DESIGN OF AN AUGMENTED HYDRAULIC PUMPING UNIT

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***ABSTRACT**: In order to promote the development of China's petroleum industry, through the study of long-stroke and low-stroke pumping units, an augmented hydraulic pumping unit is adopted as the main research content. Firstly, by comparing the hydraulic pumping unit with the beam pumping unit, it is concluded that the hydraulic pumping unit has good advantages in exploiting deep well oil, high water cut oil and heavy oil. Secondly, through the study of the design requirements of the enhanced hydraulic pumping unit, the appropriate hydraulic cylinder system of the enhanced hydraulic pumping unit is selected. Finally, the control system model of the enhanced hydraulic pumping unit is established, which is controlled by PLC. The design and analysis of the augmented hydraulic pumping unit are carried out. The results show that the compound hydraulic cylinder, a new type of electronically controlled bidirectional hydraulic lock and CPM1A-20CDR-A PLC are used as the main parts of the design to realize the upper and lower stroke of the hydraulic pumping unit, and make it more automatic and intelligent. By calculation, the hydraulic system recovers nearly 35% of the system potential energy, thus realizing the energy saving problem on the pumping unit. It can be seen that the enhanced hydraulic pumping unit designed and analyzed, has certain functions of safety, protection and alarm. Compared with the traditional pumping unit, the enhanced hydraulic pumping unit has more automation and intelligence, and saves more electric energy. Therefore, it can complete the process of slow oil absorption and fast oil extraction, which is more suitable for deep and heavy oil wells, and meets the design requirements.*

***KEYWORDS**: Hydraulic pumping unit, Hydraulic system, Programming, Design*

1. INTRODUCTION

At present, beam pumping units are basically used in China. Since its emergence, it has been a hot topic for experts and field users at home and abroad. The advantages of beam pumping unit are simple structure, low cost and good durability. The biggest disadvantage is that heavy oil and deep well oil cannot be exploited. With the continuous development of domestic oilfields, most of the eastern oilfields have entered the middle and late stages of water injection development. Deep well oil, high water cut oil and heavy oil need to be developed urgently. At present, beam pumping units are not competent, so it is urgent to meet this new demand through the development of long-stroke and low-stroke pumping units [1].

Because of the high stiffness and power-mass ratio of the hydraulic system, it can improve the energy-saving effect more than the traditional beam pumping units. Hydraulic pumping units with hydraulic energy recovery technology must be developed. Hydraulic energy recovery system is an efficient energy-saving hydraulic system, which recovers the braking kinetic energy and gravity potential energy of inertial load, and has a promising future. Hydraulic drive pumping units have obvious advantages and are eager for scale development in China. In foreign countries, hydraulic pumping units start earlier and have higher technical level. Many countries have developed their own hydraulic pumping units [2].

At present, the main production method of oilfields in China is mechanical production. Because of its durability, convenient management, strong adaptability to oilfield well conditions and wide adaptability to fluid production changes, sucker rod pumping units have formed a series of advantages such as standardization and serialization. Therefore, it has been widely used in various parts of the world, accounting for about 95% of the mechanical production wells. In rod production process, pumping units are used to provide power, which accounts for about 96% of rod production. The performance of pumping units, which provide power in the process of oil production, directly determines the output of oil wells. Existing pumping units, such as ordinary

beam pumping units, chain pumping units, rotary donkey head pumping units, double cylinder hydraulic energy storage pumping units, have problems in other aspects besides high energy consumption. For example, the stroke length of beam pumping unit is difficult to improve, and the commutation impact of mechanical pumping unit is large [3].

2. LITERATURE REVIEW

The development of pumping units in China has been nearly 70 years. In the 1960s, a hydraulic pumping unit structure was proposed in China. In the 1980s, an equipment research institute designed a long-stroke hydraulic pumping unit without beam, which is suitable for domestic production. In addition, the development of long-stroke and low-stroke non-beam hydraulic pumping units has reached a certain scale. Industrial tests have been carried out in some oilfields. New progress has been made in the development of these hydraulic pumping units and some experience has been accumulated. In addition, in recent years, a large number of hydraulic pumping unit patents have been declared in China.

Unlike China, the developed countries with advanced technology, such as the United States, have developed pumping units earlier. Of course, the development of hydraulic pumping units is much earlier, so the technology is much more advanced. In addition, because of the advanced research technology of hydraulic components such as valve body and hydraulic cylinder, China has been unable to make progress on many issues. Research technology at abroad will always be at a leading level. In order to meet the domestic demand for hydraulic pumping units, it mainly depends on imports [4].

In view of the shortcomings of beam pumping unit, Liu et al. design a hydraulic pumping unit with long stroke, low stroke number and stepless adjustable stroke. The hydraulic control system of the hydraulic pumping unit with the pulley program is designed and the suspension displacement, suspension velocity and acceleration of the hydraulic system of the hydraulic pumping unit are simulated by using AMESim software. The simulation results are consistent with the actual situation, which proves the correctness of the simulation results [5].

Wang et al. design a set of hydraulic pumping unit system for the purpose of saving energy and reducing consumption. In terms of mechanical structure, the system uses the method of mechanical counterweight to completely balance the weight of sucker rod, so that the potential energy of sucker rod dropping can be stored in counterweight and reused when pumping up, thus reducing the installed power of the system and saving energy. In terms of hydraulic control, the system uses the electro-hydraulic proportional load sensing technology to make the pressure and flow automatically adapt to the load demand in real time, which achieves efficient energy saving and accurate control [6].

Ren et al. use two-way variable displacement pump and two-way quantitative motor. The new hydraulic pumping unit consists of power transmission system, commutation system, balance system, suspension system, guide system and frame base system [7]. Its hydraulic system can realize stroke control under low pressure and avoid commutation impact. Its structure, working principle and calculation of basic working parameters are introduced. The indoor simulation test shows that the pumping unit has the characteristics of stable performance, reasonable structure, reliable commutation, low dynamic load and low power.

3. METHODOLOGY

3.1 Design Requirement

There are a lot of heavy oil and super heavy oil reserves in China's oilfields. The proved heavy oil reserves in Shengli Oilfield alone are 4.41 x 108 t. Heavy oil and super heavy oil are difficult to exploit because of their unique physical properties. The conventional beam pumping unit has the problems of low system efficiency and high energy consumption in heavy oil recovery. At the same time, most oilfields in our country have entered the post-recovery stage, and the water content of oil wells is relatively large. In order to improve production, it is necessary to take large liquid extraction and deep pumping. Whether heavy oil extraction or large liquid extraction technology, new requirements have been put forward for pumping units. Ordinary beam pumping units cannot meet the requirements of heavy oil recovery and large liquid extraction technology. In view of heavy oil recovery and high liquid yield recovery technology in China's oilfields, the design requirements are proposed as shown in Table 1.

Table 1 Design requirement

Serial number	Requirement
1	In order to meet the requirements of heavy oil recovery and large fluid extraction process, the new pumping unit should have strong lifting capacity.
2	In order to increase crude oil production, increase the life of pumping units, sucker rods and downhole equipment, the new pumping unit should have long stroke and low stroke. Long stroke guarantees output, while low stroke reduces the number of reciprocating movements of equipment. In this way, the life of equipment can be improved.
3	In order to ensure that the pumps can be full, the up-stroke time is as short as possible.

3.2 Design of Hydraulic Structure of Additional Program Hydraulic Pumping Unit

The designed hydraulic pumping unit has two hydraulic loops, which are main hydraulic loops and accumulator loops. The main hydraulic circuit of the frequency converter closed circuit is the main oil supply driving circuit, and the accumulator circuit mainly stores the energy of the main hydraulic circuit and the gravity potential energy of the load falling during the downstroke.

The working process of this type of hydraulic pumping unit system has two parts: upper stroke and lower stroke. In order to meet the design requirement, the hydraulic cylinder of the augmented hydraulic pumping unit adopts compound hydraulic cylinder.

The moving piston cylinder in the compound hydraulic cylinder of the augmented hydraulic pumping unit is fixed on the inner cylinder and the outer cylinder. The inner cylinder and the outer cylinder are fixed. Only the piston rod moves. The whole compound hydraulic cylinder is divided into three chambers.

Two-way hydraulic pump, two-way hydraulic lock, shuttle valve, relief valve and the upper two chambers of the hydraulic cylinder in the main hydraulic circuit of the augmented hydraulic pumping unit form a closed oil circuit. Frequency conversion motor provides power to bidirectional hydraulic pump, forming a closed hydraulic system with variable frequency volume speed regulation.

The shuttle valve in the main hydraulic system of an augmented hydraulic pumping unit can supply sufficient hydraulic fluid to the system when the hydraulic cylinder in the closed circuit rises or falls. At the same time, it can prevent the suction port of the bidirectional hydraulic lock from sucking air. The function of safety valve is to ensure that when the hydraulic cylinder rises or falls, the oil pressure in the circuit doesn't exceed the rated pressure of the system. The specific design is shown in Table 2.

Table 2 Design of compound hydrauli cylinder for additional program hydraulic pumping unit

Design aspect	Concrete design
Power device	The flow velocity of hydraulic oil is determined by the movement speed of the hydraulic cylinder of the augmented hydraulic pumping unit. According to the flow rate provided by the system, adjustable quantitative plunger pump can be selected as the main pump of the system. The accumulator is equipped with a filling pump, which is used to supplement the pressure oil to the accumulator when it is first used, and to supplement the oil to the pipeline when the system leaks the hydraulic oil.
control valve	According to the requirement of the hydraulic system of the augmented hydraulic pumping unit, the pressure, flow rate and direction of the system need to be controlled. Pressure control valves mainly include safety valve. Flow control valves mainly include shuttle valves. Direction control valves mainly include one-way valves, two-way hydraulic lock.
Executive device	According to the requirement of the hydraulic system of the augmented hydraulic pumping unit, the hydraulic pump provides power to drive the piston rod of the hydraulic cylinder to realize the linear reciprocating motion of the actuator. The actuator is mainly composed of the piston rod of the compound hydraulic cylinder. The compound hydraulic cylinder piston rod directly drives the sucker rod up and down to realize the pumping unit's oil production.
Hydraulic auxiliary components	The hydraulic auxiliary components of the hydraulic system of the augmented hydraulic pumping unit mainly include oil tank, hydraulic tubing, heat and cold exchanger, accumulator, indicator, stroke switch, etc. The tank is a container for storing oil for the hydraulic system. The heat exchanger regulates the temperature of hydraulic oil to ensure the normal working temperature of the system. The accumulator stores the energy of the main hydraulic circuit and the gravitational potential energy of the load drop in oil production. Indicator shows the pressure and temperature of hydraulic oil in order to monitor the operation of the system.

4. RESULTS AND DISCUSSION

4.1 Control System of Additional Program Hydraulic Pumping Unit

In order to make the hydraulic transmission system complete its operation automatically, the hydraulic pumping unit with the program added uses PLC to control the hydraulic transmission system so as to make it more automatic. It can recycle the kinetic energy when the upstream and downstream strokes are reversed and achieve the effect of energy saving. Compared with the conventional beam pumping unit of the same type, the energy consumption of the enhanced hydraulic pumping unit is reduced by more than 30%. While reducing the power consumption, it also greatly improves the oil recovery rate, which makes it more suitable for heavy oil and deep well oil recovery.

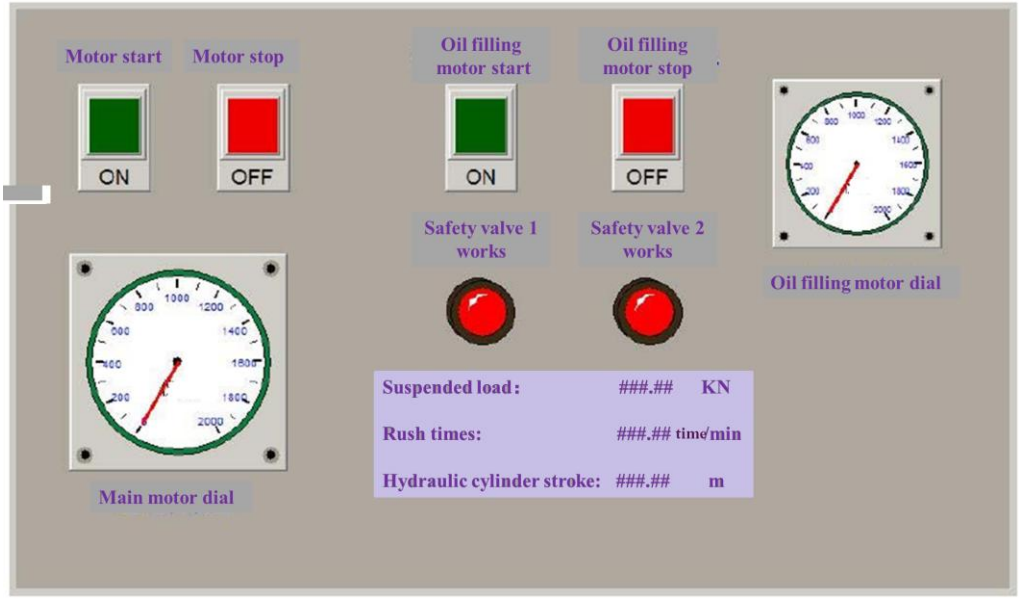

Figure 1. Control panel of an augmented hydraulic pumping unit

The function of the additional hydraulic pumping unit includes starting and stopping of the main motor, showing the rotation of the main motor, starting and stopping of the refueling motor, and displaying the rotation of the refueling motor. When the safety valve 1 exceeds the rated pressure of the safety valve 1, the alarm will work. When the safety valve 2 exceeds the rated pressure of the safety valve 2, the alarm will work. In addition, by installing the pressure reader in the cavity and the position reader in the outer cavity of the hydraulic cylinder respectively, the pressure in the cavity can be measured by installing the pressure reader, and then the suspension load of the hydraulic pumping unit can be calculated by the pressure. By installing the pressure reader in the cavity, the change period of the pressure in the cavity can be calculated. By installing the hydraulic pressure, the cylinder position reader measures the stroke position of the hydraulic cylinder. By displaying the data, the working condition of the augmented hydraulic pumping unit can be analyzed at any time to realize remote control through network, which is more convenient for the automation and self-management of the augmented hydraulic pumping unit.

4.2 PLC Selection

PLC has the advantages of small size, low energy consumption, high reliability and strong anti-interference ability. According to these advantages, PLC is very suitable for this type of hydraulic pumping unit. According to the requirements of the designed hydraulic pumping unit, the system configuration is made to meet the design requirements. When the system configuration is determined, users can modify the corresponding control procedures according to the changes of working conditions, so that they can better adapt to the needs of different working conditions.

The PLC control system designed here is a small hydraulic system controlled by a single unit. According to the function of the augmented hydraulic pumping unit, six points must be controlled. The PLC of CPM1A-20CDR-A can meet the control requirements. External input and output terminal wiring of PLC selection is shown in Figure 2. The flow chart of PLC is shown in Figure 3.

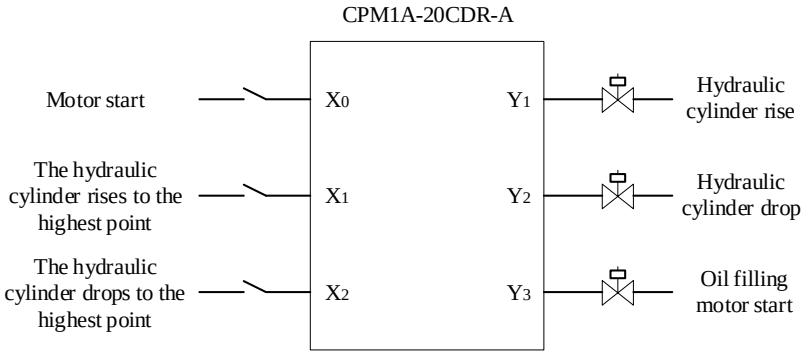

Figure 2. I/O Distribution map

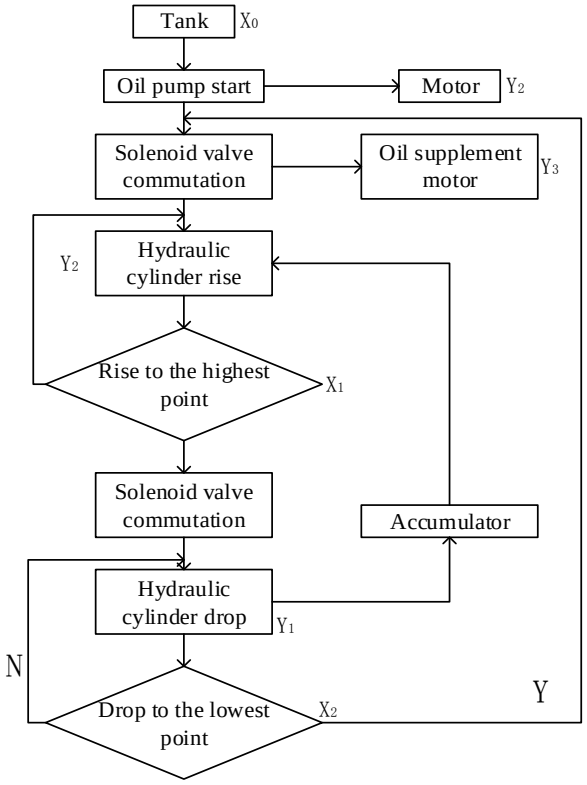

Figure 3. PLC flow chart

The electromagnetic commutation valve and other component switches in the electronically controlled hydraulic lock are used to complete the automatic reciprocating action of the system. The pump-motor structure circuit is used in the main hydraulic circuit, and the potential energy of the system is recovered with the energy storage circuit. The hydraulic system is controlled by PLC to recover the energy in the downstroke process. However, in the first start of the additional hydraulic pumping unit, the motor and the filling motor need to start at the same time. The solenoid directional valve in shuttle valve is controlled by PLC to get electricity, and the hydraulic cylinder rises under the combined action of the motor and the filling motor.

4.3 Performance Checking

During the downward stroke, the energy of the main hydraulic circuit and the gravity potential of the load drop make the energy press into the outer chamber of the hydraulic cylinder to produce pressure oil. The generated pressure oil hydraulic pressure is directed to the accumulator of the accumulator circuit, so that the accumulator can save energy for use during the upstream stroke.

Through the above analysis and calculation, according to the designed hydraulic pumping unit, the designed hydraulic pumping unit can meet the requirements of various functions. According to the known data, the mechanical performance of

the hydraulic system energy recovery mechanism of the hydraulic pumping unit is checked.

The power of the system when traveling:

$$P_S = FS * V = \frac{326.8 * 6}{7.5} = 261.44\ KW \quad (1)$$

Power of hydraulic motor:

$$P_y = P_{md} * V = \frac{105.4 * 6}{7.5} = 84.32\ KW \quad (2)$$

Output Torque of Hydraulic Motor:

$$T_{Smd} = Pmd * V = 638\ N/m \quad (3)$$

Potential energy drop power of the system:

$$P_X = \frac{FN * S}{t_2} = \frac{221.2 * 6}{7.5} = 176.96\ KW \quad (4)$$

Hydraulic motors are always output with constant power, so the potential energy of the absorbed system is reduced.

$$P_X = P_X - P_Y = 92.64\ KW \quad (5)$$

The proportion of the potential energy absorbed by the system to the rising power of the hydraulic system is as follows.

$$\eta = \frac{P_X}{P_S} = \frac{92.64}{261.44} = 35\ \% \quad (6)$$

Through the above calculation, it can be seen that the hydraulic system of the augmented hydraulic pumping unit recovers the energy stored in the main hydraulic circuit and the gravitational potential energy dropped by the load, accounting for 35% of the upper stroke process. This greatly improves the energy recovery efficiency, and the potential energy reduction power output torque can drive the normal operation of the recovery system, which can meet the operation requirements of the main hydraulic circuit and meet the design requirements. The design provides a reference for the design of an energy-saving hydraulic pumping unit.

5. CONCLUSION

With the continuous development of domestic oilfields, most of China's oilfields have entered the middle and late stages of water injection development. It is urgent for oilfields to exploit deep well oil and heavy oil through long stroke and low stroke pumping units. The advantages of hydraulic pumping units are increasingly revealed because of the considerable shortcomings of beam pumping units in this respect.

The design and analysis of a new type of augmented hydraulic pumping unit are mainly studied, which is mainly aimed at deep wells and heavy oil wells. The main conclusions include the following aspects: Firstly, according to the hydraulic design requirements, the hydraulic system schematic diagram of the hydraulic pumping unit is designed combined with the hydraulic system function of the augmented hydraulic pumping unit. The compound hydraulic cylinder is used in the hydraulic cylinder of the augmented hydraulic pumping unit. At the same time, the working process of the hydraulic system of the hydraulic pumping unit is analyzed in detail from the point of view of the working circuit. Secondly, the control system of the augmented hydraulic pumping unit is established. A new type of electronically controlled bidirectional hydraulic lock is used in the control system of the augmented hydraulic pumping unit. The electromagnetic directional valve in the bidirectional hydraulic lock is controlled by PLC to realize the two processes of up and down stroke of the augmented hydraulic pumping unit. At the same time, the whole control system of the augmented hydraulic pumping unit is controlled by PLC to make it more automatic. By calculation, the hydraulic system can recover nearly 35% of the system potential energy, thus realizing the problem of energy saving on pumping units.

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