Wireless distributed test system based on transient pressure signal detection and recognition

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Abstract: During the test on transient pressure signal in explosion field, false trigger caused by field interference can lead to test failure. To improve the stability of test system, a signal detection and recognition technology is proposed for transient pressure test system. In the process of signal acquisition, firstly, electrical levels are monitored in real time to find effective abrupt changes and mark them; then the effective data segments are detecdted totected; thus the effective signals can be acquired in turn finally. The experimental results show that the shock wave signal can be collected effectively and the reliability of the test system can be improved after removal of interferences.

Key words: signal recognition; shock wave signal; transient pressure test

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0 Introduction

In the military field, destructive power and lethality of ammunition or explosives are embodied by explosive power of shock wave signal propagated in the air. If of the structure, charge weight and test distance of ammunition are not the same, the destructive power and lethality are also different. In the development of new weapons, the measurement of shock wave is very important[1-3].

At present, there have developed various shock wave pressure test methods. The commonly-used include equivalent target method, lead electrical measuring method and storage test method, etc., among which the storage test method is most commonly used currently[4]. The storage test system is put in the experiment site in advance, and then test nodes are installed in the site followed by the evacuation of researchers until the explosion happens. Finally, experimental data are collectied and the test nodes are taken back. The stability of storage test method depends on reliable trigger. Due to harsh enviroment, large-amplitude noise, burr, etc., false trigger may happen and lead to failure of signal acquisition[5].

To solve the shortcomings of storage test system, this paper presents a wireless distributed test system based on transient pressure signal detection and recognition. Before testing, a threshold voltage is set according to the estimation formula of overpressure peak value in advance, then this voltage value can be used as an indicator of effective signal mutation. In the process of data acquisition, real-time data are detected. If the acquired data are greater than the threshold voltage, they will be marked as effective data segment and be identified, and then the test system carries out sequential storage until the memory is full; otherwise, the data are detected continually. This approach solves the problem of signal acquisition failure caused by false trigger and improves the reliability of the storage test system.

1 Detection and recognition principle

The program flow chart of transient pressure test system based on detection and recognition technology

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is shown in Fig. 1.

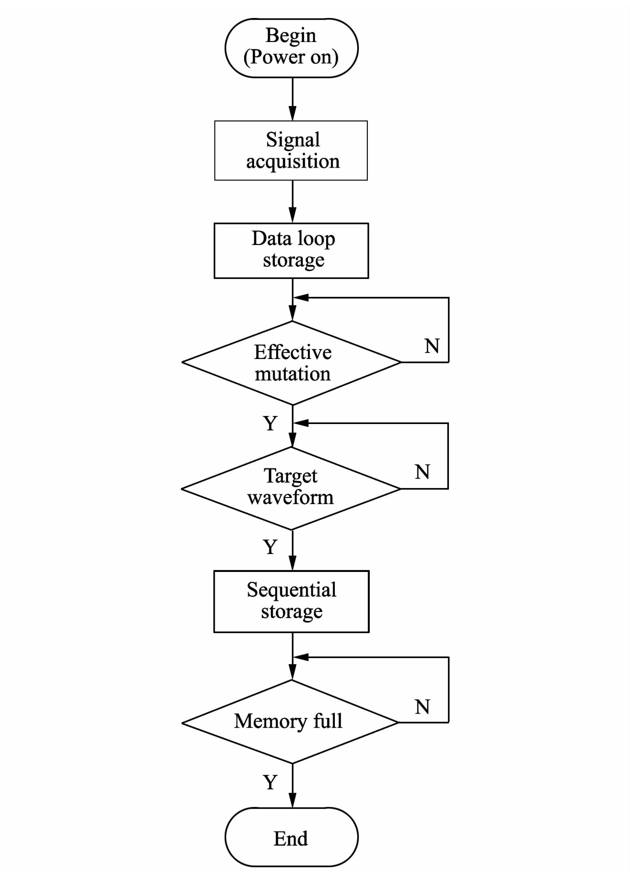


Fig. 1 Program flow chart of the system

The test system starts loop data collection after power on and detects signal instantaneous value at the same time. If the value is greater than the threshold voltage, it is considered as an effective mutation. Then the test system begins to search the peak and corresponding time to the peak in the coming time of 1 ms. Forward from the peak, the location of the first data greater than the baseline and the corresponding time can be used to judge rise time; backward from the peak, the location of the first data greater than the baseline and the corresponding time can be used to judge the positive action time. When all the conditions satisfy the needs, the system will collect the signals sequentially and then they will be stored in SDRAM as target signals. On the contrary, if any of the conditions can not meet the needs, the signal acquisition will end and the effective mutation will be detected again.

The principle of detection and identification technology is shown in Fig. 2.

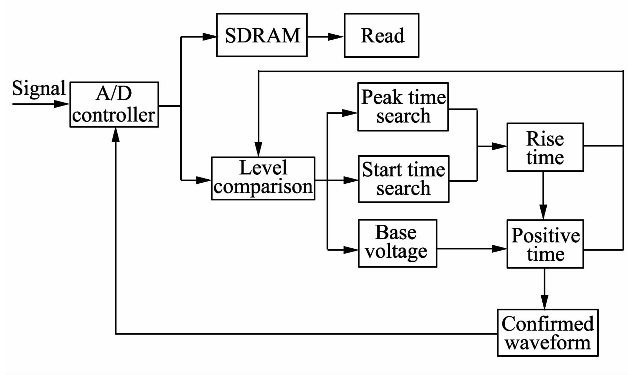


Fig. 2 Principle of detection and identification technology

2 Characteristic parameters for shock wave signal detection and recognition

Detection and recognition technology is responsible for signal detection and signal identification. In this paper, signal detection is mainly to find the effective mutation of signal. If the instantaneous amplitude of signal is greater than a certain threshold voltage, it is determined to be a valid mutation. Recognition is to determine whether the valid data segment is a valid shockwave signal or not.

2.1 Threshold voltage

Before the transient pressure test of explosive field, when arranging the test nodes in the site, to ensure that the range of the test node is greater than the estimated pressure of the corresponding test point, the peak overpressure of the explosion at a certain test point is estimated in advance. There are many empirical formulas for theoretical value estimation of overpressure, such as Henrych formula, Mills formula, Brode formula, and so on. Here Henrych formula is adopted as[6]

$$\Delta P=\begin{cases}\dfrac{1.379}{\bar{r}}+\dfrac{0.543}{\bar{r}^2}-\dfrac{0.035}{\bar{r}^3}+\dfrac{0.006}{\bar{r}^4} & 0.05\leqslant\bar{r}\leqslant 0.3,\\[2mm] \dfrac{0.607}{\bar{r}}-\dfrac{0.032}{\bar{r}^2}+\dfrac{0.209}{\bar{r}^3} & 0.3\leqslant\bar{r}\leqslant 1,\\[2mm] \dfrac{0.065}{\bar{r}}-\dfrac{0.397}{\bar{r}^2}+\dfrac{0.322}{\bar{r}^3} & 1\leqslant\bar{r}\leqslant 10,\end{cases} \tag{1}$$

where ΔP is overpressure peak; $\bar{r}=\dfrac{r}{\sqrt[3]{\omega}}$ and r is the distance between the test nodes to the explosion center; and ω is charge weight.

According to the estimated value, the appropriate threshold voltage can be determined. In this paper, the selection of the threshold voltages can be achieved by programming.

2.2 Positive action time

The shock wave signal can be expressed by

$$p(t)=\left(1-\frac{t}{T^{+}}\right)e^{-\frac{t}{T^{+}}}\quad t\geqslant 0, \tag{2}$$

where $p(t)$ is normalized pressure, T^{+} is positive action time and t is time.

After Fourier transform, Eq. (2) is rewritten as

$$p(\omega)=\int_{-\infty}^{\infty}p(t)e^{j\omega t}\,dt=\int_{-\infty}^{\infty}\left[\left(1-\frac{t}{T^{+}}\right)e^{-\frac{t}{T^{+}}}\right]e^{-j\omega t}\,dt, \tag{3}$$

and $|p(\omega)|$ is calculated by

$$|p(\omega)|=\left|\frac{j\omega T^{+2}}{(1+j\omega T^{+2})}\right|=\frac{\omega T^{+2}}{1+\omega^{2}T^{+2}}. \tag{4}$$

The maximum value of $p(\omega)$ is

$$|p(\omega)|'=0,$$

$$|p(\omega)|_{\max}=\frac{T^{+}}{2}.$$

Taking 1/100 of the spectrum peak of shock wave signal to calculate signal bandwidth, the following results can be obtained as

$$\frac{\omega T^{+2}}{1+\omega^{2}T^{+2}}=\frac{1}{100}\frac{T^{+}}{2},$$

$$\omega_1=0,\ \omega_2=200\frac{1}{T^{+}},$$

$$f_1=\frac{100}{\pi}\frac{1}{T^{+}},\ f_2=0.$$

It can be known that the frequency of shock wave signal is below 200 kHz, the relationship between high frequency and positive action time can be got as

$$T^{+}\geqslant\frac{100}{\pi}\frac{1}{f}=0.15\ \text{ms}.$$

Affected by the circuit and sensors of the test system, the lower frequency is difficult to reach 0 Hz which is equivalent to a high frequency filter in a certain range, as shown in Fig. 3.

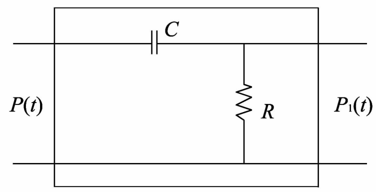


Fig. 3 High-pass filter

Suppose the time constant of high pass filter is

$$T=RC,$$

let $A=\frac{T_1}{T^{+}}$, then

$$P_1(t)=\left[\frac{A(A-2)}{(A-1)^2}-\frac{A\frac{t}{T^{+}}}{A-1}\right]e^{-\frac{t}{T^{+}}}+\frac{1}{(A-1)^2}e^{-\frac{t}{T^{+}A}}. \tag{5}$$

According to Eq. (4), if the measurement error of T^{+} is less than 5%, $A\geqslant 15$.

The lower cutoff frequencies of the piezoelectric sensor and the circuit are 0.01 Hz and 0.1 Hz, respectively, therefore the lower frequency of the test system is

$$\sqrt{0.01^2+0.^2}\approx 0.1\ \text{Hz}.$$

Then the range of the positive action time of the shock wave can be got by

$$T=\frac{1}{2\pi f_{\text{lower}}}=\frac{1}{2\pi\times 0.1\ \text{Hz}}\approx 1.592,$$

$$T^{+}\leqslant\frac{T_1}{A}=\frac{1.592}{15}\approx 100\ \text{ms}.$$

The time range is 0.15—100 ms.

2.3 Rise time

Robert Walker and Henry Wallman put forward a rule for the rise time, namely

$$\tau=(\tau_1^2+\tau_2^2+\cdots+\tau_n^2)^{1/2}, \tag{6}$$

where τ is overall rise time, and τ_n is the rise time of each stage. Accumulating each part of the rise time can make an overall assessment of the rise time of the test system.

Walker Henry and Wallman Robert also put forward another rule between rise and bandwidth. If τ is rise time, then the range of $\tau f_{-3\ \text{dB}}$ is 0.35—0.45.

Since the cutoff frequency of shock wave high-frequency signal is below 200 kHz, the shortest rise time of the test system is limited within the range of $\frac{0.35}{200\ \text{kHz}}=1.75\ \mu\text{s}$ and $\frac{0.45}{200\ \text{kHz}}=2.25\ \mu\text{s}$.

Generally considering the question conservatively, the shortest rise time 1.75 μs is adopted.

The shock wave signal rise time is ms level, therefore the range of the rise time is 1.75 μs—1 ms.

3 Interference signals

3.1 Impulse noise signal

The national military standard GJB349.28-90[7] in 1990 and GJB2A-96[8] in 1996 show the boundary of impulse noise and shock wave as 170.7 dB and 6.9 kPa, namely

$P(t)\geqslant 6.9$ kPa, shock wave signal;

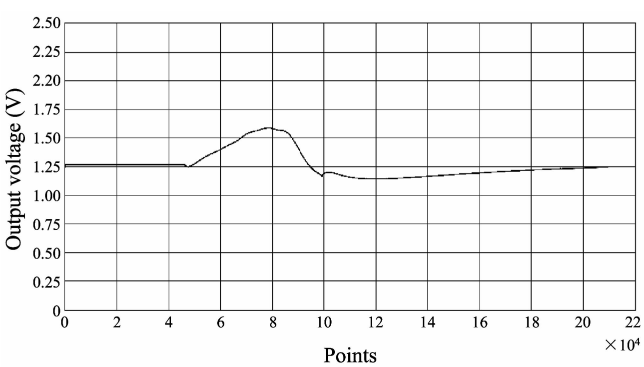
$P(t)<6.9$ kPa, impulse noise signal.

In summary, the shock wave signal can be defined by positive action time, rise time and overpressure peak value.

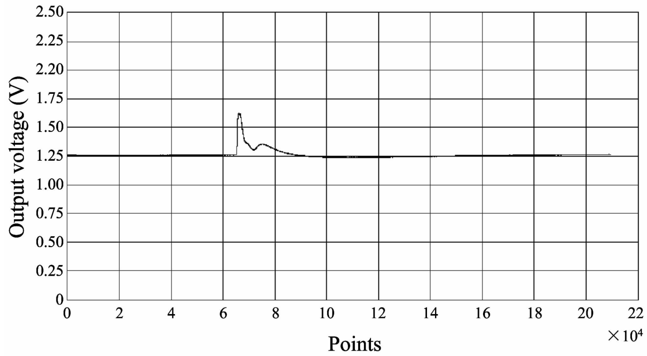
3.2 Contact interference signal

In actual range test, the false trigger is usually caused by many uncontrollable factor, for example the effect of stones and raindrops on system sensitivity. To analyze the characteristics of this type of noise, the knock signal and hit signal of different actions are collected.

Knocking the sensor with different hard objects, the signals are collected and shown in Fig. 4. Not matter which one, limited by the strength of signal, ise time and positive action time are larger than shock wave signal indicators.



(a) Knock signal (1)



(b) Knock signal (2)

Fig. 4 Knock signals

In the same way, when object falling from the sky to the sensor, hit signal is collected, as shown in Fig. 5. The signal can generate large-amplitude pressure at the moment the object hits the sensor, but the duration is very short. Therefore the positive action time is smaller than shock wave signal indicators.

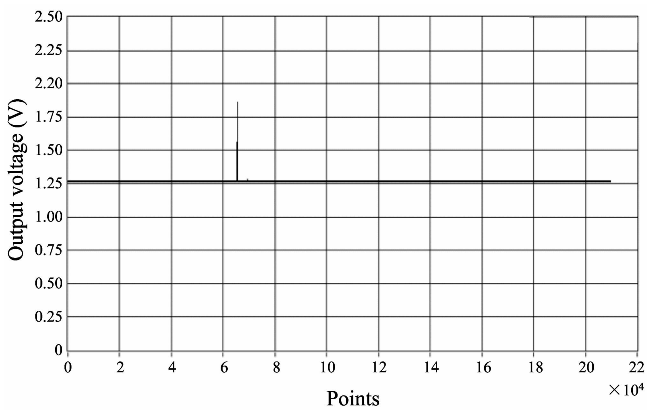


Fig. 5 Hit signal (3)

Analyzing these sgnals by means of Matlab, the results are shown in Table 1.

Table 1 Test results of interference signals

No.	1	2	3
Sampling frequency (MHz)	2	2	2
Data length (* 16 Mb)	2	2	2
Trigger level (V)	1.30	1.27	1.29
Overpressure peak (V)	1.591	1.627	1.863
Rise time (μs)	26 757	7 824	46
Positive time (ms)	422.69	261.5	0.111

4 Implementation of test nodes

In this paper, a wireless distributed test system based on transient pressure signal detection and recognition is studied. The circuit design include inductively coupled plasma (ICP) sensor, master chip FPGA, A/D converter, flash memory and WiFi communication module, etc. The overall circuit diagram is shown in Fig. 6.

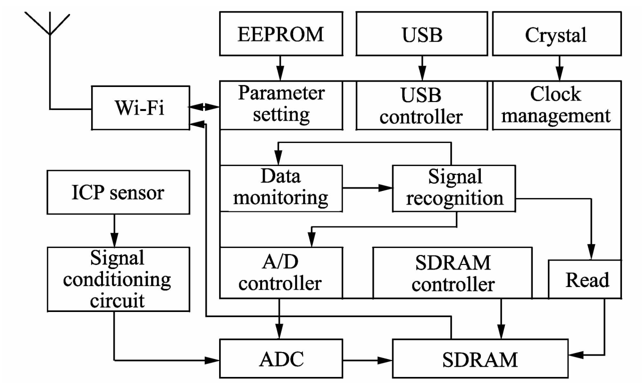


Fig. 6 Block diagram of system

Shock wave pressure sensor, signal recor circuit and wireless communication circuit form a shock wave pressure test node. The main function of the test node includes signal conditioning, data storage and wireless transmission. The system composition is shown in Fig. 7.

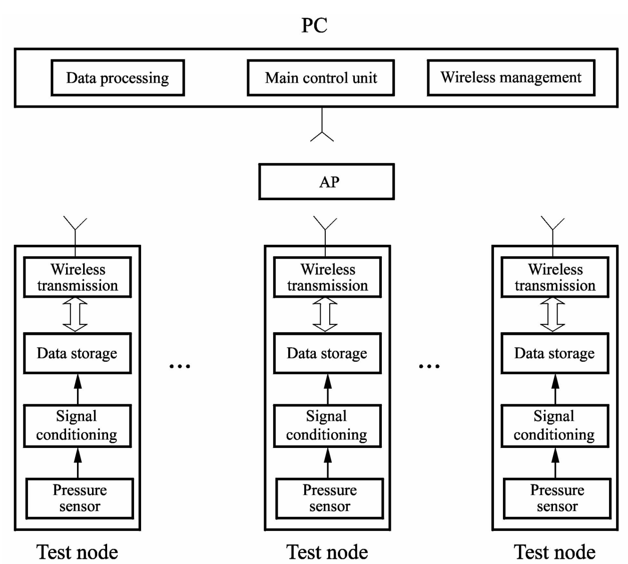


Fig. 7 Block diagram of pressure test node

The sensor signal is filtered, amplified and biased by the conditioning circuit and gets into the data storage module to be converted into digital signal by A/D converter. To meet the requirements of the test system, signal acquisition rate of the system is up to 2 Msps and conversion accuracy is 12 bit. In this test system, AD8231 by ANALOG DEVICES company is chosen which is a 12-bit chip with high speed, low power and successive approximation. It also has a parallel interface with the maximum throughput of 3 Msps. The digital signal is stored in SDRAM and finally is transmitted to wireless access point (AP) by means of communication module.

5 Experiments and analysis

In order to verify the reliability of the test system, the traditional test system as well as detection and identification test system are used to test under the laboratory conditions, respectively. By tapping the sensors of two test nodes and observing the indicator light of the test nodes, it can be shown that the traditional test system is triggered but the detection and identification test node is waiting for being triggered. The trigger signal is shown in Fig. 8.

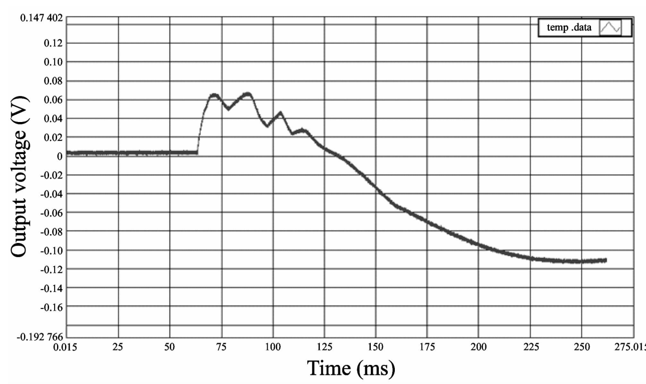


Fig. 8 Tap signal

Experimental results show that the test system based on signal detection and recognition technology can effectively prevent false trigger, therefore the designed distributed test system has high efficiency.

To verify the feasibility of the wireless distributed test system based on signal detection and recognition technology, it is used in site blasting trials with the distance of 70 m of a test node away from the blasting center installed, device preset magnification of 1.25 times and trigger level of 1.5 V. After test, the test node collects a complete shock wave signal of 160 ms, which meets the design requirements, as shown in Fig. 9. The analysis shows that the signal peak overpressure is 121.26 kPa, positive duration is 35.11 ms, and the momentum is 1 131.01 Pa • s.

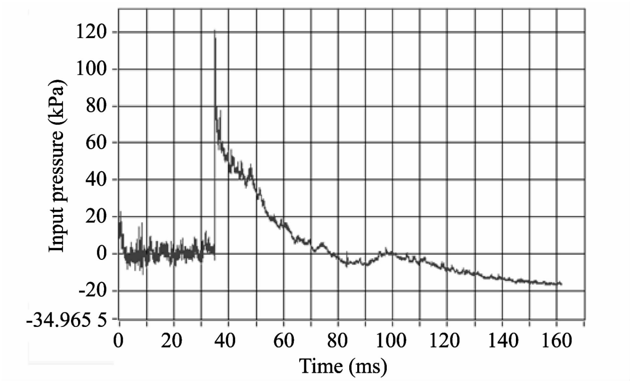


Fig. 9 Shock wave signal

6 Conclusion

For the shock wave pressure test in field explosion environment, signal detection and recognition technology is proposed. The test system can monitor signal level value at any time in the process of signal cycle collection, mark effective mutation and identify the next waveform. The system achieves sequential storage, which improves the anti-interference ability of the system.

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基于瞬态压力信号探测识别的无线分布式测试系统

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摘　要： 在爆炸场的瞬态压力测试过程中，现场干扰容易引起误触发导致测试失败。为了提高测试系统的稳定性，本文提出了一种信号探测识别技术用于压力测试系统。在信号循环采集过程中，通过实时检测电平值，标记有效突变，对有效数据段进行特征检测，从而识别出有效信号进行顺序采集。实验证明，该系统实现了冲击波信号有效采集、减少了干扰以提高测试可靠性。

关键词： 信号识别；冲击波信号；瞬态压力测试

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