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Measurement of min. ½CU² for electrostatic-spark ignition of explosible dust clouds in the spark energy range <1 mJ

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ABSTRACT
Experiments performed by various workers have confirmed that clouds in air of very fine dusts of sulphur, some metals, and some synthetic organic materials, have very low minimum electric-spark ignition energies (MIEs), in the range < 1 mJ. However, the test methods recommended by some current national and international standards for measurement of min. ½CU² for ignition of explosible dust clouds have a lower spark energy limit of 1 mJ or more. This is mainly due to the lower spark energy limits of the methods used for synchronizing the spark discharge with the appearance of the transient experimental dust cloud at the spark gap. Based on considerations of processes of accidental electrostatic charging of small metal objects it has been argued by some that accidental spark discharges of energies < 1 mJ are unlikely to occur in practice in industrial processes. Hence tests for min. ½CU² for ignition in the range < 1 mJ are regarded to be superfluous. The present paper questions this argument and instead suggests that it is possible to envisage electrostatic spark discharge mechanisms producing sparks in the ½CU² range <1 mJ. Therefore, there is also a need for test methods for min. ½CU² for ignition in this energy range. This, however, requires that adequate dust cloud/spark discharge synchronization techniques be available in this energy range. This paper presents two possible synchronization methods, one involving rather sophisticated electronics, and one quite simple, which may in fact also operate accidentally in industry.

Key-words: Dust clouds, dust explosions, ignition sources, > 1 mJ electrostatic spark discharges, minimum ½CU² for ignition, laboratory-scale test methods

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I. INTRODUCTION

Eckhoff [1] reviewed experiments performed by various workers showing that clouds in air of very fine dusts of sulphur, some metals, and some synthetic organic materials have very low min. electric-spark ignition energies, in the < 1 mJ range. The question is then whether this calls for special actions for elimination the electrostatic-spark ignition hazard of this kind of dusts in industry.

As reviewed by Eckhoff [2] all the test methods recommended by both ASTM [3] and ISO/IEC [4] for measurement of MIEs of dust clouds have a lower spark energy limit of at least 1 mJ. The limitation is mainly due to the lower spark energy limits of the various methods used for synchronizing the spark discharge with the appearance of the transient dust cloud at the spark gap in laboratory-scale test apparatus. The limitation applies to both measurement of the very lowest spark energy for ignition of clouds of a given dust in air, i.e. the minimum ignition energy (MIE), and to measurement of the lowest ½CU² for ignition by electrostatic spark discharges. According to both ASTM [3] and ISO/IEC [4]the latter measurement is to be performed without the 1-2 mH series inductance in the discharge circuit that is compulsory in MIE measurements. However, the lower spark energy limit of about 1 mJ remains.

According to Eckhoff [2] it has been suggested by some that a test for the min. ½CU² for ignition in the low-energy range < 1 mJ is superfluous. The argument has been that small objects of capacitances of the order of 1 pF encountered in industry normally have some sharp edges and/or corners, which give rise to charge drain by corona discharge as soon as the voltage of the object reaches the order of 7-10 kV. The order of the time constant RC for 'leaking' any charge on such small capacitances to earth is very short (1 s) even when the resistance to earth is of the order of 10^{12} Ω (1 tera Ω). Therefore, it is not possible to charge such small objects to any high voltages unless the charging process is extremely fast, i.e. the charging times have to be significantly shorter than the very short time constants for charge drainage to earth. It was concluded, therefore, that accidental electrostatic spark discharges of energies below about 1 mJ would be rather unlikely in the process industries.

In the present paper this argument is questioned. Instead it is suggested that accidental electrostatic spark discharge mechanisms can exist by which accidental sparks of energies in the ½CU^2 range <1 mJ can be generated.

Therefore, the present paper suggests that a test method for min. ½CU^2 in the energy range < 1 mJ is in fact needed. This, however, requires that adequate techniques for synchronizing the spark discharge with the appearance of the transient dust cloud at the spark gap be available even in the ½CU^2 range < 1 mJ.

II. AN ACCIDENTAL DUST-CLOUD-IGNITION SCENARIO WITH ELECTROSTATIC SPARKS OF ENERGIES < 1 MJ

2.1 The scenario

Eckhoff and Randeberg [5] described a situation where charging of small electrically conducting objects would be fast enough to generate very high voltages. The mechanism rendering this possible is "electrostatic influence" described by Lüttgens and Wilson [6]. To illustrate this possibility, Eckhoff and Randeberg [5] considered a small metal object (tramp metal) that enters an earthed metal silo together with an electrically insulating powder that is charged into the silo from above. Fig. 1 illustrates the situation.

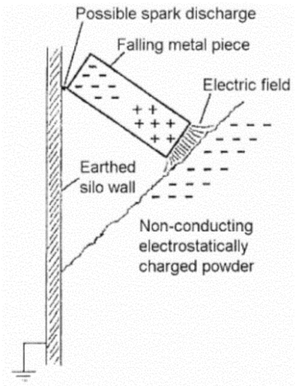

Fig.1. Illustration of how a spark discharge may be generated from an electrically neutral tramp metal piece falling into a silo, because of charge displacement in the metal piece when it enters the electric field in the silo generated by electrostatically charged powder there. From Eckhoff and Randeberg [5]

If the dust/powder has acquired a sufficient charge on its way to the silo, it will, when settling in the silo, create a strong electric field against the earthed silo wall. When a small metal object falls into this field, the electrons in the metal object get displaced extremely fast towards one end of the object by electrical influence as described by Lüttgens and Glor [7]. If one end of the metal object then approaches the earthed silo wall whilst this electron displacement exists, a spark discharge between the metal object end and the earthed silo wall may take place. Because of the very short discharge times to be expected (< 10 μs), the spark gap length will stay approximately constant during such a spark discharge. For example, an object approaching an earthed wall at 20 m/s will move only 0.2 mm during 10 μs.

2.2 A case history supporting the electrical influence hypothesis

Lüttgens et al. [8] presented a report on a dust explosion in a silo that they assumed was initiated by the type of minute spark discharge discussed in 2.1 above. The silo was part of an assembly of a number of silos, made of aluminium, and used for intermediate storage of a plastic dust. Following several years of production without any accidents, a dust explosion unexpectedly occurred during discharge of one of the silos. At the instant of the dust explosion the plastic powder occupied only about 20 % of the silo volume. After careful investigation, all other potential ignition sources than an electrostatic spark discharge could be ruled out. However, the exact mechanism of generation of the electrostatic spark remained unidentified until part of the shaft of an aluminium spade had been located close to the silo wall, just below the powder surface. It was concluded that the excess charge accumulated at one end of this object due to electrical influence, was discharged as a spark when the object, when dropping into the silo, approached the silo wall.

2.3 Incendive low-energy sparks may occur even at quite low spark gap voltages

As discussed by Eckhoff and Randeberg [5] electrostatic sparks of very low energies may not only arise from discharge of very small capacitances charged to quite high voltages. They may also result from discharge of somewhat larger capacitances charged to only moderate voltages of the order of a few kV. This would clearly also present high ignition risks with dust clouds of very low min. ½CU^2 values for ignition. With C=10 pF, and U=2 kV, the stored energy ½CU^2 equals only 0.02 mJ. At only 2 kV the natural breakdown distances of spark gaps in air are quite short. However, with dusts of MIE<<1 mJ, the quenching distances of explosible dust clouds are also most probably very small.

An indication of this is provided by the data by Proust[9], reproduced in Fig. 2.

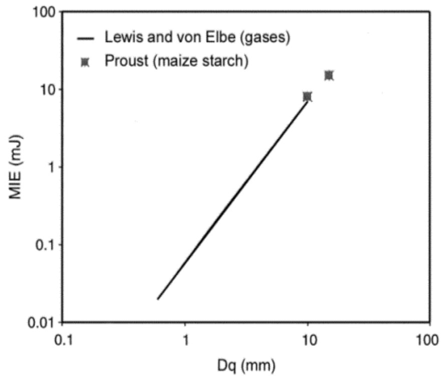

Fig.2. Min. electric spark ignition energies (MIE) and quenching distances (Dq) for two clouds of maize starch in air, showing close agreement with the classical Lewis/von Elbe correlation for gases.
From Proust[9]

The two data points for maize starch in Fig 2 is only an indication of the correlation of MIE and quenching distance (Dq) for explosible dust clouds in the spark energy range below 1 mJ being in fact in line with the classical Lewis and von Elbe correlation for explosive gas mixtures. Whether this correlation holds even in the MIE range below 1 mJ remains to shown.

III. ADVANCED ELECTRONIC METHOD OF DUST CLOUD/ELECTRIC-SPARK SYNCHRONIZATION FOR THE < 1 mJ ELECTROSTATICS-SPARK ENERGY RANGE

Figure 3 presents the electronic solution to the dust cloud / spark discharge synchronization problem as developed by Olsen et al. [10].

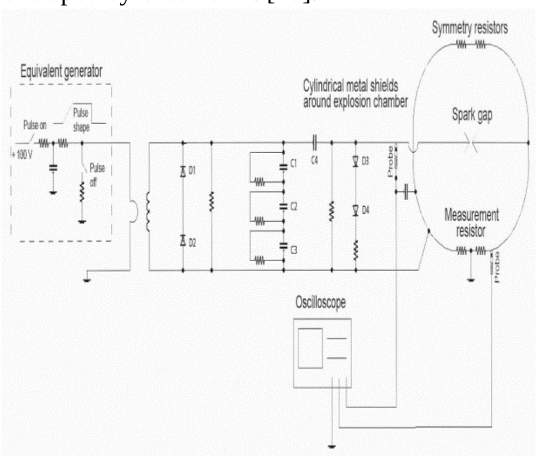

Fig. 3. Basic electronic circuit of an electric spark generator for generation of synchronized capacitive spark discharges of known energies below 1 mJ.
From Olsen et al.[10]

In this circuit the primary high-voltage pulse from the transformer is shaped in a special way. The raising phase is comparatively slow, whereas the declining phase is very fast right down to about U=0 where the voltage remains. The purpose of the diodes D1 and D2 is to prevent U from dropping below zero. During the rising phase of the primary voltage pulse the capacitor C4 is charged to a high voltage. This causes the diodes D3 and D4 to become conducting. During the subsequent rapid drop to zero of the primary voltage pulse from the transformer, a substantial part of the voltage change is transferred to the spark gap as another voltage pulse, which causes breakdown of the spark gap. This in turn gives rise to discharge of capacitors C1, C2, C3 and C_4. During the very short period of about 20 ns duration of the main spark pulse there will be some re-charging of C1, C2 and C3. But this does not cause any problems. The purpose of the C1-C3 circuitry is to prevent any significant build-up of voltage across the spark gap after the first main spark pulse, i.e. to prevent any significant amount of energy to be supplied to the spark gap after the short main pulse.

IV. A SIMPLE SYNCHRONIZATION MECHANISM THAT MAY TAKE PLACE ACCIDENTALLY IN INDUSTRY

The investigation by Eckhoff [11] was probably amongst the first to bring to light the possibility that a spark gap at a voltage somewhat lower than the natural breakdown voltage in air can be broken down if a dust cloud is blown into the spark gap region. About 50 years after these experiments Eckhoff [12] published his findings in the open literature. Eckhoff and Randeberg [13] and Randeberg and Eckhoff [14] explored this synchronization mechanism further. They found that dust explosion initiation in this way was possible with several different dust types. However, in the spark energy range >1 mJ investigated it appeared that the min. $½CU^2$ values for ignition obtained by this triggering method tended to be somewhat higher than those obtained by other commonly used triggering methods available in this spark energy range.

V. SUGGESTIONS FOR FURTHER RESEARCH

5.1 Advanced synchronization method by Olsen et al. [10]

Olsen et al. [10] only tested their synchronization method with mixtures of propane and air, for which they obtained min. $½CU^2$ values in accordance with those published by earlier workers. It therefore remains to try this method out for dusts of min. ½CU^2 values < 1 mJ. Very fine sulphur powder and very fine metal powders/dusts of Al, Ti etc. will be suitable test materials.

5.2 Direct breakdown of spark gap by the transient dust cloud itself. Remaining questions

The influence of the difference between the actual spark gap voltage and the natural breakdown voltage in air only, on the min. ½CU^2 for ignition needs to further investigation. There are two reasons for this. Firstly, the dust concentration in a transient cloud approaching the spark region will most probably be quite low at the cloud front and increase gradually as the cloud fills the spark gap region. Secondly, it is expected that the min. dust concentration needed to break the gap down increases with increasing difference between the spark gap distance for breakdown in air only, and the actual, shorter spark gap distance. Systematic experiments are also required for resolving effects of various symmetrical electrode geometries (e.g. needles, sharp corners, rounded electrodes), and also of asymmetric gaps between two electrodes of different geometries and polarities. The experimental works by Eckhoff and Randeberg [13], Randeberg and Eckhoff [14], and Eckhoff [12] may offer a starting point for such further systematic investigations.

VI. CONCLUSION

Experiments performed by various workers have confirmed that powders/dusts of some metals, sulphur and some synthetic organic materials, with very small particle sizes have minimum electrostatic-spark ignition energies (min ½CU^2) in the energy range < 1mJ. A published accident report suggests that electrostatic spark discharges of energies < 1 mJ can in fact occur accidentally in special situations in industry.

There is a need, therefore, for an experimental test method for determining min. ½CU^2 values for ignition of explosible dust clouds in the energy range < 1 mJ. This, however, requires that an adequate method for synchronizing the appearance of the transient dust cloud and the spark discharge. The present paper points at two such techniques. The first involves rather sophisticated electronics, whereas the other is quite simple and may in fact operate accidentally in industry.

However, further systematic experimental research is required in order to develop suitable test methods based on any of the two suggested synchronization techniques.

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