LabVIEW and PCI DAQ Card Based HTS Test and Control Platforms

Hui-Bin Zhao, Jian-Xun Jin, Pu-Chun Jiang, Wen-Hui Gao, and Zi-Lu Liang

***Abstract*—This paper introduces the relevant parameters and related characteristics of the LabVIEW and PCI6221 data acquisition (DAQ) card, describes in detail the approach of building the measure and control platform of virtual instrument (VI) using LabVIEW and PCI6221, specifically discusses the system's application in high temperature superconductor (HTS) research including the test of HTS volt-ampere characteristics and the HTS magnetic energy storage. The experiments prove that the VI test and control system is easy to build and convenient to use.**

***Index Terms*—Data acquisition (DAQ), high temperature superconductor (HTS), HTS device, HTS *I-V* measurement, virtual instrument (VI).**

1. Introduction

Virtual instrument (VI) is a PC-based equipment. A PC installed with relevant software and hardware can become a VI measurement and control device which can make the user operate the PC as operating his own designed professional electronic instrument. Its appearance completely breaks the situation that function of instrument can only be defined by factory and can not be changed by users. Virtual instrument with the "developable", "extensible" and other superior characteristics has more vitality and competitiveness.

The basic form of virtual machines includes computers, VI software, and hardware interface module. The hardware interface module could include plug-in data acquisition (DAQ) card, series/parallel port, IEEE 488 interface (GPIB) card, VXI controllers and other interface cards. At present the more commonly used hardware systems are the PCI DAQ system, GPIB instrument control system, VXI equipment system and combination of them.

LabVIEW produced by National Instrument (NI) is the VI software development tool based on graphic programming language. LabVIEW is widely used for test and control systems. It provides almost all the classic signal processing functions and a large number of modern high-level signal analysis tools. It is very easy to integrate with a variety of hardware and to communicate with mainstream industrial field buses. It is also easy to link with the most common standard real-time database.

PCI6221 card is a product of NI Corporation's M-series which is widely used for DAQ. The purpose of DAQ is to measure a physical phenomenon such as temperature, pressure, light or sound. PC-based DAQ uses a combination of hardware, software, and a computer to automate measurement and make data available for analysis.

This work applied the above mentioned software and hardware techniques to build HTS related measurement and control systems.

2. LabVIEW

LabVIEW is a graphical programming language that uses icon instead of lines of text to create applications. In contrast to text-based programming languages, where instructions determine program execution, LabVIEW uses dataflow programming, where the flow of data determines execution.

In LabVIEW, a user interface with a set of tools and objects can be customized. The user interface is known as the front panel. The user then adds code using graphic representations of functions to control the front panel objects. The block diagram contains this code. In some ways, the block diagram resembles a flowchart.

In LabVIEW, the node is defined as the objects on the diagram that have inputs and/or outputs and perform operations when a VI runs. Node would begin to run as long as the needed input data become effective. Thus facilitates VI to run side by side and naturally optimizes computing performance of the process.

The powerful function of LabVIEW graphical programming language is built on its structure of layers. The LabVIEW's procedure uses modular programming. It consists of various modules. Each module can be used to achieve a specific function. A large user program or project can be built after combining each module.

As an important part of LabVIEW, subVI would make the whole process clearer, more level-distinct and more readable. A VI called from the block diagram of another VI is called a subVI. A subVI node corresponds to a subroutine call in text-based programming language[1].

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3. PCI DAQ Card

The structure of the PCI6221 has been shown in Fig. 1.

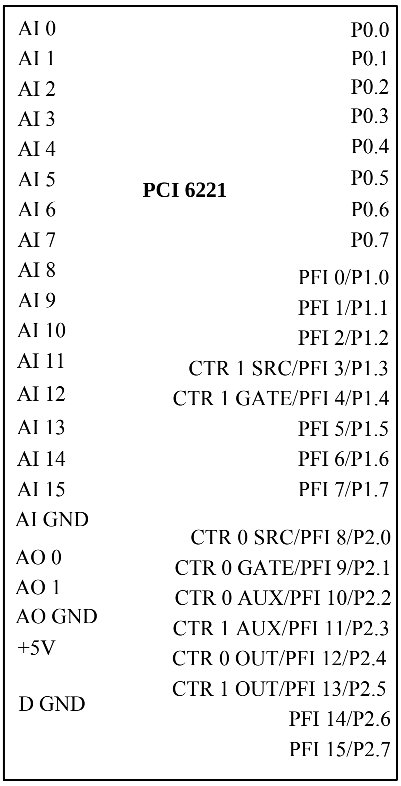

Fig. 1. The structure of the PCI6221.

The device of PCI6221 uses PCI bus. The following is the specific parameters of PCI6221.

1) 16 analog inputs (AI 0 to AI 15 in Fig. 1). Specific parameters are listed in Table 1. The range accuracy of PCI6221 is 3100 μV in maximum voltage range and 112 μV in minimum voltage range. The range sensitivity is 97.6 μV in maximum voltage range and 5.2 μV in minimum voltage range. Because the sample rate is 250 kS/s, so the largest signal frequency that can be measured by the port is 125 kHz according to sample theorem.

2) Two analog outputs. Specific parameters of which are listed in Table 2. Two output channels (AO 0 and AO 1) in Fig. 1 can output two analog signals simultaneously.

3) 24 digital I/O lines: specific parameters of which are listed in Table 3. Digital I/O of PCI6221 is made up of three ports of P0, P1, and P2 (as shown in Fig. 1); each port has eight lines. The ports and each line of ports can be used independently.

4) Two counters/timers. Resolution of which is 32 bits; maximum source frequency of which 80 MHz.

5) Six DMA channels for fast data transmission.

PCI6221 can be widely used for test and control. For test, we can use 16-bit, 250 kS/s analog inputs and 1 MHz digital lines with NI signal condition for applications including data logging and sensor measurements. For test, PCI6221 digital lines can drive 24 mA for relay and actuator control. With two analog outputs, two 1 MHz counter/timers, and six DMA channels, PCI6221 can execute multiple control loops simultaneously[2].

Table 1: Specific parameters of analog input of PCI6221

Parameters	Value	Parameters	Value
Number of channels	16SE/8DI	Maximum Voltage Range	−10 V to 10 V
Sample rate	250 kS/s	Minimum Voltage Range	−200 mV to 200mV
Resolution	16 bits	Number of Ranges	4
Simultaneous sampling	No	On-Board Memory	4095 Samples

Table 2: Specific parameters of analog output of PCI6221

Parameters	Value	Parameters	Value
Number of channels	2	Maximum voltage range	−10 V to 10 V
Update rate	833 kS/s	Minimum voltage range	−10 V to 10 V
Resolution	16 bits	Range accuracy	3230 μV
Current drive (channel/total)	5 mA	Range sensitivity	3230 μV

Table 3: Specific parameters of digital I/O of PCI6221

Parameters	Value	Parameters	Value
Number of channels	24 DIO	Maximum input range	0 V to 5 V
Timing	Hardware	Maximum output range	0 V to 5 V
Maximum clock rate	1 MHz	Current drive (channel/total)	24 mA/448 mA
Logic levels	TTL	Support pattern I/O	Yes

4. VI Measurement and Control System Built by LabVIEW and PCI6221

The multi-function VI measurement and control platform built is shown in Fig. 2. A variety of signal sensors could be equipped to do specific tests, such as temperature, pressure, magnetic field, current or voltage, photosensitive, humidity sensors and so on. The data acquisition ports of the PCI6221 collect the testing signal through the sensors. Then the signal is transmitted to the data-processing software systems composed with a computer and the LabVIEW, and the final data will be visually displayed in the form of graphics or data files.

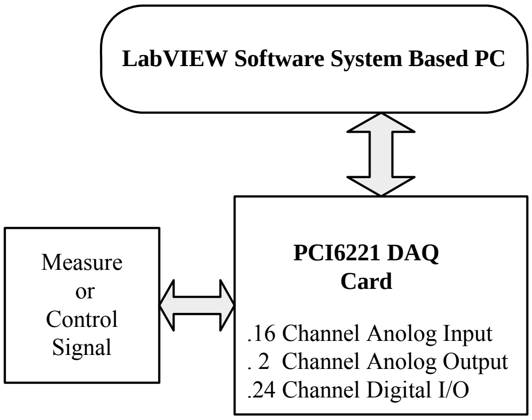

Fig. 2. VI measurement and control system constructed by PCI6221 and LabVIEW.

When the system is used to control instruments, the first steps is to program appropriate control program using LabVIEW graphic programming language on the computer, and then sends the control signals through the analog outputs or digital I/O ports of the PCI6221 card to control the instruments. For example, program can be made for the PCI6221 card to output 0 V to 5 V DC voltages in order to control the output current of the remote programmable power source.

In addition, LabVIEW has rich network services which can send data to remote computers through the networks, achieving the aim of remote test and control.

5. HTS *I-V* Testing System

A practical experiment testing system has been built to measure the HTS ampere-voltage (*I-V*) characteristics. The system structure is shown in Fig. 3.

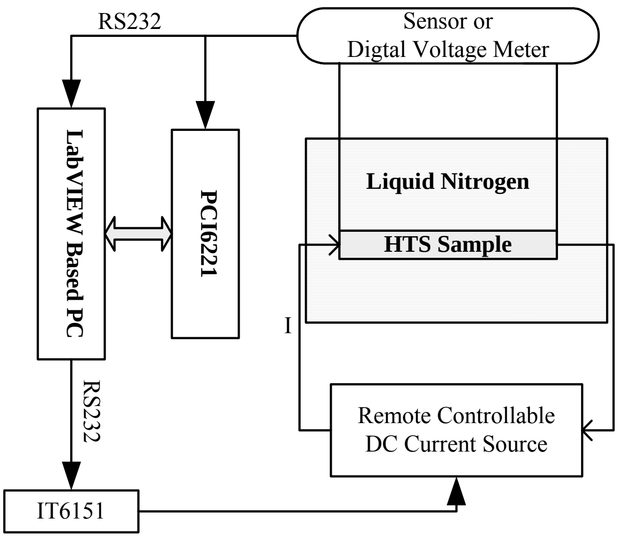

Fig. 3. The VI system structure for HTS *I-V* characteristic test.

The working process of the testing system shown in the Fig. 3 is as follow. The analog output port of the power source IT6151 or PCI6221 card generates a voltage signal to control the output current 'I' of the remote controllable DC current source. The current flows through the HTS sample. The voltmeter in the system sends the testing signals to the LabVIEW through RS232 or PCI6221. LabVIEW processes the data and displays it in the form of graph and saves to a data file.

5.1 System Hardware

As shown in Fig. 3, the HTS *I-V* characteristic test system includes the LabVIEW7.1 software environment, PCI6221 DAQ card, programmable DC source, HTS sample and cryostat (liquid nitrogen). The practical test system is shown in Fig. 4.

The programmable single output DC power source has the characteristics of quick-rising-edge speed (<20 ms) and high resolution and precision (0.1 mV, 0.1 rnA). During the test process, it generates 0 V to 5 V signal to realize the remote control of a bigger power supply having controllable current 0 A to 500 A. PCI6221 can also be used to realize the same control.

(a)

(b)

Fig. 4. LabVIEW and PCI6221 based HTS the testing systems: (a) LabVIEW based HTS *I-V-B* test system and (b) LabVIEW and PCI based HTS test and control system.

There are two methods to measure the voltage of the HTS sample. One is using PCI6221 to measure the voltage of HTS sample directly. Using this method we can edit program in LabVIEW to collect and process the signal from AI 0 or AI 1. The advantage of the method is that periphery circuit is simple and measurement is easy. The disadvantage is that precision is not high. The other method is using professional voltmeter, such as Keithley Model 2000 whose precision of DC voltage measurement is 0.1 μV. To improve test precision, we use the second method in this paper. However, the precision of Keithley Model 2000 in feeble voltage measurement is affected by many factors. We can reduce the interference using the technology such as magnetic shielding assuring HTS far away from magnetic sources, making the coil small and reducing the connection of wires. Different metal materials connected together or difference of temperature of the sample will generate noise voltage. This voltage will affect small signal to be measured. The effect can be reduced by using pure copper wire and reducing temperature changes. The error caused by thermal voltage can be decreased effectively by the method of current phase-changing measurement[3].

5.2 Software Design

The control program flow chart of measure and control system is shown in Fig. 5. The minimum, maximum, stride and wait period of current source output can be set. And the current and voltage from the testing field can be collected and displayed simultaneously.

LabVIEW graphic programming language can be used to edit friendly interface easily and effectively according to the function request of system. The main operating interface of measurement system is shown in Fig. 6. On the operating panel one can set more parameters such as input current stride length, amplitude range, wait period and whether storing the data into the files. It can also display the current and voltage value of HTS sample in real-time mode. Besides, the front panel can draw *I-V* characteristic curve of HTS sample and calculate the sample's I_c in different judge conditions.

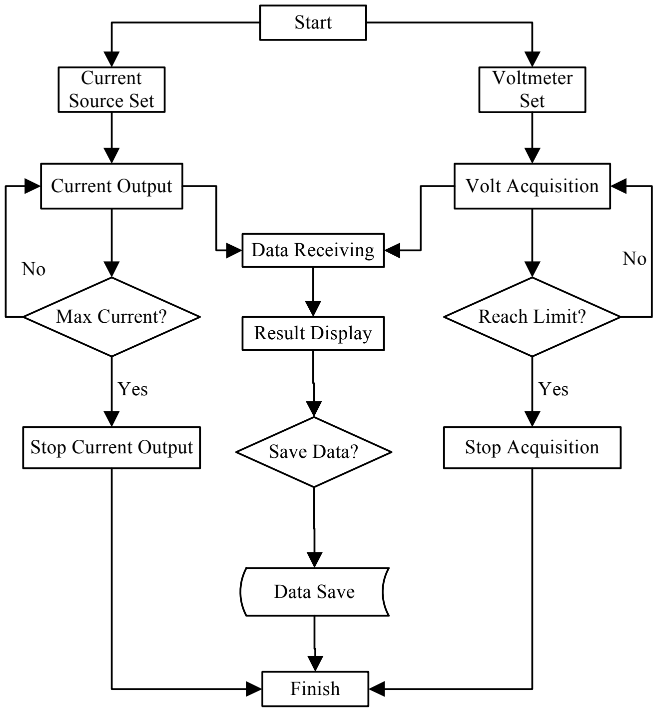

Fig. 5. Flow chart of HTS *I-V* test program.

The measurement and control system based on LabVIEW is designed in modularized style. Each function is realized by a specific module. Then the function of signal process, display and storage are added. Through the system the I_c of the HTS sample can be calculated automatically and the data can be saved to certain file. So the system can be manipulated easily and improve the working efficiency.

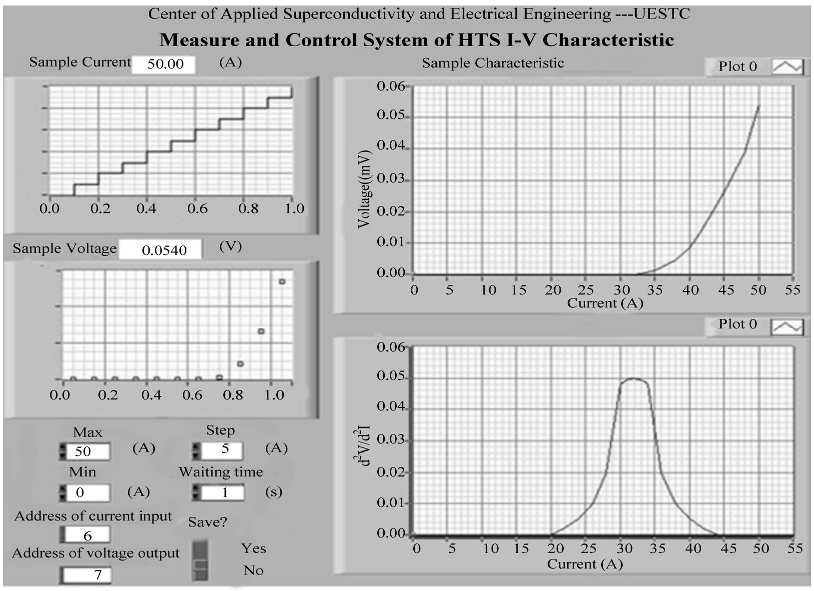

Fig. 6. The main front panel of HTS *I-V* testing system in LabVIEW.

1) Main-control module. It provides the function of controlling output current The graphic program language can set the output signal to realize the control of output current's stride length, amplitude and period of the power supply used.

2) Data acquisition module. The input voltage signal of RS-232 and sensors are collected through data acquisition function.

3) Data process module. It's the function to process the collected data, and the data is processed in block diagram program directly to achieve time saving and enhance display effect. LabVIEW provides many signal processing subVI such as Filter, FFT, DTF and so on. We can use these function to process the data immediately.

4) Data display and storage module. Data display program displays the trend of the collected data change using graphic form. Data storage module can choose storage path freely and record precisely experiment data, which makes it convenient to process and analyze data in later time.

Fig. 7 shows the *I*-*V* characteristic curve of a 2G YBCO HTS wire, where the I_c shows ~ 103 A in liquid nitrogen, with $d_{(V\text{-}V)}$ = 1 cm and 1 μV criterion, measured outside the magnet in air $B\approx 0$ T. For HTS samples, the criterion of I_c usually uses 1μV/cm as the standard to divide the superconducting state and its normal state.

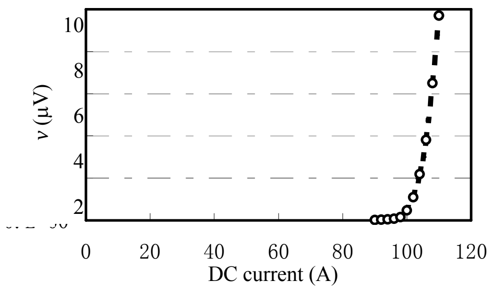

Fig. 7. A HTS sample *I*-*V* curve.

6. LabVIEW and PCI6221 Based HTS Magnet System

The designed experimental HTS magnet system shown in Fig. 8 is an universal platform for HTS magnet research and tests of superconducting and physical properties of HTS wire/block/film/magnet, and HTS devices.

The system includes a computer linked with a digital voltage meter by RS-232 or PCI6221 interface card. To measure HTS *I*-*V*-*B* characteristics, the four-point method can be used with two current leads connected with DC source, two voltage leads connected with high precision voltage meter. Magnetic field and temperature can be measured and controlled through the PCI6221. A G-M cryocooler can adjust temperature down to 4 K and allow HTS characteristics measured at different temperatures.

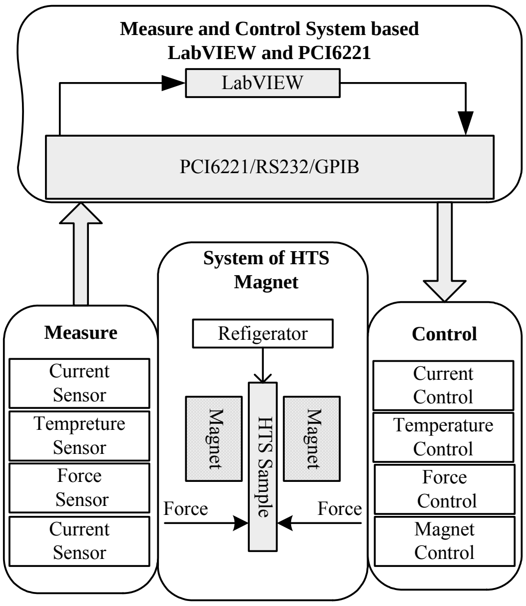

Fig. 8. LabVIEW and PCI6221 based HTS magnet experimental platform.

In the system， PCI6221's AO0 can be used to control the current output of DC current source. We can use LabVIEW to set the output signal to realize the control of current output such as stride length, amplitude and period. As an example, the front panel of the subVI is partly shown in Fig. 9.

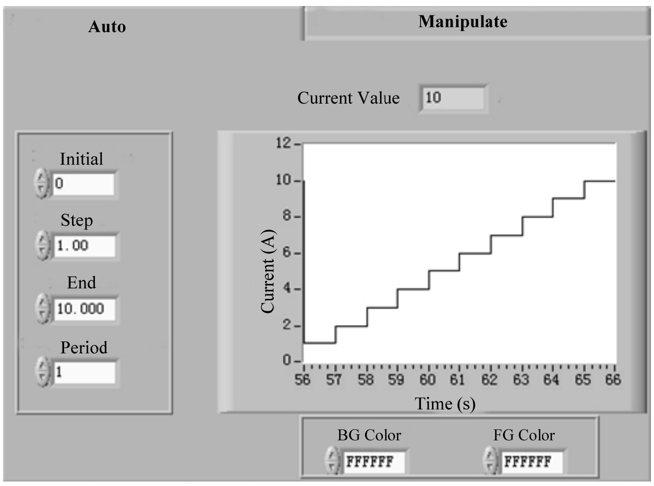

Fig. 9. An example of LabVIEW based PCI6221 system.

The method of program design is as same as last section, and the program flow chat is as same as Fig. 5. The difference is that more sensors and control instruments are added to the system. So we can get more useful data about the HTS sample such as the I_c, H_c and T_c which are important characteristics of the superconductivity

7. HTS SMES Test and Control

Superconducting magnetic energy storage (SMES) uses a superconducting coil connected in the power grid through power electronic devices to keep the surplus energy in the form of electromagnetic energy stored. When the energy needed, it will be sent back to the power grid for any other usage. An experimental HTS SEMS circuit is shown in Fig. 10.

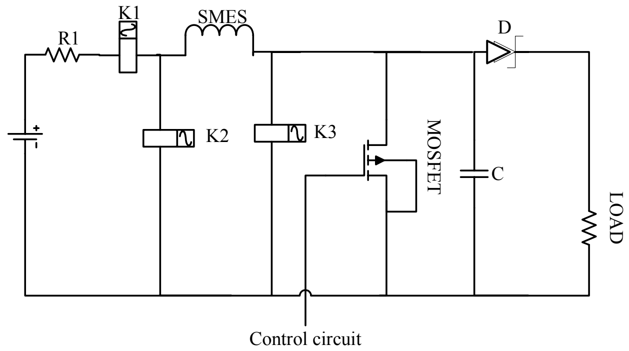

Fig. 10. An experimental HTS SEMS circuit.

As the working procedure, firstly, switch K1 and K3 are turned on and K2 is turned off in order to charge the HTS inductor. A period of time later, K2 is turned on, K1 and K3 are turned off, the inductor discharges through the diode and the load. The inductor's energy will decay exponentially and rapidly. Therefore, in the discharge circuit, a current divisional circuit using a MOSFET is added. When the inductor discharge current becomes larger than a specific value, the division current increases, and vice versa. Consequently, the current flowing through the load maintains a certain value in a period of time which makes the inductor energy release smoothly to the load[4].

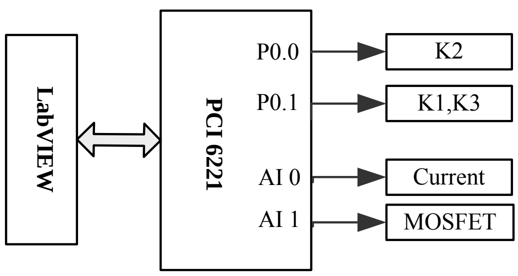

Fig. 11. VI based control and detection scheme.

Using the Digital I/O of the PCI6221 combined with LabVIEW can readily realize the system's control of charge and discharge, and the PCI6221 can sample the SMES's discharge current at the same time. The VI based control and detection flow chart is shown in Fig. 12.

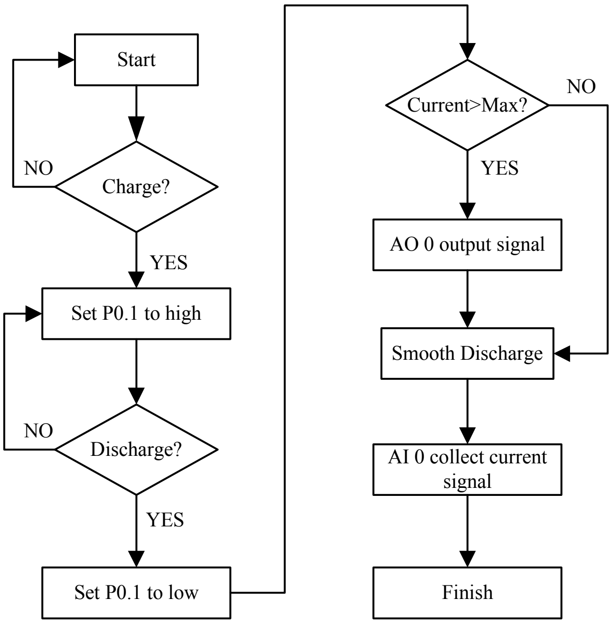

Fig. 12. PCI6221 and LabVIEW based SMES charge and discharge control flow chart.

In Fig. 11, PCI6221's P0.0, which is a digital I/O channel, is used to control the electromagnetic relay 1 for switch K2, P0.1 controls the relay 2 for switches K2 and K3. The PCI6221's correlative control flow is shown in Fig. 12. The modulated signal from AO 0 can not be added to the MOSFET directly, because the limitation of its driving ability, therefore a driving circuit is required to operate the MOSFET. The practical system developed for the HTS SMES device test and control is shown in Fig. 13.

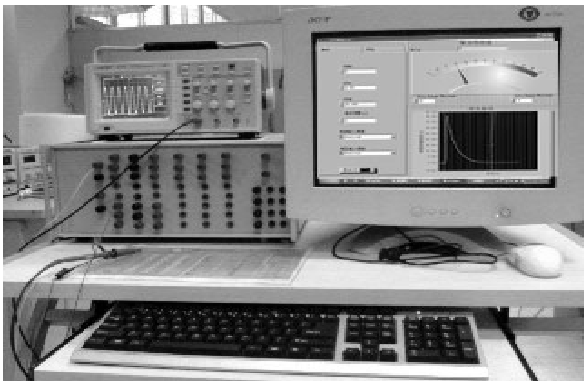

Fig. 13. The developed HTS SMES test and control system.

8. Conclusions

LabVIEW and PCI card based VI test and control systems have been developed quickly. It is a new method to measure and control especially in HTS, and the systems built with VI provide an efficient way for wide range of measurement and control in research or product line. Now the technology has been well brought to the HTS research fields to conduct HTS auto measurements and HTS device controls with easy operation, high efficiency and high reliability.

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