RESEARCH ON THE RELIEF VALVE WITH G-p BRIDGE PILOT HYDRAULIC RESISTANCES NETWORK

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ABSTRACT

This paper offered the idea of the relief valve with G-π bridge hydraulic resistances pilot circuit. Its static and dynamic characteristics were studied by theoretical analysis, digital simulation and experiment. The formula for designing the relief valve with G-π bridge hydraulic resistances pilot circuit was deduced, The theoretical analysis, digital simulation and experiment showed that the relief valve studied in this paper presents three kinds of pressure flow performances, i.e. when the overflow increases the control pressure increases, keeps constant and drops in terms of hydraulic resistance parameters of the pilot network.

NOTATION

D_1—Diameter of main poppet seat(m)
D_2—Diameter of pilot poppet seat(m)
□ $_1$—Angle of main poppet face
□ $_2$—Angle of pilot poppet face
m_1—Mass of main poppet(kg)
m_2—Mass of pilot poppet(kg)
K_x—Main spring stiffness(N/m)
K_y—Pilot spring stiffness(N/m)
V_1—volume of the inlet pipe(m^3)
V_2—volume in pilot chamber(m^3)
V_3—volume in main spring chamber(m^3)
q_1—flowrate through resistor r_1(m^3/s)
q_2—flowrate through resistor r_2(m^3/s)
q_3—flowrate through pilot poppet (m^3/s)
q_4—flowrate through main poppet(m^3/s)
a_1— area of main stage poppet seat(m^2)
a_2— area of spring chamber of main stage(m^2)
a_3 —area of piston on pilot poppet(m^2)
a_4 — a_3 minus area of pilot poppet seat(m^2)
x — displacement of main poppet valve(m)
y — displacement of pilot poppet valve(m)
x_L —initial compression of main stage spring(m)
y_L—initial compression of pilot stage spring(m)
d_1—diameter of orifice r_1(m)
d_2—diameter of orifice r_2(m)
L—length of orifice $r_1$or r_2(m)
f_1—viscous coefficient of main poppet
f_2— viscous coefficient of pilot poppet
c_{d1}—discharge coefficient of main poppet
c_{d2}— discharge coefficient of pilot poppet
F_1—spring preload of main poppet(N)
F_2—spring preload of pilot poppet(N)
K_w—flow force coefficient of main poppet
□ —effective bulk modulus
□ —density of oil(kg/m^3)
□ —dynamic viscosity

INTRODUCTION

The pilot control circuit of the relief valves which are widely used is B-half bridge resistance network. When overflow increase, the pressure controlled by the valve will increase, i.e. there is a steady state pressure override. In other words, the relief valve with pilot B-half bridge hydraulic resistors circuit always exists steady-state pressure override, i.e. when the overflow increases, the steady-state control pressure increases slightly because of spring force and steady-state flow force[1,2,3].

Steady-state pressure override can be reduced by optimum design and special construction design to compensate normalized flow force. But steady-state pressure override can not be zero, and certainly can not be negative. In order to there is a small construction, some relief valves have higher steady-state pressure override, thus, above relief valve can not keep pressure constantly.

Author offered the idea of □ bridge hydraulic resistance network and classified□ bridge hydraulic resistance network as 7 types, and defined as A□ B□ C□ D□ E□ F□ G. The pressure flow property of□ bridge was studied [4,5].

A new construction of the relief valve with G-□ bridge pilot hydraulic resistance network was proposed in this paper. The steady-state and dynamic characteristic of the relief valve were studied by theoretical analysis, digital simulation and experimental method. The result shows that the steady-state pressure override of the relief valve with pilot G-□ bridge may be positive or zero, also may be negative in terms of pilot hydraulic resistance parameters. The pilot poppet of the relief valve contains a guiding cylinder. Thus, its stability and dynamic characteristics are good.

THE PRINCIPLE OF G-□BRIDGE RELIEF VALVE

The principle of the relief valve with pilot G-□ bridge pilot hydraulic resistance network shows as fig.1. It is consist of main valve and pilot valve. r_1 and r_2 in fig.1 are invariable hydraulic resistors of the hydraulic resistance network. Pilot poppet is variable hydraulic resistor. It is defined as r_3 in fig.1. hydraulic resistance network of pilot circuit showed as fig.2. the network is G-□bridge hydraulic resistance network[6].

P_1 is inlet pressure, oil first flows into left chamber of pilot poppet through r_1, then flows into middle chamber of pilot poppet, before poppet opens, $P_1=P_2=P_3$, after inlet pressure gets the open-pressure of the pilot valve, pilot valve opens, inlet oil flow into oil box through r_1.r_2 and orifice r_3 formed by the pilot poppet, $P_3<P_2<P_1$ at the moment, main valve opens when the upward force formed by □P= P_1-P_3 is larger than the main spring force, oil flow into oil box through opening main valve.

Traditional relief valve use B-half bridge hydraulic resistance as pilot control circuit. If overflow of the relief valve increases, the opening of pilot poppet and main poppet must increase, thus spring force and flow force increase, therefore inlet force P_1 must increase.

G-□bridge relief valve use G-□ bridge hydraulic resistance network as pilot control circuit, the pressure acted on pilot poppet have pressure P_2 and P_3, when P_2 increases the opening of the pilot relief valve will increase, in the other hand, when P_3 increases, the opening of pilot valve would reduced. The variable rates of P_2 and P_3 depend on the flow area of the hydraulic resistors r_1 and r_2, different pressure flowrate characteristic can gained by different hydraulic resistors set. This is a new idea of the valve.

STEADY STATE CHARACTERISTIC OF G-□ BRIDGE RELIEF VALVE

For the pilot relief operated valve showed in fig1. Neglecting flow force of pilot poppet. Flow continuity equation and force equilibrium equation of the valve can be written as follow:

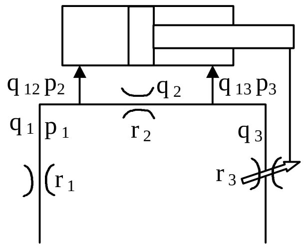

Fig.2 G-□ bridge hydraulic resistance network

Pressure flowrate equation of resistance r_1 , r_2 and r_3 formed by pilot poppet

$$q_1 = (pd_1^4/128mL)(p_1 - p_2) = c_1(p_1 - p_2) \quad (1)$$

$$q_2 = (pd_2^4/128mL)(p_2 - p_3) = c_2(p_2 - p_3) \quad (2)$$

$$q_3 = c_{d2}pD_2 y \sin a_2 \sqrt{2p_3/r} = by\sqrt{p_3} \quad (3)$$

Force equilibrium equation of the pilot poppet

$$p_2 a_3 = p_3 a_4 + K_x(y_l + y) \quad (4)$$

Pressure flowrate equation of orifice formed by main poppet

$$q_4 = c_{d1}pD_1 x \sin a_1 \sqrt{2p_1/r} = b_1 y\sqrt{p_1} \quad (5)$$

Flow continuity equation of inlet

$$q = q_1 + q_4 \quad (6)$$

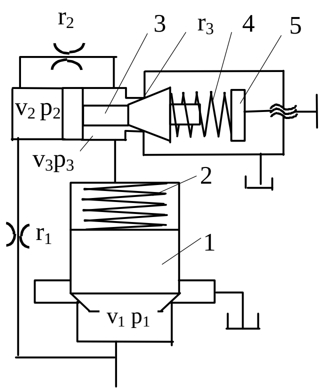

Fig.1 principle of relief valve with G-□bridge pilot circuit
1.main poppet 2.main spring 3.pilot poppet 4.pilotspring 5.adjust screw

Force equilibrium equation of the main poppet

$$p_1 a_1 = p_3 a_2 + k_x(x_l + x) + k_w x p_1 \quad (7)$$

Relation formula of P_1 and q can be gained in terms of above 7 equations, but the formula is complex, and explicit function formula can not be gained, this paper showed the digital computation result in fig.3. The pressure-flowrate performance may present three types in terms of different parameters in pilot hydraulic resistance network.

(1) control pressure of the relief valve increases with the increasing of overflow.(c_2>1.38$cm^5s^{-1}N^{-1}$)

(2) control pressure keeps constant with the increasing of overflow. (c_2=1.38$cm^5s^{-1}N^{-1}$)

(3) control pressure reduces with the increasing of overflow. (c_2<1.38$cm^5s^{-1}N^{-1}$)

Above the three kinds of pressure flowrate characteristic can be directly gained by linearizing equation. Linearizing equation (1)-(7) in steady state

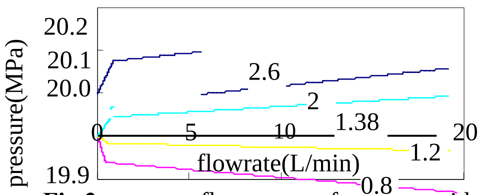

Fig.3 pressure flowrate performance with different value of c_2

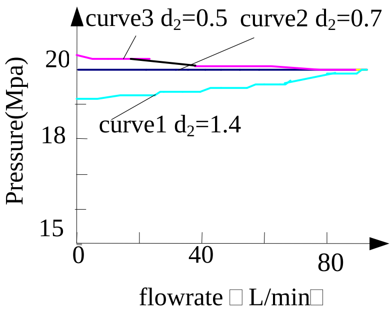

Fig.4 experiment curve of relief valve G-π bridge

point (P_{10}, P_{20}, P_{30}, q_0,q_{10}, q_{20},q_{30}, q_{40},x_0,y_0), finally we can gain:

$$Dp_1 = eDq \qquad (8)$$

The value of coefficient *e* determines the pressure flow rate characteristic of the relief valve. For the relief valve with B-half bridge pilot circuit, the value of coefficient *e* always is positive. but the value of coefficient *e* may be positive, zero, also can be negative for the relief valve studied in this paper. Thus the relief valve studied in this paper has three kinds of pressure-flowrate characteristic.

(1) *e*>0, control pressure P_1 increases with increasing of overflow.

(2) *e*=0, control pressure P_1 keeps constant with increasing of overflow.

(3) *e*<0, control pressure P_1 reduces with increasing of overflow.

If let e=0, equation (8) can be written as:

$$2a_3c_2q_{10}^2 - 2a_4(c_1+c_2)q_{10}^2 + 2k_yc_1c_2y_0q_{10} + k_y(c_1+c_2)b^2y_0^3 = 0 \qquad (9)$$

From equation (9), we know that the formula (9) only conclude parameters of pilot circuit of the relief valve, it doesn't contain main valve parameters.

Considering the value of the final term in the left of equation (9) is little or nothing than other terms, and neglecting it, we have

$$a_3c_2q_{10} - a_4(c_1+c_2)q_{10}^2 + k_yc_1c_2y_0 = 0 \qquad (10)$$

Equation (10) is parameters relation formula of the relief valve which the steady state pressure override is zero. formula (10) explains that main parameters, which determent the different pressure-flowrate performances of the relief valve with G-π bridge pilot circuit, are diameters of hydraulic resistance r_1, r_2, pilot valve spring K_y and area a_3 and area a_4. Experiment results showed in fig.4. Different pressure-flowrate performance curves can be gained by only changing the diameter of hydraulic resistance r_2.

DYNAMIC CHARACTERISTIC OF G-π BRIDGE RELIEF VALVE

Construction of G-π bridge relief valve is showed in fig.1. Flow continuity equation of all volume and motion equation of the valve, dynamic mathematics model of the relief valves are as follows:

$$\frac{dp_1}{dt} = \frac{\beta}{v_1}(q - q_1 - q_4 - a_1\dot{x}) \qquad (11)$$

$$\frac{dp_2}{dt} = \frac{b}{v_2}(q_1 - a_3\dot{y} - q_2) \qquad (12)$$

$$\frac{dp_3}{dt} = \frac{b}{v_3}(q_2 - q_3 + a_4\dot{y}) \qquad (13)$$

$$m_1\frac{d^2x}{dt^2} + f_1\frac{dx}{dt} + k_xx = p_1a_1 - p_4a_2 - F_1 \qquad (14)$$

$$m_2\frac{d^2y}{dt^2} + f_2\frac{dy}{dt} + k_yy = p_2a_3 - p_3a_4 - F_2 \qquad (15)$$

According to above mathematical model, dynamic characteristic of the G-π relief valve may be simulated, simulation result of dynamic characteristic for G-□ relief valve is shown in fig.5. Experiment result of the relief valve is shown in fig.6. The parameters of the relief valve in fig.5 and fig.6 are the same.

CONCLUSION

(1) Proposed the new construction of relief valve with G-□ bridge pilot hydraulic resistance network, there is a guiding cylinder on the pilot poppet set, thus the pilot poppet has small radial vibrating and its stabilization is good.
(2) Simulation of the stable and dynamic characteristic are finished for the relief valve with G-□ bridge pilot hydraulic resistance network. The result of simulation is in good agreement with experiment.
(3) The formula is deduced with determine parameters of the relief valve for different pressure-flow characteristic. It is theoretical computation criterion for designing relief valve with different pressure flow characteristic.
(4) Changing parameters of G-□ bridge pilot hydraulic resistance network, the relief valve may present three kinds of performances. i.e. inlet pressure of the relief valve increases, keeps constant and decreases when the overflow increases.

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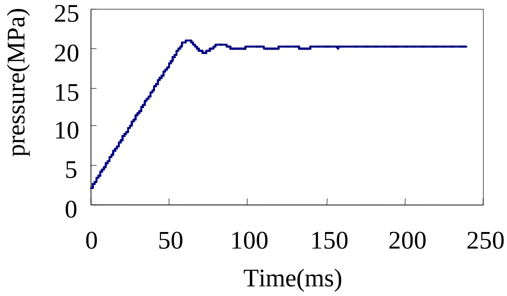

Fig.5 simulation curve of dynamic performance

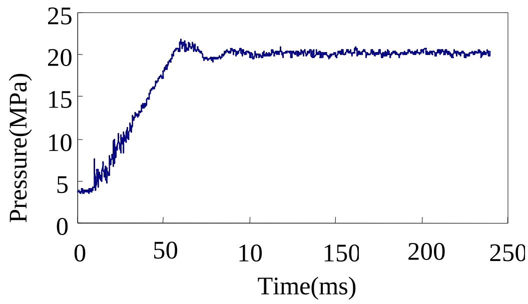

Fig.6 experiment curve of dynamic performance