Design and Test of Downhole Weight on Bit-Based Autodriller System for Horizontal Well

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Abstract — During horizontal well drilling, the pressure difference between the downhole weight on bit (DWOB) and the surface weight on bit (SWOB) will affect the service life of the drilling tool and the efficient production of oil and gas fields. An automatic drilling system device based on DWOB is designed. Choose the S7-200 smart PLC with good expansibility, combine the drilling rig automation principle, and use the Smart-700IE-V3 touch screen to design the human-computer interaction interface. Realize the real-time monitoring and prediction of DWOB. A large amount of test data shows that the new system not only has the advantages of the conventional automatic drilling system, but also can reduce or even eliminate the pressure difference between the surface and the bottom of the hole, achieve accurate control of the DWOB, improve bit performance, and reduce drilling costs.

1. Introduction

The existing automatic drilling system (automatic drilling system based on surface weight on bit) is difficult to accurately control the downhole weight on bit, and too large margin (the difference between the accurate value and the applied value) is used when controlling the SWOB (hook Load) to realize automatic drilling[1-3]. Inappropriate margin may lead to the instability of the drill string system, and there is a risk of drill string "locking up". Under such conditions of intense contact fatigue accumulation, drill tool failure and damage are prone to occur, causing stuck and other drilling accidents[4]. Therefore, it is very necessary to develop a new type of automatic drilling system (automatic drilling system based on DWOB) to eliminate or shorten this margin, which optimizes the performance of the drill bit and provides a new theory for horizontal well drilling technology.

2. Overall system design

2.1. Sampling node

The automatic drill feed system based on DWOB designed in this paper can be applied to most oil wells. For data collection and parameter status identification, there must be a central service node to capture
data for recording and analysis, mainly using various sensors and the smart meter to obtain ideal parameters. The feedback and processing of the data is realized by analog-to-digital conversion through electronic components such as programmable controllers and sensors. The sampling node and the central service node of the system data collection are transmitted by smart devices with Twist-Pair through wired transmission, which has stronger stability, reliability and confidentiality, more complete supporting equipment, and more convenient use and maintenance.

2.2. Real-time monitoring
The monitoring and modification of important drilling parameters is realized during the drilling process, which are mainly displayed on the touch screen through upper computer programming. The programmable controller realizes the status recognition, obtains the status parameters that affect the device such as the motor speed, direction, etc., to determine whether the equipment is operating normally, and alarms the failure, and let the staff take remedial measures. In addition, with the addition and improvement of functions in the design process, the system is required to have a certain degree of scalability for subsequent optimization. Therefore, electronic components such as programmable controllers with more input and output interfaces, sensors with larger ranges, etc. are selected to meet the future technical requirements.

3. Hardware design
The hardware design details must take the system functionality and cost into consideration. In order to better analyze the relationship between the DWOB and the SWOB, a set of horizontal well automatic drilling system based on DWOB is designed. A three-dimensional fine model of a small horizontal well with the same functions as the real drilling platform is established as shown in Fig 1.

3.1. Abbreviations and Acronyms
Hardware configuration
Combining the eight major systems of the oil rig, the crane and traveling block of the traveling system are replaced by pulleys. The transmission system uses a manual and automatic winch with its own brake to replace the structural function of the winch. The hoisting system selects an integrated single hook with high load-bearing capacity, and connects the pulley and the drill string through a drilling line. According to the theory of "rotor-bearing system dynamics", the drill string system can be simplified into a rotating shaft with uniform and continuous mass distribution\(^5\). Piezoresistive sensors are used in the sensor system design of various industries\(^6\). The hook sensor adopts the S-type tension pressure sensor DHZ-101. The DWOB measurement depends on the DH4011/TJL-1, a type of high-precision tensioning pressure sensor. In this experimental device, the pressure signal is converted into a current signal of 4 ma-20 ma, which is transmitted to the PLC through the high-precision measuring instrument
model DH300, and finally the measurement, display, data collection and recording of the physical parameters of the device are realized on the touch screen.

The power drive system chooses electromagnetic mechanical stepping motor, which has high control accuracy and stable performance, and is widely used in fields such as CNC machine tools and robots\cite{7}. The tricone bit in the drill string system has been successfully designed, and tricone bits are applied at home and abroad in so many years, indicating that it has a better rock breaking efficiency than conventional PDC bits, and is the first choice for horizontal well downhole assembly\cite{8}. In order to ensure that the device can simulate the relationship between downhole WOB and surface WOB in different wellbore structures, a wellbore support with a changeable wellbore structure as shown in Fig 2 is designed to simulate drilling under different wellbore structures.

3.2. Hardware platform implementation

This experimental platform uses welding manufacturing as the carrier, combined with the above-mentioned mechanical body, adopts the SIEMENS S7-200 Smart PLC controller, realizes the motor control through the high-speed pulse output port of the PLC, and realizes the communication with the Smart-700IE-V3 touch screen; Set the hook load and DWOB parameters to achieve stable, fast and accurate feedback. The device strictly complies with electrical specifications and electrical components are arranged reasonably to ensure safety and stability, and the wiring is neat and beautiful. At the same time, the platform does grounding treatment on the metal shell to ensure the personal safety of test personnel. The real platform is shown in Fig 3.
4. software design

4.1. Control program programming design and realization

The control system of this device consists of a main control module, a drive module, a power supply module and a sensor module. Control principle and realization goal, with Siemens STEP 7-MicroWIN SMART programming software, the internal program is compiled to realize the expected function. Taking the load end sensor of the hook as an example, the WOB control algorithm is programmed, and the system can adjust the WOB in real time according to the sensor signal to achieve the purpose of quickly and accurately controlling the WOB. Part of the program flow is shown in Fig 4.

Combining the Smart-700IE-V3 touch screen to design the human-computer interaction interface as shown in Fig 5, relevant research is carried out in terms of the real-time WOB acquisition mechanism of the downhole and the control strategy of the target SWOB.

The center position of the touch screen shows the trend curve of real-time hook load and real-time downhole weight during tripping and tripping, and the split screen buttons "motor speed curve", "SWOB
curve", and "DWOB curve" are set at the bottom. "It is used to display detailed curves in detail, and accurately display the curve relationship between hook load and DWOB in real time[9].

5. Test results and analysis

According to the designed intelligent automatic drilling system device based on DWOB, the actual drillability range of DWOB measured in actual tests is 0.3N-10.4N, and the settable parameter range of hook load is 1.5N - 17.4N; Under this wellbore condition, a total of 10 sets of real values of hook load and DWOB were measured, and their real average values were obtained as shown in Table 1.

| DWOB Setting value (N) | Hook load actual value (N) | DWOB actual value (N) | Hook load actual value (N) | DWOB actual value(N) | Hook load actual value (N) | DWOB actual value (N) | Hook load actual value (N) | DWOB actual value (N) | Hook load actual value (N) | DWOB actual value (N) |
|------------------------|----------------------------|-----------------------|----------------------------|-----------------------|----------------------------|-----------------------|----------------------------|-----------------------|----------------------------|-----------------------|
| 0.1                    | 17.0                       | 0.3                   | 17.1                       | 0.3                   | 17.4                       | 0.4                   | 17.0                       | 0.4                   | 16.9                       | 0.5                   |
| 1.0                    | 14.9                       | 1.1                   | 15.1                       | 1.1                   | 14.7                       | 1.1                   | 15.0                       | 1.1                   | 15.5                       | 1.2                   |
| 2.0                    | 15.4                       | 2.1                   | 15.7                       | 2.5                   | 15.5                       | 2.5                   | 15.4                       | 2.5                   | 15.2                       | 2.2                   |
| 3.0                    | 12.2                       | 3.2                   | 12.3                       | 3.2                   | 14.4                       | 3.2                   | 14.7                       | 3.2                   | 12.1                       | 3.0                   |
| 4.0                    | 10.6                       | 4.1                   | 11.1                       | 4.1                   | 10.6                       | 4.2                   | 12.4                       | 4.3                   | 9.8                        | 4.0                   |
| 5.0                    | 9.9                        | 4.6                   | 5.1                        | 4.9                   | 10.4                       | 5.4                   | 11.6                       | 5.2                   | 9.2                        | 5.1                   |
| 6.0                    | 7.7                        | 4.0                   | 7.1                        | 3.6                   | 10.3                       | 7.8                   | 11.0                       | 5.2                   | 9.0                        | 4.4                   |
| 7.0                    | 6.1                        | 4.0                   | 6.7                        | 3.6                   | 10.3                       | 7.9                   | 11.1                       | 5.6                   | 8.9                        | 4.6                   |
| 8.0                    | 5.1                        | 3.9                   | 7.8                        | 3.4                   | 10.3                       | 7.8                   | 11.0                       | 5.5                   | 8.8                        | 4.8                   |
| 9.0                    | 5.0                        | 3.8                   | 8.1                        | 3.3                   | 10.4                       | 8.0                   | 11.0                       | 5.6                   | 9.0                        | 4.9                   |
| 10.0                   | 4.0                        | 3.6                   | 8.2                        | 3.2                   | 10.3                       | 8.2                   | 11.0                       | 5.7                   | 9.0                        | 5.0                   |

Within the effective range of downhole drillability parameters, the hook load is steadily adjusted to obtain the true value of DWOB. Here, 10 sets of data are also measured and the average value is obtained, as shown in Table 2.

| Hook load setting value (N) | Hook load actual value (N) | DWOB actual value (N) | Hook load actual value (N) | DWOB actual value (N) | Hook load actual value (N) | DWOB actual value (N) | Hook load actual value (N) | DWOB actual value (N) | Hook load actual value (N) | DWOB actual value (N) |
|-----------------------------|----------------------------|-----------------------|----------------------------|-----------------------|----------------------------|-----------------------|----------------------------|-----------------------|----------------------------|-----------------------|
| 16.9                       | 17.2                       | 0.0                   | 17.0                       | 0.0                   | 17.0                       | 0.0                   | 17.1                       | 0.0                   | 17.2                       | 0.0                   |
| 15.1                       | 15.4                       | 1.4                   | 15.2                       | 1.3                   | 15.1                       | 1.4                   | 15.1                       | 1.4                   | 15.2                       | 1.8                   |
| 15.0                       | 14.9                       | 1.5                   | 15.0                       | 1.5                   | 15.0                       | 2.0                   | 14.9                       | 2.0                   | 15.1                       | 1.8                   |
| 13.5                       | 13.3                       | 3.3                   | 13.1                       | 3.6                   | 13.4                       | 3.9                   | 13.1                       | 3.5                   | 13.2                       | 3.7                   |
| 11.4                       | 11.3                       | 4.8                   | 11.3                       | 5.1                   | 11.3                       | 4.6                   | 11.2                       | 4.2                   | 11.3                       | 4.1                   |
| 10.3                       | 10.0                       | 5.6                   | 10.2                       | 5.6                   | 10.3                       | 5.3                   | 10.2                       | 5.6                   | 10.3                       | 5.5                   |
| 9.1                        | 8.9                        | 6.3                   | 8.9                        | 6.3                   | 8.9                        | 6.2                   | 9.0                        | 6.2                   | 9.1                        | 6.4                   |
| 8.0                        | 7.7                        | 7.8                   | 7.8                        | 7.6                   | 9.0                        | 7.8                   | 7.7                        | 7.9                   | 9.1                        | 7.9                   |
| 6.5                        | 6.1                        | 8.0                   | 6.2                        | 8.0                   | 8.1                        | 8.4                   | 6.3                        | 8.0                   | 8.3                        | 8.2                   |
| 5.4                        | 5.0                        | 7.8                   | 5.2                        | 7.8                   | 8.6                        | 5.4                   | 8.5                        | 5.2                   | 8.8                        | 5.1                   |
| 3.0                        | 2.8                        | 10.2                  | 2.9                        | 10.1                  | 2.7                        | 10.2                  | 3.1                        | 9.3                   | 2.6                        | 10.3                  |

According to the measured average real value of hook load and average real value of downhole WOB, the fitting curve and regression equation between the two are obtained as shown in Fig 6.
Figure 6  Fitting curve and regression equation

According to the comparison between the DWOB measured by the system and the theoretical value, the comprehensive error between the predicted value of the DWOB obtained by the actual measurement and the theoretical value is only 1.3%. The analysis of a large number of experimental data results shows that the system responds quickly and accurately, and the prediction obtained from the real measurement DWOB and the ideal DWOB match well, trend or value. The source of error comes from the tool itself, such as the vibration of the drill string system.

6.  Conclusion and recommendation
(1) A three-dimensional horizontal well model is created, the hardware body manufactured, and the system's control program and monitoring system obtained through PLC and touch screen programming. A set of physical devices of the automatic drill feed system based on DWOB was built.
(2) Field experiments are conducted. According to the fitting curve between DWOB and hook load, the regression equation between the two is obtained, and the DWOB on any well structure is predicted. The result shows that the prediction is obtained. The downhole weight of bit and the actual measured downhole weight of bit match well both in trend and value.
(3) The most obvious feature of the new system: given DWOB, the system can correctly apply hook load (SWOB) in real time to achieve DWOB stability. This process of predicting the DWOB and obtaining the SWOB if given DWOB is called automatic drilling based on DWOB.
The designed automatic drill feed system based on DWOB can enable companies or oil fields to use previously unknown DWOB as direct drilling parameters. It not only has the advantages of conventional automatic drill feed systems, but also can reduce or even eliminate the pressure difference. The downhole WOB calculation model can be integrated with the conventional automatic drilling system, thereby improving the performance of the drill bit and drilling efficiency, extending the life of the drilling tool and reducing the drilling cost. In view of the current international background in which part of the country’s oil drilling technology is restricted by others, the development of high-level horizontal well control technology with independent intellectual property rights is of great significance for breaking through foreign technology blockades and improving my country’s comprehensive national strength.

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