Linear Model of the Jet-type Hydraulic Amplifier Based on Hydraulic Resistance Network

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Keywords: Jet-type hydraulic amplifier; hydraulic resistance network; flow continuity equation; pressure characteristic; flow characteristic.

Abstract. As the core element of jet-type servovalve, the linear model of jet-type hydraulic amplifier (JTHA) is important for analyzing and controlling the jet-type servovalve. Based on the function between flow area and the jet nozzle's displacement, the linear model of JTHA is derived from hydraulic bridge's flow balance equation, then the pressure characteristic equation and flow characteristic equation are given. At last, the effect of the distance of two receivers and the area ratio on pressure and flow rate are given.

Introduction

The jet-type servovalve has strong anti-pollution capacity, high reliability, long service life and other advantages, it is widely used in flight control system and fuel control system in the aerospace field [1-5]. As the core element of jet-type servovalve, the linear model of jet-type hydraulic amplifier (JTHA) is important for analyzing and controlling the jet-type servovalve. In the dynamic performance analysis and control, the model of JTHA is needed to be linearized. This paper will introduce a linearization method of the JTHA model based on full-bridge hydraulic resistor network, this linear model can be applied to analysis and control of jet-type servovalves.

Operating principle of JTHA

Fig.1 shows the operating principle of JTHA, the jet nozzle divides the two receiver holes into four adjustable orifices. ***e*** is the distance between left and right receiver holes; ***y*** is the displacement of jet nozzle. When the jet nozzle is in the middle position between two receiver holes, due to A_1=A_2, the kinetic energy in receiver holes is equal; when the jet nozzle moves a displacement, the flow area $A_1 \neq A_2$, the kinetic energy received by receiver holes are no longer equal, one increases and the other decreases, therefore the receiver holes have differential pressure driving the spool move.

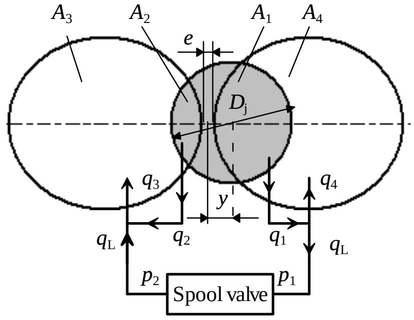


*Fig. 1 O*perating *principle of JTHA*

Model of JTHA

Flow area's model of adjustable orifices. Fig.1 shows the JTHA is the symmetry. If the friendships between flow areas and the displacement are linear, flow areas can be defined as

$$A_1(y) = A_1(0) + b\,y \qquad (1)$$

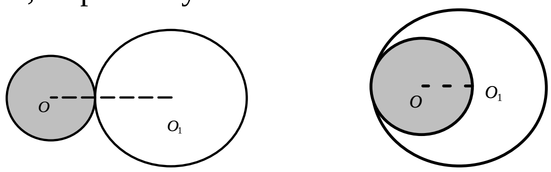
$$A_2(y) = A_1(0) - b\, y \quad (2)$$

$$A_3(y) = \pi R_r^2 - A_1(0) + b\, y \quad (3)$$

$$A_4(y) = \pi R_r^2 - A_1(0) - b\, y \quad (4)$$

Where β is area gradient near y=0.

Fig.2 shows the flow area when the projection receiver hole and the jet nozzle on the receiving plane are inscribed and circumscribed, respectively.



(a) *circumscribed* （b） *inscribed*

Fig.2 Flow areas under inscribed and circumscribed

As shown in Fig.2(a),when the jet nozzle circumscribes receiver hole, the displacement of the jet nozzle is

$$y = 0.5e + R_r / \cos q_r - (R_r / \cos q_r + R_j) = 0.5e - R_j \quad (5)$$

The flow area is

$$A_1(y)\big|_{y=0.5e-R_j} = A_1(0) + b_1(0.5e - R_j) = 0 \quad (6)$$

Where, R_r is the radius of the receive holes; R_j is the radius of the jet nozzle.

As shown in Fig.2(b), When the jet nozzle inscribes receiver hole, the displacement of the jet nozzle is

$$y = 0.5e + R_r / \cos q_r - (R_r / \cos q_r - R_j) = 0.5e + R_j \quad (7)$$

The flow area is

$$A_1(y)\big|_{y=R_j+0.5e} = A_1(0) + b_1(R_j + 0.5e) = \pi R_j^2 \quad (8)$$

Solving Eq. (6) and (8) can be got

$$A_1(0) = \frac{\pi}{2} R_j (R_j - 0.5e)\,,\ b = \frac{\pi}{2} R_j \quad (9)$$

Substituting Eq.(9) into (1)~(4) , the linear model can be written as

$$A_1(y) = \frac{\pi}{2} R_j (R_j - 0.5e + y) \quad (10)$$

$$A_2(y) = \frac{\pi}{2} R_j (R_j - 0.5e - y) \quad (11)$$

$$A_3(y) = \pi R_r^2 + \frac{\pi}{2} R_j (0.5e - R_j + y) \quad (13)$$

$$A_4(y) = \pi R_r^2 + \frac{\pi}{2} R_j (0.5e - R_j - y) \quad (14)$$

Pressure-flow model. From the above analysis, the output of JTHA can be equivalent to the full-bridge hydraulic resistor network shown in Fig. 3.

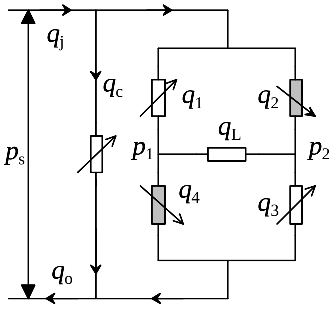


Fig.3 *Full-bridge Circuit of JTHA*

From Fig. 4 and the flow equation of continuity, the following relations can be derived

$$q_L = q_1 - q_4 = C_d A_1 \sqrt{\frac{2}{r}(p_s - p_1)} - C_d A_4 \sqrt{\frac{2}{r} p_1} \tag{15}$$

$$p_L = p_1 - p_2 \tag{16}$$

$$q_L = q_3 - q_2 = C_d A_3 \sqrt{\frac{2}{r} p_2} - C_d A_2 \sqrt{\frac{2}{r}(p_s - p_2)} \tag{17}$$

where, C_d is flow coefficient; ρ is oil density; p_s is oil pressure, p_1 and p_2 are the pressure values of left and right receiver holes, respectively.

Pressure characteristics. The pressure characteristics of JTHA are often derived from the load flow of zero, and are expressed by the relation curve between the output pressure and the jet nozzle displacement.

Substituting q_L = 0 into Eqs.(15)~(16), the pressure characteristics can be derived as

$$p_L(y) = \left(\frac{A_1^2(y)}{A_1^2(y) + A_4^2(y)} - \frac{A_2^2(y)}{A_2^2(y) + A_3^2(y)} \right) p_s \tag{18}$$

Near y=0, linear pressure characteristics can be written as

$$p_L = K_{p0} y = \frac{\partial p_L}{\partial y} y = \frac{k_{rj}}{1 + (2k_{rj} - 1)^2} \frac{2k_{rj} - 1}{(k_{rj} - 1)^2 + k_{rj}^2} \frac{4 p_s}{R_j} y \tag{19}$$

where

$$k_{rj} = \frac{A_r}{A_j} = \frac{R_r^2}{R_j^2} \tag{20}$$

Flow characteristics. Flow characteristics are generally described by the relation between the load flow and the jet nozzle displacement when the loading pressure is zero. That is to analyze, when p_L=0, the relation between the output flow q_L and the displacement y.

If $p_1 = p_2$, flow characteristics equation can be derived from equations (15) to (16) as

$$q_L = \frac{\frac{\sqrt{2}}{2} k_{rj} \frac{A_1 - A_2}{A_j} q_j}{\sqrt{\left(k_{rj} - \frac{A_1}{A_j}\right)^2 + \left(k_{rj} - \frac{A_2}{A_j}\right)^2 + 2\frac{A_1 \cdot A_2}{A_j^2}}} = \frac{\frac{\sqrt{2}}{2} k_{rj} \frac{A_1 - A_2}{A_j} C_{dj} \sqrt{\frac{2}{r} p_s}}{\sqrt{\left(k_{rj} - \frac{A_1}{A_j}\right)^2 + \left(k_{rj} - \frac{A_2}{A_j}\right)^2 + 2\frac{A_1 \cdot A_2}{A_j^2}}} \tag{21}$$

where C_{dj} is the flow coefficient of jet nozzle, which chooses 0.91.

Near y=0, linear flow characteristics can be written as

$$q_L = K_{q0} y = \frac{\partial q_L}{\partial y} y = k_{rj} \pi R_j C_d \sqrt{\frac{2}{r} \frac{p_s}{1 + (2k_{rj} - 1)^2}} y \tag{22}$$

Simulation

Based on Eqs. (19), (22) and Table 1, the linear pressure characteristics and flow characteristics curves can be plotted as Fig.4 and Fig.5.

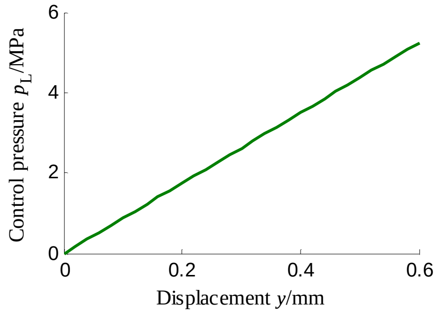


Fig. 4 *Curves of pressure characteristics*

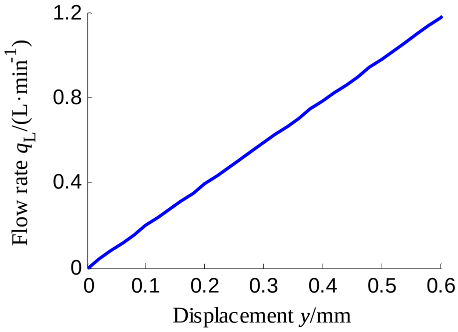


Fig. 5 *Curves of flow characteristics*

Table 1 Parameters' value of JTHA

Parameters	Symbol	value
Supply pressure	p_s	0.6MPa
Nozzle diameter	D_j	1.2mm
Receiver hole diameter	D_r	1.5mm

Conclusions

The JTHA can be equivalent to full-bridge hydraulic resistor network madding up of four adjustable orifices. When the jet nozzle and receiving hole are concentric, the control pressure and flow of JTHA reaches the maximum value.

Acknowledgments

This work was supported by the National Natural Science Foundation of China (51605145) and the Science Foundation of Henan University of Science and Technology (2015QN013).

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