Development and application of pumping unit monitoring system based on wireless dynamometer sensor node

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Abstract: For the problems of the complicated installation and removal of dynamometer card detection equipment, high cost, not convenient for real-time detection, prone to failure and maintenance workload, a kind of low cost wireless dynamometer is developed. With the implement of wireless transmission gateway, comprehensive monitoring software is programmed. This system consists of a pumping dynamometer, gateway, monitoring software and indicator diagram measuring algorithm. Finally, the wireless dynamometer was installed at RenQiu oil field, and the data shows that the system works well and can be used for the long-term working and operating state of pumping oil field monitoring.

1. Introduction
Pumping wells data monitoring generally uses the load sensor, angular displacement sensor at present, which are placed on the rope hanging device, beam superior position, the detected signal transmission to the controller by cable. The monitoring method is costly, the installation process is complicated, and the cable is easy to be artificial or natural damage, large maintenance work load, it is difficult to perform long-term safe and reliable work [1].

At present the embedded wireless sensor networks (WSNs) are systems consisting of a large number of nodes each equipped with certain amount of computational, communication, storage, sensing, and often actuation resources. The design and implementation of networks connecting several hundred sensor nodes pose several significant and interesting challenges [2].

A pumping dynamometer collection system based on WSNs greatly improves the efficiency of oil production and reduces the labor intensity, using indicator diagram analysis to calculate output of petroleum. The process of data acquisition can realized only by a execute command sending from control center.

These low-cost and low-power devices are characterized by limited computation, memory storage, and communication and battery power capabilities. Some of the key challenges in realizing such networks are scaling network protocols to large number of nodes, designing simple and efficient protocols for different network operations, and designing power-conserving protocols.
2. Pumping Dynamometer

2.1. Installation and main parameters

Pumping dynamometer is used to analyze working condition of pumping unit and measure output of petroleum, which is shown in figure.1. It obtains two signals, stress of tubing and displacement of sucker rod up and down. Dynamometer moves with pumping unit under reciprocating motion, running to the top and bottom identified one stroke.

The dynamometer developed in this paper is of wireless, which communicates with gateway via wireless sensor network at 2.4 GHz. The structure of wireless dynamometer is compact, fully considering the needs of project installing. Load range of dynamometer is 0~150kN and its resolution is 1N. The displacement of one stroke get 8m maximum and the range of stroke reaches to 1~12.

In order to reduce the power consumption, the RF and peripheral circuit of wireless dynamometer’s MCU should be shut down at most of time, i.e. low power (sleep) mode. Once the RTC timing terminal waking up, wireless dynamometer gets into the work mode again. The wireless dynamometer key parameters are shown in Table 1.

![Fig. 1 Position, shape and size of a pumping dynamometer](image)

| Items                          | Specifications                  |
|-------------------------------|---------------------------------|
| Explosive-proof grade         | Ex ib IIC T4 Gb                  |
| Protection class              | IP66                             |
| Channels                      | 2                               |
| Load range                    | 0~150 KN                        |
| Displacement range            | (0~8)m                           |
| ADC                           | 24bit                           |
| Load resolution               | 1N                              |
| Displacement resolution       | 1mm                             |
| Communication protocol        | IEEE 802.15.4(BeeLPW)           |
| RF frequency                  | 433MHz ISM                      |
| Transmission distance         | 100m                            |
| Working environment temperature | (-40~50)℃                     |
| Temperature shift             | 15ppm/℃                         |
| Power                         | 3.6V DC                         |
| Shell material                | High-grade carbon steel         |
| Weight                        | 5137g                           |
| Size (Length, width, height)  | (135×113×81) mm                  |

The wireless dynamometer is simple and convenient to use and it could eliminate the noise interference caused with wireless digital signal transmission instead of long cable transmission. The
whole system has high measurement precision and anti-interference ability and it supports hundreds of wireless dynamometer to test at the same time.

2.2. Working flow

After the connection with gateway is successful, wireless dynamometer get beacon to achieve synchronization with communication network, and it collects the indicator diagram information on certain time interval. Finally it transmits the data via RF unit to gateway and server. The work flow of wireless dynamometer is shown in Fig.2.

![Fig. 2 Working flow of dynamometer unit](image)

3. System major components and integration

3.1. Gateway

Gateway, as remote transmission unit, is responsible for receiving data packets from pumping dynamometer and forwarding these measuring data to remote server using for analysis.

In additional communication interface, e.g. RJ45, RS485, RJ23 and USB, the gateway can also communicate with remote server by mobile network through embedded GPRS module. It is fairly compatible to be applied in complex environment where no man on duty.

3.2. Communication Network

Gateway and pumping dynamometer form a star network through A11 protocol based on IEEE802.15.4 physically, which is under 2.4 GHz frequency\(^3\). The communication distance reach to 200m maximum in visible range and bitrates between gateway and pumping dynamometer is 250 kbps limiting value.

Each pumping unit can be considered as a sensor node with wireless dynamometer to collect field data and then transmit the data to gateway shortly. The wireless sensor network could consist of 65535 sensor nodes of capacity, but we define here one gateway and sensor nodes no more than 80 as one network, considering total bandwidth and practical distribution of oil field.
3.3. System integration
The pumping dynamometer collection system contains pumping dynamometer and gateway for data acquisition and transmission, which is shown Fig.3. Dynamometers communicate with gateway by means of 2.4 GHz wireless network according to A11 standard proposed by Petrol China. The gateway forwards the received data from dynamometers to remote server using GPRS network. Through indicator diagram and simulation methods, production data and output of petroleum will be present on the monitoring software embedded in remote server or PC.

4. Software development and function

4.1. Program language and theoretical power calculation method
The system software programming language is QT, which is simple and its interface is friendly. If we named the displacement of pumping unit relative to the lower dead point $S$, and named the strain of pumping unit pulling up $F$, we can get a closed curve which is based on $S$ for the horizontal axis and $F$ for the vertical axis. That closed curve is so-called indicator diagram in one stroke of pumping unit’s reciprocating motion.

The output of oil well can be calculated from the size of indicator diagram. The change of output can be obtained by analyzing the change of area value of the indicator diagram. So the change of pump efficiency of pumping unit can be further obtained according to the real time diagram. Combined with different conditions and relevant data of each well, it can analyze morphologically the pumping real-time oscilloscope diagram.

4.2. Main function
The software can be remotely controlled to work in two modes through WSNs, one is the on time collection (set the sampling period and the collection interval), and the other is manual control collection (according to the demand, the user sends the command to start collecting).

At the same time, the software has the following functions:
- Cycle sampling: setting the sampling interval and the length of each sample;
- Event trigger: set the threshold value of the event triggered, threshold value to start collecting;
- Continuous data collection: continuous acquisition and real-time transmission to the monitoring center;
Management and control of wireless sensor networks: such as setting interface of network parameters.

5. Application of the wireless pumping dynamometer node
After the wireless pumping dynamometer is developed, the system is install at ZhongYang oil field, which locate in RenQiu city of Hebei province. And the monitoring software is developed on the basis of BeeViewer, which is a set of industrial configuration software and supports ModBus, CAN, GPRS and other customized communication protocol for data output. It has friendly interface, convenient operation and powerful function. It is also easy to expand upon software structure.

The monitoring software shows information of oil well combined with geographic location map, such as on/off status and operation data. It analyzes indicator diagram (diagram superposition and parallel comparison) and generates historical data and reports of oil well production. The monitoring software shows information of oil well combined with geographic location map, such as on/off status and operation data. It analyzes indicator diagram (diagram superposition and parallel comparison) and generates historical data and reports of oil well production, and some trail data is shown in Fig.4, and the horizontal axial is displacement of pumping unit.

![Fig.4 Some test data interfaces](image)

6. Conclusion
The pumping dynamometer collection system developed here is automatic and of more efficiency, compared with the traditional methods of collecting oil well information and monitoring pumping status. The output of oil well can also be obtained from the automatic measuring system. It greatly improves the automation and information technology of oil field production. Finally, the wireless dynamometer was measured in the oil field, and the measured data shows that the wireless dynamometer has stable and reliable performance, good effect, can be used for long-term monitoring of oil well production condition.

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