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A Fault Diagnosis Monitoring System of Reciprocating Pump

Wang Yong an
School of Computer & Information Technology, Northeast Petroleum University,Daqing 163318,China

Abstract: *This paper develops the intelligent fault diagnosis system of reciprocating pump. The system takes fault diagnosis system as the core, using the Visual c++ as the software language. The software controls the data acquisition of pressure, position and flow signal synchronously. The different fault types corresponding signal curve is also different, so the main fault signal is pressure signal, flow signal is auxiliary signal. Then use the wavelet neural network which based on artificial intelligence theory and wavelet packet decomposition technique for data processing, preservation and fault diagnosis. The diagnosis results from wavelet neural network show that the intelligent fault diagnosis system of reciprocating pump has fast speed and high accuracy.*

Keywords: *Wavelet Neural Network; Reciprocating Pump; Fault Diagnosis; Diagnosis System*

I. INTRODUCTION

Reciprocating Pump is one of the most important equipment of Oilfield. Because of the high efficiency, strong adaptability, wide quantity of clean up, and it is easy and convenient to operate, moreover, working process is stable and reliable, so it is widely used in water flooding, well drilling, fracturing, in oil and gas processing station and transit[1]. Reciprocating pump is also used as an important equipment to transport light hydrocarbon in winter and filling methanol in gas. But some parts of Reciprocating pump are easy broken, such as the pump valve assembly which is the key components of hydraulic side, it often fail to work because of the bad working conditions, so it is very important to keep it in good repair and maintenance.

There are some problems during the condition monitoring and fault diagnosis of the reciprocating pump when it is working.

1) Human judgment for fault, poor adaptability. It's hard to find out various faults of reciprocating pump valve by people through 'listen' and 'see', poor adaptability means that's not conducive to promote.
2) Environment interference. Reciprocating pump working environment always inevitably be motor disturbance, environment disturbs a lot in a routine test.
3) Artificial blind operation caused greater labor intensity.
4) The protection measures are not perfect.

In order to solve the above problems, the development of wavelet analysis and wavelet neural network and the microcomputer testing technique can build intelligent fault diagnosis system of high performance, which meets the field application. Experiments show that the diagnosis system is fast speed and high accuracy.

1. The Over All Scheme Of The System

The system make up of capacitive pressure sensor, magneto-electric flow sensor, signal amplifier, A/D converter, a microcomputer. The system diagram is shown in Fig1. The design of this system mainly includes two parts, hardware design and software design.

Usually the fault of reciprocating pump valve components is judged by the pressure gauge and flow meter installed on the outlet pipe. The disadvantage of this method is that no one can determine which valve failure occurs, therefore, all valves need to be checked, which not only increases the maintenance time, but also increases the workload in this way. In recent years, vibration testing technology was applied in the fault diagnosis of valve, the vibration signal collected at valve is used as the fault information and there are many successful examples of signal processing and diagnosis. However, the structure of the reciprocating pump is complex, valve turns off one by one and forming instantaneous lash, at the same time, there are a variety of vibration source. So the fault diagnosis of reciprocating pump is mainly on single cylinder fault monitoring and diagnosis using vibration testing technology, but for the three cylinder cooperative works and multi fault simultaneous fault diagnosis is difficult to achieve, the fault characteristic signal can not be extracted from vibration signal[2]. So, the pressure sensor is installed in a reciprocating pump cylinder, and the pressure signal in cylinder is used as the fault information, this can easily determine the specific location of the occurrence of the fault. Meanwhile, the fault feature signal is extracted by wavelet packet analysis. Then, do r fault diagnosis according to the characteristic signal obtained by using wavelet neural network theory.

The process of fault diagnosis for reciprocating pump is made up of three parts: The first part is the

acquisition of the pressure signal of the pump chamber; The second part is to eliminate noise interference to improve the diagnostic sensitivity and accuracy, extracting the fault feature from the pressure signal collected, the paper uses wavelet packet analysis technique; The third part is based on the fault characteristic and other diagnostic information to make a diagnosis decision, the wavelet neural network is established in this part and determine the network structure to achieve, in practice, we first extract the signal of the teacher, training, input neural network, and then collect the actual data and then characteristic extraction, by the comparison of the two, the fault of the reciprocating pump can be diagnosed and determined.

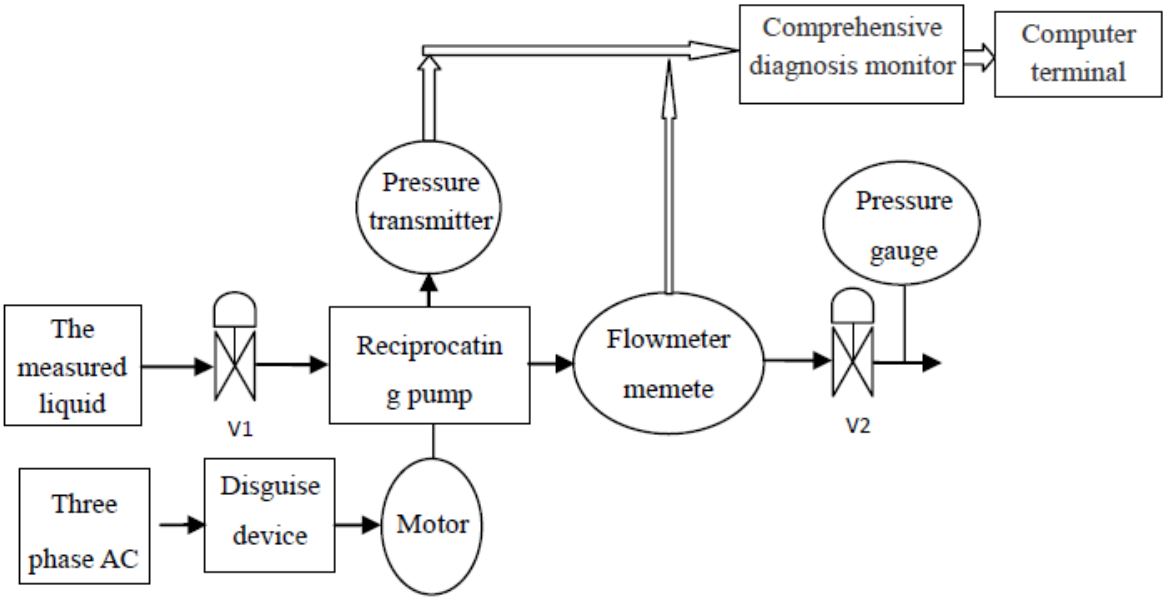

Fig1 system structure diagram

Note: (1) V2, V1 for two valves (2) ⟶ The flow direction of the liquid be measured

(3) ⟹ flow direction of date

1.1 Hardware Components of the System

The system is mainly composed of capacitance type pressure sensor, magneto-electric flow sensor, reciprocating pump system working condition diagnosis monitoring meter, micro computer. The monitoring meter based on port 485, isolation of RS-232 to RS-485 converter and two input module ADAM4520 and ADAM4017 eight analog. It is used for data acquisition system, in addition, process the data that is transmitted by the pressure transmitter preliminary, then transfer the data to the host after processing. The computer is responsible for handling, storage and analysis of the data from the off-line monitor, which can also print results when needed. The fault feature extraction and fault diagnosis are carried out using wavelet packet decomposition and wavelet neural network.

1.2 Software Design System

In this paper, an eddy current sensor is installed on the cylinder block, using it as the time signal, which can detect the plunger in the near power end in what position to stop, the outer trigger signal is obtained from the signal emitted by the signal, the pressure signal in the pump cylinder is collected by the trigger point. The specific position of the pressure transmitter in the pump cylinder of the pump is selected as the point of the measurement, the pressure transmitter is used to measure and transmit the pressure values of the required field for the test.

The software design of this system includes the following aspects:
(1) Establishment of the main programme framework;
(2) Connection mode and communication mode of the host to the monitoring meter;
(3) Real time data monitoring and save;
(4) Multichannel data real-time dynamic display.

The main interface of the system software is as Fig2. The design of the system includes the parameters

setting, the synchronization of the sampling data, the database management and the technology of multi thread.

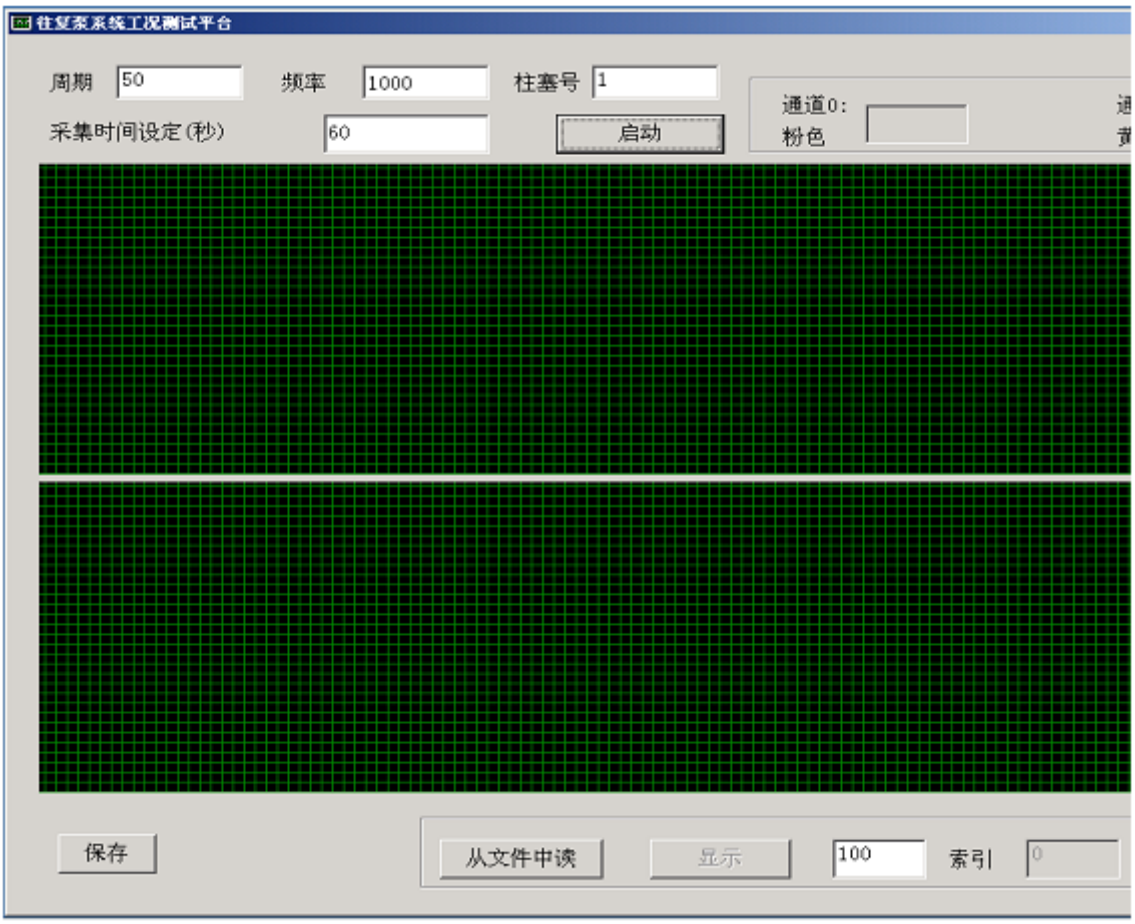

Fig2 Main interface of the system software

Parameters can be used to enter the pump parameters and sample parameters of the pump here. The corresponding parameters are shown in Table 1.

Table 1 Sampling parameters

Piston number	the pump plunger number of currently sampled
Frequency f	pump frequency, unit of HZ;
Cycle	the sample period, unit of ms;
Time setting	system sampling time, unit of s;

At the main interface, there are two display surfaces, sampled data from four complete run cycles can be completely dynamic display at the same time, one is pressure signal curve diagram composed by real-time pressure signal, and the other is traffic signal curve of the collected traffic signal. In this case, the user can carry on the reliable analysis and the essential record to the data on-line. Remote data can be displayed in real time.

Database management can realize historical data query, which is convenient offline analysis. It is necessary for this system to build multiple threads since the application is needed to carry out data sampling, dynamic display and fault analysis at the same time. When the system working, CPU rotate the time slice of the three threads, so these three work can be carried out simultaneously, this makes full use of the spare time of CPU, and avoid the user waiting for a long time for data analysis, so the real-time judgment of fault diagnosis is achieved, more importantly avoiding the occurrence of greater losses.

II. APPLICATION OF FAULT DIAGNOSIS SYSTEM

Because the method of system is using the pressure signal as the fault characteristic information, this is different from the conventional; in fact, the difference between the different faults can be seen from the waveform of the pressure signal[3,4].

2.1 The pressure curve when the system at normal works

When the system is in normal working condition, inlet valve and discharge valve work normal, sealed tight, except for normal leakage, there is no leakage caused by failure, there is no fluctuation in the pressure and pressure of the boost, the pressure curve is shown in Fig3.

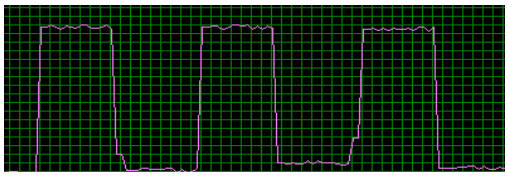

Fig3 Normal pressure curve when normal works

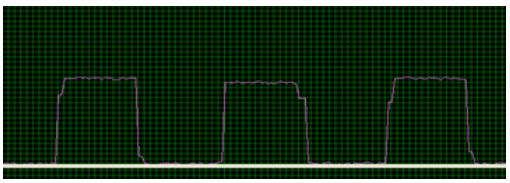

Fig4 Pressure curve of suction valve seal ring damaged

2.2 Pressure curves and analysis under various fault conditions

The main failure of the reciprocating pump occurs at the hydraulic end, and there are several forms:

(1) The pressure signal curve of the pump cylinder when the seal ring is broken

The seal ring is mainly divided into the suction valve seal damage and discharge valve seal damage. First, the suction valve seal ring damage. The appearance of the characteristic is due to the suction seal ring in damage, when the piston pump cavity liquid, pressurized liquid can leak from the suction valve sealing ring and lead to boost process lag, and discharged process, due to the sealing ring damage of the suction valve, this leads to the occurrence of the buck process in advance. The pressure signal curve is shown in Fig4.

Second, the discharge valve seal ring is in damage. The imbibition process, the pipeline liquid can flow into the pump, resulting in the phenomenon of buck lag. The pressure signal curve is shown in Fig5.

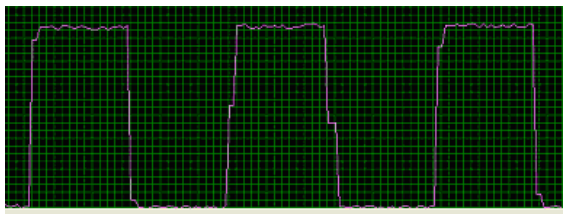

Fig5 Pressure curve of suction valve spring damage

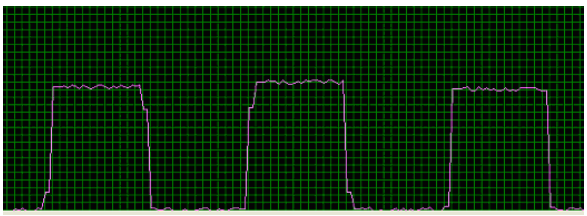

Fig6 Pressure curve of suction valve spring damage

(2)Pressure change curve of spring fault

The fault of the spring can also be divided into the suction valve spring and the discharge valve spring damage. After the suction valve spring damage, due to the valve back to the bit is not timely, resulting in the boost process lag, as shown in Figure 6. When the discharge valve spring is damaged, the pressure change is not obvious.

2.3 Pump valve damage

(1)Discharge sealing cover wears and tears, discharge valve wear failure and discharge valve sealing ring damage is basically the same, performance as boost lag, buck ahead. The pressure signal curve is shown in Figure 7.

(2)The sealing cover of the suction valve wear is shown in Figure 8.

2.4 Unreasonable operating parameters

When the speed of reciprocating pump plunger is too fast, it's easy to lead valve close lax, which can not reach the effective maximum and the minimum value of the pressure, so that the periodic secondary maximum or minimum valve appears. The pressure curves are as in Fig9

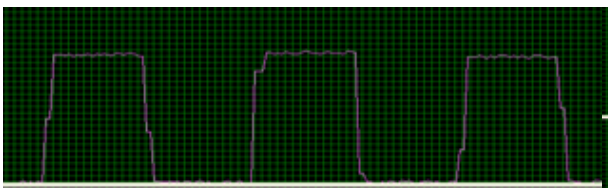

Fig7 pressure curve chart of the discharge valve sealing cover wear

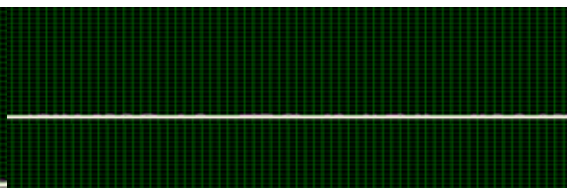

Fig8. Pressure curve diagram of suction valve cover wear

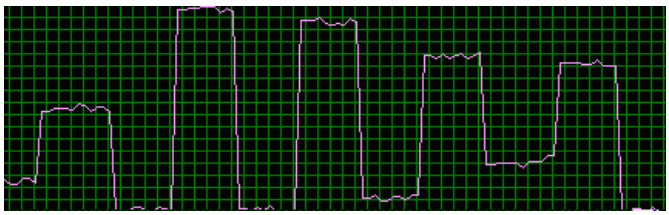

Fig9 Pressure diagram of unreasonable operation parameters

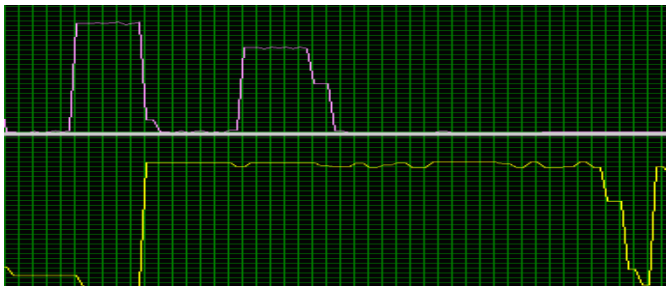

Fig10 Flow chart of leakage pressure for piston

The phenomenon disappears when the frequency drops to a certain value. This phenomenon shows that the reciprocating pump system has the optimized space.

2.5 Pressure and flow curves of plunger leakage

Pressure and flow curves of plunger leakage are shown in Figure 10.

For the fault diagnosis of the reciprocating pump, the pressure signal in the cylinder of a single pump is used as the feature signal to extract the fault feature vector. In this paper, the original pressure signal is decomposed by 3 layers of wavelet packet[5], constituted the 8 dimensional feature vectors to extract the fault feature of a reciprocating pump, and as the input vector of wavelet neural network, so the number of input nodes is 8. The author separately carries on the diagnosis to the reciprocating pump sealing ring fault, the valve wear fault and the spring fault fault in three kinds of conditions, respectively (001), (010), (100) on behalf of these 3 conditions, as the target output of the network, the output node number is 3. The wavelet neural network uses 3 layers structure, the hidden layer wavelet is Morlet wavelet, the number of hidden nodes in the determination of the use of the gradual test method. First set a error E^*, the number of nodes of the hidden layer is smaller, calculating its error E, Then compare E^* with E. If $E < E^*$, the number of the hidden nodes is what we want; Otherwise, the hidden layer node number add 1 then continue, until $E < E^*$, this can determine the number of hidden nodes. After the experiment, the number of the hidden nodes is 12. Take the initial value of the study rate $\eta = 0.5$, momentum factor $\alpha = 0.85$, the accuracy of training error is 0.005, adopting compact wavelet neural network, using 12 damaged sealed ring as sample, 12 valves wear sample and 12 spring fracture samples to train for the network, the network after 358 steps of learning to meet the accuracy requirements. Sample input to be diagnosed by the trained network; the sample and the diagnosis result see Table 2. According to the theory of Euclidean norm, the test error of the test data are 0.0027, 0.0035 and 0.0043, it can be seen that these errors are very small. In the application of this method, the correct rate of fault data of a large number of reciprocating pumps is over 94%.

Table 2 Testing samples and the results

	Fault type		
	Bad sealing ring	Valve damage	Spring damage
Verification data	0.0000 1.0021 1.6012 1.4009 0.0000 0.2591 0.6390 0.2517	0.0002 9.9896 1.7002 1.0405 0.0000 0.0101 0.0399 0.2901	0.0079 5.6498 0.8197 1.0690 0.0001 0.5601 0.0812 0.0671
Diagnostic output	0.0013 0.0030 **0.9970** Fault 1 (001)	0.0075 **1.0040** 0.0130 Fault 2 (010)	**0.9901** 0.0022 0.0301 Fault 3 (100)

III. CONCLUSIONS

This paper developed a comprehensive diagnosis monitoring system of reciprocating pump working condition based on port 485, application of wavelet neural network and wavelet packet decomposition technology for data processing, preservation and fault diagnosis.

According to the collected pressure, flow data, we can see the type of fault different, the corresponding signal curve is also different, that indicates pressure signal based and flow signal as auxiliary is an effective fault monitoring method for fault information extraction, from the results of wavelet neural network diagnosis, it can be seen that the fault identification is correct and realistic. The comprehensive diagnostic technique is adapted to all the reciprocating pump of oil field surface, now the polymer flooding has been widely spread, three yuan compound drive is also in the industrialization test, there are about 2000 wells in injection well in the oilfield, reciprocating pump has become the important equipment to injection technology in the injection system, this technology has broad application prospect.

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