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Well control remote simulation system adaptive state feedback control method

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Abstract: **In order to reduce the oil and gas overflow in the process of drilling blowout accidents, effective protection of well control equipment and control right is the key to ensure the safety of well control.Need to drilling workers, drilling well control simulation training.To drilling well control of the remote machine simulation process, need to have the corresponding well control physical equipment and physical simulation drill platform operation, in order to create a real drilling environment for training personnel, and can be objective to display the level of training personnel operating the information and skills to achieve the purpose of simulation training.In order to achieve this purpose, the method of adaptive state feedback control is applied to the well control remote control simulation system.According to the system characteristics, design the adaptive steady-state controller, combined with the PID adaptive control, proposed an adaptive well control remote pressure oil preparation simulation of steady state feedback control algorithm.Method to verify the feasibility of taking the actual project as the background of Da qing oilfield drilling company simulation calculation and experiment results show that this method can make the operator and simulated under the environment of real close operation well control equipment, commonly used to implement inspection and operation of remote console and content of real operation training and other functions.**

Keywords: Well control remote console; Hardware simulation; Adaptive steady state feedback

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1. Introduction

In recent years, the development of drilling technolog -y, make a complete set of well control equipment increasingly complex, the existing well control equipment and relying on the working condition of well control showed a lot of problems in the production practice[1]. Especially when the overflow and other emergencies happened, more than one operator were not only required to synergistically cooperate to complete shut inaction, gestures information were also passed between each operation link to confire operating conditions one by one[2].

This operation mode process complex, cooperating with triangles, the error of any one link is likely to lead to the delay of optimal timing shut in, put well control safety into potential hazards and risks. Therefore, improving the well control quality of staff and well control safety consciousness were urgent things. Among them, the training of well control remote are the key. Remote console is control unit of the ground the bop, to control the hydraulic blowout preventer valve, special equipment the movement of hydraulic pressure well open and shut, indispensable equipment of preventing the blowout out of control in the process of oil and gas drilling[3]. Under the well control equipment in good condition the cor e of the problem is always to keep enough control pressure and oil mass. At the same time, with the rapid development of computer technology, the physical simulation gets the increasingly favour of industrial development, compared with the virtual simulation, physical simulation make personnel training the most close to the real operating environment training methods. Therefore, the well control the remote computer equipment of the present hydraulic control has been improved hydraulicand telecommunidevelope the dadaptive state feed back control method of a well control remote simulation system, based on this proposed adaptive well control remote station pressure oil preparation of simulation of the steady state feedback control algorithm[4].

2. Well control remote console physical simulation system principle

It is the key to the simulation training system for modifying the original well control remote console device, and operating electric pump pressure oil preparation has been done well in the existing remote console, three four way reversing valve for bop and choke valve switch operation ,and operating manual and pneumatic pressure reducing valve pressure regulation and remote console on standby condition and based on working condition of check increased teacher training system, mechanical servo and sound simulation system and key parts of the image system, etc. Achieve the function of simulation training on real devices. System mainly consists of the following sections[5]:

Decorating with encoder on the manual and manual valve valve, by testing the valve rotation, simulating the accurate control of the valve action process of operators; Equipped with magnetic sensors, detection of manual valve position, simulation operator control action; Equipped with infrared sensor, the simulation operator perspective changes.

Modifying the accumulator, the annular blow out preventer oil supply, ram preventer oil supply pressure

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signal to be electrical signal instrument, through the use of PLC control system and computer to acquire valve position detection signal analysis and calculation, output electrical signal control voltage meter movement, simulation of air pressure, oil pressure, etc. PLC controller complete the input of analog quantity and digital conversion, switch value input, operation and control of logic function, the switch quantity output, analog quantify output and transformation, and realize the communication of teachers control computer and the control of sound simulation system.

Equipped with wireless camera and video delivery system (projector, panoramic projection screen), perform image acquisition and recognition for the key parts of teacher's teaching , through the projection system, and conduct the detailed analysis and explanation cooperating with the three dimensional animation based on virtual reality technology.

Design sound simulation system, by recording the actual working condition of the acoustics and real time delivery, we simulate the effect of actual operators.

Design mechanical servo unit, the use of electricity transmission mechanical servo technology, realize in and out of locking lever of ram preventer, the control of hydraulic plate valve switch.

Teachers controls computer to realize the control and evaluation of the training process.For the teacher through the choice of training task, set different process conditions and parameters;Collect feedback signals of the PLC system, through software programming, and evaluate the action process of the operators. The simulation training system principle as shown in Figure 1.

3. Steady state feedback control algorithm of simulation of adaptive well control remote console pressure oil preparation

3.1 PID adaptive control

Today, the adaptive control theory research get rapid development, and adaptive control theory has been widely used in social each domain, one the most widely used is model reference adaptive control system and PID self-tuning control system. The model reference adaptive control system, the adaptive control system outstanding characteristic is that it itself is attached to a reference model, this model embodies the people's the requirements of the controlled object, that is to say, the characteristics of the reference object are the ideal characteristics of controlled object[6].

Model reference adaptive control system always made the adjustment according to the deviation between the state of the controlled object (or output) and the state of the reference model (or output) timely, in some indexes, the dynamic characteristics of controlled object and the reference model features is nearly as much as possible. In this way, regardless of the actual controlled object uncertainty how to influence, it can always ensure the ideal characteristics[7]. The core of designing this kind of adaptive control system is how to design the adaptive law, namely, adaptive mechanism should follow the algorithm[8], the design of the adaptive law currently have two different design methods, a method of local parameter optimization design method for using optimization technolominimum scheduled performance index and the downside of this approach can't always guarantee the system stable in parameter adjustment process. Another kind of design method is based on the theory of stability, and its basic idea is to make sure the controller parameter adaptive adjustment process is stable, and then try to make this process faster convergence.

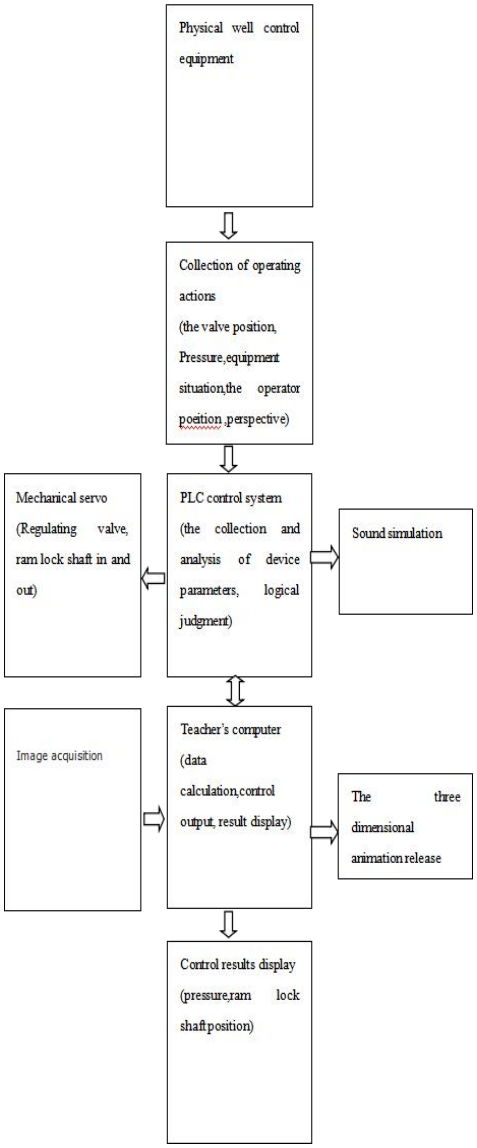

Figure 1. The principle diagram of the simulation training system.

PID control (Figure 2), the actual PI and PD control. PID controller based on the error of the system[9],makes the use of proportion, integral and differential and calculate.

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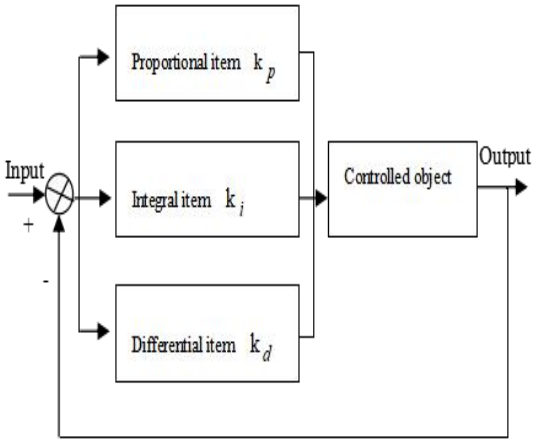

Figure 2. The principle diagram of the conventional PID control.

Typical PID can only use a fix set of parameters to control, and these parameters can't both have strong nonlinear, between dynamic performance and static performance of time-varying uncertainty system, and the contradiction between value and the disturbance rejection. Intelligent control system should be introduced by control system for this purpose, based on PID initial value by adding the modified parameters is adjusted, to improve dynamic and static performance of the system .

3.2 Steady state feedback control algorithm of simulation of adaptive well control remote console pressure oil preparation

3.2.1 Adaptive steady state feedback control

In steady state optimization of well control remote pressure oil preparation process, some dynamic transition process must exist, and its control mostly use the PID controller, and ensure the stability of the closed-loop system. Due to the highly nonlinear and complexity of dynamic working conditions of he actual well control remote console operation process of ,it is very difficult to achieve dynamic process better quality for these control . Some research based on the traditional PID feedback learning method[10], presented weighted open-loop D type, algorithm of PID type etc. For the process of the operation of the linear operation process and time delays, although its control structure is simple, there are many limitations of the method, and at the beginning of each feedback he state of the system reset to zero, but system operation is continuous, feedback select the optimal target trajectory to be certain the proportion of relations, require its type consistent, lack of flexibility, and meeting the requirement of the target trajectory is very difficult.

To explore control algorithm of suitable for the system, complete algorithm design and system simulation, based on the PID adaptive control algorithm, proposed steady state feedback control algorithm of adaptive well control remote pressure oil preparation simulation. Using the adaptive state feedback control controls the dynamic process of steady state optimization. According to the target trajectory initialization technology, after ensuring many adaptive steady-state feedback learning, follows the desired target trajectory of pressure oil preparation process, to make its the better dynamic performance, improving the feedback learning control is applied to selecting the target trajectory in steady-state optimizing control problem. Its control structure is shown Figure 3.

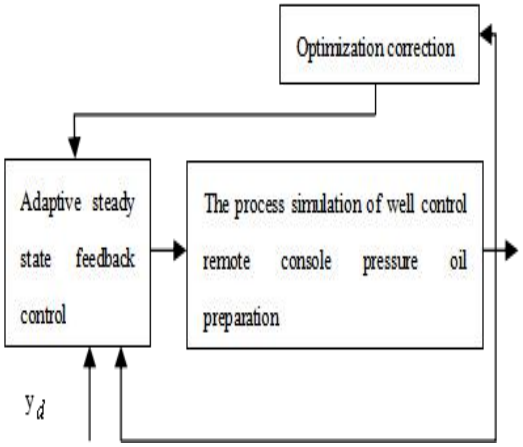

Figure 3. The controller structure.

Assuming the dynamic equation of well control remote console pressure oil preparation simulation control system is the following type of parameterized strict feedback (PSF) :

$$\begin{aligned}
\dot{x}_1 &= x_2 + \varphi_1(x_1)^T\theta \\
\dot{x}_2 &= x_3 + \varphi_2(x_1, x_2)^T\theta \\
&\vdots \\
\dot{x}_{n-1} &= x_n + \varphi_{n-i}(x_1,...,x_{n-1})^T\theta \\
\dot{x}_n &= \beta(x)u + \varphi_n(x)^T\theta \\
y &= x_1
\end{aligned} \tag{3.1}$$

$\theta \in R^P$ for the unknown parameter vector, $\beta(x)$ and $\varphi_i(x_1,...,x_i)$ for the known nonlinear function, $\beta(x) = 0$ y for system output ,u for the system's external input. u for the system' s external input. Where u is zero, (3.1) for closed-loop system of well control remote pressure oil preparation simulation process. Assuming in the process of steady state optimization of the remote console preparation of pressure oil process[11], producing the sequence of the step change of the set value range is c_1, c_2, ..., c_n, ..., and corresponding to each c_k , the system has a dynamic transition process. Today conduct feedback

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learning control for *a* series of dynamic response process of the system, Making the system output $y_k(t)$ gradually tracks the ideal target response rajectory v^k to obtain good dynamic performance. $y_d(t)$ by set value the transition to the set value c_{k-1}, and continuously on [0, T], *n* order to guide, has a good dynamic performance, *T* for the upper bound of the regulation time of each dynamic process response. Based on the thought of regulating function reverse recursive design of adaptive control[12], adaptive state feedback algorithm is put forward the control law:

$$u^k(t)=\frac{1}{\beta(x)}\left[\alpha_k^n+y_{k(n)}^d\right] \tag{3.2}$$

The parameter adaptive law:

$$\theta^k=\Gamma\tau_k^n \quad t\in[0,T] \tag{3.3}$$

Feedback variable are set as follows:

$$\begin{aligned}
&z_k^i=x_k^i-y_{k^{(i-1)}}^d-\alpha_k^{i-1}\\
&\alpha_k^i=-z_k^{i-1}-c_iz_k^i-\omega_{k^T}^i\theta^k\\
&+\sum_{j=1}^{i-1}\left(\frac{\partial\alpha_k^{i-1}}{\partial x_k^j}x_k^{j+1}+\frac{\partial\alpha_k^{i-1}}{\partial x_{k^{(j-1)}}^d}y_{k^{(j)}}^d\right)\\
&-k_i\left|\omega_k^i\right|^2z_k^i+\frac{\partial\alpha_k^{i-1}}{\partial\theta^k}\Gamma\tau_k^i \qquad (3.4)\\
&\sum_{j=1}^{i-1}\frac{\partial\alpha_k^{i-1}}{\partial\theta}\Gamma\omega_k^iz_k^j\\
&\tau_k^i=\tau_k^{i-1}+\omega_k^iz_k^j\\
&\omega_k^i=\varphi_k^i-\sum_{j=1}^{i-1}\left(\frac{\partial\alpha_k^{i-1}}{\partial x_k^j}\varphi\right)
\end{aligned}$$

Among them using *k* represents the feedback times, for the parameter output, assume

$$\bar{x}_i(x_1,\ldots,x_i),x=(x_1,x_2,\ldots,x_n),z=(z_1,z_2,\ldots,z_n)$$

The initial conditions of adaptive feedback:

$$\begin{aligned}
x^k(0)&=x^{k-1}(T)\\
\theta^k(0)&=\theta^{k-1}(T)
\end{aligned} \tag{3.5}$$

Target track initialization: Set the desired trajectory of feedback requirement in the first *k* times as $y_k^{d0}(t)$, Using $i=1,\ldots,n$, $x_i=0$, $\alpha_i=0$, $\tau_i=0$ of the signal $\delta^d(t)$ amends target trajectory $y_{d0}^k(t)$, System is designed for the tracking of reference trajectory $y_k^d(t)=\delta_k^d(t)+y_{d_0}^k(t)$,when *k* is confirmed, and satisfy Selecting $\delta_d^k(0)$, $\delta_d^{k(n-1)}(0)$,Making the trajectory $y_d^k(t)$ has the following initial value in the beginning of each feedback:

$$y_d^{k(i)}(0)=hi(\bar{x}_{i+1}(0),\theta^k(0)),\hat{i}=1,2\ldots,n$$

$$\begin{aligned}
h_0(x_1)&=x_1\\
\delta^k&=A\delta^k(t)+B_0\delta^{k-1}(t)eqno
\end{aligned} \tag{3.6}$$

$$A=\begin{bmatrix}0&&\\ \vdots&\cdots&I_{n-1}\\ 0&&\\ m_0&\cdots,&m_{n-1}\end{bmatrix}$$

In for constant matrix

of the exponential stability ,(A_0,B_0) for the complete controllability and satisfy the curve radius <1 of the linear formula of the feedback direction. Do the initialization for set the trajectory as shown (3.6), and ensures every time feedback: $z^k(0)=0$, And set $z^k(0)=0$, Admit a further level to improve dynamic quality of the feedback adaptive process again.

Feedback learning control usually require initial state to be reset on the target track line,and the industrial process is continuous, we can't interrupt system to reset initial state. By doing initialization shown in (3.7) for the target trajectory avoid the state of the system reset.

$$\begin{aligned}
\delta^k&=[\delta_1^k,\delta_2^k,\cdots,\delta_n^k]\\
\delta_i^k(0)&=\delta_d^{k^{(i-1)}}(0)
\end{aligned} \tag{3.7}$$

3.2.2 *The convergence of steady state feedback control algorithm of adaptive well control remote console pressure oil preparation simulation*

Follow the above proposed algorithm for well control remote console pressure oil preparation of this dynamic simulation system for feedback learning control. After a lot of practice, make the pressure oil preparation physical simulation process tracking of the preset trajectory output with the better precision. The convergence of algorithm given below.

A given well control remote pressure oil preparation simulation control system (3.1), Its steady state optimization, application of algorithm (3.3) and (3.4) and the initial condition (3.5) and (3.6) conducting adaptive feedback learning control are:

(1)All the signals x^k, y^k, u^k,θ^k of the closed-loop system in the $N*[0,T]$ are uniformly bounded.

(2)Along with the rising of adaptive feedback number *k*, output $y^k(t)$ consistently tend to target trajectory $y_d^k(t)$, namely $\sum_{k-1}^{\infty}\left\|y^k(t)-y_d^k(t)\right\|^2$, $L_2[0,T]<\infty$. Proof: in the first *k* times feedback, Lyapunov function is defined as

$$W_k=\frac{1}{2}z^{k^T}z^k+\frac{1}{2}(\theta-\hat{\theta^k}) \tag{3.8}$$

Design by the adaptive contrary gait $W_k\le\sum_{i=1}^n c_iz_i^{k^2}$. We know by the initial condition (3.5) and (3.6):

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$$W_{k-1}(0) \le W_k(T) \tag{3.9}$$

We know by literature [12] that the conditions of the Lapunov stability theorem of switched systems are confirmed, so the system is stable. Because of the error $y_k - y_d^k = z_1^k$, the

$$\sum_{k=1}^{N} c_1 \left\| y^k - y_d^k \right\|_{L_2[0,T]}^2 \le \sum_{k=1}^{N} \int_0^T c_i z_i^{k^2} dt$$

$$\sum_{k=1}^{N} \int_0^T \sum_{t=1}^{n} c_i z_i^{k^2} dt \le \sum_{k=1}^{N} \int_0^T W_k(t) dt$$

$$\sum_{k=1}^{N} W_k(0) - W_k(T) \le W_1(0) - W_N(T) \le W_1(0) < \infty eqno$$

(3.10)

So

$$\lim_{k\to\infty} \left\| y^k - y_{d_0}^k \right\|_{L_2[0,T]} = 0 \tag{3.11}$$

$$Y_d^k(t) = \delta_d^k(t) + y_{d_0}^k(t) \tag{3.12}$$

and

$$\lim_{k\to\infty} \delta_d^k(t) = 0 \tag{3.13}$$

$$\lim_{k\to\infty} \left\| y^k - y_{d_0}^k \right\|_{L_2[0,T]} \le \lim_{k\to\infty} \left\| y^k - y_d^k \right\|_{L_2[0,T]} + \lim_{k\to\infty} \left\| \delta^k(t) \right\|_{L_2[0,T]} \tag{3.14}$$

So when k reaches a certain large value, the output of

the physical simulation system tracking trajectory all the way. Similarly for the $\forall (k, t) \in \mathrm{N} \times [0, T]$:

$$W_k(t) \le W_k(0) \le W_{k-1}(T) < W_{k-1}(0) \le \cdots \le W_1(0) < \infty \tag{3.15}$$

So all the signals of the closed-loop system are uniformly bounded in $N\times[0,T]$, and with the constantly increasing of feedback number k, output $y^k(t)$ converges to the desired trajectory $y_{d0}^k(t)$,

4. Adaptive stable feedback control experiment of well control remote console physical simulation system

Dynamic equation of well control remote console machine preparing pressure oil process is:

$$\dot{x} = p\sin(x) + u$$

$$y = x \tag{4.1}$$

P for the unknown parameter ,assuming in the steady-state optimization process, the set point of a set of values respectively $c1$=1.0, $c2$= 0.9, $c3$=0.8, $c4$=0.7, $c5$= 0.6, $c6$=0.5. The implementation of feedback learning control on the system u for external feedback learning input, the application of the adaptive stable feedback algorithm proposed above, in the actual simulation P=3 target trajectory was taken as follows:

$$y_d^1 = 1 - \frac{1}{(1+t)^3}, y_d^2 = 0.8 + 0.2\frac{1}{(1+t)^3},$$

$$y_d^3 = 0.7 + 0.1\frac{1}{(1+t)^3}, y_d^4 = 0.7 - 0.1(1-e^{-t}),$$

$$y_d^5 = 0.6 - 0.1(1-e^{-t}), y_d^6 = 0.5 - 0.1(1-e^{-t}),$$

$$t \in [0,20] \tag{4.2}$$

The simulation results as shown in figure4, 6 times feedback tracking trajectory is given respectively. At the beginning of each feedback we is not the default route to do initialization, and from the fourth feedback, the preset trajectory has changed a lot, its type is from power function to an exponential function, but the simulation results still has good dynamic. Fig.5 for dynamic response trajectory of the whole of the steady-state optimization process output.

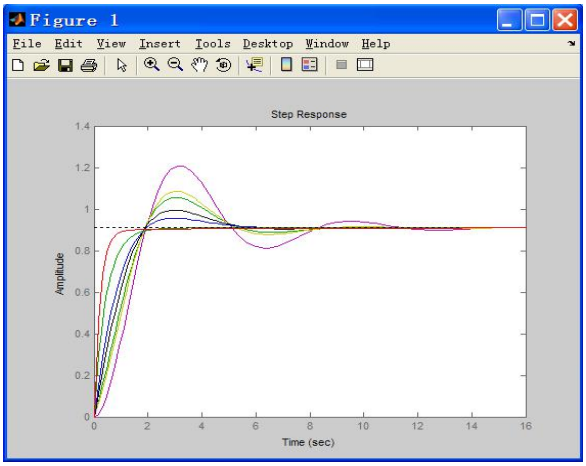

Figure 4. The system output.

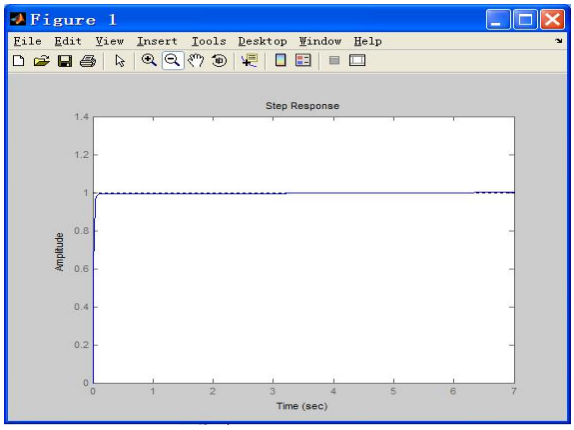

Figure 5. Dynamic response curves well control the remote console pressure oil preparation simulation process.

In well control remote console simulation study, this paper proposed the adaptive state feedback algorithm, better simulate the real system. Because of the actual operation process and the gradual change of the controlled object parameter, in this physical simulation system, the system parameters had an unrest in each

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feedback, corresponding to the steady-state value of the system,and algorithm implemented the same steady-state value every feedback system, the proposed algorithm is closer to the real system, and made physical simulation training project by using remote console preparation pressure oil an completed better, closer to the real operation condition, and reached the purpose of the training personnel well control technology and well control quality.

5. Conclusion

Well control training play an important role in the operation process of the drilling well control and the safety of the operation personnel, drilling well control personnel training work is always the focus of oil drilling well control system education content. At the same time, with the development of computer technology, compared with a virtual receptionist operation, training personnel gets plenty of exercise, training and assessment, and physical simulation is more close to the real operation, the operators really contacted operating equipment and the skill level of training personnel was improved, physical simulation training of foregrounding will become the new direction of oil industry blowout prevention work. In this paper, according to the needs of development, adaptive state feedback control method is developed for well control the remote machine pressure oil preparation of simulation system, control structure and algorithm are given, and discussed the convergence and stability of the algorithm, this method realized for no preset trajectory tracking. This method was the adaptive design method based on global Lypaunov function, this system of parametric uncertain nonlinear and existing periodic disturbance, implemented adaptive stable feedback control by this design method, and improved the dynamic performance of the physical simulation system. Eventually, achieve the most approximation effect with real operation, improve training efficiency, and reduce the safety hidden trouble of well control .

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