Effects of electrostatic discharge on the performance of exploding bridgewire detonators

Zhipeng Li∗, Ying Liu, Panjun Zhang, Zijian Lv, Yong Tian
Institute of Chemical Materials, China Academy of Engineering Physics, China
E-mail: lzpsunny@sina.com

Abstract. The performance of exploding bridgewire detonators affected by electrostatic discharge (ESD) were studied by microfocus X-ray industrial computed tomography (μCT), and high voltage stimulus to detonators was provided by an ESD simulator. Two stimulation modes were investigated, and the performance indexes of detonators after ESD were tested. The results show that there was no obvious change in bridge resistance when detonators were simulated by the mode of Pin-Pin, while the primary explosive of detonators was partly damaged by the mode of pin-shell, and the performance indexes of 2 detonators were affected by ESD. The reasons for this phenomenon were analyzed. This work contributes to understanding the performance of exploding bridgewire detonators affected by ESD.

1. Introduction

With the development of technology, the application of polymer material, micro-electronic devices and electricity explosion device has been becoming more and more extensive. At the same time, the problems caused by ESD have been paid great attentions [1]. Through the coupling and transfer of energy, ESD could make materials react. The process of heat effect could be considered as adiabatic because ESD can finish in nanoseconds or microseconds. Some serious accidents could happen when detonators were ignited by ESD.

The previous research on safety performance was mainly focused on the effects after ESD of detonators. However, for the weapon systems, the reliability of detonators is also very important. Especially with the reliability of weapon system improved, there are more requirements for both electrostatic safety and reliability. For example, it is clearly required in MIL that the reliability should not be reduced after ESD. The performance of four kinds of high-energy hot bridgewire initiators and three kinds of exploding bridgewire detonators were tested by US researchers, the results show that some problems were caused by ESD stimulus, which included detonators could not be ignited normally, or beyond the range of non-ignition or all-ignition range, the action time and threshold of exploding current were somewhat increased [2]. Qi and co-workers [3] have studied the influences on constant current igniting time of electric igniter caused by multiple ESD stimulation, the results show that constant current igniting time after ESD stimulus tends to shorten. Thus it can be seen that, the influences on performance of detonators after ESD stimulus can not be ignored. So it is very necessary to study and analyze the effects of ESD on the performance of detonators.

An ESD simulator was used to bring high voltage stimulus to exploding bridgewire detonators. The damage effects of bridgewire and primary explosive of detonators caused by ESD were investigated

∗ To whom any correspondence should be addressed.
by microfocus X-ray industrial volume computed tomography (μCT). The bridge resistance and whether the detonators could ignite after normal ignition pulse were tested, and the test results were analyzed.

2. Method
There are two main modes for ESD stimulus according to structure analysis, as shown in figure 1. The mode of Pin-Pin (A-B in figure) is same as the situation of igniting normally. The breakdown phenomenon could happen while the ESD stimulus was set between pin-shell. For the second mode, the primary explosive may be damaged, and the performance of detonators may be affected.

![Figure 1. Two modes of ESD stimulation action.](image)

Pin-Pin
Pin-Shell

There are eight kinds of ESD model reported in public literature at present [4], which includes human body electro-static discharge (HESD) model, field enhancement ESD model, machine ESD model, and so on. The electrostatic threat in the process of production, transportation, assembling of detonators is almost related to human action, which makes the electrostatic human body become the main and most common reason for those accidents caused by detonators. Therefore, electrostatic safety evaluation of detonators focuses on the HESD model. According to the reports [5], the maximum electrostatic potential value of the human body is not more than 50 kV. The rigor condition for HESD model is $C = 500 \text{ pF}$, $R = 100 \text{ Ω}$, based on these parameters, detonators were stimulated according to the way as shown in figure 2. There were 20 detonators chosen to test for both kinds of
modes respectively, and only once stimulus for each sample, and then the performances of detonators were tested.

3. Results and Analysis

Some performances of exploding bridgewire detonators after ESD stimulus were investigated, including the variation of bridge resistance value, whether the detonators can ignite normally after normal ignition pulse, and whether the single function time still meet technical requirements. The results are showed in table 1.

| ESD way | Pin-Pin | Pin-Shell |
|---------|---------|-----------|
| bridgewire resistance value | no obvious change | no obvious change |
| ignited | all 20 ignited | 18 ignited |
| single function time | meet technical requirements | meet technical requirements |

Test results show that there is no obvious change for bridge resistance when detonators were stimulated by the mode of Pin-Pin, all of 20 samples ignited normally, and the single function time still meet technical requirements. While for the mode of Pin-Shell, although there was no obvious influence on bridge resistance value, two detonators among them were not ignited after normal ignition pulse.

In order to find out the reasons, industrial CT was used to inspect the status of primary explosive. Figure 3 gives the structure diagram of bridgewire and primary explosive in detonators. A-A profile and B-B profile were observed by CT.

![Figure 3](image)

1-primary explosive; 2-bridgewire; 3-pin; 4-shell

3.1. Analysis based on CT results by the mode of Pin-Pin

Figure 4 is the industrial CT picture of primary explosive with ESD acted on detonators by the mode of Pin-Pin. It can be seen that there is no obvious change for grayscale in the area between the pin and shell, indicating that the density distribution of primary explosive still maintains the uniformity, primary explosive is no changed and ESD does not influence on bridgewire.
Stimulus condition with the mode of pin-pin can be simplified as the process detonators ignited by capacitance discharge. However, it distinguishes from the common capacitance discharge. Because discharge time is so short that the heat on bridgewire hardly diffuses outwards, the whole process can be regarded as adiabatic. Capacitance discharge energy is assigned to bridgewire and series resistor according to the ratio of bridgewire resistance and the series resistance. Bridgewire obtains little energy due to less resistance value (only several tens milliohm), so the temperature rise and heat release of bridgewire are so less that it is not enough to damage bridgewire and primary explosive, thus it has no influence on the performance of detonators.

3.2. Analysis based on CT results by the mode of Pin-Shell

CT photos of primary explosive after ESD acted on detonators by the mode of Pin-Shell are showed in figure 5. It can be seen that, grayscale distribution become lighter in some area between pin and shell as a result of the effect of ESD sparks stimulus (part of the arrow in figure 5), indicating primary explosive density decreases and a certain degree damage happens.

In order to better understand damage details and distribution of the primary explosive, different parts of the detonators were observed by industrial CT, as shown in figure 6. It can be seen that, the damage modality presents characteristic "branch" shape, which mainly distributed within the areas between bridgewire weld point and shell, and the part closer to the electrode plug is more seriously damaged, it could be related to the more concentrated discharge energy, because static electricity is more likely to release in the area closer to the shell.
When electric spark is forming as ESD acted on pin-shell, the air is ionized instantaneously and heated to a higher temperature, and shock wave is formed after the ionized air expanding rapidly. After that, the discharge breakdown channels and density loose area in the primary explosive are formed, and more rarefaction wave is produced in the transmission process of the area, deflagration reaction can not self-propagate as a result of rarefaction effect. Maybe this is the main reason why several detonators failed to ignite.

4. Conclusion
With the continuous development and application of the insensitive detonators, the electrostatic safety performance of detonators has been improved. However, reliability affected by ESD cannot be ignored. According to ESD test in this paper (50 kV, 500 pF, 100 Ω), some exploding bridge detonators misfired. The analysis indicates that, during the ESD process, the air is ionized instantaneously and heated to a higher temperature, and shock wave is formed after the ionized air expanding rapidly, resulting in density of primary explosive in discharge channels decreased. The detonators fail to ignite because of rarefaction effect. Of course, reliability research on detonators affected by ESD is a complex problem, and it is necessary to do more research work.

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