Digital Twin of Beam Pumping Unit Control and Analysis

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Abstract. The software model of beam pumping unit was built through the physical simulation pumping unit lifting system in the Internet of Things laboratory, and the lifting model was updated after mutual verification to form the digital twin system of oil and gas production lifting. Based on the digital twin of beam pumping unit and the real-time data of oil and gas production, the whole process of oil and gas lifting process production is formed, and a flexible closed-loop control method based on the digital twin is obtained. The method is based on the detailed and in-depth analysis of the whole movement, which selecting the load as the monitoring physical quantity, and improving the system efficiency. The method is to change the maximum and minimum load, reduce the input power and improve the system efficiency under the condition of maintaining a certain output. By comparing and analyzing the indicator diagram of oil well production before and after the flexible control, the flexible control method based on digital twin reduces the loss of mechanical operation and saves the consumption of electric energy, so that the efficiency of the pumping unit's lifting system reaches the maximum. At the same time, the control and analysis method based on digital twinning is a self-diagnosis, adjustment and control method of intelligent ecology, which is the inevitable trend of the development of intelligent oilfield.
1. Introduction
Currently many control and analysis methods[1-5] are put forward, but it needs long cycle from the application to the actual produce, or from practical feedback to adjust, so the analysis is relatively lag[6]. At the same time, in the practical production it is lacking of complete production experiment system, so the research of development and production can only be separated[7-8]. Thus, we put forward the research on development and production of organic combination of the actual digital twin system. At the same time, the actual working condition of the analysis is based on the indicator diagrams which can reflect certain downhole conditions by inference. Because the basic indicator diagrams install at wellhead, and acquisition of frequency is low, and it is difficult to collect precise and real-time response at downhole conditions, it is difficult to achieve the desired goal through the further control of oil well production optimization strategies and methods. Furthermore, based on the number of twin control and analysis, it can use the virtual measuring technique, while each node can be installed from the wellhead to pump monitoring indicator diagrams, and diagrams to monitor in real time. There is a certain time which led to a number of conditions change to collect a data problem, and the actual acquisition indicator diagrams can verify and adjust digital twin system, then continuously verify the upgrade of the model. The oil and gas lift digital twin system was established and verified. After the continuous improvement of accuracy, the downhole lift movement process was simulated. From the perspective of improving system efficiency, the flexible closed-loop control method was adopted to change the maximum and minimum load and reduce the input power under the condition of controlling a certain output and maintaining a certain output. Based on the flexible control method of digital twin, the operation of the lifting system is adjusted by combining the power diagram analysis, so that the power diagram operates in the state with the highest system efficiency. The failure of related control and optimization in the oil and gas lift system is overcome, which is caused by the problem that the ground power map is difficult to reflect the downhole conditions and the ground power map acquisition is not accurate enough.

2. BEAM PUMPING UNIT DIGITAL TWIN
The whole process of oil and gas production digital twin is designed and planned by combining physical simulation and software simulation, combining virtual and real scenes, complementing each other's advantages and complementing each other. Realize the simulation and quantitative research of the whole process of oil and gas production. The lifting, metering, gathering and transportation, separation, storage and transportation processes of oil and gas production will be considered and planned as a whole. Physical simulation will be carried out for key processes. If physical simulation is difficult to realize or dangerous production processes, then software simulation is carried out, so as to achieve the construction goal of the whole process simulation. The key point is the construction of oil and gas production lift digital twin. Beam pumping unit is the power part of oil and gas production. The fine motion simulation control of the whole process is an important and effective method to improve oil and gas production efficiency. The digital twin modeling of beam pumping unit is mainly to construct the 3D geometric simulation of beam pumping unit first, and then to carry out simulation modeling on the basis of the 3D model of the pumping unit to obtain its corresponding dynamic model (As shown in Figure 1).
Then the multi-body simulation model built by Simcenter Motion software and the system simulation model built by Simcenter Amesim software, they can realize joint simulation (As shown in Figure 2).

Secondly, the outputs motor of multi-body simulation model is angular velocity, the beam angular displacement, and motor speed and so on, which are the inputs into the system simulation model. Accordingly, the output torque of the motor system simulation model and beam torque are as inputs of multi-body simulation model, while at the same time step both solutions are calculated respectively and it finally realize the multi-body system model of joint simulation. Finally, the laboratory physical simulation and software simulation model of formation of oil and gas lifting digital twin validate each other, and it forms a reliable twin model, while the actual production beam pumping unit of the whole process of production data input the multi-body simulation model through the internet, and further update model, at last both data and model are used in the actual production process of simulation, monitoring and research.

3. FLEXIBLE CLOSED LOOP CONTROL BASED ON DIGITAL TWIN

The digital twin model simulates the pumping process and monitors the electromechanical parameters, crankshaft motion torque, current, impulse times, speed, and load in motion. It was found from the movement that initial movement mainly is static friction and resistance is bigger, it needs to give greater power to sucker rod movement, and once its motion change from the static friction to dynamic friction, the power is reduced. But in actual operation, there is no monitoring of the entire process of movement. It is no attention for making changes in the details so the motor power provided is still the same. That make the whole operation process of energy consumption larger, at the same time, the state stress of the rod is larger, intensifying sucker rod eccentric wear, vibration. While stress conditions of large number of sucker rod fatigue damage is reduced, the rod have shorter service life of equipment, and increase the pickup number of pump operation, so it increases operating costs. Thus, digital model of twin increase
inverter control module, such as monitoring exercise load movement characteristic, let the system a certain load in the process of initial movement, once the system begin motion, it will make the system in a state of constant motion control load, so the stress is at the minimum, and it reduces system eccentric wear, friction loss of the corresponding system optimum movement state.

Figure 3 Control schematic

On the other hand, from the perspective of system efficiency, system efficiency = effective power/input power, combined with the actual production, effective power is mainly reflected in the daily production fluid, effective head, oil pressure and casing pressure, but it basically unchanged for a certain production time for a specific well.

So its essence is that the speed change rate of four bar linkage are changed through the inverter, that the stress change of the polished rod decreases to minimum, and makes motor running at a constant speed by the original change with the change of load speed system, further makes the operation of the pumping unit suspension point load and stress change. It makes the next stroke the effective tension, and improves the balance of pumping unit, eliminates the phenomenon of the motor power. It limits the eccentric and hydraulic hammer of pump pipe and column. Due to reducing the polished rod load, the effect on the stress and strain of the position, it makes the pump rod elongation deformation to a minimum, to achieve the minimum stroke loss. Because of the super flexible operation, reducing acceleration at up stroke, reducing vacuum degree of the liquid pump suction when fixed valve open, reducing the precipitation gas of in liquid, it improves degrees of the pump, effectively avoids the phenomenon of air lock and achieves the purpose of increasing the pump efficiency. At the same time, the reduction of suspension load also reduces the load of reducer, motor and pole, also prolongs the service life of equipment and parts, and prolongs the maintenance cycle of lifting system operation. The efficiency of the pumping unit is maximized by reducing the loss of mechanical operation and saving the consumption of electric energy.

4. POWER DIAGRAM ANALYSIS BASED ON DIGITAL TWINNING

After the establishment of the simulation model of oil and gas lift system based on digital twin, the following five aspects of analysis and research are supported.

1) Control system optimization: The influence of system parameters on indicator diagram is studied under different working conditions, and then the system working parameters are optimized to ensure the efficient work of oil recovery system.

2) Virtual measurement: Under different working conditions, the system model can provide flow information including instantaneous flow, cumulative flow and mass flow through the virtual sensor. Theoretical production flow rate can be derived from defined oil properties.

3) Parameter sensitivity analysis of oil recovery mechanism: The parameter sensitivity analysis of the oil recovery mechanism's stroke, sprint, counterweight, motor control matching, etc. The influence of system parameters on oil production load and flow rate is obtained. Optimize the production process to improve the efficiency.

4) Working condition simulation: Load monitoring, oil production pressure and flow analysis under different
working conditions can be realized by setting the system simulation boundary conditions. And the characteristic analysis of indicator diagram under different working conditions.

5) Failure analysis: System performance under extreme conditions can be studied by means of system simulation. So it can provide more reference quantity for early warning and judgment mechanism. By setting different failure conditions, the performance of system monitoring quantity is obtained, and then the mapping between detection quantity and fault code is realized to improve the early warning information system.

Based on the analysis of digital twin work diagram, virtual mechanism is added to the digital twin work model to collect functions of each section of the diagram. Combined with the simulation of working conditions, the characteristics of indicator diagram under different working conditions are analyzed, and the flexible control method based on digital twin work is applied to optimize the control system.

The pump indicator diagram in FIG. 4 is parallelogram ABCD, which is the ideal figure. The horizontal coordinate is the piston stroke. The vertical coordinate is the liquid load. AD or BC is the effective stroke of the piston. The projected length of AC along AD is the piston stroke length. In general, the pump and rod cannot be pure rigid body, in addition, the liquid also has a certain viscosity, furthermore, the pump also has leakage, and that is, the indicator diagram becomes AB'C'D'. Point B itself is a rod with a certain elastic deformation, and point B' has a relatively high liquid viscosity compared to point B, so there is a certain resistance to loading, which leads to a certain loading delay. Similarly, D relative D is also the influence of liquid viscosity and tube body elasticity, and the unloading time delay is certain.

In the actual production, the comparison and analysis of the three conditions in well G23-59 based on the digital twin flexible control technology before, during and after the ground power diagram debugging shows that the overall change of the image is getting closer to the ideal situation.
Through the flexible control technology, the load fluctuation range is reduced, the minimum load of suspension point is increased by 1KN, the maximum load is reduced by 3KN in Fig6, the stroke times is reduced, the pump filling degree is increased, and the vibration load is reduced.

5. CONCLUSION

1) Digital twin of beam pumping unit system is an important experimental means to improve the efficiency of oil and gas lifting system, and it is also an inevitable trend of the development of intelligent system.

2) The flexible closed-loop control method based on the digital twin system has wide adaptability and can be set in various complex working conditions. The reasonable flexible closed-loop control method can be adjusted in real time according to the working conditions to optimize the production process and improve the system efficiency.

REFERENCES

[1] Hlady J, Glanzer M, Fugate, L. automated creation of the pipeline digital twin during construction - improvement to construction quality and pipeline integrity[C]. proceedings of the 12th international pipeline conference, 2018(2): V002T02A004.

[2] Abramkin, SE, Dushin, SE. Prospects for the Development of Control Systems for Gas Producing Complexes[C]. IEEE II international conference on control in technical systems (CTS). 2017: 150-153

[3] Leary, P, Malin, P, Saarno, T, Kukkonen, Prospects for Assessing Enhanced Geothermal System (EGS) Basement Rock Flow Stimulation by Wellbore Temperature Data[J]. ENERGIES. 1979 (10): DOI: 10.3390/en10121979

[4] Sharma, R, Nghiem, LX, Siu, A; Collins, DA; Mourits, FM. Efficient modeling of wellbore backflow[J]. JOURNAL OF CANADIAN PETROLEUM TECHNOLOGY. 1996(6): 34-41

[5] LI Jin FENG Xi,YANG Xuefeng and CHEN Lin, research on wellbore liquid-carrying capability of commingling production gas well based on computation fluid dynamics[J].Natural Gas Exploration and Development,2012(02) 31-34

[6] WANG Shun, HUANG Ya-nong, LI Shen, YU Jun, Simulation research based on AMESim for a double-acting reciprocating pump, Ship Science and Technology,2017(11),105-108

[7] CAO Ao,WEN Jiaxi,SONG Chao,LIU Fenghao, Kinematic Analysis of a Front Full Hydraulic Beam Pumping Unit Based on Rigid and Flexible Coupling, Modern Manufacturing Technology and Equipment,2018(08)12-18

[8] XU ChaoYang Research on the Numerical Algorithm for Transient Multiphase Flow and Response Characteristics of Flow Parameters in Wellbore[D], Southwest Petroleum University.