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Underwater hydraulic shock shovel control system

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Abstract: The control system determines the effectiveness of an underwater hydraulic shock shovel. This paper begins by analyzing the working principles of these shovels and explains the importance of their control systems. A new type of control system's mathematical model was built and analyzed according to those principles. Since the initial control system's response time could not fulfill the design requirements, a PID controller was added to the control system. System response time was still slower than required, so a neural network was added to nonlinearly regulate the proportional element, integral element and derivative element coefficients of the PID controller. After these improvements to the control system, system parameters fulfilled the design requirements. The working performance of electrically-controlled parts such as the rapidly moving high speed switch valve is largely determined by the control system. Normal control methods generally can't satisfy a shovel's requirements, so advanced and normal control methods were combined to improve the control system, bringing good results.

Keywords: hydraulic shock shovel; control system; PID; BP network
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1 Introduction

The hydraulic impact tool has been developing for many years. Moreover, this kind of products has been widely used. Relative technology has also been deeply studied. Different material needs different impact force. But at present, the shock frequency of hydraulic impact tool can't be verified. Therefore, the shock energy generated by the shock force doesn't match the one that the thing needs to be destroyed, which leads to wastage of energy. It is necessary to develop a kind of hydraulic shock tool which can change the output energy. The underwater hydraulic shock shovel (UHSS) studied in this paper has the character of regulating impact frequency. When the power is constant, frequency is in inverse proportion to the output energy of one shock. So UHSS can regulate impact energy. Its control system is important to the function of regulating the output frequency and will be studied below.

2 UHSS work principles

The work principle of UHSS is shown in Fig.1. The shock force is produced by piston rod 5 moving to-and-fro. The vacuum nitrogen chamber 6 connecting with the top of piston rod 5 is a high-pressure nitrogen chamber. In the back course, the piston rod 5 reduces the volume of nitrogen chamber 6 to compress high-pressure nitrogen and thus save energy. In the forth course, the high-pressure nitrogen works together with hydraulic pressure.

High-pressure oil enters into entrances I and III and entrance II is connected with the tank. The spool of the oil-distributing valve moves to-and-fro to regulate the relation of entrances IV, V, I, II and III, so as to regulate the pressure of piston chambers to make the cylinder move to-and-fro and thus form shock. When high-pressure oil moves into the high-speed switch valve 2 and the valve is connected with the tank, the spool of the oil-distributing valve moves left to the endpoint (as shown in Fig.1)[1]. Under such circumstances, entrance IV is connected with entrance II and entrance V with III. The high-pressure oil enters into the right chamber of UHSS, and the left chamber is connected with the oil tank, which makes the chamber pressure fall. The piston rod moves left. When high-pressure oil enters into the high-speed switch valve and valve 2 is connected with the tank, the spool moves to the right endpoint. Under such circumstances, entrance IV is connected with entrance I and entrance V with II. The high-pressure oil moves

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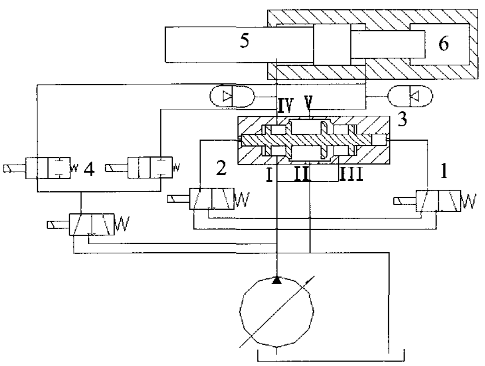
into the left chamber of the piston. The right chamber delivers high-pressure oil into the tank to reduce its pressure. The piston rod 5 moves right. Before UHSS works, group 4 of electromagnetism valves works and high-pressure oil enters into the two chambers of the cylinder, which prevents the impulsion due to too large difference of pressure at the time of startup[2]. In the end of work, group 4 works again and the hydraulic oil in the two chamber of the cylinder enters into the tank.

This UHSS is controlled mainly by two high-speed switch valves. Its rated frequency is 25Hz. The control system mainly controls the movement of the high-speed switch valve, and the valve controls the piston. If the control system can't work normally, the movement of the piston rod is directly influenced. Because of the important role of the control system, it is necessary to analyze it. The control system will be built in the following, based on the work principle[3].



1,2. high-speed switch valves; 3. oil-distributing valve; 4. a group of electromagnetic valve; 5. piston rod; 6. nitrogen chamber

Fig.1 Shovel work principle

3 Control system model

This UHSS works as the following description. Two high-speed switch valves control the motion of oil-distributing valve. By this way, the flowing direction of high pressure oil is adjusted. As a result, the piston rod moves quickly to-and-fro. In order to utilize PWM signal driving the high-speed switch, a single-chip-computer is needed to give out signals. The feedback signal from the pressure sensor is an analog signal too. The single-chip-computer is also needed to change these signals into digital parameters as judgment signals. The single-chip-computer is not good at calculation, and the program's inputted repair is very difficult. Using the system pressure to adjust shock energy in real-time, and calculation is too huge. Then it is very difficult for single-chip-computer implementing. So this control system uses master and slave computers, implementing the program calculation by master computer. The press sensor feeds the oil pressure of the hydraulic system back to the slave computer so that the slave computer gives out correct control signal. The detailed control framework is shown in the following Fig.2.

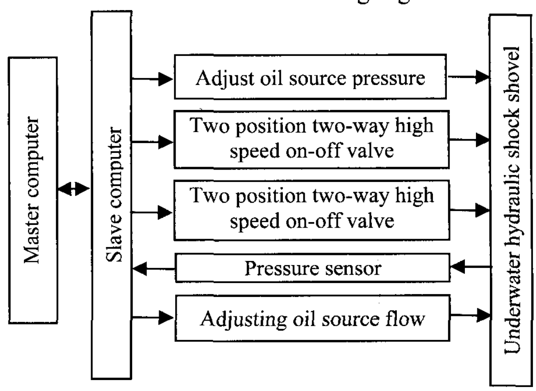


Fig.2 Control system framework of UHSS

4 Analysis of the control system

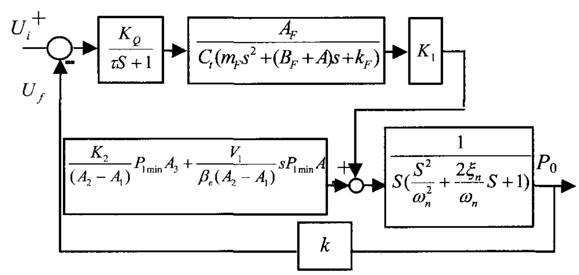


Fig.3 Control system block diagram of UHSS in the forth course

Based on above analyses, the control system is built for UHSS. The control system framework is illustrated in Fig.3. In the figure, K_Q is the flux gain of high switch valve, A_F is the loading area difference on both sides of the valve spool, m_F is equivalent mass of spool and its inner oil, x is the displacement of the spool, B_F is the damp coefficient of spool, k_F is oil equivalent stiffness in spool, C_t is leakage coefficient, A_1 is the section area of the cylinder's left chamber, A_2 is the section area of another chamber, V_1 is the volume of the cylinder's right chamber. The input is voltage in the control system and output is oil pressure of the hydraulic system. The control model is built and analyzed.

Figs.4 and 5 are open-loop control Bode diagram and open-loop transfer function step-up response curve respectively. Based on Fig.4, the control system has definite amplitude and phase extremum, and therefore, the system is steady. But the open-loop gain and the closed-loop frequency bandwidth are very low, and response speed is low, as shown in Fig.5. The system is not good at tracking because there is larger adjustment scope of amplitude and frequency, appropriate emendation method and control tactic are adopted to improve performance of the system.

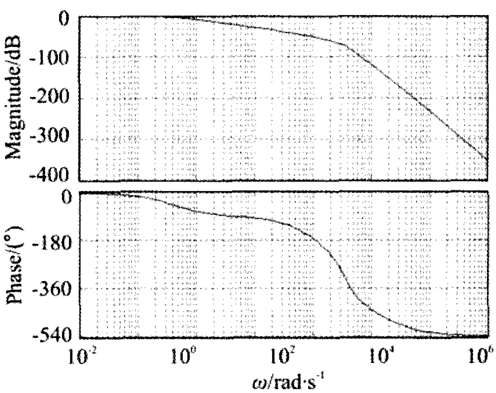


Fig.4 Bode diagram of control system

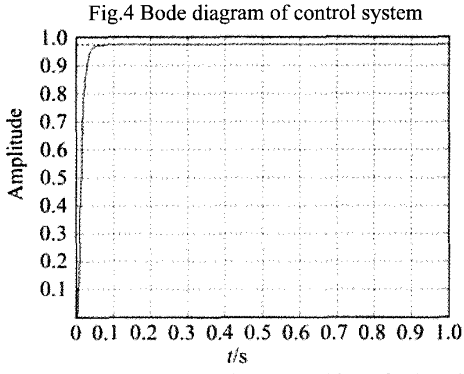


Fig.5 Step curve of control system without feed-back

In order to amend the control system, firstly the PID controller is added to the control system. Proportional element, integral element and derivative element coefficients are changed to gain different control system outputs. At last, through reasonable combination of three coefficients, the required system outputs are gained. Several PID coefficients' combination Curves are shown in Fig.6. The unmarked curve is the response curve before PID improvement. All the curves are system response to step signals. Analysis results are shown in Fig.6. Choosing the PID coefficients reasonably could improve the control system's response speed to some extent. But the time to get stabilization is more than the required one, and such response speed could not fulfill the design requirement. The UHSS controls these high speed on-off valves by judging the pressure-sensor feedback signal. In different work environments and UHSS work states, the system parameters would be different. From this point, the control system belongs to time-varying uncertain systems, and using PID controller could not get ideal results. In order to get good control results by PID controller, the proportional, integral and differential coefficient should be adjusted to form a kind of complicated nonlinear relation. It is difficult for general PID controller. To solve such problems, the neural network method is introduced to PID controller. Neural network has such ability to express any nonlinearity. By studying the system's performances, the best PID control combination could be formed. Using BP network, the self-study PID controller, including coefficients K_P, K_I and K_D, is built.

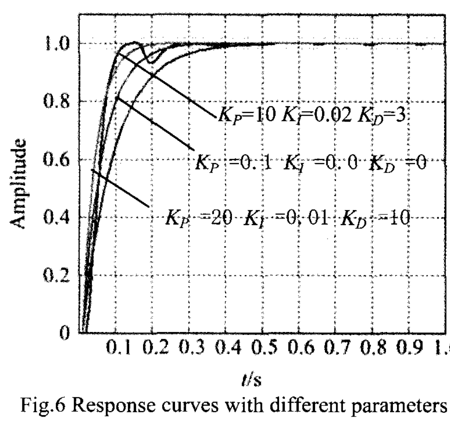


Fig.6 Response curves with different parameters

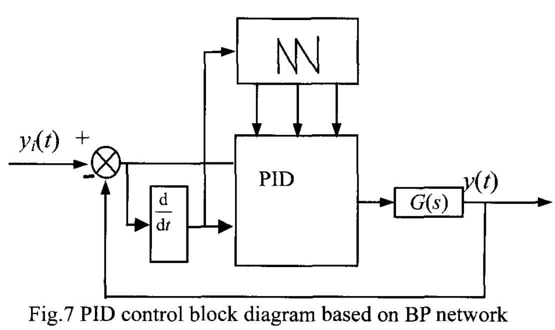
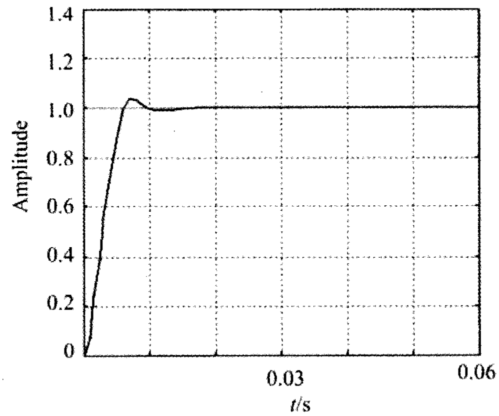
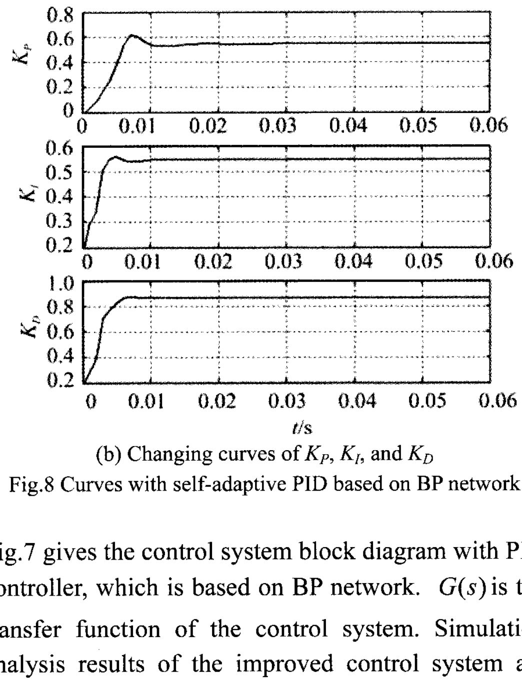


Fig.7 PID control block diagram based on BP network



(a) Step response curve



(b) Changing curves of K_P, K_I, and K_D

Fig.8 Curves with self-adaptive PID based on BP network

Fig.7 gives the control system block diagram with PID controller, which is based on BP network. $G(s)$ is the transfer function of the control system. Simulation analysis results of the improved control system are shown in Fig.8, including the system response curves and the changing curves of PID controller's three parameters. Left of the Figure is the step response signal and the right shows the changing curves of PID controller's three parameters. This control system is stable within 0.015s, and overshooting is less than 5% , rise time is 0.006 s. Therefore, after improved, the control system can fulfill requirements of the control system response speed and its stability, and implement this UHSS system control.

5 Conclusions

The control system is an important part of UHSS. Whether reasonable or not, that would directly decide the UHSS function. Its control system is analyzed and improved in this paper. As a result, the control system can fulfill the design requirements in given time and stably. With technological development, advanced control methods are introduced to the control system, which will improve the control systems notably. In the meantime, some general control methods to be implemented difficultly become easy.

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