Mining3 Whitepaper

Electronic Spark Tester

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Executive summary

Intrinsic Safety (IS) is a widely used, internationally standardised method for ensuring that electrical equipment cannot cause an ignition in flammable atmospheres, which may be present in environments such as underground coal mines. A cornerstone of IS is controlling the risk of spark ignition, which is achieved by limiting the power output of equipment. The test for spark ignition risk currently used in IS certification relies on a primitive mechanical “Spark Test Apparatus” (STA) which is unreliable [1], only usable in a laboratory, and only provides a pass/fail test result. Additionally, the current international standard provides little guidance to OEMs and end users on how to ensure intrinsic safety by design for modern power supplies and complex, integrated systems. As a result of an unreliable test method and a lack of understanding, IS certification relies on arbitrary “safety factors” which have questionable relevance to actual risk, especially in the methane atmospheres common in underground coal mines.

The electronic spark tester (EST) is a Mining3 research concept for an alternative to the STA. As the name would suggest, the EST uses an electronic apparatus to simulate the effects of an electrical spark occurring at a given point in an electrical device – usually the output terminals of a power supply unit. Measurements of voltage and current transients are made during this process. Analysis of the measurements is then used to assess the risk of spark ignition. This process substitutes for the creation of real electrical sparks and explosions in the STA.

The electronic spark tester intends to provide the following benefits.

For testing laboratories:

- Greater reliability and repeatability of test results
- A test method without hazardous metals (i.e.: cadmium) and gasses

For manufacturers:

- More informative feedback from test results, providing a proportional safety margin rather than a simple pass/fail
- Possibility of in-house pre-assessment of new designs, potentially reducing costs from multiple external test iterations
- Greater understanding of the safety implications of design variations

For end users:

- Possibility of “routine testing” of installed equipment to ensure safety compliance over the life of a product
- Better informed management of explosion risk

The project is currently in the research prototype stage. In the language of technology readiness levels (TRLs) the electronic spark tester would be considered as TRL 3. Mining3 is currently seeking the support of manufacturers and certification agencies to assist with testing the EST. This may be, for example, with suggestion of test cases and/or provision of product samples for use in trials.

Contents

1. INTRODUCTION 1

2. OVERVIEW OF CONCEPTS 2

3. TESTING 2

4. ANALYSIS 4

5. FUNDAMENTAL RESEARCH 6

6. STATUS AND OUTLOOK 6

7. ACKNOWLEDGEMENTS 6

8. REFERENCES 6

1. Introduction

The concept of intrinsic safety (IS) as a method of explosion protection has a long history. Early in the 20th century, an explosion in a Welsh coal mine killed 439 people. The incident was caused by a spark from exposed electrical wiring igniting an explosive atmosphere of air and methane. Further investigations revealed that the explosion occurred shortly after a new type of battery was deployed. Although the old type of battery would still cause sparks, only the new battery could supply enough power to the spark for ignition. This is, in essence, the concept of intrinsic safety; that a power supply whose output is appropriately limited will not produce sparks energetic enough to cause ignitions [2].

Further research was undertaken to develop an appropriate apparatus to test intrinsic safety. This work culminated in the 1967 international standardisation of a German designed device (Figure 1.1), now known as the Spark Test Apparatus (STA)[2].

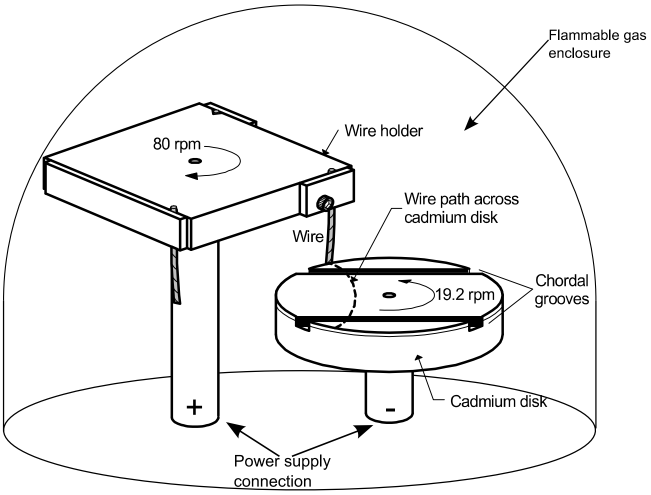

Figure 1.1: Spark Test Apparatus (STA)

At the time of this standardisation, the mechanical creation of large numbers of sparks in the presence of a confined test gas sample was seen as a good test of intrinsic safety. The ensuing decades have, however, have raised very serious concerns about the STA, including:

- **Lack of repeatability:** The STA has several sources of uncertainty inherent in its construction and operation. The condition of the disc and wire change significantly during operation. The mechanical action is also a source of uncertainty in itself.
- **Poor performance on modern equipment:** Many modern power supplies incorporate some form of functional safety measure, such as the reduction of output power when a short circuit fault is detected. The STA cannot reliably ensure that such safety measures are functioning as intended. Also, the complex transient behaviour of such devices leads to even more unpredictability in the STA.
- **No proportional measure of safety:** The STA only provides a pass/fail result, i.e.: creation (or absence) of an explosion within 400 revolutions. This provides little useful feedback to manufacturers, who are unable to assess the severity of a failure.
- **Use of arbitrary safety factors:** It is common practice to enforce safety factors with the STA by using test gas mixtures more explosive than the intended environment. This is problematic, as the complexity of the ignition process means that the relative explosiveness of different gas mixtures cannot be described by a simple factor.
- **Reliance on hazardous materials:** The use of cadmium, widely regarded as toxic and explosive gasses are necessitated by the STA. This not only poses a risk to personnel, but also means that the STA requires laboratory conditions, with no possibility of factory and/or site based testing.

2. Overview of Concepts

The Electronic Spark Tester concept is outlined in Figure 2.1. The EST is connected to a device under test in a similar manner to the STA (via a passive network – usually intended to simulate a length of cable). The EST replaces the STA's wire and disc with an "Electronic Load", which simulates a spark event. A test result is calculated from current and voltage measurements made during the simulated spark event and takes the form of a safety metric termed "ignitability", providing a proportional measure of safety. This replaces the test gas and explosion chamber of the STA.

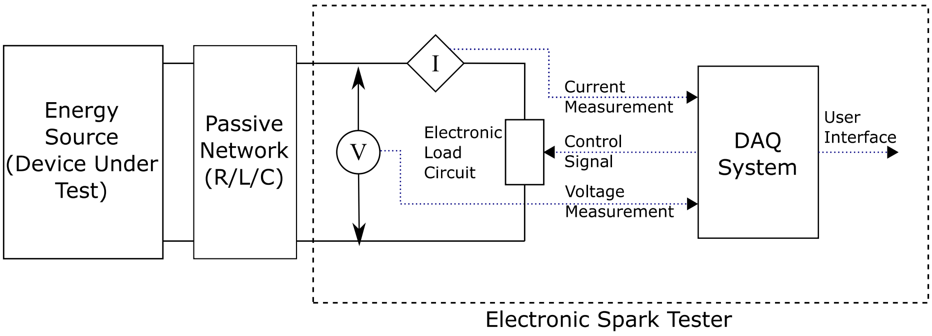

Figure 2.1: EST concept overview

The electronic spark tester concept thus consists of:

- **Testing –**the simulation of the spark event through appropriate control of the electronic load, and recording of the resulting voltage and current data
- **Analysis –** making a determination of the explosion risk, based on the recorded data

3. Testing

Electrically, the spark can be considered as a load transient, and has a distinctive voltage and current signature. An example of transient voltage and current measurement from a spark event in the STA is shown in Figure 3.1.

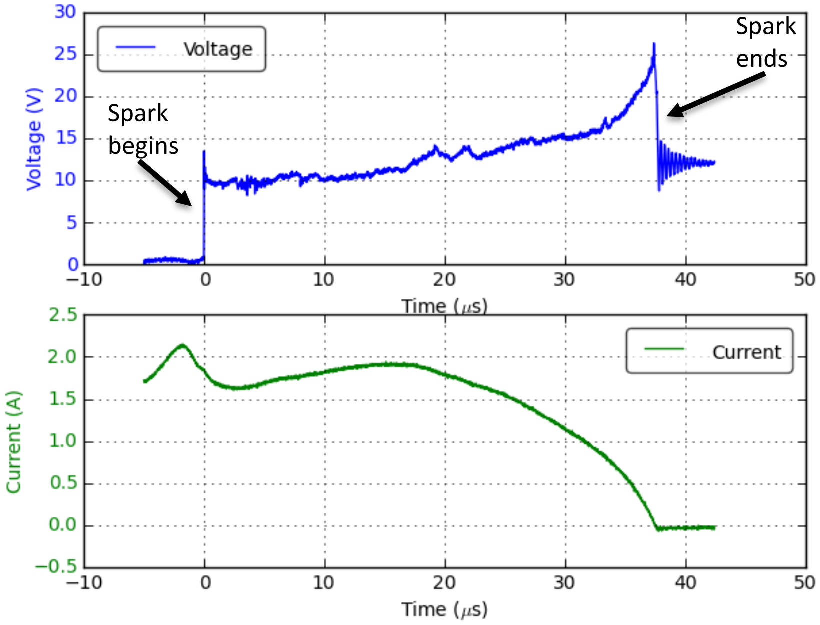

Figure 3.1: Example of transient spark/voltage and current

The distinctive features include a sudden rise in voltage up to slightly above 10V and the current falling to zero, which signify the start and end of the spark. This example is typical of a so called "break-spark" occurring when electrical contacts such as the wire and disc of the STA separate. When contacts are brought together, “make-sparks” which have different characteristics, may also occur. Make sparks do not generally pose an ignition risk at the low voltages found in the EST’s intended range of application (i.e.: equipment for Group I hazardous areas), so are currently not considered.

The duration of the spark may vary widely, from tens of microseconds to several milliseconds, depending on the mechanical movement of the STA’s wire and disc, as well as the electrical circuit characteristics. For these reasons, a spark cannot be electronically simulated by a fixed voltage/current profile, and a model is required to determine the voltage current relationship of the spark event.

Previous research has found that, for a large range of circuit and spark types, the voltage and current transients can be predicted by a relatively simple, non-linear resistance model, similar to those used in classical theories of switching arcs [3]. The model relates spark voltage (*v*) to current (*i*) and the physical length (*l*) of the discharge, and is given by the formula

$$v = v_0 + al\left(1 + \frac{b}{i^n}\right)$$

where v_0, *a*, *b* and *n* and tuning parameters fitted from experimental data. The length *l* changes over time due to the movement of the electrodes in the spark test apparatus. In practice, this movement can be well approximated by a constant opening speed. As a wide range of contact opening speeds occur in the STA, those which pose the most significant risk must be simulated by the EST.

An example prediction is shown in Figure 3.2.

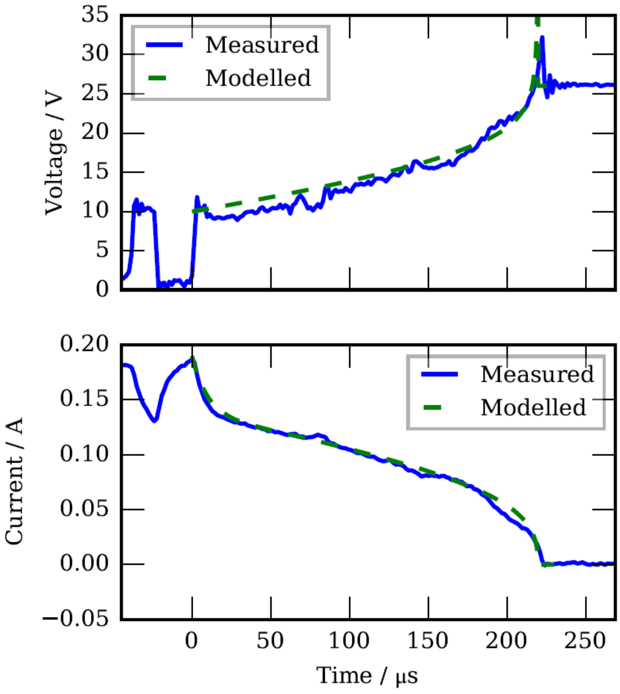

Figure 3.2: Comparison between a real spark and one predicted by the model

The role of the EST’s electronic load is to create a load transient at the output terminals of a device under test conforming to the model equation. This is accomplished using a MOSFET device with appropriate control and drive circuits. As the relationship between the input control signal and the output at the terminals of the device under test is highly nonlinear, software compensation is performed to obtain the desired load transient. An example of a simulated spark event compared to a real spark produced in the STA is shown in Figure 3.3.

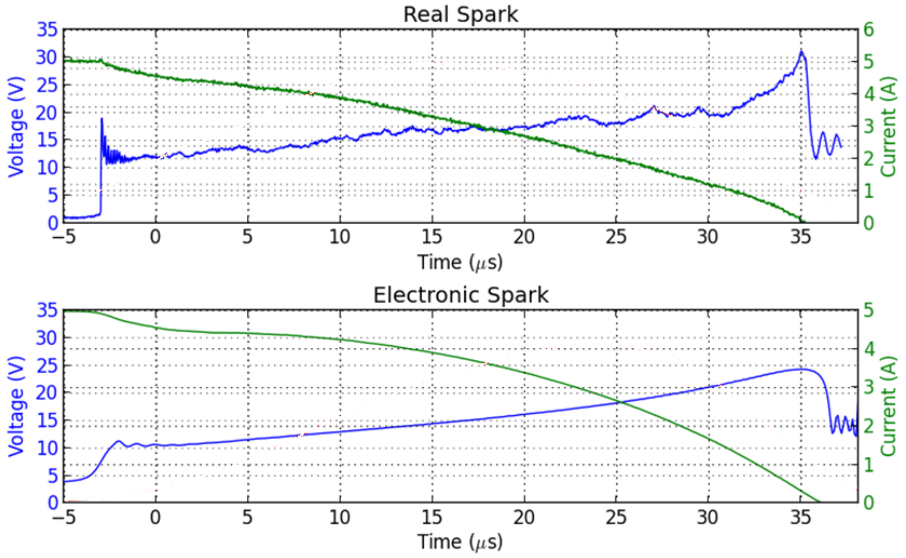

Figure 3.3: Comparison of a real spark and one electronically simulated by the EST

Another important factor is the interaction between the spark (real or simulated) and the device under test. As noted in section 1, modern devices have somewhat complex transient characteristics. One example of this is an increasingly common feature of newer power supply units, which detects a short circuit load and reduces the output current significantly below the rated value. This is referred to here as a shutdown. There is often a time delay between the short circuit fault occurring and the shutdown being triggered, as shown in Figure 3.4.

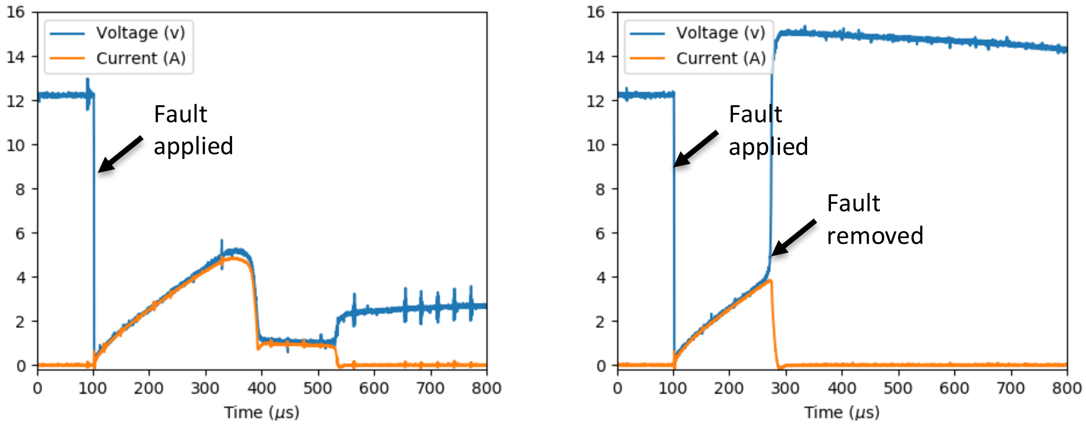

Figure 3.4: Example of shutdown behaviour. If the short circuit fault is of sufficient duration, the shutdown will be triggered (left), otherwise not (right).

Sparks cannot occur when a power supply unit is in shutdown mode due to the low voltage. The spark ignition risk is therefore posed by an intermittent short circuit, with a spark occurring within a period too short to trigger the shutdown. This scenario may occur sporadically and unpredictably in the STA. The EST, however, can detect the presence of shutdown behaviour and reliably apply a simulated spark under this worst case scenario.

4. Analysis

Once the measurement of one or more simulated spark events is complete, and data such as that of Figure 3.3 is recorded, the next step is the analysis of this data to determine explosion risk. In general, the relationship between the electrical transient and the ignition of a flammable gas is very complex. In simplified terms, however, it can be understood as a sequential process involving multiple conversions of energy into different forms, as shown in Figure 4.1.

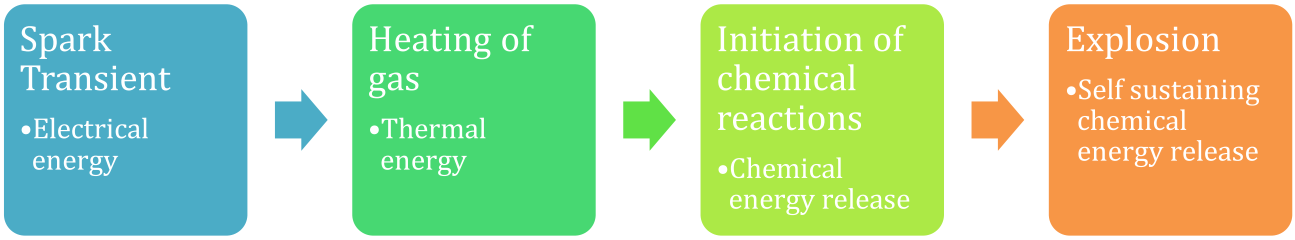

Figure 4.1: Simplified explanation of explosion initiation

At each stage of the process, energy storage and losses occur due to various mechanisms. If the losses are sufficiently high compared to the energy input, the process ceases at that stage and no explosion occurs. The goal of the analysis is to predict the effects of these losses, given the quantity and rate of energy delivered into the spark transient, as measured during the electronic spark test.

Although making this prediction in the general case would be very difficult, research has shown that a simplified, "heuristic" approach is feasible, for a limited range of applications [4]. This approach is based on calculating an effective spark power, intended to represent the amount of energy transferred into heating the gas. The effective spark power is defined by

$$p_e = (v - 10)i$$

as per the usual definition of electrical power, where the subtraction of 10 volts (the approximate starting voltage of the spark in Figure 3.1) accounts for power lost to the contacts. Applying this calculation to the recorded voltage and current data produces a third curve for effective power. A moving average of the effective power waveform is next taken to account for the energy dynamics of the gas heating and the initiation of chemical reactions. This averaged effective power is termed "ignitability". An example of ignitability calculated from the voltage and current data of a simulated spark event is shown in Figure 4.2.

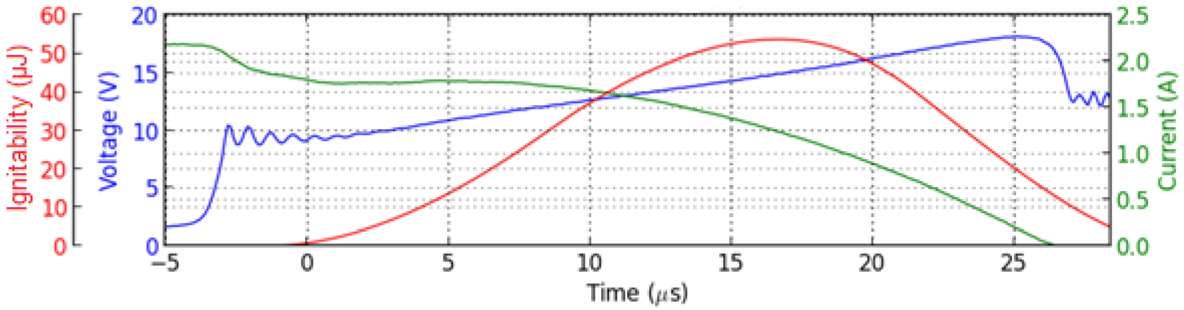

Figure 4.2: Example ignitability calculation

The final stage of the analysis is selecting the peak value of the ignitability over the duration of the spark event. This peak value is compared to a safety threshold. If the peak ignitability is below the threshold value, the device under test is considered safe. The difference between the peak ignitability and the threshold provides a proportional margin of safety or failure.

Key details of the analysis process are the period of the moving average for calculating the ignitability, as well as the value of the safety threshold. These must be determined by experiment, and vary depending on the hazardous area gas group of the target application. The applicability of this analysis process is also restricted to a defined set of electrical circuit parameters (i.e.: output voltages and currents), which, for the time being, covers most applications in hazardous area gas group I applications. Further information on the analysis process may be found in the previously published research [4].

5. Fundamental Research

Although the above described analysis approach is adequate for testing under well-defined scenarios, a longer-term goal is a method which is more broadly applicable, without requiring calibration for different types of device under test. For this purpose, fundamental research has been undertaken. This work examined the physics of the discharge and explosion phenomena using computational models of gas flow and thermochemistry, together with direct measurements of laboratory scale explosions [5], [6]. This work has been undertaken through collaboration partners and is intended to continue in the future.

6. Status and Outlook

The ultimate goal of the work is to gain recognition for the electronic spark test apparatus from the international body responsible for standards in explosion protection, namely technical committee 31 of the International Electrotechnical Commission (IEC). This committee has appointed a working group in charge of improvements to spark testing in intrinsic safety, which has been briefed on developments in the EST concept.

The project is currently in the research prototype stage. Progress towards formal recognition will require a broad base of support from industry. It is for this purpose that Mining3 is conducting a test and demonstration program to allow manufacturers and testing laboratories to familiarise themselves with the EST and to evaluate its utility to them. Mining3 is currently seeking the support of industry in this program, for example through the provision of sample products to test the EST, as well as ideas for potential use cases.

7. Acknowledgements

This research is funded by the Australian Coal Association Research Program.

Parts of the research were conducted collaboratively with the Physikalisch-Technische Bundesanstalt (PTB), Germany's national metrology institute.

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