

Development of Test System for Dynamic Balancing Machine Based on LabVIEW

Qingyu Zhu¹, Jintong Han², Shuo Han³, Yunpeng Ren³, Hui Li^{4*}

1. School of Mechanical Engineering, Dalian University of Technology, Dalian, China 116024
2. Northeast Yucai Foreign Language School, Shenyang, China 110179
3. Shenyang Zhizhen Technology Co., Ltd., Liaoning, China
4. School of Mechanical Engineering & Automation, Northeastern University, Shenyang, China 110819

Abstract: In this paper, a dynamic balance test system is developed based on the virtual instrument testing technology, combining LabVIEW programming technology with signal processing technology and other methods. The software system mainly includes six sub modules: acquisition parameter setting, rotor parameter setting, dynamic balance acquisition, single-sided dynamic balance test, double-sided dynamic balance test and exit test system. Through the software, the acquisition and analysis of vibration signals, the accurate extraction of swing frame vibration amplitude and phase, and the accurate calculation of rotor unbalance information can be realized. The designed dynamic balance test software is featured by perfect functions, accurate numerical calculation, efficient signal analysis and processing, and good human-computer interaction.

Keywords: Dynamic balance test system; LabVIEW virtual instrument programming; Digital signal processing; Digital filtering

1 Introduction

The design of the dynamic balance test system is the key to balance technology research, and the development and research of dynamic balance directly affects the final performance of the balance test. Dynamic balancing of the rotor is a fundamental requirement for the smooth operation of any turbomachinery. Unbalance in a machine is recognized as one of the major factors that can lead to machinery malfunction and even catastrophic failure, and may result from its initial manufacturing process or may occur as a result of various operating factors such as machine erosion, thermal effects or unbalance buildup of process material on impellers and surfaces of the rotor^[1]. There

* Corresponding author (lh200300206@qq.com)

is a steadily growing demand for reliable, versatile measurement rotor balancing system which can be used to determine the machine unbalances behavior^[2].

The emergence of virtual instruments quickly replaces traditional instruments and is widely used in the research of testing technology. LabVIEW is a powerful programming software for instrument test and measurement developed by National Instruments. It is an integrated development environment for virtual instrument test. With simple and efficient software program compilation function, LabVIEW is widely used in testing technology research. In literature^[3], detection method of dynamic balance of motorized spindle based on LabVIEW can intuitively test vibration characteristics, the accurate detection of online dynamic balance is helpful to improve the rotation precision of the high speed spindle and realize high quality parts processing. Yang Jian^[4] proposed a new digital signal processing method to separate vibration signals of inner and outer rotors for a dual-rotor rotating system with very little difference in rotating speed. Magnitudes and phase values of unbalanced weights are obtained directly by sampling the vibration signal synchronized with reference signal. The proposed new method has been successfully implemented in field dynamic balancing instruments of overall machine with dual-rotor system in two rectifying planes with DSP technology. Liu J et al.^[5] proposed a new digital signal processing method to separate vibration signals of inner and outer rotors for a dual-rotor rotating system with very little difference in rotating speed. Magnitudes and phase values of unbalanced weights are obtained directly by sampling the vibration signal synchronized with reference signal. The proposed new method has been successfully implemented in field dynamic balancing instruments of overall machine with dual-rotor system in two rectifying planes with DSP technology. A lot of information needs processing in time in dynamic balance testing, but the current intelligent dynamic balance instruments and the controlling box of dynamic balance machines made up of single microcontroller can not meet the request. Aiming at which Tang Yike, et al.^[6] a method that the DSP-Microcontroller is used directly in the system of the intelligent dynamic balance instrument by using embedded design technique.

The dynamic balance test system mainly includes the signal acquisition modules (sensors), signal processing modules (data acquisition and analysis equipment and software) and signal display modules (personal computer) of the test system. The selection of test system hardware is related to the accuracy of the data during the dynamic balance test. This paper firstly completed the selection and coordination of signal acquisition front-end sensors, and the selection of the data acquisition card of the signal processing end. Then, the measuring and processing methods of the rotating speed signal and the signal analysis and processing methods for the extraction of unbalanced vibration signals were studied. Finally, based on the research of virtual instrument technology, the software of dynamic balance test system was compiled and developed to realize the accurate extraction and measurement of unbalanced vibration signals.

2 Overall design of dynamic balance test system

The test system of the dynamic balancing machine is an important part of the system design. The design of the test system mainly includes hardware and software. The combination of software and hardware implements sensor acquisition, A/D conversion, circuit amplification compensation, software design programming, and vibration signal analysis and processing. The hardware system of the dynamic balance test system is mainly based on virtual instrument test technology, which uses sensors, data acquisition equipment to connect with the computer, and transfers the collected analog signals to the computer processing system after analog-to-digital conversion and preprocessing. The requirements of the software design of the test system are to display the vibration information accurately and clearly, to calculate the influence coefficient of the single-side dynamic balance and double-side dynamic balance, to accurately extract the amplitude and phase of the unbalanced vibration, and to have a powerful signal processing technology. The software system design aims to combine virtual instrument technology, signal analysis processing technology and computer technology, and develop a set of dynamic balance test system software based on the designed hard-support dynamic balancing machine platform. The software mainly completes the functions of parameter setting, data collection and analysis, data storage and management.

As shown in Fig.1, the designed dynamic balance test system is mainly composed of four parts, including signal acquisition unit, signal pre-processing unit, signal processing unit, result output and display unit.

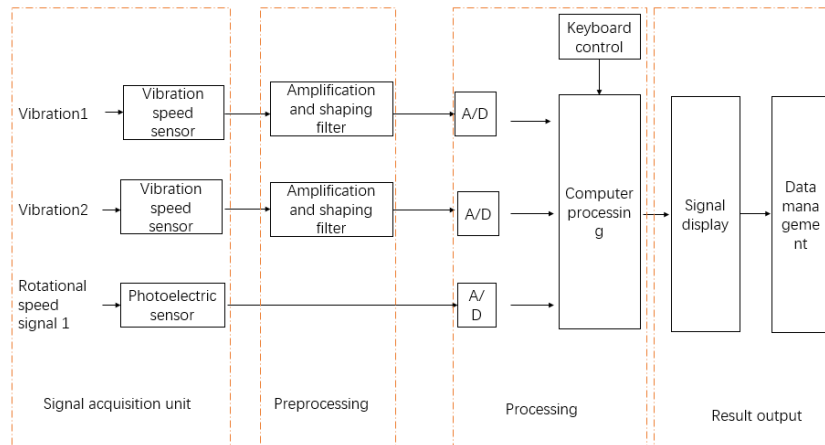


Fig.1 Composition of the test system

3 Hardware construction of test system

According to the research of the dynamic balance test system, the construction of the hardware system mainly includes the selection and collocation of the vibration sensor, the revolution speed sensor and the data acquisition equipment. The test system is shown in Fig.2. The sensitivity, technical indicators of the sensor and signal pre-processing functions of the data acquisition card are directly related to the accuracy of the experimental measurement data. Therefore, when selecting a sensor, it is necessary to consider its performance indicators, such as sensitivity, response characteristics, stability, and accuracy, and pay attention to the sensor installed correctly, to ensure the signal is accurate and reliable.

The vibration sensor is a CS-YD-022 piezoelectric speed sensor. The vibration speed sensor is installed by the magnet at the end to be stably attracted to the position where the vibration of the supporting swing frame is large. The signal collected by the sensor during the working process is the superposition of various vibration signals. The installation of the photoelectric sensor is perpendicular to the rotation axis of the rotor under test. The NI9234 data acquisition card is used to collect the speed signal and the vibration signal. It is mainly used to receive the input analog signal and can collect the eddy current displacement signal, speed signal, acceleration signal, voltage and current signal, etc.

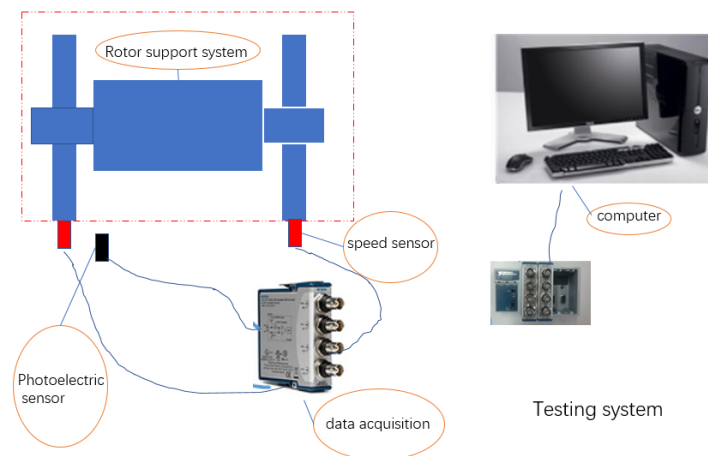


Fig.2 The construction of hardware systems

4 Signal analysis and processing in balance test technology

The frequency value of the fundamental frequency component of the vibration signal of supporting swing frame can be obtained by measuring the working speed of the rotor of the dynamic balancing machine, and the phase of the unbalanced vibration signal can be obtained by comparing the phase difference of the speed pulse signal and the vibration fundamental frequency signal. Therefore, the measurement processing of the

speed signal in the balance test is very important. The speed signal is mainly measured by a photoelectric sensor by pasting a reflective mark on the unbalanced rotor. The frequency and period of the speed pulse signal can be obtained through the software. By observing the peak lag of the unbalanced vibration signal or the angle value of the peak of the speed pulse signal which ahead of the same period, the phase difference between the two can be obtained. Therefore, the phase information of the rotor unbalance amount is determined, as shown in Fig.3.

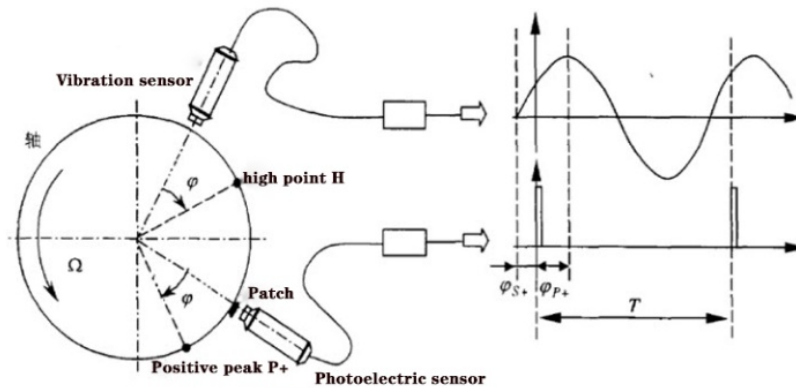


Fig.3 Phase measurement

5 Software development for dynamic balance test

Based on the LabVIEW software platform, combined with the signal analysis and processing technology in the dynamic balance test process, a complete set of dynamic balance test software was developed to measure the rotor unbalance information and complete the rotor balance correction. The software system is mainly composed of six parts: acquisition parameter setting, rotor parameter setting, dynamic balance acquisition, single-sided dynamic balance test, double-sided dynamic balance test and exit test system. Among them, numerical analysis, signal analysis and processing, waveform and result display and data storage management and other functions are included in each module, which meets the design requirements of dynamic balance test software. The operation process of the software of the dynamic balancing machine test system is shown in Fig.4.

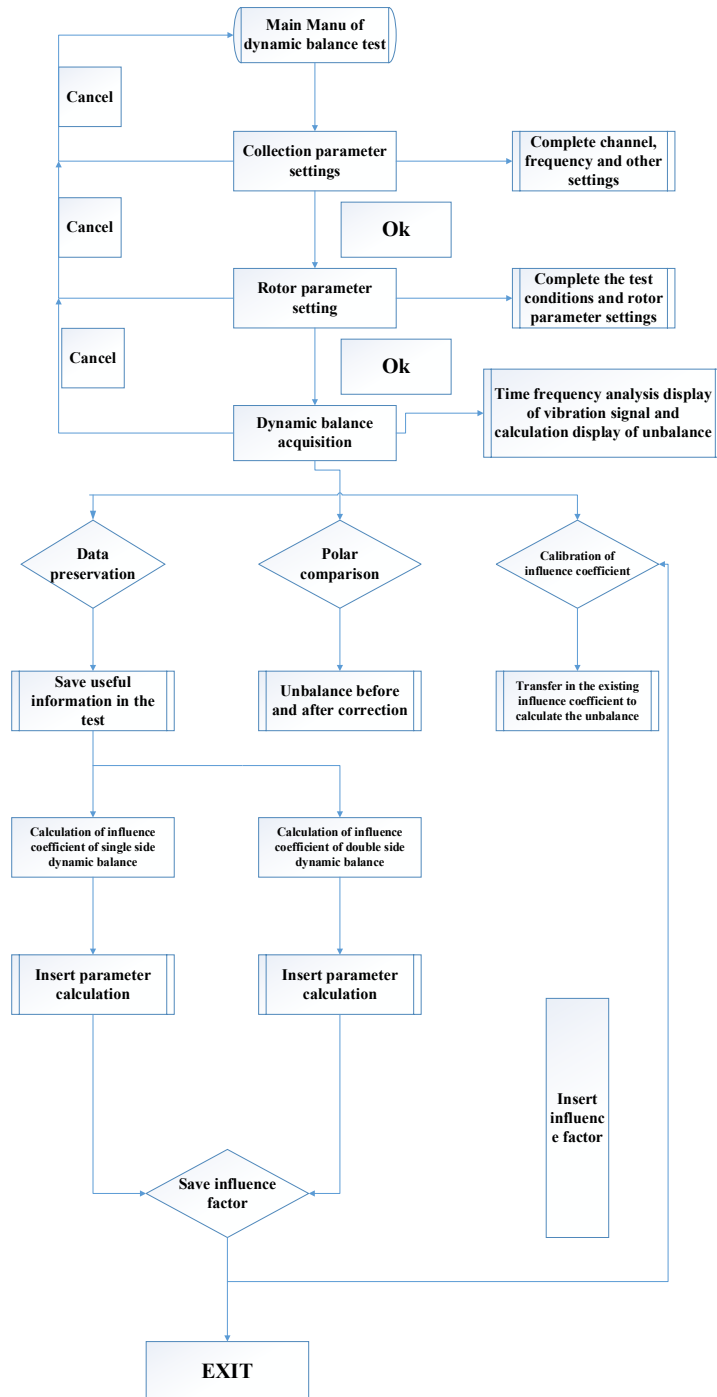
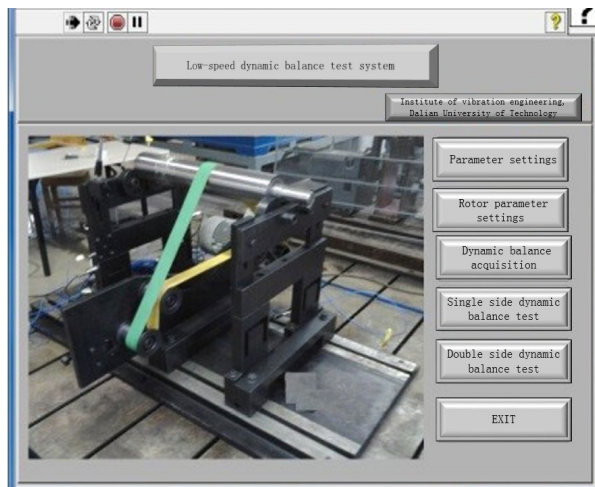


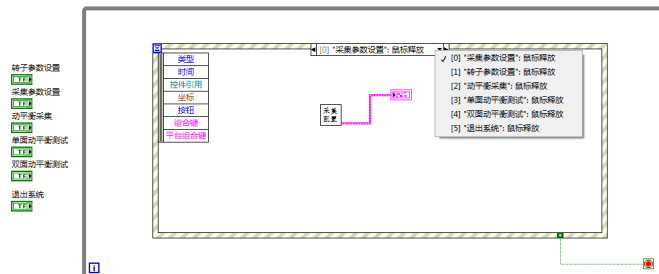
Fig.4 The process of dynamic balance test

(1) The main interface of the test system

As shown in Fig.5, the main interface of the test system software shows that the test system mainly has six sub-modules: acquisition parameter setting, rotor parameter setting, dynamic balance acquisition, single-sided dynamic balance test, double-sided dynamic balance test, and exit test system. The modules are both independent and in contact with each other. The user can enter each operation interface by clicking the button of each module to complete the corresponding task.



(a) Front panel



(b) program diagram

Fig.5 The interface and block diagram of main test

(2) Collection parameter setting module

Before the start of the dynamic balance test, you need to set the parameters required for the test in advance. Click the acquisition parameter setting button on the main interface of the program, and a window will pop up. The user can complete the corresponding parameter settings according to the acquisition requirements of the

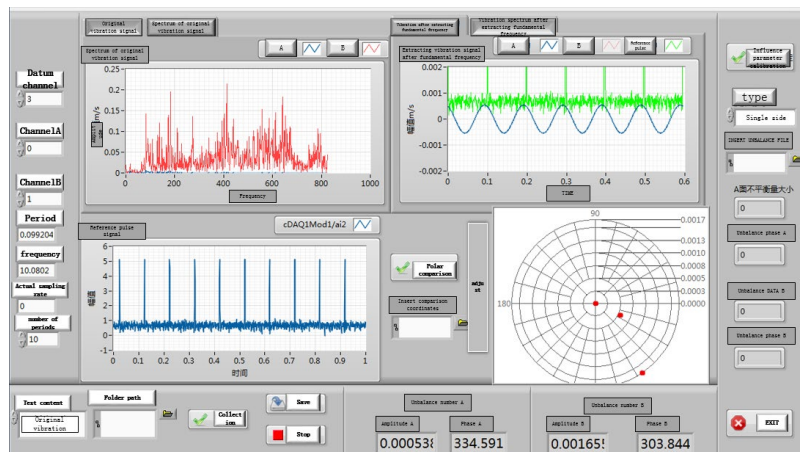
experiment, such as the channel selection of photoelectric speed sensor, sensor sensitivity setting, sampling frequency and file save path, etc.

(3) Rotor parameter setting module

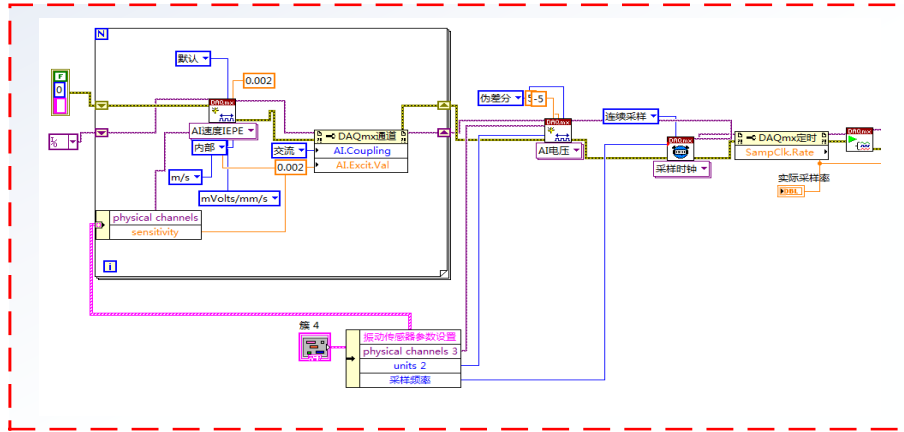
Enter the rotor parameter setting window through the selection of the main interface. This module mainly sets various parameters of the unbalanced rotor in the dynamic balance test, such as rotor diameter, rotor length, rotor quality, test type, balance speed and other parameters, and all these information is saved in a text file named "Rotor Parameter Settings", which is convenient for users to analyze and manage the test data later.

(4) Dynamic balance acquisition module

After completing the parameter setting preparations, you can enter the dynamic balance test module, as shown in Fig.6. This module is the core part of the software. The vibration signal collected by the dynamic balance test and the analysis and processing waveform curve of the unbalanced rotor speed signal will be displayed in this interface. The vibration signal of the supporting swing frame and the rotor speed signal in the process of testing are collected and analyzed. The program is shown in Fig.7. The results of time-domain waveform and spectrum analysis are displayed in real time on the interface, and the vibration state of the rotating subsystem is monitored. According to the dynamic balance test process, it mainly completes the dynamic balance acquisition tasks of the rotor vibration in the original state, the rotor vibration after the A side is heavier, the rotor vibration after the B side is heavier, and the rotor vibration after balancing. Observe the time-domain signal, spectrum analysis result of the original vibration signal, reference speed pulse signal and vibration signal analysis and processing results under different test conditions. The user can save and manage the sampling data during the test.



(a) Front panel



(b) program diagram

Fig.6 Dynamic balance test

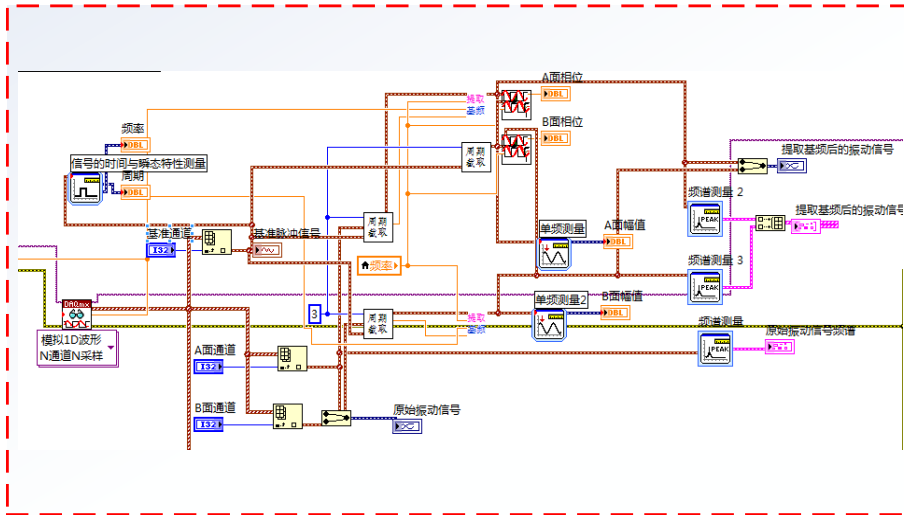


Fig.7 The program of signal analysis and processing

Period interception is mainly through the "peak detection" module in LabVIEW software, as shown in Fig.8, using the speed pulse signal data as a reference, according to the needs of data analysis, from a certain peak of the reference pulse waveform to the end of the integer number of cycles, intercept the vibration signal waveform of the specified length. The signal must be intercepted in a full cycle before the relevant filtering to ensure the accuracy of the extracted fundamental frequency signal.

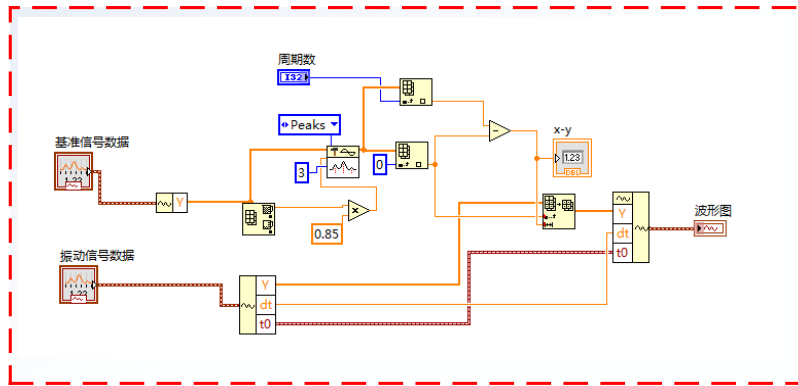


Fig.8 The program of whole cycle interception

The collected reference pulse signal will enter the peak detection in the form of a single array or continuous data blocks. It is especially important to note that in real-time signal processing, until the data points that the number of data are half of the width passes, the "peak detection" module can detect the peak or valley of the signal waveform. Assume that peak detection is used to find all the peaks of the data signal waveform sampled within one second, and the location of each peak of the signal is determined (that is, the value of the sampling point where the peak is displayed).

When the dynamic balance test process is stable and the signal data observed from the acquisition interface is good, the user can save the signal. In the whole process of dynamic balance testing, it is necessary to perform multiple start-ups and shutdowns, and conduct multiple tests under different working conditions. It is necessary to collect the signals of the original vibration of the rotor, the vibration of the rotor after adding the test weight to A side, and the vibration of the rotor after adding the test weight to B side, and measure the vibration amplitude and phase information of the supporting swing frame measuring points A and B. These data will affect the calculation of the impact coefficient, so it is necessary to classify and save the data reasonably, as shown in Fig.9.

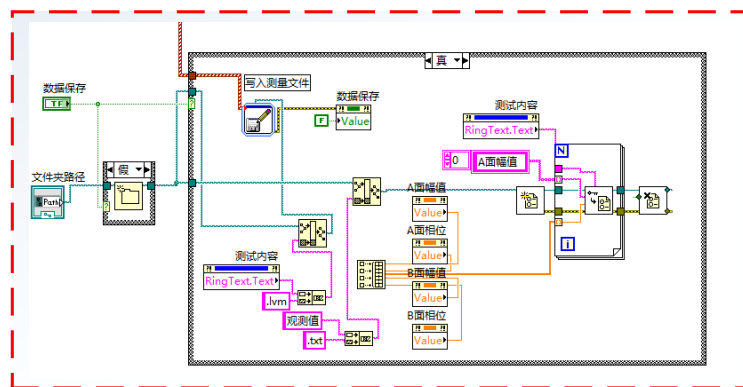


Fig.9 The program of data storage

(5) Single-sided and double-sided dynamic balance calculation module

The single-sided and double-sided dynamic balance calculation module mainly completes the calculation and storage of the single-sided and double-sided impact coefficient, as shown in Figs.10, 11. Through the data collected by the single-sided and double-sided dynamic balance test, the rotor's impact coefficient and the weight and phase of the counterweight required for balancing the rotor are calculated.

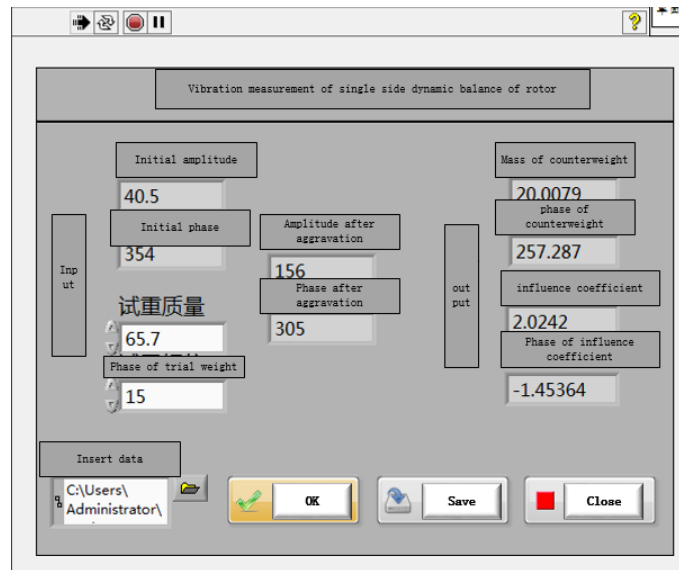


Fig.10 Calculation of single-sided influence coefficient

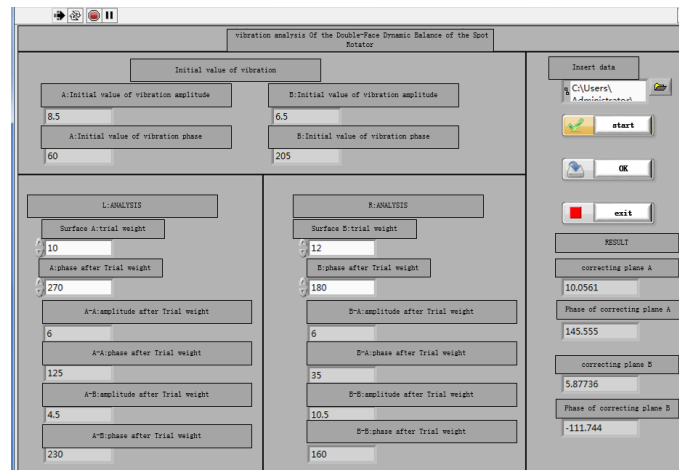


Fig.11 Calculation of double-sided influence coefficient

6 Conclusion

Based on the designed and manufactured dynamic balance machine platform, a dynamic balance test system is built. The hardware system is built through the selection and matching of sensors and data acquisition equipment. The measurement and processing methods of the speed signal are analyzed and studied, a set of dynamic balance test software is designed based on virtual instrument technology.

(1) The amplitude and phase of the fundamental frequency vibration are extracted from the complex vibration signal based on the correlation filter measurement principle, and the simulation signal is used to verify the correctness of the software algorithm. Using the speed pulse signal as a reference, the phase measurement of the vibration signal is achieved by calculating the phase difference.

(2) The design of the dynamic balance test system realizes the software application of the hardware system of the test process. Through the program designed, combined with the related theories of dynamic balance, numerical calculation methods such as influence coefficients and phase differences, and related signal analysis and processing technologies. The test system can observe and analyze the vibration data in the time domain and frequency spectrum during the dynamic balance test, real-time and visually. The dynamic balance test software meets the user's basic test requirements, such as single-sided and double-sided dynamic balance tests, calculation of influence coefficients, real-time display of signals, test data storage management, etc. The test system has comprehensive functions, accurate numerical calculation, and good human-computer interaction.

References

1. Alexandru T, Ion F, Considerations regarding the dynamic balancing of complex rotors, *Review of the Air Force Academy*, 2015(3):51-54.
2. Swith Claude B A, Grover Z V, Designing and development of a dynamic vibration balancing machine for industrial applications, *Investigación & Desarrollo*, 2019, 19(1).
3. Wang Z, Tu W, Online Dynamic balance detection method of high speed motorized spindle based on LabVIEW, *Applied Mechanics & Materials*, 2017, 868:369-374.
4. Yang J, Dynamic balancing instrument for dual-rotor system with very little speed difference based on DSP technology, *Chinese Journal of Scientific Instrument*, 2002, 23:331-334.
5. Liu J, Pan S X, Yang K J, Research on digital filtering algorithm used in measurement system of balancing machines, *Journal of Mechanical Strength*, 2005, 027(001):38-43.
6. Tang Y K, Lin K, Xie Z J, Embedded intelligent dynamic balance testing system and its digital filter designing, *Journal of Chongqing University*, 2003, (3)1.