Design and Simulation of the Key Parameters of Speed Control Valve Based on MATLAB

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Abstract. MATLAB was used to realize the characteristic curve of inlet and outlet pressure difference and flow rate, the characteristic curve of hydraulic force and spring force in speed control valve, and obtain key parameter values. SIMULINK was used to model speed control valve, and the parameter values were substituted into the modeling for simulation verification.

1. Introduction

Speed control valve is an important component in hydraulic system; its dynamic performance plays an important role in the speed stability of the working element in hydraulic circuit. The design process of the speed control valve involved many parameters and the selection of parameter valves had a great impact on the working performance, especially the design of the main parameters is more critical. The main parameters affecting the dynamic performance of the speed control valve were introduced in the literature [1]. A manual method was introduced to obtain the spring stiffness, initial compression amount, maximum/minimum load on the spring, and other main parameters in the literature [2]. In this paper, the main design parameters were obtained through MATLAB, and the parameter values were substituted into the modeling of speed control valve for simulation verification, reduced the design work [3-6].

2. Working Principle of Speed Control Valve

The speed control valve is mainly composed of a throttle valve and a constant differential pressure reducing valve, including valve body, adjustable port, and spring and valve core of reducing valve. Its structure is shown in the Figure 1.

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{figure1.png}
\caption{The working principle of speed control valve}
\end{figure}
The throttle valve of the speed control valve through the flow,

\[ Q = C_{A2} \sqrt{\frac{2}{\rho}} (P_2 - P_1) \]  \hspace{1cm} (1)

When the inlet pressure \( P_1 \) or outlet pressure \( P_2 \) changes, the valve core of speed control valve moves to the left or right. At this point, there will be new changes in spring force and steady-state hydraulic force, and the force balance equation of the valve core at a new balance position was as follows,

\[ P_2 - P_3 = \frac{(F_i \pm \Delta F_i) - (F_{RS} \pm \Delta F_{RS})}{A_i} = \frac{(F_i - F_{RS}) + (\pm \Delta F_i \mp \Delta F_{RS})}{A_i} \] \hspace{1cm} (2)

Trying to make the spring force \( F_i \), steady-state hydraulic force \( F_{RS} \) as close as possible, so that the pressure difference remains unchanged.

3. Design Actual Example

3.1. Characteristic Curve

Give an example, the working pressure of the speed control valve was 15MPa and the working flow speed control valve was 25L/min. The speed control valve inlet and outlet pressure difference and flow rate characteristic curve of MATLAB procedures as follows,

```matlab
posion=1e-6:1e-6:0.5852e-3;
for i=1:size(posion,2)
    x=posion(i);
    Lam1=Cd2*A2*sqrt(2*K*x0/ro/A3);
    Lam2=1/x0;
    Lam3=2*Cd2^2*0.3583679495*A2^2/(A3*Cd1);
    Lam4=ro/(2*Cd2^2*A2^2);
    Lam5=Cd2^2*A2^2/Cd1^2;
    q=Lam1*sqrt((1-Lam2*x)/(1+Lam3/(w1*x)));
    p=Lam4*q^2*(1+Lam5/(w1*x)^2);
    Q(i)=q;
    p1p3(i)=p;
end
[p1p3,sequence]=sort(p1p3);
Q=Q(sequence);
[value,sequence2]=min(abs(p1p3-deltapmin));
[value,sequence3]=min(abs(p1p3-pg));
Qmax=max(Q(sequence2:sequence3));
Qmin=min(Q(sequence2:sequence3));
eta=2*(Qmax-Qmin)/(Qmax+Qmin);
plot(p1p3(1:sequence3),Q(1:sequence3));
xlabel('pressure difference p1-p3(Pa)'),ylabel('flow rate Q(m^3/s)');
fprintf('flow rate variation ratio=%d
',eta);
```

The flow rate variation ratio was 4.3%, and the speed control valve inlet and outlet pressure difference and flow rate characteristic curve was as follows,
The procedure for calculating the spring stiffness and initial compression amount was as follows,

\[ x = 10^{-6} : 10^{-6} : 0.5852 \times 10^{-3} \]

for \( i = 1 : \text{size}(x,2) \)

\[ F_w(i) = \rho_0 Q_g^2 / (C_d l * w_1 * x(i)) \]

\[ F_{\text{min}} = Q_g C_v l * \sqrt{2 \rho_0 (15 \times 10^6 - 0.2 \times 10^6)} * 0.3583679495 \]

\[ [F_{\text{min}}, \text{poi}] = \min (\text{abs}(F_w - F_{\text{min}})) \]

\[ F_y = 0.2 \times 10^6 * A_3 \]

\[ F_t = F_w(\text{poi:end}) + F_y \]

\[ p = \text{polyfit}(x(\text{poi:end}), F_t, 1) \]

\[ K = -p(1) \]

\[ x_t = p(2) / K - 0.5852 \times 10^{-3} \]

\[ \text{line} = K * x(\text{poi:end}) + K * (x_t + 0.5852 \times 10^{-3}) \]

\[ \text{plot}(x(\text{poi:end}), F_t, '-k', x(\text{poi:end}), \text{line}, ':b') \]

\[ \text{xlabel}(\text{displacement of valve core /m}), \text{ylabel}(\text{force/N}), \text{legend}(\text{steady-state hydraulic force + hydraulic force,'spring force'}) \]

The spring stiffness was 16879N/m and initial compression amount was 0.0045m, and characteristic curve of hydraulic force and spring force in speed control valve was as follows,
3.2. Simulation Verification

When inlet pressure or outlet pressure was changed, the dynamic characteristic analysis of speed control valve was mainly to analyze the dynamic balancing process of valve core of reducing valve. When valve core of reducing valve did not reach the new balance position, it was subject to the pressure, spring force and steady-state hydraulic force, and also transient-state hydraulic force and viscous resistance of hydraulic oil.

Steady-state hydraulic force,

\[ F_{Rs} = 2C_{d1}C_w x (P_1 - P_2) \cos \theta \]  

(3)

Transient-state hydraulic force,

\[ F_{Rt} = -LC_{d1}w_1 \sqrt{2\rho (P_1 - P_2)} \frac{dx}{dt} \]  

(4)

Viscous resistance of hydraulic oil,

\[ F_s = B \frac{dx}{dt} \]  

(5)

Spring force,

\[ F_s = K(x_0 - x) \]  

(6)

Stress condition of valve core,

\[ M \frac{d^2x}{dt^2} = K(x_0 - x) + P_1 A_1 - P_2 (A_4 + A_5) - 2C_{d1}C_w x (P_1 - P_2) \cos \theta - LC_{d1}w_1 \sqrt{2\rho (P_1 - P_2)} \frac{dx}{dt} - B \frac{dx}{dt} \]  

(7)

and \( P_2 \) pressure value,

\[ P_2 = \frac{C_d^2 \omega^2 x^2 P_1 + C_d^2 A_1^2 P_3}{C_d^2 \omega^2 x^2 A_1^2 + C_d^2 A_2^2} \]  

(8)

Eq.8 generation into the equation Eq.7, so we had,
The dynamic model of speed control valve was established by SIMULINK, as can be seen from Figure 4. The dynamic model of speed control valve contained fluid pressure, steady-state hydraulic force, transient-state hydraulic force and flux. The previous parameter values were substituted into the model, and the simulation results were shown in the Figure 5.

\[
M \frac{d^2x}{dt^2} = K(x_0 - x) + P_x A_x - \frac{C_x^2 P_x + C_x^2 \omega_x^2 x^2}{C_x^2 A_x^2 + C_x \omega_x^2 x^2} (A_y + A_x) - 2C_d C_l \omega_1 x \frac{C_2^2 A_c^2}{C_2^2 A_c^2 + C_1^2 \omega_1^2 x^2} (P_1 - P_2) \cos \theta
\]  

\[
+ L C_d d \theta + \frac{2P_l^2 A_c^2}{C_1^2 A_c^2 + C_1^2 \omega_1^2 x^2} (P_1 - P_2) \frac{dx}{dt} - B \frac{dx}{dt}
\]  

The dynamic model of speed control valve contained fluid pressure, steady-state hydraulic force, transient-state hydraulic force and flux. The previous parameter values were substituted into the model, and the simulation results were shown in the Figure 5.

**Figure 4.** The dynamic model of speed control valve

**Figure 5.** The displacement curve of pressure reducing valve valve core and flow
According to the simulation results, when the inlet pressure $P_1$ remains unchanged and the outlet pressure $P_3$ rised, the valve core was finally in a new equilibrium position through the servo feedback of the speed control valve itself. During the dynamic change of valve core, the flow rate was basically maintained at 8.2L/min. When the outlet pressure $P_3$ rised suddenly, the flow rate rised after a sudden drop due to hydraulic shock.

4. Conclusions

Through MATLAB programming, it was easy to obtain the characteristic curve of the pressure difference between the inlet and outlet of the speed control valve and the flow rate, flow rate variation ratio was 4.3%. MATLAB was used to realize the characteristic curve of hydraulic force and spring force in speed control valve, and obtain key parameter values, for example the spring stiffness was 16879N/m and initial compression amount was 0.0045m. SIMULINK was used to model speed control valve, and the parameter values were substituted into the modeling for simulation verification. This paper provided a graphical method for designing the structural parameters of the speed regulating valve.

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