An investigation into the sensitivity of commonly used electric igniters

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Abstract: A variety of commercially available and commonly used electric igniters were tested for sensitivity to shearing, crushing and static stimuli in an attempt to reproduce "real World" usage of igniters and to determine which igniters were more or less sensitive to the various stimuli used. The apparatus was designed and build to be able to be reproduced by anyone in order for them to gain a better understanding of the sensitivity of the igniters they use in their displays.

Introduction

The use of electric igniters in firework and pyrotechnic displays has increased significantly over recent years with the adoption of new firing techniques and designs and new firing systems.

In very rough terms in the last 30 years there seems to have been a 100-fold increase in the use of igniters in firework displays

- 30 years ago a few igniters would be used to fire a large front of effects, particularly low level effects or at the finale – say a total of 10 igniters per show
- 15 years ago each shell sequence or battery of Roman candles would have a single igniter fitted, with delays being achieved between effects using various types of pyrotechnic delays – say a total of 100 igniters per show
- Now each shell will have its own separate igniter and much more use is made of single shot devices (eg fired from structures) - say a total of 1000 igniters per show

Similarly there has been an increase in the use of theatrical pyrotechnic devices used on stages.

This has led to 2 significant features:-

Firstly, the numerical increase has meant that there is an increased risk during handling, rigging and derigging of the display

Secondly, that the increased use has driven a demand for cheaper, perhaps more sensitive, igniters as their use becomes an increasingly significant part of the overall cost of the display.

Historical accidents

There have been a number of accidents and incidents around the World in recent years where the use (or misuse) igniters can be considered as a root cause.

The authors have witnessed first-hand two accidental ignitions of igniters which were, thankfully, not attached to any other device when they functioned. The authors have also been involved in post-accident investigation which sadly ultimately led to fatalities, where the use of igniters is at least implicated. [1]

Aims of the study

From the outset it was decided to design and develop simple tests and apparatus that could be built and used by anyone in order to get a qualitative "feel" for the sensitivity of the igniters they were using rather than to develop more sophisticated quantitative equipment that would be prohibitively expensive to reproduce.

Furthermore the tests were designed to simulate real-World ignition stimuli found during the rigging and derigging phases of a display.

Various studies have been conducted with igniters of various types before [2] but the essence of these tests was their simplicity and application to use by others in obtaining sensitivity information.

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Ignition stimuli

Initially the following stimuli were determined:-

- Crushing or Impact – as in a hammer blow to the igniter bead during rigging
- Shearing – as in the shearing of the bead by a pair of pliers during fixing of the igniter and quickmatch to a support
- Friction – as in inserting or pulling the igniter into or from a piece of quickmatch
- Static discharge – as in discharging from a body during rigging

Types of igniter chosen

5 different types of electric igniters commonly used in the UK were obtained for the trials.

The igniters and identifiers are shown in Table 1 below.

Initial results

Trials were carried out using simple apparatus to determine if there was evidence for the perceived variation in sensitivity to various stimuli. The tests were:-

- Impact (crushing) – hammer on igniter bead on metal plate. It proved difficult to obtian reproduceable results from this test, and this was evident in later tests too. We believe in addition to the human factors (how hard the hammer is wielded) it seems critical as to the orientation of the igniter bead and the exact angle of impact
- Shearing – crushing the igniter bead outside the internal solid support structure in the jaws of a pair of pliers. This test proved to be quite reproduceible and formed the basis of the subsequent tests
- Static – positioning the igniter in the spark gap of a Wimshurst machine. This test prdoduced interesting initial results which are discussed below. It also was apparent that there was no correlation between sensitivity in the shearing tests and in the static test
- Friction tests – it proved impossible to obtain reliable and reprodicible ignitions when pulling an igniter bead through a piece of piped blackmatch

Electrostatic tests

Igniters were tested in various orientations and conditions:-

1. Spark discahrged across open igniter wires
2. Spark discahred across single igniter wire – the other lead being earthed
3. Spark discharged across head of igniter bead – wires being shunte
4. Spark discharged across head of igniter bead – wires open
5. Spark discharged across soldered terminals on igniter bead – wires shunted or open

It was only the last tests (#5) that led to significant and reproducible ignitions of the igniter.

In this test there was no difference if the wires were open or shunted.

It was particularly suprising that discharge across the open wires of the igniter (test #1) caused no ignitions to occur.

We also believe (as has been noted by practitioners) that it is the integrity of the laqueur coating of a typical igniter bead (or lack of it) that leads to sensitivity – particularly where the igniter composition has been exposed, often through the formation and subsequent "popping" of a bubble in the laqueur during manufacture.

Development of tests

The initial tests were refined as follows to carry out experiments of a variety of igniter types.

Shearing tests

The shearing tests involved placing the tip of the igniter under a steel hinged assembly and dropping a weight onto the hinge from a fixed height to shear the igniter bead between the jaws of the hinge. The igniter was arranged such that the closing of the jaws did not impinge on the bead substrate – ie that the jaws were not restricted in their movement.

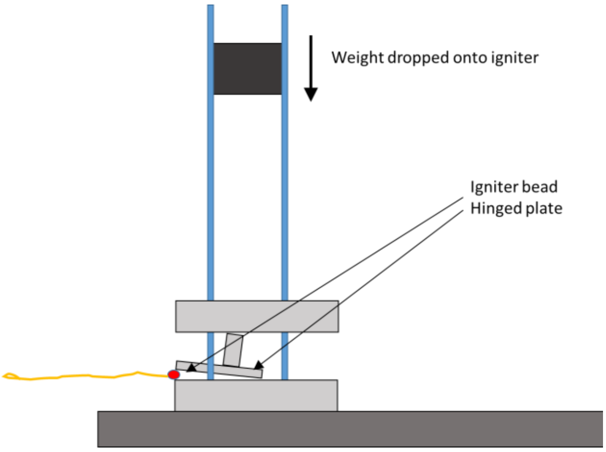


Figure 1 - Schematic of shearing test

The energy of the stiumulus needed to cause ignition was recorded as the mass of the weight dropped.

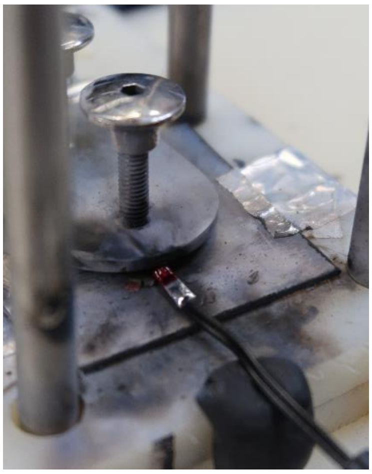


Figure 2 - Shearing test setup

Crush - Drop (impact) tests

The drop test involved plaving the igniter bed between two steel plates and dropping a weight onto the top plate from a fixed height.

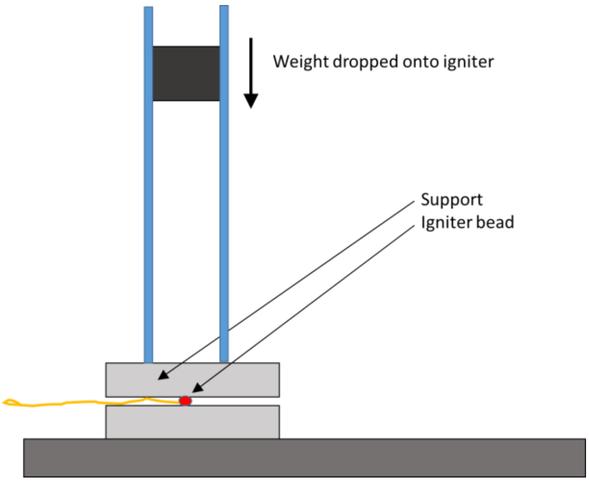


Figure 3 - Schematic of Crush test

The energy of the stiumulus needed to cause ignition was recorded as the mass of the weight dropped.

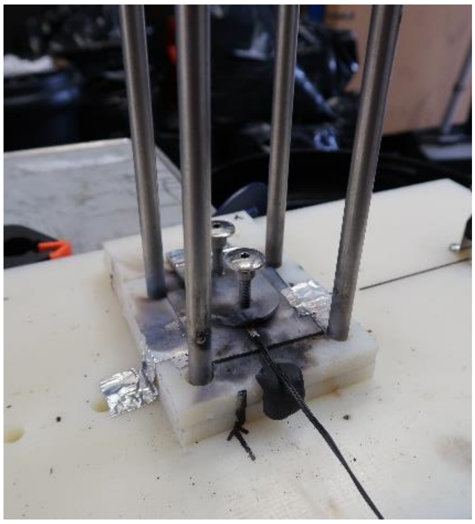


Figure 4 - Drop test setup

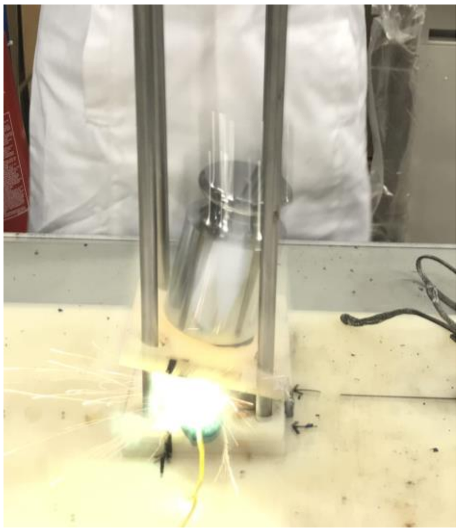
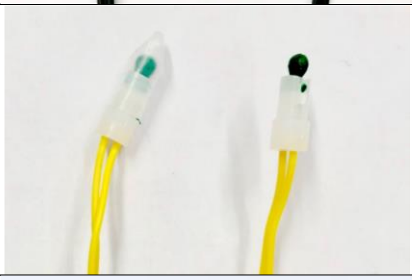
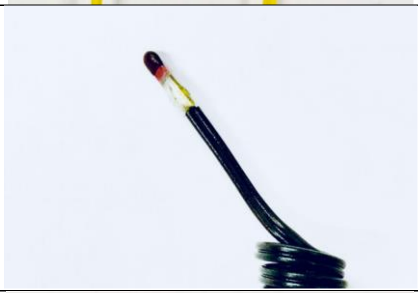
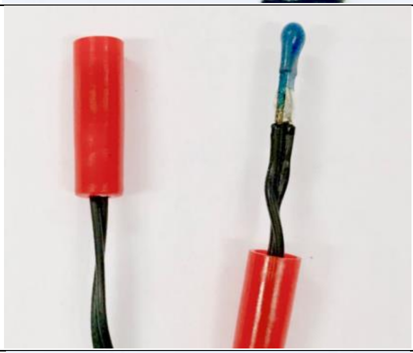
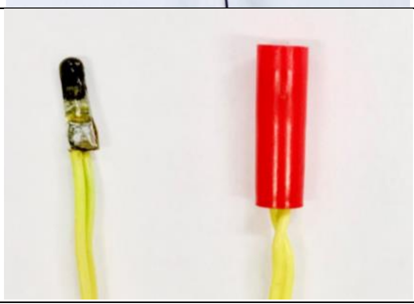


Figure 5 - Drop test ignition

Static tests

An initial test was carried out using a simple van-der-Graff generator on the manufactuerer's "Low", "Medium" or "High" setting. This test proved difficult to reporoduce and it was considered that it did not allow quantification of the stimulus, nor easy reproducibility for end users. The machine was also relatively expensive (c. 200 GBP) as opposed to the Wimshurst machine used subsequently (c 40 GBP).

Table 1- Image of igniters and identifying letters

Igniter	Image	Specification and Comments
A		Manufacturer: Bickford Item #: 2001 Resistance: 1.6 ± 0.3 ohm No fire current: 0.20 A for 10 s All fire current: 0.60 A for 3 ms
B		Manufacturer: Privatex-Pyro sro Item #: EMP-NO-2 NEC: 0.04g
C		Manufacturer: Martinez Resistance: 0.9± 0.15 ohm No fire current: 0.30 A All fire current: 1.5 A
D		Manufacturer: Foti Item #: FEI-1 Resistance: 1.3-1.7 ohm No fire current: 390 mA All fire current: 600mA
E		Manufacturer: ESF Item #: unknown Resistance: 2 ohm
F		Manufacturer: JTec Item #: 7 (877-ematch 3)

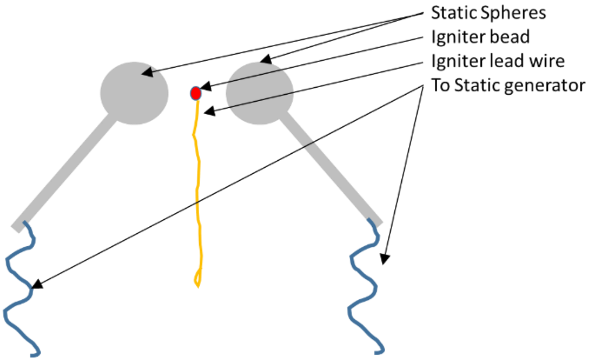


Figure 6 - Schematic of static test

In the Wimshurst test, the igniter bead was supported by clamp between the discharge probes so that it was equidistant from each probe. The machine was powered up until a spark was discharged between the probes and across the igniter.

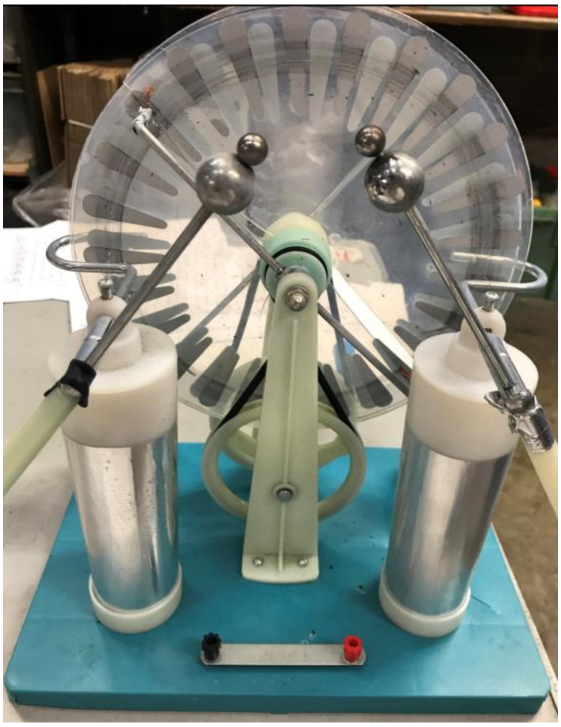


Figure 7 - Wimshurst machine

The energy of the stimulus needed to cause ignition was recorded as the distance between the machine's probes, and the greater the distance the greater the energy of the spark created.

Figure 8 - Ignition from static test

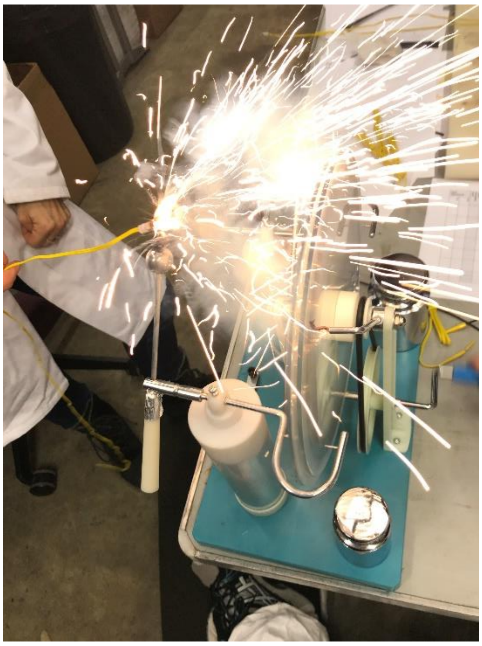


Figure 9 - unexpected sparks from static test

Figure 9 shows generation of very significant sparks during the ignition of the igniter – more than from just functioning the igniter with a battery.

Friction test

It proved impossible to obtain consistent results in a friction test, but the schematic below is given for completeness.

We intend to continue to develop and refine this test as we believe it is one of the most likely and frequent causes of accidental ignition with igniters.

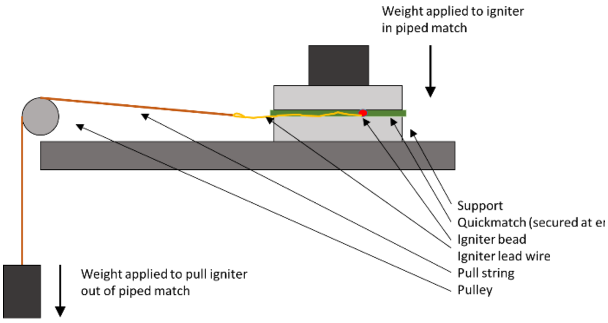


Figure 10 - Friction test

Ignition Results

Each test was repeated with a number of igniters in order to determine whether ignition occurred or not.

The energy required to ignite approximately 50% of the igniters in any specific test is recorded below. We attempted to use the Brueton method [3] but decided that for routine use this was overly sophisticated and used too may igniters. We do not believe users would adopt this method.

We do appreciate that it might be considered appropriate in a safety related experiment to record the minimum energy required to cause any ignition of an igniter – but felt that recording the 50% value gave a more realistic range of ignition energies.

The results are given in table 2.

The approximate 50% ignition stimuls was recorded. We did not employ the Bruceton methodology [2] because we did not find it useful where perfect reproducibility was not achieveable, and because we felt it less likely to be adopted by end users. We appreciate and understand the limitations of our methodology, but consider it adequate for the purposes of this study.

Ranking of igniter sensitivity

Table 2 also ranks the sensitivity of the igniters to various stimuli. Note that these rankings are entirely subjective and relate only to the specific test.

- RED – the most sensitive (ie most easily ignited) to the stmulus
- AMBER – medium sensitivity
- GREEN – the lowest sensitivity to the stimulus

Discussion

There are important findings from the results.

It is immediately obvious from the ranking of results that the different igniters reacted differently to the various stimuli and that, for instance, high sensitivity to one stimulus (eg shearing) does not infer high sensitivity to a different stimulus (eg static).

It is also apparent that in most tests there is a wide range of sensitivities to any particular stimulus. It is likely that the design of the tests means that absolute reproducibility is very difficult to achieve and hence some variation in whether a particulr stimulus does cause ignition is to be expected. The design of the tests was fundamentally simple, to allow companies to recreate the tests simply and cheaply and therefore actually carry out such tests.

It is also obvious that the crush test led to no ignitions even with the maximum drop weight (2000g) applied. This is consistent with the screening studies carried out, but not with the real-World observation that hitting an igniter bead with a hammer can cause ignition in some cases.

Several igniter beads were crushed, split or otherwise deformed in the crush tests even though no ignitions occurred.

Physical damage to igniters

The foloowing images show physical damage to igniters where ignition did not occur. In many cases the igniter bead (fusehead) was split or destroyed without ignition occurring. This result is somewhat surprising but we believe that the failure to achieve ignition in our crush tests may reflect the fact that a crude hammer test actually involves some shearing and that the failure to ignite in "pure" crushing of the bead actually is explained by the test plates stopping once the substrate of the igniter is between the jaws of the test.

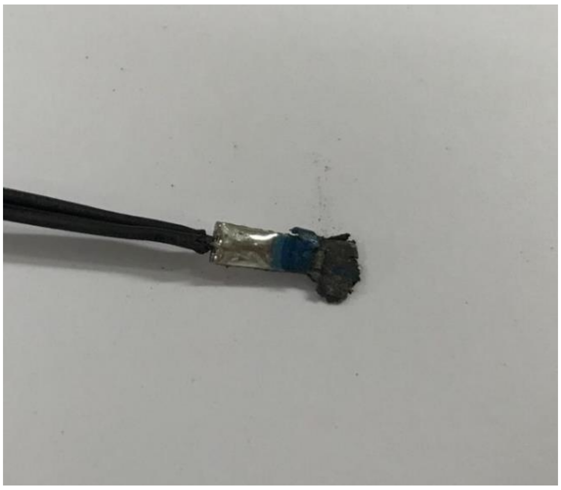


Figure 11 - Foti igniter crushed in 2kg crush test

Table 2 - Results

X=YES O=NO		A	B	C	D	E	F
		Bickford	**Czech**	**Martinez**	**Foti**	**ESF**	**JTec7**
		Black	**Yellow**	**Black**	**Black**		
Sheering (no shroud)	2000g	XXXXXXX	OOOOOOO	XXXXXXX	OOOOOOO	n/a	OXOXXXX
	1000g	XXXXXXX	OOOOOOO	XXXOXXX	OOOOOOO	n/a	OOOXXXX
	500g	OXXXXXX	OOOOOOO	OOOXOOX	OOOOOOO	n/a	XXXOOOO
	300g	XOXXXXX	OOOOOOO	OOOOOOO	OOOOOOO	n/a	OOOOOOO
	200g	OOOOOOO	OOOOOOO	OOOOOOO	OOOOOOO	n/a	OOOOOOO
Approx 50% ignition		**400g**	**>2000g**	**1000g**	**>2000g**	**n/a**	**500g**
Sheering (w shroud)	2000g	OOOOOOO	OXOOOOO	n/a	OOOOOOO	OOOOOOO	OOOOOOO
	1000g	OOOOOOO	OOOOOOO	n/a	OOOOOOO	OOOOOOO	OOOOOOO
	500g	OOOOOOO	OOOOOOO	n/a	OOOOOOO	OOOOOOO	OOOOOOO
	300g	OOOOOOO	OOOOOOO	n/a	OOOOOOO	OOOOOOO	OOOOOOO
	200g	OOOOOOO	OOOOOOO	n/a	OOOOOOO	OOOOOOO	OOOOOOO
Approx 50% ignition		**>2000g**	**>2000g**	**n/a**	**>2000g**	**>2000g**	**>2000g**
Crush (w shroud)	2000g	OOOOO	OOOOO	n/a	OOOOO	OOOOO	OOOOO
	1000g	OOOOO	OOOOO	n/a	OOOOO	OOOOO	OOOOO
	500g	OOOOO	OOOOO	n/a	OOOOO	OOOOO	OOOOO
Approx 50% ignition		**>2000g**	**>2000g**	**n/a**	**>2000g**	**>2000g**	**>2000g**
Crush (no shroud)	2000g	OOOOO	OOOOO	OOOOO	OOOOO	n/a	OOOOO
	1000g	OOOOO	OOOOO	OOOOO	OOOOO	n/a	OOOOO
	500g	OOOOO	OOOOO	OOOOO	OOOOO	n/a	OOOOO
Approx 50% ignition		**>2000g**	**>2000g**	**>2000g**	**>2000g**	**n/a**	**>2000g**
Static screen	Low	XX		OOXXXXX	OOOOO	OOXXXXOX XX	XXOOOOO
	Medium			XXX			
	High			X	OOOOO	OXXX	OOOOO
Approx 50% ignition (Screen test only)		**n/a**	**n/a**	**n/a**	**n/a**	**n/a**	**n/a**
Wimsh urst	2.5cm	OOOOO	XXXXXXX	XOOXXX	OOOOO	OOOOO	OOOOO
	1.5cm	OOOOO	XXXXXXX	XXXXXX	OOOOO	OOOOO	OXOXX
Approx 50% ignition		**<1.5cm**	**>2.5cm**	**2cm**	**<1.5cm**	**<1.5cm**	**1.5cm**

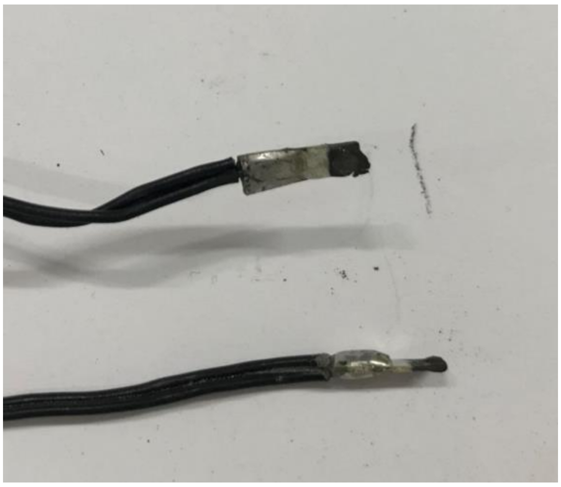


Figure 12 - Bickford igniter rushed in 500g test

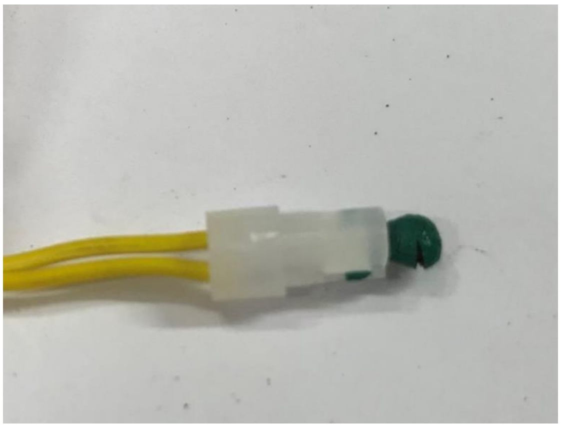


Figure 13 - Czech igniter split - weight of plate only

Igniter protection issues

Typically electric igniters are available in shrouded and unshrouded varieties.

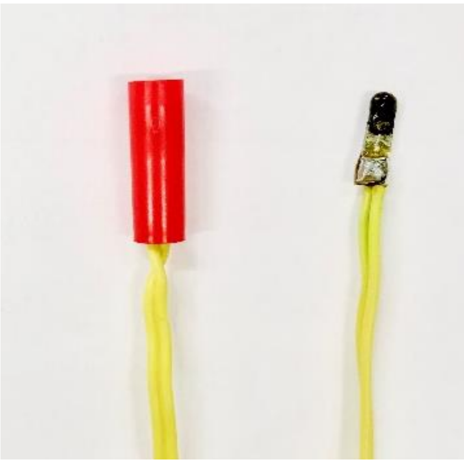


Figure 14 - Typical igniter with shroud in place and removed

There has been much discussion of the purpose of such a shroud, and disagreement between users and manufacturers as to whether the shrouds provided protection from accidental ignition.

The primary purpose of such a shroud is, according to manufacturers, to provide directionality and concentration of the incandescent sparks created when the igniter functions and which ultimately leads to more reliable ignition of the subsequent elements in the explosives train. For instance Bickford specifies "2001 series igniters are equipped with a small cylindrical shroud over the fusehead, giving a directional effect to the output".

Users, on the other hand, seem to regard the shroud as providing very significant protection against, often un quantified, stimuli.

We believe that the shroud does indeed provide significant protection against the crush and shearing stimuli examined but that in real-world use, where, for instance, black powder may be trapped between the bead and shroud the protective effect may be eliminated completely.

Caution is advised.

Conclusions

This paper attempts to quantify, in a simple manner, the sensitivity of a range of igniters to a variety of stimuli.

The use of igniters has increased significantly in recent years, and hence the risk from accidental ignition has also increased (even if that risk remains low).

However we believe that often users treat igniters and the potential for accidental ignition with relative contempt – and we fear that this will lead to more numerous and more significant incidents if users do not have an appreciation of the sensitivity of the igniters they are using.

This research demonstrates that there is a wide range of energies required to initiate a variety of igniters subject to different stimuli, and that furthermore there seems to be no correlation between sensitivity to one stimulus to the sensitivity to another stimulus.

The research also demonstrates that the shroud covering an igniter can afford significant protection in the tests carried out, although we believe in real-use the reduction in sensitivity may be less marked.

Further work

Further work is planned to address the following issues:

1. The development of a reproducible tests for friction
2. Extension of the test for crushing

3. The testing of other pyrotechnic igniters as they become available

4. The testing (for comparitive purposes) of non-pyrotechnic igniters

We also intend to carry out more historical investigation of incidents.

Acknowledgements

We gratefully acknowledge financial support from the following organisations

Explosive Industry Group of the CBI – see www.eig,org.uk

Bristish Pyrotechnists Association – see www.pyro.org.uk

The Event Suppliers Association and the Event Industry Forum – see www.tesa.org.uk

We aslo thank our colleagues in industry for helpful suggestions.

References

1. There have been several reported accidents relating to electric igniters although we would urge a degree of caution in the conclusions of non-scientific studies. It is also important to distinguish between electric igniters (e-matches), squibs and detonators.

   See, for example:- http://blog.skylighter.com/fireworks/2012/02/are-electric-matches-really-safer.html

2. For further information on testing of igniters see, for example:-

   http://www.jpyro.com/wp-content/uploads/2012/08/Kos-614-633.pdf

3. For a brief explanation of the Bruceton method see:- https://en.wikipedia.org/wiki/Bruceton_analysis