Research on Intelligent Control Algorithm for Automatic Drilling of Vehicle-mounted Rig

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Abstract. The adaptability of traditional PID, fuzzy PID and feedback linearization sliding mode variable structure control intelligent algorithm to automatic drilling is analyzed. The results show that the feedback linearization sliding mode variable structure control algorithm has more ideal response speed, control accuracy and robustness, which solves the nonlinear problem of the electro-hydraulic control system of the truck-mounted drilling rig and improves the tracking control accuracy of the system during automatic drilling.

Keywords: PID control algorithm; Fuzzy PID control algorithm; Feedback linearization sliding mode variable structure control algorithm; Automatic drilling

Introduction

1. Introduction
The vehicle-mounted drilling rig is a special drilling construction equipment formed by integrating the drilling function module on the chassis of a special vehicle. It is mainly used for shallow oil and gas extraction holes, geothermal wells, engineering holes and emergency rescue wells. With the increasing demand for ground drilling construction safety, construction efficiency and mechanization reduction, vehicle-mounted drilling rigs are rapidly changing from machine-hydraulic control to electro-hydraulic automatic control, and are gradually exploring intelligent control technology[1,2]. And with the development of electronic and computer-related technologies, automatic drilling intelligent control algorithms have gradually become a hot topic of research[3].

Vehicle-mounted drilling rig is a large-scale construction equipment integrating electromechanical and hydraulic integration. The electronic control system is the brain and nerves[4]. The reliability and adaptability of the control algorithm of the electronic control system play a decisive role in the quality and accuracy of the execution of electromechanical hydraulic system actions. The research of drilling intelligent control algorithm has important theoretical significance and engineering application value [5,6].
2. Research status of automatic drilling technology
Automatic drilling employs sensor technology to detect electro-hydraulic system parameters, and then the control signal is output through the calculation of the intelligent algorithm, which controls the solenoid valve of the electro-hydraulic system to adjust the pressure, flow and direction of the hydraulic system, and drive the feed and rotation to take action[7,8]. At the same time, each sensor monitors the parameters of the electro-hydraulic system, and transmits, displays, and feeds back these drilling parameters through the electronic control system to achieve closed-loop automatic control, fault diagnosis, alarm and other function.[9,10] The driller is liberated from the heavy, harsh, and dangerous working environment through automating the physical and mental labor in the control process of material flow and information flow, and the mechanized substitution and automatic reduction of personnel are realized, which has a significant social and Economic benefit. SPE has specifically set up technological breakthroughs and research directions for automatic and intelligent drilling technology. Automatic drilling, especially intelligent drilling, will be an important development direction for drilling rigs in the future[11].

3. Integration of automatic drilling system for vehicle drilling rig

3.1. Feeding Mechanical System of Automatic Drilling
The vehicle drilling rig's automatic drilling feeding mechanism adopts hydraulic cylinder-wire rope telescoping mast with double-speed feeding mechanism (Fig.1), which can realize the functional requirements of large pulling force, fast feeding and efficient drilling.

![Feeding mechanical system](Fig.1)

3.2. Automatic Feeding Hydraulic System
In order to meet the requirements of fast drilling with low pressure and large flow rate and slow drilling with high pressure and small flow rate, the feed hydraulic system is designed in the form of dual pumps and dual main control valves. The main and auxiliary pumps control the hydraulic cylinder feed through the large flow M7 valve and the small flow M4 valve. The main and auxiliary pumps generate pilot pressure through the shuttle valve and the pressure reducing valve, and control the slow feed reversing valve M4 and the fast feed reversing valve M7 respectively through the pilot handle, and the feed or pull pressure of the feed hydraulic cylinder is controlled through overflow valve. A balanced explosion-proof valve is mounted on the oil port of the rodless cavity of the hydraulic cylinder to prevent the feed mechanism, power head and drill rod from falling when the hydraulic pipeline bursts.

3.3. Automatic Drilling System Integration
As shown in Fig.2 through the integration of the electro-hydraulic system, driven by the controller and hydraulic power system, the control console handle realizes the adjustment of the feed device mast pressure and flow through the reversing valve to complete the automatic drilling action. Implementation.
Fig. 2 Automatic drilling system integration

4. Research on Intelligent Control Algorithm of Automatic Drilling

The automatic drilling control system of the vehicle-mounted drilling rig integrates PLC and computer control technology. The drilling parameters are measured by sensors, and the computer judges the drilling status to make decisions. At the same time, it outputs control signals to drive the execution of components. The implementation of control decisions through the intelligent algorithm of the electro-hydraulic controller realizes automatic drilling, which can reduce the driller's labor intensity, reduce the long-term concentration and fatigue of the workers; improve the response speed and sensitivity of the control, and reduce the accidents in the hole. It can reduce the wear of the drill bit and increase the life of the drilling tool; increase the drilling speed and reduce the drilling cost; through the precise control of the position and force of the feed system, the drilling quality is improved.

Due to the complex and changeable formations encountered in drilling, it is characterized by strong time-varying, nonlinear and large random interference. The key technology in the automatic drilling process is to realize the integration of the vehicle-mounted drilling rig's mechatronics and hydraulics and match the system's displacement and force output characteristics with control expectations.

The accurate control of the displacement and force of the feed hydraulic cylinder during the drilling process is the guarantee for the realization of efficient automatic drilling. The core of automatic drilling is the precise control of the electro-hydraulic position and force of the valve-controlled hydraulic cylinder of the feed system. The control algorithm of the electro-hydraulic controller is the guarantee for automatic drilling, and the adaptability of the control algorithm determines the control quality and characteristics.

Mature intelligent control algorithms include traditional PID control, fuzzy control, sliding mode control, adaptive control and auto disturbance rejection control. At present, the automatic drilling electro-hydraulic system generally adopts PID control; the position and force drilling control objects have large non-linear and time-varying characteristics. For such complex uncertain systems, intelligent controllers based on fuzzy algorithms are effective method; as a representative of nonlinear robust control, sliding mode variable structure control has a strong application prospect in such nonlinear and strong interference control of automatic drilling.

4.1. Research on PID Control Algorithm

PID control is a linear controller based on classic control theory, which combines the proportional, integral, and differential linearity of the input error to form a controlled variable to control the object, and the output is used as a feedback signal to form a closed-loop control.

The PID control law is:

\[ u(t) = K_p e(t) + \frac{K_p}{T_i} \int_0^t e(t) \, dt + K_p T_d \frac{de(t)}{dt} \]

The transfer function form is:
AMESim and MATLAB/Simulink are applied for co-simulation, then the PID algorithm controller model is established in Simulink, as shown in Fig.3. Random force signals are chose to simulate external disturbances such as rock breaking resistance, hole wall friction and vibration during automatic drilling. AMESim is treated as a time discretization module to establish a communication interface module. The communication interface module and PID algorithm in Simulink are defined by S-Function function, and the algorithm and interface program are written in the m function text.

![Fig.3 PID control model](image1)

\[
\frac{U(s)}{E(s)} = K_P + \frac{K_P}{T_I s} + K_P T_D s
\]

The sine signal with amplitude of 0.15, offset of 0.15 and frequency of 0.4π rad/s is taken as the tracking target curve. The displacement output tracking control result of the PID closed-loop feedback model of the feed hydraulic cylinder piston position during the automatic drilling process is shown in Fig.4. It has a good tracking effect and the adjustment time and system overshoot are both small. The initial adjustment time is 0.36 s, and the tracking phase difference is almost 0. However, Large chatter appears at the peak of the sin curve, indicating that PID control accuracy and robustness have some shortcomings.

![Fig.4 PID control result](image2)

4.2. Fuzzy PID compound control algorithm

Fuzzy control has stronger adaptability and robustness. It can automatically tune the control parameters in the dynamic process of automatic drilling. It can take advantage of the strong adaptability of fuzzy control and refinement of PID control combined with PID. In the process of numerical calculation and analysis, the linear difference table is used to determine the value of output u:
The fuzzy PID control model is shown in Fig. 5. The sine signal with an amplitude of 0.15, an offset of 0.15, and a frequency of 0.4π rad/s is input as the tracking target.

The results of fuzzy PID tracking control in the process of automatic drilling are shown in Fig. 6. It can be seen that fuzzy PID control has better robustness and higher accuracy than PID, weakens system vibration, and improves anti-interference, but the stable adjustment time gets 0.48 s, indicating that the dynamic response speed of the fuzzy PID control algorithm is slightly lower than that of the traditional PID control.

4.3. Feedback linearization sliding mode variable structure control algorithm

For the automatic drilling electro-hydraulic control system with typical nonlinearity, the feedback linearization method is used to obtain the input and output global linearization model, and the sliding mode variable structure control algorithm can solve the unstable closed-loop control system caused by external interference, which has strong robustness.

The feedback linearization sliding mode control law is:

\[
u = \frac{\alpha \dot{e} + \beta \ddot{e} + \ddot{e} - k_{sat}(\Phi) - L_{f} \dot{h}(x)}{L_{g} L_{h}(x)}
\]

The sliding mode variable structure control model is established in MATLAB/Simulink (Fig. 7), and the result of sliding mode control is shown in Fig. 8. It can be seen from the figure that the sliding mode variable structure control algorithm based on feedback linearization can effectively suppress the influence of random sudden changes and interference of external load on the control quality of the
automatic drilling electro-hydraulic system, and has good tracking control accuracy, response speed, robustness and stability.

![Fig.7 Feedback linearization sliding mode controller model](image1)

**Fig.7** Feedback linearization sliding mode controller model

![Fig.8 Feedback linearization sliding mode control result](image2)

**Fig.8** Feedback linearization sliding mode control result

5. Conclusion
Through research on the adaptability of traditional PID, fuzzy PID and feedback linearization sliding mode variable structure control algorithm to automatic drilling position tracking control, the results show that traditional PID and fuzzy PID compound control and sliding mode variable structure control can effectively solve the problem of precise control of the electro-hydraulic control system under external load sudden changes and interference conditions during the automatic drilling process of the vehicle-mounted drilling rig. However, the feedback linearization sliding mode variable structure control algorithm has more ideal response speed, control accuracy and robustness.

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