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RESEARCH OF AUTO-DRILLING TECHNOLOGY BASED ON PARAMETERS' SELF-TUNING FUZZY CONTROL

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ABSTRACT

Due to the shortcomings of the traditional drilling way, as well as the complexity and difficult mathematical model of the drilling process, etc， this paper briefly analyses the principle of auto-drilling system on AC frequency conversion and the relationship among all factors that affects on the auto-drilling and puts forward a technology that combines parameters' self-tuning fuzzy control with constant WOB(Weight On Bit) auto-drilling technology on AC frequency conversion. Through the judgment of drilling pressure trend, the application of parameters' self-tuning fuzzy control realizes the control of the rig's speed. The algorithm does not need accurate mathematical model, and it can learn to fix control parameters in real time by itself. The test shows that the control system has good performance and ensures constant WOB and stable speed in auto-drilling, and the control algorithm can also be used in other auto-drilling systems.

Keywords: *Conversion Rig; Constant WOB Auto-drilling; Parameters' Self-tuning; Fuzzy Control*

1. INTRODUCTION

In the process of drilling, the purpose of sending-drill is to control send-drilling speed and make the pressure of drill smooth and steady as far as possible. The traditional drilling is mainly that the mechanical brake is manually controlled by the driller[1].With the development of computer technology, auto-drilling system based on the main motor with AC frequency conversion of the electric driving and auxiliary motor has been more and more extensively applied in drilling site. The system uses motor anti-drag to realize constant WOB when drilling and precise control of quadrant operation of the motor realizes the direct control of the motor output. In normal drilling, auto-drilling with a required WOB can basically make a WOB constant by controlling the output of the motor and don't need drillers to operate machinery disk-brakes to control drilling any more, which can greatly improve the speed and stability of drilling and drilling quality .Mechanical disk-brakes no longer wear. At the same time, the bus system of combining PLC with frequency converter always monitors electrical system completely and interlocks with dish-brake security clamp. When misuses or malfunctions of the electrical system came, it can brake automatically and securely to avoid churn drill, which greatly improves drilling safety and performance.

According to the differences of drilling parameters, Auto-drilling can be divided into constant WOB control, constant drilling-speed control, constant torque control, constant pump pressure control, but constant WOB control is most widely used. With the continuous development of intelligent control technology, the fuzzy control, the neural network control [2], etc algorithms are continuously put forward, but rarely is practically applied in the field. This paper proposes a kind of algorithm based on parameters self-tuning fuzzy PI control, which revises control parameters, output drilling speed in time, and realize drilling with constant WOB and steady speed.

2. DRILLING SYSTEMS AND PARAMETER ANALYSIS

2.1 Influence Factors of WOB Changes In Drilling Process

In the process of drilling, WOB is influenced by geological structure, rock properties, drilling fluid properties, sidewall resistance, etc [3], The changes of WOB 'P' is related by drilling speed 'v', rotary speed 'ω', stratigraphic hardness 'γ', the pressure of drilling fluid circulation 'Pm' and concentration C, formula 'H', etc many kinds of factors: $P= f(v\ \omega, \gamma, Pm, C, H)$ (1)

The quality of drilling is affected by two factors.

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One is the objective factors which cannot be arbitrary changed, such as geological conditions etc. The other is the controllable variables including the drilling bit type, WOB, rotation speed etc. In the controlled variables, once the drilling equipment is confirmed, the appropriate bit type can also be done. Therefore, in the drilling process, WOB and rotation speed are the two main parameters need to be controlled.

About mathematical expressions between parameters above all, the most influential and authoritative mathematical expression is the model of drilling speed by Young F.S. in 1969, known as the Young mode, and the fixed Young mode is now widely used as formula 2[4]:

$$V = K_1 C_P C_H (P - M) n^{\lambda} \frac{1}{1 + C_2 h} \quad (2)$$

The meaning of parameters are as follows: V is ROP;K1 is the coefficient of rock that can be drilled, and relates to rock hardness and type of the drill; CP is influence coefficient of pressure difference and relates to mud density, etc; CH is the influence coefficient of hydraulic parameters; P is drilling pressure of bottom hole; M is the threshold WOB and relates to the nature of the rock; n is the speed of rotary table; λ is rotary speed exponent, relates to rock properties;C2 is wear coefficient of drill teeth, and relates to characteristics of teeth and rock; h is drill teeth wear, which changes with time. It can be seen that under the condition of keeping rotate speed 'n' and other parameters invariable, after overcoming threshold WOB 'M', ROP is direct proportional to WOB 'P'.

2.2 Drilling Systems and Parameter Analysis

WOB and rotate speed are the basic parameters of a direct effect on the bottom hole with broken rocks, which not only affect ROP, but also affect the wear rate and work life of drill. Therefore, in optimization of WOB and rotate speed, their impact must be taken into consideration [1].

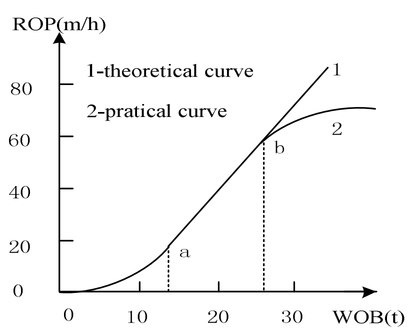

Figure 1 The relation curve between WOB

From figure 1, in the ab section, with the increase of WOB, the corresponding amount of detritus increases, but because of the constant hydraulic parameters, purifying conditions of the bottom hole gradually become poor, the growth rate of ROP decreases step by step and there is a linear relationship between ROP and WOB. From figure 2, it can be seen that rotate speed is in direct ratio with ROP under the purification of bottom hole fully.

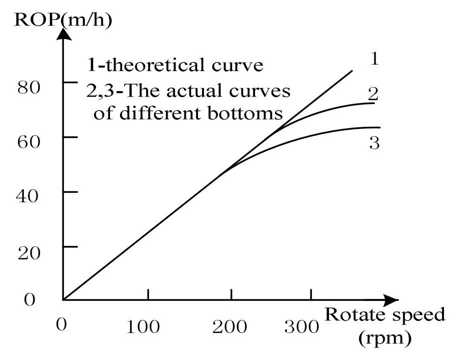

Figure 2 The relation curve between ROP and rotate speed

2.3 Pure lag phenomenon

According to experiences, drill pipe can be regarded as a rigid in the range of a certain length, but because the well depth are large (thousands of meters), the drill pipe has elastic properties with the increase of the drill pipe length. In the drilling process, although the down speed of the winch has changed, the ROP of drill in the deep well doesn't immediately change, so the pure lag phenomenon happens, that is, there is a delay from the change of drill-pipe speed to WOB change of bottom hole.

3. AUTO-DRILLING PRINCIPLE ON AC TRANSDUCTION

3.1 Auto-drilling System with Constant WOB

Auto-drilling system will process the deviation of set value and actual sampling value of the WOB in PID algorithm, control speed of winch sending-drill motor through frequency conversion, and use the control mode of three closed loops, t hat is, the outside loop is for WOB, the second is for speed, and the inside is for current. So the inner loop can self-adjust interference in the process and weaken the influence about controlled variable of the outside greatly abate. In addition, the inertia of inner loop is self-adjusted, which improves the response speed of complete system, especially when the inertial time constant is greater, the effect is obvious.

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3.2 Auto-drilling of the Main Motor

Like figure 3, according to actual WOB collected the set value and other drilling parameters, it uses the algorithm to control the speed of sending drill. When the control unit of sending drill fails, the system can also make a switchover from auto-drilling to manual through the conversion switch and continue to work so as to improve the reliability. In addition, the system sets up the local negative feedback loop which consists of speed encoder, which helps to improve the stability of system, the nonlinear system and the control precision of auto-drilling motors' speed.

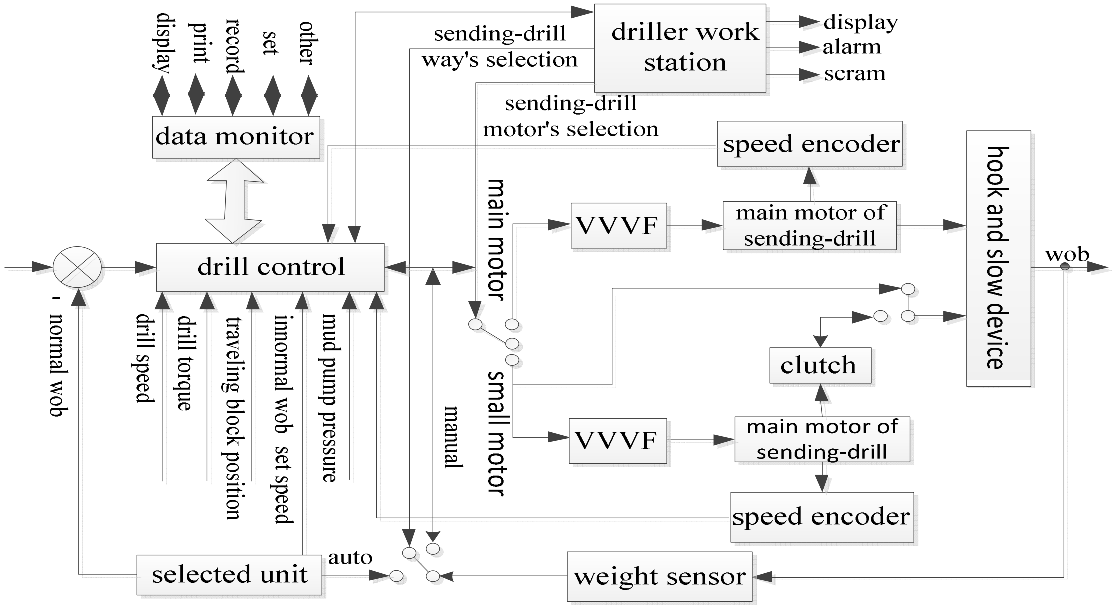

Figure 3 The relation curve between WOB

In addition, the system has a monitoring function of superior industrial PC, can display, store, print the parameters of drilling and realize the alarm and emergency brake etc. through monitoring WOB, drill torque, mud pump's pressure and traveling block's position.

3.3 Auto-drilling of the Small Motor

In auto-drilling process, the main motor has simple structure and convenient operation but lower running frequency, which is more vulnerable to harmonic signal interference, cuts down the control precision of system and makes performance poor, so the auto-drilling system of a auxiliary motor in front or behind of winch with the basically same principle as the main motor is mostly applied. It responses sensitively and the auxiliary motor can meet emergencies when the main motor breaks down. Because low speed and big torque are needed in auto-drilling process, the small motor needs a gearbox with big reduction ratio. [1]

4. CONSTANT WOB AUTO-DRILLING

At present, the domestic manufacturers of auto-drilling control system mostly use traditional PID algorithm to calculate ROP for controlling frequency converter to realize closed loop control of ROP. When layer changes, the parameters of auto-drilling system need to be adjusted manually according to stratum situation, and it makes the system's operation complex, maintenance performance poor, adaptability bad. Based on it, this paper will combine WOB's control with fuzzy control and design a kind of parameters' self-tuning Fuzzy-PI controller to complete auto-drilling.

4.1 Traditional PID Algorithm

Control field widely adopted PID control like formula 3:

$$u(t) = K_p[e(t) + \frac{1}{T_i}\int e(t)d(t) + T_d\frac{de(t)}{dt}] \quad (3)$$

The conventional PID can obtain satisfactory effect on accurate mathematical model. But because the drilling process system itself also has time lag, time varying, nonlinear, etc and it is very difficult to establish precise mathematic model of the system, the traditional control theory is very difficult to realize accurate control.

4.2 Design of Parameters' Self-tuning Fuzzy-PI Controller

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4.2.1 Simple Fuzzy Controller

From figure 4, K1, K2, K3, E, EC and U are respectively quantification factors, scaling factor, linguistic variables of e, $\dot{e}$ and u. Control rules of fuzzy controller are as follows:

$$\begin{aligned} &if \quad E = A_i \quad and \quad EC = B_j \quad then\ U = C_{ij}, \\ &i = 1,2,\cdots,m;\ j = 1,2,\cdots,n. \end{aligned} \tag{4}$$

Ai, Bj, Cij stand respectively for PL, PM, NL, etc. The fuzzy relation

$$R = \underset{i,j}{\vee} A_i \wedge B_j \wedge C_{ij} \tag{5}$$

Namely

$$\mu_R(x,y,z) = \underset{i,j}{\vee} \mu_{A_i}(x) \wedge \mu_{B_j}(y) \wedge \mu_{C_{ij}}(z) \tag{6}$$

If e and $\dot{e}$ are respectively A and B,

$$U = (A \times B) \circ R \tag{7}$$

Namely

$$\mu_U(z) = \underset{x,y}{\vee} \mu_R(x,y,z) \wedge \mu_A(x) \wedge \mu_B(y) \tag{8}$$

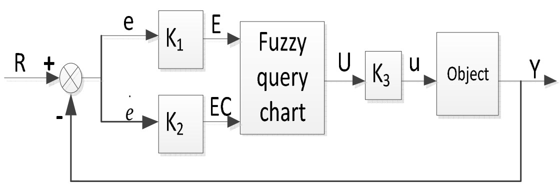

Figure 4 Simple fuzzy controller

4.2.2 Parameters' Self-tuning Fuzzy-PI Controller

Simple fuzzy controller is not the controller of good performance, because its output response is slow and has a big difference. In view that PI can get a high precision and speed up the dynamic response; it will improve the control performance to introduce PI structure into fuzzy controller. The relation between inputs with output of Fuzzy-PI controller is

$$U(t) = K_P \cdot U + K_I \cdot \int_0^t U dt = K_P \cdot U_i + K_I \cdot T \cdot \sum_{i=0}^{t} U_i. \tag{9}$$

In order to further improve the performance of the controller, an idea of K1, K2, KP and KI self-adjusting is proposed based on Fuzzy-PI controller, which makes them self-adjust with the difference between e and $\dot{e}$ .When e or $\dot{e}$ is bigger, substantial adjusting is applied, that is, smaller K1 and K2 and lower resolution of e or $\dot{e}$, at the same time, use bigger control quantities, such as bigger KP and KI. On the contrary, take the opposite strategies [5].Parameters' self-tuning fuzzy-PI controller is figure 5.

For simplicity's sake, the multiples of enlarging K1, K2 (or narrowing) is selected as same as that of narrowing KI, KP (or enlarging).Let the language variable N about magnification times as following fuzzy subset: N={AB, AM, AS, OK, CS, CM, CB} ,where AB, AM, AS, OK, CS, CM, CB denote a set of fuzzy concept such as big-amplifying, middle-amplifying, small-amplifying, changeless, small-concentrating, middle-concentrating, big-concentrating respectively. The N-domain is regulated as: N= (1/8, 1/4, 1/2, 1, 2, 4, 8). The fuzzy subset and membership assignment of E and EC of fuzzy-PI controller is still the same as that of the conventional fuzzy controller. The idea of parameters self-adjusting will be carried out according to the rules of table 2.

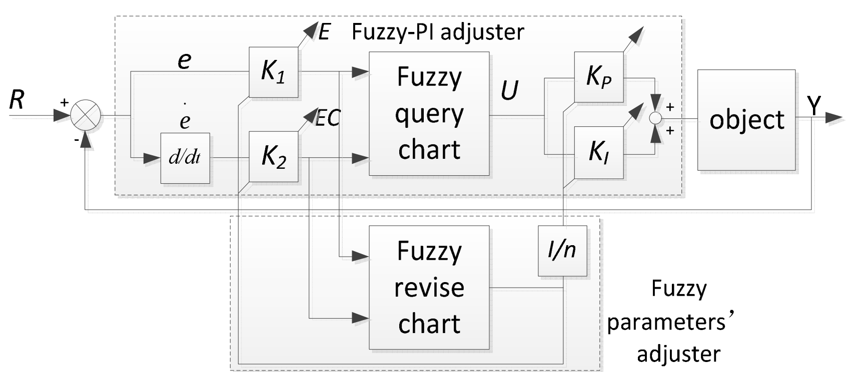

Figure 5 Parameters' self-tuning fuzzy-PI controller

Combining the composition algorithm as same as that of conventional fuzzy controller with an artificial modifying, we can deduce the parameters fuzzy modified table (shown as Table.4). The complex self-adjustment operation is actually equivalent to the simple look-up table. For one

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thing, we use the original K1, K2 to quantify e and $\dot{e}$, and then look up the parameters modified table to get the parameters enlarging (or decreasing) multiples n, after that we can calculate K1=K1n, K2=K2n, KI=KI/n, KP=KP/n as fuzzy controllers' new parameters.

Table 1 Fuzzy variable N's membership assignment table

	1/8	1/4	1/2	1	2	4	8
AB	0	0	0	0	0	0.5	1
AM	0	0	0	0	0.5	1	0.5
AS	0	0	0	0.3	1	0.5	0
OK	0	0	0.3	1	0.3	0	0
CS	0	0.5	1	0.3	0	0	0
CM	0.5	1	0.5	0	0	0	0
CB	1	0.5	0	0	0	0	0

Table 2 Parameters modified rules table

N		EC						
		NB	NM	NS	O	PS	PM	PB
E	NB	CB	CM	CS	OK	CS	CM	CB
	NM	CM	CS	OK	OK	OK	CS	CM
	NS	CS	OK	OK	AS	OK	OK	CS
	NO	OK	OK	AM	AB	AM	OK	OK
	PO	OK	OK	AM	AB	AM	OK	OK
	PS	CS	OK	OK	AS	OK	OK	CS
	PM	CM	CS	OK	OK	OK	CS	CM
	PB	CB	CM	CS	OK	CS	CM	CB

5. TYPICAL APPLICATION OF SYSTEM

The algorithm has been successfully used in the auto-drilling's device of 40LDB rig and the control effect is ideal. Figure 6 ~ 7 are field operation screenshots. Purple, green and red curve denote the actual ROP, the actual WOB and the set WOB respectively. The figures show that after auto-drilling system starts, it gradually adjusts ROP according to the fluctuation range of WOB until the suitable ROP under the conditions of current stratum. Under the condition of ensuring constant WOB, it operates steadily, feeds back sensitively and has smoother ROP and efficiently adaptive performance in the drilling process. From figure 7, once the stratum or the given value changes, the system will eventually turn stable after a period of self-learning.

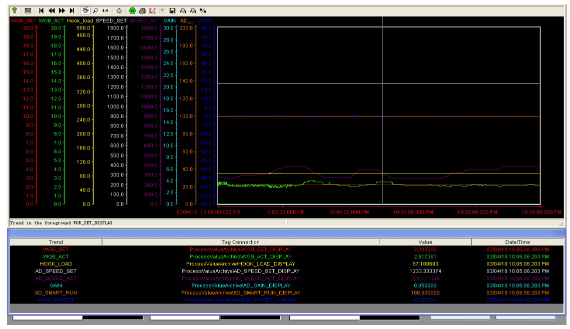

Figure 6 system's operation after parameters' self-tuning

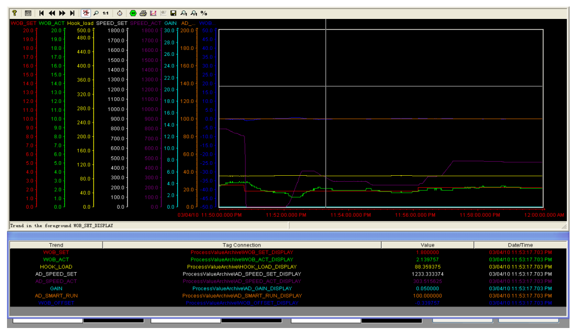

Figure 7 system adjustment trend after modifying set WOB

6. SUMMARY

Based on the conventional PID controller with accurate model, this design applies fuzzy PI control in auto-drilling process, adjusts parameters itself on line and improves the efficiency, self-adaptability, robustness and high precision of system's adjusting. Through the field application, it confirms that the algorithm's control effect is superior, and it can make steady precision within ±0.5T as well as sending-drill more smooth.

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