

On energy discharge profile in spark test apparatus

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Abstract. Even if the prospects for using hydrogen as an energy vector fluctuate, current trends will increase the incidence of hazardous areas, especially those due to hydrogen. In the context of increased intelligence implemented to control and improve the efficiency of technological systems, low-current installations are of greater importance. Certification is a process that confirms the implementation of explosion protection in equipment and systems through a legal means. An important step in this process, in addition to evaluation, is the testing of the equipment. For confirmation of the type of intrinsic safety protection by test, reference curves from the specific standard or the spark test apparatus (STA) are used. The method, which is based on the use of the STA, is influenced by a stochastic process. This raises problems with the consistency of the results. This fact was highlighted in a proficiency testing session, which at the end showed a dispersion of relative values in the range of -100%+400%. With the present work, the authors aim to statistically analyze the discharges in terms of energy, identify and characterize an emerging dispersion profile. Preliminary tests have revealed the existence of additional noise that may affect the measurements; therefore, part of the present effort is to identify and filter out this interference. In the first part of the paper, the STA and its relevant parameters are presented. Also on this occasion, the test stand used to obtain the energy discharged into the device in its calibration process is presented. The next part was devoted to the presentation of the results and discussions. An important conclusion of the work is that, for the test conditions used, the energy discharged in the STA exhibits nonuniform dispersion of energy values and is characterized by several attractors.

1 Introduction

In today's technological environment, demands for efficiency, flexibility, and security are constantly increasing. To meet these needs, information systems are playing an increasingly important role.

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Industrial facilities often use flammable materials, thus creating areas at risk of explosion. The use and marketing of equipment for potentially explosive atmospheres in the European Economic Space is regulated by ATEX directives.[1, 2].

This directive [2] specifies the technical requirements that determine the explosion protection category of equipment. In the case of low-voltage electrical equipment, the requirements are detailed in specific standards. [3 4].

Low-current equipment and installations [5], which use the electric current to transfer information, must comply with specific requirements in order to operate in high-risk environments due to the presence of flammable substances.

The explosion hazard associated with the use of technical equipment in potentially explosive atmospheres can be caused by ignition by electric sparks, electrostatic discharges, mechanical impact, etc. Similarly, mixtures of air and flammable substances can be ignited by high-temperature surfaces [6].

Intrinsic safety type of protection intervenes on electrical and thermal sources to reduce their ability to ignite explosive mixtures. This type of protection also applies a specific strategy that takes into account component failure, faulty connections, and circuit interruptions.

Explosion protection measures must be considered from the time of the design stage, both for normal operation and for fault conditions. In this regard, the requirements of the ATEX Directive on classification into categories (1, 2, or 3) and the IEC standard for protection levels (a, b, and c) apply. [2].

For equipment protected against explosions by an intrinsic safety type of protection, preventing ignition by sparks is an important consideration in addition to ignition from hot surfaces.

Explosion protection is confirmed by subjecting the equipment sample to various tests. If the equivalence of the energy source is characterized by a non-linear characteristic or cannot be reduced to such a source, tests are carried out in explosive test mixtures.

The equipment used to perform the tests is called a spark test apparatus (STA).

The testing method using the STA contains a stochastic component, which makes it difficult to model the phenomena involved in the ignition of explosive test mixtures.

To identify characteristics that characterize the ignition of explosive test mixtures, this paper aims to identify a profile of energy discharges resulting from a large number of sparks.

2 Material and methods

According to the specific standard [4], tests of intrinsically safe circuits in explosive test mixtures are performed using a STA. This consists of an enclosure of approximately 326 cm³ containing a system of parts in relative rotational motion.

The upper support, in which 4 tungsten wires are embedded, and the lower cadmium disc, which has two parallel grooves on the upper side. These two parts are electrically isolated from each other but are electrically connected to the STA terminals. The gear mechanism that ensures the transmission ratio and synchronization of the discs is made of electrically insulating material.

During the time when the two discs are in motion, the tungsten wires make intermittent contact with the lower disc. These contacts are circuit closing contacts, circuit opening contacts, and surface transition contacts.

To prevent the explosion from spreading to adjacent gas installations, the enclosure assembly is connected to the test explosive mixture preparation circuit by using two valves that isolate the enclosure from the rest of the pneumatic circuit during the tests.

Since the number of electrical events occurring in the explosive mixture test is quantified by the number of rotations of the electrode port, the STA is also equipped with a system for counting the rotations of the electrode port body to determine the completion of the test time.

Due to the mechanical structure involved and the nature of the electrical circuit, the STA assembly causes a pseudo-random manifestation of electrical parameters during the test.

Due to the pseudo-random nature of the electrical manifestation of the STA circuit, the singular monitoring of the electrical parameters of individual sparks may not be relevant for characterizing the ignition capacity of the explosive mixture tested by the circuit assembly together with the STA. For this purpose, it is proposed the analyze the energy discharged in the STA circuit for a large number of events (sparks).

The infrastructure used to perform the tests, according to the block diagram in Figure 1, is based on a STA. A resistive-inductive circuit used to calibrate the STA, a DC voltage source, and an oscilloscope are used too. The oscilloscope allows the simultaneous measurement of voltage and current in the electrical circuit and the calculation of the energy of transient processes (sparks) by using the VBS and XDEV options activated.

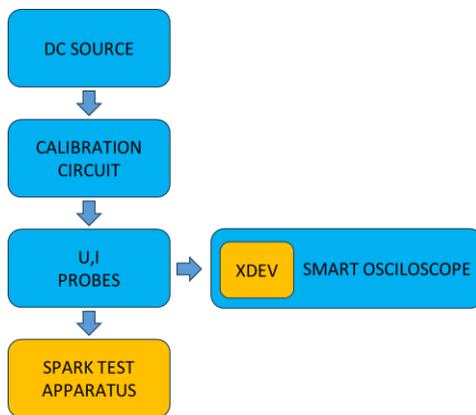


Fig. 1. Block diagram of the test circuit.

To characterize the total electrical energy discharged in the STA circuit through sparks and transient phenomena, the integral of instantaneous electrical power was used. This instantaneous power is calculated based on the product of the voltage and current intensity measured by the oscilloscope at the STA terminals.

Due to the supposition which states that the ignition capacity of the tested circuit connected to the STA circuit is not affected by the direction of the electric current flowing through the circuit, according to equation 1, the absolute value of the power before integration according to equation 1 was taken into account to obtain the energy.

Additionally, due to the fact that the tested circuit is affected by the presence of superimposed electrical noise, it is necessary to also take into account the native value of the power discharged in the STA circuit before integration according to equation 2 to obtain the energy.

$$W_a = \int_0^{t_p} |u(t) \cdot i(t)| dt \tag{1}$$

$$W = \int_0^{t_p} (u(t) \cdot i(t)) dt \tag{2}$$

Where: W_a and W are the electrical energies discharged in the STA circuit; $u(t)$ and $i(t)$ are the instantaneous voltage and current measured during the transient period of the electrical impulse; t_p is the duration of the transient phenomenon of the electrical impulse.

3 Results and discussions

The components and parameters of the test stand are: STA according to [4], EA-PS 7104 A power supply, with voltage set to 24 V and current set to maximum value 4 A; air induction coil with inductance of 100 mH, slider rheostat with maximum 960 ohms, Metra Hit 26S multimeter used as a voltmeter, Fluke 87V multimeter used as an ammeter, HDO9304 oscilloscope with XDEV option [7], Teledine Lecroy 30A current probe, PP023 voltage probe.

The test stand was configured to obtain the STA calibration circuit for subgroup IIC safety coefficient 1, 24 V, and current intensity 30 mA, according to the specific standard.

The parameters configured for the oscilloscope are: sampling rate 1 GS/s, memory 1 MS, which corresponds to 1 ns / 1 point for 1 ms.

First of all, the conditioning of the disc according to the procedure mentioned in the specific standard was done. The acquisition of electrical parameters was made with air only, without an explosive test mixture. By using the XDE option and the VBS, the oscilloscope performed the measurement and the computation of energies according to equations 1 and 2. These values were recorded and processed [8, 9] to obtain the descriptive diagrams.

The resulting diagram of the energies discharged in the STA with respect to time is shown in Figure 2. This diagram contains 1701 points. Each point represents the energy of each single event obtained by the oscilloscope trigger.

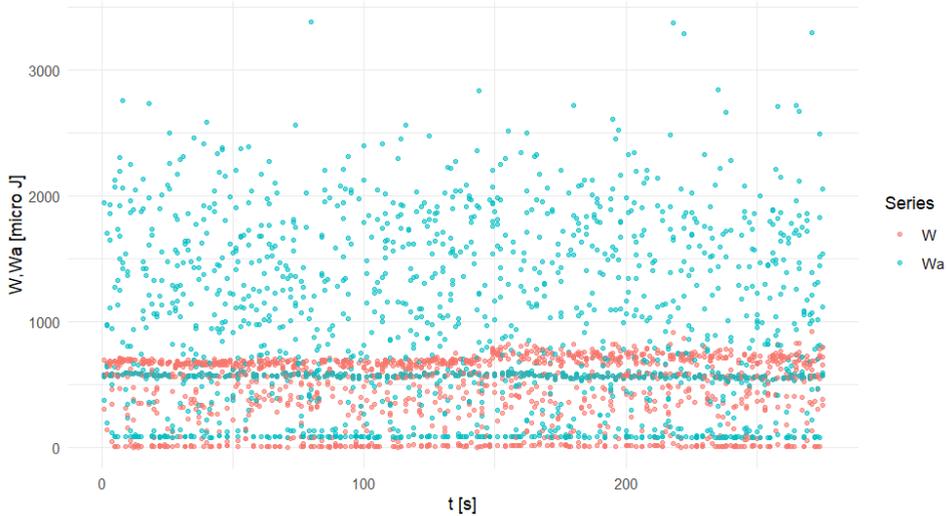


Fig. 2. Diagram of energies discharged in time within the STA.

By the analysis of the image in Figure 2, it can be seen that the absolute energy values W_a are much more affected by noise, as expected. Both energies tend to accumulate around certain values. Statistical analysis of the values revealed the summary of values presented in Table 1.

Table 1 Summary of energy values discharged in STA

Parameter	W [micro J]	Wa [micro J]
Min	3.466	532.79
Mean	573.481	925.29
Max	928.659	3382.50

The exposure of the measurement system to open circuit, noise resulted is defined by the set of points represented in the first bisector in the diagram in Figure 3. All other points, shown above this first bisector, represent the energies of sparks discharged in the STA.

The adoption of absolute energy Wa , even though it tends to accumulate noise, the analysis of Figure 3 highlights the favourable effect of using it.

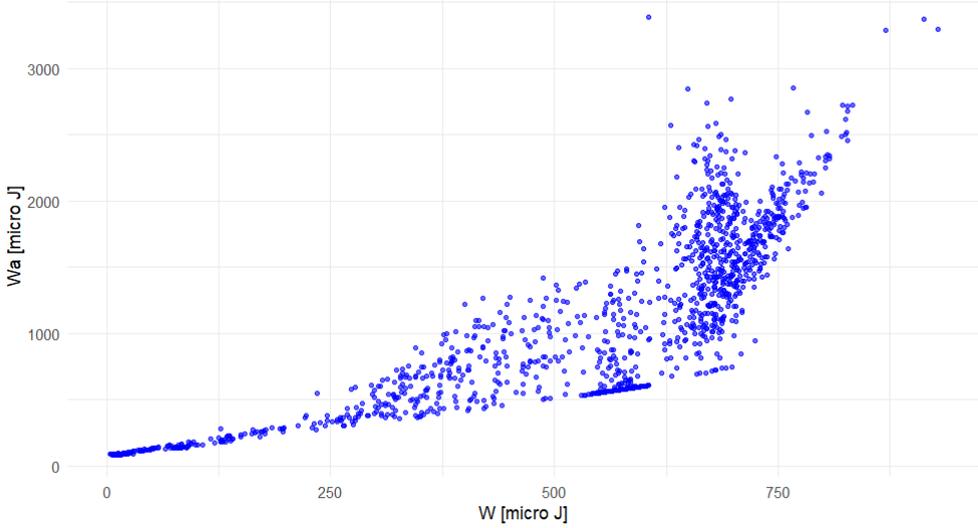


Fig. 3. Diagram of energies discharged in the STA.

To identify the profile (fingerprint) of the discharges in the STA, a density diagram of the distribution of values was drawn, with the z-axis calculated as the logarithm of the density. This diagram is shown in Figure 4.

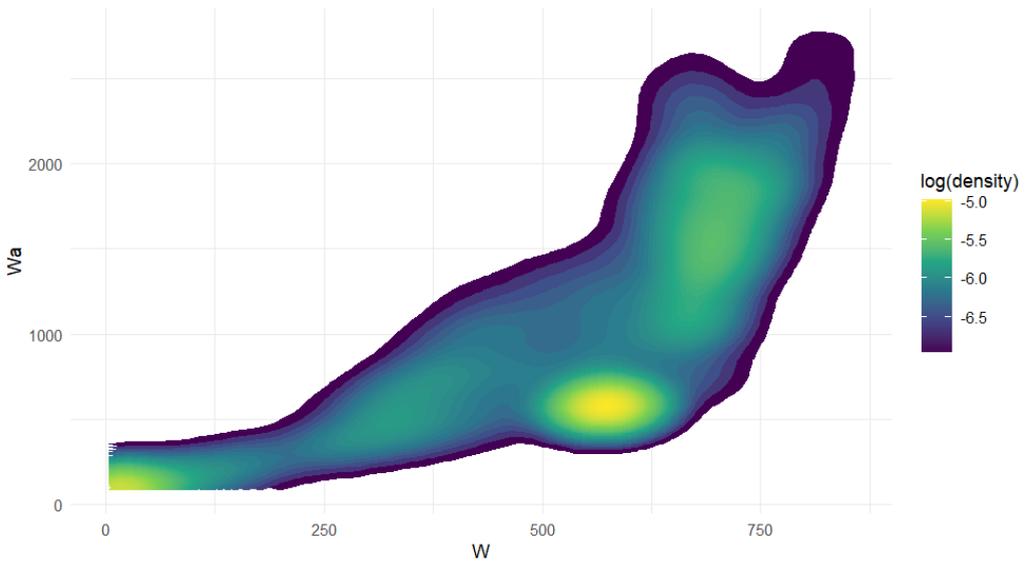


Fig. 4. Density diagram of energies discharged in the STA.

The density diagram analysis highlights the existence of four clusters, of which the three lower ones represent the distribution of noise-induced values specific to the open circuit, and

a cluster that highlights the higher regime of energies discharged in the STA. This last cluster is most likely the one that is responsible for the ignition phenomena.

4 Conclusions

Analysis of the energy values discharged in the STA revealed their stochastic distribution. Due to limited memory and acquisition rate configuration, the duration of transient phenomena was limited to 1 ms.

The analysis of a large number of values for the discharged energy characterizing transient phenomena allowed the identification of some attractors.

The two definitions taken into account for energy allowed the identification of a distribution profile of the energies discharged in the STA.

The energy discharges attributed to open circuit noise have a very high weight in the distribution of values.

A V-shaped profile was identified for the higher energy discharge cluster.

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The bibliography references were managed with Mendeley.

References

1. European Parliament and Council, “Directive 1999/92/EC on minimum requirements for improving the safety and health protection of workers potentially at risk from explosive atmospheres,” (1999).
2. European Parliament and Council, “Directive 2014/34/EU on the harmonization of the laws of the Member States relating to equipment and protective systems intended for use in potentially explosive atmospheres,” (2014).
3. International Electrotechnical Commission, “EN IEC 60079-0: Explosive atmospheres – Part 0: Equipment – General requirements,” (2018).
4. International Electrotechnical Commission, “EN IEC 60079-11: Explosive atmospheres – Part 11: Equipment protection by intrinsic safety ‘i,’” (2023).
5. V. M. Pasculescu, N. I. Vlasin, D. Florea, and M. C. Suvar, “Improving the quality of the process for selecting electrical equipment intended to be used in potentially explosive atmospheres,” *Quality - Access to Success*, vol. 18, no. S1, pp. 97–102, (2017).
6. L. Moldovan, S. Burian, M. Magyari, M. Darie, and D. Fotău, “Factors influencing the determination of maximum surface temperature for explosion-proof luminaires,” *Environ Eng Manag J*, vol. 16, no. 6, pp. 1309–1316, (2017) https://ui.adsabs.harvard.edu/link_gateway/2017EEMJ...16.1309M/doi:10.30638/eemj.2017.139.
7. Teledyne LeCroy, “XDEV: Custom Analysis Software Toolkit,” (2025), Chestnut Ridge, NY.