The Application Research of Fuzzy Control with Self-tuning of Scaling Factor in the Energy Saving Control System of Pumping Unit

Zhongda Tian, Xianwen Gao, and Dehua Wang

Abstract—**How to save energy in the production process of oil field is an important issue. The beam pumping unit in the oil field has the serious nonlinear and strong load disturbance. It is difficult to establish an accurate mathematical model. The classical control theory cannot solve the problem of energy saving and efficiency of the pumping unit. In order to improve the automation level, an energy saving control system is composed of remote main control system and local energy saving control system is designed. Oil engineers can obtain operating conditions of the pumping unit through remote monitoring software. And in the case of inadequate supply of oil, local energy saving control of the pumping unit will be enabled. In this paper, a fuzzy control strategy is proposed based on the study of the fuzzy automatic control system. Aiming at the problem of variable control effect when the disturbance changes too much, an adaptive fuzzy control strategy is proposed to improve the control performance of the whole system, which is utilized to adjust the scale factor. The self-tuning scaling factor fuzzy control system is discussed in detail, and then the software and hardware of the energy saving control system are designed respectively. For the extraordinary industrial environment of oil field, it takes some effort to resist the interference of the software and hardware. According to the principle of modular design, the monitoring interface and the software of the local energy saving control system are implemented. In the field test, by comparing the experimental data before and after the use of proposed energy-saving control system, it is found that pump efficiency is improved, and the system is more efficient. The results showed that the energy saving control system achieved the energy efficiency goal.**

***Index Terms*—frequency control; energy conservation; fuzzy control; self-tuning scaling factor; working fluid level**

I. INTRODUCTION

As mostly oil field in China is depleted field, we have to use water and electricity to make oil, so that the electricity fee cost a lot in the petroleum mining of China. Thus, the oil industry pays great attention to electricity saving [1]-[3]. In the actual oil production process, the installed capacity of the beam pumping unit motor usually chooses a larger one. At the same time, the motor is right on a light load. Especially in the middle and late time of the oil field exploitation, some oil field supply inadequate oil and the pump is usually in an inefficient working state because of the decline of formation pressure, which leads to "pumping nothing" phenomenon. In some cases, we can only pump little or even no oil. It leads large electricity waste [4]-[7]. Often using indirect pumping method not only affects the yield but also leads oil well cannot work properly.

Over the years, the experts have been much research work in the pumping unit energy savings, the advanced frequency conversion technology and integrated motor energy-saving control technology leads the pumping unit changes from the traditional rough low efficiency type to intelligent high efficiency type. The practice has proved that the application of the frequency conversion control technology can make the oil production more efficient, the energy-saving enhancement, the labor intensity reduction, and comprehensive benefits raising [8-9].

Oil production system includes pumping oil, injection water, geology and other complex process, which have serious nonlinear and large load disturbance, so that it is difficult to establish a precise mathematical model of the system. However experienced experts of oil pumping unit can judge the working conditions of the pumping unit according to dynamic liquid working fluid level depth, indicator diagram data, current, load and other factors, and then control the oil production system, which can obtain certain effect of saving energy. Nowadays, the energy-saving intelligent control of the pumping unit has become a hot research [10]-[13].

In this paper, aiming at fluid shortage and power consumption problem, from point of dynamic matching machine - bar - pump can achieve excellent oil production; we put forward a solution of beam pumping units control strategy. Because the working fluid level is controlled by the frequency of inverter, this paper will regard frequency of inverter as the controlled parameter. The self-tuning scaling factor fuzzy control algorithm is introduced to improve energy saving. The experimental results in Liao He oil field in Panjin, Liaoning Providence, China shows that the designed energy saving control system in this paper achieved the energy efficiency goal.

II. THE WHOLE STRUCTURE OF THE SYSTEM

The architecture of the whole control system is composed of remote main control system and local energy-saving control system on beach, which communicate by the network and

Manuscript received November 26, 2015; revised March 30, 2016. This work was supported by the Liaoning Province Doctor Startup Fund under Grant 20141070.

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digital radio. The scheme is based on frequency conversion transformation in the field, which is not necessary to change the original equipment; thereby it can reduce the costs. The architecture of energy saving control system is illustrated in Fig. 1.

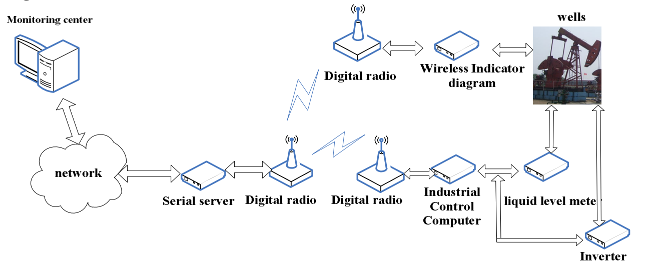

Fig. 1. The architecture of energy saving control system

The monitoring center runs the remote monitoring software coded by Visual Basic 6.0. The remote main controlling and monitoring center on the land connected the serial port server through the oil field local network, and then through the wireless digital radio obtain the working parameters of the pumping unit, such as voltage, current, frequency, flush times, the indicator diagram data collected by the indicator diagram wireless collecting system, etc. We can know the operation status of pumping unit. When we found the inadequate liquid underground through the indicator diagram data and judge that we need to enable energy control system, we can start energy saving control system in a long distance. This paper is focused on the energy saving control system, so that the other parts are not described in detail.

Local energy saving pumping unit control system is the core part of the whole beam pumping unit energy saving control system. In order to enhance adaptive ability of the local energy saving control system, this paper uses micro program control unit (MCU) to achieve the self-tuning scaling factor fuzzy control algorithm. When the fluid supply is insufficient, the adjustment of the pumping unit energy saving system can make the fluid supply capacity match pumping unit extraction ability, improve pump's filling, obtain better effects of energy conservation. The block diagram of local energy saving control system is shown in Fig. 2.

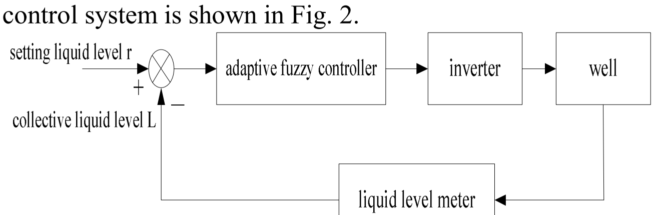

Fig. 2. The block diagram of local energy saving control system

III. THE DESIGN OF THE SELF-TUNING SCALING FACTOR FUZZY CONTROL SYSTEM

As one of the most important branches of intelligent control [14]-[15], fuzzy control is widely used in various fields including the petroleum industry control [16]-[19]. In this paper, we use a two-dimensional incremental fuzzy controller with two inputs and single output to design the energy saving control system, and realize fuzzy control algorithm coded in MCU.

In this paper, the structure of improved fuzzy controller is shown in Fig. 3. When the local pumping unit energy-saving control system is running, the next fuzzy controller carries out the basic fuzzy control algorithm, the scaling factor of the previous tuning scaling factor fuzzy controller system is used by the next fuzzy control algorithm.

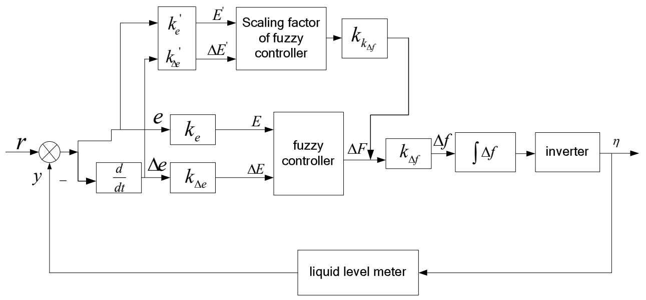

Fig. 3. The structure of improved fuzzy controller

A. The design of the basic fuzzy controller

We regard the deviation between the given depth and the current dynamic liquid level depth e and the change of error Δe as input, and inverter frequency increment Δf as output. The fuzzy language of e, Δe and Δf is E, ΔE and ΔF. The deviation and deviation variety of the system at k moment is defined as:

$$e(k) = r - L \tag{1}$$

Where r is the setting value of dynamic fluid level, L is the actual dynamic working fluid level.

$$\Delta e(k) = e(k) - e(k-1) \tag{2}$$

The schematic of basic fuzzy controller of control system is shown in Fig. 4.

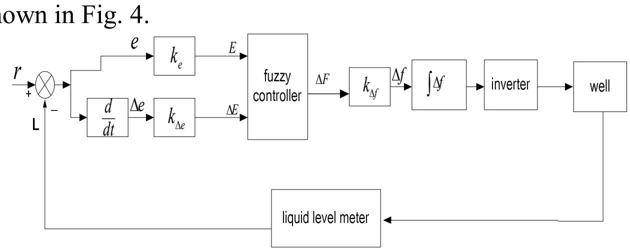

Fig. 4. The schematic of basic fuzzy controller of control system

According to the production experts professional knowledge and on-site operators control experience, we set the changes basic domain of deviation e, deviation change Δe and frequency incremental Δf as $[-18,18]$, $[-8,8]$, $[-6,6]$, and set the fuzzy domain of e, Δe and Δf as: {-6,-5,-4,-3,-2,-1,0,1,2,3,4,5,6}. After we set the basic domain of variables and the fuzzy domain, the quantization scaling factors are also determined, if we use k_e, $k_{\Delta e}$ represent the quantization factor of deviation e, deviation change Δe, and then:

$$k_e = \frac{6}{18} = \frac{1}{3} \tag{3}$$

$$k_{\Delta e} = \frac{6}{8} = \frac{3}{4} \tag{4}$$

We use $k_{\Delta f}$ represent scaling factor, then：

$$k_{\Delta f} = \frac{6}{6} = 1 \tag{5}$$

The membership function of the fuzzy controller's input and output variable is commonly triangle membership function. In order to improve the stability of the system, when the deviation is small, the shape of membership functions is slow. Table I, Table II and Table III represent the

TABLE I MEMBERSHIP VALUE OF E

	-6	-5	-4	-3	-2	-1	0	1	2	3	4	5	6
NB	1	0.8	0.4	0.1	0	0	0	0	0	0	0	0	0
NM	0.2	0.7	1	0.7	0.2	0	0	0	0	0	0	0	0
NS	0	0	0.1	0.5	1	0.5	0.3	0	0	0	0	0	0
ZO	0	0	0	0	0.2	0.6	1	0.6	0.2	0	0	0	0
PS	0	0	0	0	0	0	0.2	0.6	1	0.5	0.1	0	0
PM	0	0	0	0	0	0	0	0	0.2	0.6	1	0.5	0.2
PB	0	0	0	0	0	0	0	0	0	0.2	0.3	0.7	1

TABLE II MEMBERSHIP VALUE OF ΔE

	-6	-5	-4	-3	-2	-1	0	1	2	3	4	5	6
NB	1	0.6	0.3	0.1	0	0	0	0	0	0	0	0	0
NM	0.1	0.6	1	0.7	0.2	0	0	0	0	0	0	0	0
NS	0	0	0.2	0.7	1	0.5	0	0	0	0	0	0	0
ZO	0	0	0	0	0.2	0.5	1	0.6	0.2	0	0	0	0
PS	0	0	0	0	0	0	0.1	0.4	1	0.6	0.2	0	0
PM	0	0	0	0	0	0	0	0	0.1	0.5	1	0.5	0.1
PB	0	0	0	0	0	0	0	0	0	0.1	0.4	0.6	1

TABLE III MEMBERSHIP VALUE OF ΔF

	-6	-5	-4	-3	-2	-1	0	1	2	3	4	5	6
NB	1	0.7	0.4	0.2	0	0	0	0	0	0	0	0	0
NM	0.1	0.6	1	0.6	0.1	0	0	0	0	0	0	0	0
NS	0	0	0.2	0.6	1	0.8	0.2	0	0	0	0	0	0
ZO	0	0	0	0	0.1	0.5	1	0.5	0.1	0	0	0	0
PS	0	0	0	0	0	0	0	0.6	1	0.5	0.2	0	0
PM	0	0	0	0	0	0	0	0	0.2	0.7	1	0.5	0.1
PB	0	0	0	0	0	0	0	0	0	0.1	0.4	0.8	1

membership assignment table of deviation E, deviation change ΔE and frequency incremental ΔF. The fuzzy control rule is the core design part of the fuzzy controller. In this paper, the fuzzy control rule of fuzzy controller determines the frequency changes of the transducer based on the dynamic liquid level depth deviation and deviation change. The fuzzy control rules can be expressed as IF E AND ΔE THEN ΔF. According to the production expert's professional knowledge and on-site operators control experience, the fuzzy rules are shown in Table IV.

TABLE IV FUZZY RULES

ΔF / E / ΔE	NB	NM	NS	ZO	PS	PM	PB
NB	PB	PB	PM	PM	PS	ZO	ZO
NM	PB	PB	PM	PM	PS	ZO	ZO
NS	PB	PB	PM	PS	ZO	NM	NM
ZO	PB	PB	PM	ZO	NM	NB	NB
PS	PM	PM	ZO	NS	NM	NB	NB
PM	ZO	ZO	NS	NM	NM	NB	NB
PB	ZO	ZO	NS	NM	NM	NB	NB

Assuming A_i is the fuzzy set of the fuzzy controller's input error E, B_i is the fuzzy set of the fuzzy controller's input error change ΔE, and C_i is the fuzzy set of the output variable ΔF, then there is a fuzzy conditional statement, that is IF $E = A_i$ AND $\Delta E = B_i$ THEN $\Delta F = C_i$. According to the above fuzzy control rule table, we can calculate the fuzzy relation R_i decided by A_i, B_i and C_i:

$$R_i = (A_i \ and \ B_i) \to C_i \tag{6}$$

Considering 49 fuzzy control rules, the fuzzy implication relations is:

$$R = \bigcup_{i=1}^{49} R_i \tag{7}$$

Based on the approximate inference rules, we can get the input fuzzy sets $A^{'}$ and $B^{'}$ and the corresponding output fuzzy sets $C^{'}$:

$$C^{'} = (A^{'} \ and \ B^{'}) \circ R \tag{8}$$

The result of fuzzy reasoning is a fuzzy set. We use the weighted average method to make it clear. The fuzzy control table of the control system is shown in Table V.

B. The design of the self-tuning scaling factor fuzzy controller

The algorithm based on the scaling factor fuzzy controller is an effective method of self-tuning scaling factor fuzzy control applied to the real-time control [20]. For oil production system of beam pumping unit, it is a machine - bar - pump system, influenced by geological factors (sand, excessive gas, paraffin wax and other factors), equipment factors (wrong choice between bush and the piston clearance, etc.) and so on. There will be some changes in the dynamic characteristics of the controlled object. At the same time, under the shaft sizes and time of perturbation are random. In the former basic fuzzy controller, after the quantification factor and scaling factor is

TABLE V FUZZY CONTROL TABLE

ΔF \ E / ΔE	-6	-5	-4	-3	-2	-1	0	1	2	3	4	5	6
-6	6	6	5	5	4	4	4	2	1	0	0	0	0
-5	6	6	5	5	4	4	4	2	1	0	0	0	0
-4	6	6	5	5	4	4	4	2	1	0	0	0	0
-3	6	6	5	5	4	4	4	0	1	0	-2	-2	-2
-2	6	6	5	5	4	4	1	0	0	-3	-4	-4	-4
-1	6	6	5	5	4	4	1	-1	-3	-3	-4	-4	-4
0	6	6	5	5	4	1	0	-4	-4	-5	-5	-5	-6
1	4	4	4	3	1	0	-1	-4	-4	-5	-5	-5	-6
2	4	4	4	2	0	0	-1	-4	-4	-5	-5	-5	-6
3	2	2	2	0	0	0	-1	-4	-4	-5	-5	-5	-6
4	0	0	0	-1	-1	-3	-3	-4	-4	-5	-5	-5	-6
5	0	0	0	-1	-1	-2	-3	-4	-4	-5	-5	-5	-6
6	0	0	0	-1	-1	-1	-3	-4	-4	-5	-5	-5	-6

determined, if the load disturbance is too large, the control effect will be worse. In order to improve the ability to follow the load change quickly, we use on-line self-tuning scaling factor method. Keeping on k_e and $k_{\Delta e}$, if we increase $k_{\Delta f}$, the rising rate will increase, the over-regulation will increase and the response time will decrease.

However, if $k_{\Delta f}$ is too large, it will cause the rising rate of the output is too large, resulting in excessive overshoot and oscillation and divergence, it will seriously affect the homeostasis work; and if $k_{\Delta f}$ is too small, the system forward gain will be very small, the rise rating of system's output will be small, the system will be slow. We can obtain the next conclusion by $k_{\Delta f}$,

$$\text{IF } E' = A_i \text{ AND } \Delta E' = B_j \text{ THEN } K_{\Delta f} = C_l$$

$$i, j = 1,2,\cdots,\text{m}; l = 1,2,\cdots,\text{p}$$

A_i and B_j is the linguistic value of its corresponding domain, which is NB, NM, NS, ZO, PS, PM, PB. $K_{\Delta f}$ is the language variable of the scaling factor, C_l is the linguistic value of its corresponding domain. In this design, that is very big (VB), big (B), middle (M), small (S). Its fuzzy domain is stetted as $\{1,2,3,4,5,6,7\}$. Membership value of $K_{\Delta f}$ is shown in Table VI.

According to the above tuning principle of the scaling factor, we can get the tuning principle of the basic fuzzy controller parameter $k_{\Delta f}$, as shown in Table VII. When the system is operating, the parameter will be self-tuning according to the sampling deviation e and deviation variety Δe . Eventually, the query table for $k_{\Delta f}$ tuning is shown in Table VIII.

TABLE VI MEMBERSHIP VALUE OF $K_{\Delta f}$

	1	2	3	4	5	6	7
VB	0	0	0	0.1	0.4	0.8	1
B	0	0	0.2	0.7	1	0.7	0.2
M	0.4	0.8	1	0.8	0.4	0	0
S	1	0.8	0.5	0.2	0	0	0

TABLE VII RULE TABLE FOR $K_{\Delta f}$ TUNING

$K_{\Delta f}$ \ E' / $\Delta E'$	NB	NM	NS	ZO	PS	PM	PB
NB	VB	VB	VB	B	M	S	S
NM	VB	VB	B	B	S	S	M
NS	VB	B	B	M	S	M	B
ZO	VB	B	M	S	M	B	VB
PS	B	M	S	M	B	B	VB
PM	M	S	S	B	B	VB	VB
PB	S	S	M	B	VB	VB	VB

TABLE VIII QUERY TABLE FOR $k_{\Delta f}$ TUNING

$K_{\Delta f}$ $\Delta E'$ \ E'	-6	-5	-4	-3	-2	-1	0	1	2	3	4	5	6
-6	7	7	7	7	7	6	5	4	3	2	1	1	1
-5	7	7	7	6	6	5	4	3	2	1	1	1	1
-4	7	7	6	6	5	4	3	2	1	1	1	1	2
-3	7	6	6	5	4	3	2	1	1	1	1	2	3
-2	7	6	5	4	3	2	2	1	1	1	2	3	4
-1	7	5	4	3	2	2	1	1	1	2	3	4	5
0	6	5	4	3	2	2	1	2	2	3	4	5	6
1	5	4	3	2	1	1	1	2	2	3	4	5	7
2	4	3	2	1	1	1	2	2	3	4	5	6	7
3	3	2	1	1	1	1	2	3	4	5	6	6	7
4	2	1	1	1	1	2	3	4	5	6	6	7	7
5	1	1	1	1	2	3	4	5	6	6	7	7	7
6	1	1	1	2	3	4	5	6	7	7	7	7	7

C. The process of fuzzy control

In this paper, the control law of self-tuning scaling factor fuzzy controller is performed by the program of MCU. Then take one step fuzzy control algorithm for example, illustrate each control cycle of the local pumping unit energy saving control system, obtain the dynamic liquid level depth from level instrument, and then transmit it to MCU. According to the collected dynamic liquid level depth of L**,** MCU calculates the deviation e and deviation variety Δe, compared it with the setting value r . According to the fuzzy control requirements, fuzzy quantizing deviation e and deviation variety value Δe, we obtain the corresponding fuzzy quantity. We get ΔF of the controller output through querying the fuzzy control table. At the same time, according to the corresponding fuzzy quantity of the deviation and deviation variety, we query scale factor setting query table to get the scaling factor $K_{\Delta f}$, get incremental frequency Δf from clarity multiplies scaling factor. We obtain the frequency of inverter at current moment through frequency increments at current moment add frequency at the last moment.

According to the frequency signal sent by controller, inverters regulate the rotational speed of the motor, and then regulate the stroke frequency of the pumping unit, carry out the fast match between the shaft fluid supply capacity and pumping unit extraction ability, maintain a high full degree of the pump, improve the efficiency of the system, finally carry out the energy saving control of the pumping unit.

IV. THE HARDWARE DESIGN OF THE SYSTEM

The hardware block diagram of the system is shown in Fig. 5. The whole system is composed of MCU minimum system, digital radio, RS485 communication module, RS232 communication module, liquid level meter and other components.

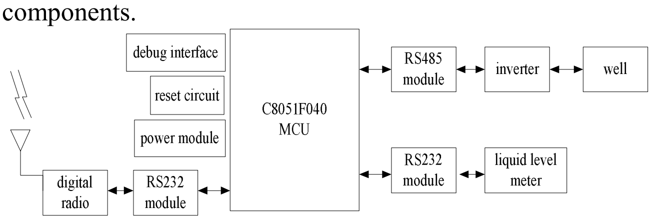

Fig. 5. The hardware block diagram of local energy saving control system

The main controller performance is directly related to the success of the system design, in this paper, we select the C8051F040 of USA Silicon Company as MCU, which is belongs to the industrial level MCU with a strong stability and anti-interference ability, can withstand a temperature range from - 40℃ to 85℃ and satisfy the oil field complicated production environments.

RS-485 communication interface is used to carry out the data exchange between C8051F040 and inverter Danfoss FC300. In the industrial environment, the scene is very complex, and there is plenty of interference, so that it must be segregated. The solving methods: one is using of DC-DC power supply isolation chip D0505S to carry out the power isolation between RS-485 and transceiver MAX487. Another is using for chip SI8402 to carry out receiving and transmitting control signal isolation between C8051F040 and RS-485 transceiver MAX487.

We use RS232 communication interface exchange data between a wireless station, liquid level meter and MCU. The hardware entity of MCU is shown in Fig. 6.

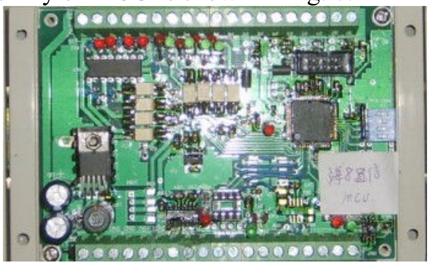

Fig. 6. MCU Hardware entity

V. THE SOFTWARE DESIGN OF THE SYSTEM

The hardware of local pumping unit energy saving control system is relatively simple; the smaller hardware spending requires relatively complex software design for compensating. In accordance with the functions divided the whole program of the local energy saving system into the following several modules.

1. System initialization module. The system will be initialized when powered on. The initialization process includes the system clock, the watchdog timer, LCD module, timer counter, UART module, voltage reference, PCA module, interrupt and all kinds of global variables used by program, etc.
2. Time reference module. Using Timer 3 generates 25ms timing function, and then set data acquisition cycle of the level data acquisition and frequency converter.
3. Fuzzy control algorithm module. It is the essence of energy-saving control system. Through the fuzzy reasoning process output control function, it carries out energy saving control of the system. When we found the energy saving control flag bit is set, we choose this algorithm to control the pumping system.
4. Software interrupts service program module. Software serial port interrupts service program modules are used to receive the data packet of the remote PC host computer. After receiving a complete data packet, if the packet contains insufficient fluid supply information, the energy-saving control flag bit is set.
5. Liquid level data acquisition module. Through sending the inquiry command to the liquid level instrument, we now begin to collect data. UART 0 interrupt service program module completes the working fluid level data reception.
6. Converter data acquisition module. This module includes two subroutine modules: start data acquisition module and the UART 1 interrupt service program module. Start data acquisition module through sending the inquiry command to the transducer, start data acquisition. UART 1 interrupts service program module carries out the data reception of the transducer.

The main program initializes the peripherals of MCU, including a timer, serial port, PCA, watchdog timer, then start timer 3 to produce a 25ms reference time clock, and then enters the main loop. When the remote control center begins energy-saving control, we collect the data of dynamic liquid level depth and transducer regularly. The flow chart of the main program is shown in Fig. 7.

In the software design of the whole system, the fuzzy control algorithm module is the core and difficult part. For this system, we carry out fuzzy control algorithm by fuzzy control table and a scale factor tuning query table. Using this method to perform fuzzy control, it saves a lot of time and ensures the timeliness control. Aiming at characteristics and control requirements of the system, in order to improve the stability of the system, based on the fuzzy control algorithm, we add a counter Cnt to determine the times of the current error absolute value $|e|$ is less than the error threshold e_0. When the counter value reaches the preset value, it means that the error e has to meet the requirements of precision, can make the output of the control frequency unchanged, and carries out a stable output of system. The flow chart of fuzzy control algorithm is shown in Fig. 8.

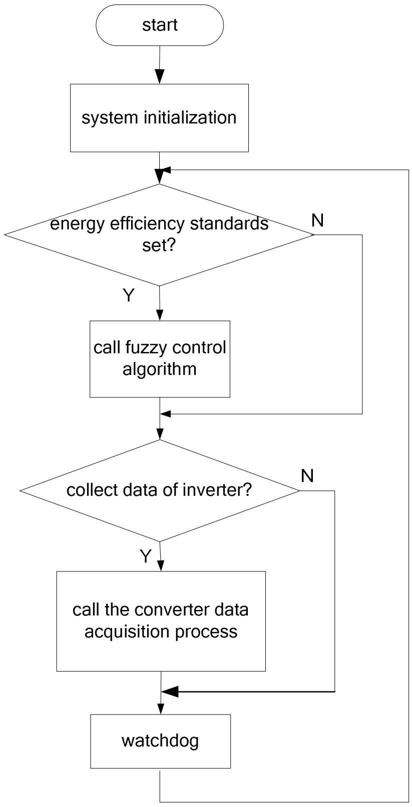

Fig. 7. The flow chart of the main program

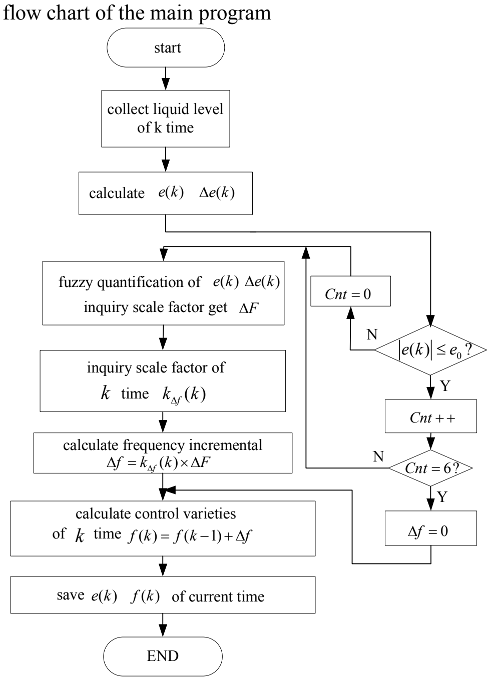

Fig. 8. The flow chart of fuzzy control algorithm

The software interrupts service program receives the message about the insufficient fluid supply sent by the remote monitoring center and change the motor frequency, its flow diagram is shown in Fig. 9.

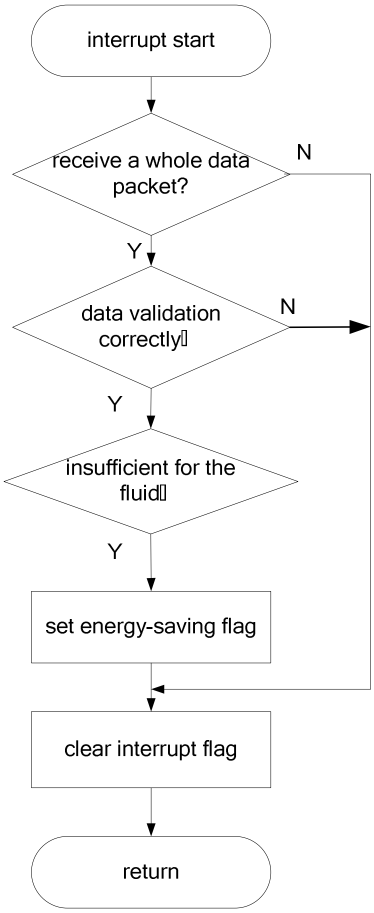

Fig. 9. The flow charts of software serial port interrupt service routine

VI. THE FIELD EXPERIMENT

After the hardware and software of the energy-saving control system are completed, we need to test the energy saving control effect of the system. The field experiments were carried out in Liaohe Oil field in Panjin, Liaoning Province, China in July 2015. In the field experiments, the working parameter of the used beam pumping unit are rated load of suspension point is 50kN, maximum rod stroke is 2.5m, and reducer rated torque is 18kN·M. The motor of beam pumping unit is the three-phase asynchronous motor, its main parameters: the rated power is 30kW, the rated voltage is 380V, and the rated current is 50A.

In the first test, before using energy-saving control system, the area of the indicator diagram is small. It shows under the shaft fluid supply capacity is poor, the filling degree of the pump is low, the motor energy consumption is serious. When the local energy-saving control system starts, the diagram area increases significantly, the pump's filling degree is greatly improved, the pump's efficiency is significantly improved. Thus, energy saving control system carries out the target of the energy saving control. The indicator diagram before and after using the energy saving system is shown in Fig. 10 and Fig. 11.

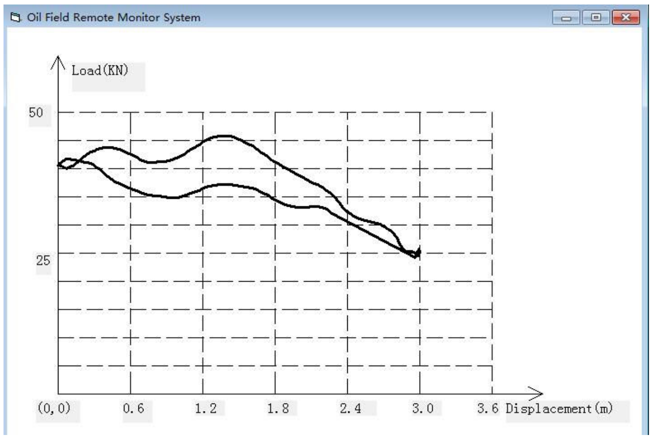

Fig. 10. The indicator card before using the energy saving system in the first test

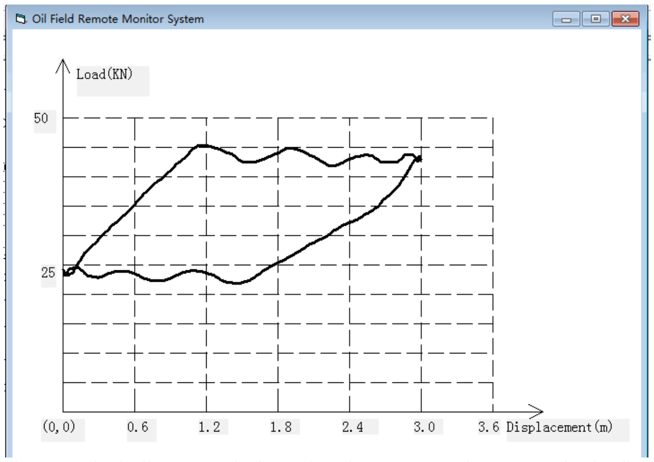

Fig. 11. The indicator card after using the energy saving system in the first test

In the second test, the indicator diagram before using the energy saving system is shown in Fig. 12; the area of an indicator diagram is smaller than the first test. It shows under the shaft fluid supply capacity is poor, the filling degree of the pump is low, the motor energy consumption is serious. After the remote beach local energy-saving control system starts, the indicator diagram after using the energy saving system is shown in Fig. 13, the area of indicator diagram is as good as the one in Fig. 11, it also has increased significantly, the pump's filling degree is greatly improved, the pump's efficiency is significantly improved. Through two experiments, it shows the energy saving control system can get good effect of energy saving when the well condition is changed.

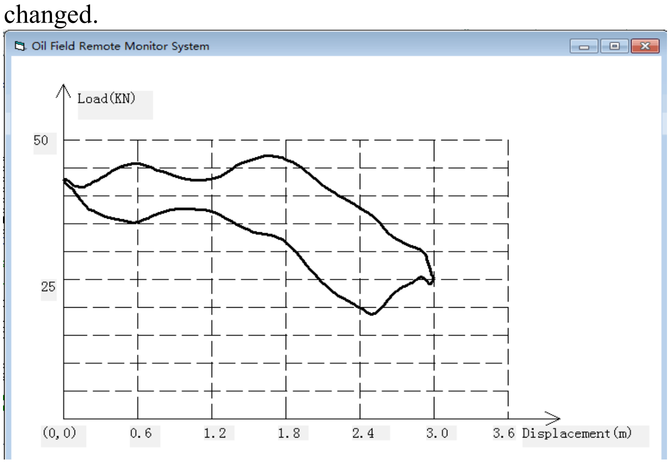

Fig. 12. The indicator card before using the energy saving system in the second test

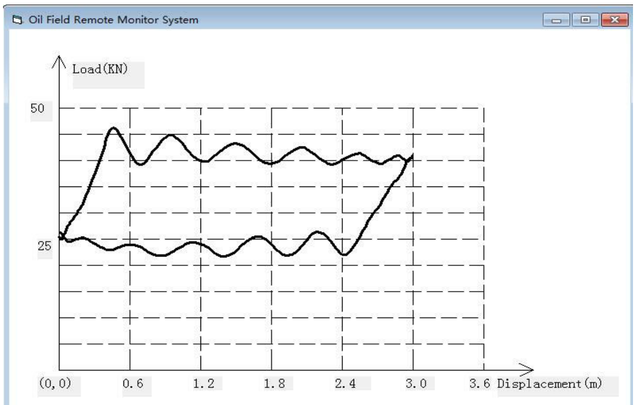

Fig. 13. The indicator card after using the energy saving system in the second test

Through analysis of the indicator diagram data, it preliminary validates the reasonable control of the beam pumping unit energy saving control system. At the same time, before and after using energy-saving control system, by comparing oil pumping system efficiency with unit power consumption changes, we can quantitatively analyze the energy saving effect of the energy saving control system. With help of Liao He oil field professional workers, some determination data include the effective lift height of pumping, active power consumption, yield per unit area, system efficiency is obtained. Table IX lists the determination data.

TABLE IX SYSTEM DETERMINATION DATA

	Rated power (KW)	Effective lift height (m)	Active power (KW)	Yield per-unit electricity (KWh)	System efficiency (%)
Before using	30	1796	6.72	132.6	9.6
After using	30	1732	4.65	91.3	14.8

As is shown in the above table, before using beam pumping unit energy saving control system, the yield per unit electricity is 132.6KWh, the system efficiency is 9.6%; after using beam pumping unit energy saving control system, the yield per unit electricity is reduced to 91.3KWh, system efficiency increased to 14.8%. So the using of pumping unit energy saving control system can reduce the power consumption, increase the efficiency of the system, which shows the energy saving control system has a good energy saving effect.

VII. CONCLUSION

This paper focuses on the energy saving research for the beam pumping unit. Analyzing the well fluid supply shortage, we can conclude that the pump efficiency reduction is the main reason why the low efficiency of the pumping system. We design a fuzzy control pumping unit energy saving control system, with controlled parameter as frequency of inverter, based on online tuning scaling factor; through the system tuning, it carries out the dynamic matching between the shaft fluid supply capacity and pumping unit extraction ability, greatly improves the pump's filling degree. Finally it achieves energy efficiency goals. The test results show that the pump filling degree and efficiency is improved, and the yield per unit electricity is decreased. The energy saving control system in this paper is applicable.

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