THEORY AND APPLICATION OF π BRIDGE HYDRAULIC RESISTANCE NETWORKS①

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ABSTRACT Pressure flow properties of seven basic π bridge hydraulic resistance networks are studied and the pressure flow characteristic curves are obtained by simulation, while the pressure gain and flow gain of π bridge are deduced. Half bridge hydraulic resistance is only a special case of π bridge network. The pressure control valve with the π bridge pilot control circuit has some pressure flow properties that the valve with half bridge pilot control circuit dosen't have. For example, with the increasing of the overflow, the relief valve presents three kinds of performances, i.e. the control pressure increases, keeps constant and drops when the hydraulic resistance parameters in π bridge pilot circuit changes.

Key words hydraulic resistance network theory application

1 INTRODUCTION

There are two kinds of hydraulic networks, i.e. 4-arms bridge hydraulic resistance network and half bridge hydraulic resistance network, which are widely used in hydraulic control valves. Half bridge resistance network is usually used in the pilot control circuits of the valves, while 4-arms bridge resistance network is usually used in the 4-ways spool valves for servo control and proportional control valves.

The properties of 4-arms bridge and half bridge networks have been studied systematically[1-3]. But 4-arms bridge and half bridge hydraulic resistance network can not be used to solve some technology problems because of their limitations. For example, pilot relief valves always exists steady-state pressure override, i.e. when the overflow increases, the steady-state control pressure increase slightly. Although pressure override can be reduced nearly to zero by many special technical means, but the steady-state pressure can't decrease up to now when the overflow of the valve increases[4-6]. If the half bridge pilot circuit of the relief valve is replaced by the network with three hydraulic resistances, theory analysis and experiment results show that the relief valve can not only keep the override zero easily but also make the pressure reduce when the overflow of the valve increases[7]. Systematic studying of the three hydraulic resistance networks lays theoretical foundation for developing new property valves.

This paper studies systematically the properties of three hydraulic resistance network (call π bridge hydraulic resistance network), and shows the experiment results of the relief valve with π bridge pilot control circuit as the application example of π bridge network.

2 CLASSIFICATION OF π BRIDGE NETWORK

π bridge hydraulic resistance networks consist of three hydraulic resistance R_1, R_2, R_3 as shown in Fig.1. They are classified as 7 types in terms of variable or fixed R_1, R_2, R_3, and defined as A, B, C, D, E, F, G.

① Project supported by the Open Fund of the State Key Laboratory of Fluid Power Transmission and Control of Zhejiang University
Received May 4, 1998; accepted Oct. 26, 1998

The control principle of basic π bridge networks for all types is shown in Fig.1. Hollow arrow represents hydraulic resistance value reducing, while solid arrow represents resistance value increasing when the displacement y of the valve spool increases. p_1, q_{v1} are the input parameters; p_2, q_{va} are the output parameters of outlet port A (left outlet port), and p_3, q_{vb} are the output parameters of outlet port B (right outlet port). The flow through resistance R_1, R_2 and R_3 are q_{v1}, q_{v2} and q_{v3} sequentially.

3 PROPERTIES STUDY OF BASIC π BRIDGE NETWORKS

The hydraulic resistance networks in Fig.1 are basic π bridge control networks, in which the cylinder controlled is double-rod-end cylinder. Assuming no leakage and fluid to be incompressible, the steady-state flowrate q_{va} to the cylinder on port A must equal to steady-state flowrate q_{vb} from the cylinder on port B. Therefore, for these basic π bridge network, following equations exist:

$$q_{v1} = q_{v3} \tag{1}$$

$$q_{va} = q_{v1} - q_{v2} \tag{2}$$

$$q_{vb} = q_{v3} - q_{v2} \tag{3}$$

The flow equations of the hydraulic resistance R_1, R_2, R_3 for type A are

$$q_{v1} = (y_0 + y)\, b_1 \sqrt{p_1 - p_2} \tag{4}$$

$$q_{v2} = (y_0 - y)\, b_2 \sqrt{p_2 - p_3} \tag{5}$$

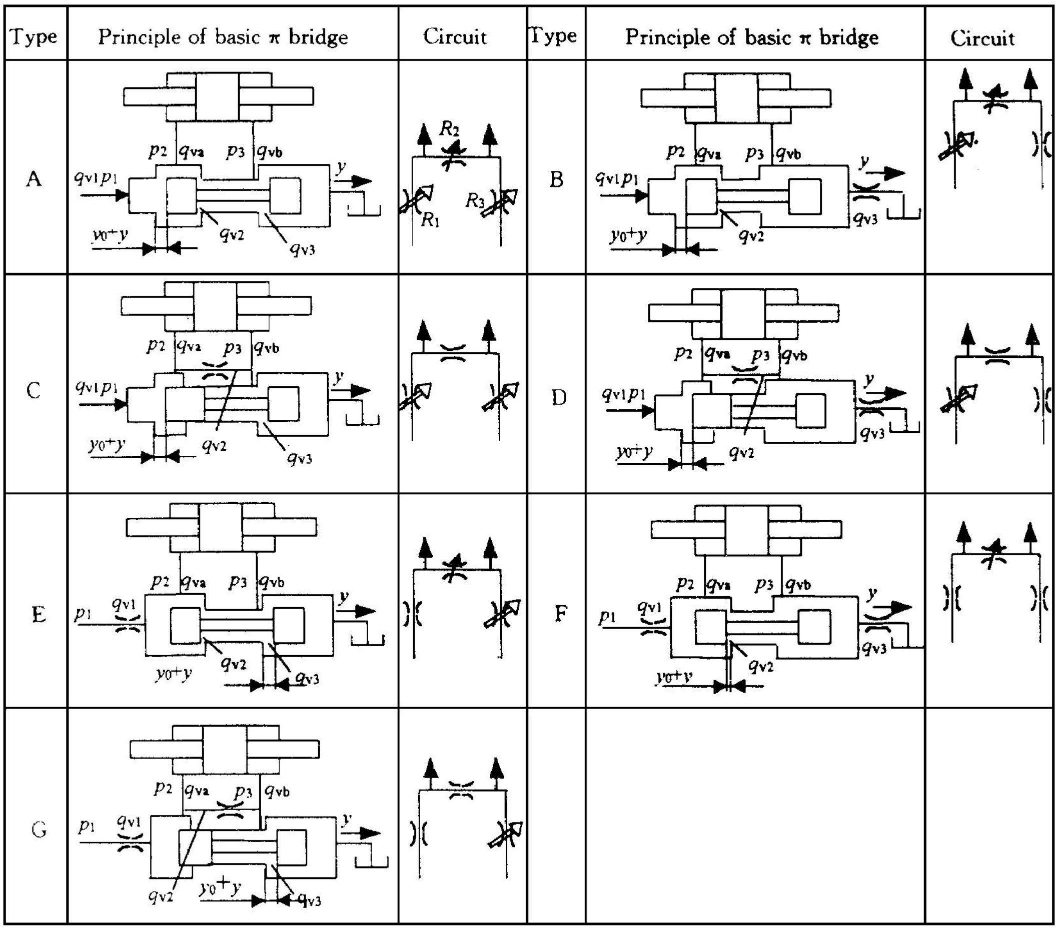

Fig.1 Principle of π bridge hydraulic resistance networks

$$q_{v3} = (y_0 + y) b_3 \sqrt{p_3} \quad (6)$$

where $b_1 = \alpha_1 w_1 \sqrt{2/\rho}$, α_1 is the orifice coefficient of R_1, ρ is fluid mass density, w_1 is circumference of R_1; $b_2 = \alpha_2 w_2 \sqrt{2/\rho}$, α_2 is the orifice coefficient of R_2, w_2 is circumference of R_2; $b_3 = \alpha_3 w_3 \sqrt{2/\rho}$, α_3 is the orifice coefficient of R_3, w_3 is circumference of R_3; y is valve spool displacement; y_0 is pre-opening of hydraulic resistance.

For basic π bridge networks, assume $b_1 = b_2 = b_3 = b$.

Solve Eqns.(1) ~ (6), get the flow equation of outlet control ports A and B

$$q_{va} = (y_0 + y) b \sqrt{p_1 - p_2} - (y_0 - y) b \sqrt{2 p_2 - p_1} \quad (7)$$

$$q_{vb} = (y_0 + y) b \sqrt{p_3} - (y_0 - y) b \sqrt{p_1 - 2 p_3} \quad (8)$$

The possible maximum flow for all types is

$$q_{v\max} = y_0 b \sqrt{p_1} \quad (9)$$

Dividing Eqns.(7) and (8) by (9), the dimensionless flow equations of type A is obtained, set $y_1 = y/y_0$, then

$$q_{va}/q_{v\max} = (1 + y_1)\sqrt{1 - p_2/p_1} - (1 - y_1)\sqrt{2 p_2/p_1 - 1} \quad (10)$$

$$q_{vb}/q_{v\max} = (1 + y_1)\sqrt{p_3/p_1} - (1 - y_1)\sqrt{1 - 2 p_3/p_1} \quad (11)$$

The dimensionless flow equations of other types can be obtained by the above method. The dimensionless characteristic curves of the basic π bridge networks are obtained by emulating, Fig. 2 shows all dimensionless characteristic curves of π bridge networks outlet ports A and B.

The main characteristic parameters of π bridge networks are pressure gain and flow gain. The pressure gain and flow gain for outlet ports A and B of type A are as follows:

Pressure gain: $k_{pa} = \partial p_2/\partial y = 4 p_1/9 y_0$,
$k_{pb} = \partial p_3/\partial y = -4 p_1/9 y_0$

Flow gain: $k_{qa} = \partial q_{va}/\partial y = 2 b \sqrt{p_1/3}$,
$k_{qb} = \partial q_{va}/\partial y = 2 b \sqrt{p_1/3}$

The characteristic parameters of type B, C, D, E, F, G can be obtained by the same method. All the characteristic parameters are shown in Table 1.

For usual π bridge control network, the force on the piston of the cylinder controlled is described by Eqn.(12).

$$F = p_2 A_1 \pm p_3 A_2 \quad (12)$$

Assume $A_1 = A_2 = 1$, The force gain is

$$\partial F/\partial y = \partial p_2/\partial y \pm \partial p_3/\partial y \quad (13)$$

where A_1 —the effective area of the piston on outlet port A. A_2 —the effective area of the piston on outlet port B.

In terms of above analysis, the properties of basic bridge control network are concluded as follows:

(1) π bridge control network has 14 control forms, while half bridge control network has only 3 forms.

(2) The average value of force gain for π bridge control network (take $\partial F/\partial y = \partial p_2/\partial y + \partial p_3/\partial y$) is approximately equal to the pressure gain of half bridge. For example, the force gain of A type π bridge is $8 p_1/9 y_0$, while the pressure gain of A type half bridge is p_1/y_0. The force gains of B ~ G type π bridges are $6 p_1/9 y_0$ or $4 p_1/9 y_0$, while the pressure gains of B and C type half bridges are $p_1/2 y_0$.

(3) The three hydraulic resistances are series in π bridge, usually the pressure drop in π bridge is greater than those in 4-arms bridge and half bridge. Therefore, it had better take π bridge control network in pilot control circuit.

(4) Basic A, C, and F type π bridges are symmetrical network. The values of pressure and flow gains of outlet ports A and B are the same, but the pressure gains have opposite signs, while the characteristic curves are image curves. Basic B, D, E, G type π bridges are asymmetrical networks, the pressure and flow gains of two outlet ports are different.

4 APPLICATION OF π BRIDGE HYDRAULIC RESISTANCE NETWORK

Let the hydraulic resistance value of R_3 in π bridge network be zero, then the π bridge network will become half bridge network. Therefore, half bridge network is a special kind of π bridge network. Usually, the π bridge network

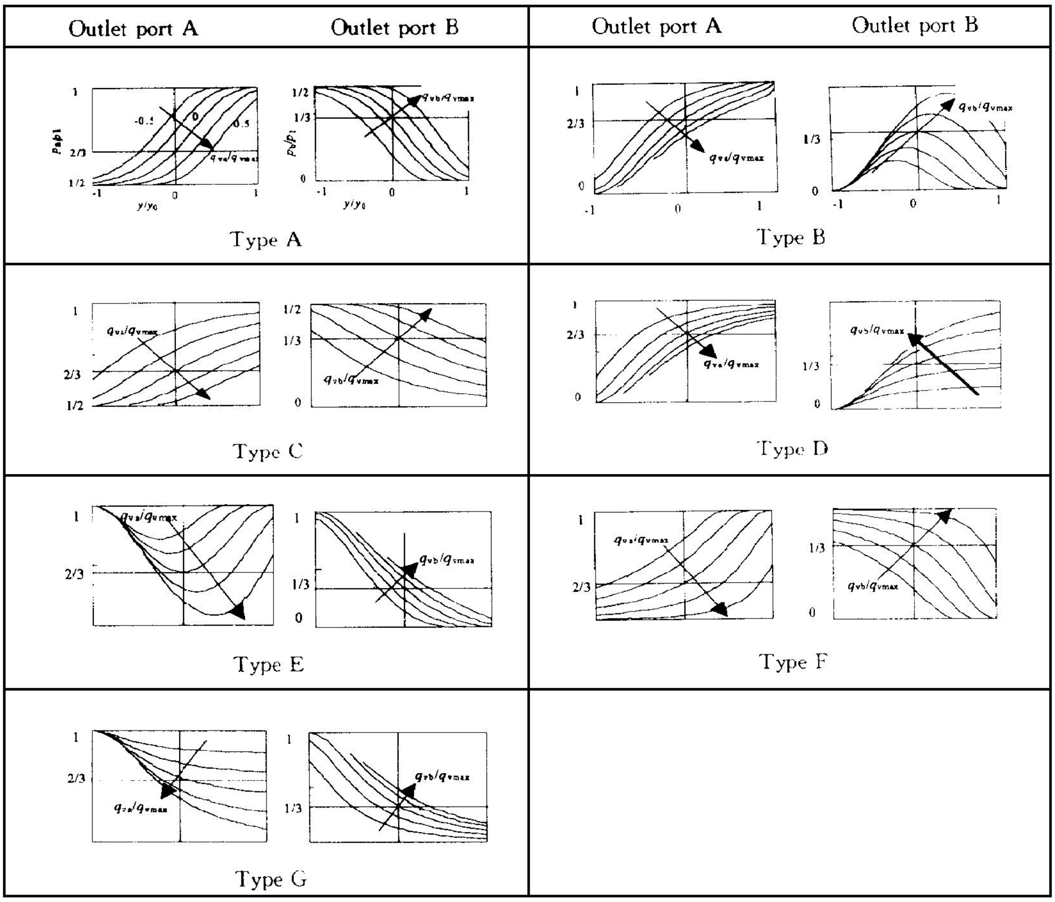

Fig .2 Dimensionless characteristic curves of π bridge networks

Table 1 Pressure gain and flow gain of basic π bridge

Pressure gain	Flow gain	A	B	C	D	E	F	G
Outlet port A		$4p_1/9y_0$	$6p_1/9y_0$	$2p_1/9y_0$	$4p_1/qy_0$	0	$2p_1/9y_0$	$-2p_1/9y_0$
Outlet port B		$-4p_1/9y_0$	0	$-2p_1/9y_0$	$2p_1/9y_0$	$-6p_1/9y_0$	$-2p_1/9y_0$	$-4p_1/9y_0$
	Outlet port A	$2b\sqrt{p_1/3}$	$3b\sqrt{p_1/3}$	$b\sqrt{p_1/3}$	$2b\sqrt{p_1/3}$	0	$b\sqrt{p_1/3}$	$-b\sqrt{p_1/3}$
	Outlet port B	$2b\sqrt{p_1/3}$	0	$b\sqrt{p_1/3}$	$-b\sqrt{p_1/3}$	$3b\sqrt{p_1/3}$	$b\sqrt{p_1/3}$	$2b\sqrt{p_1/3}$

can be used where half bridge is used.

As an application example of π bridge network, in this paper the characteristic performances of relief valve with π bridge pilot control circuit was studied.

4.1 Principle of relief valve with π bridge pilot control circuit

The principle of the relief valve with π bridge pilot control circuit is shown in Fig.3. The pilot circuit consists of three hydraulic resistances R_1, R_2, R_3, which form F type π bridge network. R_1 is a fixed resistance, R_2 is a variable resistance on the pilot cone valve edge, R_3 is a fixed resistance of an orifice on the piston of pilot cone.

4.2 Experiment of relief valve with π bridge pilot circuit

The parameters of the experimental relief valve are as follows[8]: nominal size 10 mm, the diameter of orifice R_1, $d_{R_1} = 0.6$ mm; the orifice R_3 have 3 kinds, their diameters are $d_{R_3} =$ 1.0 mm, 1.1 mm and 1.3 mm respectively. Fig.4 shows the steady-state experimental results of the relief valve.

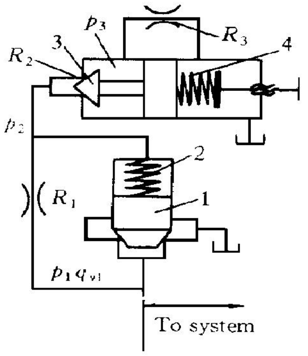

Fig.3 Relief valve with π bridge
1 — Main puppet; 2 — Main valve spring;
3 —Pilot puppet; 4 —Pilot valve spring

In Fig.4, all constructional parameters of the experimental valve are of the same except d_{R_3}. The pressure flow experimental curves of the valve present three types in terms of the value of d_{R_3}: (1) $d_{R_3} = 1.0$ mm, the pressure reduces with increasing of overflow in curve 1; (2) $d_{R_3} = 1.1$ mm, the pressure basically keeps constant, it does not change with increasing or reducing of overflow in curve 2; (3) $d_{R_3} = 1.3$ mm, the pressure increases with increasing of overflow in curve 3. From experimental results in Fig. 4, it is easy to gain pressure flow curve

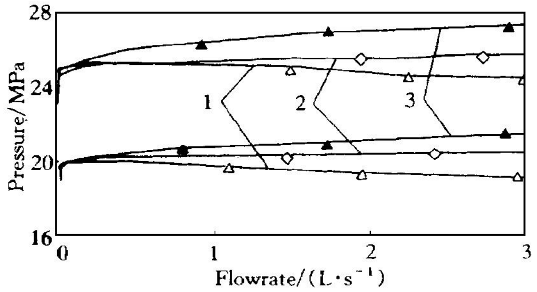

Fig.4 The pressure flow experimental curves of the relief valve
△ — $d_{R_3} = 1$ mm; ◇ — d_{R_3} —1.1 mm;
▲ — $d_{R_3} = 1.3$ mm

with zero override by selecting suitable value of d_{R_3}. Only the relief valve with π bridge pilot network has the first kind of performance, i.e. the control pressure reduces with increasing of overflow.

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(Edited by He Xuefeng)