

Modeling and Simulation Research of Driving Force Generation Speed Control System

Wei WANG¹, Yu-Heng FAN^{2,a,*}, Jian-Feng WANG³, Chu-Feng RAO⁴ and Ze-Hao PANG⁵

¹Air Force Engineering University, Air Defense and Antimissile Institute, Xi'an China

²Air Force Engineering University, Air Defense and Antimissile Institute, Xi'an China

³Air Force Engineering University, Air Defense and Antimissile Institute, Xi'an China

⁴Air Force Engineering University, Air Defense and Antimissile Institute, Xi'an China

⁵Air Force Engineering University, Air Defense and Antimissile Institute, Xi'an China

^a614110756@qq.com

*Corresponding author

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Abstract.According to the shortage of the power supply mode of equipment vehicle, a driving force generation speed control is set up to achieve vehicle self-generating when it running. System adopts the high efficiency's hydraulic volume speed-modulating circuit. A constant speed control system which composes of variable displacement pump and fixed displacement motor is researched, and the mathematical model of hydraulic system's each link is established. Using the software of Matlab/Simulink emulates the pump controlled motor system's responding situation, and results show that control system has better speed control ability. The influence of the structure parameters of speed control's performance is investigated and the research also provides the effective reference significant for the achievement of vehicle-based generator system.

1 Introduction

With the rapid development of modern science and technology, especially in modern warfare, Traditional power-supply modes, such as parked power generation[1], this model requires vehicles to produce electricity in a quiescent state, thus greatly limiting vehicle flexibility. Therefore, it is necessary to realize self-extracting power generation in the process of driving[2-3]. The power of the engine is converted into the constant-speed input of the generator through the power take-off device to realize stable power generation. In recent years, many scholars at home and abroad have done in-depth research on vehicle power generation speed control system, and achieved some research results[4,5], thus promoting the application of driving force generation technology in equipment vehicles.

Through building the modeling analysis of all aspects of the system, using Matlab's Simulink module to simulate the response of the system, and finally the actual experiments are used to verify the model. In addition, the influence of the structural parameters of the speed control system is simulated and analyzed, which provides an effective reference for the control law of the power system and the future improvement of the system.

2 Establishment and Verification of Hydraulic Speed Regulating System Model

2.1 The Composition of Hydraulic Speed Regulating System

Hydraulic speed control circuit with throttle speed control circuit, volume control circuit and volume throttle circuit[6], and the three speed control methods both have their own advantages and disadvantages. Volume control circuit produces less heat and has high efficiency. In this paper, the hydraulic speed control loop is adopted which uses the variable displacement pump control of the

fixed displacement motor to realize the constant speed output of the generator under the variable speed disturbance and load disturbance.

The speed control system can control the output of the pump by changing the angle of the pump swashplate by changing the proportional solenoid valve's voltage, and then adjusting the motor speed. The speed control system structure as follows:

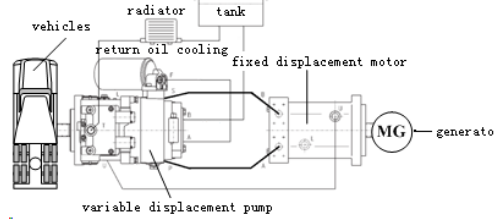


Fig.1 Driving force generation speed control system structure

2.2 Mathematical Model Establishment of Hydraulic Speed Regulating System

1) Variable Adjustment Mechanism Composition and Working Principle

In this paper, the axial piston variable pump is adopted, and its variable adjusting mechanism is integrated in the variable pump. Variables mainly was composed of the electro-hydraulic proportional valve, three four-way valve control hydraulic cylinder, variable swashplate and other parts.

2) Mathematical Model of Current Transfer of Proportional Electromagnet:

$$\frac{I(s)}{U_i(s)} = \frac{1}{Ls + R_e} = \frac{\frac{1}{R_e}}{\frac{s}{\omega_r} + 1} \quad (1)$$

In the formula: $\omega_r = \frac{R_e}{L}$ is the frequency of the electrical inertia link of the proportional solenoid coil, R_e is the internal resistance of the coil

3) The Mathematical Model of the Servo Valve:

$$\frac{x_v(s)}{I(s)} = \frac{K}{\frac{s^2}{\omega_{nv}^2} + \frac{2\xi_v s}{\omega_{nv}} + 1} \quad (2)$$

In the formula: x_v is the spool displacement, $\omega_{nv} = \sqrt{\frac{K_y + K_f + K_{fv}}{m_T + m_v}}$ is the servo valve hydraulic natural frequency, K_y is the sum of displacement force gain and zero spring stiffness, K_f is the spool feedback spring stiffness, K_{fv} is acting on the spool on the steady-state hydraulic dynamic stiffness coefficient, m_T is the quality of the armature assembly, m_v is the spool quality,

$\xi_v = \frac{1}{2} \sqrt{\frac{(B_T + B_v)^2}{(m_T + m_v)(K_y + K_f + K_{fv})}}$ is the servo valve dimensionless damping coefficient, B_T is the armature components of the damping coefficient, B_v is the spool damping coefficient, $K = \frac{K_I}{K_y + K_f + K_{fv}}$ is the gain coefficient of the servo valve

4) Mathematical Model of Valve-controlled Hydraulic Cylinder

The variable displacement mechanism of the variable displacement pump is composed of a three-position four-way valve-controlled symmetrical double-acting hydraulic cylinder position servo mechanism. The transfer function of the piston displacement of the valve cylinder is:

$$\frac{x_p(s)}{x_v(s)} = \frac{\frac{k_q}{A_p}}{s(\frac{s^2}{\omega_h^2} + \frac{2\xi_h}{\omega_h}s + 1)} \quad (3)$$

In the formula: x_p is piston displacement, A_p is the hydraulic cylinder piston effective area, ω_h is the hydraulic cylinder natural frequency, ξ_h is the pump control motor damping coefficient, k_q is the proportion of steady-state operating point flow gain

5) Mathematical Model Establishment of Pump-Motor System

Combined with the study of the speed control system's requirements, the model is simplified. The pump hydraulic motor transfer function is showed as follows :

$$\theta(s) = \frac{\frac{k_{qp}n_p}{D_m} - \frac{C_t}{D_m^2}(1 + \frac{V_0}{\beta_e C_t}s)T_L}{s(\frac{s^2}{\omega_c^2} + \frac{2\xi_c}{\omega_c}s + 1)} \quad (4)$$

In the formula: k_{qp} is variable pump flow gain, n_p is the pump input

speed, D_m is motor displacement, C_t is the pump motor total leakage coefficient, V_0 is the total volume of the pump-controlled motor, T_L is the motor output torque, ω_c is the hydraulic natural frequency, $\omega_c = \sqrt{\frac{\beta_e D_m^2}{V_0 J_t}}$, ξ_c is the damping ratio, $\xi_c = \frac{C_t}{2D_m} \sqrt{\frac{\beta_e J_t}{V_0}} + \frac{B_m}{2D_m} \sqrt{\frac{V_0}{\beta_e J_t}}$, β_e is hydraulic oil elastic modulus, J_t is the moment of inertia of the motor

6) Mathematical Model of Speed Sensor

The dynamic response of the sensor can be seen as a first-order proportional link, the transfer function can be expressed as:

$$\frac{U(s)}{\theta(s)} = k_f \quad (5)$$

According to above all the pump control motor all aspects model, and ultimately the driving force generation speed control system mathematical model is established, the structure is shown in Figure 2.

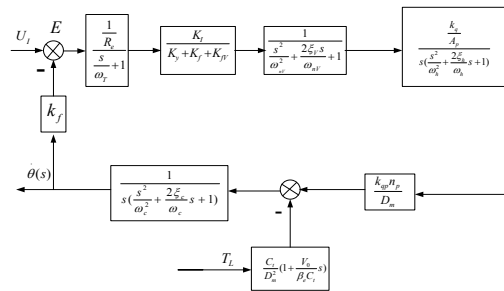


Fig.2 Structure diagram of the mathematical model of the speed-regulating system

2.3 Control Principle of Hydraulic Speed Regulation System

Control schematic diagram is shown in Figure 4. The core control strategy of the system is: the control method is based on the combination of PID and feedforward. Feedforward compensation of speed disturbance and voltage signal control of proportional solenoid valve are adopted[7]. In the system, motor output speed as the feedback part and the pump input speed as the feed-forward part. the motor speed is set at 1500r/min, the measured motor speed is compared with the set value and the error value is obtained. Then by adjusting the proportion of the solenoid valve voltage signal, which changes the displacement of pump to make the motor speed stable at 1500r/min.

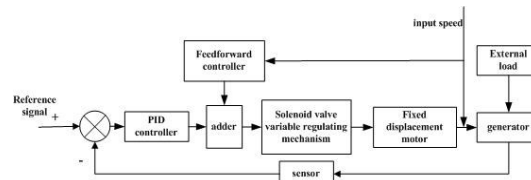


Fig.3 hydraulic speed control system control schematic

3 Simulation and Verification of System

According to the mathematic model of the speed control system established in the previous section, the simulink module of Matlab is used to simulate and analyze. The simulation module is shown in Fig.4

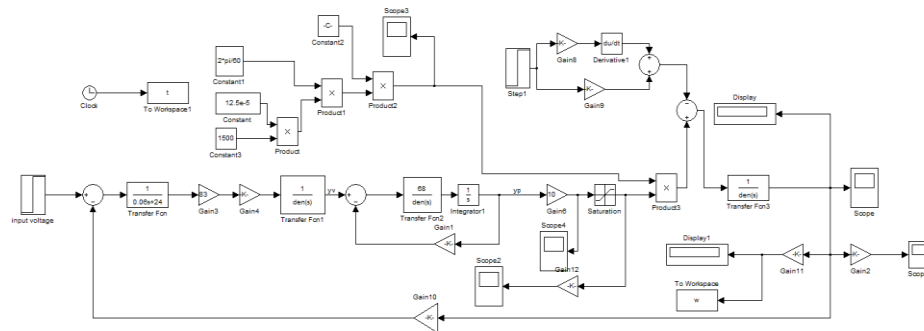
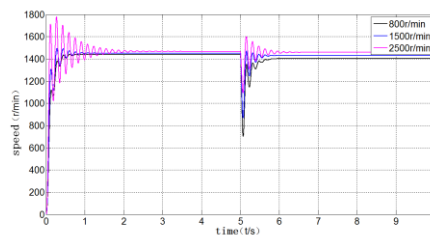


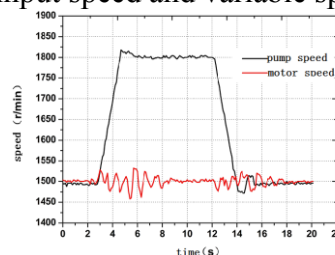
Fig.4 Simulation model of pump control motor speed system

3.1 Simulation and Verification of Speed and Load Fluctuation

In order to verify the accuracy of the model, the actual response of the system is verified by setting up a test-bed. Under the conditions of input speed fluctuation and load fluctuation, the control ability of the system is analyzed, and the control law of hydraulic system is obtained. In this paper, the conditions of abrupt change of input speed and external load under different input speed are studied. In figure 5, the speed fluctuation simulation is studied when the input speed is 800r/min, 1500r/min and 2500r/min separately. Due to the experimental conditions is limited, the experiment was carried out to verify the speed fluctuation at 1500r/min.



(a) Different input speed and variable speed is 300r/min

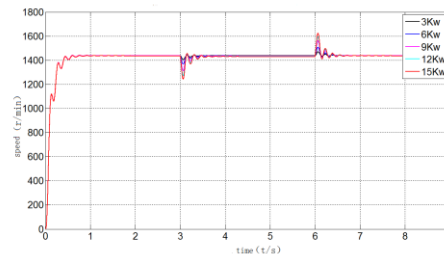


(b) Input speed is 1500r/min, mutation speed is 300r/min

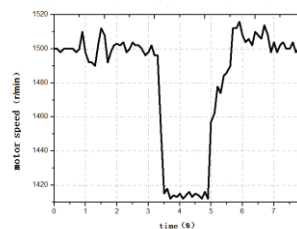
Fig.5 Simulation of the speed fluctuation and comparison of the experimental results

From the results, The motor speed keeps at the 1500r/min steadily in the motor speed fluctuation, the range of fluctuations is in ± 50 r/min and the motor speed stability time is less than 3s, and the change curve is basically the same when the motor is at two different speeds which shows that the system has good tunability to the speed disturbance.

In the figure 6, the speed control system's response to the sudden changes in load conditions is showed.



(a) Input speed is 800r/min and load is changed



(b) Load mutation 9Kw

Fig.6 When the input speed is 800r/min, the simulation of load fluctuation is compared with the experimental results

It can be seen from the figure above when the load changes 9kW suddenly, motor speed deviation can reach the maximum 90r/min, and in the process of loading and unloading, the system speed changes faster, the response time is not more than 300ms. When load changes suddenly, the motor speed's decrease range is larger than the rising range. Motor speed keeps stable in 2s, steady-state deviation is about 0.5%, and the maximum instantaneous deviation is 6%. The system reaches the national Class III power generation requirements.

4 Analysis of Structural Parameters on Stability's Influence of Hydraulic Speed Control System

As a hydraulic transmission system, the response characteristics of the system must take into account the system's leakage, hydraulic oil elastic modulus, oil viscosity, and motor output load inertia of the system. In this paper, the internal factors of the simulation analysis is took which can provide a reference for the system design and optimization.

4.1 Influence of Elastic Modulus of Hydraulic Oil on System

As the hydraulic system in the course of the work, there will be air into, which will affect the elastic modulus of hydraulic oil, In figure 7, when the elastic modulus were 700e6, 1000e6, 1400e6Mpa ,speed response curve were showed.

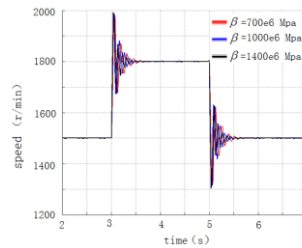


Fig.7 Effect of oil elastic modulus on system response

It can be seen from Fig. 8 that with the increase of the elastic modulus of the hydraulic oil, the response time and overshoot of the system are reduced, and the amplitude of the system shock is also reduced. But the number of shocks remains basically unchanged, indicating that the elastic modulus of oil on the system's stability is less affected.

4.2 Influence of Leakage Coefficient of Hydraulic Speed Control System on System Stability

In figure 8, the response of the system at three different leakage factors is showed.

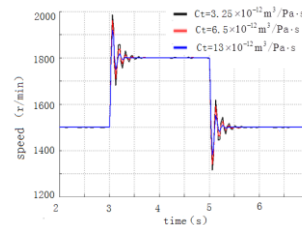


Fig. 8 Effect of leakage coefficient on system response

It can be seen that with the increase of the system leakage coefficient, the overshoot quantity decreases, the system response time and the number of times of oscillation do not change obviously, and the system response condition basically remains unchanged. As the system leakage coefficient is only related to the system damping ratio, the system damping ratio increases when the system leakage increases, so system should increase the leakage coefficient to improve the stability of the system but reduce the system's efficiency. So it is not suitable for the hydraulic speed control system to increase the leakage coefficient to improve the stability of the system.

4.3 Influence of The Motor Shaft's Rotational Inertia on The Stability of the System

In figure 9, the variable pump input speed is 1500r/min, the hydraulic speed control system response curve is showed when the hydraulic motor moment of inertia were 0.035,0.07,0.15 kg•m².

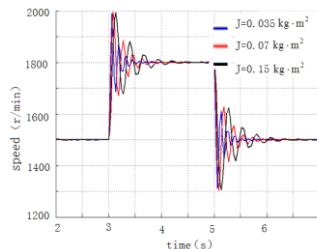


Fig.9 Effect of motor load moment of inertia on system response

From the response curve of Fig.9, the overshoot increases with the increase of the moment of inertia of the motor, and the dynamic adjustment time becomes longer and the system response becomes gentler. It shows that the dynamic response of the hydraulic speed control system under the low load quality is better than the high load quality.

5 Conclusion

In this paper, Simulink module of Matlab is used to simulate and analyze all the links of power generation, and the experimental system is built to validate the model. The results show that the system has good speed characteristics, can effectively reflect the actual working conditions, the power generation system meets the national power generation III requirements finally.

The simulation results show that the input speed of the variable pump has little effect on the response characteristics, and the load fluctuation has a great influence on the response of the hydraulic pump control motor system. So in the hydraulic speed control system, the motor speed should overcome the impact which is caused by load fluctuations furthest, so that the system can have better speed performance. The elastic modulus can be appropriately increased to improve the transient index of the system. At the same time, the system can obtain a better response characteristic through the improved leakage coefficient, but the efficiency will be reduced. And when system is under the low load, the system of the hydraulic speed regulation system's quality response is better than high load. Therefore, the system should be preferred in the design process with higher modulus of the oil, and should maximize the system sealing performance, and choose the low inertia load which has better balance.

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