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Static and Dynamic Characteristics of Direct Spring Operated Pressure Relief Valve

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Abstract: *This paper is dealing with static and dynamic performances of direct operated pressure relief valves. The subject of research is Polyhydron Pvt. Ltd.'s Pressure relief valve type DPRS06K315. A mathematical model of the valve is obtained and simulink model is developed using MATLAB/SIMULINK. Theoretically obtained static and dynamic characteristics of the valve with respect to the different values of the inlet volume are presented in few graphs.*

1. INTRODUCTION

The pressure relief valve is a main component in every hydraulic system [1]. The function of the relief valve is to limit the maximum pressure that can exist in a system. Under ideal conditions, the relief valve will bypass the excess oil to the tank. Pressure relief Valves are spring-loaded valves designed to open and relieve the excess pressure, then immediately close, preventing any loss of fluid flow after normal conditions have been reinstated. Pressure relief valves are designed to act as a safety device in hydraulic system [2-3]. It is a device designed for the automatic release of oil from hydraulic system when the pressure exceeds the preset pressure to protect system. In spite of the high development status of the conventional pressure relief valves, there is an important research demand on the investigation of them, because these are the most used devices for protections of human life, environment and equipment.

2. FUNCTIONAL DIAGRAM OF THE VALVE

Fig. 1a) and b). Shows a schematic of the studied spring operated direct acting pressure relief valve. The valve consists of a poppet valve (2), rigidly attached to a damping spool (1).

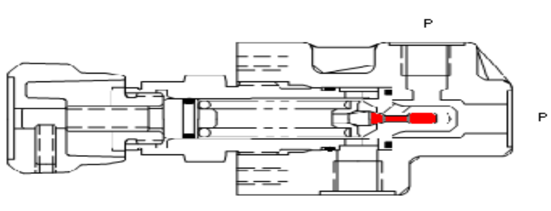

Fig. 1a): DPRS06K315 Valve

The poppet is loaded by a spring of stiffness K. the spring is pre- compressed by an adjustable pre-compression displacement, X_0. When the valve is not operating, the spring pre- compression

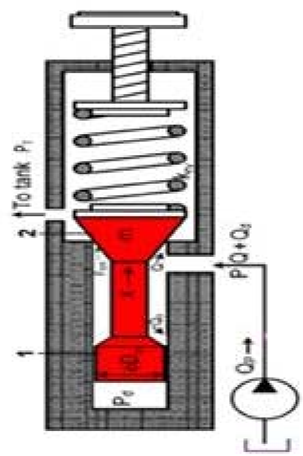

Fig. 1b): Physical System of Pressure Relief Valve Model

force ($K*X_0$) pushes the poppet against its seat. The seat produces an equal seat reaction force F_{SR}. When the input pressure P is increased, the liquid flows to the damping chamber through the clearance of the damping spool, $Q_{d.}$ The pressure, P_d increases and acts on the damping spool. When the valve is closed, the pressure P at the valve inlet chamber does not produce any axial force on the moving parts. But as the poppet valve opens, the poppet area subjected to inlet pressure A_P becomes less than the damping spool area A_d. The pressure P acts on the area difference (A_d-A_p) to the left. Neglecting the jet reaction forces, the motion of the damping spool and poppet is governed by the spring force, the seat reaction force and the pressure forces. When the pressure force (P_d*A_d) exceeds the spring force ($K*X_0$), the poppet displaces, opening the path from the inlet port to the drain port, with a pressure P_T. The variation of the pressure P_d is resisted by the clearance, which throttles the connection of the inlet port with the damping spool chamber.

The relief valve is connected to the delivery line of a fixed displacement pump rotated by a constant speed. A bypass valve is connected to the pump delivery line to control the loading pressure.

3. MATHEMATICAL MODEL

Considering that the total mass of the moving parts m is equal to the mass of the plunger plus one third mass of the spring [4-5], the differential equation of the dynamic behavior is derived as follows

The dynamic behavior of the valve is described by the following set of mathematical relations. The effect of the transmission lines is neglected[6-7].

The Poppet Valve Throttling Area.

The following mathematical expression for the poppet valve area Ap

$$\mathrm{Ap} = \pi(\mathrm{R}^2 - (\mathrm{R} - \mathrm{X} * \tan(\mathrm{alpha}))^2) \tag{1}$$

Where R- radius of the poppet, X–poppet displacement

Equation of Motion of the Poppet

$$\mathrm{M}.\frac{d^2\mathrm{X}}{dt^2} + \mathrm{Fv} + \mathrm{Fs} - \mathrm{F_{SR}} - \mathrm{Ad} * \mathrm{Pd} - \frac{\mathrm{Qs}^2\rho}{\mathrm{Ap}} * \cos 20^0 = 0 \tag{2}$$

where: x–poppet displacement, t–time, Fv–viscosity friction force, Fs–spring force,
F_{SR}–Seat reaction force, A–poppet area normal to pressure, Pd–system pressure,

Viscosity friction force

$$\mathrm{Fv} = \mathrm{C}.\frac{\mathrm{dx}}{\mathrm{dt}} \tag{3}$$

where: C–viscous force coefficient.

Spring force

$$\mathrm{Fs} = \mathrm{K}^*.(\mathrm{X_0} + \mathrm{X}) \tag{4}$$

Where K–spring stiffness, X_0- pre –compressed spring length, X- poppet displacement.

Seat Reaction Force

The poppet displacement in the closure direction is limited mechanically. When reaching its seat, a seat reaction force takes pla ce due to the action of the spring stiffness.

$$\mathrm{F_{SR}} = \begin{cases} 0 & \mathrm{X} \geq 0 \\ \mathrm{K} * |\mathrm{X}| - \mathrm{P} * \mathrm{Ad} & \mathrm{X} < 0 \end{cases} \tag{5}$$

Flow Rate Through the Clearance of the Damping spool

$$\mathrm{Qd} = \frac{\mathrm{pi} * \mathrm{Dd} * c^3 * (\mathrm{P} - \mathrm{Pd})}{(12 * \mathrm{mu} * \mathrm{L})} \tag{6}$$

Flow Rate Through the Poppet Valve

$$\mathrm{Qs} = \mathrm{Cd}.\mathrm{Ax}.\sqrt{\frac{2 * (\mathrm{P} - \mathrm{P0})}{\rho}} \tag{7}$$

Where A_X–poppet valve area

Continuity Equation Applied to the Damping spool Chamber

$$\mathrm{Q}_d - \mathrm{Ad} * \frac{\mathrm{dX}}{\mathrm{dt}} = \frac{\mathrm{V_0} + \mathrm{Ad} * \mathrm{X}}{\mathrm{B}} * \frac{\mathrm{dP}_d}{\mathrm{dt}} \tag{8}$$

by applying the flow continuity equation to the volume of trapped oil between the pump and valve. In this case, the input flow is held constant by the steady speed of the pump motor, and the volume does not change. The transformed equation is

$$\frac{\mathrm{dP}}{\mathrm{dt}} = \frac{\mathrm{B}}{\mathrm{Vp}}(\mathrm{Qp} - \mathrm{Qs} - \mathrm{Q}_d - Qleak) \tag{9}$$

Parameters

Numerical simulation data used for the simulation study are as follows.

Table 1: Parameter Values

Sl. No	Parameters	Symbol	Value	Unit
1.	Density of mineral oil	ρ	872	Kg/m3
2.	Pump Flow rate	Qp	4.2	Litre/min
			7*10-5	m3/s
3.	Effective Volume from pump to valve inlet	Vp	7.72*10-4	m3
4.	Bulk modulus of mineral oil	Bo	1.38*109	N/m2
	Bulk modulus of steel pipe	Bp	175*109	N/m2
	Effective bulk modulus	Bef	1.39*109	N/m2
5	Damping spool area	Ad	1.9478*10-5	m2
6.	Radial clearance of the damping spool	c	0.01*10-3	m
7.	Discharge coefficient	Cd	0.61	-
8.	Damping spool diameter	Dd	4.98*10-3	m
9.	Damping spool length	L	10*10-3	m
10	Stiffness of Spring	K	55600	N/m
11	Damping coefficient	C	117.3*103	N-s/m
12	Dynamic viscosity	μ	40.11*10-3 (46Centistoke)	Pas.
13	Mass of poppet plus 1/3rd spring mass	M	12.366*10-3	kg
14	Initial compression of spring	X0	11*10-3	m
15	Initial volume of the damping spool chamber	V0	2.5*10-7	m3
18	Poppet cone vertex angle	α	20	Degree

4. RESULTS AND CONCLUSION

For transient response of the specified valve a steady state flow of 4.2 l/min was set. Different experiments for different volume in front of the valve were made. The results of the theoretical model are presented in Fig. 2.

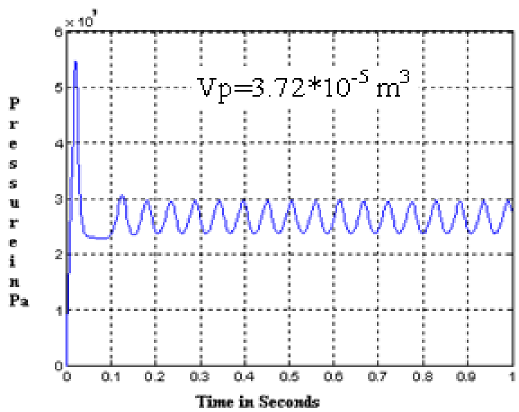

Fig. 2.a): Simulated Results of inlet volume of 3.72*10^{-5} m^3

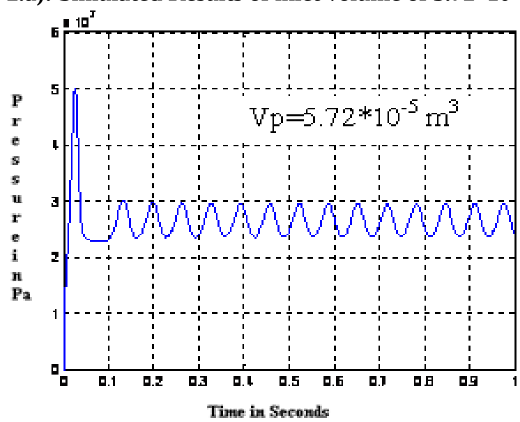

Fig. 2.b): Simulated Results of inlet volume of 5.72*10^{-5} m^3

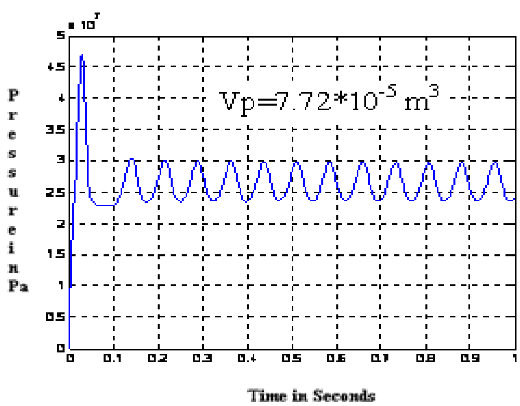

Fig. 2.c): Simulated Results of inlet volume of 7.72*10^{-5} m^3

Fig. 2 a), b), c) shows the theoretical dynamic characteristics for different values of the volume at the inlet port for the 260 bar pressure

As can be seen at Fig. 2 a), a response for inlet volume of 3.72 *10^{-5} m^3 ,the settling time is around 20 ms and the overshoot is 520 bar for pressure of 260 bar

As can be seen at Fig. 2 b), a response for inlet volume of 5.72 *10^{-5} m^3, the settling time is around 25 ms and the overshoot is 500 bar for pressure of 260 bar.

As can be seen at Fig. 2 c), a response for inlet volume of 7.72 *10^{-5} m^3, the settling time is around 30 ms and the overshoot is 460 bar for pressure of 260 bar

A very fast response for lower inlet volume of oil is obtained and by increasing the inlet volume, the overshoot can be reduced.

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