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Feature Extraction and Diagnosis System Using Virtual Instrument Based on CI

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ABSTRACT

Through investigating intelligent diagnosis method of Computational Intelligence (*CI*) *and studying its application in fault feature extraction, a gear fault detection and Virtual Instrument Diagnostic System is developed by using the two hybrid programming method which combines both advantages of VC++ and MATLAB. The interface is designed by VC++ and the calculation of test data, signal processing and graphical display are completed by MATLAB. The program converted from M-file to VC++ is completed by interface software, and a various multi-functional gear fault diagnosis software system is successfully obtained. The software system, which has many functions including the introduction of gear vibration signals, signal processing, graphical display, fault detection and diagnosis, monitoring and so on, especially, the ability of diagnosing gear faults. The method has an important application in the field of mechanical fault diagnosis.*

Keywords: *Virtual Instrument* (*VI*), *Computational Intelligence* (*CI*), *Fault Diagnosis, Feature Extraction, Gear System*

1. Introduction

At present, a gear transmission is one of primary driving-forms in mechanical transmission and is broad applied in practical engineering. Gears are used in most of equipments such as aero-engine, vehicle and machine tool. However, studies have shown that 60% faults in gear system cases are caused by gear failure and 90% gear failures are due to partial failure, such as crack, wear abrasion of tooth and so on. Therefore, the condition monitoring and fault diagnosis for gears can not only avoid the decline of equipment's accuracy during working in order to reduce or to cease the appearance of accident, but also adequately exert the potential gear work. It has an important significance in both of economic and social benefit [1].

After combining the analysis method of time-domain, frequency-domain, and some intelligent diagnosis methods such as the ones based on support vector machine, artificial neural network and so on, in the field of gear fault diagnosis, it is necessary to develop a virtual instrument system of gear failure analysis so that these analysis methods can are expediently applied in gear fault diagnosis [2]. In the traditional time-domain and frequency-domain analysis and the ones based on Support Vector Machine, artificial neural network, pattern recognition, it is related to the portion such as numerical calculation, signal processing, graphical display etc. Therefore, it is necessary to synthesize the above studies mentioned to empolder a virtual instrument diagnosis system. Wan and Tong designed a fault diagnosis system based on virtual instrument, which was successfully applied to SDF-9 generator [3]. Lv and Zhang used virtual instrument technique designed a fault diagnostic system, which solved the problems of state prediction and trouble-mode recognition of warships equipment [4]. The literature [5] studied the remote fault diagnosis for complex equipment based on virtual instrument (VI) technology. Xu *et al.* introduced a fault testing and diagnosis system of bearing in armored vehicle based on information fusion technology [6]. However, above the most are subject to the restrictions of their software system, the diagnostic functions of system are not very comprehensive, and the diagnosis systems lack the functions of online real-time detecting and monitoring.

Virtual instrument (VI), which brings the fault identification and diagnosis to a higher level, is an important development trend with combination of testing technology and fault diagnostic techniques. It considers computer software as its core. It possesses all the functions of signal collection, analysis, processing, display, identification, diagnosis, alarm, monitoring, and it is the developing direction of intelligent detection and diagnosis. Wang and Gao investigated the design, optimization, and

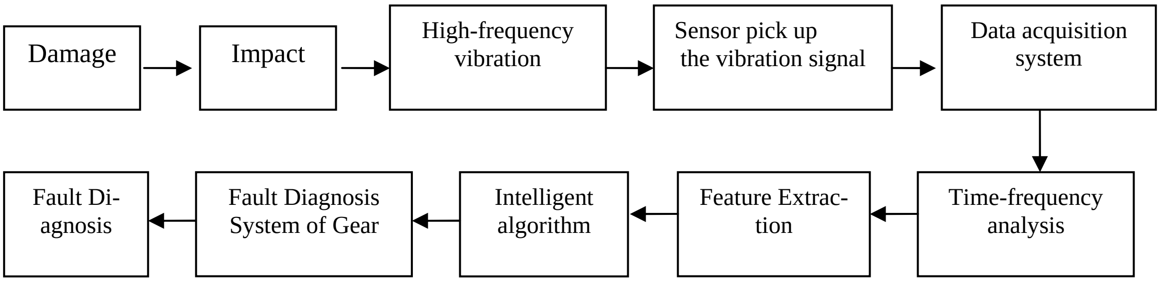


Figure 1. Block diagram of signal extraction and fault diagnosis

implementation of virtual instrument (VI), which was an essential part of integrated bearing condition monitoring system [7]. The literature [8] introduced an approach combining virtual instrument with rough set theory (RST) for FPC on-line fault diagnosis. Betta *et al.* analyzed the use of Support Vector Machines (SVMs) in software-based instrument fault accommodation schemes for automotive systems [9]. The literature [10] researched the application of virtual instrument and grey theory in the fault diagnostic system. However, nowadays the virtual instrument systems have Labview, Labwindows/CVI, HP VEE, and so on. But due to these software systems' limitation, it is difficult to run independently without the inherent system respectively.

MATLAB, which has strong graphical display capability, is a very powerful matrix and mathematical software package for engineering and scientific calculations with advanced file I/O. VC++ is a very useful language widely used in computer-controlled measurement system as well. The combination of MATLAB and VC++ can play their respective advantages with powerful functions such as: analysis and processing of signal, visualization, diagnosis and monitoring, etc. The interface developed by VC++ is friendly to user, and the system developed with MATLAB has the following functions, such as numerical analysis and calculation, graphics display, testing and detecting, etc. The literature [11] introduced a MATLAB and VC++ mixed programming method, which is used in their differential optic absorption spectroscopy (DOAS) atmospheric pollution monitoring system. Xu *et al.* studied a hybrid programming method, which is combined with VC++ and MATLAB, applied to power system fault analysis and identification system [12]. Chen *et al.* investigated several common mixed programming methods between VC++ and MATLAB based on their respective characteristics [13].

Therefore, this paper based on technology platform of virtual instrument will empolder the main program of gear failure analysis software systems by using MATLAB software tools and VC++ language. The interface of between VC++ and MATLAB is developed. Using the two hybrid programming method, the calculation of test data, signal processing and graphics display are completed by MATLAB. Utilizing MATCOM tool, it transforms program written the MATLAB into program functions called VC++ which is used to design the main interface and achieve the sub-interface's call, then develops a gear failure analysis software system. It can run independently without MATLAB, and possesses the functions of virtual instrument diagnosis system, included many functions, such as signal collection, signal analysis, processing, display, identification, on-line diagnosis, alarm and monitoring.

2. Fault Diagnosis and Feature Extraction Mechanism

Vibration diagnosis is a basic method in fault diagnosis technology, it commonly used in the mechanical equipment condition monitoring [14]. Vibration will be increased when an exception occurs in the machine. Therefore, according to the measurement and analysis for the mechanical vibration signal, we can know the estate of their deterioration and the property of failure without stopping running and disassembly. The process of fault diagnosis using vibration signal is shown in Figure 1.

The diagnosis method is a very active research field in the fault diagnosis, and the key of diagnosis method is the research of extraction mechanism of failure feature. Namely, which measure method has been taken and what kind of sensitive signals have been extracted to improve the identification accuracy and detecting ability of system. How to achieve the most effective real-time monitoring and diagnosis will be the key of modern fault diagnosis and monitoring. It has become a hot topic in the current research on how to detect mechanical fault in time and forecast the developing trend of equipment operation condition. It is the key of diagnostic success in how to develop a compositive system which is combined with software and hardware to achieve real-time, on-line diagnosis for mechanical drive system. The rapid development of virtual instrument technology, which introduces the mechanical fault diagnosis and testing technology into the higher level field, it is an important trend of development of testing technology and fault diagnosis technology [15,16].

Computational Intelligence (CI), which developed from Fuzzy, AI, Neuron (a joint name "FAN"), is a burgeoning modern signal processing and control theory with decennary development. It is a strongly all-around advanced theory with a unique advantage which is related to many fields such as AI (artificial intelligence), Fuzzy, Neural Network, GA (genetic algorithm), Chaos, Fractal, Granular Computing, and Biomedicine. Using CI can extract coupling highly order useful features from random non-linear and non-stationary data and remove the effect of adscititious noise. It has become a brand-new method for pattern recognition and fault diagnosis of complex dynamic system, and a hot spot in current international research [17] as well.

Virtual instrument (VI), a new instrument concept put forward in early 90s of 20th century, is a combination of computer and instrument with a breakthrough for traditional instrument concept. Using adequately the intelligent computer-function such as computing, storage, playback, call, display and document management, complex information processing, it has achieved the specialized function of traditional instrument by software. The new instrument, whose appearance and function are completely identical with the traditional hardware instruments, fully share the computer intelligence resources. It has become the developing direction of instruments and equipment. Therefore, software development is the key of the virtual instrument exploiture [18,19].

To establish a fault detection system needs to do as follows: including modern signal processing technology with artificial neural networks, support vector machines, genetic algorithms and other computational intelligence methods to extract failure feature of mechanical systems, then diagnose the typical fault of mechanical system and establish the fault detection system [20,21]. With the investigation of fault diagnosis system based on the virtual instrument technology and establishment of the software and hardware system of virtual instrument, which can collect signal, analyze and diagnose signal, the development of entire fault diagnosis system is completed. It can also achieve the on-line detection and diagnosis of failure for mechanical drive system. Consequently, a low-cost, highly intelligent, detection and diagnosis system is introduced to meet the needs of practical engineering.

In this paper, the detection and diagnosis system based on the VI platform include two major parts, hardware and software are developed. Hardware takes PC (or platform) and I/O interface devices, as well as data acquisition cards to complete the task of signal acquisition. Software is the primary part of entire systemic development to complete the signal analysis and detection, fault diagnosis and results display. Under the support of hardware platform considering computer as the core, the instrument function is achieved by software programming (such as the use of MATLAB and C++ language, etc.) design, and multifarious testing and fault diagnosis analysis functions are achieved by the combination of different software modules of the test function.

3. Conceiving of Virtual Instrument Diagnosis System

The two major characteristics of MATLAB are powerful matrix calculation and graphical display. It integrates numerical analysis, matrix computation, signal processing and graphical display into a convenient, user-friendly environment. However, some shortcomings of MATLAB itself restrict its application:

1) MATLAB is an interpretative language, so its real-time efficiency is very poor.

2) MATLAB program cannot run without their environment, so it can not be used for commercial software development.

3) The source code of MATLAB can be seen directly, so it doesn't avail to confidentiality of algorithm and data.

The object-oriented visual programming of VC++ is used to develop software applications from the bottom to the user-oriented software and other. By utilizing its various practical tools, developers can easily develop powerful high-performance Windows applications program. However, in practical engineering development, compared with MATLAB:

1) VC++ is not as good as MATLAB in numerical disposal analysis and algorithms tool and other aspects.

2) VC++ is not as good as MATLAB in accurately and expediently mapping data Graphics (data visualization).

Therefore, if we combine the advantage of MATLAB in numerical calculation, algorithm design and data visualization and other areas with VC++ application system, it can not only fully meet the need in data calculation and display of system, but also improve system efficiency and stability to reduce the difficulties of achieving algorithm, shorten the cycle of software development and improve software quality. It has highly valuable in practice. This system designedly makes use of its two major characteristics to achieve analysis process, diagnose and related graphics display of gear vibration signal.

The software, which could be run without MATLAB, can be developed by MATCOM transform method. VC++ is responsible to open the document and for the main interface, while MATLAB is responsible for numerical computation, signal processing and graphics display and other functions. The M-file can be converted into transferable cpp-file and relevant h-file of VC++ by MATCOM. Finally, the development of system is completed. The system, which has multi-functional interfaces, includes its chief: the main function interface, the various interfaces of gear vibration signal analysis, the various interfaces of gear vibration signal diagnosis and identification, the interfaces of gear vibration signal detection and monitoring. Each interface includes corresponding sub-interface possessing functions of analysis and diagnosis, as shown in Figure 2.

4. Exploitation of Virtual Instrument Diagnosis System

The software supports to collect the vibration acceleration signal data of gear system, including 4-channel data and 2-channel data. Because the program in signal analysis interface has been converted into cpp-file and corresponding h-file, so the software can run without MATLAB software environment in the Windows operating system and has been successfully tested under Windows XP.

4.1 Data Acquisition System

Gear system testing device is shown in Figure 3. In the figure, electromotor drive the entire system, and the coupling transfer the power to reducer gear, and after reducer export the power which pass the gear-coupling and torque speed sensor, the power is transmitted to the magnetic loader. The common experiment method is via testing the vibration signal of gear box, which the sensor stick on, to test the dynamic characteristics of system and gear, however, with a large system noise, the characteristics of gear fault signal will be weakened when it reach gear box. To highlight the characteristics of test signals to minimize the effects of noise on gear failure signal, in this experiment the acceleration sensors should be fixed on the gear and the sensors should be near the symmetrical location of gear fault. Driving-gear is set as fault-gear with the use of transmission ring, because of which the signal acquired from the rotary acceleration sensor is transmitted out fully. Because the signal acquired from the acceleration sensor is comparatively faintly, the signal has to be amplified by amplifier to collect. In the test, by using control cabinet, we observe and control the magnitude of the torque and speed, and observe the magnetic loader to control the magnitude of load given by system.

The running of gear system has four levels of speed: no-load with speed of 300r/min, load 10N.m with 300r/min, load 8N.m with 900r/min, load 6N.m with 1200r/min, load 6N.m with 1500r / min. Three typical failures (crack at the gear root, crack at the gear's reference circle and the wear abrasion fault on tooth surface) and various composite faults are set on driving-gear and tested at above four levels of speed. CRAS signal acquisition software system is used for signal acquisition and analysis, and the algorithms mentioned above are used for feature extraction and diagnosis.

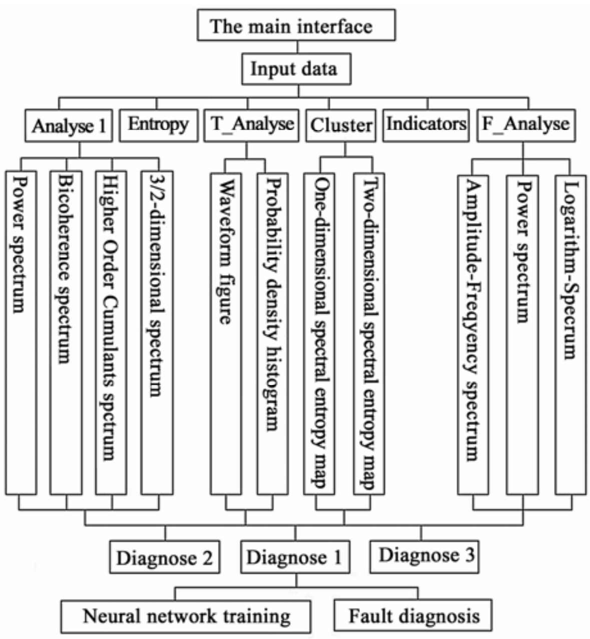


Figure 2. Software system structure

4.2 The Introduction and Test of Signal

The main interface is shown in Figure 4. It mainly achieves the signal acquired from the actual gear transmission testing system in order to facilitate subsequent analysis, identification, and diagnosis. The top column is used to show the physical address of imported data; "ChannelNum" is used to set the total channel number of data files; "Channel" is used to set the channel sequence of importing data; "DataLength" is used to display imported data length; "Fs (Hz)" is used to set the sampling frequency. After the parameters have been set, pressing the "InputData" button, we can open the dialog frame of data file to select the data which will be analyzed. If the data format is correct, the bottom graph-displayed frame will display the waveform of the imported data, so it shows the success of importing data. The right column of buttons, whose functions and manipulations would be introduced one by one in the latter parts, is used for signal processing, calculation and analysis, diagnostic tests.

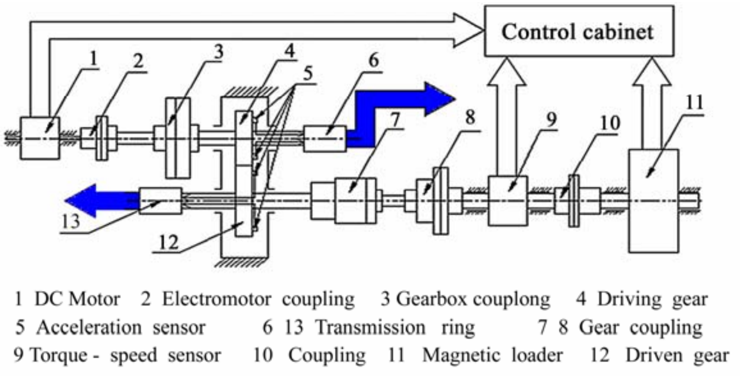


Figure 3. Testing equipment and data acquisition of gear system

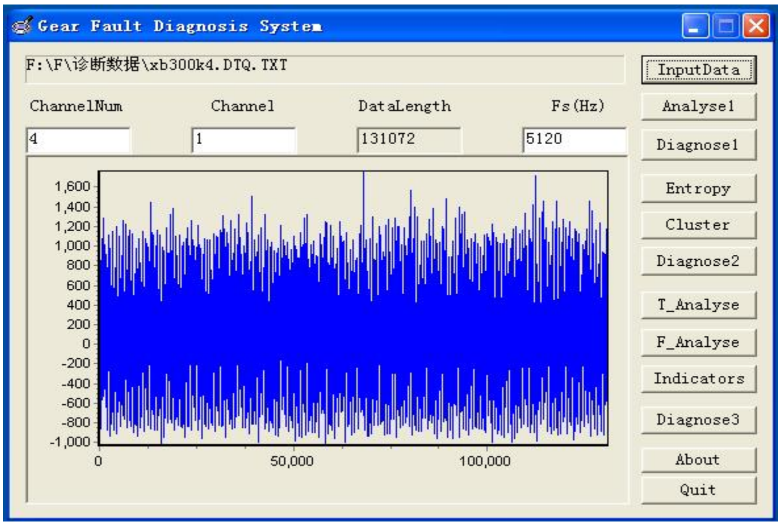


Figure 4. The main interface of software system and the display of interface after importing data

4.3 Signal Analysis and Process

Signal process and analysis include six buttons of Analyse1, Entropy, Cluster, T_Analyse, F_Analyse, Indicators. The following introduce respectively their function and detailed operation.

1) The function and operation of Analyse1

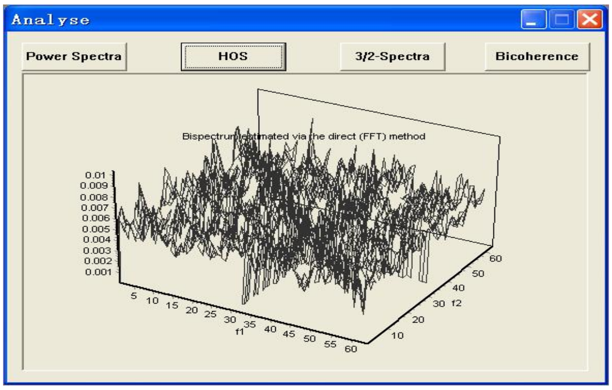
Analyse1's part of the interface is shown in Figure 5. Function: It can realize the analysis calculation and figuring graph of power spectrum, higher-order cumulant spectrum, 3/2 dimensional spectrum, bicoherence spectrum. Data power spectrum is plotted by clicking the Power Spectra button; 2 dimensional (contour map) and 3 dimensional (grid chart) spectrogram of higher-order cumulant of data can be displayed by clicking HOS button, as shown in Figure 5(a); Clicking the 3/2-Spectra button is used to achieve the drawing of 3/2 dimensional spectrum; 2 dimensional (contour map) and 3 dimensional (grid chart) spectrogram of bicoherence spectrum of data can be displayed by clicking Bicoherence button, as shown in Figure 5(b).

2) The function and operation of Entropy

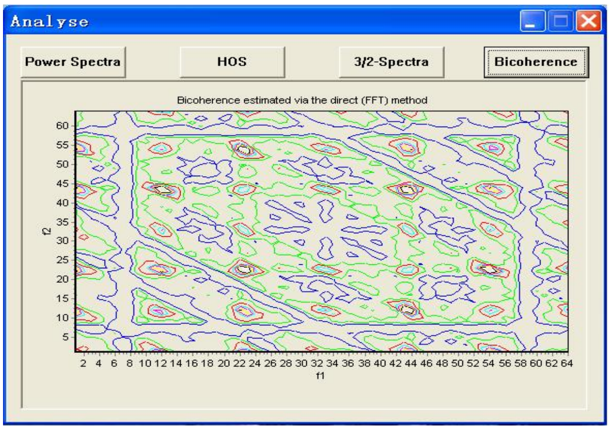
Entropy's part of the interface is shown in Figure 6. Function: It calculates the spectral entropy of the imported data owning numbers of cycles. "Mean" denotes the mean of spectral entropy, "Max" denotes the max of spectral entropy, "Min" denotes the min of spectral entropy, "Beta" denotes the kurtosis of spectral entropy, and "S" denotes the variance of spectral entropy. The underside graph display frame shows the distribution of calculated value of spectral entropy.

3) The function and operation of Cluster

Cluster's part of the interface is shown in Figure 7. Function: It is used to cluster analysis for the imported data, including the K-mean method and the den-grid method. In the figure, "•" denotes wear abrasion faults, "×" denotes crack faults, "*" denotes the feature of without faults. It is obvious that this method can accurately cluster for different signals of gear system.



(a) Three-dimensional grid spectrum of higher-order cumulant



(b) Two-dimensional contour line of bicoherence spectrum

Figure 5. The display interface of Analyse1

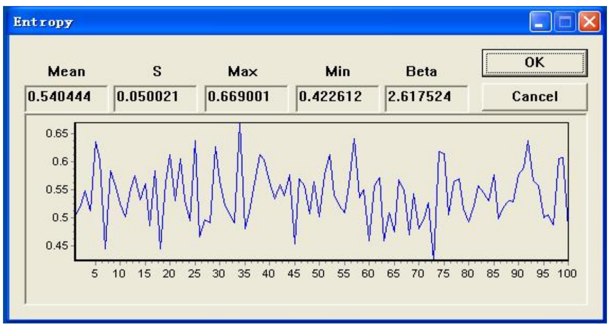


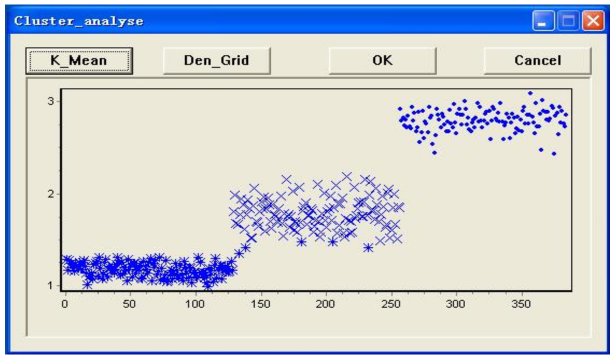
Figure 6. The display interface of Entropy

4) The function and operation of T_Analyse

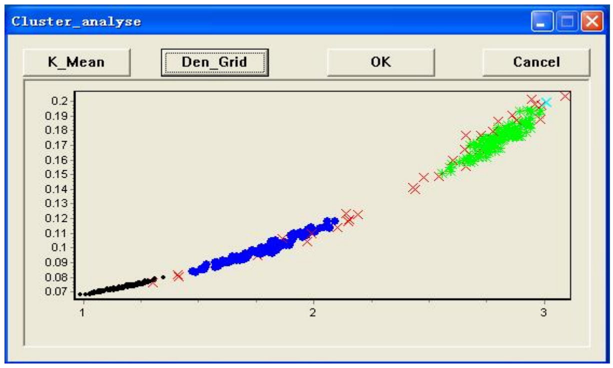
T_Analyse's part of the interface is shown in Figure 8. Function: It displays the time-domain waveforms and probability density histogram after that the imported data have been amplified.

5) The function and operation of F_Analyse

F_Analyse's part of the interface is shown in Figure 9. Function: To display amplitude-frequency diagram of the imported data of gear vibration signal (abscissa is the frequency, unit is Hz, ordinate is the amplitude of vibration acceleration), Power spectrum diagram (abscissa is the frequency, unit is Hz,

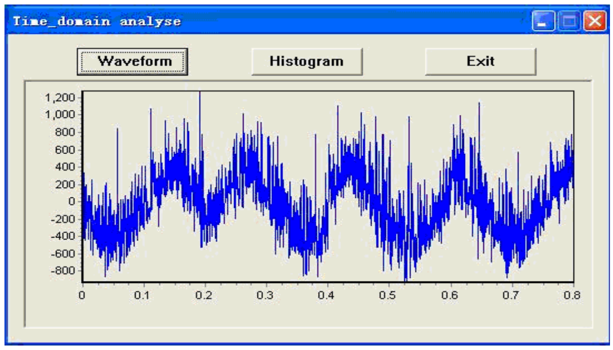


(a) The analysis results by K_Mean method

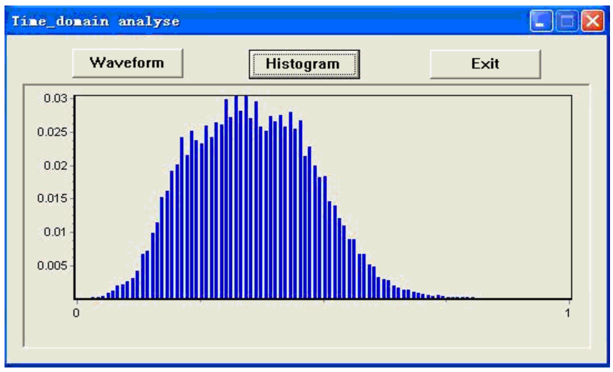


(b) The analysis results by Den_Grid method

Figure 7. The display interface of Cluster



(a) Time-domain waveform



(b) Probability density histogram

Figure 8. The display interface of T_Analyse

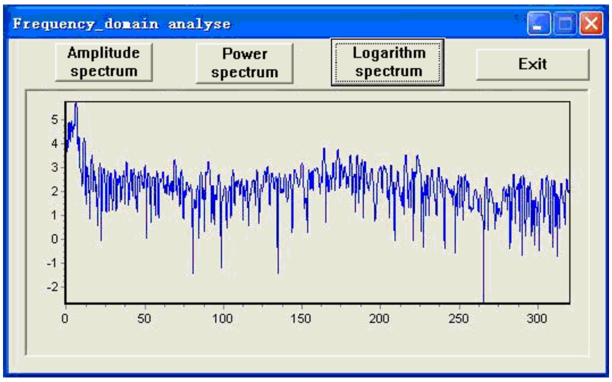


Figure 9. The display interface of F_Analyse

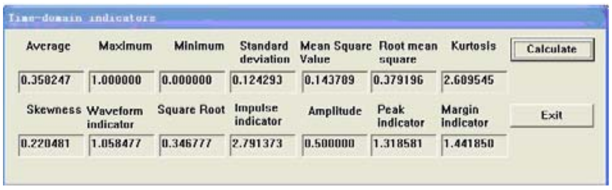


Figure 10. The display interface of Indicators

ordinate is the power of vibration acceleration), logarithm spectrum diagram (abscissa is the frequency, unit is Hz, ordinate is the amplitude, converted into logarithm, of vibration acceleration).

6) The function and operation of Indicators

Indicators' part of the interface is shown in Figure 10. Function: It calculates and shows the time-domain parameters of the various indicators.

4.4 Fault Diagnosis and Identification

Signal diagnosis includes Diagnose 1, Diagnose 2, and Diagnose 3. Functions are as follow:

The interface of Diagnosis 1 is shown in Figure 11. Functions: Neural Network Algorithm is used to train and identify the imported data, finally, to get the fault type of the imported data. Producing the data sample, training the data sample, introducing the trained weight, diagnosing and getting test result, it can identify three kinds of faults: the crack at the gear root, the crack at the gear's reference circle and the wear abrasion on tooth surface.

After the Diagnose 1 button is clicked, a new window (Figure 11(a)) appeared. In the new window, it should be set the corresponding parameters. StartPT is the starting position of the interception segment, SampLen is the data length of each piece, SampNum is the number of data segment. Select the training sample fault type in the drop-down menu including three kinds: crack at tooth root, crack at teeth top and tooth wear abrasion. Select New if create a new sample file, select Old if add samples into old sample files. BlockNum and L are same to the part above; P is time-serial_model order; Variance is used to direct time-serial analysis error. After the setting is finished, click the MakeSamps button, a save location window of the created samples pop-up to select store directory in it, and then click OK in the following window. The creation of sample is complete after clicking OK button in the prompt window. Then, click Train button, select the created sample to train. After training is completed, click GetWeight button, select the trained weight, and finally click the Diagnose button to get the diagnostic results. As shown in Figure 11(b).

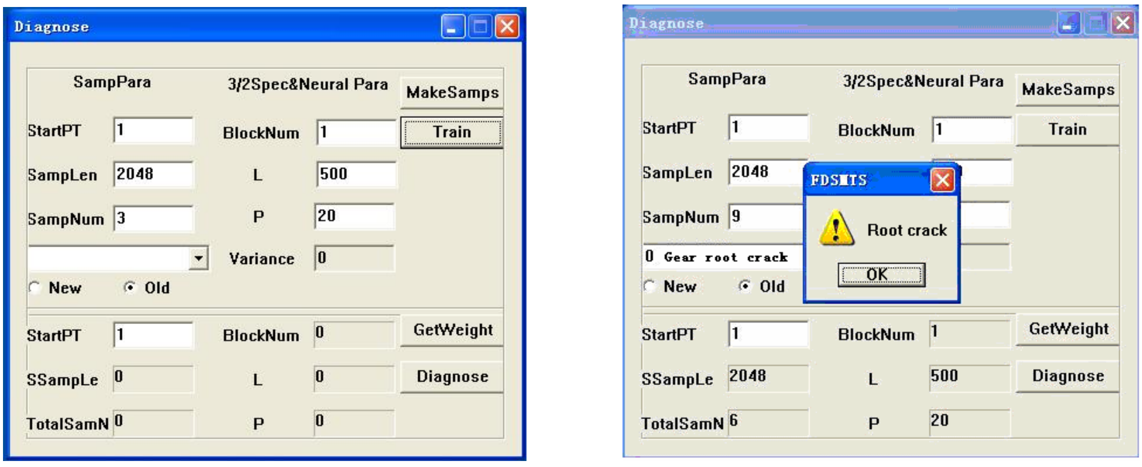
The interface of Diagnose 2 is shown in Figure 12. Function: The faults can be recognized by the spectral entropy algorithm. By importing vibration signal at different running condition, its time-frequency characteristics are analyzed, and the spectral entropy of the signal are calculated. Because of the cluster analysis, the fault of the gear can be diagnosed. As shown in Figure 12, Speed is used to set the speed of running system, Cycle-Num is used to set the tested sample number, Entropy is used to display spectral entropy value of the tested sample, Fault-style is used to output diagnostic results. After clicking Diagnose 2 button, setting every parameter in the prompt window and clicking OK button, the diagnosis can be done.

The interface of Diagnose 3 is shown in Figure 13. Function: Through analysis, according to the rotational speed and the measured sample number, the proposed system can be effectively used in diagnosis of different faults of gear system, such as the crack, and the wear abrasion fault. As shown in Figure 13, clicking Diagnose 3 button and setting the speed and number of the tested samples in the prompt dialog box, then clicking the fault identification button, we can directly get the tested samples fault type. It can process, diagnose and identify three kinds of data measured from experiment: normal gear, crack gear and wear gear.

Via above analysis and test diagnosis, it shows the accuracy and feasibility of the fault analysis, detection and diagnosis system of the gear transmission system. At the same time, it also shows that the virtual instrument diagnostic system possesses the basic functions of gear transmission vibration signal processing, such as, analysis, display, identification, diagnosis and so on, and the results are very good.

5. Summaries

This paper discusses the requirements, functions and development of gear failure analysis software system. Via VC++ and MATLAB mixed programmer, virtual instrument Diagnosis System of Gear Fault Analysis, which can run under Windows platform, is successfully developed; by importing the vibration signal data measured at practical test, it demonstrates the functions of



(a) The main interface of Diagnose 1

(b) The diagnostic result of using neural network

Figure 11. The display interface of Diagnose 1

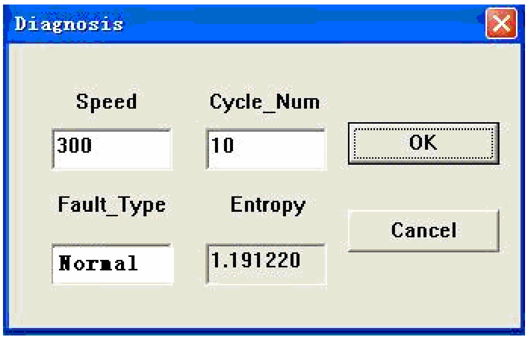


Figure 12. The interface of Diagnose 2

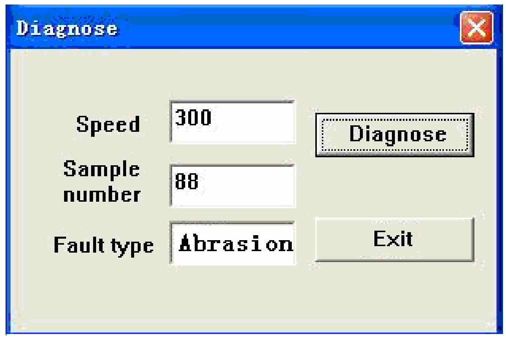


Figure 13. The interface of Diagnose 3

the virtual instrument system in analysis, processing, diagnosis and identification of gear vibration signal. It validates the correctness and effectiveness of this system in identification and diagnosis of gear vibration signal, and gets the relative graphics and calculation results. It also shows that this software system can be used for analysis, processing, diagnosis and identification of vibration signal of gear system, and the proposed method can be effectively used in engineering diagnosis of gear different faults.

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