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Design on Program-Controlled Initiation System of the SCB explosive devices Based on Optical Fiber Communication

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Design on Program-Controlled Initiation System of the SCB explosive devices Based on Optical Fiber Communication

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Abstract. A control system for Semiconductor Bridge explosive devices is designed based on optical fiber Communication, which can make the explosive devices perform better in the complex electromagnetic environment. By the combination of programmable bus controller, ignition unit and the optical fiber communication, the ignition of the explosive devices in chronological order could be realized. After the system design was completed, the major function and anti-electromagnetic interference capability were tested. The results indicated that the system had remote-control ability, high reliability, high security and good electromagnetic compatibility. The system can be used in more complicated electromagnetic environment than the conventional initiating explosive devices.

1. Introduction

With the advantages of small size, good synchronization and high safety, SCB (Semiconductor Bridge) explosive devices are widely used in many ignition mechanisms, rocket ignition devices, and so on. The ignition function of SCB explosive devices is realized by using semiconductor film as the ignition element [1~5], which features lower ignition energy than that of the bridge-wire explosive devices and faster acting time than that of the bridge-wire explosive device by 1-2 orders of magnitude due to the negative resistance effect. Combined with good synchronization performance, it has been widely used in the fields of smart weapons, satellites, ammunition, civil anti-collision airbags and blasting engineering, and so on. The new type of SCB explosive devices has been validated in stereotyped products to meet product safety requirements, showing high reliability in the condition that the ignition voltage is more than 11V with a certain margin of not less than 50μs. Besides, it has the advantages of lower ignition time with small dissociation and supporting simultaneous working of multiple mission.

With the development of science and technology, the coverage of radio radar is expanding and the application of electromagnetic pulse weapon is increasing. At the same time, the electromagnetic environment of the traditional electric explosive is becoming worse and worse [3~6]. In order to develop explosive devices working in complex electromagnetic environment, a large number of related studies have been carried out [7.8.9]. For example, the laser-ignition explosive devices have been invented [10 ~ 14]. However, there are still some key technologies of laser-ignition explosive devices that have not been solved effectively yet, such as continuous detection of the optical path, the test of the reflection characteristics of the optical windows [15.16]. Moreover, the cost is high and no mature products have been used in the experiments at present.

This paper introduces a programmable initiation system of the SCB explosive devices based on optical fiber communication. Combining the advantages of traditional electric-ignition explosive devices and laser-ignition explosive devices, the control signal and the initiation signal are separated by using the optical fiber as the communication medium. The control signal is converted by the optical fiber converter and transmitted to the ignition unit through the fiber, which adapts to the environment of harsh temperature, strong shock and vibration as well as the complex electromagnetic effect. The initiation signal is connected with explosive devices by a 1m-long shielded twisted-pair wire, to avoid accidental ignition caused by coupling electromagnetic energy. The system enables the characteristics of remote control, high safety, high reliability and high stability.

2. System Design and Test Scheme

2.1. System design

Program-controlled initiation system of the SCB explosive devices based on the optical fiber communication is divided into two parts, i.e. a bus controller (control end) and an ignition unit (trigger end). The bus controller is arranged at a remote operation end of the testing field, the control instruction is sent out by the microcontrollers and can be programmed. Then the control signal is transmitted to the optical fiber converter which converts it into the optical signal which can resist complex electromagnetic environment. The ignition unit is arranged at the working end of the testing field and is close to the explosive devices, of which the control system is also mainly composed of the microcontrollers. In the operation, the initiation signal is sent out after the control signal is received. The full-ignition confidence interval of the input voltage at the output end is between 14.42 V and 14.83V when the reliability is 0.999. The full-ignition confidence interval means that the explosive devices can be ignited when the voltage is greater than 14.4V and the width is broader than 50μs.

2.1.1. Bus Controller. The main function of the bus controller is to generate the control signal and encode the ignition sequence of several explosive devices, and simultaneously detect the current status of the explosive device. It consists of a power supply module, a screen, a keyboard, a master MCU module, a protective diode and a crystal oscillator, as shown in Fig. 1:

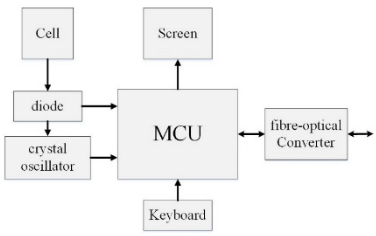

Fig 1. Structure diagram of the bus controller system

The cell mainly provides power supply for the screen and the MCU, consisting of an external power supply or batteries. The screen is an LCD used to synchronously monitor the status of SCB explosive devices and control multiple ignition units at the same time. The main control MCU and keyboard are the core components of the bus controller. The keyboard is used for the signal input. The main control MCU is a PIC18F4580 embedded microcontroller to program the 12-channel control signals, and the control time precision can reach 1ms. Each of the control signals uses PIC16F877A embedded microcontroller as the control module. The communication module adopts 485 bus with the isolation as the interface between the bus controller and the ignition unit. The control signal goes through a long-distance transmission in the form of optical signal via the optical fiber converter, i.e. RS485, as shown in Fig.2.

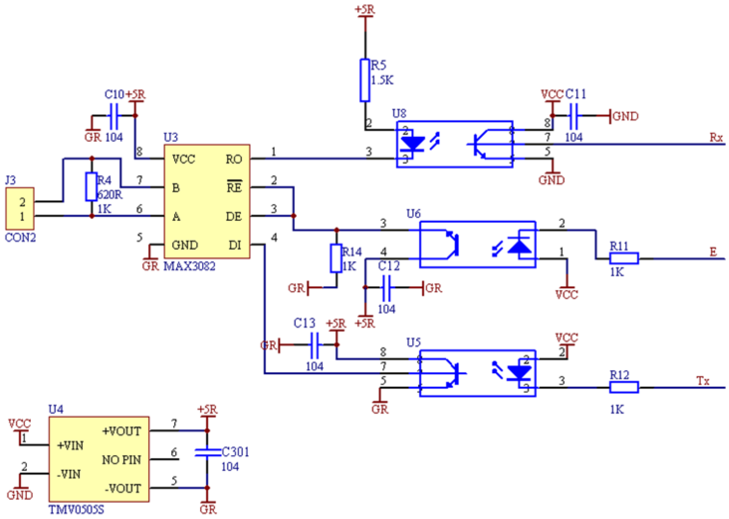

Fig 2. Schematic diagram of the RS485 communication interface isolation circuit

The principle of the isolation circuit is illustrated as below. The control signal is transmitted to the RS485 communication chip U3 after the isolation module of the optical coupling relays U5, U6 and U8. The electric-optical conversion is realized by the optical fiber converter, and the control signal is transmitted for a long distance in the form of optical signal via the single mode fiber. It enables the system to realize the long-distance reliable communication and the data transmission in the environment of harsh temperature, strong shock and vibration as well as complex electromagnetic circumstance.

2.1.2. Ignition unit. The main function of the ignition unit is to generate ignition energy and monitor the status of SCB explosive devices, consisting of power supply, isolation module, main control MCU module, ignition energy storage capacitance, ignition control switch, constant current power switch, resistance sampling circuit, optical fiber converters, optically coupled relays, and SCB initiators, etc., as shown in Fig. 3:

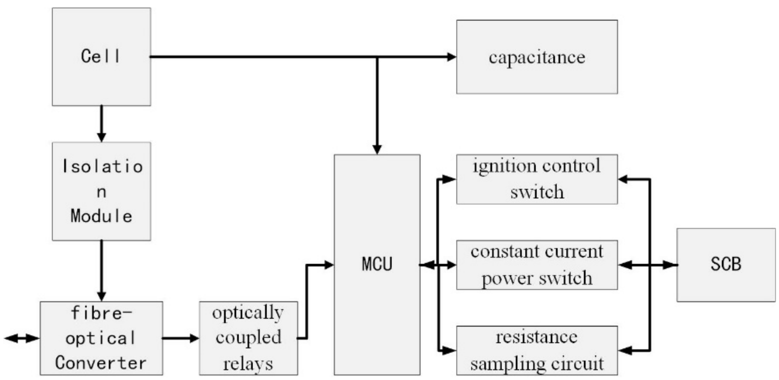

Fig 3. System diagram of the ignition control unit

The cell mainly provides energy for the main control MCU and the capacitance. The capacitance and the control switch output ignition energy to the SCB explosive device. The resistance sampling circuit monitors the internal resistance of the initiating explosive device and feedback the information to the main control MCU module. The main control module transmits the detected condition of the initiating explosive device to the LCD of the bus controller through the optical fiber converter, and sends the ignition signal to the explosive device after receiving the control signal.

The resistance sampling circuit detects the resistance value of the channel to be measured by a 10 mA constant current source. After the analogy signal processing circuit is processed, the AD collection is carried out by the MCU and then the measured resistance value is calculated. The status of the system can be monitored and returned to the bus controller without destroying the circuit and the working state of the SCB in the complex field by detecting the explosive devices' resistance. The schematic diagram of the detection circuit is shown in Fig. 4.

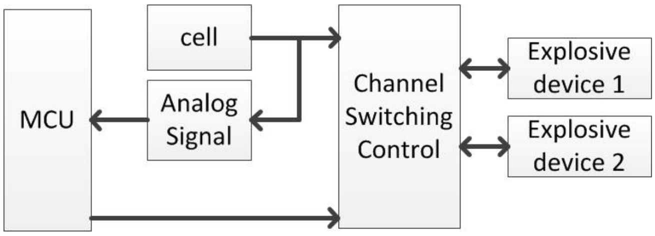

Fig 4. Principle block diagram of resistance detection circuit

2.1.3. Simulation. According to the basic composition of the ignition circuit, the simulation is carried out based on the circuit simulation software Proteus to determine the appropriate resistance and capacitance model. The simplified simulation circuit is shown in Fig. 5. The input voltage is set to 24V. The protection resistance value is set to 3000Ω to ensure the current safety in the circuit. The control signal is a pulse with time width of 50ms. The protection current of the MOS tube is 17A. The output of the system is simulated by changing the resistance R2 and the capacitance C1.

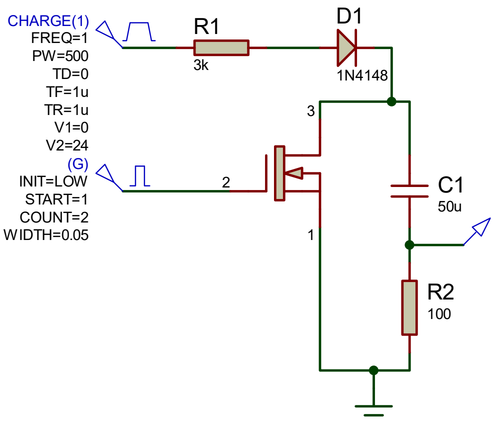

Fig 5. Design of equivalent simulation circuit

The parallel resistance value of the initiating explosive device is 100 Ω. The capacitance value is changed to 50,100,150,200μF, and the other conditions are fixed. In order to compare the simulation results, the delay time is set to 60ms. The simulation results are shown in Fig. 6. With the increase of the capacitance, the value of the negative pulse voltage decreases gradually, and meanwhile the time of the voltage drop increases gradually. Due to the characteristics of SCB explosive device, the capacitance value of 100μF is selected to meet the application requirements.

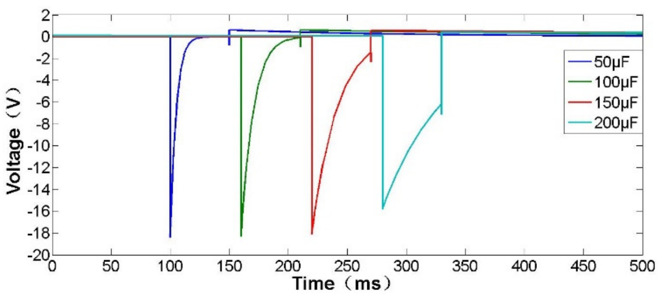

Fig 6. Effect of the capacitance value on the output signal

When the capacitance value is determined, the resistance value is changed, and the delay time is 60ms. The simulation results are shown in Fig. 7. With the increase of the resistance, the negative pulse voltage increases, but the increment is small. The increasing amplitude of the voltage drop time will result in large energy loss and increases the loss of circuit elements. When the resistance value is 100Ω, it can meet the application requirement.

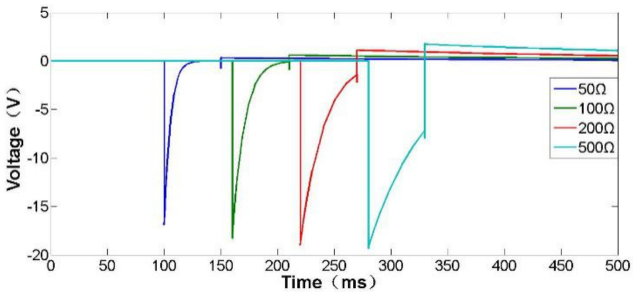

Fig 7. Effect of the resistance on the output signal

According to the simulation results, the ignition circuit is designed, as shown in Fig. 8. It consists of power-type MOS IRLR3410 and the circumjacent circuit elements. The energy-storage capacitance is parallel with two 220μF capacitors, and the parallel resistance value is 100Ω. When the control signal is transmitted to the ignition unit, the output port receives the high-level voltage signal. And then the MOS tube turn on, and the capacitor discharges to produce the negative pulse signal. At last, the SCB explosive devices is ignited.

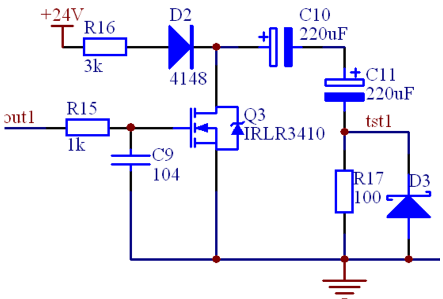

Fig 8. Working diagram of the ignition control unit circuit

2.2. *Experiment*

After the design, the basic characteristics and the anti-electromagnetic interference performance of the ignition control unit were tested. Furthermore, its synchronous and asynchronous initiation functions were tested respectively.

2.2.1. Ignition Unit Test. The ignition unit receives and processes the control signal, then determines the signal content according to the communication protocol, such as charging, ignition, detection and discharging. Aiming at the ignition performance of the ignition unit, the test is carried out.

The input signal of the ignition unit is a set of digital signals. Taking the first set of received signal as an example, i.e. AA 01 20 FF FF, 01 represents the sequence of the ignition control units and 20 represents the ignition instructions. The other bits are filled bits, and each bit adds a start-and-stop byte, where the start bit is 0 and the end bit is 1. The oscilloscope is connected to the output port of the optical fiber converter to monitor and record the ignition signals. The high voltage is 0 and the low voltage is 1. The results show that the signal integrity is good, and is consistent with the data content proposed in the communication protocol.

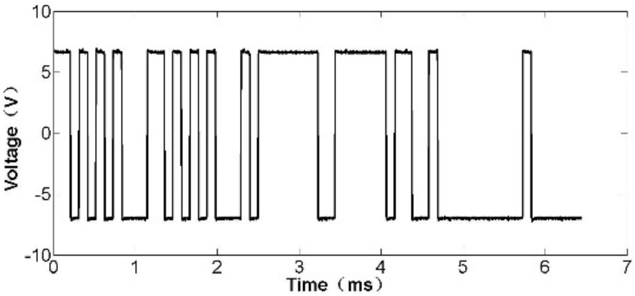

Fig 9. input signal of ignition control unit

2.2.2. Synchronous ignition experiment. The bus controller and the ignition unit are connected by a 1 km-long optical fiber. The ignition control unit No.12 is selected as the trigger signal source for the oscilloscope. The oscilloscope connected to 12 sets of ignition control units is used to monitor the output signal.

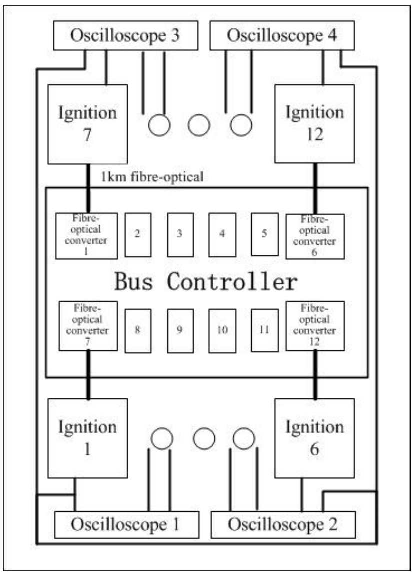

Fig 10. Diagram of experimental schematic

The output signal of the ignition control unit is monitored by the oscilloscope in synchronous mode. It is seen that when the 12-channel ignition units receive the control signal, the ignition signal is released synchronously. The ignition signal is a negative pulse of 16V with an operating time exceeding 10ms at 10V level. The test results show that the synchronous initiation effect is achieved and the ignition signal meets the application requirement.

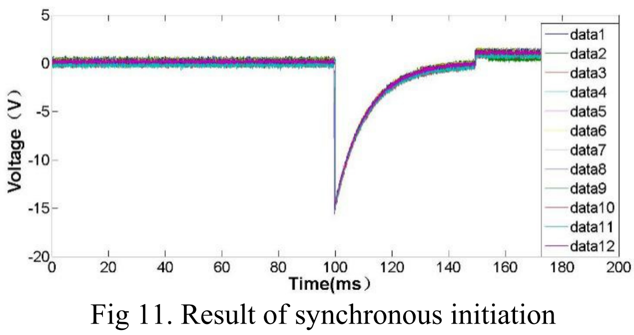

Fig 11. Result of synchronous initiation

Further, the synchronization performance of the synchronous signal is tested. Because the bus controller sends the initiation information by the broadcast signal and the propagation time of the optical signal in the optical fiber is neglected, the error of synchronous signal mainly exists in the ignition circuit. The maximum error time of the 12-channel ignition control units is about 40μs, which can meet the application requirements of most site test of SCB explosive devices, such as mineral development, aerospace testing, where multiple initiating explosive devices are required to work in different locations.

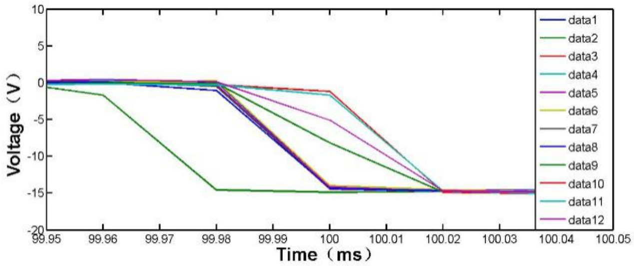

Fig 12. Error result of synchronous ignition

2.2.3. Asynchronous ignition experiment. Four sets of ignition units are chosen to realize asynchronous ignition mode, of which each two ignition control units comprises a group and the interval between the two groups is set to 100ms. The oscilloscope monitors and records the output signal. Two groups of the ignition units output the ignition signals after receiving the control signals. The two ignition units of each group simultaneously output the ignition signals, which meets the requirements of program-control design and realizes the asynchronous ignition function. This function is suitable for site test where time-sequential ignition is required, such as stratospheric airship release.

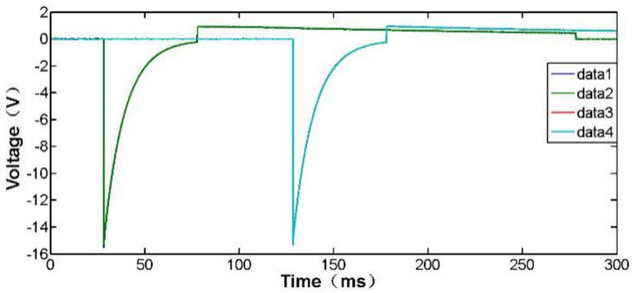

Fig 13. Results of group ignition

2.2.4. Anti-Electromagnetic interference experiment. As a signal transmission medium, the optical fiber is almost not subject to the electromagnetic interference. Besides, the initiating explosive device itself has good anti-electromagnetic interference performance. Moreover, the shielded twisted-pair is adopted to connect the ignition unit and the explosive device. So, the main factors that affect the anti-electromagnetic interference ability of the system are the conduction interference caused by the connection among the power lines and the radiation interference caused by the exposed shielded wires.

The main way of the conduction interference test is to add interference signal to the power cord，including two items as below：

1） The signal with the peak value of 200V, the pulse width of 0.15μs and the repetition rate of 8pps is applied to the positive and negative poles of the ignition units for 3min.

2） Five kinds of damped sinusoidal transient signal with the repetition frequency of 1 pps were applied to the power supply wires respectively, i.e. 0.5A/0.1MHz, 5A/1MHz, 5A/10MHz, 5A/100MHz, and each frequency wave is applied for 5 min.

As a result, no wrong ignition signal is detected at the output of the ignition unit. When the ignition unit issues the ignition command, the ignition signal can be normally monitored. The detected output signal is shown in Fig. 14.

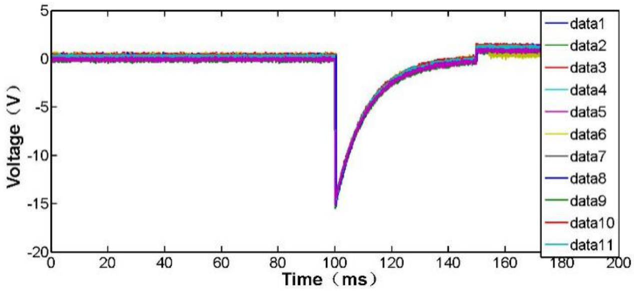

Fig 14. Experimental results of anti-electromagnetic interference

According to the relevant literature [17,18], the main factors affecting the radiation strength of the shielded twisted pair include the material, pitch, length and end exposure of the twisted pair. The test method of the radiation interference is using the laboratory-standard device which can generate transient electromagnetic pulse electric field to produce electric field whose internal electromagnetic field is spherical traveling wave. The twisted-pair cable is a copper-core insulated light-duty shielded cable. The conductor structure is made of 19 single copper wires with diameter of 0.12 mm. In the experiment, the length of the twisted pair is 1 m, the pitch is 20mm, and the bare end is set to 70 mm. The twisted pair is placed on a mirror with an arc shadow centered at the feed point with a radius of 0.3 m, where the maximum field strength is 400 V/m and the width is 0.5 ns, as shown in the Fig. 15.

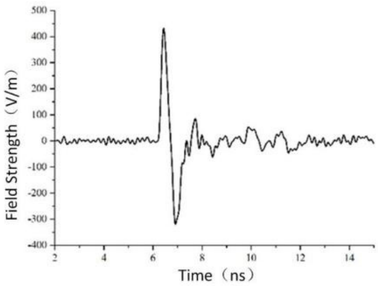

Fig 15. Electric field intensity distribution

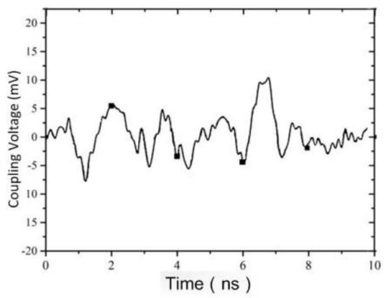

Fig 16. Coupled voltage result of twisted-pair wire

The coupling voltage is recorded by the oscilloscope, and the maximum coupling voltage is about 10mV, as shown in Fig. 16. It is far lower than the minimum ignition voltage of the confidence interval voltage of the SCB explosive devices, even though the experimental conditions are much higher than the standard electric field intensity (20-50V/m) in the site test, which indicates that the system can still work normally under the condition of strong electromagnetic interference.

3. Conclusion

The program-controlled initiation system of the SCB explosive devices based on optical fiber communication consist of bus controller and ignition unit, which not only realizes the remote-control in the test to ensure the safety of the tester, but also improves the safety and reliability of SCB explosive devices in complex electromagnetic environment. The system has the programmable ability to realize the time sequence control of single point to multi-point initiation, and the control precision can reach 1ms. The system combines the advantages of the traditional electrical explosive device and the new laser initiating device, realizes the stable and reliable initiating control mode of the explosive device. However, the separation of the control signal and the ignition signal makes the system complex. It is necessary to ensure reliability of the control program, fibre-optical performance, bus performance and hardware switch reach, to realize the effective ignition of the SCB explosive devices.

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