

Dynamic Characteristics of Hydraulic Motor in Tunnel Heading Machines

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Abstract. The hydraulic motor in tunnel heading machines is studied. The process of the motor movement is analyzed, and the schematic diagram of the hydraulic system is drawn. Then, the power bond graph of each component is established, and the subsystem model of each component in the working window of Simulink is created according to the power bond graph. Finally, by giving the simulation parameters of each cylinder, the hydraulic cylinder system of the motor is simulated and analyzed. The simulation results show the influence of the parameters such as the load type, the change of volume elastic modulus, the diameter and length of the hydraulic motor on the dynamic characteristics of the hydraulic motor.

1. Introduction

Bolt drilling machine is the main supporting roadheader machine supporting machinery. It is used to drill the bolt hole in the surrounding rock of the roadway and complete the excavation support task with the boring machine [1, 2]. Boring machine and bolt drilling machine cross sequence operation, when the boring machine to complete rock breaking action, start the bolt drilling machine, the roof of the roadway and the two sides to help fight anchor work [3]. Bolt drilling rig has a separate hydraulic system, pipeline complexity, low safety, in the pipeline oil cannot be cooled in time to keep the liquid has been kept at high temperatures, resulting in serious leakage of hydraulic system, exacerbated the hydraulic components of the damage rate, increased maintenance time, limiting the speed of driving [4, 5]. Therefore, in order to give full play to the function of the whole machine, to realize the integration of heading and bolting, and to improve the speed of heading, the research on the hydraulic system of bolting rig is especially important [6].

Hydraulic system is the driving part of the anchor drilling rig. Power transmission is the main principle. The anchor machine starts during the operation, and the movements, reversing and stopping are very frequent [7]. Nowadays, there are few researches on the hydraulic system of bolting machine, and the research on the hydraulic system of bolting machine is very rare [8]. Hydraulic system may appear shock vibration, noise and parts malfunction disorders, affecting the stability of the hydraulic system, but also directly affect the stability of the host, which are caused by the instability of the dynamic characteristics of the hydraulic system. In fact, to verify the hydraulic system can work properly and to evaluate its various performance indicators, it is required that the system must complete the action according to the regulation, meet the static characteristic standard, and should have good dynamic characteristics. In order to prevent the above problems in the hydraulic system of the bolt drilling rig, it is very important to study its dynamic performance.



2. Design of hydraulic motor oil circuit

The power source for a bolt rig is provided by a hydraulic pump station at the roadheader. Bolt drilling machine hydraulic system by the three-ball valve, shunt manifold valve, reversing valve, hydraulic lock, hydraulic cylinder and hydraulic motor. Hydraulic motors convert hydraulic energy into mechanical energy for rotary motion equipment. Bolting machine drilling motor is a low speed hydraulic motor, the general use of cycloidal motor. Bolting rig hydraulic motor through the three-ball valve and shunt manifold valve and a motor oil transport road connected.

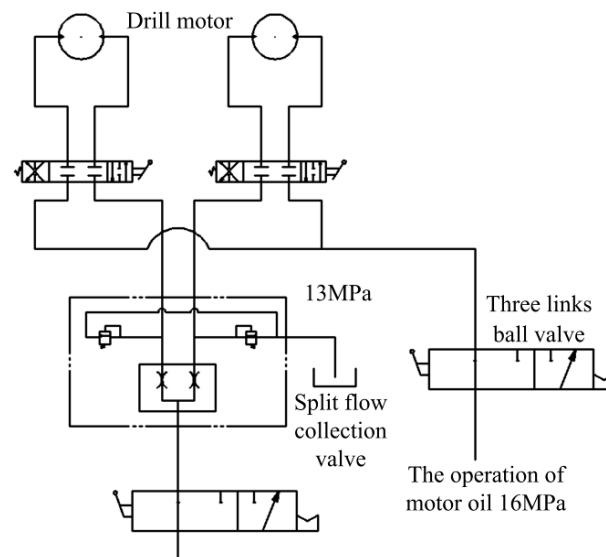


Figure 1. Schematic diagram of hydraulic motor system.

As is shown in Figure 1, the hydraulic motor of two bolt drilling rigs is connected to the motor oil path through a manual reversing valve and a current diverter. Three-way ball valve to the role of the commutation, when the three-position ball valve to switch to the right position, a transport motor and diverter manifold connected to the diverter valve diverting valve from the role of diversion, but at the same time to the two motor oil, The flow through the hydraulic motor is also adjusted. The role of relief valve is to control the pressure into the hydraulic motor to prevent system pressure overload. And the manual reversing valve is used for motor commutation.

3. Model setup

Motor power bond diagram is shown in Figure 2, the input for the flow and pressure of oil, the output speed and torque. The dynamic model of hydraulic motor based on the power bonding diagram is established.

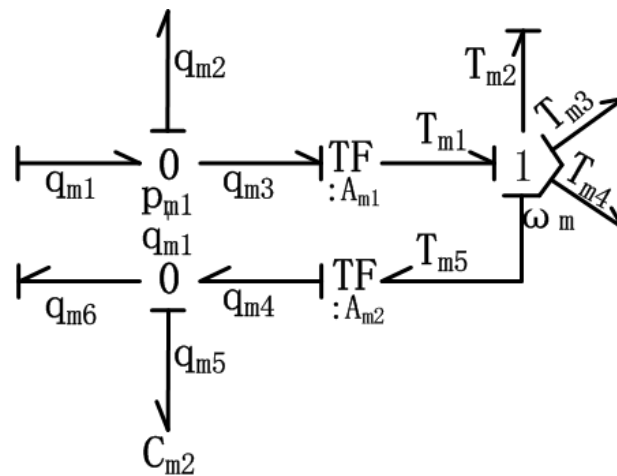


Figure 2. Power bonds graph of hydraulic motor.

In the figure,

C_{m1} —fuel inlet chamber fluid capacitance of hydraulic motor, $4.12 \times 10^{-12} \text{ m}^5 \cdot \text{N}^{-1}$;

C_{m2} —fuel outlet chamber fluid capacitance of hydraulic motor, $4.12 \times 10^{-12} \text{ m}^5 \cdot \text{N}^{-1}$;

I_m —moment of inertia of hydraulic motor, $1.125 \times 10^{-6} \text{ kg} \cdot \text{m}^2$;

S_{em} —torque of the load to the hydraulic motor, $\text{N} \cdot \text{m}$;

R_m —Viscous friction fluid resistance of hydraulic motor, $0.15 \text{ N} \cdot \text{s} \cdot \text{m}^{-1}$;

For complex models, the simulation system will become very large, in the use of Simulink modeling and simulation, the model needs to be scientific and systematic planning. The basic requirements of using Simulink modeling are as follows: (1) When the model has pertinence modeling, we must first determine the research purpose of the system and the features of the constructed system subsets should only relate to the purpose-related content. There are many models for a particular system, but the specific models differ depending on the purpose of the study. (2) the division of subsystems to be distinct structure A larger system usually consists of many subsystems, so the system corresponding to the model often consists of many sub-models. In addition to the necessary link between the sub-models, the coupling situation should be as small as possible. (3) Accuracy of the model should be appropriate When the accuracy of the model is higher, the longer the simulation takes, the more time is wasted when the system is modified. When the accuracy of the model is low, the authenticity of the simulation results will be reduced, and sometimes will not converge. Therefore, the correct accuracy is very important for the model.

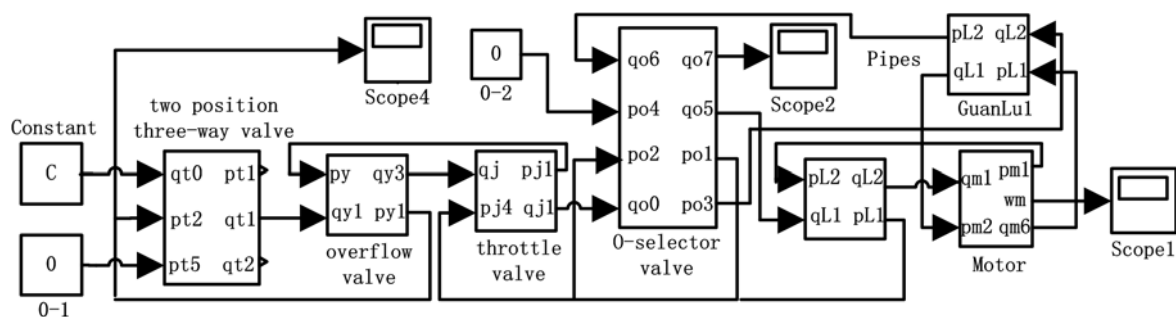


Figure 3. Simulation model of hydraulic motor system.

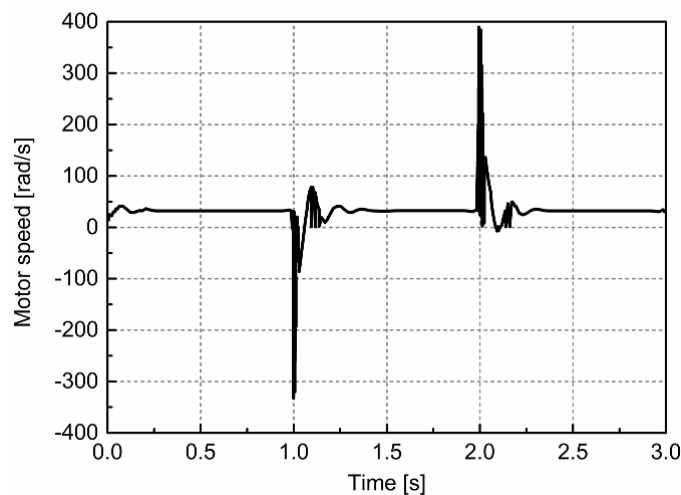
Table 1. Hydraulic motor system parameters.

Flow coefficient of valves		Pipes parameters	
$K_t / (\text{Pa}^{1/2} \cdot \text{m}^3 \cdot \text{s})$	4.83×10^4	$D / (\text{mm})$	10
$K_v / (\text{Pa}^{1/2} \cdot \text{m}^3 \cdot \text{s})$	2.57×10^4	$L / (\text{mm})$	4.50×10^3
$K_j / (\text{Pa}^{1/2} \cdot \text{m}^3 \cdot \text{s})$	9.03×10^4	$R_L / (\text{N} \cdot \text{s} \cdot \text{m}^{-5})$	7.59×10^8
$K_o / (\text{Pa}^{1/2} \cdot \text{m}^3 \cdot \text{s})$	1.84×10^4	$I_L / (\text{N} \cdot \text{s}^2 \cdot \text{m}^{-5})$	5.16×10^7
$C_j / (\text{m}^5 \cdot \text{N}^{-1})$	7.51×10^8	$C_L / (\text{m}^5 \cdot \text{N}^{-1})$	3.93×10^{13}

Because the hydraulic system of bolt drilling rig involves many components and the simulation model is huge, the system module is divided into several independent functional modules first, then these sub-modules are encapsulated, the performance of the sub-modules is simulated and analyzed separately, and finally all the sub-modules are integrated together for debugging. Figure 1 shows the hydraulic motor system working process, and Figure 2 shows the power bonds graph of hydraulic motor. Then, the hydraulic components of the Simulink model connected in sequence to form a hydraulic motor system Simulink model is established, and is shown in Figure 3. In the figure, the input flow volume q_{t0} is $800.16 \times 10^{-6} \text{ m}^3 \cdot \text{s}^{-1}$. The motor's parameters are from the Power Bonds Graph in figure 2. And the parameters of valves and pipes are shown in table 1.

4. Simulation results analysis

The simulation format is ode45, and the simulation time is 3 s, using variable step mode, the relative error of 1 e^{-5} or less. Add the load of the hydraulic motor during the simulation: When the hydraulic motor is working, it starts with no load and after 1 s, a step load of $180 \text{ N} \cdot \text{m}$ is applied to start the drilling work. After 1 s, the load is reduced to $20 \text{ N} \cdot \text{m}$. Simulation results are shown in Figure 4 and Figure 5.

**Figure 4.** Rotational speed curve of hydraulic motor.

As is shown in Figure 4, at start-up, the peak value of 40 rad/s is reached after 0.07 s and then reaches a steady state value of 31.5 rad/s after 0.23 s; at 180 s after 1 s torque is applied There is a short negative value then reached a peak of 75 rad/s over 0.1 s and reached a steady state value of 31.5 rad/s over a period of 0.3 s. At 2 s the load was reduced from $180 \text{ N} \cdot \text{m}$ to $20 \text{ N} \cdot \text{m}$ and the speed was short surge, and then reach a steady state value of 31.5 rad/s at 2.4 s.

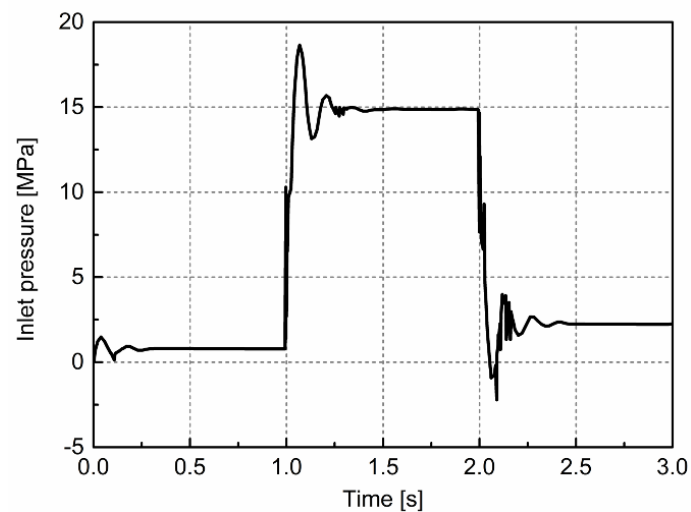


Figure 5. Pressure curve of hydraulic motor.

As is shown in Figure 5, the pressure at the inlet of the motor reaches 1.35 MPa after 0.03 s at start-up, reaches steady state value 0.676 MPa at 0.4 s after 0.37 s, and 180 N · m at 1 s. After the torque, the pressure at the inlet suddenly increased, reaching peak value of 18 MPa after 0.07 s and then reaching the steady state value of 14.8 MPa at 1.5 s after 0.43 s. At 2 s, the load was reduced from 180 N · m to 20 N · m, a sudden drop in pressure at the inlet and then a steady state value of 2.25 MPa at 2.5 s.

5. Conclusion

In this paper, the Simulink model of each component in the hydraulic system of the tunnel heading machine is established. The hydraulic cylinder system of bolter hydraulic motor are simulated and analyzed. After the load is added, the rotational speed shows a short negative value and continued for about 0.2 s and then reaches a steady state value. When the load is reduced, the speed is short jump and then steady. The pressure shows an accompany tendency with the load increasing or declining. However, both the rotational speed and pressure of the hydraulic motor are stable.

Acknowledgments

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References

- [1] Y. Zhao, H. Pan, H. Wang, and H. Yu, Dynamics research on grouping characteristics of a shield tunnelling machine's thrust system, *Automat. Constr.* 76 (2017) 97-107.
- [2] Z. H. Liu, C. L. Du, Y. L. Zheng, Q. B. Zhang, and J. Zhao, Effects of nozzle position and waterjet pressure on rock-breaking performance of roadheader, *Tunn. Undergr. Sp. Tech.* 69(2017)18-27.
- [3] J. Huo, N. Hou, W. Sun, L. Wang, and J. Dong, Analyses of dynamic characteristics and structure optimization of tunnel boring machine cutter system with multi-joint surface, *Nonlinear Dynam.* 87 (2017) 237-254.
- [4] M. Yue and L. Guo, Double closed-loop adaptive rectification control of a shield tunnelling machine with hydraulic actuator dynamics subject to saturation constraint. *J. Vib. Control.* 22 (2016) 309-3190.
- [5] H. Shi, G. Gong, H. Yang, and X. Mei, Compliance of hydraulic system and its applications in thrust system design of shield tunnelling machine, *Sci. China Technol. Sc.* 56(2013) 2124-

- 2131.
- [6] H. Shi, H. Yang, G. Gong, H. Liu, and D. Hou, Energy saving of cutterhead hydraulic drive system of shield tunnelling machine, *Automat. Constr.* 37 (2014) 11-21.
 - [7] W. Zhao, Z. Hu, and D. Huang, Global stability analysis on combination self-excited vibration of BTA deep-hole boring rotor materials, *Key Eng. Mater.* 667(2016)75-81.
 - [8] X. Yu, J. Zhang, C. Fan, and S. Chen, Stability analysis of governor-turbine-hydraulic system by state space method and graph theory, *Energy*. 114(2016)613-622.