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Dynamic Analysis for Hydraulic System of Jet Deflector Based on Bond Graph

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Abstract

This paper used the power bond graph method to establish hydraulic system dynamic model for Jet deflector, and derived the equation of state. Simulation of the dynamic characteristics of the hydraulic system is achieved in Matlab/Simulink environment. The delivery pressure of hydraulic pump, the hydraulic cylinder without rod gun pressure, the piston rod speed and other parameters on the dynamic response of the system were analyzed. The simulation results show that the power bond graph method has characteristics of convenient, intuitive and accurate to model and simulate the hydraulic system.

***Keywords**: power bond graph, hydraulic system, dynamic performance analysis*

1. Introduction

According to the basic principles for conservation of energy, The various physical quantities can be transform to four variables, which include the potential variable(e), the flow variable(f), the generalized displacement (p(t)) and the generalized momentum(g(t)) by the power bond graph. through basic bond graph unit, which includes impedance component R, capacitive element C, inertial element I, settlement "0" and "1", TF converter, GY gyrator, the dynamic characteristics of the system can be represented by using the power bond graph, which can represent the signal flow direction both components and the causality of control signal. With modern mechanical and electrical system is becoming more and more complex, the traditional methods need to write a lot of process modeling to analysis, which is tedious, and error-prone. The bond graph method is a simple graphical way intuitively which can reveal the dynamic characteristics of system, the model is easy to modify and perfect, and according to the model, the equation of state can be easily deduced, make the work to establish the mathematical model of the system simplified. The bond graph method has been widely applied in electrical, mechanical, fluid mechanics, thermodynamics engineering. Combined the power bond graph method with MATLAB/Simulink software, the dynamic characteristics of the hydraulic system of the jet flow deviation plate can be simulated.

2. The Hydraulic System of Jet Flow Deviation Plate

The hydraulic system of jet flow deviation plate is mainly composed of pump set assembly, fuel tank assembly, valve assembly, accumulator assembly, supporting pipe fittings (as shown in Figure 1). The rated working pressure is 13 Mpa, the hydraulic medium is L - AN46 hydraulic oil, the pump group as the power source of the system are composed of two electric motors and two parallel axial plunger pump.

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When the electromagnetic directional valve works rightward, the hydraulic cylinder piston rod spreads, the flow deviation plate ascends, by contraries, the electromagnetic directional valve works leftward, the hydraulic cylinder piston rod draws back, the flow deviation plate descends.

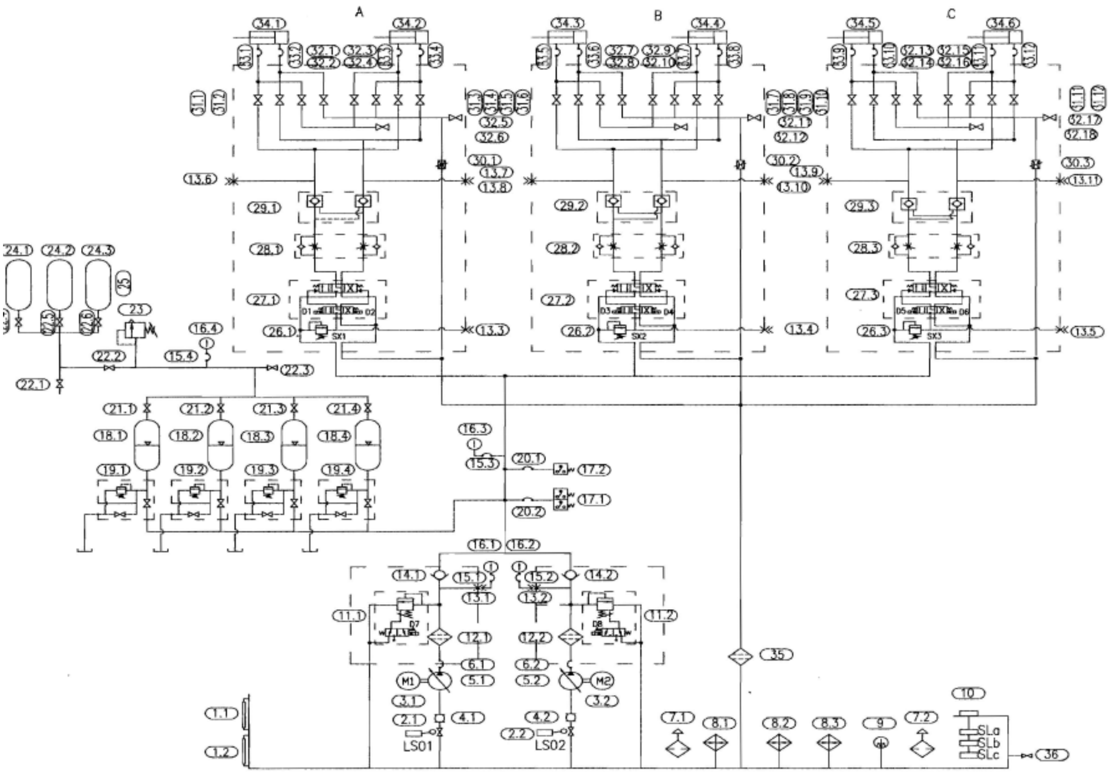


Figure 1. The Principle for the Hydraulic System of Jet Flow Deviation Plate

From the Figure 1. We can conclude that: the hydraulic system of jet flow deviation plate is a very complicated system, when the system characteristic is analyzed, if all the components are taken into account, which will result that the system characteristic cannot be analyzed because of too complex model and too coupling variables. So the components have been larger influence on the system's dynamic characteristics can be keep, the system equivalent and simplify the process as follows in the Figure 2.

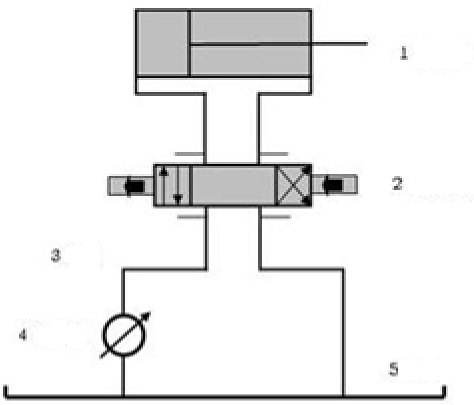


Figure 2. The Simple Principle for Hydraulic System of Jet Flow Deviation Plate

In the Figure 2, 1: hydraulic cylinder; 2: electromagnetic valve; 3:pipe; 4: hydraulic pump; 5: gasoline tank.

3. Drift Hydraulic System Modeling

3.1. Drift Hydraulic Power System Diagram

The power diagram can not only represented simply and clearly the power transmission, gathering, transformation and dissipation between the components in the system, but also can accurately judge the causal relationship between the powers and establish the equation of state conveniently.

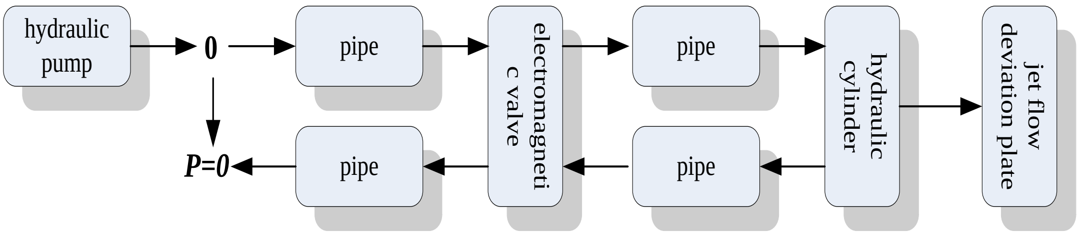


Figure 3. The Power Diagram for Hydraulic System of Jet Flow Deviation Plate

3.2. Key Element Processing for Hydraulic System of Jet Flow Deviation Plate

(1)Bond graph model for hydraulic pump

The hydraulic pump, relief valve, check valve, can be deem as a constant voltage source Se, the bond graph model as shown in Figure 4

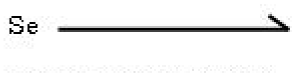


Figure 4. The Bond Graph Model for Hydraulic Pump

(2) Bond graph model for the electromagnetic valve

The electromagnetic valve in the system is three-position four-way hydraulic valve and its structure principle as shown in Figure 5, there are four ports which connected with the system. The port S is Oil supply port, and the port E is the oil return port. The port A, B connect the two hydraulic cylinder. The relative position of the valve core and valve body has form the four valve ports SA, AE, SB, BE. When the oil flow through the valve, the fluid resistance come into being, in this article they have been respectively set to R19, R20, R25, R26. The bond graph model is shown in Figure 6.

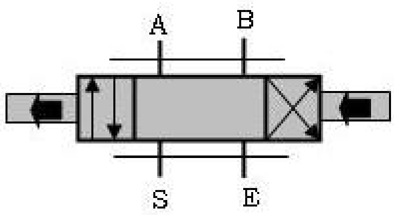


Figure 5. The Principle for the Electromagnetic Valve

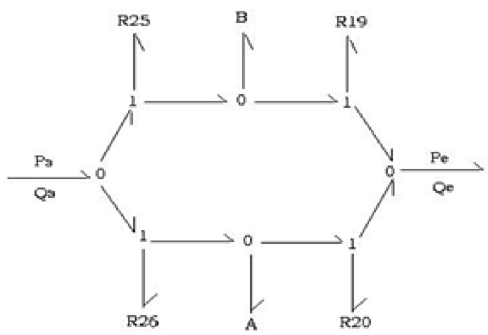


Figure 6. The Bond Graph Model for the Electromagnetic Directional Valve

As the valve core moves from middle to left, the R19 and R26 increases, the R20 and R25 decreases, and the oil cavity pressure of the hydraulic cylinder connected to the valve port B rise, and the oil cavity pressure connected to the valve port is reduced, the piston moves under the action of pressure difference.

(3) Bond graph model of hydraulic cylinder

The hydraulic cylinder (Figure 7) is the main components in the system by which the hydraulic pressure can be converted into mechanical energy, ignored the oil leaks, the compressibility of the friction and piston, piston rod and oil cavity inertia, in this paper, the oil cavity fluid volume and external load which influence the dynamic characteristics are considered.The bond graph model of hydraulic cylinder as shown in Figure 8.

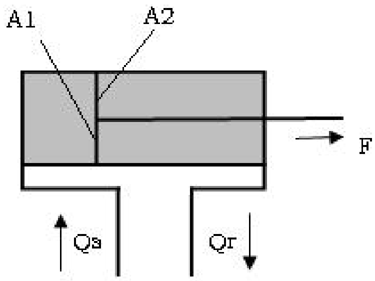


Figure 7. The Principle for the Hydraulic Cylinder

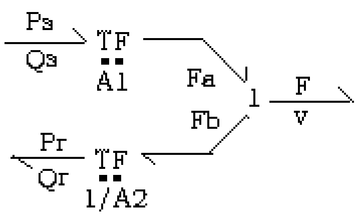


Figure 8. The Bond Graph Model for the Hydraulic Cylinder

(4) Bond graph model for pipe

Considering the fluid pipeline fluid resistance, fluid capacitance and fluid inductance, the system piping model is established, the model as shown in Figure 9.

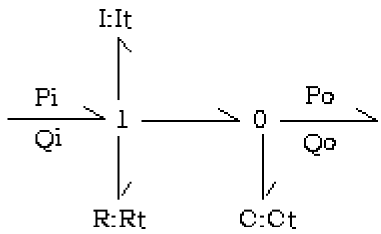


Figure 9. The Bond Graph Model for Bond

(5) Bond graph model for hydraulic system of jet flow deviation plate

Ignore components which have small influence on the system's dynamic characteristics, the hydraulic pump, the electromagnetic directional valve and hydraulic cylinder as the basic components, the bond graph of hydraulic system has been established, as shown in Figure 10.

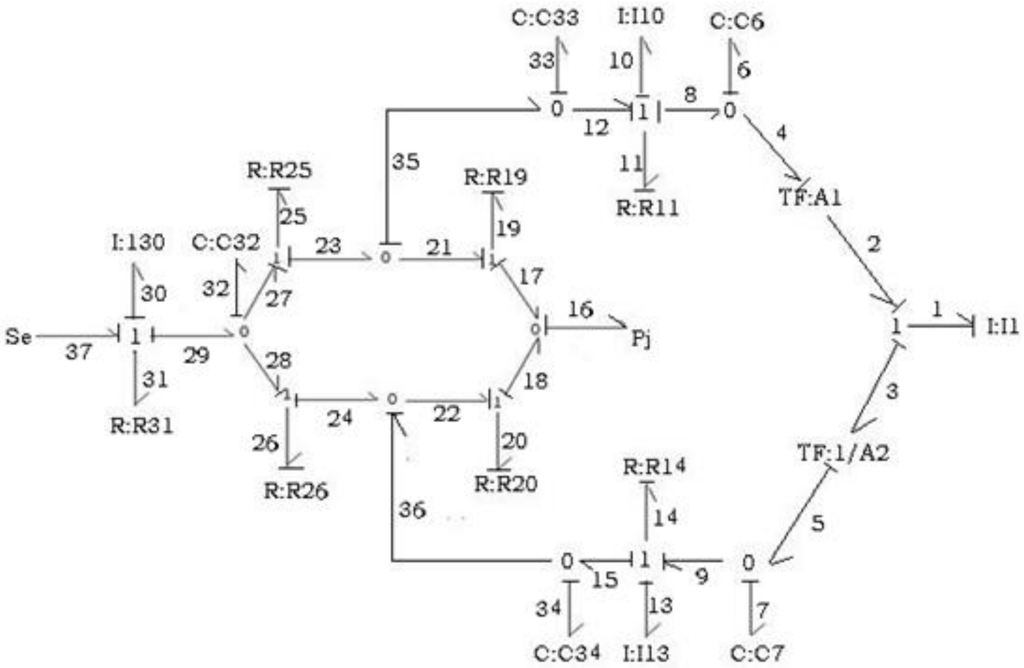


Figure10. The Bond Graph Model for Hydraulic System of Jet Flow Deviation Plate

Se ——Constant voltage source
I1 ——The load moment of inertia
Pj——System back pressure
A1、A2——rod and rodless hydraulic cylinder cavity effective area
C6 、C7——rod and rodless hydraulic cylinder cavity fluid liquid capacitance
I10、 I13、 I30——Pipeline liquid inductance
R31、R11、 R14——Pipeline liquid resistance
C32 、C33 、C34 ——Pipeline liquid capacitance
R19、R20 、R25、R26 ——Fluid resistance of electromagnetic directional valve port

3.3. The Establishment of the Hydraulic System State Equation

Among the writing the equation of state, the assumptions as follows:

(1) The hydraulic pump is regard as constant voltage source, and ignored their own liquid capacity and liquid resistance;

(2)The leak is ignored between pipe and hydraulic pump, reversing valve, hydraulic cylinder joint leak, between rod and rodless hydraulic cylinder cavity;

(3) The electromagnetic directional valve adopts circular valve port, valve port flow value is turbulence;

(4) The density of the oil, bulk modulus, viscosity, temperature are regard as constant.

According to the power bond graph, only two variables between energy storage effect is differential or integral relationship, so the inertia variable I and capacitive variable C are selected as state variables, the dynamic mathematical model of system is deduced:

$$\begin{cases} \dot{P}_{30} = S_e - \dfrac{V_{32}}{C_{32}} - \dfrac{R_{31}}{I_{31}} P_{30} \\ \dot{V}_{32} = \dfrac{P_{30}}{I_{30}} - \left(\dfrac{1}{R_{25}} + \dfrac{1}{R_{26}}\right)\dfrac{V_{32}}{C_{32}} + \dfrac{V_{33}}{R_{25}C_{33}} + \dfrac{V_{34}}{R_{26}C_{34}} \\ \dot{V}_{33} = \dfrac{V_{32}}{R_{25}C_{32}} - \left(\dfrac{1}{R_{25}} + \dfrac{1}{R_{19}}\right)\dfrac{V_{33}}{C_{33}} + \dfrac{P_j}{R_{19}} - \dfrac{P_{10}}{I_{10}} \\ \dot{V}_{34} = \dfrac{P_{13}}{I_{13}} - \left(\dfrac{1}{R_{20}} + \dfrac{1}{R_{26}}\right)\dfrac{V_{34}}{C_{34}} + \dfrac{P_j}{R_{20}} + \dfrac{V_{32}}{R_{26}C_{32}} \\ \dot{P}_{10} = \dfrac{V_{33}}{C_{33}} - \dfrac{V_6}{C_6} - \dfrac{R_{11}}{I_{10}} P_{10} \\ \dot{P}_{13} = \dfrac{V_7}{C_7} - \dfrac{V_{34}}{C_{34}} - \dfrac{R_{14}}{I_{13}} P_{13} \\ \dot{V}_6 = \dfrac{P_{10}}{I_{10}} - \dfrac{A_1}{I_1} P_1 \\ \dot{V}_7 = \dfrac{A_2}{I_1} P_1 - \dfrac{P_{13}}{I_{13}} \\ \dot{P}_1 = \dfrac{A_1}{C_6} V_6 - \dfrac{A_2}{C_7} V_7 \end{cases}$$

3.4. Fixing On Each Parameter Value in the State Equation

(1) Hydraulic cylinder MAX range of 0.6 m, diameter D1 = 0.1 m, the piston rod diameter D2 = 0.05 m, assuming that the initial position from left side is 0.01 m from the valve core, Then calculated:

Rodless cavity volume： $V_6=7.85\times10^{-5}m^3$

Rod cavity volume : $V_7=3.47\times10^{-3}m^3$

Rodless cavity fluid volume :$C_6=V_6/K=7.85\times10^{-14}m^5\cdot N^{-1}$

Rod cavity fluid volume : $C_7=V_7/K=3.47\times10^{-14}m^5\cdot N^{-1}$

Rodless cavity effective area A1 = 0.00785 m^2

Rod cavity effective area A_2 = 0.00589 m^2

(2) Hydraulic pipe diameter for D3 = 0.025 m, the average length l = 20 m, l - AN46 hydraulic oil used in the system, density σ = 870 kg/m3, dynamic viscosity u = 4610^{-6} m^2s, calculated:

Liquid capacitance: $C_{32}=C_{33}=C_{34}=V_0/K=4.9\times10^{-13}m^5\cdot N^{-1}$

Liquid resistance: $R_{31}=R_{14}=R_{11}=128\ ul/\pi\ d^4=8.4\times10^5 Ns\cdot m^{-5}$

Liquid inductance: $I_{10}=I_{13}=I_{30}=ul/\pi\ r^2=3.55\times10^4 kg\cdot m^{-4}$

The oil bulk modulus: $K=1.0\times10^9 M$

4. Simulink Simulation and the Result Analysis

Using MATLAB/Simulink software, according to the system's equation of state established, The model block diagram is created, as shown in Figure 11.

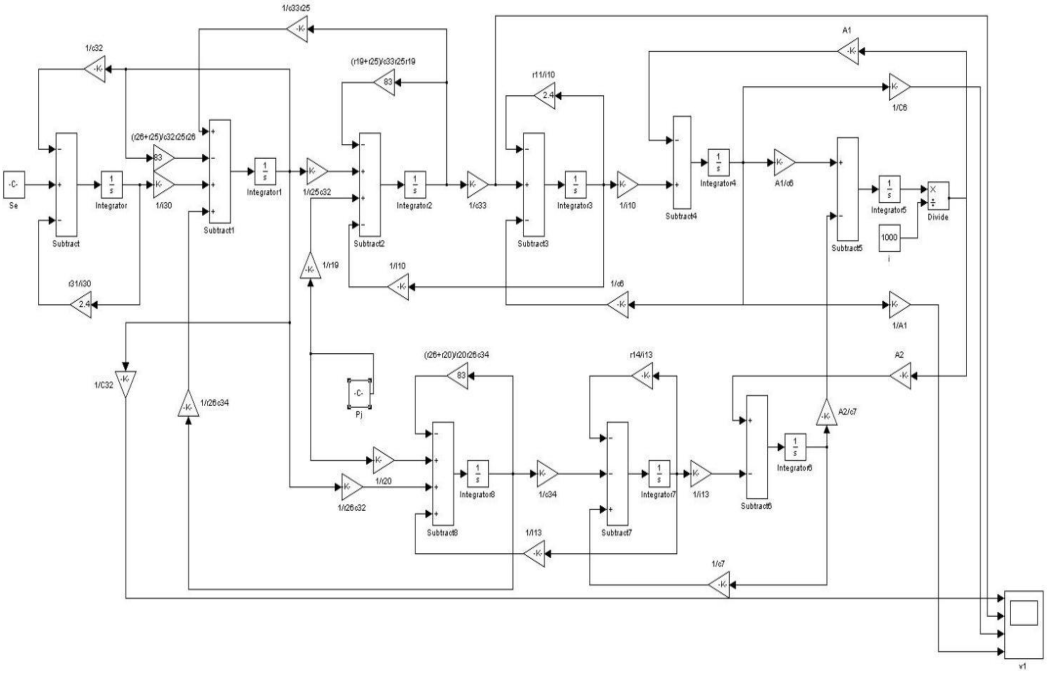
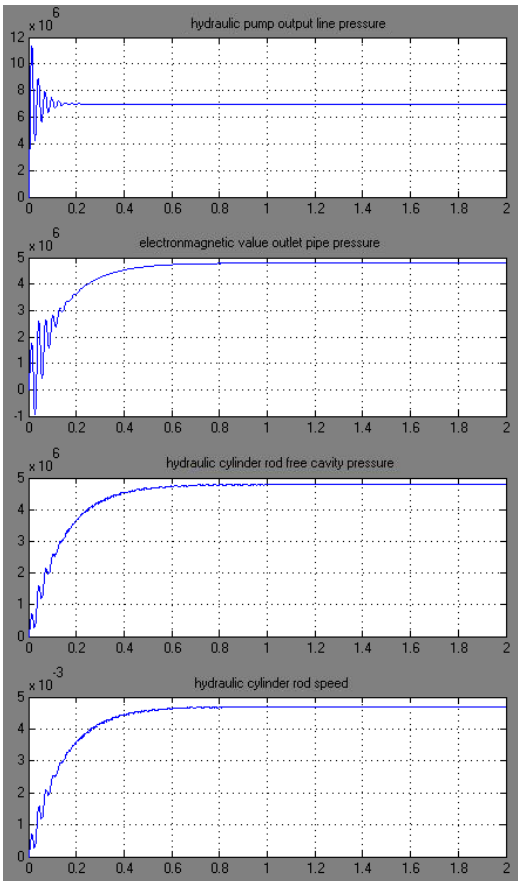


Figure11. The Simulink Model for Hydraulic System of Jet Flow Deviation Plate

The main factors influence the dynamic characteristics of the hydraulic system as follows: the output pressure of hydraulic pump, hydraulic cylinder rodless cavity pressure and speed of the piston rod, so simulation analysis are based on its response. In this paper, using ODE45 method the Simulink simulation has been carried through.

(1) The system back pressure is 3 MPa, the load inertia is 1000 kg, the simulation results are shown in Figure 12 and 13.7 MPa for hydraulic pump pressure, after 0.6 s, the hydraulic pump output pressure stable in 7 MPa, the electromagnetic valve output pressure steady at 4.8 MPa and rodless hydraulic cylinder cavity pressure steady at 4.7 MPa, the hydraulic cylinder piston rod speed stability in $4.6\times10^{-3}m/S$; the hydraulic pump pressure to 13 MPa, after 0.6 s, the hydraulic pump output pressure stable in 13 MPa, the electromagnetic valve output line pressure steady at 7.8 MPa, the rodless hydraulic cylinder cavity pressure stable in 7.7 MPa, the hydraulic cylinder piston rod speed stability in $7.6\times10^{-3}m/S$.



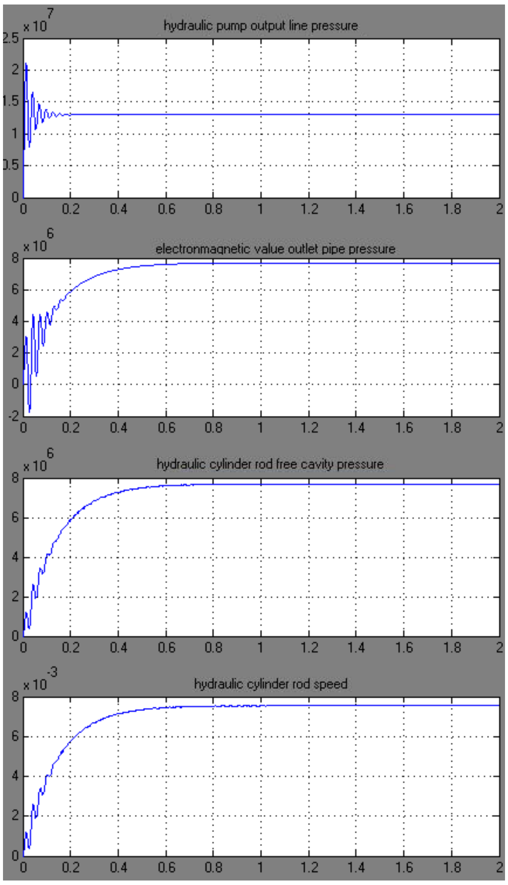


Figure 12. Pj=3MPa P=7MPa **Figure 13. Pj=3MPa P=13MPa**

(2) The hydraulic pump pressure is 13 MPa, the load inertia is 1000 kg, the simulation results are shown in Figure 14 and 15. The system back pressure is 1 MPa, after 0.6 s, the hydraulic pump output line pressure stable in 13 MPa, the electromagnetic valve output pressure stable in 7 MPa and the rodless hydraulic cylinder cavity pressure steady at 6.9 MPa, the hydraulic cylinder piston rod speed stability in $6.7\times10^{-3}m/S$; System back pressure of 5 MPa, after 0.6 s, the hydraulic pump output pressure stable in 13 MPa, the electromagnetic valve output pressure steady at 8.7 MPa and the rodless hydraulic cylinder cavity pressure steady at 8.7 MPa, the hydraulic cylinder piston rod speed stability in $8.5\times10^{-3}m/S$;

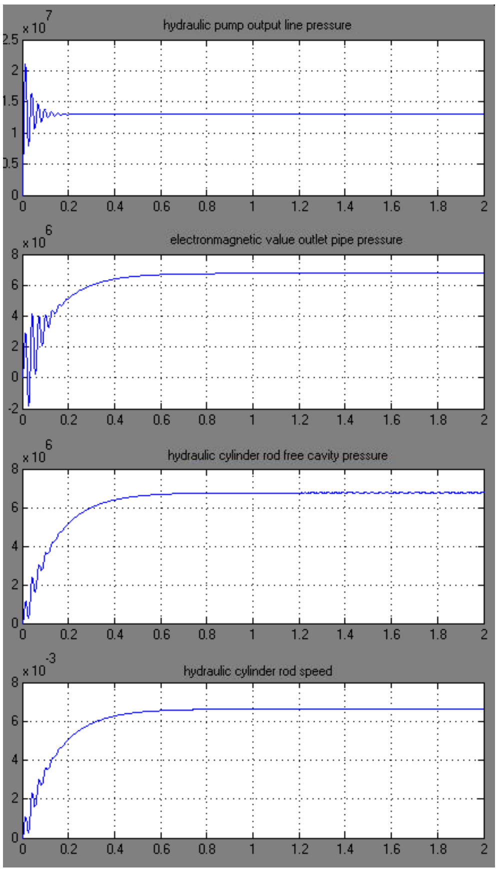


Figure 14. Pj=1MPa P=13MPa

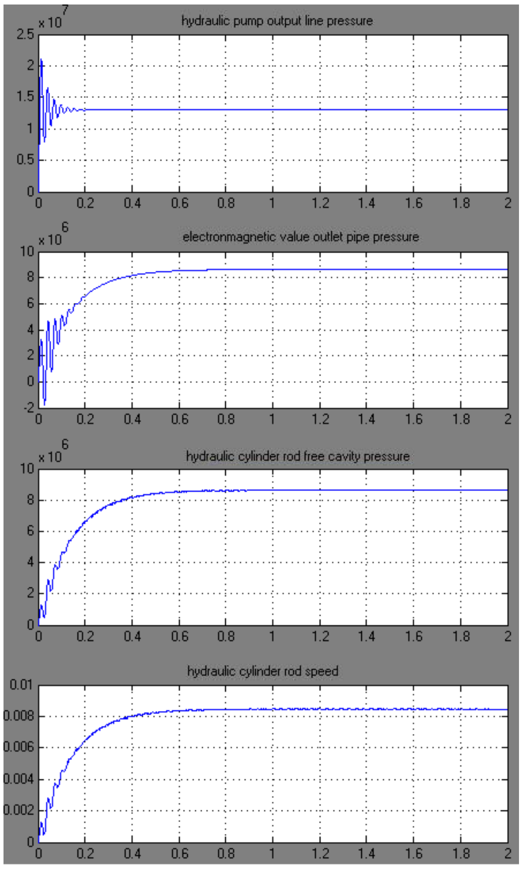


Figure 15. Pj=5MPa P=13MPa

(3) The pressure of hydraulic pump is 13 Mpa, the system back pressure is 3 Mpa, the simulation results are shown in Figure 16, 17.The load moment of inertia of 1000 kg and 5000 kg respectively, after 0.6 s the system reach steady state. By a graphic the load inertia size affect system stability of initial state, which will have little impact on the system steady state parameters.

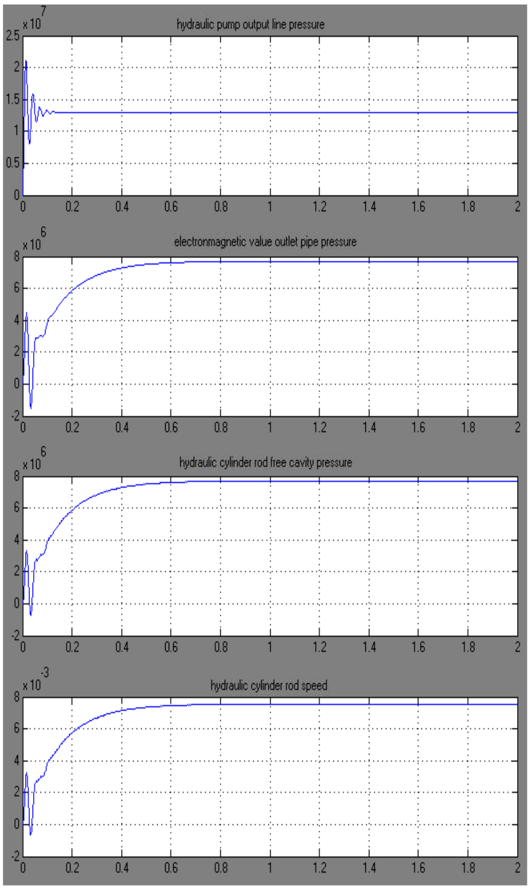


Figure 16. Load Inertia I=5000kg

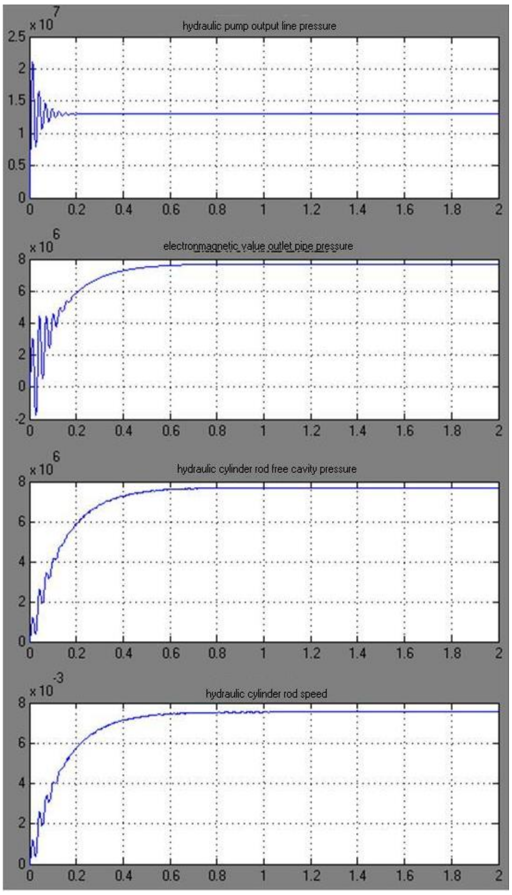


Figure 17. Load Inertia I=1000kg

From the simulation results we can be conclude,

(1) When the reversing valve by the adjustment to the left, the output of the hydraulic pump pressure rise rapidly, as the oil into the hydraulic cylinder, rodless cavity pressure rising, the piston rod speed increasing, after 0.6 s system to reach steady state. The model can reflect real drift plate under the action of hydraulic system in constant voltage source, the changes of the parameters of the simulation results according to the hydraulic cylinder under the action of constant voltage source, the response speed and stability of the good.

(2) The hydraulic pump pressure and back pressure under the steady state system had a greater influence on the performance of the system, load inertia influence the stability of the system initial state.

(3) The pipeline pressure loss is small, the system pressure loss mainly concentrated in the electromagnetic valve, so in the actual project the structure has been strengthen to optimize to the electromagnetic valve, which is the key to reduce the system energy loss.

5. Conclusion

(1) Ignore the small impact on the system components, the hydraulic system has been analyzed, the power bond graph and the dynamic characteristics of state equation have been established, using MATLAB/Simulink software, the key factors that affecting the hydraulic system have been simulated.

(2) The power bond graph can effectively reflect the causal relationship between all the power in the complex system, combined with MATLAB/Simulink simulation software, without a lot of program, the operation of the system can been accurately reflected.

The bond graph model has good expansibility, the submodule can been add and subtract at any time to simulate verification, for the product design and parameter selection which provides a theoretical basis.

(3) Due to ignore some of the elements in the process of modeling, which may lead to the results of simulation have error, and which can be solved by adding these elements of sub module.

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References

[1] Johnny, "Based on power bond graph of wind turbines is analyzed.studying hydraulic system dynamic characteristic analysis', North China electric power university, **(2013)**.
[2] A.-L. Wang and L. Yun, "Dynamic similarity analysis of complex electromechanical system bond graph method", Journal of mechanical engineering, **(2010.05)**.
[3] S.L. Sheng, "Power electronic circuit based on bond graph model of fault diagnosis technology research", Nanjing university of aeronautics and astronautics, **(2014)**.
[4] "Bond Graph Method And Its Application In Mechanical and electrical system dynamics modeling and simulation", Qiqihar university, **(2013)**.
[5] Y.-C. Guo, L. C. Hwan and H. Kun, "A step adaptive extraposition hydraulic system modeling and simulation study", Journal of mining machinery, vol. 12, **(2014)**.
[6] Z. Zhuo and H.W. Suzhen, "Uav model research and simulation of hydraulic ejection system", Journal of machine tools and hydraulic, vol. 22, **(2014)**.
[7] J. Wang, K. Fan and Y. Su, "Grey analytic hierarchy process applied to aero-engine Healthy assessment", Service Operations and Logistics, and Informatics, 2008. IEEE SOLI 2008. IEEE International Conference on IEEE, vol. 2, **(2008)**, pp. 1947-1952.
[8] P. Xu, Z. Wang and V. Li, "Prognostics and Healthy management (PHM) system requirements and validation", Prognostics and Healthy Management Conference, 2010. PHM'10. IEEE, **(2010)**, pp. 1-4.

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