Workover Simulating Based on the Theory of Automata

Xiaojun Chen, Kan Ji and Jing Zhang

ABSTRACT

In order to solve the problem that workover simulator cannot respond any operation, a design scheme of workover simulator based on automata theory is proposed. This paper analyzes the current problems existing in the workover simulator, and puts forward the necessity and feasibility of solving the problem. Taking running tubing as an example, this paper analyzes the steps in the operation procedure, and designs the relation between the status and actions, using the theory of finite automata to achieve arbitrary operation response during workover simulation. The result shows the flexibility and stability of the system.

1. INTRODUCTION

Workover, is a technique of well maintenance after drilling. During drilling, drilling string break and often fall into the well. Fish the tools with workover technique so that production can be continued[1,2]. If workover cannot be completed, the drilling equipment or the well may be damaged and cause great economic loss. As workover training on site is of great difficulty, and with high risk, the training can be carried out by workover simulator. Workover simulator is a set of equipment used to training workover operation. The operation result will be displayed in the form of 3D animation, and provides an immersive training environment[3]. Therefore, training with workover simulator can shorten the training time, save the training costs, reduce the safety risk on late actual workover.
At present, the main developer of workover simulator aboard is Drilling System Company. The simulator developed by them has a disadvantage of poor 3D graphics, while it is good at making up string and operating arbitrarily. Thus, adding arbitrary operation in the current developing workover simulator will adding competitive advantage of simulators in China, and fill the blank of current workover simulator in China.

2. SYSTEM ANALYSIS

In order to simulate workover technology completely, workover simulator is composed of software and hardware, as shown in figure 1. Hardware part contains workover console, choke console, BOP console, etc. Software part contains parameter software, master control software and graphics software. Parameter software is responsible for collecting front hardware information and send the information to master control software; Master control software judges the operation through the front hardware information and sends the result of the operation to graphics software; Graphics software received the command from master control software and displayed the corresponding 3D graphics[4]. According to the above analysis, during system running, master control software mainly judges the operation of users and output the parameter information and graphics information of the operation. Therefore, the authenticity of workover simulator master control software simulation determines the operability of workover simulator. So, in order to comply with the workover technology and satisfy the demand of international competition, it is necessary to modify workover simulator master control software.

3. FINITE AUTOMATION

If the system need to respond to the arbitrary combination of drill string and operation, workover technology process should be comprehensive analyzed, and drilling string involved in each procedure and the operation should be processed.
The system should be designed according to the mathematical model of finite automaton.

Finite automaton has a finite state set and finite input symbol\[5,6,7\]. If one of the state and input symbol is variable, through applying transition function to the state, there will be another definite state. As there is one and only state on each input, automaton can only transfer from current state to this state, therefore, this kind of automaton is deterministic finite automaton. Take formula 1 as an example, the quintuple is a finite automaton, of which, \(Q\) is state set, \(\varepsilon\) is input symbol; \(\delta\) as formula 2, is state transition function; \(q_0 \in Q\), \(q_0\) is the original state; \(F \subseteq Q\), \(F\) is accepting state set. Generally, automaton reflect the state conversion through transition graph. If in formula 3, \(\varepsilon\) is 0 or 1, transition function \(\delta\) will respond like this, when \(Q\) is at the state \(q_i-1\), it will transfer to next state in the effect of input symbol \(\varepsilon\). Input 0 upon \(q_0\), and it transits to \(q_1\); input 1 upon \(q_1\), and it transits to \(q_2\).\(q_2\) is accepting state. The transition graph is as shown in figure 2. Thus, it can be seen, for the complicated technology process, finite automaton can show transitions between technology operations for corresponding drill string assembly.

\[
A = (Q, \varepsilon, \delta, q_0, F) \tag{1}
\]

\[
Q \times \varepsilon \rightarrow Q \tag{2}
\]

\[
Q = \{q_0, q_1, q_2\} \tag{3}
\]

![Figure 2. State transition graph.](image)

4. SYSTEM DESIGN

In the allowed range of workover technology, when user assembles any drill string, the system will display the corresponding 3D graphics. In order to realize this function, workover procedure should be fully understood and the operation procedure involved in the technology should be designed all together. As the technology is complex, running tubing is taken for analyzing. The aim of running...
tubing is to running the string make-up used in workover to the designed well section. While the designed well section may be at the position thousands meters below ground. The string cannot be lowered to the designed well section for once. Therefore, in this process, it need to pick up tubing for several times in order to increase string length. There are two steps in running tubing: first, move hook to monkey board. Board worker lower the tubing and hang it to the hook. Raise the hook and put tubing to wellhead and connect it to wellhead string, and make up; second, raise the hook. Worker remove the elevator. And lower tube to wellhead. Then Worker set the elevator, then loose the links and disconnect elevator[7, 8]. According to automaton theory, the input motion and the state after transition of each time should be found out from the procedures[9]. Thus, the technology can be decomposed into pick up tubing, make up, remove elevator and loose links. The following are the detailed description of each motion:

Pick up tubing: move hook to monkey board. Board worker put one stand of tube from setback to links and close links.

Make up: when tube is moved to wellhead, connect the tube to wellhead string with tubing tong.

Remove elevator: remove the elevator from wellhead, so string can be lowered.

Set elevator: set elevator to wellhead to get wellhead string stuck.

Loose links: open the valve on wellhead elevator. Raise the hook to separate elevator from string.

There are totally 4 states during all these operations, which is referred as A1, A2, A3, A4. According to automaton theory, \( Q = \{p_1, p_2, p_3, p_4\} \), \( \epsilon \) is operation set, the following transition graph can be concluded according to the analyzed motions and state set.

![State transition graph of running tubing procedure.](image-url)

Figure 3. State transition graph of running tubing procedure.
From the graph, when it is at state A1, if picking up tube is done, then it transfers to state A2; when it is at state A2, if making up is done, it transfers to A3. According to the transition graph, if the features of the technology state can be determined, state transition can be realized. The following are the features of each state:

A1: Empty hook, links open: there is elevator at wellhead.
A2: Tube hung under the hook: there is elevator at wellhead, tube under hook is not well connected with wellhead string.
A3: String under hook is well connected and is in mud: there is elevator at wellhead get stuck the string.
A4: String under hook is well connected and is in mud: there is no elevator at wellhead.

5. SYSTEM REALIZATION

All the above states are related to whether hook is empty, whether links are closed, whether tube is hung on links, whether elevator is at wellhead, whether the whole string is in the mud. If 0 and 1 is used to refer to the state, 1 refers to closed, and 0 refers to open. The following procedure state design table as shown in TABLE I can be concluded.

<table>
<thead>
<tr>
<th></th>
<th>whether hook is empty</th>
<th>whether links are closed</th>
<th>whether tube is hung on links</th>
<th>whether elevator is at wellhead</th>
<th>whether the whole string is in the mud</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pick up tubing</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>make up</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>raise elevator</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>set elevator</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>loose links</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
</tbody>
</table>

In the above table, hook is empty-1; tube is hung on links-1; elevator is at wellhead-1; string is in the mud-1; hook is not empty-0, links are open-0; no tube on links-0; string is not in the mud-0; According to the table, program flow chart can be designed as follows:
6. CONCLUSIONS

The workover technology is restudied on account of the existed problem of current simulator. The states features during the technology process are analyzed with the theory of finite automaton. New system is designed.

After system design, the system can respond with 3D animation in accordance with technology process to user’s arbitrary operation. The developed 3D scene of the system is as shown in figure 5. Currently, the system has the features of high flexibility and high stability.
REFERENCES