Study on the Gas Detonation Experimental System of Human Body Electrostatic Discharge

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Abstract—The modeling system of the gas detonation by the human body electrostatic discharge (ESD) in coal mine is developed successfully, and the body’s dynamic ESD model is established. To obtain a gas concentration causes by the explosions most easily in coal mine environment. The results provide an academic and experimental evidence for the safe electrostatic production and management in coal mine. The system adopts 77E58 as control core and the circuit optimized design, to take dual protection to the gas path and circuit of the system, systematic operation is safe and reliable. The experimental results show that the system can be carried out series of experiments of the human body ESD model detonating mixed gas, the measuring accuracy of gas concentration is 0.1%. And draws a conclusion that the gas concentration which causes the explosions most easily is 8.7%, but not the higher gas concentration is, the more explosive is.

Keywords—microcontroller; experimental system; design hardware; design software; ESD model.

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1 Introduction

The static electricity discharge is ubiquitous in the dry environment, electrostatic charge can gather together into static source which can go up to ten thousand volts, the burning and blast will be made in case of form loop, and will cause serious casualties and serious damage to property. Static is one of the sources of gas blast, according to statistics, during tenth five year, the death number is over 8694 people only due to gas blast in China’s coal mine, the death toll accounted for 34 percent of coal mine safety of China’s production\(^1\), accounted for 37.69 percent during the eighth five-year plan, and 50.79 percent during the ninth five-year plan. After testing we found that the peak of the dynamic electrostatic potential on human body is 10 times of normal working human body. So, discharging of the dynamic static electricity is more hidden, dangerous and accidental. As gas concentration is high in coal mine, diffusing difficulty, the range of gas concentration which can result in blasting may be reached easily, and underground worker can be equivalent to the moving isolated static body, the friction between worker’s dress and external material produce a lot of the accumulation of electrostatic charge, which provided for the gas detonated the basic condition. So research and development of electrostatic discharge on human body result in detonate gas simulation test device, accessing to some of the important data of the detonating gas provide a scientific, theoretical and experimental basis for coal mine safety production and management. The experimental device can measure the gas concentration of explosion and electrostatic potential on human body discharge, resistance and capacitance values by different oxygen concentration and temperature.

2 Principle of the system

2.1 A Construction of ESD model and its parameter

ESD model consists of RC circuits, among that, capacitance includes two parts: one part is Cg that is the capacitance between tread and ground, the other part is Cs that see the human body as a isolate conductor between the walls or the space.
capacitance is $C = C_g + C_s$. Human body’s resistance is discharge loop. As shown in figure. 1.

![Figure 1. Human body ESD model](image)

By simulating the stainless steel tube of the narrow trench, we tested the different weight, height and full miners dress (uniform labeling) boys, and randomly selected 10 male in 60 students from the measured data, and the measured data suchas table 1, table 2.

Where SR-AS is the abbreviatioen of Surface resistivity of antistatic shoe and VR-AS is volume resistivity of antistatic shoe and HB-ESC is human body electrostatic capacitance.

Experiments show that: the human body capacitance has little to do with height and weight, but have to do with the antistatic capability, human body electrostatic capacitance range from $350 \sim 4000\, \text{pF}$.

Table 1 Human body capacitance of the boy

<table>
<thead>
<tr>
<th>No.</th>
<th>SR-AS $\rho_s/\Omega$</th>
<th>VR-AS $\rho_v/\Omega \cdot \text{m}$</th>
<th>HB-ESC $C/\text{pF}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>$1.6 \times 10^6$</td>
<td>$4.2 \times 10^5$</td>
<td>39000</td>
</tr>
<tr>
<td>2</td>
<td>$1.6 \times 10^6$</td>
<td>$1.2 \times 10^6$</td>
<td>28000</td>
</tr>
<tr>
<td>3</td>
<td>$5.7 \times 10^7$</td>
<td>$3.0 \times 10^6$</td>
<td>24000</td>
</tr>
<tr>
<td>4</td>
<td>$3.3 \times 10^7$</td>
<td>$4.8 \times 10^6$</td>
<td>18500</td>
</tr>
<tr>
<td>5</td>
<td>$5.7 \times 10^7$</td>
<td>$1.2 \times 10^7$</td>
<td>15000</td>
</tr>
<tr>
<td>6</td>
<td>$9.8 \times 10^8$</td>
<td>$1.5 \times 10^7$</td>
<td>14000</td>
</tr>
<tr>
<td>7</td>
<td>$5.1 \times 10^9$</td>
<td>$2.2 \times 10^8$</td>
<td>3280</td>
</tr>
<tr>
<td>8</td>
<td>$6.5 \times 10^10$</td>
<td>$3.4 \times 10^9$</td>
<td>2800</td>
</tr>
</tbody>
</table>

Test conditions: humidity: 49%, temperature: 26°C

Test of dynamic resistance of human body: according to the principle of RLC series vibration damping \(^{[2-4]}\) $C$ is human-to-ground capacitance. $R$ is resistance of total consumption. $L$ is the inductance coil of the tested line, as shown in figure. 2.

Table 2 Human body capacitance of different boys

<table>
<thead>
<tr>
<th>No.</th>
<th>Height $H$ $\text{cm}$</th>
<th>Weight $W$ $\text{kg}$</th>
<th>SR-AS $\rho_s/\Omega$</th>
<th>VR-AS $\rho_v/\Omega \cdot \text{m}$</th>
<th>HB-ESC $C/\text{pF}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>172</td>
<td>60</td>
<td>$4.1 \times 10^6$</td>
<td>$2.7 \times 10^9$</td>
<td>1700</td>
</tr>
<tr>
<td>2</td>
<td>168</td>
<td>66</td>
<td>$4.1 \times 10^6$</td>
<td>$2.7 \times 10^9$</td>
<td>1300</td>
</tr>
<tr>
<td>3</td>
<td>165</td>
<td>80</td>
<td>$4.1 \times 10^6$</td>
<td>$2.7 \times 10^9$</td>
<td>1600</td>
</tr>
<tr>
<td>4</td>
<td>180</td>
<td>70</td>
<td>$4.1 \times 10^6$</td>
<td>$2.7 \times 10^9$</td>
<td>1500</td>
</tr>
<tr>
<td>5</td>
<td>170</td>
<td>64</td>
<td>$4.1 \times 10^6$</td>
<td>$2.7 \times 10^9$</td>
<td>1700</td>
</tr>
<tr>
<td>6</td>
<td>168</td>
<td>57</td>
<td>$4.1 \times 10^6$</td>
<td>$2.7 \times 10^9$</td>
<td>1900</td>
</tr>
<tr>
<td>7</td>
<td>175</td>
<td>80</td>
<td>$4.1 \times 10^6$</td>
<td>$2.7 \times 10^9$</td>
<td>1800</td>
</tr>
<tr>
<td>8</td>
<td>176</td>
<td>67</td>
<td>$4.1 \times 10^6$</td>
<td>$2.7 \times 10^9$</td>
<td>1400</td>
</tr>
<tr>
<td>9</td>
<td>170</td>
<td>57</td>
<td>$4.1 \times 10^6$</td>
<td>$2.7 \times 10^9$</td>
<td>1400</td>
</tr>
<tr>
<td>10</td>
<td>178</td>
<td>69</td>
<td>$4.1 \times 10^6$</td>
<td>$2.7 \times 10^9$</td>
<td>1700</td>
</tr>
</tbody>
</table>

Test conditions: humidity: 48%, temperature: 24°C
Discharge to L after the human body charged, vibration current is formed. According to current waveform envelope, the dynamic resistance of human can be calculated. When the right time to switch losing, loop current i, there are equation

\[ LC \frac{d^2 i}{dt^2} + RC \frac{di}{dt} + (1 + C \frac{dR}{dt}) i = 0 \]

(1)

Chose to test system, let \[ R \frac{C}{2 \sqrt{L}} < 1, C \frac{dR}{dt} < 1 \]

According to the initial conditions get the root of equation:

\[ i = \frac{U_0}{BL} e^{-\frac{t}{2L}} \sin(Bt) \]

(2)

Where

\[ B = \sqrt{\frac{1}{LC} \left(1 - \frac{R^2C}{4L}\right)} \]

(3)

\[ U_0 \] is the human-to-ground start voltage.

by \[ \frac{di}{dt} = 0 \]

\[ \sin(Bt) = \frac{B^2 + B^2}{\sqrt{B^2 + R^2/4L^2}} \]

(4)

Take it into, get the Envelope equation:

\[ i' = U_0 \sqrt{\frac{C}{L}} e^{-\frac{Kt}{2L}} \]

(5)

Test of dynamic resistance of human body will decline due to the increase of discharge voltage. Imposing discharge voltage of 500V on the human body would reduce dynamic resistance of human body to under 300Ω. Resistance of human body is in the range of several hundred to thousands of ohms.

2.2 Construction of Control System

Because the gas detonating experiment have a definite risk and a series of operation of experiment is controlled by host machine, automatic control the operations status of methane, the air intake measurement, the air back measurement and static on human body discharge unit. Take the protection of interlocking control both software and hardware, display the data measured by real time, that is, oxygen concentration, cavity temperature, gas concentration and system status.

3 System analysis and design

The system consists of cylindrical cavity experiment, electrostatic discharge on human body to detonate gas unit, control unit, gas examination unit, oxygen examination unit, temperature unit, alarm, display and host machine etc, block diagram such as figure. 3. Gas surveying sensor is the key device of system. Measuring accuracy and stability is crucial to the system performance. The system adopts gas sensor of non-dispersive infrared and electric modulation (NDIR) of high accuracy, the measuring accuracy is 0.1%, high dependability. The optical part consists of three parts: source and air chamber and detector, standard output is 4-20mA.

The system can simulate gas mixed environment of the narrow coal trench, carrying out oxygen density, threshold concentration of the gas explosion at different temperature and human body discharge electric potential, resistance and capacity value measurements.

3.1 Chip Microcomputer

It is the system center: data acquisition and processing and display on big screen of the gas concentration, oxygen concentration and temperature, control ignition part of human body ESD detonation
unit, sequence control of each solenoid valve action, communication with host machine and accepting the orders issued.

3.2 Human body ESD detonation unit

It consists of the experiment cavity, the human body ESD unit and high-voltage source. It is a closed device consisting of organic glass. The solenoid valve control by the single-chip microcomputer let gas enter the experiment cavity to simulate the narrow mine tunnel environment. The human body ESD unit: It consists of human body RC circuit and the point turn on electricity. The RC circuit is charged by high-voltage source in order to realize high voltage tip discharge.

4 Design and development of system

4.1 Design of hardware

As showed in figure. 4 is Principle circuit of system, Adopting microcomputer of 77E58 chip as the control core. The P0 port used to methane inlet, the air intake measurement, the air back measurement and each port of the cusp discharging solenoid valve, It isolates through photoelectric coupler 521-X; P2 port connect with TLC2543, going along temperature, oxygen, gas conversion; P1.0, P1.1 used to Serial Interface, connecting with host machine through MAX232 and watchdog circuit X25045. Selecting type QB2000 of standard output 4-20mA. Used to measure the oxygen, using type DS18B20 digital temperature sensor of the highest resolution 0.0625℃ and measuring accuracy ±0.5℃ measure the temperature of the experiment cavity.

4.2 Design of software

The system used WeiFu simulator. The control process was written by assemble language and module, the main modules design include contents: main program module, data acquisition module, Data Processing module, Serial communication module, detonating process controlling module etc.

Main flow chart is shown in figure.5. The system initialization includes setting clock, phase-locked loop, watchdog, timer_ B, timer _A and serial port P1.0, P1.1 startup.

![Figure 5](image)

Fig 5. The flow chart of main program

Display subprogram: constantly refreshing the data displayed, through the timer interrupt.

Data Acquisition: through I / O port, timer to read data of the gas concentration, oxygen concentration, temperature and other sensor transformation, through the conversion to send large-screen display. Serial communication format: data format of 8N1. The command code F1 is measurement into, F2 is measurement out, F3 is gas into, E2 is activation of the cusp discharging component of human body ESD unit, E3 is initial state, EE is changing the display mode, F0 reset function.

5 Experimental results

The gas detonation experimental system of human
body electrostatic discharge, discharge to the mixed gas experiment cavity and adjusting gap of the human body ESD unit. Gas concentrations increase from low to high until to set off gas. As showed in table 3 is the experimental data and in figure 6 is photo of the gas explosion.

![Photo of the gas explosion](image)

**Fig 6.** Photo of the gas explosion

<table>
<thead>
<tr>
<th>No.</th>
<th>gas oxygen %</th>
<th>ESR pF</th>
<th>gap mm</th>
<th>HB-E SC</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>8.4</td>
<td>20.9</td>
<td>336</td>
<td>0.3</td>
</tr>
<tr>
<td>2</td>
<td>8.4</td>
<td>20.9</td>
<td>336</td>
<td>0.6</td>
</tr>
<tr>
<td>3</td>
<td>8.5</td>
<td>20.8</td>
<td>336</td>
<td>0.9</td>
</tr>
<tr>
<td>4</td>
<td>8.5</td>
<td>20.8</td>
<td>336</td>
<td>0.9</td>
</tr>
<tr>
<td>5</td>
<td>8.4</td>
<td>20.8</td>
<td>336</td>
<td>1.2</td>
</tr>
<tr>
<td>6</td>
<td>8.5</td>
<td>20.8</td>
<td>336</td>
<td>1.2</td>
</tr>
<tr>
<td>7</td>
<td>8.7</td>
<td>20.8</td>
<td>336</td>
<td>1.2</td>
</tr>
</tbody>
</table>

Test conditions: humidity: 52%, temperature: 22°C

### 6 Conclusion

By this system the results of Massive experiments showed that: It has the advantages of process operation simple, safe and reliable and steadiness, clear display and visual etc. It can carry out a series of experiments of the human body ESD model to detonate mixed gas. It has great practical value. Gas concentration measurement accuracy is 0.1% When the capacitance of the human body is 1800pF, as long as the human body provide 600-volt electrostatic voltage, not only can produce more than 0.28mJ energy of human body electrostatic discharge to meet the to detonating gas, but also provide field strength which can puncture the gas gap of 0.3mm mixed gas, To provide adequate gas blasting conditions. Most likely to set off gas concentration is about 8.4 ~ 8.7%, rather than the more easily the higher concentration to detonate gas.

### References


