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Development and Application of On-line Monitoring Device of Transformer Vibration

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Abstract

A real time on-line transformer vibration monitoring system based on the Labview is proposed and applied in the monitoring of abnormal vibration of transformer caused by DC bias in this paper. The monitoring of the transformer body vibration and the signal online analysis can be well performed by this system. The vibration signals of the transformer body are detected by three acceleration sensors, and the signal features are studied in both the time domain and the frequency domain, which provides the data for the operation condition assessment and fault diagnostics. Combined with the background data base, a virtual instrument technology has been used to realize man machine interface and the real time multifunction and multi-channel monitoring. Compared with the previous similar installations, this monitoring system makes the best use of powerful computer, the flexibility of Labview in the instrument development, and the new data store technology. The experiment results suggest that the installation fully meets the requirements of real time monitoring. Some conclusions of transformer abnormal vibration under the condition of DC bias are gained. The system facilitates the detection of the early signs of transformer mechanical failures.

Keywords: *transformer vibration, on-line monitoring, virtual instrument, DC bias*

1. Introduction

The main characteristic of the modern transformer is that the single machine capacity becomes bigger and voltage level becomes higher [1], which increases the intensity of the internal electric field and magnetic field of the transformer. The corresponding electromagnetic force produced through the mechanical coupling is continuously increasing, especially under the condition of DC bias [2-3], which causes electronic and mechanic problems of the internal core, coil and even the transformer body itself [4-5]. As an external observable parameter, the vibration condition of transformer body is one of the most important indicators. In addition, although the manufacturers have taken the influence of vibration on transformer performance into consideration when they were designing the device, but during the transportation, installation and debugging process, the vibration impact is inevitable. The vibration may affect the transformer itself, cause fasteners to loose or make the inherent frequency of the transformer change, which may cause serious accidents during normal operations. Therefore it is necessary to implement transformer vibration condition monitoring, especially the online operation monitoring [6]. Through the monitoring of the device, the condition of the internal components can be detected, which turns the periodic inspection of mechanic structure of the transformer into the state inspection and therefore prolongs the working time of the transformer.

A monitoring system which is applied in the acquisition and real-time analysis of vibration signal of transformers is proposed in this paper. Combined with the LabView software, the system performs real-time analysis by transforming the vibration signal into frequency domain using the Fast Fourier Transform (FFT), and has been applied to the research of transformer abnormal vibration experiments. The experiment result proves that the system has realized the real-time and accurate online data acquisition.

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2. Transformer Vibration Mechanism

The main source of the transformer vibration is the iron core and winding vibration and the cooling device vibration. Usually the frequency of the vibration signal produced by the cooling apparatus is low, frequencies are mainly distributed around 100Hz in the experiment which can be filtered during the experiment. The vibration signal of the device itself mainly comes from the core which is caused by the magnetostriction of the steel sheet; the core vibration provoked by the electromagnetic force which is caused by the magnetic leakage between the core steel sheet joints and the sheets; the winding vibration provoked by the electromagnetic force which is caused by the currents in different windings or the currents between different lines of the same winding; and the vibration of the oil tank wall caused by magnetic leakage. In recent years, studies show that the vibration caused by the magnetic leakage can be ignored compared with the core vibration caused by magnetostriction and the coil vibration caused by the electromagnetic force, and along with the transformer core manufacturing process improvement, the vibration affected by the electromagnetic force at the joints of core steel sheets and the force between the sheets is greatly reduced. Thus we suppose that the main sources of the vibration of transformers are the vibration of the core magnetostriction and the one of the coil winding affected by electromagnetic force [7].

It is commonly believed that the main transformer magnetic pass stays the same either the transformer is load-free or the load changes. According to the phenomenological theory of magnetostrictive material, the core magnetostriction quantity will not change, it means that core vibration situation is basically the same [8], therefore, in order to study the vibration characteristics of transformer core, we can obtain core vibration characteristics through sensors which are reasonably distributed on the transformer in the load-free situation. When load is connected, the current existing in the coil is more of a load current in addition to the excitation current of the load-free situation, which means the vibration characteristics would vary with the change of the load. Therefore, the transformer vibration signals measured in the loaded situation include both the core vibration signal and the coil vibration signal. Since the core vibration does not change with the load, it is possible to obtain the vibration property of the coil by comparing the vibration conditions when transformer is load-free or loaded.

3. The hardware structure of the on-line monitoring system

This system consists of front type LC0166T acceleration sensors, LC0201-3 type signal conditioner, Advantech PCI-1714UL data acquisition card, man-machine interface which is based on virtual instrument technology, and the database of offspring monitoring system platform, as shown in Figure 1.

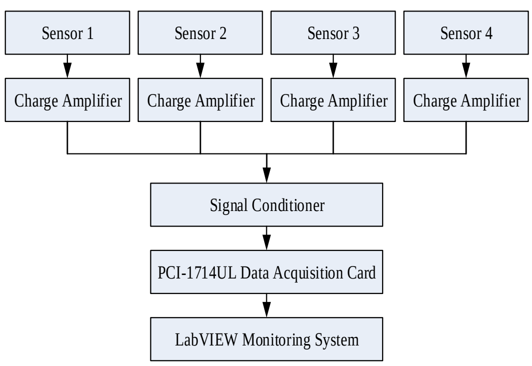

Figure 1. Hardware Structure System

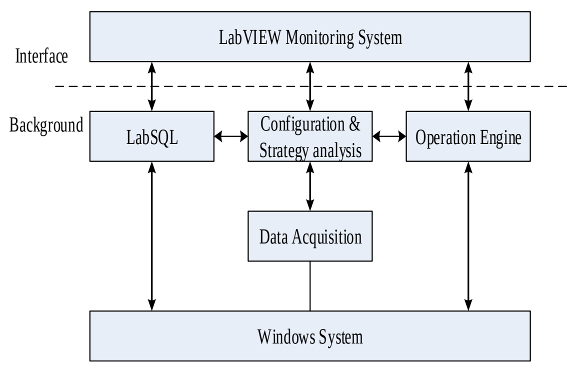

Figure 2. Monitoring System Overall Block Diagram

The bandwidth of the LC0201-3 signal conditioner is between 15 KHz to 2 MHz, its gain is 40db, and the noise level of the device is low, thus it can be closely connected to the LC0166T acceleration sensor through the cable connector interface. The data acquisition module of the on-line monitoring system is the PCI-1714UL data acquisition card developed by the Advantech Company. PCI-1714 is a high speed synchronous 4 road analog data acquisition card, its sampling rate can reach 10MS/s. It has the function of synchronous sampling, the use of the four the same circuit and A/D converter for each analog channel, each channel with 32kbit of FIFO storage area, which ensures that data transmission has the best speed and data integrity. Therefore, the real-time online monitoring system can achieve synchronous parallel acquisition of transformer vibration signal through 4 channels, which brings convenience to the study of the reasonable distribution of the sensors on the transformer device.

4. The Monitoring System based on the Virtual Instrument

The human-machine interface detection system platform based on the virtual instrument technology consists of five modules which are the data acquisition, human-machine interface (HMI), configuration and strategy analysis, running engine and data storage, as shown in Figure 2. The data acquisition is realized by programming through the PCI-1714UL driver; the HMI realizes the man-machine dialogue and the visualization of software functions; the configuration and strategy analysis servers as a background control center which accepts configuration and strategic information from users, analyzes data, contacts each function module and transports data between them; the running engine makes it possible to run without the LabView virtual software. The signal data acquired by the PCI-1714UL can be stored into database or text files for later analysis.

4.1. The Interface of Man-machine System

The on-line monitoring system software has been developed by using the virtual instrument of LabView [9], the HMI mainly realizes initialization setting, channel signal real-time display, spectrum graph display, channel selection, triggering setting, data storage function. Compared with the traditional testing instruments, the system combines the traditional instrument hardware with computer, expands the function of the traditional instruments, and is capable of implementing data collection, analysis and display. Therefore, the virtual instrument technology is used to develop transformer vibration signal online real-time monitoring system, the system flow chart is shown in Figure 3.

The system runs the main program after initialization. After data has been acquired through the acquisition channel, they are processed and displayed on the screen, and then if the peak value of the signal is greater than the trigger value, the data acquisition would be stopped and the data is to be stored and analyzed; otherwise the data acquisition would be continued. The data signal display includes multi-channel real-time monitoring and single channel real-time monitoring. Multi-channel real-time monitoring window displays signals from all the acquisition channels, while the single channel real-time monitoring need the specific selection of channel to realize the real-time monitoring, and it also provides corresponding single channel spectrum monitoring. At last, the program would be terminated if the system monitoring would end, otherwise the data acquisition would continue.

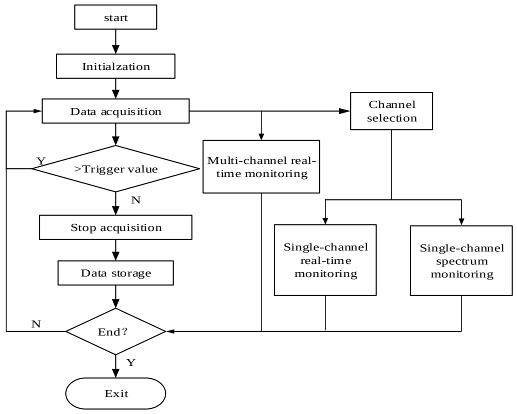

Figure 3. Program Flow Chart

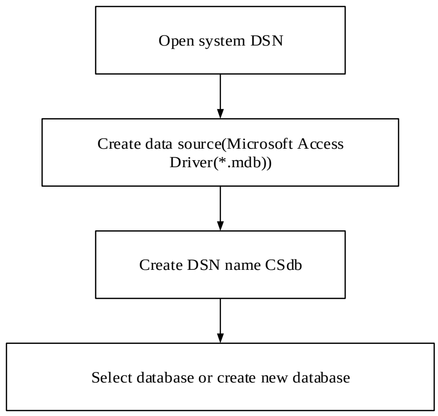

Figure 4. Create and Achieve DSN

4.2. Data storage.

One of the goals of this paper is to create a database to manage complicated monitoring task, storage, monitoring data, and to summarize the monitoring results of the monitoring system by using the database access technology. However the LabView does not have database access function.

LabSQL is a free, multi-database, cross-platform database access tool for LabView. In this paper, visits and management between the LabView and AQLServer database is realized with LabSQL, which effectively makes up the insufficiency of database access and management of LabView. LabSQL encapsulates a series of LabSQL VIs by using Microsoft ADO and SQL. It can access SQLServer database and Microsoft Access database. The object library used is this paper system adopts Microsoft Access database.

Before using LabSQL, a data source name (DSN) should be created in the open database interconnection of the Windows operating system, the data source in this system is called CSdb. The connection between LabSQL and database is based on DSN. The creation step of the DSN is shown in Figure 4. When DSN has been created, LabSQL would be able to visit database with the DSN.

4.3. Analysis and Processing of Vibration Signal

Frequency domain analysis is of great importance in the condition monitoring and fault diagnosis. Spectrum would change according to different failures, thus different faults must reflect different spectrum changes, e.g., frequency, phase, and amplitude. The system implements spectrum analysis of vibration signal by using the spectrum measurement in the Express VI of LabView8.2 signal analysis. Its screen measurement is based on the spectrum calculation of FFT, which assumes that a cycle of the periodic signal is represented by the finite domain of the digital signal. The spectrum calculated according to the effective period extended signal shows the energy that enters the frequency band, the original signal does not contain these frequencies. In order to reduce spectrum leakage, this system uses Hamming window to reduce sharp transients.

In practical applications, the distance between the acceleration sensor which collects signals and the data acquisition card is 5 meters. The collected vibration signals need to be preprocessed, during which a band pass filter is used to obtain the signal sharing the same bandwidth of the acceleration sensor. In order to avoid spectrum distortion, according to the Shannon sampling theorem, the sampling frequency is set to two times higher than the maximum frequency of the signal. The spectral characteristics of the vibration signal are obtained by performing FFT on the band pass filtered signal and measuring the peak amplitude on the spectrum. The amplitude and the main frequency of the transformer vibration are displayed on the screen, from which one can tell the vibration condition and the internal mechanical structure of the transformer after a further analysis.

5. System Operation and Experiment

The signal acquisition and the operation interface are shown in Figure 5 which includes the initialization of parameters, channel parameter setting, multi-channel and single channel real-time waveform monitoring, single channel spectrum monitoring, data storage, and channel playback function module.

It’s necessary to discuss the distribution of sensors before we analyze vibration condition. Due to the large transformer unit body, and the overall vibration of transformer presents different vibration state in each measuring point for the reason of the transformer structure. Hence, it’s unreasonable to describe the overall vibration state depending on the data acquired from only one sensor. But it’s also impossible to distribute sensors on the whole body of transformer, because the cost would be too high in the practical application. Therefore scholars have studied the distribution of sensor, and some conclusions have been drawn. In this paper, we are not to discuss these conclusions. Instead, they are applied to achieve the full description of transformer vibration. Data shows that vibration is more obvious in the place near the silicon-steel sheet which is used as the main magnetic pass path, also in this place, the vibration state of winding coiled around the core leg could be measured. Hence vibration sensors are placed on the surface of the transformer body as shown in Figure 6. The vibration signal is transmitted to the signal conditioner through signal line which is connected with PC. In this paper, three acceleration transducers which are numbered as A, B, C are placed on the body of the transformer.

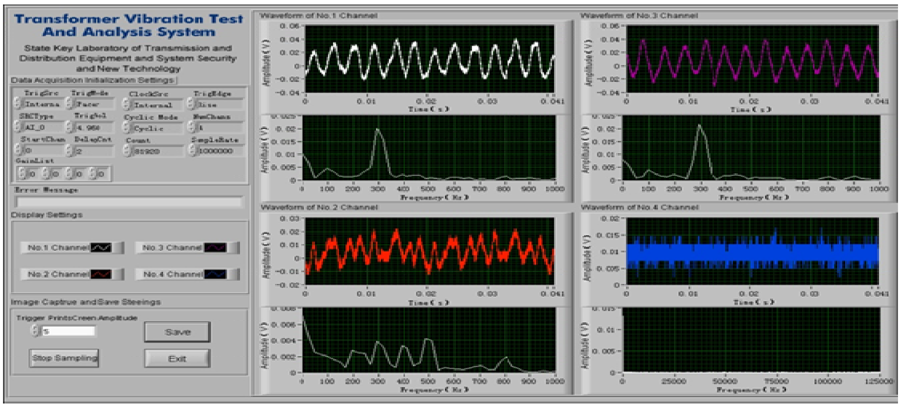

Figure 5. Monitoring System Operation and Select Interface

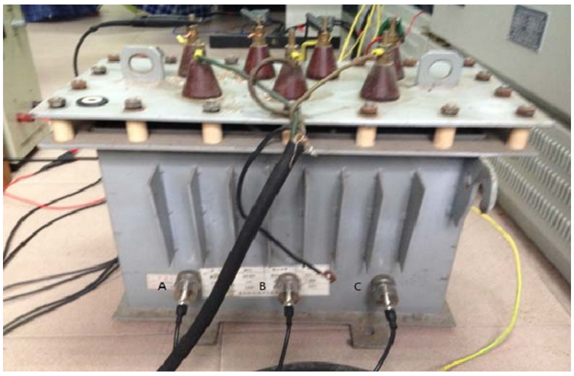

Figure 6. The Distribution of Acceleration Sensor

5.1. Transformer Load-free Operation Experiment

When DC bias current I_{DC}=0A, i.e., no DC bias, the vibration signals acquired from sensor A, B, C and their spectra are shown in Figure 7.

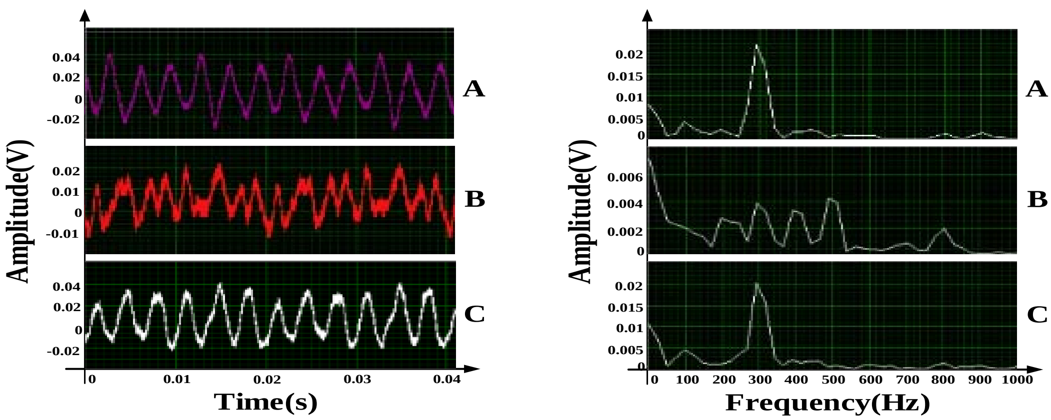

Figure 7. Load-free Condition I_{DC}=0A Vibration Signal and Spectrogram

It can be observes in Figure 7 that under load-free operation, the vibration fundamental frequency of the transformer body is 100Hz; vibration signals collected from the three the sensors are different, but signal acquired from A is approximately equal to that from C, signal from sensor B is much different from the signals of A and C; vibration signal collected from A and C have obviously dominant frequency band (300Hz), but signal from B is evenly distributed on 200Hz, 300Hz, 400Hz, 500Hz, frequency band.

When DC bias I_{DC}=2.1A, the vibration signal and its spectrum are shown in Figure 8.

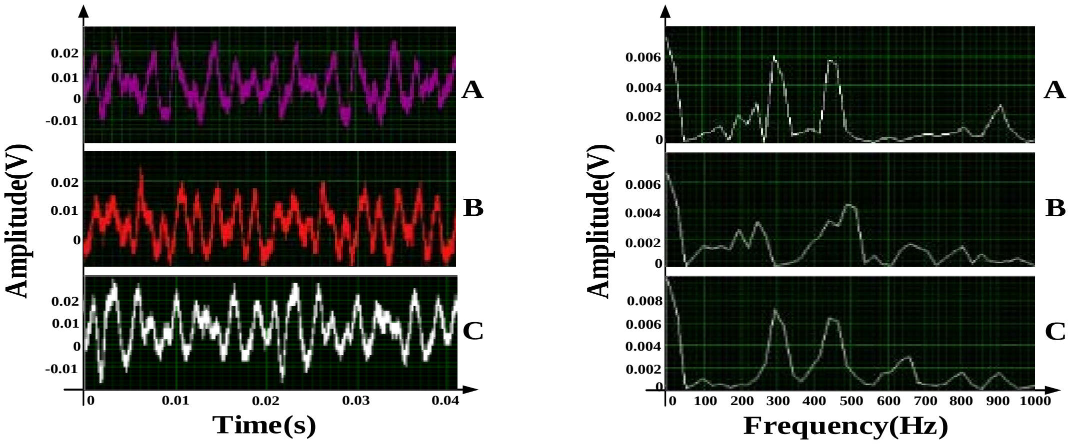

Figure 8. Load-free Condition I_{DC}=2.1A, Vibration Signal and Spectrogram

Compared with the vibration state without DC bias, the change is obvious. Signals collected from sensor A and C are still similar, but on the spectrum chart, at 300Hz and 450Hz, two wave peaks appear. Frequency distribution of the signal collected from sensor B is relatively unsystematic.

5.2. Transformer Operation Experiment with Rated Load

The current experiment without DC bias is carried out first. Vibration signals acquired from the sensor A, B, C and their spectra are shown in Figure 9.

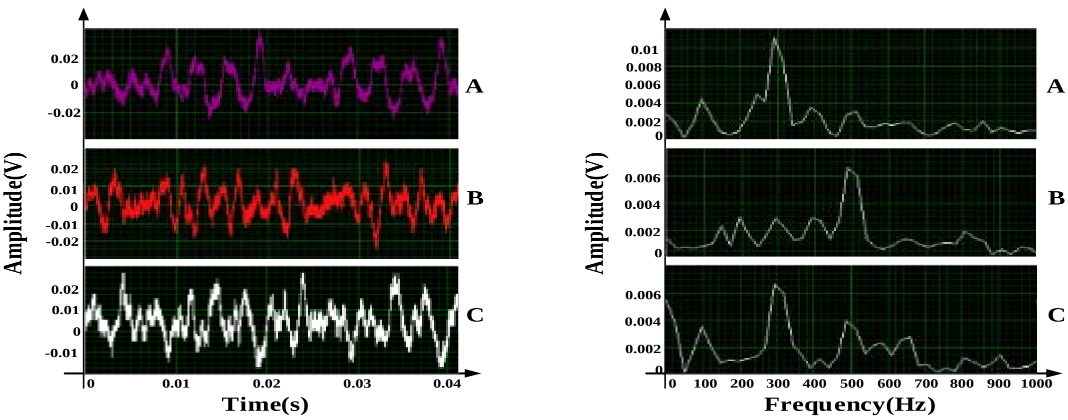

Figure 9. Rated Load Condition I_{DC}=0A, Vibration Signal and Spectrogram

Compared with the load-free experiment, the main characteristics of the signal collected from symmetric measuring point A, C are basically identical. Besides of the obviously dominant frequency band (300Hz), there are also frequency distributions in the high frequency range, this is the biggest difference between the load-free vibration signal and the rated load signal. The superior band, 500Hz, appeared on the spectrum of the signal from sensor B.

When DC bias current I_{DC}=2.1A, vibration signal and its spectrum are shown in Figure 10. Peak of dominant frequency component appears at 450Hz on the spectrum of the signal from sensor B.

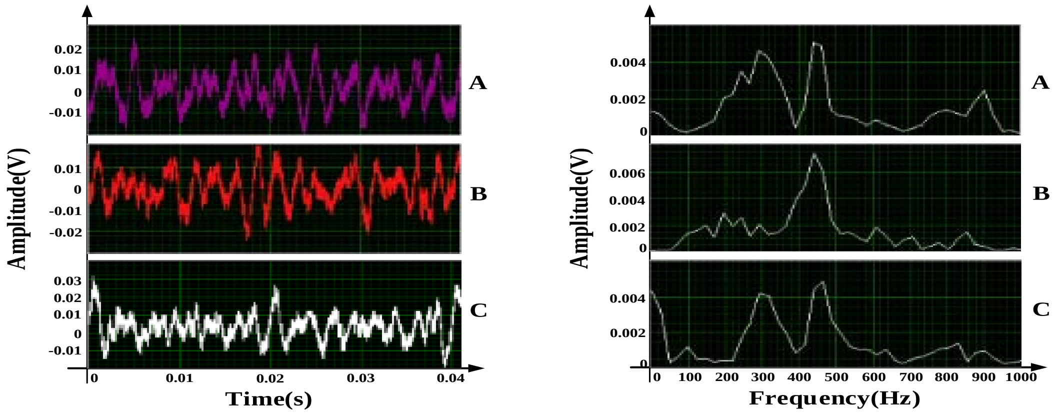

Figure 10. Rated Load Condition I_{DC}=2.1A, Vibration Signal and Spectrogram

The vibration signal acquisition device proposed in this paper can collect data accurately and carry out time domain and frequency domain analysis fast, therefore providing reliable data for the study of vibration caused by the transformer DC magnetic biasing.

6. Conclusion

The monitoring system not only can realize the on-line monitoring of the vibration signal, but also can be used as a general digital storage oscilloscope, and makes best use of the computer powerful function and the flexibility of LabView in instrument development. The experiments which have achieved good results show that device initialization, real time display of channel signal, spectrum display, channel selection, trigger setup, data storage, and other functions have been realized by the vibration signal monitoring device proposed in this paper. This monitoring system has been applied to the transformer abnormal vibration monitoring caused by DC biasing. According to the experiment, we can draw the following conclusions: (1) The signals collected from symmetric measuring point are almost the same; (2) when transformer is running under normal state, 100Hz is the fundamental frequency of the body vibration. But when DC bias intrudes, frequency multiplication of 50Hz would arise. (3) Compared with the load-free operation state, much higher frequencies would appear during the rated load operation; (4) two peaks would appear on the spectrum when DC bias intrudes, while only one peak would appear during normal operation. The application shows that this system fully meets the requirements of the laboratory surveillance, and lays the foundation of subsequent data analysis and processing.

Acknowledgments

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