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Test System for Node Efficiency of Progressive Cavity Pump Based on Wireless Communication Technology

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Abstract: In order to acquire the data of the energy consumption and operation efficiency of progressive cavity pump wells, a new test system for node efficiency of progressive cavity pump based on wireless communication technology has been developed. The system is comprised of input device, wireless signal transmission device and output device. And it can test the node efficiency of progressive cavity pump very conveniently and accurately. The system has been tested in oilfield, and the results of tests were accurate and reliable. It can be widely promoted in testing for node efficiency of progressive cavity pump in the oilfields in future. *Copyright © 2013 IFSA.*

Keywords: Wireless test system, Progressive cavity pump, Node efficiency, Strain gauge, Test of torque.

1. Introduction

Progressive cavity pump has been widely used as effective artificial lift equipment in oilfield productions due to its numerous technical advantages, especially in oil recovery of high viscosity, high sand content and high gas. The progressive cavity pump consists of a single helical rotor rotating eccentrically inside a double threaded helical elastomeric stator of twice the pitch length. Cavities in which oil is stored are created between the rotor and the stator, and as the rotor moves the cavities move helically. The contact line between rotor and stator seals the cavities among themselves [1-4]. According to different driving systems, the progressive cavity pump oil recovery systems are divided into two types. One is surface-driven, and another is downhole-driven. In China, surface-driven system is preferred by the oil producers. There are more than 5000 progressive cavity pumps operated among oilfield in China to date [5].

In order to acquire the data of the energy consumption and operation efficiency of progressive cavity pump wells, the node efficiency of progressive cavity pumps which are working in wells must be tested. And the test data can be used evaluating the well conditions and status of pumps. Because of the limitation of the test technology, the efficiency of system only can be calculated indirectly by input parameters, such as voltage and current of motor, and output parameters, such as rate of flow and pressure of pump. But the node efficiency can't be acquired in this way. Since there are many different kinds of progressive cavity pumps used in oilfields and the using conditions are different, the node efficiency is crucial for evaluating the efficiency of surface parts and downhole parts of the progressive cavity pump oil recovery system correctly. So the node efficiency must be tested. The key of acquisition of node efficiency is how to obtain the torque of rod. If the value of torque be acquired, the node efficiency can

be calculated by multiplying the torque and rotation speed of rod.

Based on the above theory, two methods used in testing of node efficiency of progressive cavity pump have been developed previously. The first method is using input electrical parameters of motor to deduce the power of rod. The principal of the method is calculating the torque of output shaft of motor by testing parameters of motor, such as current, voltage and power factor, dozens of times per second. And then using the value of the torque multiplied by the mechanical efficiency of reduction gearbox, the torque of rod can be calculated. Because of the fluctuation of load and change of power factor, the result may have some errors [6].

The second method is testing the load of polished rod directly by dedicated sensor fixed on it [7-9]. Then the value of torque can be acquired. And the result may be more accuracy. However the installation of sensor must use crane, and every pump need to be installed one set of test device. The cost is high and the maintenance of device is inconvenient. More than that, the sensor may be creep because of the change of weather, and then the result may be incorrect.

Because of the disadvantages of the above two methods, this paper presents a system which based on wireless communication technology to acquire the node efficiency of progressive cavity pump. And this system can obtain the torque of rod directly and conveniently. Then the node efficiency of progressive cavity pump oil recovery can be calculated.

2. Research of Test System of Torque

2.1. System Composition

According to the characteristics of progressive cavity pump oil recovery system, a new test system based on wireless test technology has been presented here. The system can test the node efficiency of progressive cavity pump system quickly and easily. The whole system includes the test system of the torque and the test element of rotation speed. The test system of the torque of rod will be presented first.

The test principle of the torque of rod is explained as follows. The strain gauge is pasted up the rod to test the strain of rod, and connected to wireless signal emission device to compose measuring bridge. The strain of rod is transformed to electrical signal by the strain gauge. Then the electrical signal is handled by bridge, and transmitted by wireless signal emission device. The wireless signal receiving device connected to computer transforms the electrical signal to value of torque, and the computer records and analyzes the data in real time. The characteristic of this test system is that it can be installed on the rod very conveniently, and the position of installation can't be damaged (Fig. 1).

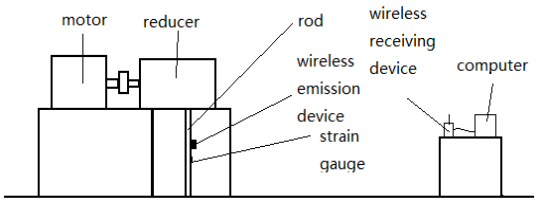

Fig. 1. Test system.

The whole test system is comprised of input device, signal transmission system and output device. The input device is measuring bridge comprised by four strain gauges, which can transform the strain to electrical signal. The signal transmission system includes wireless signal emission device and receiving device. The wireless signal emission device transforms the weak voltage signal which is amplified and filtered to digital signal, and emits by wireless communication module. The wireless signal receiving device inputs the received signal to computer. As output device, the computer calculates and analyzes the digital signal to test and judge in real time [10-11] (Fig. 2).

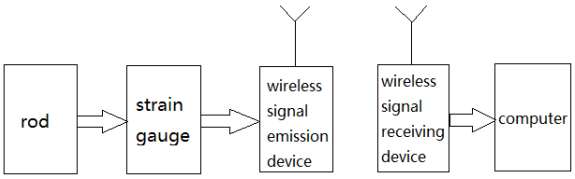

Fig. 2. Module of test system.

2.2. Sensing Element of Torque Test

In the system, the strain gauge as sensing element of torque test transforms the strain of rod to electrical signal. The deformation of rod deforms the strain gauge, and the resistance value of the strain gauge will change. The measuring device can test the change of resistance value, and then transforms it to strain value.

The testing circuit of strain is as shown in Fig. 3.

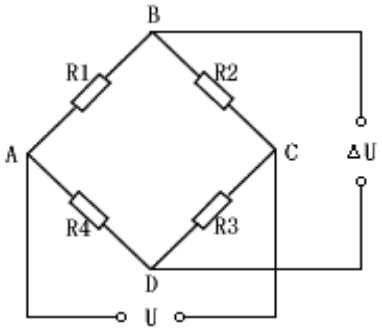

Fig. 3. Wheatstone bridge.

The strain gauges are the bridge arms of Wheatstone bridge. Based on the principle of electrical engineering, when the input voltage is U_I, the output voltage U_O is

$$U_O = \frac{R_1R_3 - R_2R_4}{(R_1 + R_2)(R_3 + R_4)}U_I, \quad (1)$$

where R_1, R_2, R_3, R_4 are the resistances or strain gauges. When U_O =0, the Wheatstone bridge is balanced. So the condition of balance is $R_1R_3=R_2R_4$. If the resistances of bridge have variation of ΔR_1, ΔR_2, ΔR_3, ΔR_4, the output voltage will be changed as

$$U_O \approx \frac{U_I}{4}\left(\frac{\Delta R_1}{R_1} - \frac{\Delta R_2}{R_2} + \frac{\Delta R_3}{R_3} - \frac{\Delta R_4}{R_4}\right), \quad (2)$$

If the same strain gauges have been accessed in the bridge, the output voltage will have relation to the value of strain as

$$U_O = \frac{KU_I}{4}\left(\varepsilon_1 - \varepsilon_2 + \varepsilon_3 - \varepsilon_4\right), \quad (3)$$

where ε_1, ε_2, ε_3, ε_4 are the values of strain [12].

According to mechanics of material, the direction of the principal strain is with axial 45 degrees. To linear-elastic and isotropic materials, the direction of the principal stress is same to the principal strain. And the principal stress is proportional to the principal strain based on generalized Hooke's law. Then the torque of the rod can be calculated by the principal stress using the relevant formula [13]. So the torque of rod can be tested by measuring bridge which is comprised of strain gauges directed with axial 45 degrees. The power of rod can be calculated by the torque and rotation speed.

2.3. Wireless Signal Transmission System

2.3.1. Emission Device

The emission device (Fig. 4) is comprised of signal conditioning module, analog/digital converter (ADC) and signal transmit module. The signal conditioning module is including of amplifier and filter, and it can amplify and filtering the weak strain signal. ADC is used for convert analog signal to digital signal. And the signal transmission module emits the digital signal based on wireless communication technology.

The signal conditioning module is comprised of amplifier and filter. The output voltage of measuring bridge is too weak to handle by following circuit, so the signal must be amplified. The instrument amplifier which formed by three-stage operational amplifiers is used in this system because of the demands in stability, time, gain accuracy and ability of resisting common mode interface (Fig. 5). Compare with the normal integrated operational amplifier, the instrument amplifier has very stable high closed-loop gain, low noise, low drift, high output impedance and high ability of resisting common mode interface.

Fig. 4. Wireless signal emission device.

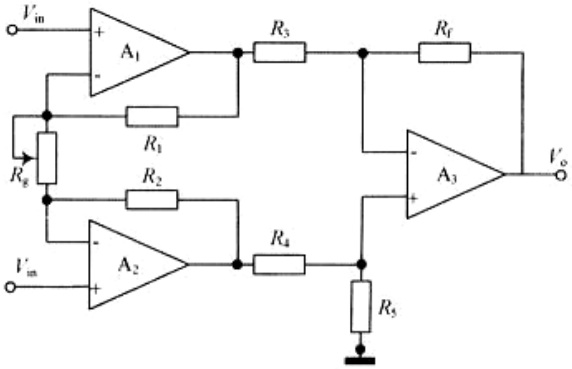

Fig. 5. Instrument amplifier.

The filter is equipment for frequent selecting. It can decrease void signal in the system and get useful signal passed in. According the frequency selective function of filter, there are four basic types of filter. They are low-pass filter, high-pass filter, band-pass filter and band-stop filter. Based on the characteristics of the system, second-order low-pass active filter has been chosen (Fig. 6). The filter is including two RC filtering circuit and in-phase proportional amplifier. The composition of signal which is lower than the specific frequency, like f, can pass through the filter without attenuation, and the composition of signal which is higher than f will decay. It has high input impedance and low output impedance [14-15].

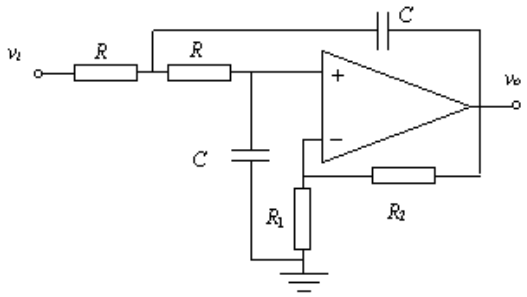

Fig. 6. Filter.

ADC convert analog signal to digital signal by the process of sampling, maintaining, quantizing and coding. According to different working principles, ADC can be divided into two types, direct ADC and indirect ADC. Direct ADC convert analog signal to digital signal directly, and the speed of conversation is fast. Successive-approximation ADC is belonging to direct ADC. The indirect ADC convert analog signal to an intermediate quantity (time or frequency), and then convert the intermediate quantity to digital signal. So the speed of conversation is slow relatively. To meet the requirements of the system, the successive-approximation ADC has been chosen.

Signal transmission module uses wireless radio frequency data communication chip which integrated all high-frequency components. The chip combined with micro-processor and peripheral components can form a wireless data communication module. Radio frequency data communication chip uses modulation type of frequency shift keying (FSK), works in industrial scientific and medical frequency range (2.4GHz), and uses simple data transfer protocol. The parameters such as working frequency and emission frequency can be set by software, and wireless data communication can be realized by setting control word of chip [16]. Its advantages like small size, high anti interference ability and low power consumption makes it suitable for the test system.

2.3.2. Receiving Device

The chip used in wireless signal receiving device is same to emission device (Fig. 7). When the device receives the signal, it transmits the signal into computer by USB interface. And the data handled by computer.

Fig. 7. Wireless signal receiving device.

3. Sensor for Testing of Rotation Speed

The rotation speed is tested by the Hall sensor. The Hall sensor is a magnetic-electrical sensor. It transforms the measured value to electric potential based on the Hall Effect. Because of the ability to reflex the change of magnetic field, the simple structure, the small volume and low noise, the Hall sensor has been widely used in measuring.

The main principle of Hall sensor is Hall Effect. When the current flow through the metal which is put on the magnetic field, the electric potential vertical to the direction of current and magnetic field will generated. This physical phenomenon is the Hall Effect. The Hall sensor is a semi-conductor manufactured based on the Hall Effect. It is always produced in the material of N-type semi-conductor. The Hall sensor can catch the change of the electric potential, and transforms it to electrical signal. Then the internal circuit of sensor will amplify and filtering the signal to square signal. So the first stage of testing the rotation speed of rod is to fix one metal part on the rod, which can change the magnetic field around the sensor [17-18].

In this system, an inductor fixed on the rod rotates with it, and the Hall elements of the test system can acquire the rotation speed by recording the number of pulse signals which generated when the inductor passed the Hall elements. Fig. 8 is the Hall sensor used in this system.

Fig. 8. Hall sensor.

4. Field Trials and Analysis

4.1. Field Trials

For test the performance and reliability of the system, the system was tested in an oilfield in August 6th and 7th, 2013. Two progressive cavity pump wells were tested. The test data is in follows.

Well.1

Table 1. Condition of well.1.

Parameters	Values	Units
Back pressure	0.80	MPa
Casing pressure	0.00	MPa
Density of mixture	0.9954	t/m^3
Water content	94	%
Density of crude oil	0.9226	t/m^3
Liquid production	30.9	t/d
Working fluid level	660	m
Depth of the pump inlet	1203.4	m
Hydraulic head	781.7	m
Active power of motor	7.24	kW
Reactive power of motor	11.12	kvar
Output power of pump	2.74	kW

(1) Test data of torque and rotation speed of rod

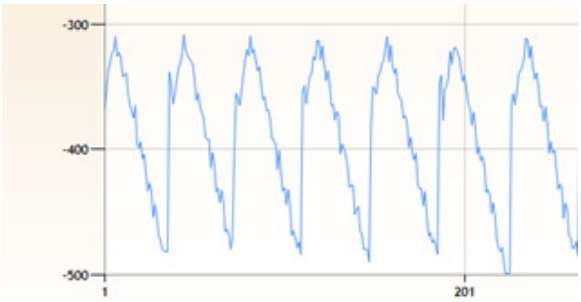

Fig. 9. Curve of torque of rod.

average torque $M = 390Nm$,
rotation speed $n = 100r/\min$
power $P = \frac{M \times n}{9549} = \frac{390 \times 100}{9549} = 4.08kW$
active power of motor $P_i = 7.24kW$
output power of progressive cavity pump $P_o = 2.74kW$

(2) Efficiency
efficiency of surface

$$\eta_i = \frac{P}{P_i} = \frac{4.08}{7.24} \times 100\% = 56.4\%,$$

efficiency of downhole

$$\eta_o = \frac{P_o}{P} = \frac{2.74}{4.08} \times 100\% = 67.2\%,$$

efficiency of whole system

$$\eta = \frac{P_o}{P_i} = \frac{2.74}{7.24} \times 100\% = 37.8\%,$$

Well.2

Table 2. Condition of well.2.

Parameters	Values	Units
Back pressure	0.80	MPa
Casing pressure	0.00	MPa
Density of mixture	0.9755	t/m^3
Water content	32	%
Density of crude oil	0.964	t/m^3
Liquid production	3.9	t/d
Working fluid level	358	m
Depth of the pump inlet	1594.3	m
Hydraulic head	456.2	m
Active power of motor	2.77	kW
Reactive power of motor	2.51	kvar
Output power of pump	0.20	kW

(1) Test data of torque and rotation speed of rod

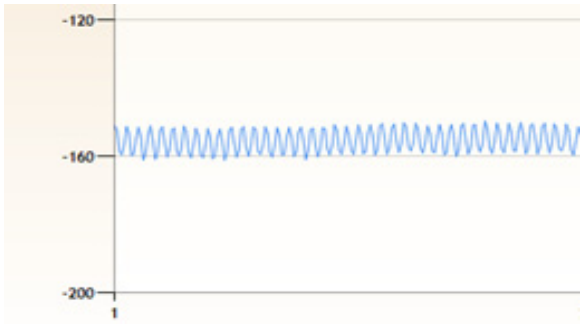

Fig. 10. Curve of torque of rod.

average torque $M = 155Nm$
rotation speed $n = 62r/\min$
power $P = \frac{M \times n}{9549} = \frac{155 \times 62}{9549} = 1.01kW$
active power of motor $P_i = 2.77kW$
output power of progressive cavity pump $P_o = 0.20kW$

(2) Efficiency
efficiency of surface

$$\eta_i = \frac{P}{P_i} = \frac{1.01}{2.77} \times 100\% = 36.5\%$$

efficiency of downhole

$$\eta_o = \frac{P_o}{P} = \frac{0.20}{1.01} \times 100\% = 19.8\%$$

efficiency of whole system

$$\eta = \frac{P_o}{P_i} = \frac{0.20}{2.77} \times 100\% = 7.2\%$$

4.2. Analysis

1. The fluctuation of the torque of rod in well.1 can be observed obviously. The amplitude is between 300 to 500 Nm. This significant fluctuation may be resulted by eccentric wear between rotor and stator of the pump. There are many factors that can lead to the eccentric wear, such as the irrationality of the well structure, the influence by the produced fluid, the condition of installation of the centralizer, the irrationality of the rotation speed of production and other human factors. The measures to improving the conditions include the control of the irrationality of the well structure, decreasing the water content of the production zone and the adjustment of the produce factors [19-20].

2. The efficiency of surface between the two wells has difference. The efficiency of surface of well.1is 56.4% and well.2 is 36.5 %. We think the difference of lubrication condition of the gearbox results the difference of the efficiency of surface between the two wells. These two wells all have poor

lubrication conditions; so much power transmitted from the shaft of motor was consumed in the friction of the reduction gearbox. So if we want to improve the efficiency, the good lubrication condition of the reduction gearbox is essential.

3. From the calculation results, we can find that the system efficiency of Well.2 is low. There are many reasons can generate this phenomenon. The first one is because of the low volumetric efficiency of progressive cavity pump which resulted of high viscosity of crude oil [21]. And the second reason is the high viscosity of crude oil may increase the resistance of movement of the rotor of pump, which results the mechanical efficiency of downhole is low.

4. In addition, the efficiency of whole system is also low. Except of the above reasons, the motor may do not work in its range of rated power. And this condition should be adjusted.

5. Conclusions

According to test data above, the system can test the change of torque accurately, and the accuracy and reliable of wireless communication technology have been proved. And the node efficiency is very important to evaluate the operation of the progressive cavity pump. However it was ignored before. So the development of this system of testing the node efficiency of the progressive cavity pump is very timely. Due to the stability and accuracy of the test result, the device can be widely used in oilfield.

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