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Research Article

Study and Design of Diaphragm Pump Vibration Detection Fault Diagnosis System Based on FFT

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Abstract: This study has proposed a fault diagnosis system based on vibration detection. The system mainly includes four modules: signal acquisition module, signal processing module, state identification module, fault diagnosis and alarm module. The system uses CMSS 2200 acceleration sensor to collect vibration signals, processing spectrum with FFT (Fast Fourier Transform) which is used effectively in current industry and finally achieve fault diagnosis and prediction for diaphragm pump. Through collection and analysis of the history signal data, set threshold value in the fault diagnosis system. According to the characteristics of different types, set the corresponding effective threshold value. The simulation results show that, the spectrum after FFT transformation processing, can really and effectively reflect equipment operating condition of the diaphragm. This system is not only simple and stable, but also can predict pump failure effectively, so that it reduces equipment downtime, plan maintenance time and unplanned maintenance time.

Keywords: Diaphragm pump, fault diagnosis, FFT, threshold value, vibration detection

INTRODUCTION

The pipeline transport is the fifth-largest modes of transport after rail ttransport, road transport, maritime transport and air transport. Pipeline transport is not only zero-pollution and low energy consumption, but also almost no destruction for the ecological environment (Weisheng *et al*., 2009). When traffic is inconvenient and the substance spilled easily or leaking easily by the traditional modes of transportation, the pipeline transport reflects its exceeding advantages. In recent years, the pipeline transport industry has developed rapidly, but there is an urgent problem that how to ensure the security and stability of the pipeline transport.

The diaphragm pump which is the core power output device of pipeline transport is one of the most important equipments for pipeline transport, so security issues of diaphragm pump is the key security issues of pipeline transport. The diaphragm pump is generally composed of valves and actuation. Diaphragm pump forms pressure difference in the fluid to produce power, with the power to change the flow rate and flow of the fluid. Only keeping diaphragm pump operating effectively can ensure the normal operation of the pipeline transport. Diaphragm is shown in Fig. 1.

Fig. 1: Diaphragm pump

As the pipeline transport is an emerging mode of transport, the research of pipeline security issues is less, or even blank. At present, the failure diagnosis of diaphragm pump is basically to rely on workers' production experience and detection methods are generally oil analysis and temperature detection. Oil analysis needs for removing equipments which may be demolished and the work intensity is high; temperature detection is susceptible to be influenced by the ambient temperature environment. The generation of vibration signal is accompanied by the failure of equipments and vibration index is the most convenient and the most effective parameters for real-time monitoring diaphragm pump. It has the following features:

- Equipment operation synchronous vibration signal is synchronously generated by equipment running

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and the failure information is contained in the vibration signals.

- It easy to implement online monitoring and diagnosis.
- The high failure rate is signed by increased vibration, the vibration of the common faults have obvious signs of characteristics, easy to identify.
- Testing means, methods, theories are relatively mature.
- The method is simple, easy to operate and less investment. So it is necessary to assess diaphragm pump operating conditions through the vibration detection.

This study has proposed a fault diagnosis system based on vibration detection. The system mainly includes four modules: signal acquisition module, signal processing module, state identification module, fault diagnosis and alarm module. The system uses CMSS 2200 acceleration sensor to collect vibration signals, processing spectrum with FFT (Fast Fourier Transform) which is used effectively in current industry and finally achieve fault diagnosis and prediction for diaphragm pump. Through collection and analysis of the history signal data, set threshold value in the fault diagnosis system. According to the characteristics of different types, set the corresponding effective threshold value. The simulation results show that, the spectrum after FFT transformation processing, can really and effectively reflect equipment operating condition of the diaphragm. This system is not only simple and stable, but also can predict pump failure effectively, so that it reduces equipment downtime, plan maintenance time and unplanned maintenance time.

FAST FOURIER TRANSFORM (FFT)

In the actual industrial pipeline, there are strict requirements on the size of particles and the concentration for the transported material. The pipeline is a closed environment and diaphragm pump operating environment is airtight and indoor, so the signal generated is similar stationary signal. Fast Fourier Transform (FFT) processing stationary signal is very effective. FFT is commonly used in industrial production, which is a more mature spectral analysis method (Rahmani *et al*., 2010). Because of its stability and reliability, FFT is used in an extremely wide range in industrial production. So Fast Fourier Transform is the best option for the industry pursuing stable and effective.

Fast Fourier Transform algorithm are 2 methods, one is the time extraction algorithm; and other is frequency extraction algorithm (Qingkai and Xiaoguang, 2010).

Set x(n) for limited long sequence, points N, namely when $n = 0 \sim N-1$, $x(n)$ have value; when other n, x(n) = 0. It is a cycle of $\tilde{x}(n)$ for cycle sequence of the cycle of N and the $\tilde{x}(n)$ as the cycle extension period of x(n), they are expressed (1) and (2) as follows:

$$x(n) = \begin{cases} \tilde{x}(n), 0 \le n \le N-1 \\ 0, \quad other \end{cases} \tag{1}$$

$$\tilde{x}(n) = \sum_{r=-\infty}^{\infty} x(n + rN) \tag{2}$$

Usually the first cycle ($n = 0 \sim N-1$) of $\tilde{x}(n)$ is defined as the "main interval", so x(n) is the main value sequence of $\tilde{x}(n)$. Between the different r, the values of x(n + rN) do not overlap each other, so that can be rewritten as: $\tilde{x}(n) = x$ (n modulo N) $= x((n))_N$, $((n))_N$ represent (n modulo N), command $n = n_1 + mN$, $0 \le n_1 \le N-1$, m is integer, so n_1 is that n remainders N. Regardless of n_1 plus the number of times N, the coefficient is n_1, that is the $x((n))_N$ values periodically repeated are equal.

Similarly, the cycle of the frequency-domain sequence $\tilde{X}(k)$ can be regarded as the continuation of the cycle of finite length sequence X(k) and the finite-length sequence X(k) is the sequence of the main value of the periodic sequence $\tilde{X}(k)$, as the expression (3) as follows:

$$\tilde{X}(k) = X((k))_N \tag{3}$$

The (4) and (5) are the Fourier transform equations:

$$X(k) = DFT[X(N)] = \sum_{n=0}^{N-1} x(n) W_N^{nk} \tag{4}$$

The inverse equation of Fourier transform is:

$$x(n) = IDFT[X(k)] = \frac{1}{N} \sum_{n=0}^{N-1} X(k) W_N^{-nk} \tag{5}$$

x(n) and X(k) are a double of finite-length sequences discrete Fourier transform. Given one sequence, we can determine another unique sequence. X(n) Points and X(k) points are both N, the information are equal.

As Fourier transform, discrete Fourier transform algorithm can be simplified, but multiplication times and addition times are in proportion with N^2. When N is large, the required computational work is considerable (Guangshu, 2003). In order to further reduce the computational time, the FFT algorithm with a positive integer power of 2 is proposed, the FFT is not a new algorithm for Fourier transform, just only requires the sequence length of the test signal is a power of 2.

SYSTEM DESIGN

System basic requirements analysis: For the design and development of this system, the following requirements:

- Through the condition monitoring techniques, to predict equipment failure trend and to provide the basis for the development of accurate maintenance program
- Through monitoring and analysis, to find hidden equipment problems to achieve accurate forecasting and early warning, to avoid major equipment outage or the possibility of greater damage and loss of equipment and personnel
- Through combining spectrum and practical experience of worker, to clear the failure parts of equipments and the parts needed replacement finally, so that reducing the unnecessary equipment maintenance
- Through reducing the failure rate of the key equipment and reducing the overall maintenance time, to further improve the equipment trouble-free operation cycle and the equipment reliability

System basic framework: According to the system architecture requirements, the basic modules of the diaphragm pump fault detection system including: signal acquisition module, signal processing module, state identification module, fault diagnosis and alarm module. A detection point of the system design briefly basic framework is shown in Fig. 2.

- **Signal acquisition:** As each diaphragm has inherent frequency signal, detecting the state of the running diaphragm pump through acceleration sensor to obtain valid vibration signal. The correct detection of the status of the operation of machinery and equipment can obtain reasonable signal. Signals are the information carrier of equipment malfunction or failure and only fully real acquisition to enough signals can be able to objectively reflect its operating condition. Therefore, the sensor type, performance, quality and the installation location are often decided the key to diagnosis information distortion or omission.
- **Signal processing:** Amplifying the analog signals collected by acceleration sensors and doing some initial processing, then converting the analog signals into digital signals after A/D conversion (Ruizhong *et al*., 2001). the collected signals are the characterization of the original state signals of the running diaphragm pump, but they contain a lot of noise signals that have nothing to do with the failure diagnosis. In order to improve the sensitivity and reliability of fault diagnosis, it is necessary for signal processing, filtering and de-noising that can extract the useful fault information from the large amount of background noise and interference. After processing the original clutter signals, the most direct and most sensitive characteristic parameters will be got.

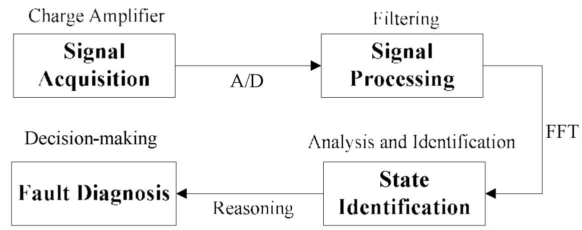

Fig. 2: Basic block diagram of the system

- **State identification:** Processing and analyzing the extraction of the vibration fault signals through Fast Fourier Transform (FFT), to form a clear spectrum. Computer analyzes the spectrogram, comparing and identifying it to judge whether the diaphragm pump is running normally. Maintenance administrators view and reference the vibration spectrum information which is displayed on the computer, so that reasoning and decision-making.
- **Fault diagnosis and alarm:** When the diaphragm pump appears abnormal operation, the system does automatic simple identification and determination on the frequency spectrum. And according to the different vibration circumstance of equipments, it warns the equipment maintenance administrator (If there is any abnormal vibration).

According to the judgment of the equipment state, determine the necessary policies and measures, Maintenance administrators rely on the current signal forecast equipment state may trend to development for trend analysis.

SYSTEM HARDWARE DESIGN

The vibration of mechanical equipment is a kind of dynamic signal, vibration test equipment can obtain the corresponding vibration signal such as displacement, velocity, acceleration, through the analysis and processing vibration signal can get characteristic parameters describing the equipment vibration state such as the vibration amplitude, frequency, etc. Acceleration, speed and displacement are the differential relationship. As the vibration signal is high-frequency signal, acceleration sensor is suitable for collecting high-frequency range signal and sensitivity of acceleration sensor is stably far from the influence of the cable length.

So the system uses CMSS 2200 acceleration sensor to collect vibration signals of the diaphragm pump to analyze. The data acquisition card selection of the Altai USB2002 data acquisition card, the card's maximum sampling rate for 400 kHz, A/D conversion

Fig. 3: CMSS 2200 acceleration sensor

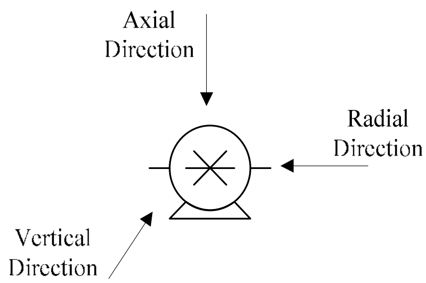

Fig. 4: Installation position of acceleration sensor

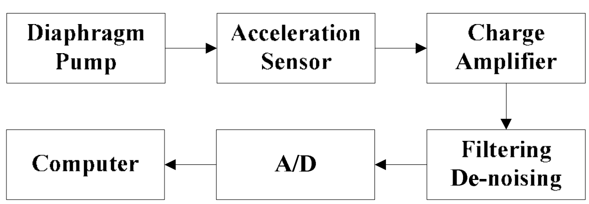

Fig. 5: Structure of the system hardware design

resolution of 14, 32 single-ended input or 16 differential input. At the same time, small size, easy to carry, plug and play.

CMSS 2200 acceleration sensor: CMSS 2200 was developed by SKF (Svenska Kullager Fabriken) company in Sweden. It is a general purpose, low profile and side exit industrial accelerometer that incorporates the latest technology to meet the demanding CE (Conformite Europeenne), EMC (Electro Magnetic Compatibility) and low noise level requirements. CMSS 2200 can work stably and reliably in low noise, low frequency and high temperature condition. Sensitivity: 100 mV/g, 2-core, side outlet, bolt. Figure 3 shows CMSS 2200 acceleration sensor.

Selection and arrangement of measuring points: The choice of measuring points is extremely important. The selection and arrangement of measuring points must be reasonable and they will directly affect the authenticity, effectiveness and credibility of the collected data.

In order to make the acceleration sensors collect scientific and accurate data, it has chosen 3 directions of acceleration sensor installed on the pump, respectively, for the radial direction and the axial direction and the vertical direction. As shown in Fig. 4.

System hardware framework: This system needs to collect a large number of vibration data and data analysis and processing in real-time, so it highly demands for stability and effectiveness of the system hardware. Hardware design organization of the system is shown in Fig. 5.

Accelerometer sensors collect data signals, after charge amplifier and then filtering de-noising and then A/D conversion, finally data signals will transmit into computer. The computer does the further analysis.

SYSTEM SOFTWARE DESIGN

Software uses the OOA (Object-Oriented Analysis) method to analyze and the programming software VC++ programs to develop, which is commonly used in the IPC (Industrial Process Control) application development. Database uses Microsoft SQL Server 2003. VC++ provides an ActiveX communication control and through the communication control can complete the task of serial communication. The working principle of communication control of is similar to interrupt way of working. when there is a communication event occurs (such as sending data, receiving data, etc.), it will trigger OnComm event, invoke GetCommEvt () function in the event handler, know the type of event the through return value and then make the appropriate treatment.

The historical data signals are stored in the database. The system uses mathematical statistical theory and methods to analyze the historical data signals and then fitting out the corresponding spectral curve trend (Zengliang and Laibin, 2003). It can get the monitoring diaphragm pump running characteristic parameters through the analysis of spectrum diagram, therefore providing accurate and effective help to equipment maintenance administrator for making the maintenance decisions. Equipment administrator can operate the database to query the historical data and fault records of equipment operation. It compares the spectrums between the abnormal operation and the normal operation to identify changes in the failure of the spectrum.

Through the history of the signal data collection and analysis, establishing equipment normal operation model and setting threshold value in the fault diagnosis system. According to the characteristics of different models (the number of motor and diaphragm, the diaphragm pump flow and monitoring results evaluation, etc.), it sets the corresponding effective threshold value (David and Ruoyu, 2011). If spectrum appears abnormal in scope threshold value range, it can be considered as normal equipment operation; If the

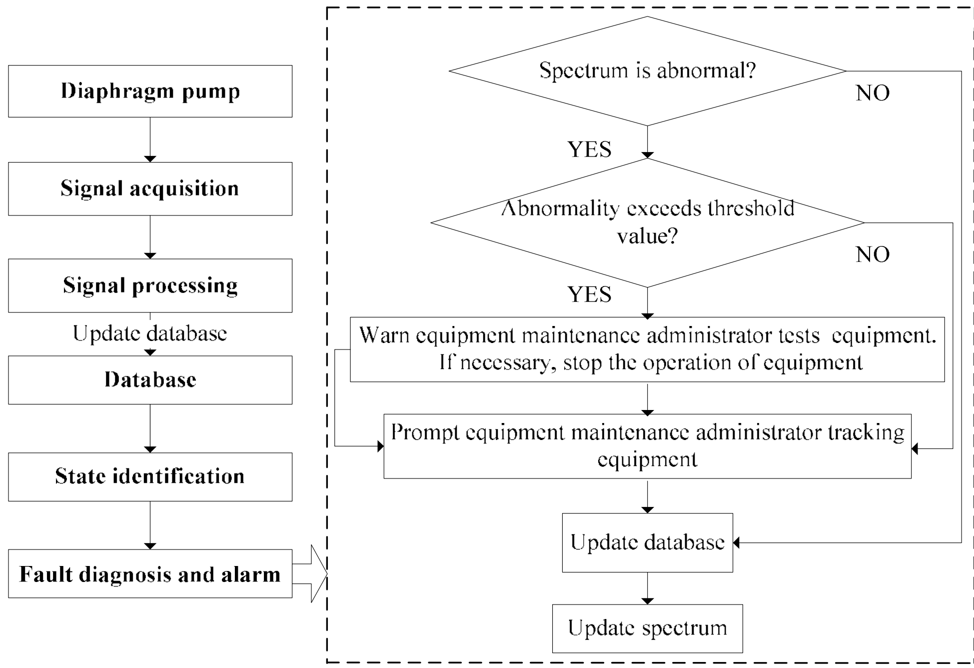

Fig. 6: Structure of system fault diagnosis and alarm

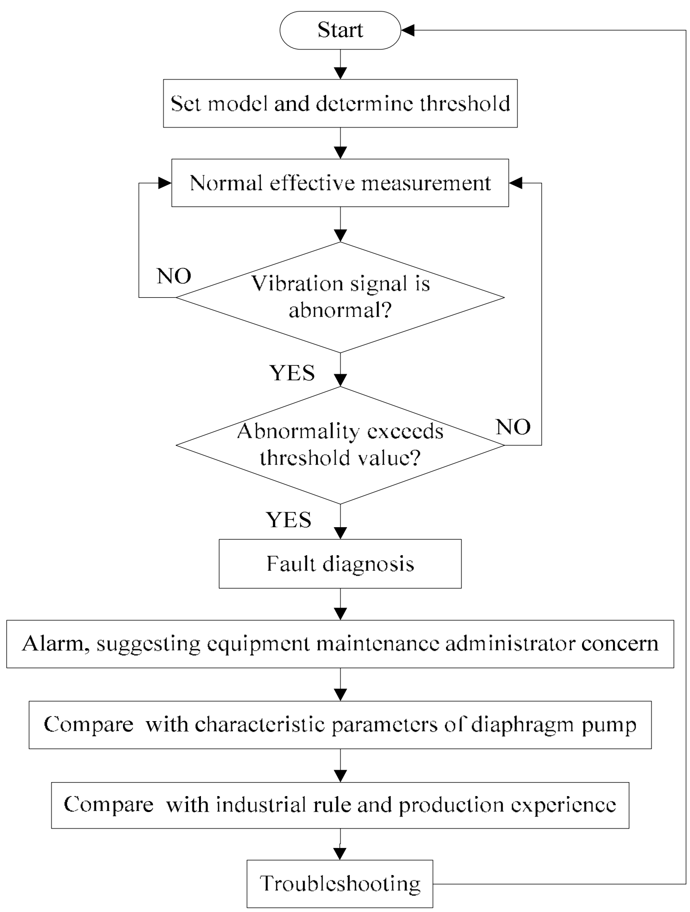

Fig. 7: Fault diagnosis and alarm flow chart

abnormal range of spectrum exceeds the threshold range, it can be considered as equipment failure, then alarming equipment maintenance administrator tracking and concerning and even immediately shutting down equipment for inspection and maintenance if it necessary. It stores all of diaphragm pump running vibration signal data in the database and computer displays the relevant spectral information based on database updated The system failure diagnosis and alarm structure as shown in Fig. 6.

Setting the reasonable threshold based on diaphragm own historical vibration data to avoid false alarms caused by the different device models and the different environment and ensure the effective operation of the equipment. According to ISO7919 "rotating machine shaft vibration measurement and evaluation in China", for the vibration measurement and evaluation of coupled industrial machines. If the vibration amplitude change is more than 25% of the normal vibration amplitude, no matter increasing or decreasing, warning equipment maintenance administrator to detect equipment (Zhengjia *et al*., 2010). Normal vibration amplitude is based on the average history vibration data of trouble-free running equipment and it generally uses the average data of the last 10-20 times. When abnormality of spectrum exceeds the threshold value, workers need to analyze vibration failure comprehensively by combining the industrial rule, the production experience and the specific characteristic parameters of diaphragm pump and finally doing fault diagnosis and rule out problems.

The system fault diagnosis and alarm flow chart shown in Fig. 7, as follows: system initialization, monitor the vibration signal of the normal operation of equipment, establish the operation database, set the threshold and then take normal effective measurement on equipment. When the vibration signal is abnormal, determining whether it exceeds the threshold value. If abnormal vibration signal does not exceed the threshold value, then consider that equipment is operating normally; if abnormal vibration signal exceeds the threshold value, then take fault diagnosis and alarm equipment maintenance administrator to track and concern. Equipment maintenance administrator analyzes vibration failure comprehensively by combining the industrial rule, the production experience and the specific characteristic parameters of diaphragm pump and finally doing fault diagnosis and rule out problems.

SIMULATION RESULTS

In the experimental condition, it can be simulation experiment with MATLAB. MATLAB set of numerical analysis, matrix computation, signal processing and graphical display in one. The key of MATLAB signal analysis is read data into the MATLAB workspace, almost any algorithm language has commonly used several input and output file formats. MATLAB can use

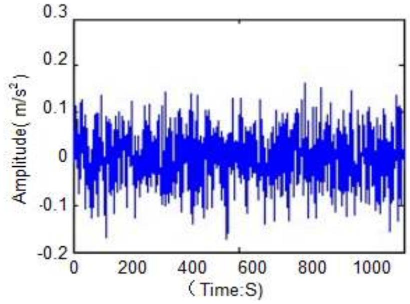

Fig. 8: Original signal

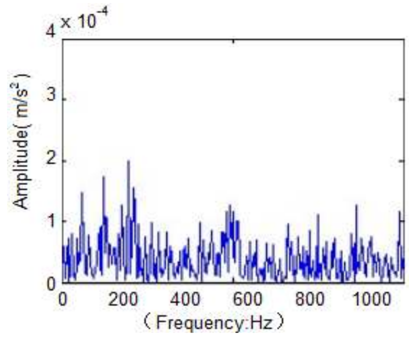

Fig. 9: Signal after FFT

these types of formats read and write, so ensure it can connect to other languages at this level. Therefore it can be automatically read the data generated by other software or instrument measurement into MATLAB and output drawn graphics after analysis and processing.

In industrial production, the actual vibration signals are relatively complex and there is not only the fundamental frequency, but also multiple frequencies and some random noise. The simulation begins with the baseline zero, sampling frequency for 1000 Hz and data sampling points for 1024. Figure 8 shows the original signal, which is the time domain waveform before FFT transformation. It can be seen from Fig. 8 that it is difficult to effectively identify and analyze the signal in the strong background noise.

The frequency domain characteristic of the signal has a specific physical significance. The frequency characteristic is the objective nature of the signal, in many cases, its ability of reflecting the basic characteristics of the signal is better than the time-domain analysis. Therefore, it generally needs transform the signal of time domain into frequency domain to analyze.

Figure 9 shows the frequency domain spectrogram after FFT transformation. The simulation results shown that, obviously, the frequency domain analysis method of FFT can effectively transform time domain signal which is less information, lower signal to noise ratio and difficult to identify and analyze into frequency domain signal for analysis in diaphragm pump vibration fault detection. With more effective and straightforward, it is beneficial to the equipments maintenance administrator for monitoring and analysis.

In the process of fault diagnosis, it can also consider the facet of energy change for fault diagnosis as a supplement (Dan and Vasile, 2005). There are 2 ways to use the point of view of energy change for equipment fault diagnosis: one is the total size of the energy for the basis; another is the distribution of the energy for the basis. It is often difficult to classify fault diagnosis from the perspective of the total energy, limitation of finding the cause of the malfunction, but grasp overall from the equipment operating state. And the fault diagnosis method based on the energy distribution can determine and classify the power spectrum through all or some of the peak changes in fault, so it is superiority in the practical application of fault diagnosis. It can be a very good supplement for the spectrum transformed by FFT analysis through the energy change and provide equipment management administrator with effective reference value.

CONCLUSION

The simulation results show that, the spectrum after FFT transformation processing, can really and effectively reflect equipment operating condition of the diaphragm pump in time. The equipment maintenance administrator can understand the spectrum conveniently and find and solve problems easily. This system is not only simple and stable, but also can predict pump failure effectively. According to actual operating condition of the diaphragm, it can provide alerts to the equipment maintenance administrator. It timely provides reliable equipment operation information to the equipment maintenance administrator to ensure the equipment running effectively and improve the rational use of equipment, improve safety and economy of running and prolong equipment using period, optimize the use of equipment reasonably. Thereby it can reduce the equipment downtime and also reduce the plan maintenance time and unplanned maintenance time.

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