*Sensors & Transducers, Vol. 182, Issue 11, November 2014, pp. 62-68*

**Sensors & Transducers**

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# Intelligent Balanced Device and its Sensing System for Beam Pumping Units

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*Received: 14 July 2014 /Accepted: 30 October 2014 /Published: 30 November 2014*

**Abstract:** In order to save the energy of the beam pumping unit, the intelligent balanced device was developed. The device can adjust the position of the balanced-block automatically by the single chip microcomputer controller, and the fuzzy PD control algorithm was used to control the servo motor of the device. Since some signals should be inputted into the intelligent balanced device to calculate the balanced index of the pumping unit, the signals sensing system were designed. The sensing system includes the electric current sensor and voltage sensor of the main motor, the displacement sensor and the force sensor of the horse head. The sensing network has three layers: slave station, relay station and master station. The data transmission between them is based on ZigBee and GPRS method which can adapt the environment of the oil field. The results of application show that the intelligent balanced device and its sensing system can have the effect of reducing the power consumption, working reliability and communication efficiently. *Copyright © 2014 IFSA Publishing, S. L.*

**Keywords:** Intelligent, Sensing system, Beam pumping unit, Saving energy, ZigBee, GPRS.

## 1. Introduction

There is a widely application of the beam pumping units to the oilfield, which attains the 90 % of the oil production equipment [1]. However, the pumping units have to consume a large number of electric power every year. In order to save the energy of the pumping units, the balanced block is often used to storage and release energy for the pumping units, or the energy saving electric motor is used [2-3]. There are three kinds of balanced ways for the beam pumping units, which are crank balanced way, beam balanced way and compound balanced way. However, these balanced methods have a bad effect when the load acting on the horse head changes. The reason is that the position of the balanced block is constant and can't be adjusted automatically. So some new balanced method have been developed, such as the automatic balance regulating device, overrunning clutch device, and the kinetic energy equilibrator [4-7].

Among the new balanced method, the automatic balanced regulating device has the better effect, which can adjust the position of balanced block in real-time. However, its servo motor may sometimes consume a lot of energy, so it counteracts the energy saving which produced by using the balanced device. Aiming at the problem, the intelligent balanced device and its sensing network are designed in this paper, which the servo motor can be powered by the solar batteries and wind power generators. So it can realizes the actually energy saving for the pumping units.

The intelligent balanced device need the electric signal of the main motor to calculate the balanced index of the pumping unit, and the administrators of the oil field need also acquire many real-time parameters of the pumping unit to know the work condition of the oil production. So the sensing network is designed in this paper. The sensors include the electric current sensor and voltage sensor of the main motor of the pumping unit, the displacement sensor of the horse head, and the force sensor of the horse head. The sensing network is divided into three layers: slave layer, relay layer and master layer. The data transmission is based on the ZigBee and GPRS method, which can adapt the environment of the oil field [8-10].

The paper is organized as follows: the structure of the intelligent balanced device of the pumping units is introduced in Section 2. Then, the structure of the sensing network is discussed in Section 3, followed by the sensor's signal processing and software structure in Section 4. Next, the application of the device is presented in Section 5. Finally, the conclusions are drawn in Section 6.

## 2. The Structure of the Intelligent Balanced Device of the Pumping Units

### 2.1. The Whole Structure of the Intelligent Balanced Device

The whole structure of the intelligent balanced device of the pumping units is shown in Fig. 1. The horse head of the pumping unit can be moved reciprocated vertically driven by the main motor of the pumping unit. Since the load of the rod is very large and variable, which is often from 30 kN to 100 kN, the balanced block can be used to decrease the driving torque of the main motor of the pumping unit. Here the two balanced block can be installed in the pumping unit, i.e. the balanced block I and the balanced block II, as is shown in Fig. 1.

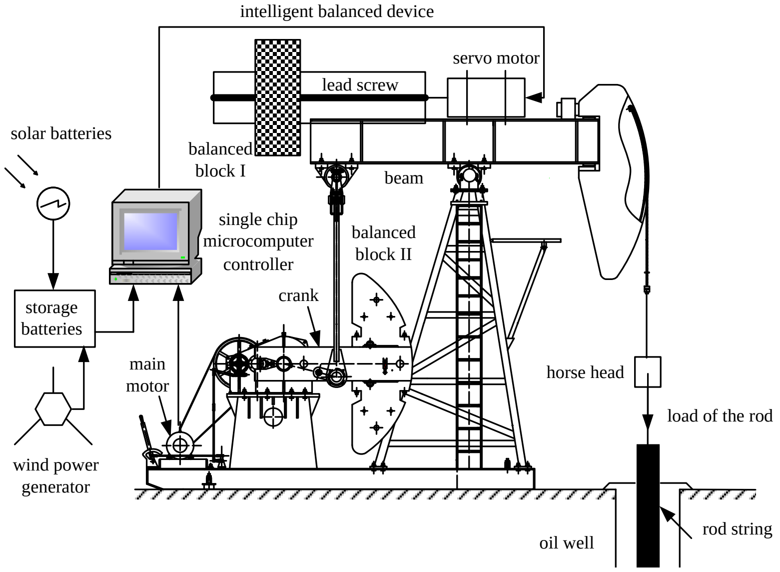


**Fig. 1.** The whole structure of the intelligent balanced device.

The balanced block II is fixed on the crank of the pumping unit and it can't be moved. Whereas, the balanced block I can be moved axially along the intelligent balanced device. The balanced block I is installed on the lead screw of the intelligent balanced device, and the lead screw is linked by the servo motor. When the servo motor is turn on, the lead screw rotates about its axis driven by the servo motor. Then the balanced block I can be moved along the lead screw. Since the intelligent balanced device is located on the beam of the pumping unit, the movement of the block I can change the balanced effect for the pumping unit. When the load of the rod acting on the horse head is bigger, the balanced block can be moved toward the left in order to increase the length of the arm of force. But when the load of the rod is smaller, the balanced block can be moved toward the right.

For the conventional balanced device, although the balanced block I on the beam can decrease the electric power consumption of the main motor of the pumping unit, the servo motor has to consume the electric power actually. The power consumption of the servo motor is sometimes equal to the power saving of the main motor of the pumping unit. So this type of balanced device can't save the energy actually.

So, the intelligent balanced device is designed in this paper. The key point of the intelligent balanced device is the method of power supply for the servo motor. Here the servo motor is powered by the solar batteries and the wind power generator. Then, the servo motor need not consume the power which supplied for the pumping unit. So it can realize the energy saving actually compared the other method.

In Fig. 1, the servo motor is controlled by the single chip microcomputer controller, and the current signal is inputted into the single chip microcomputer controller. In addition, the solar batteries and the wind power generator are also connected to the single chip microcomputer controller through storage batteries. The detailed control structure is shown in Section 2.2.

### 2.2. The Control System for the Servo Motor of the Intelligent Balanced Device

The structure of the control system for the servo motor of the intelligent balanced device is shown in Fig. 2.

The wind power generator is connected to the storage batteries through the adaptor I. Since the output voltage of the wind power generator will change with the variation of the wind strength, the adaptor I can convert the voltage into a standard voltage for the storage batteries. As the same way, the solar batteries are also linked to the storage batteries through the adaptor II because the output voltage is changed with the sunlight strength. The storage batteries is connected to the voltage stabilizing power supply, which can provide a constant DC voltage for the transmitter, single chip microcomputer controller, driver and servo motor. In order to check the balanced condition of the pumping unit, the single chip microcomputer controller must know the electric current of the main motor of the pumping unit in a cycle. So, the current sensor of the main motor are linked to the single chip microcomputer controller through the transmitter. The main function of the transmitter is to convert the signals generated by the sensors into a standard value for the single chip microcomputer controller. The single chip microcomputer controller is connected to the driver, which the control signal for the servo motor is inputted into the driver. The driver is linked to the servo motor, which amplifies the signal to drive the servo motor.

## 3. The Structure of the Sensing Network

### 3.1. Sensing Network Based on ZigBee and GPRS Method

The structure of the sensing network is shown in Fig. 3. The sensing network in the pumping unit includes four sensors, which are voltage sensor and current sensor of the main motor, displacement sensor and force sensor on the horse head.

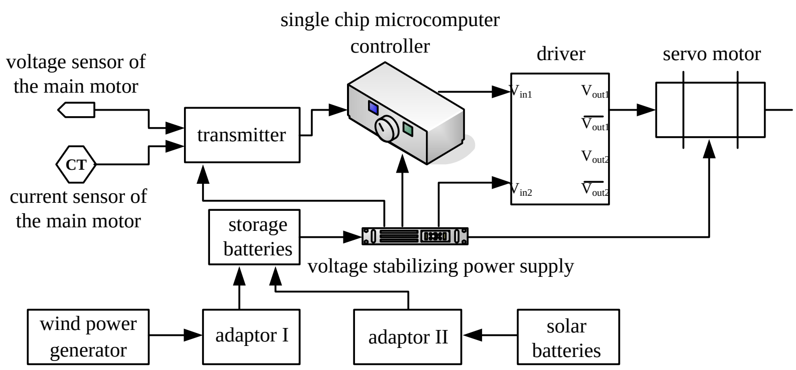


**Fig. 2.** The structure of the control system.

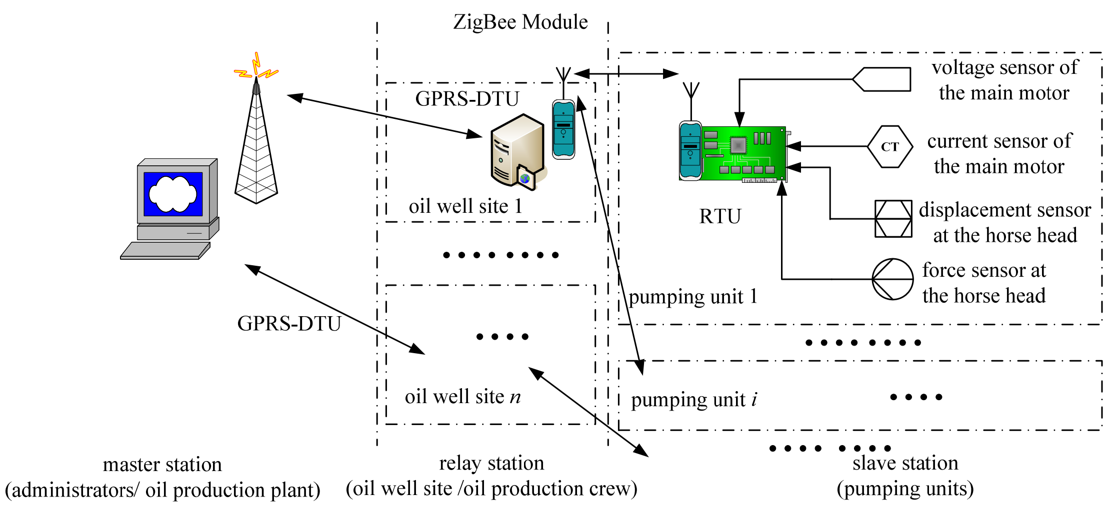


**Fig. 3.** The structure of the sensing network.

Compared with the Fig. 2, the displacement sensor and the force sensor are added in the Fig. 3. That is because these data is very important for the oil field administrators to determine the oil production condition. There are often 5 to 10 pumping units in an oil well-site, and the distance between the pumping unit and the oil production crew is no more than 30 meter. So the communication between the sensor and computer server in the oil production crew is based on ZigBee method, which can decrease the electric power consumption of the circuit of the sensors. However, the distance between the oil production crew and the oil production plant is often very far, for example hundreds kilometers. So the GPRS method is used to communicate between the oil production crew and the oil production plant.

Because the displacement signal and force signal of the horse head include a large amount of data, the sensing network is divided three layers: master station, relay station and slave station. In slave station, the displacement and force of the horse head can be changed into electrical signal and is amplified by transmitter. Then, the signals are transmitted to the relay station by ZigBee module. Since the current is very small by using the ZigBee module, the RTU in slave station has small power consumption. In the relay station, the ZigBee module receives the signals from the slave station and transfers it to the GPRS module (GPRS-DTU). The GPRS module then transmits it to the master station. The relay station is often located in the room of the oil well site near from the slave station and the municipal electric power (220 V) can be provided for the GPRS-DTU. So, although the electricity consumption is large slightly, it can still work well. In master station, the GRPS-DTU receives the signal from the different relay station and inputted it into the monitoring computer. Parameters of the various pumping units can be displayed on the screen of the computer.

## 3.2. Structure of the Slave Station

The signals form the four sensors are inputted into the slave station and are processed by the slave station. The structure of the slave station is shown in Fig. 4, which includes four sensors (voltage sensor, current sensor, displacement sensor and force sensor), interface circuit and ZigBee module.

Sensors: The range of the voltage sensor is AC 0~380 V; the range of the current sensor is 0~60 A; the range of the displacement sensor is 0~3 m; and the range of the force sensor is 0~100 kN.

ZigBee module: transmitting and receiving frequency: 2.4 GHz; transmitting power: 1 mW; communication distance: 100 m; data transfer rate: 9600 bps. The data sampling interval is 300 seconds (or it can be set by the master station).

In the transmitter, the outputs of the four sensors are changed into digital signal and are inputted into the ZigBee module. It is powered by the storage batteries.

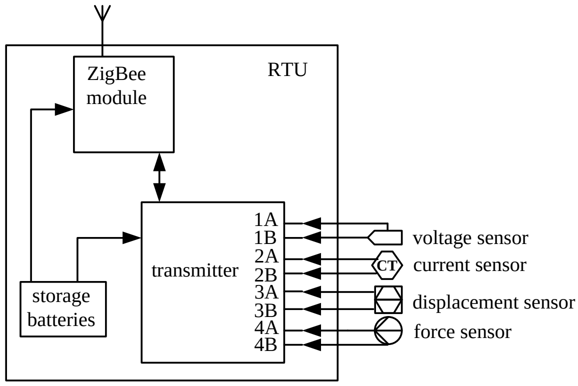


**Fig. 4.** The structure of the slave station.

The transmitter, GPRS module are installed in a sealed box which is called RTU. The box has a water-resistance capability, so it has a high reliability.

## 3.3. The Hardware of the Relay Station

The hardware of the relay station includes ZigBee module, interface circuit, GPRS module and power supply. The ZigBee module is the same as that in the slave station. The function of the interface circuit is signal conversion and connection between the ZigBee module and GPRS-DTU. Firstly, the ZigBee module receives the signal from the slave station and inputs it to the interface circuit. Then, the signal is converted to proper format by the interface circuit and is inputted into GPRS-DTU. The connection port between the interface circuit and the GPRS-DTU can be RS232 or TTL ports (here the TTL is used).

The type of GPRS-DTU is G200 made in Jammy Communication Company. The main advantage of the G200 is that the master station does not need the fixed IP address. The G200 communication module includes host module and subordinate module. The host module is often installed in the master station, and the subordinate module is in the relay station. The way of communication is one point (host module) to multi-point (slave module), which is seen in Fig. 3.

## 3.4. The Hardware of the Master Station

The hardware of the master station includes GPRS-DTU, monitoring computer, interface circuit and power supply. GPRS-DTU (G200) module is set as host GPRS module. The data from the different relay stations can be displayed on the screen of monitoring computer. The communication between the monitoring computer and the GPRS-DTU is through RS232 serial port. The function of interface circuit is to convert the output TTL voltage of

GPRS-DTU to RS232 voltage of monitoring computer. The hardware of the master station is shown in Fig. 5.


**Fig. 5.** The hardware of the master station.

## 4. Signal Processing for the Sensors and Software Structure

### 4.1. Signal Processing for the Displacement Sensor and Force Sensor

When the horse head moves from the highest position to the lowest position and then moves to the highest position again, it is called a stroke. The distance of a stroke of a pumping unit is often 1.5-2.5 meters, and the time during a stroke is often 7-15 seconds. There are more than 200 displacement data and force data sampled by the sensors in a stroke. These data is easy to be interfered by the electromagnetic signal of the main motor and the mechanical vibration signal of the pumping unit. So the moving average filtering is used to eliminate these noises, which is as follows:

$$\begin{aligned} x_k = (x_{k-10} + x_{k-9} + \ldots + x_{k-1} + x_k \\ + x_{k+1} + \ldots + x_{k+9} + x_{k+10}) / 21 \end{aligned}, \quad (1)$$

where $x_k$ means the displacement signal or the force signal at the current point, $x_{k\text{-}1}$ is that at the previous point, $x_{k+1}$ is at the next point, and so on.

### 4.2. Signal Processing for the Electric Current Sensor of the Main Motor

In order to acquire the best balanced effect for the pumping unit, the data from the current sensor of the main motor is used to control the rotation of the servo motor. If the balanced condition of a pumping unit is good, the current of a main motor in one cycle changes slightly. The current signal of the current sensor is inputted into the single chip microcomputer through the transmitter, which is seen in Fig. 2.

Aiming at the characteristic of the intelligent balanced device, the fuzzy PD control strategy is used to adjust the input signal of the servo motor. The structure of the control algorithm is shown in Fig. 6. Firstly, the expected balanced value is inputted, which is often 1.0~1.2 [11]. Then, the data from the current sensor of the main motor is inputted into the balanced effect calculation module. The real balanced value of the pumping unit is calculated by the module and inputted into the adder. The adder outputs the error *e* between the expected balanced value and the real balance value.

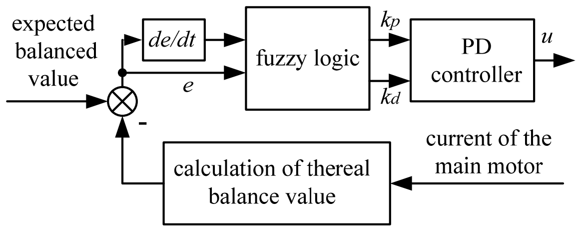


**Fig. 6.** The structure of signal processing for the current sensor of the main motor.

The fuzzy PD controller includes the PD controller and the fuzzy controller, which parameters of the proportional coefficient $k_p$ and the differential coefficient $k_d$ in the PD controller can be adjusted by the fuzzy logic in real time. The inputted parameters of the fuzzy logic are the balanced value error *e* and its differential *de*/*dt*. The fuzzy variable of the fuzzy logic are {NB, NS, ZE, PS, PB}, and triangle membership function is employed. There are 25 fuzzy rules in the fuzzy logic.

The fuzzy logic and the PD controller can be written as follows:

$$\begin{aligned} u = k_p(B_j - B_0) + \\ k_d\left(\frac{(B_j - B_0) - (B_{j-1} - B_0)}{\Delta t}\right), \end{aligned} \quad (2)$$

where $k_p$ is the proportional coefficient, $k_d$ is the differential coefficient, $B_j$ is the balanced value at the current sampling time, $B_{j\text{-}1}$ is the balanced value at the previous sampling time, $B_0$ is the expected balanced value, *t* is the sampling time-interval, and *u* is the voltage for control the servo motor which can be positive or negative.

### 4.3. Data Transfer Protocol for the Sensors in the Slave Station

The communication protocol (ZigBee) between the relay station and the slave station is IEEE 802.15.4 [12], and the communication protocol between the master station and the relay station is MODBUS. The communication between the master station and relay station is based on GPRS-DTU (G200), and the ZigBee communication between the relay station and the slave station is transparent for the master.

There are four sensors in a pumping unit, and there are 5-10 pumping units in a single oil well site. So each pumping unit should have a single address when all sensors' signals are transmitted to the relay station through ZigBee way. Each sensor's signal can be saved in the registers of relay station according to the MODBUS protocol. In addition, some information is also saved in the registers, such as:

1) The voltage of the storage batteries of the slave station;

2) Received signal strength of the relay station;

3) The data sampling interval between relay station and slave station;

4) CLOSE command for the slave station.

Since the slave station is transparent for the master, the user can only send MODBUS command in the monitoring computer to the relay station and the slave station will send back the corresponding command. The MODBUS command in master station can be divided into 2 kinds: lookup command and responding command. The address of GPRS-DTU in master station is often 00H because it is host module. If we set the address of Oil Well-Site 1, Oil Well-Site 2, …, Oil Well-Site n in the slave station is 01H, 02H, …, 0nH, the format of lookup command is shown in Table 1, and the format of responding command from the relay station is shown in Table 2.

### 4.4. Monitoring and Control Software in the Master Station

The function of the software in the master station is to display, save and print the data from the slave station. The software has been developed by using configuration software, which can easily integrate the hardware (GPRS-DTU) into the software and send MODBUS command [13-14].

**Table 1.** Format of lookup MODBUS command in master station.

| Address of Subordinate module | Function code | The first address of the register | | The umber of the registers | | Error-checking code | |
|---|---|---|---|---|---|---|---|
| [1Byte] | 03H | High byte | Low byte | High byte | Low byte | High byte | Low byte |

**Table 2.** Format of responding MODBUS command in master station.

| Address of Subordinate module | Function Code 03H | The number of the reading register | The value of the first register | | … | The value of the last register | | Error-checking code |
|---|---|---|---|---|---|---|---|---|
| [1Byte] | [1Byte] | [1Byte] | High byte | Low byte | … | High byte | Low byte | [1Byte] |

The software includes seven modules. The main interface displays a map which has all the location of slave station (the oil well site). If the user wants to lookup the sensor's data of a slave station, he just clicks the name of that slave station on the map. Real-time data display module output the current and voltage of the main motor, the displacement and the force of the horse head and batteries' voltage of a slave station. Data statistics and printing module can make statistics and printing the data from the slave station. Database linking module can build a database to save the large amount of data from the slave station. Web publishing module will publish all the real-time data to the internet and the user can browse the data every slave station through the internet.

## 5. Applications

The system in this paper has been tested in the Yan Chang oilfield in China. The result shows that the balanced value of the pumping unit decreases from 1.59 to 1.03 after the intelligent balanced adjustment device is used. Moreover, the electric current of the main motor in the pumping unit can reduced accordingly. The sensing network of the pumping unit can also work well. The displacement signal and the force signal at the horse-head are transmitted to the relay station via ZigBee method, and the electric current signal and the voltage signal of the main motor are transmitted to relay station via ZigBee method and are transmitted to the single chip microcomputer controller by wire. The relay station can receive the data of the slave station reliability, and accurately. Once the master station sends a MODBUS command to a slave station, it can receive the responding command of that slave station in 1-3 seconds. The sampling interval in the slave station is 500 seconds.

## 6. Conclusions

In order to improve the balanced effect and save the energy for the pumping units, the intelligent balanced device was designed. Compared with the other device available, this device is powered by the solar batteries and wind power generator. Since the servo motor need not consume the power supplied for the pumping unit, it realizes the actual energy saving. The servo motor of the intelligent balanced device is controlled by using the fuzzy PD algorithm according to the signal from the electric sensor, which can acquire a good effect.

In addition, the sensing network for measuring the parameters of the pumping unit was designed to transmit the data to the administrators of the oil field. The structure of the sensing network has three layers: slave station, relay station and master station. The parameters of the pumping units are firstly sent to the relay station through ZigBee, and then the data of relay station are transmitted to the master station by using GPRS-DTU. This structure has the advantages of high data transmission reliability and high speed. The results of application shows that the system has more stability and power saving.

## Acknowledgements

This paper was supported by the Scientific Research Project of Shanxi Province (2014K07-20). The authors want to give their gratitude to them.

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