Research and application of key technology of submersible oil reciprocating pumping unit

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Abstract. The submersible oil reciprocating pumping unit is a new generation of rod-less oil recovery equipment for low permeability reservoirs. The optimization and upgrading of key technologies is conducive to its large-scale application and cost reduction and efficiency enhancement. This paper proposes a series of optimization and upgrading methods for the problems existing in oilfield production, including the research of closed-loop control technology based on power carrier communication, the research on harmonic suppression technology of inverter output, and the research and development of wireless IOT remote oil recovery equipment management system. Research on new low-cost clear wax-proof process and intelligent composite material coiled tubing supporting technology. At the same time, indoor and on-site test evaluation is carried out. The effect shows that the new process of optimization and upgrading can improve the reliability, adaptability and economy of the submersible reciprocating pumping unit, laying the foundation for its intelligent, digital and large-scale development. It has certain practical significance.

1. Introduction
In the development of oilfields, the artificial lift production wells mainly consist of two pumping and screw pumps, which account for about 90% of the total number of oil wells, but there are rods in the application of low permeability and heavy oil reservoirs. Serious partial wear and high energy consumption [1]. In foreign countries, the application of linear motors to underground oil pumping units has not been reported. It has formed small-scale applications in China, and the prospects are good. However, the test wells of submersible oil reciprocating pumping units generally have open-loop control methods that cannot achieve operating parameters. Automatic optimization and fault warning, low system efficiency, serious frequency harmonic pollution, high cost of clearing anti-wax, low level of intelligence, etc., resulting in a short cycle of overall process inspection [2], urgently needed to carry out in-depth research and optimization of key technologies. Based on this, this paper creatively proposes a series of optimization and upgrading methods: research on closed-loop control technology based on power carrier communication, research on harmonic suppression technology at inverter output, research and development of wireless IOT remote oil recovery equipment management system, and development of new low-cost cleaning wax. Research on technology and intelligent composite material coiled tubing supporting technology. At the same time, indoor and on-site test evaluation is carried out. The effect shows that the new process of optimization and upgrading can improve the reliability, adaptability and economy of the submersible reciprocating pumping unit, laying the foundation for its intelligent, digital and large-scale development. It has certain practical
significance.

2. Research on closed-loop control technology

2.1. Overall system design

As shown in figure 1, the original control system of the submersible reciprocating pumping unit is an open-loop control mode, which is a constant rigid drive. There are problems such as instantaneous hard start and serious commutation impact. It is impossible to realize automatic optimization of operation parameters and fault warning [3,4]. A closed-loop control technology based on power carrier communication, clear design scheme, and indoor test, indicating that the closed-loop control system works normally, laying a foundation for the intelligent and digital development of the submersible oil reciprocating pumping unit.

![Diagram of submersible oil reciprocating pumping unit](image)

Figure 1. Submersible oil reciprocating pumping unit.

The closed-loop control system consists of ground control equipment and downhole monitoring equipment. The system uses submersible cable and cable suede as transmission channels to supply power to the underground monitoring system through star point equipotential method, and uses the suede as the ground line to transmit monitoring signals. Real-time monitoring and automatic adjustment of the operating state of the submersible reciprocating pumping unit to optimize equipment operation and prolong pumping cycle.

2.2. Development of underground monitoring equipment

Equipment composition: multi-parameter sensors and various types of circuits, downhole single-phase reactors, cable traversers, drain seals, stainless steel capillaries, anti-vibrators, mechanical structural parts and seals.

Design requirements: design a cylindrical structure with an outer diameter of Φ114 mm, connected to the tail of the submersible linear motor, determine the type of monitoring of the working conditions, technical indicators, various circuit designs and low-power performance and reliability of the device, and then mechanical structure. The parts and seals form a high pressure seal chamber that houses all components in the sealed chamber and is isolated from the external well fluid.

Process requirements: All joints are quenched and tempered, which can be reliably installed in the lower part of the downhole motor or pump, requiring sealing, oil immersion, vibration resistance, pressure resistance and temperature resistance. Performance indicators are as shown in table 1:
Table 1. Monitoring parameter types and performance index requirements.

| Acquisition parameter | Measuring range | Precision | Resolution |
|------------------------|-----------------|-----------|------------|
| Inlet pressure         | 0 ~ 6000Psi     | 0.1%      | 1psi       |
| Outlet pressure        | 0 ~ 6000Psi     | 0.1%      | 1psi       |
| Ambient temperature    | 0 ~ 150℃       | 0.1%      | 0.1℃       |
| Motor temperature      | 0 ~ 250℃       | 0.1%      | 0.1℃       |
| Export flow            | 0 ~ 30000bbi/day| 5%        | 1bbi/day   |
| Vibration (x and z)    | 0 ~ 10G         | 1.0%      | 0.01G      |
| Leakage current        | 0 ~ 25mA        | 0.05%     | 1μA        |
| Supply voltage         | DC, 0 ~ 120V    | 0.2%      | 0.1V       |

3. Insulation index: 25℃/85% humidity/2500vdc/, insulation resistance ≥2000mω

4. Sealing performance: pressure bearing capacity ≥ 40MPa

2.3. Research on underground communication method

Downhole communication methods include two aspects of downhole power supply and signal transmission [5,6]. The power supply mode of the underground monitoring equipment mainly includes cable power supply, battery power supply, power input from the motor and star point DC power supply. Among them, the cable power supply method needs to be put into a special power supply cable, which has high cost and is limited by the working space under the well; battery-powered mode, because the battery itself has limited battery life, regular replacement of the battery requires the oil well to stop production and construction work; The way of taking power at the input end will affect the balance of motor power supply, damage the sealing and insulation performance of the motor, and the implementation process is complicated. The star-point DC power supply mode can meet the power requirements of the downhole sensor without affecting the normal operation of the AC-driven motor. The implementation method is simple. Therefore, the star-point DC power supply method is the most ideal and most suitable power supply mode for the underground oil reciprocating pumping unit downhole monitoring system.

Transmission methods of downhole monitoring signals mainly include dedicated signal cable transmission, sound wave transmission, and power carrier communication. Among them, the use of dedicated signal cable transmission is not susceptible to external interference, easy to achieve high transmission accuracy and speed, but the dedicated signal cable needs to work in high temperature, high pressure, strong corrosion downhole complex environment, insulation performance and reliability is difficult to guarantee, and The cost is higher; based on acoustic wave transmission, the sound wave is transmitted by the oil pipe to transmit the specific frequency, but the noise of the submersible reciprocating pumping unit is large, the frequency is difficult to extract, and the communication based on the power carrier is the use of the submersible cable. The physical entity medium selects a reasonable signal transmission form according to the channel characteristics, does not need to develop a special signal cable, can realize power supply and signal transmission at the same time, has strong reliability and anti-interference ability, and is a submerged oil reciprocating pumping unit downhole signal. Ideal for transmission, this article uses the submersible cable to transport the signal as a ground wire.

2.4. Development of ground control equipment

Equipment composition and requirements: The ground control equipment and the frequency conversion control system are integrated into a cabinet structure, which mainly includes a three-phase reactor and a secondary instrument (a power module, a data storage module, a data wireless transmission module, a data display module, a control unit, Data demodulator, etc.), to realize data
demodulation processing, real-time communication of monitoring data and frequency conversion control system, and remote data transmission. The design requirements should have certain moisture, dust, rain, snow and oil proof functions, and the process is safe and reliable.

3. Research on negative problems of variable frequency drive

The variable frequency control system drives the submersible linear motor. There is “harmonic pollution” at the output end of the inverter. When it is used for long-distance submarine cable (800 m—3000 m), there are a series of negative problems [7-9]: (1) The severe harmonic current and harmonic voltage in the cable will generate overvoltage and overcurrent, which will cause the cable to heat up continuously, forming skin effect and proximity effect, generating harmonic reactive power and reducing power factor; (2) Harmonics The submersible motor coil is continuously heated, generating high-frequency damped oscillation, and operating malfunction; (3) Harmonics seriously affect the life and accuracy of electronic and electrical equipment in the downhole monitoring instrument and control system. Eventually, the insulation pressure of the rod-less oil production equipment is intensified, resulting in insulation aging, breakdown or burning of the submersible cable and the motor. The overall process vibration is severe, and as the cable length increases and the harmonic frequency increases, the harmonic hazard is continuously amplified.

The harmonic suppression at the output of the inverter is mainly from three angles: First, the inverter control system is optimized and upgraded, including the optimization of the inverter control strategy and the applicable filtering device. This method is convenient for finding economical and practical suppression measures and improving the motor efficiency; Second, the optimization and upgrading of submersible cables, including improving the cable structure, reducing the cable distribution capacitance, improving the cable insulation level, thermal stability, and overvoltage and current resistance, but the cost is large. At the same time, the connection mode of the submersible cable connector is optimized and upgraded, and the flat and flat cable joints are integrated, no manual connection is required at the site, and the connector between the small flat and the motor lead is plugged to improve the insulation performance and reliability of the joint; third, the submersible motor Optimize and upgrade, add electrostatic shielding layer between the motor stator and mover and increase the insulation performance of the motor winding.

In order to suppress the higher harmonics generated at the output of the variable frequency control system of the submersible reciprocating pumping unit, to realize the protection of the submersible cable and the linear motor, reduce the failure rate of the overall process, and prolong the inspection cycle, this paper designs a sine wave. The filter is a kind of rlc low-pass filter, which is mainly composed of output inductor, bypass capacitor and damping resistor. The installation position and topology are shown in figure 2.

![Figure 2. Sine wave filter structure.](image)

Considering the rated electrical parameters of the submersible reciprocating pumping unit, the length of the submersible cable, the fundamental frequency, the switching frequency, the output voltage drop, the power factor, the harmonic THD value and other factors, the sine wave filter is set. The cutoff frequency f is 800 Hz, the filter inductance Lf is 15.25 mH, the filter capacitor Cf is 4.2 μF, and the damping resistor Rf is 0.02 Ω. Carry out the indoor test, the voltage waveform of the output
end of the inverter is shown in figure 3. After installing the sine wave filter, the output voltage waveform is shown in figure 4. It can be seen that the sine wave filter is designed by adding the design to the output end of the inverter. After that, the harmonic components are significantly attenuated and the output waveform is significantly improved.

4. Main supporting technologies

4.1. Wireless IOT remote Oil production equipment management system

The application of the wireless IOT remote device management system realizes the digital management of the process, which is mainly composed of management software and hardware. The software part is composed of office remote management control system and mobile remote management monitoring system; the hardware part consists of data management server, management office computer, mobile data management equipment, wellhead remote terminal control system (rtu), Internet of Things data transmission equipment (dtu), Protocol converter, intelligent linear motor control system, pressure monitoring system, temperature monitoring system, electric metering equipment.

The management system continuously records the real working conditions through the continuous collection and analysis of data, and quickly responds to abnormal working conditions. The manager can realize data storage, management analysis, production parameter setting and office in the office or any other place. Operation status monitoring, real-time monitoring of the operation status of each production well by using a computer or an authorized Android system connected mobile terminal, including parameters such as real-time electricity, current curve, downhole pressure, downhole temperature, etc., and coordinate analysis by protocol converter to set a straight line Motor rotor running frequency, stroke, stroke and other parameters to ensure that the submersible reciprocating pumping unit operates stably under the optimal conditions. Dtu can transmit encrypted work data through mobile or China Unicom network. At present, 86 wells are tested in the field, and the application effect is good.

4.2. New low-cost anti-wax process

The submersible oil reciprocating pumping unit belongs to the rod-less oil recovery process, which is prone to tube and wax formation. The application of the electric heating rod clearing and anti-wax process basically meets the production demand, but the cost is high and the production and operation cost is high. Based on this, a new type of low is developed. Cost of solid chemical anti-wax process research. Analyze the physical properties of oil in the oilfield block, and use the content of wax, colloid and asphaltene as the reference basis for the formulation of the targeted formula. After
repeated trials, the best ratio can be obtained. At the same time, in order to solve the problems of short effective cycle of solid anti-wax technology, high cost of periodic dosing operation and complicated operation, a solid chemical anti-wax device capable of fishing is developed, and a solid anti-wax agent wellhead dosing method is proposed. There is no need to use a moving column, which greatly facilitates the replenishment of solid anti-wax agents. The medicament can be taken into the wellbore with the disposable wax-proof device, and the dosage is determined according to the production condition of the wellbore; the oil well does not need to be periodically heated, the heat washing cost is saved, and the oil layer is protected from water damage; Low technical advantages of low fishing process.

The anti-wax device is composed of a salvage dekaler, a solid anti-wax device and a well lower limiter. According to the single well production and the well fluid flow rate, the solid anti-wax agent charge and the sustained release rate of the chemical are determined, and the production liquid is prevented. The hollow portion of the wax device flows upward, and the flow process slowly dissolves the anti-wax agent. At the time of delivery, the salvage stripper is docked on the ground with the solid wax-proof device. After the wire rope winch is lowered into the wellbore to reserve the depth, the tail of the solid wax-proof central tube enters the center hole of the stopper to achieve the fixed position. Then, the card unloader and the fishing head are disengaged, and the wire rope can be lifted to complete the device placement. The anti-wax agent is continuously released during the production process. When the predetermined period of use is reached, the salvage dragger is lowered from the wellhead, docked with the anti-wax head, and replaced with a new wax-proofing device as needed. At present, 224 oil wells are tested in the field, and the application results are shown in figures 5 and 6.

![Figure 5](image1.jpg)  ![Figure 6](image2.jpg)

Figure 5. The liquid wax crystals were extracted before the measures.
Figure 6. The liquid wax crystals were extracted after the measures.

It can be seen from the comparison of the wax crystals that the anti-wax agent makes the volume of the wax crystals in the oil flow significantly smaller, showing a dispersed state, and the crystallization rate of the crystal nucleus is reduced, thereby slowing the waxing speed of the wellbore, and the effectiveness of the medicament is proved.

4.3. Research on the matching technology of intelligent composite material coiled tubing
At present, the rod-less oil recovery of the submersible oil reciprocating pumping unit is continued by metal fuel pipe, and then the armored submersible cable is bundled on the outside of the metal pipe to achieve oil lift, and there are pipe wall scaling, waxing, corrosion, etc. The problem is that the external cable is frequently damaged during the construction operation and operation, the repetition rate is low, and the operation process is complicated. Based on this, this paper proposes an intelligent composite material coiled tubing supporting submersible linear motor technology. The coiled tubing consists of intelligent inner lining layer, fiber reinforced layer and outer protective layer. Its technical features are power cable, signal transmission cable and heating cable. Three kinds of cables are built in the intelligent inner liner to solve the above practical problems. At the same time, the heating cable is used to clear the wax; the structural layer is composed of fibers impregnated with thermoplastic resin, and is subjected to internal pressure, external pressure and axial tensile force; the outer protective layer can be It has a protective function in transportation, operation and production. Six wells were tested in the
field, and the operation was normal, and the technical advantages were outstanding.

5. Conclusion
The submersible reciprocating pumping unit is a new generation of rodless oil recovery equipment. The in-depth research and large-scale application of key technologies is an inevitable trend of its development. This paper creatively proposes the optimization method of the process: research on closed-loop control technology based on power carrier communication, research on harmonic suppression technology at inverter output, research and development of wireless IOT remote oil recovery equipment management system, and development of new low-cost clear wax prevention process. Research on supporting technology of intelligent composite coiled tubing. The indoor and field test results show that the new process of optimization and upgrading can further improve the reliability of the submersible reciprocating pumping unit and its supporting technology, and broaden the technical and economic adaptability. At the same time, this paper points out the future research direction of the process, and provides technical support for the development of intelligent, digital, high-efficiency, energy-saving, safety and environmental protection, and lays a foundation for further research and development of the process to adapt to deep wells.

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