

# Research on Data Acquisition and Signal Processing of Fault Diagnosis System for Electromechanical Equipment

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**Abstract**—Data acquisition and signal processing is the basis of condition monitoring and fault diagnosis system for electromechanical equipment. The paper analysis the general technology of data acquisition and signal processing used in fault diagnosis system. A portable equipment of motor fault diagnosis is designed as an applied example. It has been proved that using appropriate technology of data acquisition and signal processing is very important to extract the fault characteristic signal and realize the function of electromechanical equipment diagnosis.

**Keywords**—electromechanical equipment; fault diagnosis; data acquisition; signal processing

## I. INTRODUCTION

The device diagnostic technology applies the real-time monitoring of status information of devices to analyze and predict the possibility of equipment failure, so as to find the faults at the early stage. In this way, with the analysis of fault reasons, fault localization and tendency predication, appropriate decisions can be made [1]. The device fault diagnosis system consists of data acquisition, signal processing, extraction and output of feature parameter, fault diagnosis and decision-making, and can integrate condition monitoring with fault diagnosis of electromechanical device. The structure of the diagnosis system is shown in Figure 1.

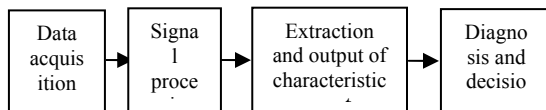


Figure 1. The structure of the diagnosis system

It can be seen from the figure that data acquisition is the basis of condition monitoring and fault diagnosis. Correct and reliable data acquisition technology is based on the detection and diagnosis of devices. Moreover, characteristic signals of minor equipment failure or abnormalities are often modulated in strong interference signals. To obtain characteristic signals of faults, the diagnosis system needs to apply corresponding signal processing techniques based on the features of interference signals, so as to suppress interference signals, and effectively extract characteristic signals [2].

## II. DATA ACQUISITION TECHNOLOGY

Data acquisition technology is an integrated technology based on sensors, measurement and processing of signals, and other high technologies such as microcomputer. In the fault diagnosis, “data acquisition” refers to the conversion of analog quantities such as current, voltage, temperature, pressure, flow and displacement into digital quantity, and the storage, processing or printing by computers. The corresponding system is referred to as data acquisition system.

The task of the data acquisition system is to collect the analog signals from the sensor and to convert them into digital signals that can be read by computers, which are then sent to computers. According to different needs, the computers will conduct calculations and processing for the needed data. The efficiency of data acquisition system depends on its precision and speed. Under the premise of ensuring the precision, the sampling speed should be much improved to achieve real-time acquisition, real-time processing and real-time control and decision-making.

### A. Typical Data Acquisition Technology

With the development of computer and measurement and control technology, there are diversified structures of data acquisition systems. Yet, fundamentally, the most extensively applied structures in the diagnosis system of devices include Microcomputer Data Acquisition System and Distributed Data Acquisition [3].

#### 1) Microcomputer Data Acquisition System

A typical microcomputer data acquisition system consists of sensor, analog multiplexer, programmable amplifier, sampler/keeper, A/D converter, microprocessor interface circuit, computers and peripherals as well as application software. In the signal path of the typical microcomputer data acquisition system, the input sample and hold amplifier is increased to realize the simultaneous sampling of input signals and to constitute the pseudo-synchronous multi-channel data acquisition system. In each signal path, A/D converter is increased to realize simultaneous sampling of input signals and synchronous conversion. Signals are

separately stored to form the synchronized multi-channel data acquisition system. In the microcomputer data acquisition system, computers are the core of the entire system. Sampling control, signal processing, signal analysis and calculation are carried out by the computer.

According to different requirements of the acquisition system, different computers are selected, varying from the microprocessor, Single Chip Microcomputer (SCM) to Intel-based Industrial Personal Computer (IPC).

The structure of microcomputer data acquisition system is simple and inexpensive. IPC can work in harsh environment. Besides, I/O modules and software of microcomputers are complete and easy to form a system. Due to the convenient application and maintenance, the microcomputer data acquisition system has been extensively used in medium-sized and fault diagnosis system.

## 2) *Distributed Data Acquisition System*

Distributed data acquisition system is a product of the computer network technology. It consists of several "data acquisition stations" and a master station as well as communication lines. Data acquisition station (also referred to as data acquisition terminal) is located near the production equipment, and can independently accomplish data acquisition and pre-processing. Moreover, it can transmit data to the master station in the form of digital signals. Data acquisition station is generally formed by SCM data acquisition device. The master station displaces data from each data acquisition station on the screen, prints data in reports, or stores data on disk in the document format. Moreover, it can send control parameters of the system to each station to adjust the working status of each station. The master station is practically a general-purpose computer (or IPC), also equipped with a printer and a drawing machine. Data transmission between data acquisition stations and the master station is achieved by asynchronous serials. Data communication usually applies the master-slave mode and the master station decides the station for data transfer.

Distributed data acquisition system uses several data acquisition stations with SCM as the core. In the system, the stations work in "parallel". Hence, this system provides high reliability and effective real-time response. In addition, this system replaces analog signal transmission with digital signal transmission, which can effectively eliminate the interference of the differential mode and common mode. This especially fits the working environment with strong electromagnetic interference

## B. *Digital Processing of Analog Signal*

Physical quantities used in the condition monitoring and fault diagnosis include electrical quantities (current, voltage, etc.) and non-electrical quantities (vibration, temperature, pressure, flow, noise, etc.). Electrical quantities are converted into electric signals of the appropriate size through a variety of transmitters. Non-electrical quantities need to be converted into electrical signals with proper transducers to facilitate the measurement and processing. Signals are practically divided into analog signals and digital signals.

Usually, signals obtained from the sensor are analog signals. Digital signal is the focus in the computerized development of equipment fault diagnosis. Analog signals used in the operation of electrical and mechanical devices need to be converted into digital signals and transmitted in the computer.

### 1) *Signal Preprocessing*

In the diagnosis system, signals can be obtained by the sensor. Some are useful signals, which reflect symptoms of the fault locations. Some are not required in the diagnosis. Thus, useless signals should be removed, which is also known as the signal preprocessing.

The signal preprocessing indicates the analog treatment of signals before digital processing. The purpose of the signal preprocessing is to filter the interference noise signal and to turn signals into a form suitable for digital processing, thus reducing the difficulty of the digital processing. The signal preprocessing mainly involves demodulator, amplifier, filter, blocking circuit and so on.

### 2) *Sampling*

Sampling refers to the extraction of a series of discrete sample values from the continuous-time signal  $x(t)$  according to the sequence of sampling pulses  $p(t)$ , which then turn to the sampling signals  $x(n\Delta t)$  ( $n=0, 1, 2, 3, \dots$ ).  $\Delta t$  is known as the sampling interval and  $f_s=1/\Delta t$  is the sampling frequency. To put it simple, sampling is to turn continuous-time signals into discontinuous-time digital signal.

This process is achieved through analog switches. Analog switch opens and closes at every certain time interval. A continuous signal passes this switch and forms a series of pulse signals, known as the sampling signal.

In general, the higher the sampling frequency  $f_s$  is, the more dense sampling points are, and the closer the obtained digital signals are to original signals. Meanwhile, when sample length  $T$  is certain, the higher  $f_s$  is, the larger the data quantity  $N=T/\Delta t$  will be, and more storage and calculation load of the computer will be needed. Conversely, when the sampling frequency is reduced to a certain extent, original signals will be lost or distorted. Shannon sampling theorem indicates that if the frequency band of the signal is limited while the sampling frequency is at least two times from the highest frequency of signals, the original signals can be completely restored according to the discrete sample values.

After sampling, although the signals are discontinuous in time, the amplitude is still continuous. The signals cannot be input in the computer until quantized, encoded and converted into digital signals.

### 3) *Frequency Alias and Elimination Measures*

According to the sampling theorem, the sampling frequency  $f_s$  must be larger than the highest frequency two times of signals ( $f_s > 2f_s$ ). If the sampling frequency is too low, the high frequency part of signal  $x(t)$  will be multiplied to low-frequency part. This is known as frequency aliasing [3].

In the diagnosis system, original analog signals obtained by the sensor are generally not limited bandwidth, and signals contain the high-frequency part. To effectively eliminate frequency aliasing, in the actual signal analysis, the analog signal  $x(t)$  is processed with lowpass filtering. Unwanted high-frequency parts are filtered and the sampling frequency is increased to more than 3 times the filter cutoff frequency  $f_c$ , so as to effectively eliminate the aliasing. In this way, the obtained digital signals can be ensured to reflect the useful part of the original continuous signal  $x(t)$ .

#### 4) Structure Control of Data Acquisition System

The sampling of data acquisition system consists of random and sequential working modes. The input and output control of the analog signal practically applies I/O dedicated addressing, or memory unified addressing. For any addressing technology, the input and output interface of analog signal must have a hardware address decoder for interface addressing.

Controlling means of data acquisition include the hardware timing method, unconditional sampling, the program control channel I/O transfer (PIO structure) and direct memory access (DMA) and so on. In the diagnosis system, I/O transfer and DMA are often applied. For fault diagnosis devices with a small data volume, program control channel I/O transfer involves less hardware and less production expenses. The programming is simple. For fault diagnosis devices with a large data volume, in order to realize high-speed data acquisition, the monitoring of several mechanical and electrical devices is generally realized by direct memory access.

#### C. Anti-interference Technology of Data Acquisition System

In engineering practices of the data acquisition system, circumstances like the abnormal working state of the system in fieldwork with correct hardware design and successful the program debugging. This may be attributed to interferences between the external or internal components. Common interference forms include electrostatic interference, magnetic field coupling interference, electromagnetic radiation interference, the conductance pathway coupled interference and leakage coupling interference and so on<sup>[3]</sup>.

In the diagnosis system, the input pathway of analog signal is the information exchange channel between data acquisition card and microcomputer as well as the sensor. The interference of the information channel is caused by public ground electrodes. In addition, when the transmission line is long, the information channel may also be influenced by static electricity and electromagnetic noise. The interference of the input pathway greatly influences the accuracy and reliability of the sampling signals and should be eliminated or suppressed. Commonly used anti-interference measures of input channels of analog signals include photoelectric isolation, isolation amplifier, filter, the floating installation of lines, shielding lines and coaxial cables to prevent electromagnetic interference.

### III. SIGNAL PROCESSING TECHNOLOGY

In the fault diagnosis of electromechanical devices, the tested signals are used as a function of time. The analytical processing in the time domain is known as time-domain analysis. Signal processing techniques such as Fourier transform can take the detected signals as a function of frequency, and the analytical processing in the frequency domain is known as frequency-domain analysis. With the signal processing techniques, "noise" in the time-domain signals can be suppressed and fault characteristic signals in a specific frequency segment can be extracted from the frequency domain. In the actual engineering, commonly used signal processing technologies include Fourier transform, STFT, refined spectral analysis and wavelet transform and so on.

#### A. Fourier Transform and Zoom Spectrum Analysis

Function  $f(t)$  is the absolutely integrable function ( $f(t) \in L^1(R)$ ) defined in  $(-\infty, +\infty)$  and the Continuous Fourier Transform of  $f(t)$  can be defined as:

$$F(\omega) = \int_{-\infty}^{+\infty} f(t)e^{-j\omega t} dt \quad (3-1)$$

The inverse Fourier transform of  $F(\omega)$  can be defined as:

$$f(t) = \frac{1}{2\pi} \int_{-\infty}^{+\infty} F(\omega)e^{j\omega t} d\omega \quad (3-2)$$

The frequency refining technology is a supplement and improvement of signal Fourier analysis, making the optionally band frequency analysis possible. There are many refinement ways to increase the frequency resolution, mainly including ZOOM-FFT, phase compensation refinement, Chirp-Z transform, maximum entropy spectral analysis and continuous refined Fourier transformation.

In the premise of not increasing sampling length, continuous refined Fourier transformation applies frequency-domain curves of continuous Fourier transformation for the refinement of the spectrum of the Fourier transform in the designated area for specified density. This greatly increases the frequency resolution of the spectrum, which is conducive to the extraction and analysis of fault characteristic features of mechanical and electrical devices. Thus, continuous refined Fourier transformation presents important engineering significance in the fault diagnosis area of electrical and mechanical devices<sup>[4]</sup>.

#### B. Short Time Fourier Transformation and Wavelet Analysis

If the function  $w(t) \in L^2(R)$ ,  $tw(t) \in L^2(R)$ , and  $w(t)$  is regarded as window function and the STFT of  $f(t)$  can be expressed as:

$$S(\omega, t) = \int_R f(t)w(t-b)e^{-j\omega t} dt \quad (3-3)$$

In practical applications, the choice of the window function is a core question in the short time Fourier transformation. In the analysis of engineering problems, Gauss window function is often used. Gauss window

function presents fast attenuation in the time domain and the frequency domain, also having the localized optimized performance of time [5]. Gauss window function is defined as:

$$g_a(t) = \frac{1}{2\sqrt{\pi}a} e^{-t^2/(4a)}, a > 0 \quad (3-4)$$

Assume the function  $\psi(t)$  is a square integrable function that meets  $\psi(t) \in L^2(R)$ , and its Fourier transform is  $\hat{\psi}(\omega)$ ,  $\hat{\psi}(\omega) = \int_{-\infty}^{+\infty} \psi(t) e^{-j\omega t} dt$ . When  $\hat{\psi}(\omega)$  meets the wavelet admissibility condition, the continuous wavelet transform of any function  $f(t) \in L^2(R)$  is defined as:

$$W_f(a, b) = \langle f, \psi_{a,b} \rangle = \frac{1}{\sqrt{|a|}} \int_R f(t) \psi^* \left( \frac{t-b}{a} \right) dt \quad (3-5)$$

The continuous wavelet transform for any function  $f(t)$  indicates the projection of a one-dimensional time function to the two-dimensional time-scale phase plane, which is conducive to extract substantive characteristics of non-stationary signals. The basis function of the wavelet transform  $\psi(t)$  presents the diversity. The choice of the basis function of the wavelet transform is very important in wavelet analysis and applications. In practical engineering application, the real function or complex function with compact support or approximate compact support as well as regularity and attenuation is normally chosen as the basic function of wavelet transform.

#### IV. CASE STUDY- DATA ACQUISITION AND SIGNAL PROCESSING SYSTEM OF PORTABLE MOTOR FAULT DIAGNOSTIC DEVICE

Portable fault diagnostic device can conduct online detection of the main operating parameters of the motor, and can store the data in the memory with a large capacity. The maintenance and management staff can transfer the stored data in the memory to the host computer for storage, display and printing through the communication port. Also, according to the data and the waveform of signal processing, the maintenance and management staff can detect and monitor common faults of the motor [6].

According to the signal characteristics of motor faults, the fault diagnostic device divides the whole system into the host computer and the lower computer from the aspect of structure. The hardware circuit of the detection system consists of various sensors, signal conditioning and input buffer sampling holder circuit, data acquisition and A/D converter and RS232 communication interface circuits, as shown in Figure 2.

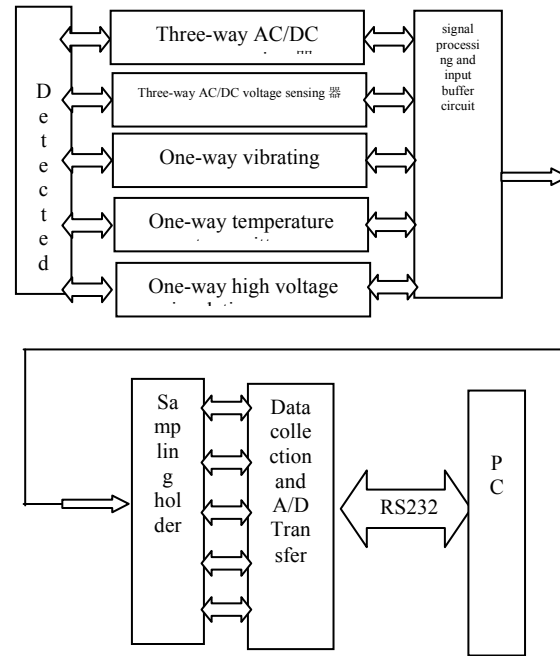


Figure 2. the block diagram of the diagnosis system

Accordance with the requirements of the entire system, the microcontroller needs to complete two tasks: firstly, choosing different channels for data acquisition with the software; secondly, according to the requirements of the host computer, transfer the corresponding data. Due to the real-time property of the system, on the basis that the hardware (sensor) has confirmed to be connected with the detected equipment (motor), the host computer gives commands of acquisition, and the lower computers collect data. As for the synchronous acquisition of three voltages and three currents, the program will apply data collection of six cycles. As the sampling holder is used, the synchronization of data acquisition of three voltages and currents can be ensured. In each collection, five groups of data will be used and stored in the external RAM. AT89C51 SCM from ATMEL Company is selected, which has the program memory space for 4KB and data storage space for 128 bytes.

SCM uses RS232 communication, and one SCM does not generate multimachine communication problems. Therefore, the 10-bit asynchronous transmission is used, specifically involving 8-bit data bits (LSB first), a stop bit and the baud rate of 9600bps. The host computer applies the query to send command words while the lower computer applies the interrupting approach and launches corresponding subroutine processing according to the command words. Due to the correctness requirement of the program to data, in the data transfer, each data is transferred for two times to ensure the correctness of data. The entire program adopts the interruptive relieving and query sending.

The data acquisition system uses a filter to eliminate the interference of electromagnetic noise. Decoupling capacitor is equipped in each chip, which absorbs the instant charge and discharge energy between opening and closing doors of

integrated circuit and filters the high-frequency noise of the device<sup>[7]</sup>.

The software of data acquisition system is designed with modular design, and the lower computer adopts C language for SCM program, which mainly includes the main program of the microcontroller, A/D sampling control program, timeset and read program, storage control program and communication program.

The software of the host computer mainly achieves the operating parameters and time settings, the motor operating parameter storing, displaying, and diagnosis of motor fault state for lower machines. The software of the host computer adopts VC++6.0 as the program development tool. VC++ has an abundant graphical development environment, and can easily adopt Microsoft Basic class library functions and other useful tools to improve the efficiency of programming<sup>[7]</sup>. The diagnosis program of the host computer includes various subroutines such as the Fourier transform, refined spectral analysis, adaptive filtering, wavelet analysis and the extraction of the fault characteristics. In this way, the sampling data can be processed with the motor current spectrum analysis, the vibration spectrum analysis, winding impedance calculation and voltage symmetry analysis. On this basis, with the comparison of databases, programs such as the extraction of the fault characteristic signal can diagnose, record, display and alarm of common faults of the motor.

## V. CONCLUSIONS

Data acquisition and signal processing is a key part of condition monitoring and fault diagnosis of electromechanical devices<sup>[8]</sup>. In the engineering design and

development of the actual diagnosis system, functions of the system should be considered, as well as the technical indicators and the working environment, so as to select the appropriate data acquisition and signal processing technology. In addition, the hardware and software should be well integrated and the internal and external electromagnetic interference should be suppressed, thus effectively monitoring the operating parameters of electromechanical devices and extracting characteristic signals of faults for the real-time identification of the working status of devices.

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