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Design and Implementation of Wind Load Resistance Performance Data Acquisition System of Building Curtain Wall

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Abstract

With the development of the curtain wall industry and expiration of the curtain wall structures which designed and built in the early life, the testing for building curtain walls will be increasingly focused on. In this paper, a Client/Server structure acquisition system of the curtain wall wind pressure resistance characteristics data, which is based on the Advantech data acquisition card PCI-1747U, has been designed and implemented for the GB/T 15227-2007 (Test method of air permeability, watertightness, wind load resistance performance for curtain walls). The hardware of the data acquisition system contain three major components: The sensor part; The signal conditioning circuits part, which consists of sensor supply circuit, I-V conversion circuit and filter circuit; data acquisition part consists of Advantech card PCI-1747U and Advantech industrial computer 610L. The software of the system contain the data acquisition Server and data processing client. They communicate through TCP/IP protocol and complete the sensor calibration, static test and dynamic test of the wind load performance data, query and output historical data and other functions. Microsoft SQL Server 2000 database was used to management the test data. After running and debugging, the system's sample time and accuracy reached the requirement of wind load resistance performance test.

Keywords*: Wind Load Resistance Performance, Data Acquisition, Client/Server Structure, Data Base, Curtain Wall*

1. Introduction

The Building curtain wall industry [1-3] in China was started in the early 80 's. After years of development, China's curtain wall industry has a considerable size; In 2013, there was 121.74 million square meters the building curtain wall in China [4]. Curtain wall with its stylish appearance, light quality, excellent energy efficiency and other advantages rapidly filling Chinese market, there are growing concerns about its safety. In recent years, caused by quality problems of curtain wall and extreme weather, curtain wall fracture events and caused personal injury incidents happens all the time. China promulgated curtain wall performance and detection methods and other relevant standards to regulate the curtain wall market. The latest testing standard GB/T 15227-2007 was introduced in 2007. The standard is "Test method of air permeability, watertightness, wind load resistance performance for curtain walls". We called it "The Test Method" in this paper.

In the field of curtain wall testing in China, Shanghai Jiao Tong University has an in-depth study, but concentrated in the air pressure control field. And have not designed a data acquisition system as a whole and movable system for this test. This kind of design had a negative impact on the experiment place and the size of the detected curtain wall. In foreign countries, the curtain wall testing systems started earlier. And mainly sales wind pressure control equipment in the curtain wall testing systems, prices tend to be high. With the development of the curtain wall industry,

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and expiration of the curtain wall structures which designed and built in the early life, the testing for building curtain walls will be increasingly focused on.

In this paper, a C/S structure acquisition system of the curtain wall wind pressure resistance characteristics data, which is based on the Advantech data acquisition card PCI-1747U, has been designed and implemented for the " The Test Method". The data acquisition server was putted on the test site, to complete the displacement and pressure data acquisition, and transmitted the data over the network to the data processing client. The data processing client receives the data and then complete static testing and dynamic testing. Test data saved to a SQL Server 2000 database, and could query, output the historical data and other functions.

In this paper, the hardware and software design and implementation of the large scale building curtain wall testing data acquisition system are described in detail. Section 2 gives the overall architecture of the system. Section 3 introduces the hardware system design and implementation detailed. Section 4 introduces the software design and implementation in detail. Section 5 gives the experiment and results.

2. Overall Design of the System

According to "The Test Method", wind pressure characteristic data consist of the air pressure inside and outside of the test chamber and the deformation of the curtain wall when the air pressure data changes. Due to the high power devices used in testing, the testing scene has strong electromagnetic interference. The data acquisition system should be close to the sensor to reduce signal transmission distance. Data acquisition equipment should also increase anti-interference measures: the sensor signal should be filtered before the data acquisition; Put data acquisition equipment into airtight grounded metal cabinets. Meanwhile, the fans and water pumps and other power equipment used, especially under the positive and negative pressure control, the noise of the test site will be very strong. The physical and mental health of the testers in the field would be strongly impacted. The C/S structure used in this system will let the testers away from the field. Overall design of data acquisition system for wind pressure resistance characteristics as shown in Figure 1.

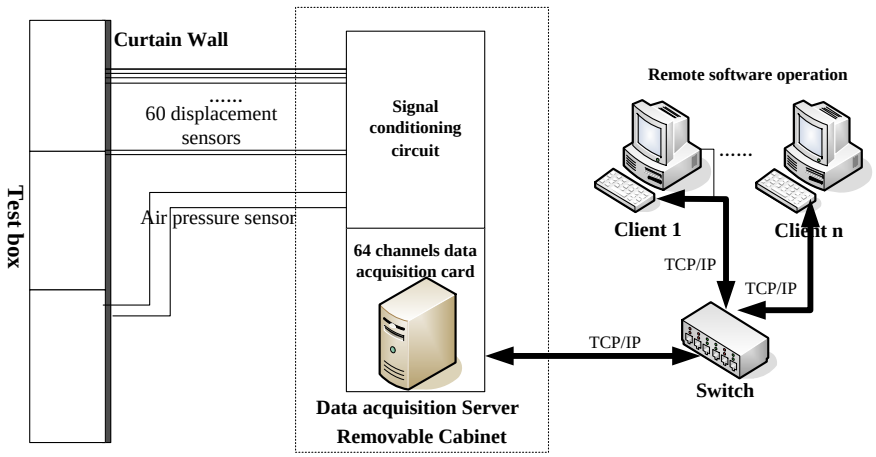

Figure 1. Overall Design of Data Acquisition System

The hardware of the data acquisition system use the Advantech PCI-1747U data acquisition card to complete the 60 channels displacement data, 2 channels wind pressure data acquisition. The data acquisition server was putted on the test site to complete the displacement and pressure data acquisition, and transmitted the data over TCP/IP to the data processing client. The client processing the received data

and then complete static testing and dynamic testing. Test data saved to a SQL Server 2000 database, and could query, output the historical data and other functions.

3. Hardware Design of the System

The hardware of the data acquisition system consists of three major components: The sensor part; The signal conditioning circuits part, which consists of sensor supply circuit, I-V conversion circuit and filter circuit; data acquisition part consists of Advantech data acquisition card PCI-1747U and Advantech industrial computer 610L.

3.1. Sensor

Sensor is the most important component in the curtain wall testing system. Choose sensor model reasonably can improve the accuracy of detection and reduces system cost [5]. According to "The Test Method", curtain walls testing need to measure the deformation of different parts of curtain wall under periodic wind pressure and extreme wind pressure.

3.1.1 Displacement Sensor

Displacement sensor can be divided into potentiometer, resistance strain gauge, capacitive, inductive, magnetic susceptibility, photoelectric, ultrasonic displacement sensor. Taking into account that the testing environment is complex, the installation is difficult and disturbance is serious, the sensor should have simple structure and easy to maintain. Under the detection methods and practical requirements, the design choose Germany TEX-200 linear displacement sensor which has 200mm measuring range, real as shown in Figure. 2.

Figure 2. The TEX-200 Displacement Sensor

The key performance indicators of TEX-200 sensor are as follows[6]:

✧ Operating range up to 200mm
✧ resolution better than 0.01 mm
✧ Repeatable 0.01mm
✧ outstanding linearity up to ±0.05%
✧ very long life up to 50 million movements
✧ Can be used in a variety of harsh environments (humidity, dust, grease)

Displacement sensor TEX-200 sensor accuracy is better than 200*0.25%=0.5mm in “The Test Method”.

3.1.2 Air Pressure Sensor

In the Curtain wall testing system, air pressure sensor to detect the changes of the air pressure the inner and outside of the tank. We choose air pressure sensor NS-I1 as the air pressure sensor in this system. The sensor entity is as shown in Figure 3. The measurement range is 0-15Kpa, meet the requirements of “The Test Method” and its measurement accuracy is 0.1%F.S.

Figure 3. NS-I1 Air Pressure Transmitter

3.2. Signal Conditioning Circuit

3.2.1 Sensor Supply Circuit

In this acquisition system, the 60 channels displacement data is the major measurement parameter. The schematic diagram of the selection displacement sensor TEX-200 is shown in Figure 4.

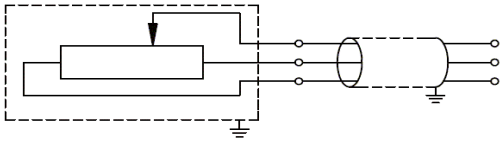

Figure 4. The Schematic Diagram of TEX Displacement Sensors

TEX-200 linear displacement sensor is similar to a precision sliding rheostat. The resistance value of displacement sensors is 10KΩ. In order for the sensor to achieve design accuracy, high precision power supply for the sensor must be used.

This design requires the precision of displacement sensor must be better than 0.1mm. When the voltage power supply circuit supply 0~5V and 0~10V, the voltage precision must be better than 0.2%V and 0.3%V. The voltage acquisition ranges of the Advantech PCI-1747U acquisition card are 0~10V, 0~5V, 0~2.5V, 0~1.25V, bipolar ±5V, ±10V, ±2.5V, ±1.25V, ±0.625V. The card has a good flexibility of acquisition. The design finally selected 10V power supply scheme and LM105 power regulator chip to design the sensor power supply circuit.

LM105 main parameters are as follows [7]:

Output voltage adjustable range: 4.5V to 40V

Output currents up to 10A by adding an external transistor

DC line regulation guaranteed at 0.03%/V

Load regulation better than 0.1%

The designed sensor power supply schematic circuit diagram is shown in Figure 5. According to the LM105 design specification, the output voltage should be $V_{OUT} \approx 1.72\frac{R3+R5}{R5}\text{V}$. By adjusting the resistance of R3 and R5, the output voltage would close to 10V. Finally, the R3, R5 resistance were selected as 11K, 2.4K. In order to guarantee the output accuracy of sensor supply circuit, 0.1% precision resistors selected.

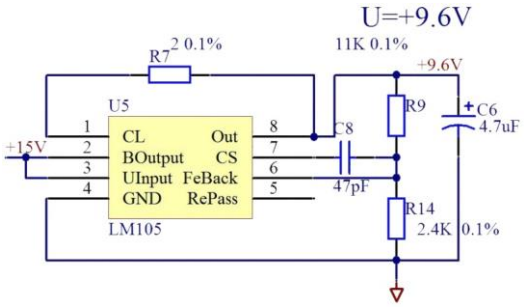

Figure 5. Sensor Supply Circuit Schematic Diagram

3.2.2 I-V Conversion Circuit

Due to the choice of NS-I1-type pressure transmitter's output is 4-20mA current, the signal should be converted to voltage before we use the PCI-1747U to acquisition the data. The designed I-V conversion circuit was shown in Figure 6.

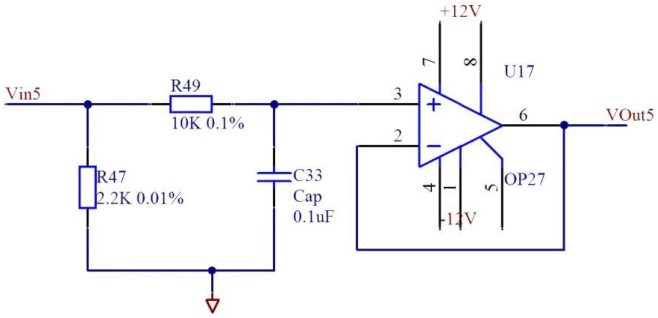

Figure 6. I-V Conversion Circuit

3.2.3 Filter Circuit

Test site has fans, pumps and other power equipment, the test environment have large electromagnetic and vibration interference. To ensure the accuracy of measurement data, the detected signal filtering is required to filter out interference. According to The Test Method, the signal of air pressure and deformation of the curtain wall is slowly varying signal, In order to achieve better filtering result, the second order low pass filter was chosen as the filter circuit finally. The filter circuit design as shown in Figure 7.

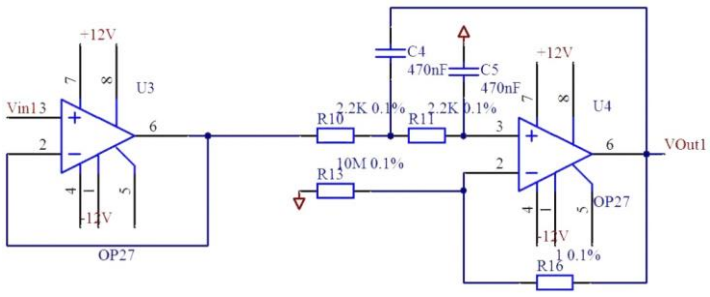

Figure 7. Schematic Diagram of Filter Circuit Design

3.3. Data Acquisition

The part of data acquisition consists the Advantech PC data acquisition card PCI-1747U and the Advantech IPC 610L. The data detected by the sensor need to go through the signal conditioning circuit before acquisition by PCI-1747U card. PCI-1747U is a 16-

bit sample precision card. For 0-10V detection range the detection resolution is 0.1 ‰V, corresponding to 200mm range is 0.003mm resolution can be achieved, fully meet the design requirements for accuracy.

The main parameters of Advantech PCI-1747U data acquisition card are as follows [8]:

- ✧ 64 Single-Ended or 32 Differential AI, or a combination
- ✧ 16-bit high resolution for analog input
- ✧ Up to 250 KHz sampling rate
- ✧ Bus-mastering DMA data transfer
- ✧ Universal PCI bus

PCI-1747U has 64 analogue acquisition channels. Among them, 60 channels used as displacement data acquisition, 2 channels used as pressure data acquisition, the remaining 2 channels standby. Due to wind resistance characteristic data are slowly varying signals, and in order to take full advantage of acquisition card PCI-1747U's acquisition performance, every single channel sampling rate set as 2~3KS/S. In order to reduce the burden of IPC, acquisition cards to take the DMA modes.

4. System Software Design

The software of the wind load resistance data acquisition system acquire the displacement and pressure data of curtain wall testing. Then the software will process the data, display the data in list or view, save the data to database or export the data to Excel. The software of the acquisition system take the separation Client/Server(C/S) mode. The server is running on the IPC on the test site, complete the displacement and pressure data acquisition and transmitted the data over the Internet to the data processing client. The client received the data and realized the dynamic testing, static testing and historical data query of the resistance data.

The acquisition server running on the dedicated industrial computer (IPC), use the WINDOWS XP operating system. The data process client running on the computer which have a network interface, use the WINDOWS XP or above operating system.

4.1. Software Design Platform and Key Technology

The integrated development environment is Microsoft Visual C++6.0 platform. The design language is C++. Database management system uses Microsoft SQL Server2000.

4.1.1 Advantech Data Acquisition Card

Advantech provides a drive for its products in the VC environment, the acquisition card PCI-1747U driver need to be installed before use Advantech data acquisition card. Before using Visual C++6.0 to design the system, you need to include C/C++ library adsapi32.lib and Advantech equipment driver header file driver.h in your project. Acquisition card PCI-1747U is working at double buffered mode, when query the buffer's half full signal, the data should be transferred out in time, in order to avoid being overwritten.

In this design, the acquisition mode of the Advantech PCI-1747U the acquisition card was chosen as DMA mode. The DMA mode does not need CPU intervention, and does not require scheduled queries, saved CPU's resources.

4.1.2 Multi-Thread Technology

The application of multithreading technology can make one CPU running multiple threads to perform multiple tasks at the same time. The multithreading technology is CPU take turns executing different thread for the same time. As CPU running very fast, multiple threads can be considered running at the same time. The

application of multithreading technology, make the data display smoothly when data acquisition.

In this design, the multithreading technology is mainly used in screen displays in the foreground, data communications in the background, and data processing. The function AfxBeginThread() used to create a new thread. There are several ways to end a thread, the mandatory terminate a thread will result in resource leaks. In this design, a termination flag added in a thread, the set and reset of the flag make a thread natural end.

4.1.3 Client/Server Model

This design used the Client/Server mode (Client/Server, referred to as C/S) [9]. Its working process is that the Client requests service to Server through the TCP/IP protocol, the Sever receive the request and provide the resources and services [10]. With this mode, the data acquisition and data processing tasks can be separated. The data processing equipment and testers could arrange away from the noisy detection scene.

While the C/S structure used in this design, the acquisition data is sent to client, but the data is stored on the server side to facilitate multi-client to query and manage the testing data. At the same time, the workload in client side would be simplified to save CPU resources for future extension.

4.1.4 Communication Protocol

The used of the C/S mode, the data sent between client and server have the acquisition data, login information, shutdown commands, device connection information and other data. In order to distinguish the information between the client and the server, a set of communications protocols need to be designed. The designed communication protocol is shown in Table 1.

Table 1. Communication Protocol between Client and Server Protocols

Protocol	Client to Server	Server to Client
Login and real-time data	$L,id,ip,port,DOTC#	@D,xx,xx,xx,xx,#
Heartbeat and respond	$D,id,#	@X,#
Reboot and respond	$C,id,Restart,#	@C,Restart,#
Shutdown and respond	$C,id,Shutdown#	@C,Shutdown,#

4.1.5 Database Management

When test the curtain wall's wind load resistance performance, amount of data need to be recorded. Manual archive the test data is a cumbersome task and it was very difficult to query and find relevant data. Using database management software to manage the acquisition data can reduce the workload of testers and managers and improve the efficiency greatly.

This design uses the Microsoft SQL Server 2000 as the data management software to save and maintain the acquisition data. SQL Server 2000 access in several ways, this design uses ADO method to access databases. To operate the database using the C ++ programming language to execute SQL language, can improve data storage efficiency.

4.2. The Design of Data Acquisition Server

Data acquisition server is running on the dedicated IPC on test site. Complete the displacement and pressure data acquisition, and use the TCP/IP to transmit the wind

load resistance performance data to the data processing client. The main function of the data acquisition server as shown in Figure 8.

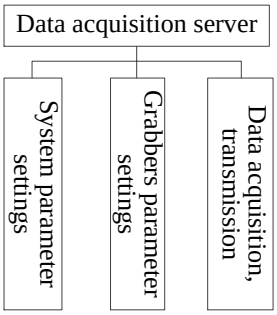

Figure 8. The Functional Diagram of Data Acquisition Server

System parameter setting Set the server IP, port and server operation mode.

Grabber parameter setting Select the data acquisition card, set the acquisition range of each channel.

Data acquisition, sending After setting the system parameters, acquisition and send the wind load resistance data to the client according to the client's operating command.

The main task of the data acquisition server were acquired and sent data. The divided into two independent threads of acquisition and send function ensure that the server could acquisition data at the same time the data sent to the client in a timely manner. In order to debug software easily, a data display interface was designed. The data acquisition server software architecture as shown in Figure 9.

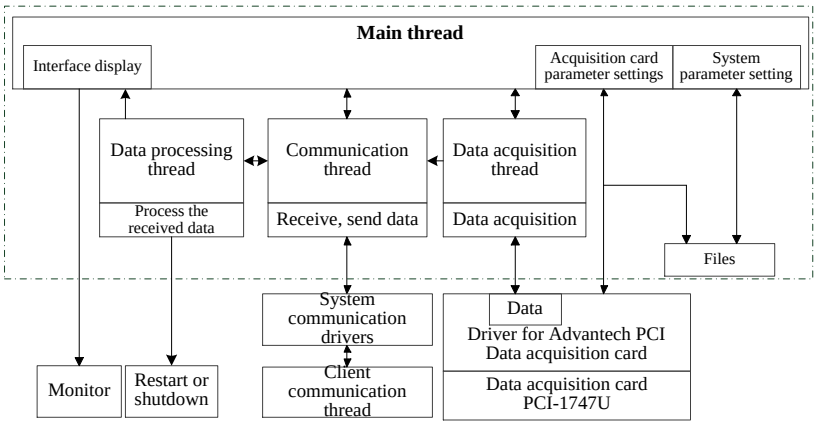

Figure 9. The Designed Block Diagram of Acquisition System Server Software Structure

Figure 9 introduced the main threads running on the server. Among them, the acquisition thread is the main thread, whose main task was to acquire data and send it to the client. The workflow of the acquisition was checked the event of the acquisition card by the function DRV_CheckEvent after start the DMA mode acquisition and trigger different handling functions according the status of the event. This design uses DMA mode for data acquisition, the cached change event flag ADS_EVT_BUFCHANGE need to be detected. The function DRV_FAICheck was used to detect the buffer half full symbol and the function DRV_FAITransfer was used to transfer the data out from the cache of the card to avoid the data being rewritten. The data would be transfer to client after the data encoded by the communication protocol between the client and server.

Data transit needs to call communication thread firstly. Communication thread was established when started the service automatically or manually. Its main job was to

establish a C/S structure of communicate connection based on TCP/IP communication protocol, received and sent data from the client. When the communication thread received data from client, the thread would send a message of TCP/IP received data to the message queue. The message would trigger data processing thread. Data processing thread's work was decoded the data under the designed communication protocol as shown in Table 1. The flow chart of the server software's main function as shown in Figure 10.

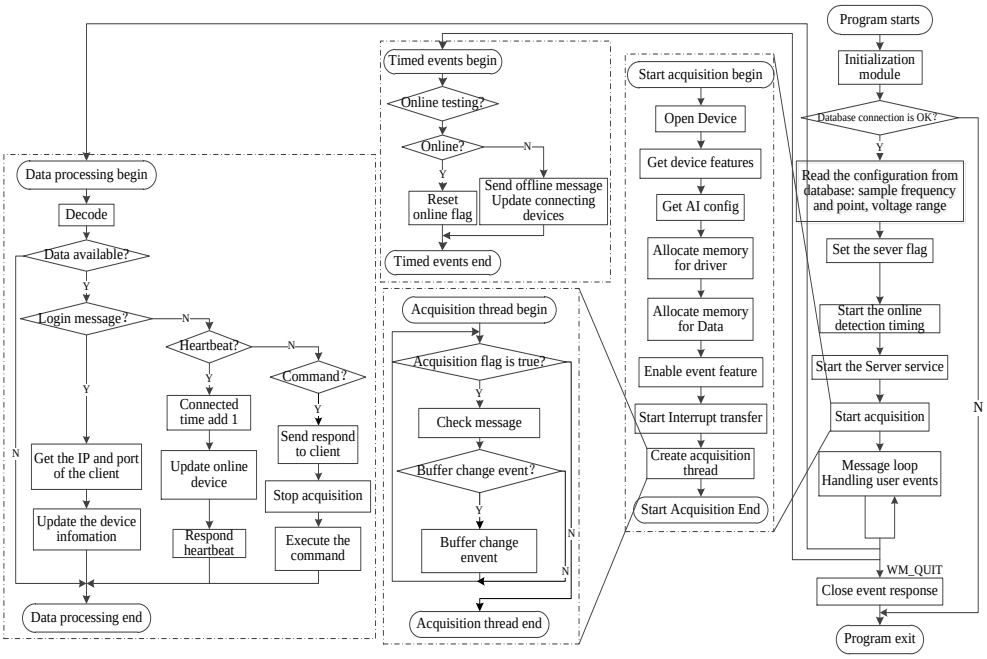

Figure 10. Flow Chart of Server Software Key Functions

4.3. Processing Client Design

4.3.1 Function Design of Client Data Processing

The data processing client received the data from server to achieve the static testing and dynamic testing of wind load resistance performance data by completing the data processing, display, storage functions or other functions. The main functions of data processing client as shown in Figure 11.

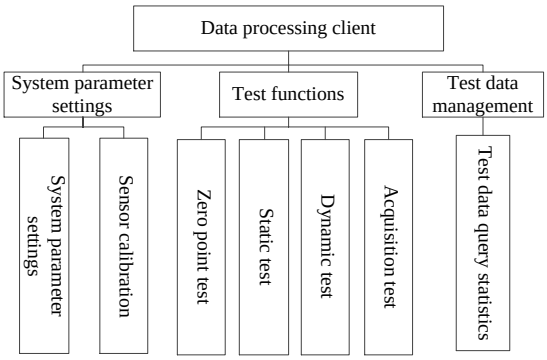

Figure 11. Main Functions of Data Processing Client

(1) System parameter setting

System Parameter Setting Set the number, description, IP address, service port and the connection mode of the client to the server of the data acquisition data acquisition client

Sensor Calibration The procedure of sensor calibrate is to use a certain level non-electric instrument or equipment to generate a certain signal (such as standard displacement). Use the signal as the input of the sensor could get the output variable. Compared the sensor's output volume with entered volume, could get a series of curve which called calibration curve. Through the analysis and processing of the curve, could get the sensor's characteristics.

(2) Testing function

The test functions include zero point test, static test, dynamic test and data acquisition test.

Zero Point Test In the deformation detection, repeated pressure detection and safety testing of the wind load resistance performance testing, positive and negative air pressure and displacement of curtain wall need to be tested. Before the acquisition of the data started the starting position of the sensor need to be detected. The zero point testing was performed after performing the sensor installation.

Static Test When the system is pressurized to a certain value stability, the test for wind load resistance performance called static test. Take average of the measured values after sampling many times could improve the system's accuracy.

Dynamic Test Dynamic test's main work was to acquire every sensor's state in a time period. Complete the test of the curtain wall's data under the repeated pressure like cycle pressure or extreme pressure.

Acquisition Test The test before the real test to test system's connection. According to the test result, the working state of the client and server and the connection between them could be tested.

(3) Test data query function

The test data query function's main work was to query and output the test data which was stored in the SQL Server 2000. The selected data could be inquire, view and delete. And the test data could be exported to an Excel file for subsequent processing.

4.3.2 Interface Design

According to the functional design of the data processing client, the operation of the client have sensor calibration, zero point detection, acquisition test, static test, dynamic test and test data query and so on. Since the zero point of sensor was the foundation of the data acquisition system and the installation location of each test is different, the client didn't recorded or displayed the zero point data in an individual interface. The designed interface of data processing client as shown in Figure 12. The deigned sensor calibration interface's layout as shown in Figure 12(a). The designed static test and dynamic test's layout as shown in Figure 12(b). The designed data acquisition test's interface as shown in Figure 12(c). The designed test data query interface's layout as shown in Figure 12(d).

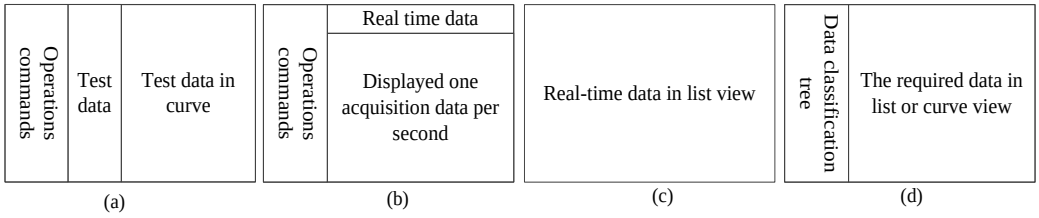

Figure 12. Client Interface Layout Design

4.3.3 The Architecture of Data Processing Client

Data processing client have multiple functions and interfaces, the data and view was separated when using C++ to design the software. The data processing client need several interface to different test. Create different thread for the different interface would make large waste of system resource. In this design, the display of the interface was in the main thread of the system. The different test interface achieved by updating the view of main thread. The update of data designed by the difference between the tasks.

The main tasks of the data processing client were processing and display the data sent by the data acquisition server based on different functions of the client. To ensure the view didn't occur stagnation, separate thread created for the reception, transmission and processing of data. The view of the interface was in the main thread of the software. The architecture of the processing client's software as shown in Figure 13.

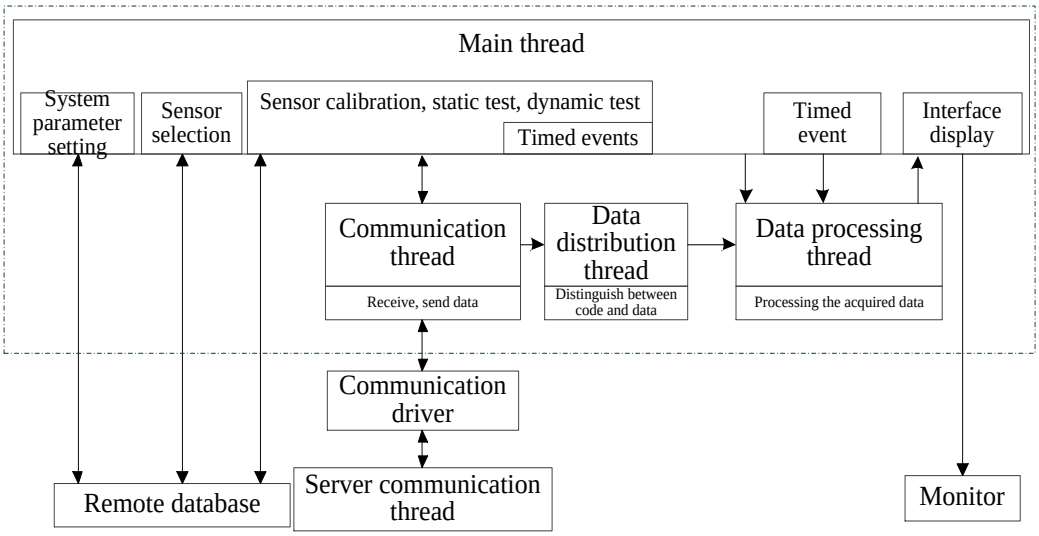

Figure 13. The Architecture Diagram of Data Processing Client

Communication thread was established when started the service automatically or manually. When the client received data from data acquisition server, the client would trigger a data distribute thread. Its main work was decoding the received data into wind load performance data, heartbeat data and the respond data of the command. The main jobs of the triggered timed events in the main thread were the common operations of all the functions. Such as the online tese, send the heartbeat message to server and the timed display of the acquisition data in static and dynamic test.

Data processing client need to finish the dynamic and static air pressure test. The static and dynamic test were acquired data within the test length and triggered the data processing thread to convert the acquired data to the value with the actual physical meaning. After data acquisition, the data would be displayed in the form of list view in the interface or in curve of the selected channel. The data could be saved in SQL Server 2000 and export to Excel files. The different between the static and dynamic test was there was one data for each test in static test. The main function 's flow chart of the client as shown in Figure 14.

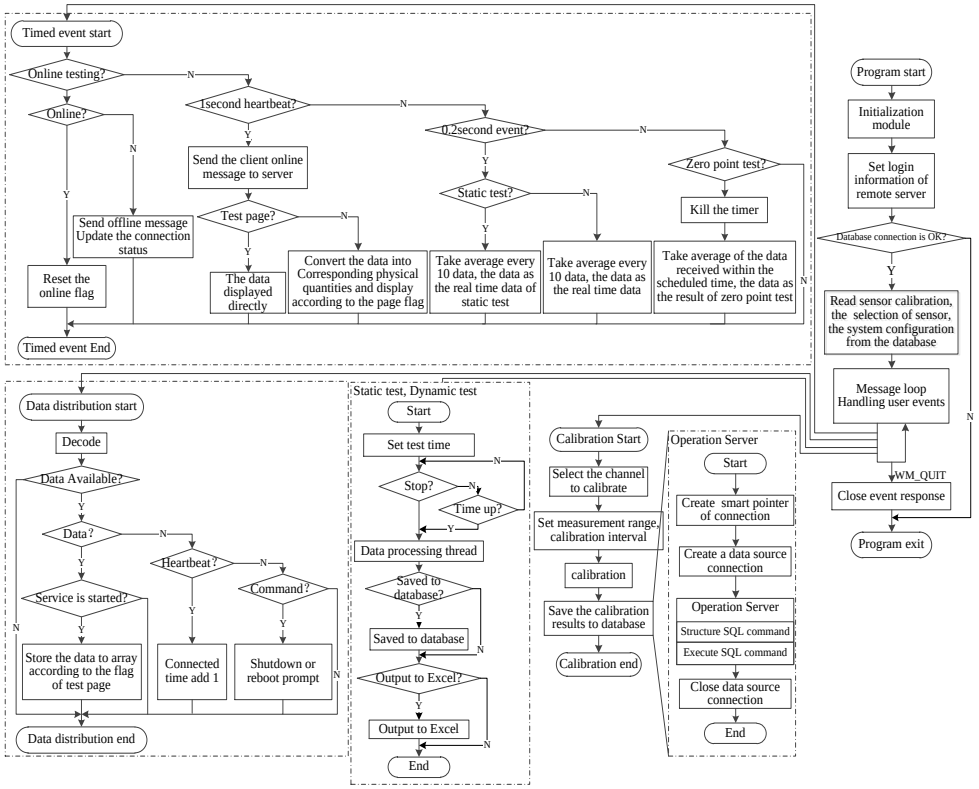

Figure 14. The Flow Chart of Server Software's Main Function

5. Experiment and Results

The data acquisition server's running interface as shown in Figure 15, the server could display the connected client's name and IP address. And the real-time sample data could be chosen to display or not. Selected not display could reduce the overhead of the server side.

The data processing client's running interface as shown in Figure 16. In the home page, different testing project could be chosen. The sensor calibration running interface as shown in Figure 17. Selected the channel which needed to calibrated and then set the measuring range and the interval of the calibration, the data list which needed to calibrated would be automatically generated. Input the standard displacement or air pressure and acquired the voltage of the sensor. Successive complete the acquisition one by one. In the right of the calibration page, the calibration curve would be generated automatically when calibration the point. The static and dynamic test page as shown in Figure 18, 19. After set the test time and test information start the test, the client would acquire data in the time period. The data would be processed after time out and result would be displayed in list view. The result could be displayed in curve of the selected channel, the curve as shown in Figure 20.

The acquired data could be queried after the test work is done. The data query interface as shown in Figure 21, the test data was classified by test type, test dates, test number, tester, test item. The classification was displayed in a tree-structure view. The history test data could be queried, modified and outputted to Excel files. The history data could be displayed in list view or curve view as shown in Figure 22.

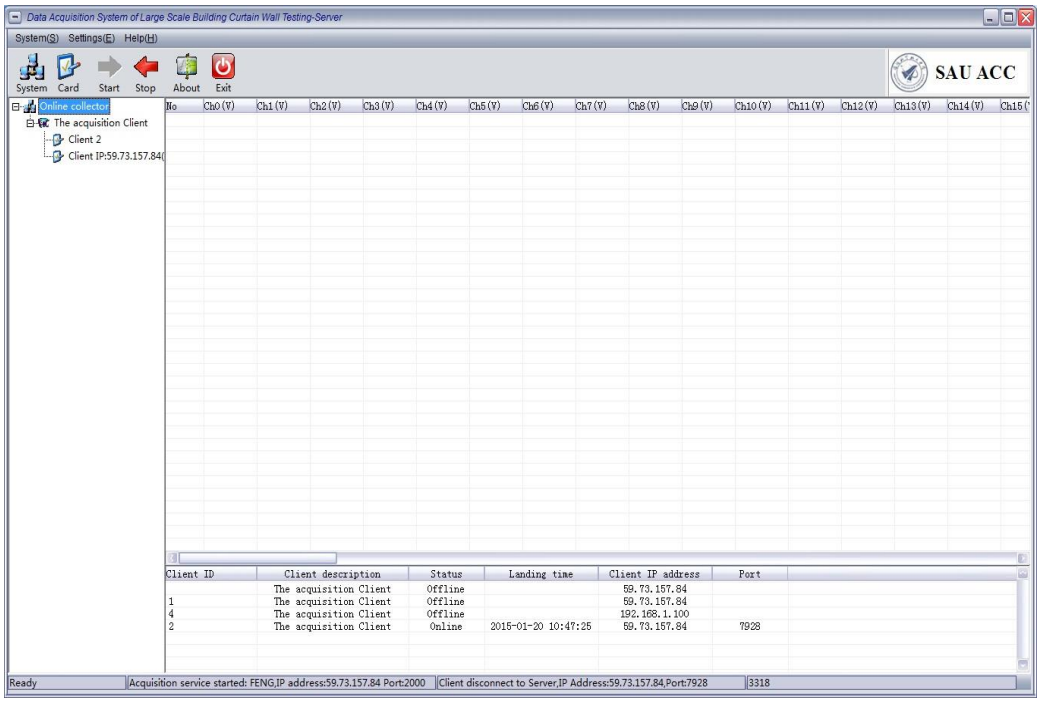

Figure 15. The Interface of Data Acquisition Server

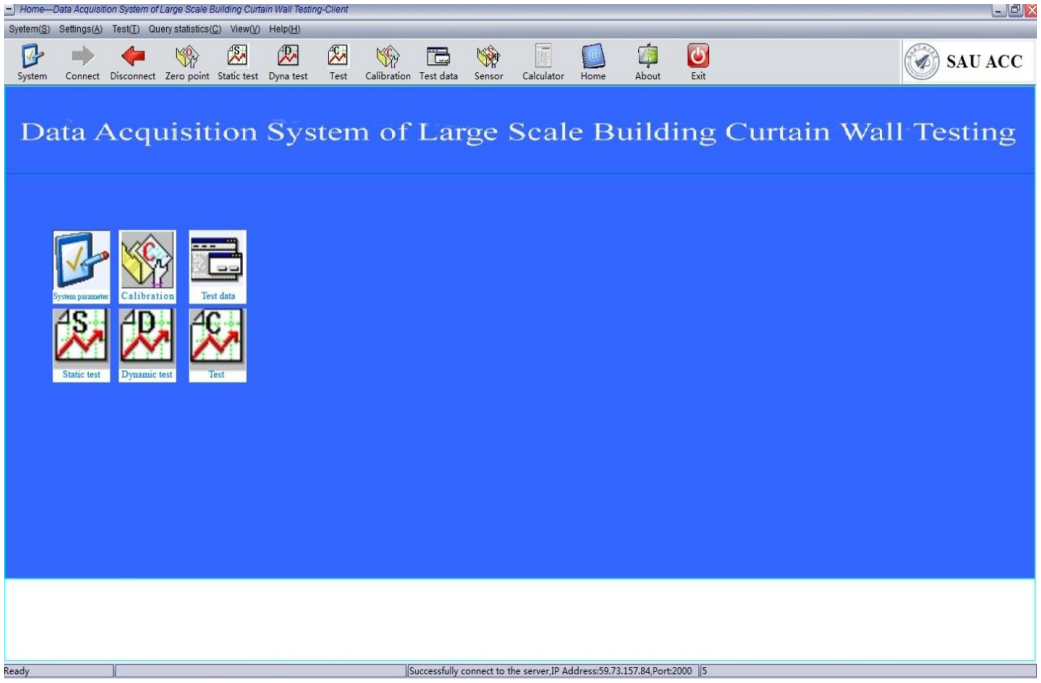

Figure 16. The Interface of Data Processing Client

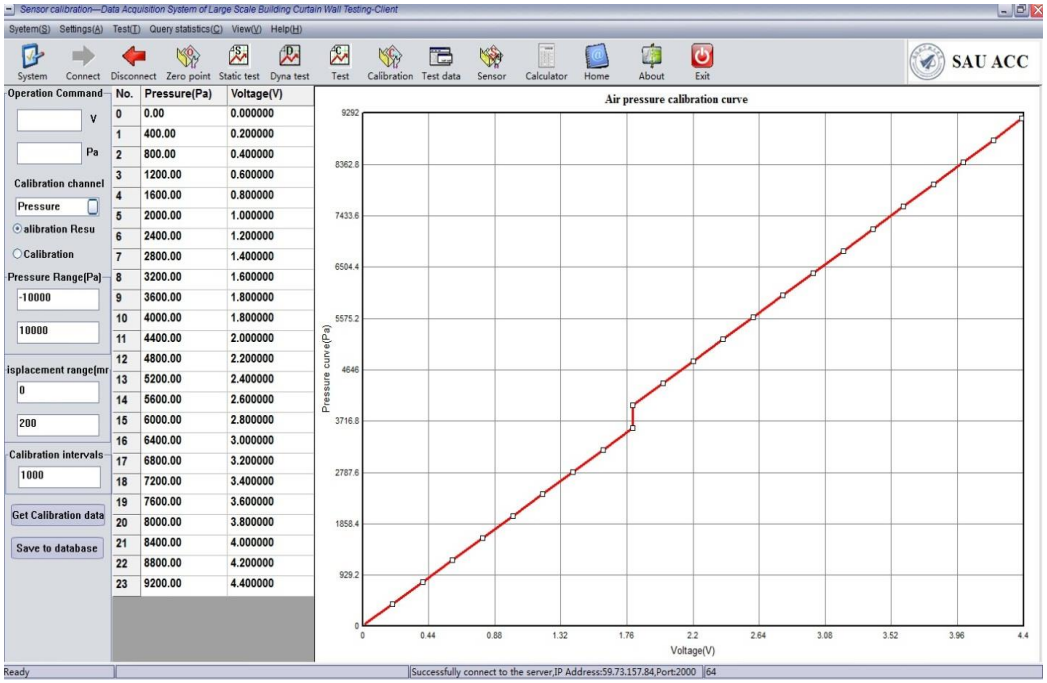

Figure 17. The Interface of Sensor Calibration

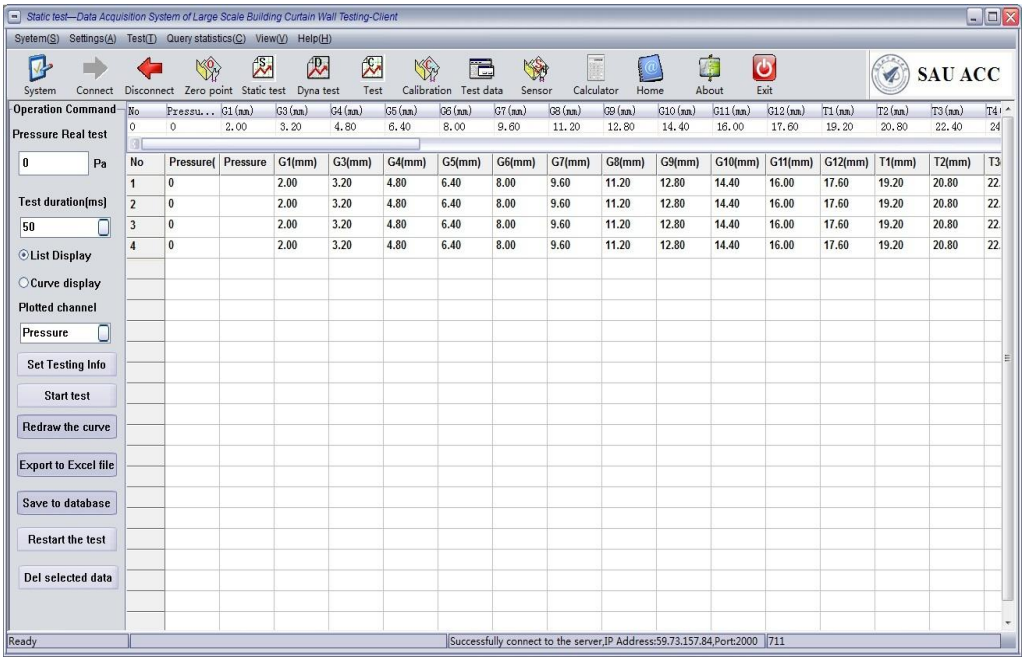

Figure 18. The Interface of Static Test

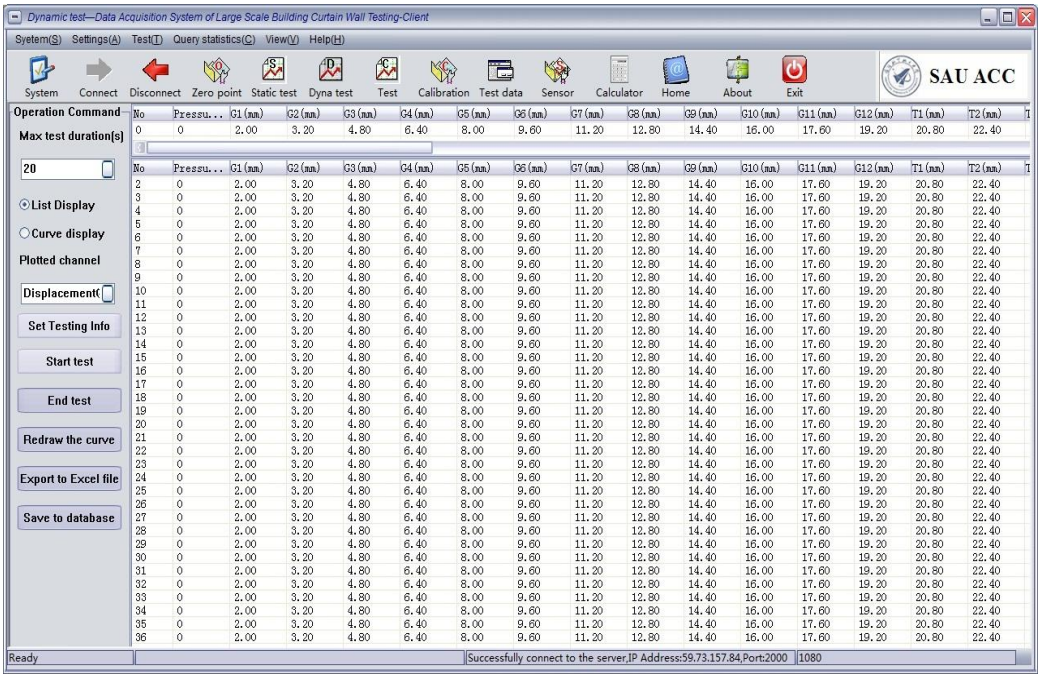

Figure 19. The Interface of Dynamic Test

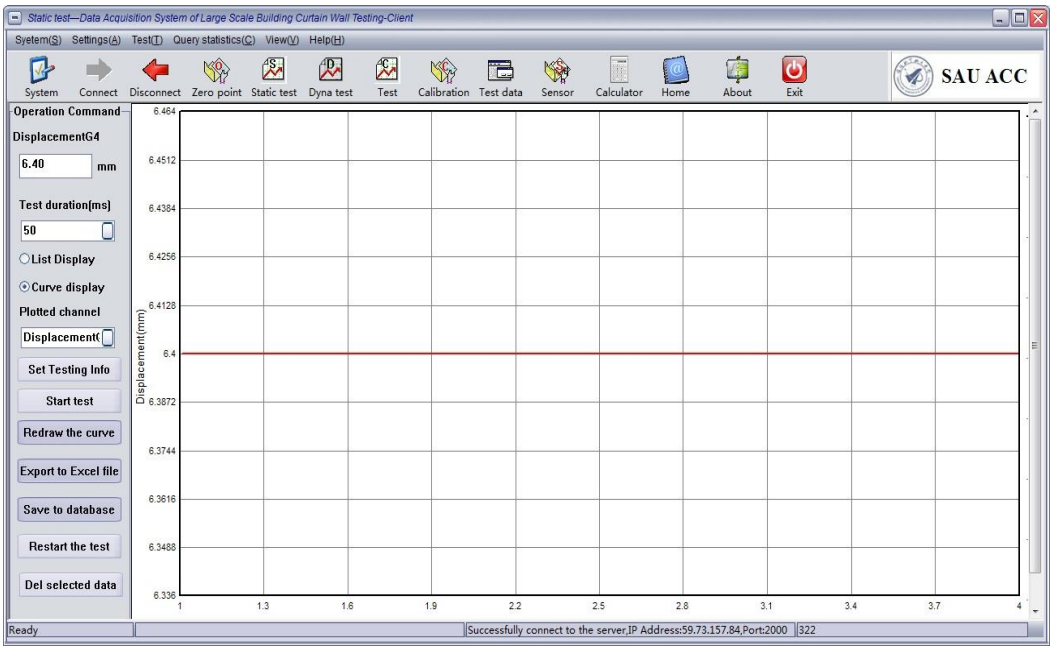

Figure 20. The Test Data Displayed in Curve View

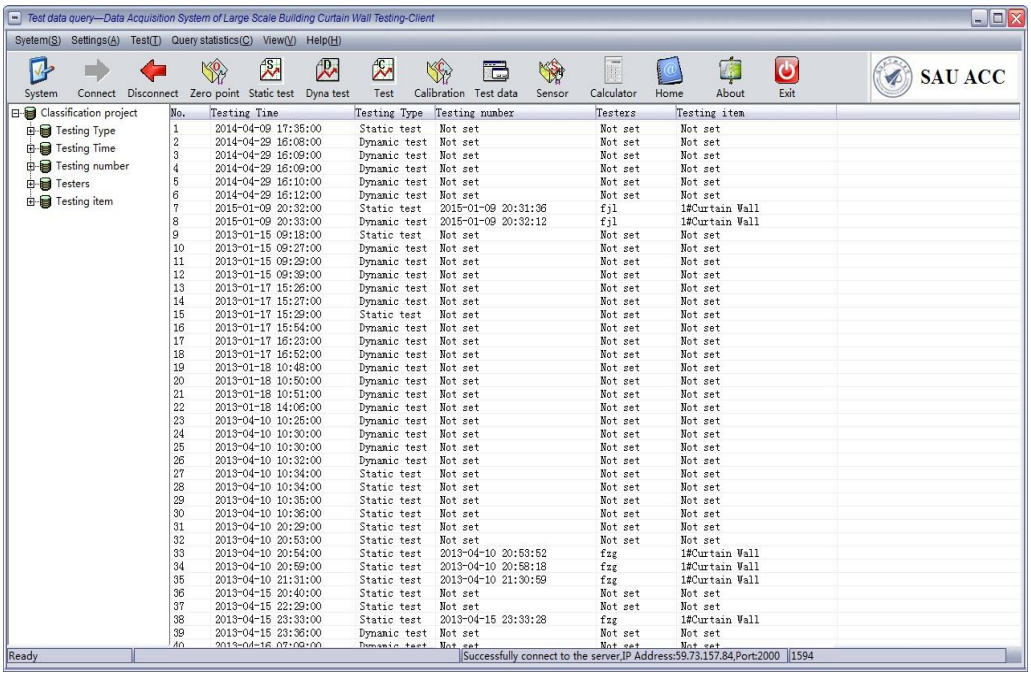

Figure 21. The Interface of Data Query

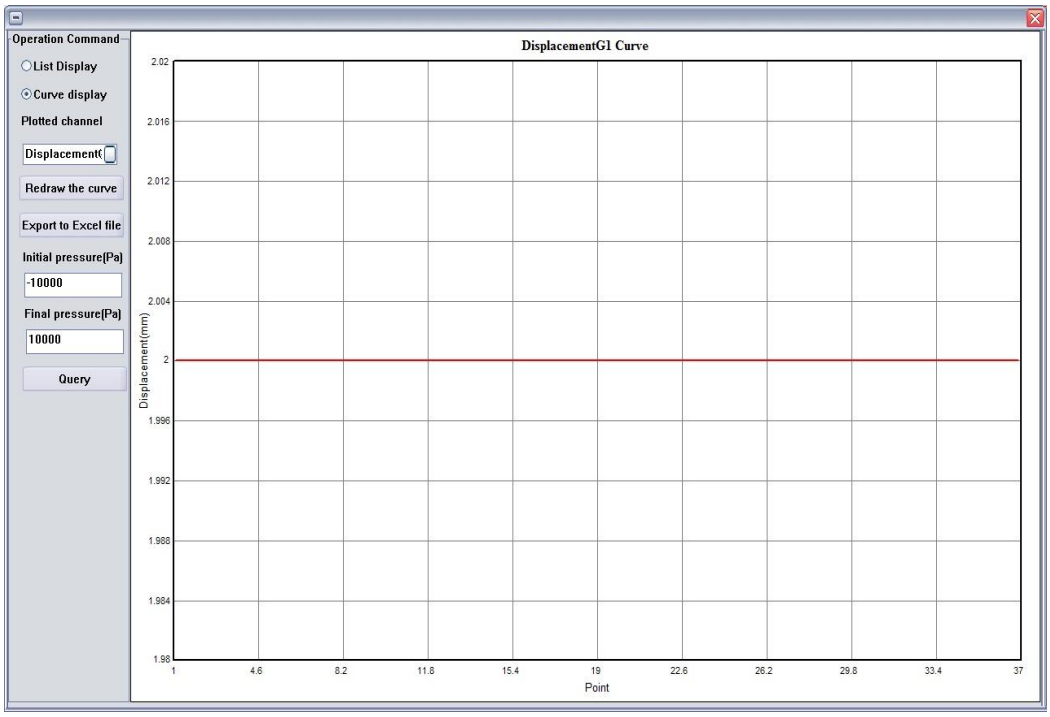

Figure 22. The History Data Displayed in Curve View

6. Conclusions

In this paper, a C/S structure acquisition system of the curtain wall wind pressure resistance characteristics data, which is based on the Advantech data acquisition card PCI-1747U, is designed and implemented from the hardware selection to PC software. The experiment results show that: This system can achieve the acquisition of 64 channels wind load resistance performance data and the sample frequency is 120S/s for each channel after mean filter algorithm; The precession of displacement data and pressure

data can reach 0.1mm and the indicating value's 1%; The data acquisition server completed the management of multiple client and function of data acquisition and sent; The data processing client can completed the acquire test, static test and dynamic test of the curtain wall test; The test data stored in a Microsoft SQL 2000 database and can be queried modified and output to Excel file.

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