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Explosive Thermal Analysis Monitoring System Based on Virtual Instrument

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Abstract: To determine and check explosive thermal vulnerability, cook-off test and vented pipe test are general methods in experimental research. Heating temperature and internal temperature real-time monitoring are important for experimental research. Aimed at the risk of the explosive thermal analysis and the portability of field environment test instrument, potable temperature monitoring system had been developed based on NI cDAQ hardware equipment. The monitoring system uses NI cDAQ 9184, NI Compact DAQ4, NI 9214 data acquisition module to realize the acquisition of the temperature data. The data transmission module uses wireless AP. The software developed by LabVIEW8.5 realizes the development of modules with the ability of data real-time display and data storage. The system had the advantage of small size, light weight, high precision, real-time and the ability of real-time measurement of explosive temperature change in 500 m far away. It is a reliable temperature test instrument for the study of explosive thermal analysis.

Key words: explosive thermal analysis; virtual instrument; wireless acquisition; industrial explosives

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To determine and check explosive thermal vulnerability, cook-off test and vented pipe test are general methods in experimental research. Heating temperature and internal temperature real-time monitoring are important for experimental research[1-5]. As there exists risk of explosion for the explosives under heat, the personnel and instrument and equipment protection should reach the strict requirements. The traditional temperature monitoring system for explosives with thermal vulnerability, monitors heating temperature and the internal temperature curve of explosives with temperature sensors generally and record the temperature curve with a recorder. After that testers read temperature curve and process the test results on the computer. The testers can not understand the real-time heating process of the explosives, which brought a lot of uncertainty to the test.

Aimed at the risk of the explosive thermal analysis and the portability of field environment test instrument, potable temperature monitoring system had been developed based on NI (National Instruments) cDAQ (Compact Data Acquisition) hardware equipment. The monitoring system uses NI cDAQ 9184, NI Compact DAQ4, NI 9214 data acquisition module to realize the acquisition of the temperature data. The data transmission module uses wireless AP. The software developed by LabVIEW8.5 realizes the development of modules with the ability of data real-time display and data storage. The system had the advantage of small size, light weight, high precision, real-time and the ability of real-time measurement of explosive temperature change in 500 m far away. It is a reliable temperature test

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instrument for the study of explosive thermal analysis.

1 Overall Design of the Wireless Temperature Monitoring System

NI provides three platforms of PXI, CompactDAQ and CompactRIO. CompactDAQ platform provides two connection interfaces of RJ-45 Ethernet port and USB. And it can be connected with a PC or laptop very conveniently with only a USB data cable or network cable. Eight CompactDAQ data acquisition modules at most can be placed in a CompactDAQ chassis. CompactDAQ has the advantage of compact, low power consumption, easy to carry, and low cost compared with the other two platforms. Considering the entire cost of the project, this topic researches the development of wireless temperature monitoring system with NI CompactDAQ Ethernet interface acquisition platform.

The temperature monitoring system based on NI CompactDAQ hardware is divided into two parts of hardware and software, as shown in Fig. 1. The hardware includes the NI CompactDAQ standalone chassis 9184 as a multi-channel synchronization acquisition control core, a NI 9214 data acquisition card, an ECB-3220 wireless AP bridge, a notebook and a power supply management module. The temperature monitoring software is developed by the LabVIEW graphical programming language. With the use of multi-threaded technology and virtual instrument software architecture technology, the software realizes multi-task operation of the instrument to ensure the stable and reliable of the system.

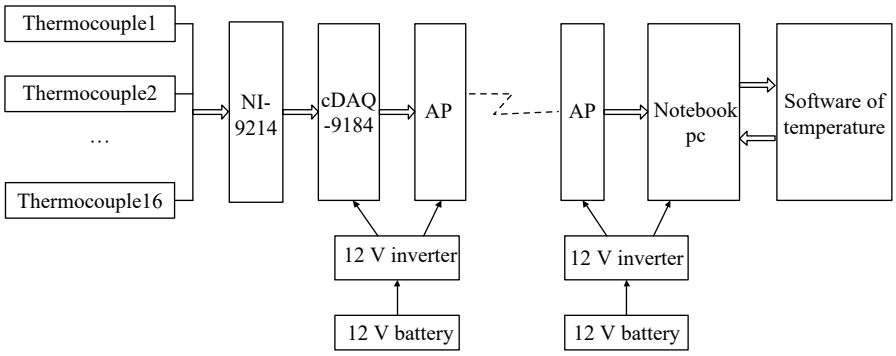


Fig. 1 Hardware function diagram of wireless temperature monitoring system

The working principle of the whole system: the internal temperature changing signal of the test sample on site is converted into the thermoelectromotive force changing through the thermocouple sensor, and then converted into a voltage signal through the NI 9214 temperature acquisition module. The NI 9184 control chassis connected with the wireless AP transmits data to data receiving end, the host computer receives the data sent by the lower computer through the wireless AP. The virtual instrument software installed on the computer can collect real-time data. The software can configure the hardware acquisition parameters of the lower computer, and can display the interface of acquisition channel, and can continuously preserve collection task data.

According to the overall design of the temperature monitoring system for the thermal analysis of explosives, the main hardware devices required for the temperature monitoring system are NI cDAQ 9184 chassis, NI 9214 module, wireless AP and power supply equipment.

(1) NI cDAQ 9184 Ethernet chassis[6]

There are great risks of the explosives' thermal analysis test. Generally, we carry out the tests in the surrounding relatively safe or the field with no residence. Therefore, the requirements of the test instrument are facilitate to power supply, suitable for wide temperature changes and good stability of the equipment. The project uses NI cDAQ 9184 four-slot Ethernet

chassis as the main controller of the test system, as shown in Fig. 2.

Fig. 2 NI cDAQ 9184 Ethernet chassis

The cDAQ 9184 has four built-in 32-bit general counters/timers that are designed for distributed or remote measurements in extreme environments. Its operating temperature range is –40 ℃ to 70 ℃, and it can withstand 50 g shock and 5 g vibration. For applications involving orthogonal encoders, PWM, event counting, pulse sequence generation, and periodic or frequency measurements, these counters can be accessed by a parallel digital C series module (e.g. NI 9401 or NI 9402). Through the RJ-45 Ethernet port of the front panel, cDAQ 9184 chassis connects controller to the computer Ethernet port directly. It can communicate with the computer normally and transfer data to the computer through Wifi. After the chassis is powered on, the software is installed to the chassis and the network settings are configured in MAX. It is easy to call all I/O modules after establishing real-time projects with LabVIEW.

(2) NI 9214 module[7]

The NI 9214 is a 16-channel thermocouple input module. Each channel of the NI 9214 is implemented by a 24-bit analog-to-digital converter (ADC) via a differential filter and a multiplexer. Its max sensitivity is up to 0.02 ℃ and its maximum sampling frequency is 68 Hz. It has the function of cold end compensation and supports 8 types of models thermocouples for J, K, T, E, N, B, R and S. It is used to test the heating temperature and the internal temperature data of the sample among the thermal analysis of explosives, as shown in Fig. 3.

Fig. 3 NI 9214 module

(3) K type thermocouple

The NI 9214 acquisition module supports 8 types of thermocouple sensors of J, K, T, E, N, B, R and S. In the explosive thermal analysis test, the general temperature acquisition frequency is not high, the temperature is below 1 000 ℃, explosives may detonate, the sensors are easy to damage. Considering the bad environment and the economy, we select K-armored thermocouple as the temperature sensor in the project.

K-type thermocouple has good linearity, large thermoelectromotive force, good uniformity and stability, high sensitivity, strong oxidation resistance, can be used for oxidative inert atmosphere and measure the steam and gas, liquid and solid surface temperature directly. Its measure temperature ranges from 0 ℃ to 1 300 ℃, and its price is cheap. As a temperature sensor, K-type thermocouple consists of the installation and fixed devices, temperature sensors, junction boxes and other major components. It is usually used together with the display instrument, recording instrument and electronic regulator supporting, as shown in Fig. 4.

Fig. 4 K type thermocouple

(4) ECB 3220 wireless AP

Explosive thermal analysis may lead to explosions. If the computer and other equipment are placed completely on the test site, the per-

sonnel and equipment may be damaged. If we connect the test signal to the test center with cable, the production site is not suitable for long-distance wiring. Considering the use of wireless data transmission mode, multi-slot Ethernet NI Compact DAQ can transmit data at the speed of about 10 MB/s in the ideal situation. Therefore, the wireless transmission equipment must work at the speed of greater than 10 MB/s, to ensure that the field test signal is not distorted. This project is composed of two ECB 3220 wireless APs. One is connected with NI cDAQ 9184 of the lower computer through the cable. The ECB 3220 long distance wireless AP bridge connected with the lower computer uses 2.4G transmit antenna to gain signal, and ensures the system data is transmitted continuously and reliably in real time. Another piece of ECB 3220 wireless AP is connected with the host computer through the cable, and it receives the real-time temperature data from the lower computer.

The wireless ECB 3220 AP bridge complies with the standard IEEE 802.11b/g and uses the RJ-45 Ethernet interface to connect directly to the selected NI cDAQ 9184 chassis. It supports battery power and overcomes the shortcomings of field work. It supports MAC address filtering, so that data security is guaranteed. Its transmission rate is up to 54 M/s, which ensure the reliability of the continuous real-time transmission of data. Its maximum communication distance is 8 km, which meets the transmission requirements of the system and is more suitable for continuous collection of wild environment. Fig. 5 shows the ECB 3220.

Wireless ECB 3220 is configured through RTLAPConf software. In the host computer, if you can see the two APs of the host computer and the lower computer through the RTLAPConf.exe, it indicates that the wireless APs of the host computer and the lower computer are connected successfully. And then it can realize the wireless connection of the temperature data. Fig. 6 is the installation diagram of the host computer in the control room. Fig. 7 is the monitoring diagram of RTLAPConf software.

Fig. 5 ECB 3220

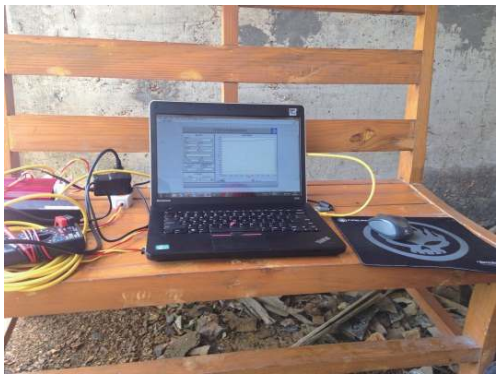


Fig. 6 Installation diagram of the host computer in the control room

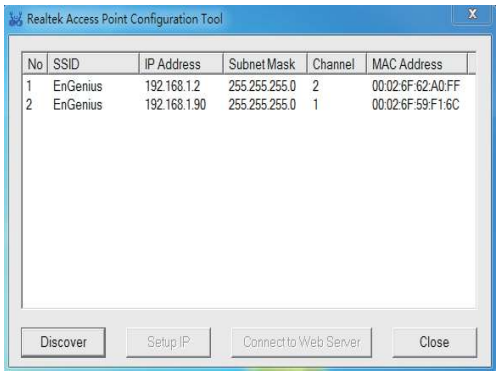


Fig. 7 Monitoring diagram of RTLAPConf software

(5) Design of the power supply

NI CompactDAQ 9184 standalone chassis is powered by a 9-30 V DC power supply. A NI 9214 capture card obtains power and signal through the chassis DB9 pin slot. ECB 3220 wireless AP need the 12 V DC power supply,

notebooks are generally equipped with adaptive AC power adapter which need 220 V AC. There is no 220 V AC power supply in the field. In order to test conveniently, we choose two 12 V 55AH large capacity lithium batteries as the power supply and two BESTEK 300 W car inverters. Then the 12 V lithium battery is converted into 220 V AC, which can be the power supply to the scene 9184, wireless AP and the computer. It can provide more than 24 hours of power supply through the field test. Batteries and inverters are shown in Figs. 8–9.

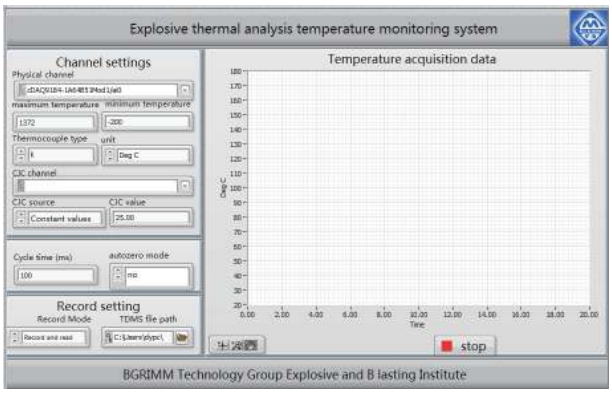
Fig. 8 12 V 55AH large capacity lithium battery

Fig. 9 Car inverter

2 Development of Temperature Monitoring Software for Thermal Analysis of the Explosives

We use LabVIEW 8.5.1 of full version as the development software. LabVIEW 8.5.1 has two forms of programming structure of traditional DAQ and DAQmx(National Instruments 2014). The programming structure is selected according to different data acquisition card. The driver programming structure of the NI cDAQ module is DAQmx. We use DAQmx to develop the program. The biggest advantage of LabVIEW is complying into a separate VI for different functions. Every different VI is able to call each other, so that the program is very convenient to achieve.

Fig. 10 is the interface diagram of the temperature monitoring software for the thermal analysis of explosives. There are four main functions of the software including channel settings, thermocouple type compensation settings, timing settings and recording settings. Channel settings include the channel choice and the maximum and minimum temperature settings. Timing settings include the main sampling rate, sampling number, cycle time and other settings. Thermocouple type compensation settings include thermocouple type, unit, compensation channel, compensation temperature and other settings. Recording settings include recording modes, storage path and other settings. Fig. 11 is a block diagram of the system.



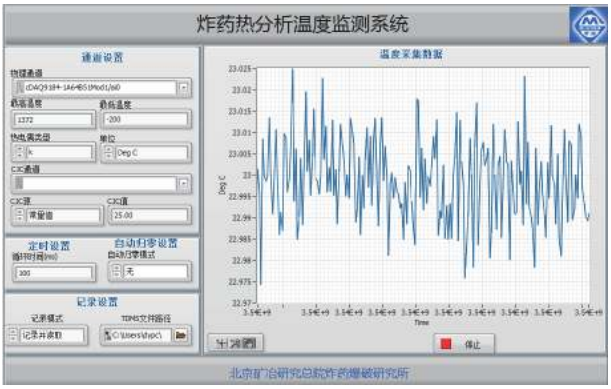


Fig. 10 Temperature monitoring diagram of thermal analysis for explosives

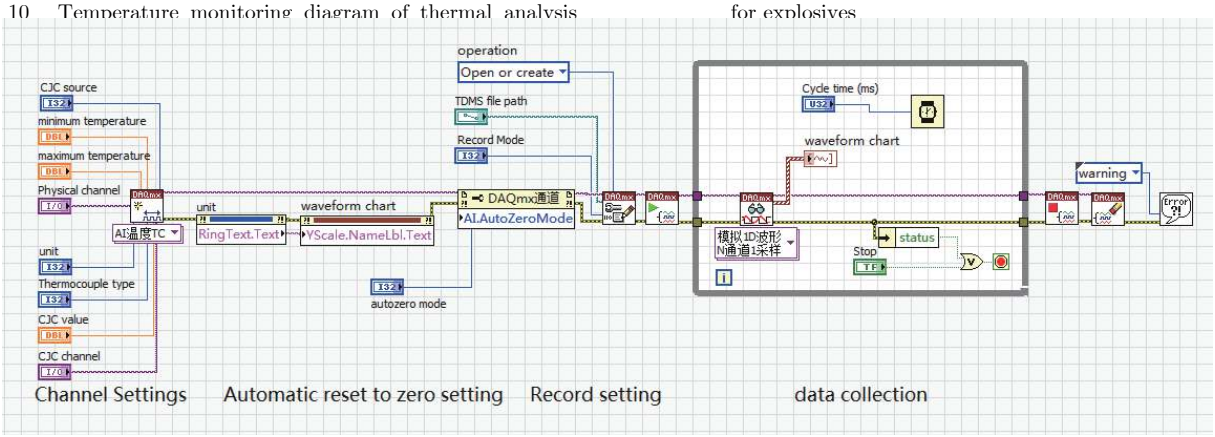


Fig. 11 Block diagram

3 Hardware and Software Testing

Step 1, connect the K-type thermocouple sensor and NI9214 capture card correctly. Connect the host computer and the 9184 network port with the cable. Start the power switch. Once the chassis lights began flashing, it indicates that the instrument has started running. Pay attention to shut down the host computer firewall before starting 9184, or it may bring out failure of connection during the process due to the shielding of the firewall. In addition, it is best to disable the wireless network connection in the "Change Adapter Settings" at the same time.

Step 2, look for the IP address of the 9184 at runtime, open NI MAX on the desktop, double-click the "NI cDAQ 9184" under the remote system. The IP address will be found in the right list. Configure the 9184 IPv4 address as a static address, and then save the configuration for 192.168.1.80.

Step 3, change the host computer's IP address (such as IP: 192.168.1.120), so that its IP address and NI cDAQ 9184 IP address are in the same LAN. Specific operations are as follows. Select "Change Adapter Settings" in "Open Network and Sharing", double-click the local connection, and set its properties. Select "Internet Protocol Version 4 (TCP/IPv4)" to enter the correct host address. At the same time, set the ECB 3220 wireless AP IP address, which should be in the same LAN with the notebook and cDAQ9184. Two ECB 3220 IPs were set to 192.168.1.2 and 192.168.1.90.

Step 4, test the connection between the host computer and the lower computer with the use of RTLAPConf software. Start the software RTLAPConf.exe on the laptop. If you can see both wireless APs of the host computer and the lower computer at the same time, it indicates that the wireless APs of the host computer and the next machine are also connected successfully and we can acquire signal from the lower computer.

Step 5, click "Run" in the Start menu, enter "ping 169.168.1.80" and press the Enter key. If the connection is successful, the host computer and the lower computer are able to start communication.

4 Experimental Research

To verify the reliability of the test system,we refer to the ventilating pipe test device and method in the United Nations standard "Transport of dangerous goods-Test method of acceptance and classification for explosives" GBT14372-2013 to test whether explosion can occur under the thermal action of the latex matrix and evaluate whether the latex matrix produced by the explosives factory is suitable for tank truck to transport. The test sample is the latex matrix produced by an explosive factory, and the sample weight is 30 kg. Fig. 12 is the system diagram of the MVPT ventilation pipe test device.

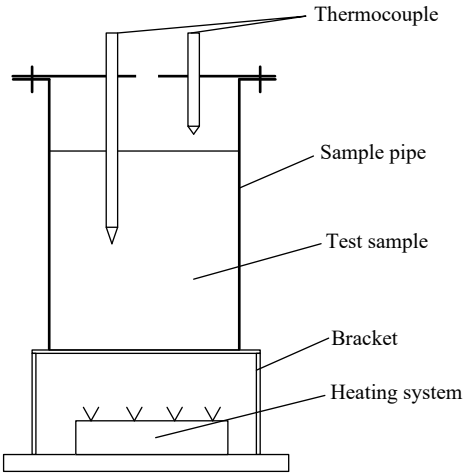


Fig. 12 Ventilation pipe test device

The temperature test system adopts the wireless temperature test system for thermal analysis developed in this paper. The K-type sheathed thermocouple is used in the test. There are two main models of thermocouple: WRNK-191-2PBO; specifications: Φ2×500×10 000 mm; measurement range: 0-1 200 ℃; WRNK-291-2PBO; specification: Φ3×50×10 000 mm; measurement range: 0-1 200 ℃. During the test, three thermocouples are used to measure the temperature changes of flame (T1), sample (T2) and upper space of sample (T3). The lengths of thermocouples are 500 mm, 500 mm and 50 mm. The sampling frequency of thermocouples is 6 times per second. Fig. 13 is the field diagram of the temperature test system, and Fig. 14 is the temperature profile monitored during the experiment.

Fig. 13 Temperature test system diagram

5 Conclusion

This paper developed a temperature monitoring system for thermal analysis of explosives with the VI technology and based on NI's Compact

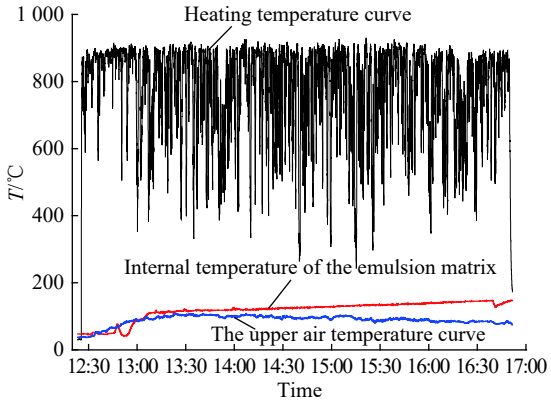


Fig. 14 Temperature profile

DAQ hardware, wireless ECB 3220 AP and computer. The system realized the functions of temperature data acquisition, wireless transmission, storage, display and signal real-time processing. Compared with the traditional acquisition system, this system has the advantage of short development period, high efficiency, reliability, stability and test precision. Besides, it has good expansibility and maintainability. In the field of testing and analyzing the thermal stability of explosives, this system has wide application prospect.

References:

[1] Chen Lang, Li Beibei, Ma Xin. Research on the cook-off characteristics of DNAN explosive [J]. Chinese Journal of Energetic Materials, 2016, 24(1): 27-32.

[2] Zhou Jie, Zhi Xiaoqi, Wang Shuai, et al. Rheological properties of Composition B in slow cook-off process [J]. Explosion and Shock Waves, 2020, 40(5): 052301.

[3] Li Xiaodong, Sun Hongyan, Song Changgui, et al. Effect of binder on the properties of CL-20 /FOX-7-based polymer bonded explosive [J]. Chinese Journal of Explosives & Propellants, 2020, 43(1): 51-56.

[4] Zhou Jie, Zhi Xiaoqi, Liu Zide, et al. Analysis of the heat transfer characteristics of DNAN-based melt-cast explosive in slow cook-off test [J]. Acta Armamentarii, 2019, 40(6): 1154-1160.

[5] Xu Sen, Shen Zukang, Wu Xiaohong, et al. Transport of dangerous goods-test method of acceptance and classification for explosives[S]. Beijing: China Standards Press, 2013. (in Chinese)

[6] National Instruments. NI cDAQTM-918x/919x User manual[M]. Austin, Texas: National Instruments, 2014.

[7] National Instruments. Operating instructions and specifications NI 9214 with NI TB-9214[M]. Austin, Texas: National Instruments, 2010.