure in hydraulic system as quick as possible. Hence to know the response, sensitivity and performance consistency of the pressure control valves are very much essential. These factors play major impact in the precision hydraulic control systems.

The approaches adopted to study the performance of the valves are mainly experimental and computer numerical simulation study. Many researchers have experimented and analyzed the valves for the fluid characteristics, operating parameters, and the coefficients such as discharge coefficient and pressure loss coefficient .From the viewpoint of practical application, this method is more reliable and suitable, since the real situations are usually simulated in the experiments.

A pressure control valve can be used to limit the maximum pressure (a relief valve), to set a back pressure (a counter balance valve), or to pass a signal when a certain pressure has been reached (sequence valve). The principal feature of most pressure controls is that the hydraulic forces are resisted by a spring.

2. Pressure Relief Valve

The most widely used type of pressure control valve is pressure relief valve, since it is found in every hydraulic system. It protects the system against overpressure, which may occur due to excessive actuators loads or due to the closing of the valves. It is normally a closed valve whose function is to limit the pressure to a specified maximum value by diverting pump flow back to the reservoir.

Direct operated pressure control valves are limited as the flow increases due to the space required for the control spring. A larger flow requires a larger poppet or spool diameter. The area and hence the spring force increases proportionally to the diameter squared. In order to keep the space required for these valves down to a sensible level, two stage (pilot operated) valves are used.

Two stage valves is a pilot operated relief valve which gives good regulation of pressure over a wide range of flow. They are used to limit the operating pressure or limit and unload the operating pressure by means of solenoid operation.

3. System response and stability

Rapid response is generally an essential requirement of a hydraulic servo system. However, if the response is too rapid the system can become unstable, in which case damping has to be introduced. The necessary degree of system damping for stability will depend upon:

- ◼ The system response
- ◼ The load inertia
- ◼ The back-lash of the system

A system is said to be 'underdamped' when the output resulting from a step input is oscillatory but ultimately reaching a steady condition. Critical damping is that at which the system just ceases to oscillate and the output achieves a steady state in the minimum possible time. When the damping is greater than the required for critical damping the system is said to be 'overdamped'.

4. Operational description

The pilot valve is a direct operated pressure relief valve. The pressure present in system line P acts on main spool. At the same time, the pressure is fed to the spring-loaded side of the main spool via control lines containing orifices and also to the poppet element in the pilot valve.
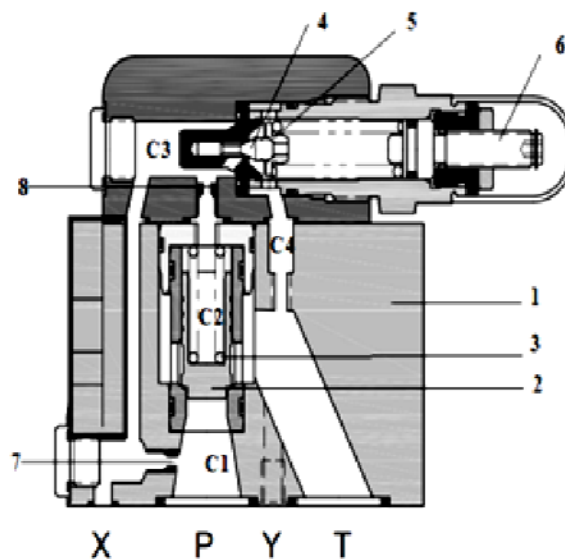
(1- Valve housing; 2 – Main Spool; 3 – Spring; 4- Pilot Poppet; 5 - Spring; 6- Screw; 7 – Orifice 1; 8- Orifice 2 ; P- Pressure line port ; T- Tank port)

Fig. 1. Sectional view of the valve (PPRV20)

If the pressure increases in system line to a above that set by spring, poppet element opens against spring. It creates unbalance on the main spool and it will lifts off its seat to permit larger flow into the tank. Since main spool compresses only the light spring, and hence very little override occurs compared to the single stage pressure relief valve.
This valve can be observed as a system consisted of three subsystems: main spool 1(cylindrical poppet) , pilot poppet 4 and fixed orifices 7,8. In neutral position both pilot poppet and main spool are closed under the influence of the springs 3 and 5, and there is a balance of forces at the closing element of the main spool 1. When inlet pressure will reach higher value than the preset spring force 5 of the pilot poppet, the closing element of the pilot poppet 2 is opening and through the orifices there is beginning to flow some little amount of pilot flow.
The pressure in the upper part of the main spool is maintaining approximately constant by the pilot poppet. With further increase of the inlet pressure the pressure drop continues to increase and main valve relieve the major flow to the tank.

5. Experimental Investigation

Two Stage Pressure Relief Valve tested on the developed experimental setup to investigate the transient response of the valve. On the existing double-pump hydraulic test rig, arrangements were

made shown in the Fig.5. It consists of a high-pressure, low volume pump P1 in conjunction with a low-pressure, high-volume pump P2. Two pressure transducers and output data logger digital storage oscilloscope (DSO) is used to record the pressure transient response of the valve.

Application of this system is used where wide range pressure – flow regulations required. This system eliminates the necessity of having a very expensive high-pressure, high-volume pump. The valve fitted on the hydraulic test rig as shown in the fig. Before switching on the system, all the pressure relief valves kept open. Then pressure built on the system by energizing the solenoid valve to close. The maximum pressure of the system set by operating the relief valves. Test valve loaded by setting the cracking pressure, which is lower than the system pressure.

When solenoid directional control valve is energized, the pressure built in the line of pressure relief valve. Once the pressure exceeds the set pressure, test valve gets cracked and releases the flow back to the reservoir. During this process, transient response of the valve is observed through the data acquisition system. Here through the oscilloscope and pressure transducers, the transient response of the valve is studied.

Fig.4 shows the hydraulic circuit of the test stand for determination of transient response of the specified pressure relief valve.
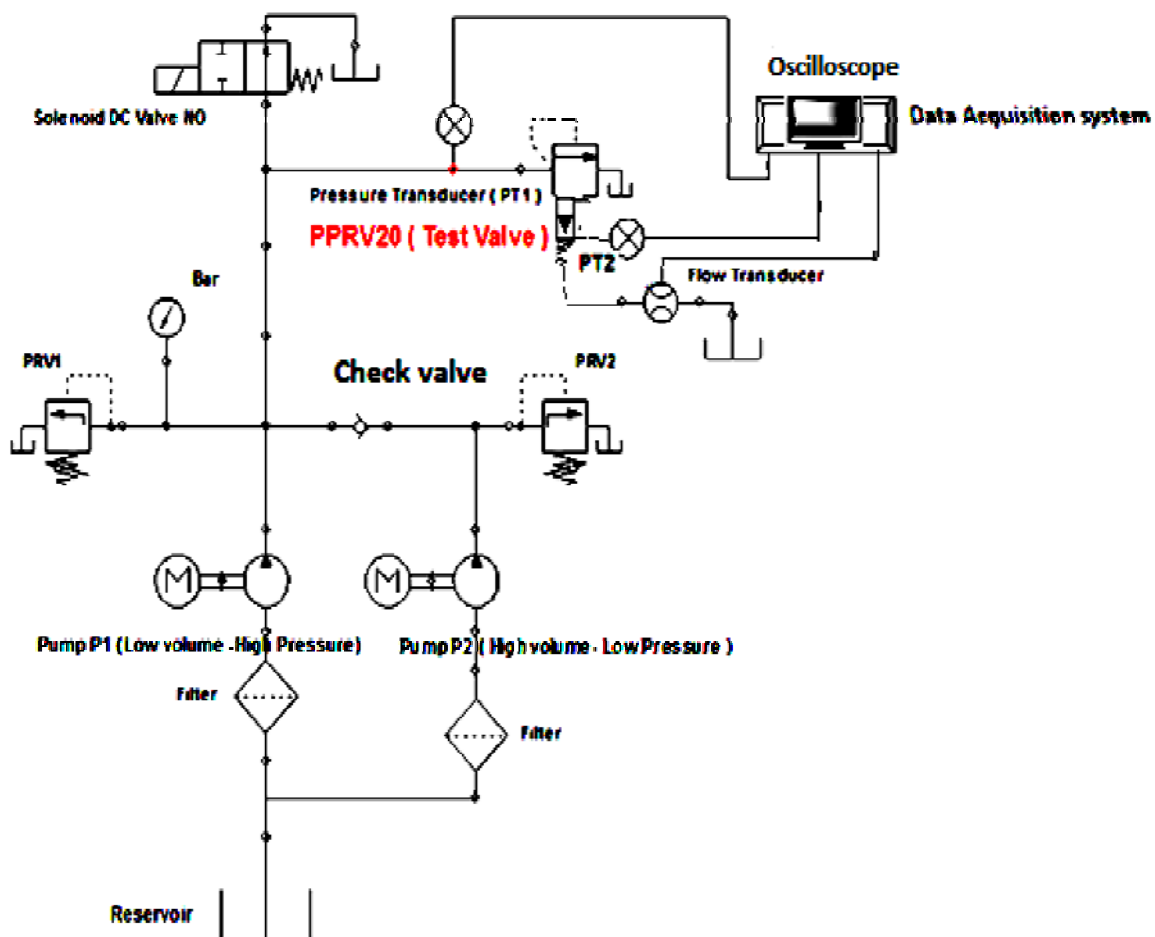

Fig. 2. Test Rig Hydraulic circuit

6. Results and discussion

Here the transient response of the pilot relief valve and main relief valve investigated separately and plotted the graphs.

Pilot valve Relief Pressure = 180 bar, Main valve Relief Pressure = 188 bar

The following parameters are used for the determination of the response.

Delay time: The time required for the output to reach 50% of the steady Output.
Rise time: The time required for the output to rise from 10% to 90% of the final output value
Maximum overshoot: The time at which the maximum overshoot occurs.
Settling time: The time for the system to reach and stay within a stated plus-and-minus tolerance band around the steady-state output
Pressure peak p_{Emax}:

$$P_{Emax} = V_m / p_E * 100$$

The maximum overshoot V_m is the largest deviation of the response from the set command value after the transient tolerance has been overshoot for the first time.
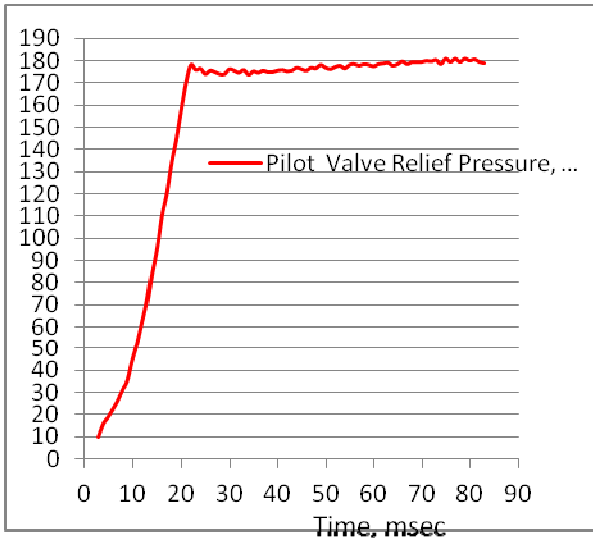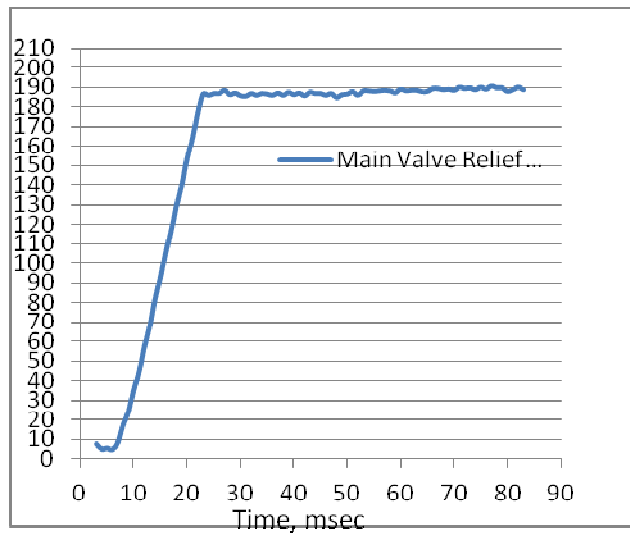

Fig. 3. Transient response of pilot relief valve   **Fig. 4.** Transient response of main relief valve

TABLE 1: Response time

Time in , msec	Pilot Valve	Main Valve
Delay time ,	14	16
Rise time	15	13
Max over shoot time	---	----
Settling time	70	67
Pressure Peak	0.44 %	0.68%

From the graphs it is observed that, overshoot not exist in the valve. There is a pressure decrease in front of pilot poppet after it cracks i.e. just open. Due to this pressure drop, imbalance occurs on the main cylindrical poppet and lifts off from the seat against the light spring. It releases the major flow to the tank without much working on the oil.
This is the first technical paper to present the new method to measure the pressure override characteristics of the valve in the form of transient response curves of both pressures in the form of graph. It is seen that, there is a reduction in the pressure, as pilot valve cracks and later it stabilizes to the set pressure.
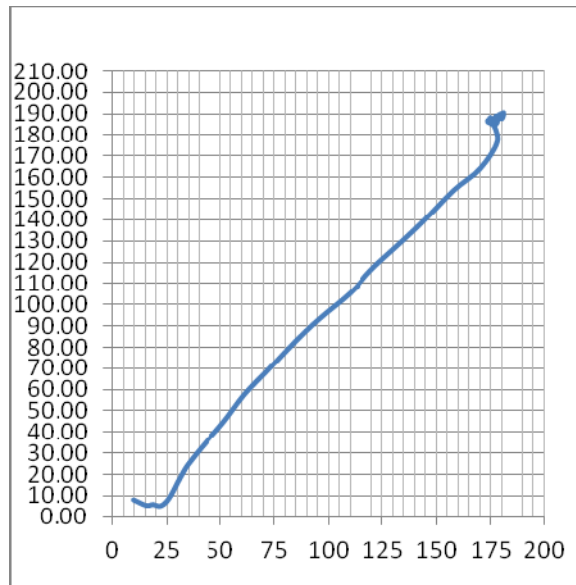
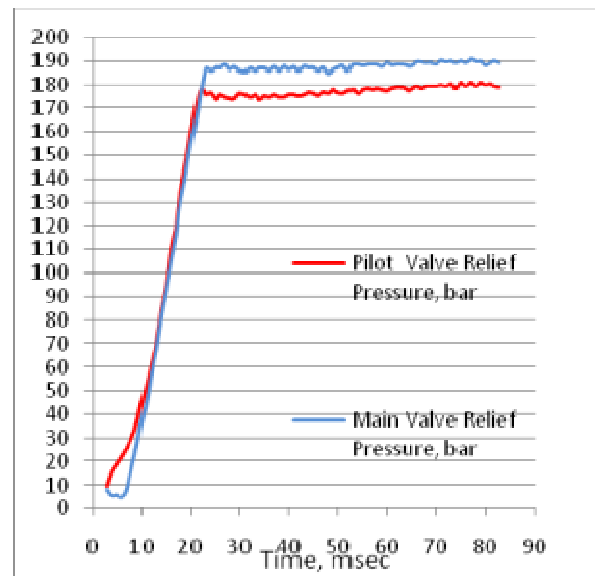**Fig. 5.** Pilot relief pressure v/s Main relief pressure

Fig. 6. Transient Response of both stages

From the transient pressure curves, both the pressures of poppet relief valve and main relief valve remain same, till the pilot valve cracks. The pressure override of this valve is 8 bar and which is less compared to the single stage relief valve. Pressure override is the difference between the cracking pressure or opening pressure and the pressure drop across the valve when it is passing the maximum rated flow at the same valve setting.

7. Conclusion

From this experimental investigation and literature survey, it concludes that its pressure override is less compared to the single stage pressure relief valve. The highlight of this research work is to correlate the pressures of both pilot relief valve and main relief valve in the form of graph.

The ability to understand and utilize the response information obtained from the individual component manufacturers is very much necessary while observing the response of a whole hydraulic system.

Based on the transient response curves, the dynamic behaviour of the valve is presented in the form of time response parameters.

But on the other hand, this method is very expensive in time, manpower and facilities. For further research work, computer simulation is also used to investigate and validate with the experimental results.

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