Stability Analysis of Flow Control Valve

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Abstract. The speed regulating valve is used to control the motion speed of the executive components of the hydraulic system by regulating flow rate for accomplishing the uniform and stable motion. The valve is a combined flow valve by two valves in series, one is a constant differential pressure reducing valve, and the other is a throttle valve. The pressure reducing valve automatically compensates the influence of load, and the pressure is always kept constant. However, it does not change and eliminates the influence of load change on flow, but this flow stability range of the flow control valve is limited, that is, there is a limit to pressure change on the inlet and outlet. This paper introduces the structure principle and flow stability analysis of the flow control valve.

Keywords: Speed Governor Valve, Bleed-off System, Flux Stability

1. Introduction

The speed regulating valve is a combined flow valve by two valves in series, one is a constant differential pressure reducing valve, and the other is a throttle valve [1]. The throttle valve is used to adjust the flow rate through the speed regulating valve, while the other valve automatically compensates for the impact of load changes on the flow rate, and always keeps the pressure constant, so that the influence of the change of the load $F_1$ on the flow is eliminated, and the movement speed of the actuator remains uniform and stable. However, the speed stability range of the speed regulating valve is limited, that is, there is a limit to the adjustment of the inlet and outlet pressure changes, otherwise it will not work properly [3].

2. Structure of Speed Control Valve

Structure and graphic symbols of the speed control valve is shown in figure 1. 1 is a fixed differential pressure reducing valve, 2 is a throttle valve, the speed control valve is composed of two in series [3]. The inlet pressure of the speed regulating valve is $p_1$, which is adjusted by the relief valve 4 at the
pump outlet, which is basically kept constant. The pressure oil enters the speed regulating valve, after the application of pressure reducing valve 1, the pressure decreases to \( p_1 \); under the action of throttle valve 2, \( p_2 \) drops to \( p_3 \), and flows into the hydraulic cylinder 3. The size of \( p_3 \) is determined by the back pressure and the load \( F_L \). Oil with pressure \( p_2 \) flows into the large-end annular cavity c and the small-end bottom oil cavity e through the holes d and f. The oil with pressure of \( p_3 \) flows into the spring cavity b at the big end of the pressure reducing valve core through hole a after throttling [4].

In steady state operation, if the spool's dead weight, friction and hydraulic power are not taken into account, the force balance equation [5] is \( p_2 A = p_3 A + F_1 \) and \( \Delta p = p_2 - p_3 = \frac{F_1}{A} \). Where: \( A \) — the area of the large end of the pressure reducing valve core; \( F_1 \) — the springforce. Since the spring has a small stiffness and a small amount of movement of the spool during operation, the change in the spring force \( F_1 \) is also small. The \( \Delta p \) therefore is essentially regarded as a constant [6]. This makes the flow of the speed control valve only change with the openness of the throttle, and has nothing to do with the load.

![Fig. 1. Principles of speed control valve](image)

When the inlet and outlet pressures \( p_1 \) and \( p_3 \) of the speed regulating valve are affected by the load, it will cause the pressure reducing valve core to move up and down, thereby changing the opening of the port. When the opening changes, \( p_2 \) changes the same, so that \( \Delta p \) is regarded as a constant [7]. This valve plays a role of automatic pressure compensation.

3. Governing Valve Flow Characteristic Equation

There are two aspects of the static characteristics of the speed regulating flow valve, the first is the flow stability range, and the second is relationship between the flow and the outlet and inlet pressure difference within this range. It can be seen from the working characteristics of the valve, \( Q_i \) is the flow through port of differential the fixed pressure reducing valve:

\[
Q_i = C_1 A_i \sqrt{\frac{2}{\rho} (p_1 - p_2)}
\] (1)

Where: \( C_1 \) — fixed pressure reducing valve flow coefficient; \( A_i \) — fixed pressure reducing valve flow area; \( p_1 \) — fixed pressure reducing valve inlet pressure; \( p_2 \) — fixed pressure reducing valve outlet pressure. Flow \( Q_2 \) through throttle valve:

\[
Q_2 = C_2 A_2 \sqrt{\frac{2}{\rho} (p_2 - p_3)}
\] (2)

Where: \( C_2 \) — flow coefficient of throttle valve port; \( A_2 \) — flow area of throttle valve port; \( p_3 \) —
— throttle valve outlet pressure. Because the flow is continuous\(^8\), excluding leakage, there are:

\[
Q_1 = Q_2 = Q
\]  

(3)

The force balance equation is:

\[
p_2A = p_3A + K(X_0 + \delta - X) - F_s
\]  

(4)

Where: \(A\) — the effective area of oil pressure of valve core; \(K\) — reduced spring stiffness; \(X_0\) — reduced valve spring pre-compression; \(\delta\) — the opening length; \(X\) — working opening length of valve; \(F_s\) — hydraulic force of liquid flowing through valve port\(^9\).

\[
F_s = \rho \frac{Q_2}{C_1A_1} \cos \alpha \quad \text{where: } \alpha \text{ — direction angle when the fluid flows into the pressure reducing valve port}\(^{10}\).
\]

Put \(Q_2 = C_2A_2 \sqrt{\frac{2}{\rho}} (p_2 - p_3)\) into the above formula:

\[
F_s = \rho \frac{2(C_2A_2)^2}{C_1A_1}(p_2 - p_3) \cos \alpha
\]  

(5)

Put formula (5) into formula (4) and sort it out:

\[
p_2 - p_3 = \frac{K(X_0 + \delta - X)}{A + \frac{2(C_2A_2)^2}{C_1A_1} \cos \alpha}
\]

\[
= \frac{K(X_0 + \delta)}{A} \left[ \frac{1 - \frac{X}{X_0 + \delta}}{1 + \frac{2(C_2A_2)^2}{C_1A_1A} \cos \alpha} \right]
\]  

(6)

The expression of the flow rate \(Q\) flowing through the speed regulating valve is:

\[
Q_2 = C_2A_2 \sqrt{\frac{2}{\rho}} (p_2 - p_3)
\]

\[
= C_2A_2 \sqrt{\frac{2}{\rho}} \frac{K(X_0 + \delta)}{A} \left[ \frac{1 - \frac{X}{X_0 + \delta}}{1 + \frac{2(C_2A_2)^2}{C_1A_1A} \cos \alpha} \right]
\]  

(7)

4. Analysis of the Stability of the Flow Rate of the Speed Regulating Valve

From the analysis of equation (7), it can be seen that the improvement of the flow rate stability of the governor valve mainly depends on the following three factors:

(1) Flow coefficient \(C\) of throttle valve port. The magnitude of the flow coefficient is related to the Reynolds number \(Re\). When \(Re\) reaches or exceeds a certain value, the flow coefficient is constant.

(2) Throttle valve orifice flow area (throttle opening area). After the throttle is adjusted, the opening area \(A_2\) is theoretically unchanged. However, when the length of the opening is very small, the area of
the opening will change due to the accumulation of dirt and polarized molecules. In order to prevent the above phenomenon, the orifice should be smooth, the material should be demagnetized, the structure should use thin blades, the hydraulic radius should be increased as much as possible, and the wet circumference length should be reduced. Generally, round and square holes are suitable. Avoid slot and triangular grooves.

\( (3) \Delta p = p_2 - p_3 \). From equation (6), it can be seen that after the structural form, geometric size, and spring parameters are determined, \( \Delta p \) before and after the throttle is stable and constant under certain conditions of the throttle opening. Whether the working opening length \( X \) is stable or not. The amount of change in \( X \) affects the value of \( \Delta p \) by changing the spring force \( F_i = K(X_0 + \delta - X) \) on the one hand, and on the other hand by changing the size of the hydraulic force \( F_s \) at the valve port to influence the value of \( \Delta p \) (the latter influence can partially compensate the former influence). The working opening length \( X \) of the pressure reducing valve is changed. Therefore, it is impossible to completely eliminate the influence of the working opening length \( X \) on \( \Delta p \), and only appropriate measures can be taken to minimize its influence.

When \( \frac{X}{X_0 + \delta} \ll 1 \), the effect of \( X \) on the spring force \( F_i \) can be reduced. There are three specific methods:

First, reduce the spring stiffness \( K \), increase this spring precompression amount by \( X_0 \) appropriately.

Second, increase the pre-opening length \( \delta \), but the value should not be too large, otherwise the starting time of the valve into operation will be prolonged, which will cause a “jump” of flow.

Third, appropriately reduce the working opening length \( X \) of the fixed differential pressure reducing valve. Due to the decrease, \( X \) means that the slope of the valve flow area \( A_2 \) to \( X \) increases when working in the same flow rate range. Therefore, if the opening is too small at low flow rates, clogging tends to occur, and the spool will not be stable. This should be carefully considered.

Structural measures are taken to reduce the change in hydraulic force \( F_s \). There are three specific approaches:

First, appropriately increase the effective area \( A \), so that when the range of the hydrodynamic \( F_s \) changes is the same, the effect on the pressure difference \( (\Delta p = p_2 - p_3) \) before and after the throttle valve is minor.

Second, take \( A_1 \gg A_2 \), which can reduce the proportion of hydrodynamic force. However, since \( A_1 \) changes frequently during work, the conditions of this inequality are not easy to guarantee.

Thirdly, it is effective to reduce the influence of hydrodynamic \( F_s \) on \( (\Delta p = p_2 - p_3) \) by making the middle part of the spool into a tapered structure.

In fact, the friction between the valve body and the valve body also has a certain effect on the pressure difference \( (\Delta p = p_2 - p_3) \) before and after the throttle. Since this kind of influence exists, the machining accuracy of the part should be improved, and a pressure equalizing groove should be opened in the valve core to reduce the hydraulic radial force.

5 Conclusion

From the above discussion, the following conclusions can be drawn: ① Due to the automatic regulation of the pressure reducing valve, the constant differential pressure reducing valve does not
work when the reverse flow occurs.;② Fixed differential pressure reducing valve in the speed regulating valve does not control front-to-back pressure difference of itself.③ The constant differential pressure reducing valve in the speed regulating valve is connected in series with the throttle valve, and the front and rear pressure difference of the throttle valve can be controlled by the pressure reducing valve. ④ The flow stability range in governor valve is limited, that is, there is a limit to the change in the inlet and outlet pressure, otherwise it will not work properly.

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