Review of Determination of Minimum Ignition Energy of Combustible Gases or Dusts

Gang LI(李 刚)
(*Fire & Explosion Protection Laboratory*, *Northeastern University*, *Shenyang* 110004, *China*)

Abstract – **MIE is an important parameter to be used to rank the ignition risk of the combustible materials. Commonly used electric circuits for generating spark have been reviewed and their features are analyzed in detail. Attention to avoiding test errors is stressed. Ranking of ignition risk is suggested based on MIE data.**

Key words – ***MIE***; ***spark generation circuit***; ***risk assessment***

Manuscript Number: 1674-8042(2011)03-0209-04

doi: 10.3969/j.issn.1674-8042.2011.03.002

Many severe dust or gas explosion accidents have revealed the fact that electric discharge is an important ignition source in coal mines as well as in industrial plants.

Electric discharge can be capacitive, inductive or resistive, and the type of the energy discharges can be spark, cone, corona, brush or propagating brush discharges[1]. Generally, corona discharges from electrostatically charged bodies will not ignite dust clouds. The energies of propagating brush discharges can be several joules and can ignite a wide range of dust clouds. Practically, using capacitive sparks is a common way to test the ignition sensitivity of dusts or gases for electrical discharge. Capacitive sparks can be generated in the active electric circuits or be caused by triboelectrically generated electrostatic charges. Minimum Ignition Energy (MIE) is a widely acceptable parameter to be used for assessing the risk of a sample to be ignited by an electric discharge source. In several domestic and international standards[2-5] MIE is defined as the electrical energy discharged from a capacitor, which is just sufficient to effect ignition of the most easily ignitable concentration of fuel in air under the specified test conditions.

Though more than 100 years has passed since dust clouds were firstly demonstrated to be able to be ignited by electric sparks, accurately determining the MIE of dusts or gases is still a challenge to people. This paper aims to review the determining methods of MIE suggested in the standard of ASTM[4], and some limitations or shortcomings are pointed out. In addition, some developments in how to measure the net spark energy discharged between the electrodes more precisely are reviewed.

1 Current capacitive spark generation principles

Many circuit principles have been used for generating electric sparks for gases and dusts ignition[2-5]. The following is reviewed mainly based on the two references unless it is indicated on other references.

1.1 Triggered by voltage increase (Trickle charging circuit)

Fig. 1 illustrates the spark generating circuit triggered by voltage increase. A high voltage dc supply slowly raises the potential of the capacitor until a spark occurs. The switch still connects after the first spark and C_0 will be charged continuously, so continuous spark may be generated between the two electrodes. The series of sparks have approximately the same stored energy $0.5C_0V^2$. Sparks of any energy level from 1 mJ upwards can be readily produced in this circuit by varying the value of the capacitor, and the discharge voltage if necessary.

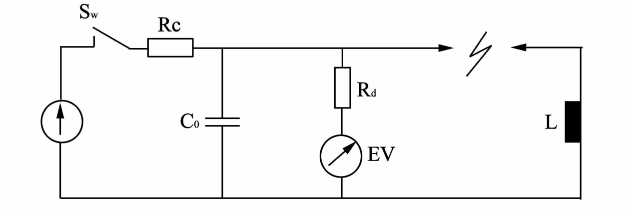

Fig. 1 Trickle charging circuit

In practice the storage capacitor C_0 is charged to a potential value just before break-down. The spark is initiated by the dispersed dust cloud. So, how to synchronize the spark and dust dispersion can be difficult to achieve. Continuous charging of the storage capacitor may also cause a problem of multiple sparks within the time frame of the dust dispersion. In order to generate single sparks of low energy, very high resistor (*i.e.*, 10^{11} Ω) may be used.

The trickle charging circuit is one of the simplest methods for producing sparks of known energy

※ **Received**: 2011-02-21
Corresponding author: Gang LI(ligang@mail.neu.edu.cn)

for dust-air mixtures, in which the dust particles play a major part in the triggering process. But it may be the only one that resembles the reality in industry because it is unlikely that dust dispersion and an electric spark should be triggered independently each other at the optimal conditions for ignition[6].

1.2 Triggered by auxiliary spark (broken down by high voltage and sustained by low voltage)

Fig. 2 illustrates the spark generating circuit triggered by auxiliary spark. A storage capacitor C is charged to voltage V_i, which is typically less than 2 500 V and incapable of causing spark breakdown at the gap G. When C is fully charged, the stored energy is $0.5CV_i^2$. In order to cause breakdown at the gap, a trigger capacitor C_{tr} is discharged through the primary transformer T which results in a transient high voltage to break down at the gap G. At this moment the electric field strength of the gap is becoming very low, so the storage capacitor C can discharge through the gap.

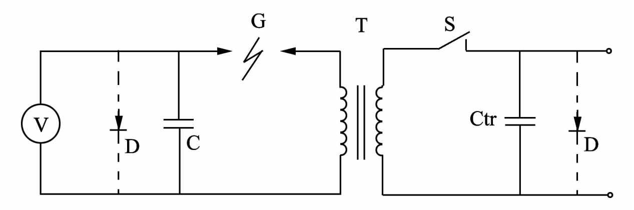

Fig. 2 Auxiliary spark circuit

When the trigger capacitor C_{tr} (i.e., 0.47 μF) is charged to 165 V and an automobile ignition coil is used as the step-up transformer the additional energy from the auxiliary spark is approximately 5 mJ. For the dusts with higher MIE value, e.g. hundreds of ten Joules, this part can be neglected. But if it is less than 10 mJ the imported energy is not ignorable.

1.3 Triggered by high voltage relay

Fig. 3(a) illustrates the spark generating circuit triggered by high voltage relay[5]. The capacitor C_0 storing ignition energy is charged by means of the high voltage charging unit across a resistance R, which limits the charging current to 1 mA. Once the capacitor is fully charged, the high voltage relay switches on to electrode and the spark will be discharged at the gap.

For low energies, the unavoidable stray capacitance C_p of the electrode arrangement is of the same order of magnitude as the storage capacitor, i.e. some pF, and must be taken into account when the energy stored in the circuit is calculated prior to discharge. The breakdown voltage can be determined by Eq. (1) and the discharging energy by Eq. (2)

$$U_p = U_0 \cdot C_0/(C_0 + C_p), \quad (1)$$

$$E = 0.5 \cdot (C_0 + C_p) \cdot U_p^2. \quad (2)$$

If the energy stored in the capacitance C_0 is so small or the voltage charging C_0 is so low the spark may not occur, because the energy is dissipated in the circuit. Another kind of 3-electrode type apparatus is suggested in the standard (Fig. 3(b)). The free end of the auxiliary electrode is angled toward the main spark gap. In this case C_0 is charged to such a high voltage that can not breakdown cannot occur by itself. Only after ionization is initiated by the third electrode the spark at the main gap is discharged simultaneously. Usually the auxiliary spark is a kind of inductive type generated by breaking up the current flowing in the primary winding of the ignition coil. The energy of the auxiliary spark is limited to not more than 1/10 of the energy of the storage capacitor C_0.

Both of the apparatuses are suitable for testing very low MIE values because the high voltage relays are easily aged for large discharge current.

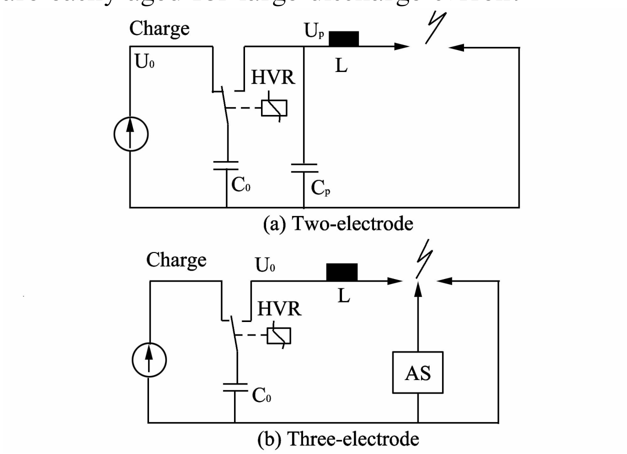

Fig. 3 Triggered by high voltage relay

1.4 Triggered by moving electrode

Fig. 4(a) illustrates the spark generating circuit of the test apparatus. The earthed electrode is adjustable by a micrometer screw. The electrodes′ gap is achieved by screwing forward or backward. The other electrode, to which the high voltage is applied, is attached to the pushrod of a controllable, double-acting pn′eumatic piston. The high voltage electrode is connected electrically to a capacitor, which is charged to a high voltage with the electrode gap so wide that breakdown is beyond reach. When the stored dusts are dispersed up, the high-voltage electrode is shot into the position after the predetermined time intervals, and the energy stored in the capacitor is liberated at the spark gap. In CEN standard[6] only the earthed electrode is movable, as shown in Fig. 4(b).

During the movement of the electrodes the energy stored in the capacitor C_0 will decrease due to the corona discharge on the electrode tips.

This type of spark triggering circuit is practical only for MIE values above 10 mJ, where this corona discharge loss is negligible.

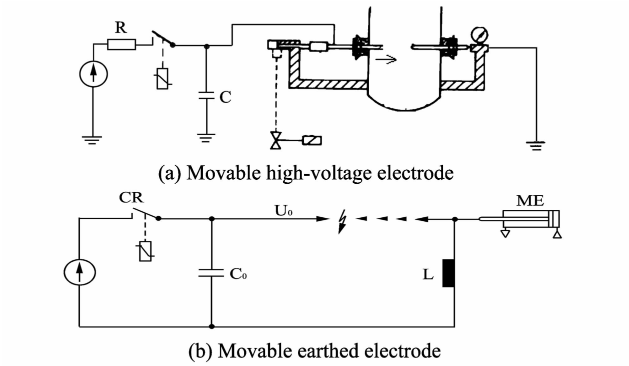

Fig. 4 Triggered by moving electrodes

1.5 Synthetic analysis of the mentioned circuits

The above suggested spark generating circuits are in common used for MIE tests in different laboratories in the world. The apparatus based on these circuits have different features, which are analyzed from the points of spark initiation, requirements on the circuit elements, error sources and suitability for different MIE values in Tab. 1.

It should be noted that some dusts very easily stick to the electrode if it has very high potential before dust dispersion. The apparatus triggered by increasing voltage circuit has high liability of this phenomenon. It will deduce that the spark can not discharge even with high voltage. That means a higher MIE value will be obtained. E Randeberg found this fact when testing MIE of niacinamide and niacin dusts respectively[6]. Besides the reason of high turbulence at time of spark onset the sticking dusts impeding spark discharging is another reason. M. Bailey and P. Hooker[7] found the same fact when joining a Robin Test by using an such apparatus.

Tab. 1 Comparision of the apparatuses using different circuits

Triggering type	Spark initiated by	synchronization of dust dispersion and ignition	High voltage capacitance (>2 kV)	High voltage Relay (>2 kV)	Sticking dusts on electrodes	Error sources *	Suitable for MIE /mJ
increasing voltage	dispersed dust cloud	difficult	needed	not needed	high for some dusts	resistive dissipative	>10
auxiliary spark	preionization of the gap	easy	not needed	not needed	low	auxiliary spark energy	>10
high voltage relay	high voltage	moderate	needed	needed	very low	stray capacitance dissipation	<10
moving electrode	decreasing gap	easy	needed		middle	corona loss	>10

* The residual energy in the storage capacitance is a common factor for error sources and not listed

2 Determination of the spark energy

The spark energy is normally calculated based on the stored capacitor energy prior to breakdown, or on direct measurement of current and voltage as a function of time during the discharge and integration of the power versus time curve. The former is simple and suggested in the mentioned standards though it is relatively rough. The latter is suitable to precisely deduce the net energy of the discharged spark at the gap.

2.1 Calculated based on the stored energy

The simplest method to calculate spark energy is based on the energy formula, i.e. the difference between the stored energy before and after the discharge

$$E = \frac{1}{2}C(W_B^2 - V_A^2), \tag{3}$$

where C is the capacitance, V_B is the capacitor voltage before discharge and V_A is the voltage after discharge. Usually, $V_B \gg V_A$, thus the energy can be calculated approximately by Eq. (4) when using the circuit triggered by high voltage relay eq.

$$E = \frac{1}{2}CV_B^2, \tag{4}$$

2.2 Integration method

Up to now, using Eq. (3) or Eq. (4) to estimate the gross capacitance energy discharged at the gap is still suggested in the related standards estabilshed draft for dust clouds[2-5] though there are some kinds of energy inevitably lost, and not delivered to the spark.

For low MIE values the lost amounts of energy can be as large as the MIE itself. Accurate determination of the net energy of the discharged spark is necessary for such small MIE values.

A common integration method is adopted for solving this problem. The energy of the spark can be calculated by Eq. (5), where, v is the voltage just before breakdown and i the current during the discharge.

$$E = \int vi\,dt, \tag{5}$$

v and i can be measured by using a numerical oscilloscope as shown in Fig. 5.

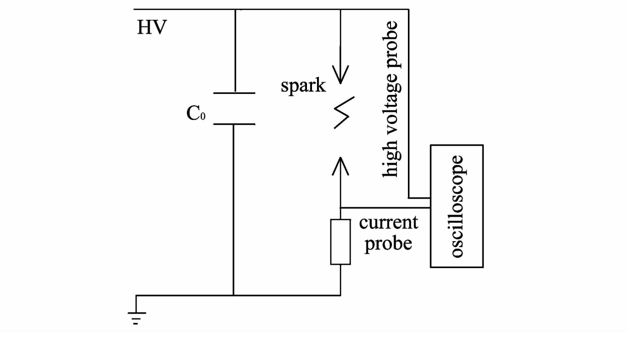

Fig. 5 Scheme for measuring of voltage and current when breakdown

Unfortunately, the measuring process for v and i is very confusing because the discharging procedure is a kind of highly transient phenomenon and electromagnetic noise will unavoidably occur in the spark initiation process[8]. For very small energy the measured signal may be of the same order as the superimposed noise signal[7]. More measuring techniques may be needed for such precise tests.

2.3 Determination of the MIE value

2.3.1 Step method

It is impractical to approach to the absolute minimum ignition energy of the combustible mixtures. A kind of step method is suggested as

$$W_1 < \mathrm{MIE} < W_2, \tag{6}$$

where W_1 is the highest energy, at which ignition fails to occur in ten successive attempts to ignite the dust-air mixture, and W_2 the lowest energy at which ignition occurs once at least within ten successive attempts. And the ratio of the energy steps should be less than 2.3, for example 1 mJ, 3 mJ, 10 mJ, etc.

2.3.2 Bruceton method

Using Bruceton experiment method the MIE can be obtained with a probability of 50% labeled as E_{50}. At first, the sensitive conditions should be designated, such as concentration, storage capacitance, electrode gas. Then, begin with a charging potential U. If ignition is successful ΔU of the charging potential should be decreased and increased if unsuccessful, till 50 times of experiments are conducted

$$E_{50} = 0.5CU_{50}^2, \tag{7}$$

where U_{50} is the average potential, at which ignition can happen with 50% of probability[3].

3 Evaluation of ignition risk of combustible materials based on the MIE value

Generally, the smaller the MIE value is the more sensitive of the electrical spark ignition is to the tested materials. In industry, the conditions of accidental electrical discharge are such that the released energy is much more adequate to cause ignition of the released flammable gases and dusts. As a result, accurate information on the MIE value is not a requirement. Normally, the range of the MIE value existing is easily to be used for the ignition risk assessment. An example is given in Tab. 2.

Tab. 2 General comments for different MIE value

Minimum Ignition Energy of the Powder (mJ)	Comment
500	Low sensitivity to ignition: Earth plant when ignition energy is at or below this level.
100	Consider earthing personnel when ignition energy is at or below this level.
25	The majority of ignition incidents occur when ignition energy is below this level. The hazard from electrostatic discharges from dust clouds should be considered.
10	High sensitivity to ignition. Take the above precautions and consider restrictions on the use of high resistivity materials (plastics). Electrostatic hazard from bulk powders of high resistivity should be considered.
1	Extremely sensitive to ignition. Precautions should be as for flammable liquids and gases when ignition energy is at or below this level.

References

[1] R. K. Eckhoff, 1991. Dust explosions in the process industries, butterworth-heinemann, Oxford, p. 15-19.

[2] GB/T 16428, 1996. Determination of the minimum ignition energy of dust cloud.

[3] GB/T 14288, 1993. Determination of minimum ignition energy of combustible gases and flammable liquid vapors.

[4] ASTM, 2003. Standard test method for minimum ignition energy of a dust cloud in air, ASTM International E 2019, West Conshohocken.

[5] CEN, 2002. Determination of Minimum Ignition Energy of Dust/Air Mixtures, European Standard EN 13821, European Committee for Standardization, Brussels.

[6] E. Randeberg, R. K. Eckhoff, 2006. Initiation of dust explosions by electric spark discharges triggered by the explosive dust cloud itself. *Journal of Loss Prevention in the Process Industries*, 19: 154-160.

[7] R. Erlend, O. Werner, K. E. Rolf, 2006. A new method for generation of synchronised capacitive sparks of low energy. *Journal of Electrostatics*, 64: 263-272.

[8] Shen Tian, Jun-bi Liao, Liang Ma, et al, 2008. EMC research of aviation igniter spark energy measuring system. *Journal of SICHUAN University (Engineering science edition)*, 40(6): 192-196.

[9] M. Bailey, P. Hooker, P. Caine, 1998. Incendivity of electrostatic discharges in dust clouds: the minimum ignition energy problem, Zeneca Ltd., Manchester, U. K.

[10] Hui Yang, Wen-ying Li, 1996. Measurement of the minimum electrostatic ignition energy for LPG. *OGST*, 15(6): 45-47.