Research on simulation of human body electrostatic discharge on detonating gas in coal mines

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Abstract. Static electricity is one of the reasons for gas explosions in coal mines. When miners leave the narrow tunnel exit of a coal mine, the body voltage may increase by more than ten times with the body capacitance decreasing quickly to 1/10 of its original value, and the body electrostatic discharge (ESD) energy can increase greatly to become a dangerous gas ignition source. In this work, simulation research of human body ESD detonating the gas in a coal mine was conducted. Based on the analysis of the human body electrostatic leakage rules, it is found that electrostatic half-life is mainly relative to the medium resistivity. Therefore it is important to establish a standard for anti-static attire. A series of gas explosion experiments were also conducted by the simulation system, and the results showed that the gas in coal mines might be detonated when the human body capacitance was in the range of 100-1800 pF and the discharge gap between 0.3-1.2 mm. Moreover, gas concentration at approximately 8.5% was most likely to induce an explosion.

1. Introduction
In recent years, many coal mine accidents have happened, especially for gas explosion accidents have happened frequently in the coal mine. Gas explosion occurs for a variety of reasons. As one of the natural hazard sources of society; electrostatic discharge always caused a great of loss and damage [1]. For the gas explosion caused by electrostatic discharge, it is usually think that some insulating materials such as high-polymers produce static spark discharge in the coal, but ignore that the human body is an isolated conductor producing electrostatic discharge [2, 3]. In fact, the human body electrostatic discharge is more danger than that of material in coal mine. Therefore, it is necessary to investigate human body electrostatic discharge [4]. In this work, the relationship between electrostatic discharges of human body and gas explosion under different conditions in coal mine environment has been investigated.

2. Human body electrostatic potential
In this experiment, JDY–3A electrostatic potential dynamic tester and TDS1001B oscilloscope are used to test the electrostatic potential of miners in the coal mine, as shown in figure 1 (a). It is the peak waveform figure of human body electrostatic potential when miners take off rapidly, the peak value of the transient voltage is more than ten times, and the figure 1(b) is the peak waveform of human body electrostatic potential when miners fall suddenly, the peak value of the transient voltage is more than ten times. When the body voltage rise suddenly ten times such as from 50 V to 500 V, the human body

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resistance is reduced to 1/10 the original or less, it affords the conditions for electrostatic rapid leakage.

3. Human body capacitance
Miners work is in the narrow tunnel of underground mining. The tunnel around the human body is coal wall, and the coal is conductor. We have designed a stainless steel cylinder of 1 meter in diameter and 3 meters high to simulate the narrow tunnel in mine. Men and women with different height and weight, in miners’ clothes and dressed in different resistivity antistatic boots go into the cylinder, and the human body capacitance in different locations are tested simulated in narrow tunnel.

![Figure 1. Peak waveform figure of human electrostatic potential.](image1)

Figure 1. Peak waveform figure of human electrostatic potential.

Figure 2 shown human’s capacitance depend on the surface resistivity of anti-static boots; figure 3 shown human’s capacitance depend on the volume resistivity of anti-static boots.

![Figure 2. Human’s capacitance depend on the surface resistivity of anti-static boots.](image2)
Figure 3. Human’s capacitance depending on the volume resistivity of anti-static boots.

Table 1 shows the human body capacitance’s results in the different locations of the tunnel. The conditions are as follows: temperature is 19°C, relative humidity 35%, height range 158-181 cm, and weight 50-73 kg. Outside was referred to the capacitance out of the cylinder, which was only 145-175 pF. And inside, the capacitance was not much difference. Obviously, the human body capacitance had no direct relation to human’s sex, height and weight. The results shown that the outside capacitance of the cylinder is obviously lower than inside, the human body capacitance increased ten times in tunnel more than it at other place. When the miners are in the narrow tunnel exit, the capacitance reduces to rapidly less than a tenth than it in the tunnel. When the human body static electricity did not change significantly, human body voltage will suddenly increase more than ten times. It’s easy to be a source to ignite the gas. Therefore, the narrow tunnel exit is easy to be the source for accidents of human body electrostatic discharge.

Table 1. Results of human body capacitance in different locations of the narrow tunnel. (Temperature: 19°C, Relative humidity: 35%).

| Number | Sex | Height (cm) | Weight (kg) | Outside | Front | Center | Back | Right |
|--------|-----|-------------|-------------|---------|-------|--------|------|-------|
| 1      | male| 170         | 67          | 155     | 2610  | 2820   | 2620 | 2730  |
| 2      | male| 173         | 72          | 150     | 2400  | 2810   | 2800 | 2610  |
| 3      | male| 181         | 73          | 155     | 2710  | 3020   | 3000 | 2700  |
| 4      | male| 177         | 72          | 160     | 1700  | 1550   | 1520 | 1300  |
| 5      | male| 170         | 60          | 145     | 2900  | 3050   | 2910 | 2720  |
| 6      | female| 158       | 54          | 175     | 2800  | 3200   | 3150 | 2820  |
| 7      | female| 162       | 50          | 150     | 1800  | 2180   | 2100 | 2200  |
| 8      | female| 167       | 57          | 155     | 1610  | 1950   | 1520 | 1810  |
| Average|     | 156         | 2316        | 2573    | 2453  | 2361   |      |       |

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4. Human body electrostatic leakage rules

Human body static electron leaks in two ways, one is the medium surface, and the other is the medium inner. The former is related to surface resistivity, the latter is related to volume resistivity. The electrostatic leakage rules can be expressed by discharge half-life.

A gaussian face is taken from inner of the medium, the current through the closed surface between the current density vector \( \vec{\delta} \) and medium electrical quantity \( Q \) meet:

\[
I = \int_S \vec{\delta} \cdot d\vec{S} = -\frac{dQ}{dt},
\]

\( \vec{E} = \rho \vec{\delta} \)

\[
\int_S \vec{E} \cdot d\vec{S} = \frac{Q}{\varepsilon_0 \varepsilon_r}
\]

\[
\int_S \rho \vec{\delta} \cdot d\vec{S} = -\rho \frac{dQ}{dt}
\]

or

\[
-\rho \frac{dQ}{dt} = \frac{Q}{\varepsilon_0 \varepsilon_r}
\]

\[
\frac{dQ}{dt} = -\frac{dt}{\varepsilon_0 \varepsilon_r \rho}
\]

\( Q' = Q e^{-\frac{t}{\varepsilon_0 \varepsilon_r \rho}} \)

The time of electrical quantity leakage 1/2 is half-life,

\( Q' = \frac{1}{2} Q \), so

\[
\frac{1}{2} = e^{-\frac{\tau_{1/2}}{\varepsilon_0 \varepsilon_r \rho}}
\]

or

\( \tau_{1/2} = 0.69 \varepsilon_0 \varepsilon_r \rho \)

\( \tau_{1/2} \) is electrostatic half-life, \( \varepsilon_0 \) is vacuum dielectric constant, \( \varepsilon_r \) is relative dielectric constant, the value is from 3 to 9, electrostatic half-life is mainly relative with the medium’s resistivity. Therefore the index of the miners’ clothes anti-static is vital whether it is qualified.

5. Human body electrostatic discharge model detonated gas experiment

The apparatus is “Human body electrostatic discharge model detonated gas experiment system”. The system is composed with gas mixture cavity, control unit, gas measuring unit, oxygen measuring unit, temperature measuring unit, body ESD model ignition devices, alarm display, PC and gas supply device. The system frame is shown in figure 4. The measurement accuracy of the gas concentration and the oxygen concentration for the system is 0.1%.
The experiment is carried out in the closed cavity, and the simulation system is controlled by computer, the cavity supply with the gas by gas supply device, and the environmental conditions oxygen content 20.9%, mixed gas temperature 22°C, and humidity 48%. The experiment began from gas concentration 5% slowly increased at a speed of 0.1% s⁻¹, until the gas concentration is up to 16%. In addition, the temperature, the concentration of oxygen and the gas were measured by sensors and infrared analyzer in different time. Different body capacitances are chosen to ignite, simulate different human body capacitance in the coal. Through adjusting the discharge gap, observe the detonation in the tunnel. Detailed data is shown on table 2. It is seen that the gas may be detonated, where the human capacitance range change in 100-1800 pF and the discharge gap is between 0.3-1.2 mm. And the gas concentration at approximately 8.5% is most likely to induce explosion.

| Number | Gas concentration (%) | Human body capacitance (pF) | Human body resistance (Ω) | Discharge gap (mm) | Result |
|--------|-----------------------|-----------------------------|--------------------------|-------------------|--------|
| 1      | 8.8                   | 1800                        | 250                      | 0.3               | explosion |
| 2      | 8.5                   | 950                         | 350                      | 0.6               | explosion |
| 3      | 8.3                   | 489                         | 350                      | 0.6               | explosion |
| 4      | 8.4                   | 470                         | 350                      | 0.9               | explosion |
| 5      | 8.2                   | 280                         | 350                      | 0.9               | explosion |
| 6      | 8.7                   | 150                         | 350                      | 1.2               | explosion |
| 7      | 8.7                   | 100                         | 350                      | 1.2               | explosion |

Figure 4. System diagram.
6. Summary
At moving action, the body’s electrostatic potential increase instantly more than ten times when people get out of the narrow tunnel exit, the human body’s capacitance reduced instantly to only a tenth of the original, so the body’s voltage increase instantly more than ten times, discharge energy increase greatly becoming a dangerous source to ignite gas. Based on the analysis of the human body electrostatic leakage rules, electrostatic half-life is mainly relative with the medium resistivity. Therefore the index of the miners’ clothes anti-static is very important. The results shown: The human body capacitance range is in 100-1800 pF and the discharge gap is between 0.3-1.2 mm, it easily detonates the gas, and the gas concentration at about 8.5% is most likely to induce explosion.

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