ispark supplement main

(inside, physics, examples & more)

CONTENT

ANNEXE (separate Document *ispark* supplement annexe)

0 Foreword

This part of ***ispark's*** documentation is directed to those persons who do not only want to use the method for daily work but are interested in the physical and technical background. Most common reason may be to achieve a better understanding of ***ispark's*** properties in a context of other assessment methods. But it's intended to pick up the chance also to transfer knowledge about sparks and spark ignition to support further investigations in and outside PTB. Also included are some examples and explanations with distinct circuits and ***ispark's*** treatment of some special topics. Understanding can help you to develop very new ideas for your applications.

Please note: the version 7.1 for the first time introduces new spark parameters for to improve matching the standard's ignition data. It seems not to be necessary to revise this document accordingly because differences usually are small. But cited numbers may not be exactly met.

And please notice the newly included annexe G...J.

0.1 This document's overview

Chapter 1: Sparks within the scope of actual standards

For an overview, requirements of actual standards are presented with respect to quantities and procedures.

Chapter 2: More spark ignition quantities

Besides spark properties presented within standards, a lot more information is available; some of it is reported here.

Chapter 3: Some reflections about uncertainties with ignition data

As with all experimental data, there are uncertainties in the area of reported intrinsic safety data also. These uncertainties do constitute the margin, more artificial methods like ***ispark*** have to stand.

Chapter 4: A physical view on sparks with the standardized test apparatus

Experiments with the standardized spark test apparatus in general are targeted on their interaction with certain circuits delivering a macroscopic insight only. Nevertheless some details are known and reported here.

Chapter 5: *ispark's* working in principal

ispark incorporates a distinct model structure and appropriate model parameters within its implementation. Both are presented in this chapter.

Chapter 6: Spark types, failure aspects and circuit topology

Besides the ‚natural behavior' of a spark, circuit properties like inductances and capacitances of the circuit impose characteristic appearances as well as the arrangement of components within the circuit. Additionally, the required failure assumptions have severe consequences. The latter additionally have to distinct also between a lumped or a distributed character.

Chapter 7: Data to be declared

There is a reasonable data range with intrinsically safe circuits for common use. Despite ***ispark's*** procedures may comprise some more head space, user's data are restricted to the tabulated ones in this chapter.

Chapter 8: Comparing *ispark's* results to experimental data

Every modeling has to show its compliance with experimental results. Some of this proofs are reported here.

Chapter 9: Examples and explanations

Within the systematic presentation of ***ispark's*** properties, some special topics may be left out. The most important known are picked up here.

Chapter 10: Some delicate considerations

All traditional methods do carry some ballast with themselves. A discussion from an actual point of view is tried in this chapter.

Chapter 11: Contact

For questions and explanations, you find my contact data here.

Chapter 12: Errata

Annexe: Here are demonstrated some special situations and the kind, ***ispark*** deals with them. May be there is some future common use possible.

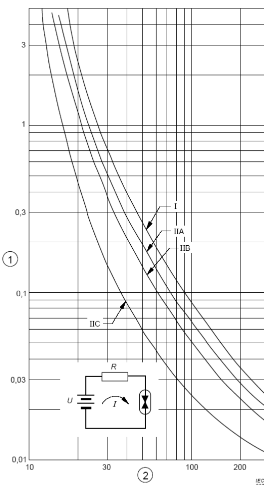
1 Sparks within the scope of actual standards

1.1 Sparks within the scope of IEC 60079-11

IEC 60079-11 shall be taken as a typical example of a recognized standard for intrinsic safety. Some others exist (for example FM 3610), but most statements and procedures are basically almost the same with the treatment of spark ignition.

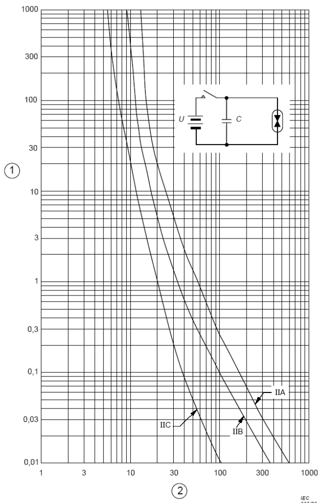
1.1.1 Circuits and quantities

Spark ignition quantities are reported within IEC 60079-11, among some others, by diagrams as follows :



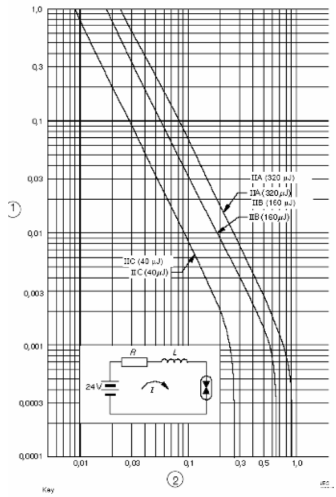
Key
1 Minimum ignition current I (A) 2 Source voltage U (V)

Figure A.1 – Resistive circuits



Key
1 Capacitance C (µF) 2 Minimum igniting voltage U (V)

Figure A.3 – Group II capacitive circuits



Key
1 Inductance L (H) 2 Minimum igniting current I (A)
1 – The circuit test voltage is 24 V
2 – The energy levels indicated refer to the constant energy portion of the curve.

Figure A.4 – Inductive circuits of Group II

Figures include the electrical circuits used to experimentally determine ignition quantities. It's clearly to be seen, that all these circuits are of very simple structure; either there is included a capacitance **or** an inductance **or** none of them. An additional weakness with the capacitive limiting curve is a feeding source of (nearly) infinite resistance, with the inductive curve reference is made to 24 V only.

There is no information about realistic electrical circuits, which normally comprise both, capacitance and inductance and a non negligible source. And none with sources of non linear characteristic. Only a statement is been found in IEC 60079-11 to "search for experts advice" if applicability is in doubt.

1.1.2 Assessment procedure

Ignition data related assessment procedure according to IEC 60079-11 normally consists of three steps:

a) check in figure A.1 whether or not the point represented by U_o and the 1.5'th I_o does exceed the given limiting curve
b) determine in figure A.3 a suitable capacitance using the 1.5'th of U_o

c) with the 1.5'th I_o search for a permissible inductance in figure A.4

This procedure is straight forward and easy to use. Unfortunately, manufacturers who usually want to let appear their products at their best, tend to bail out each of the given limiting curves itself. They often do not take into account the warnings of the standard to use an increased safety factor in such cases.

1.1.3 Conclusion

IEC 60079-11, as other intrinsic safety related standards, offers a simple assessment procedure but incorporates restrictions also, which are not yet quantified. As a result, a proper design and assessment of intrinsically safe circuits suitable for real use often is impossible.

1.2 Considerations with IEC 60079-25

1.2.1 General

IEC 60079-25 among other topics deals with the problem of interconnected active intrinsically safe circuits. It's useful especially for establishing intrinsically safe circuits in the pre-installation phase.

The standard distincts between interconnection of linear sources only and any other combinations and gives different procedures for each case. Annex B covers the first case, tracing it back to the application of data given in IEC 60079-11. All others are destinated to be covered by Annex C which reports procedures and limiting values of its own.

1.2.2 Annex C relationship to *ispark*

Relation of *ispark* and Annex C is of a very simple nature:

While *ispark*, in the kind you know it, calculates maximum permissible L_o and C_o for a predetermined electrical source, its basic functioning can be reversed to determine maximum electrical values for given L_o and C_o. That's the way, the diagrams of Annex C were revealed, one set of curves for rectangular shaped sources and another for linear ones.

This is the reason, why those basic source characteristics are covered exactly by Annex C, while all others underlay some kind of interpolation resulting in an uncertainty of the achieved safety factor. Diagram's limits with respect to U_o and I_o are chosen to preserve a safety factor of 1.0 at least.

Note: The content of Annex C was originally published as PTB Report ThEx-10 in 1999.

1.2.3 Conclusion

Use of Annex B, IEC 60079-25, obviously results in almost the same difficulties and restrictions as mentioned in chapter 1.1.3.

Taking Annex C is significantly more meaningful with respect to yielded safety and should be used for pure linear interconnections too, but will preserve only a safety factor of 1.0 surely. Both methods therefore are intended for field considerations and safety level ib rather than for certification data.

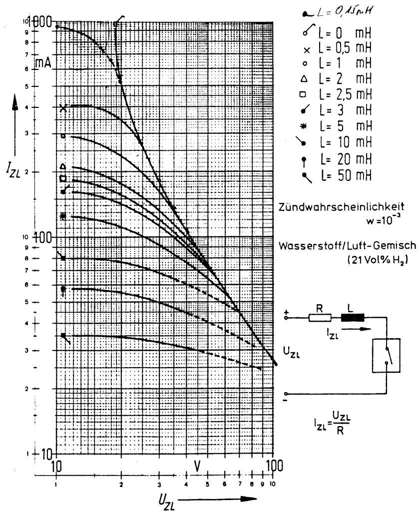
2 More spark ignition quantities

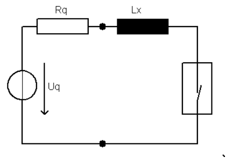
Since several decades PTB performs research work with the objective of a better and more precise assessment of intrinsically safe (or not) circuits based on experimentally gathered ignition data. Pure ohmic and capacitive circuits are not detailed in discussion here because there are less severe doubts about their quantities.

In the following, reported data are valid for the gasgroup IIC only. Some are existing for IIB also; they would not give a great more insight because they are following the same general tendencies just with different parameters.

It would be highly appreciated that experts outside PTB would report data they have experienced to check the overall matching and eventually correct this essay.

2.1 Linear inductive circuit with variable voltage





Formerly reported ignition data with linear inductive circuits were restricted to an open loop voltage of 24 V.

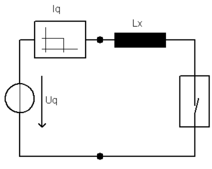
To fill the remaining gap, PTB investigated such circuits experimentally for further voltages and gained the diagram shown at the left.

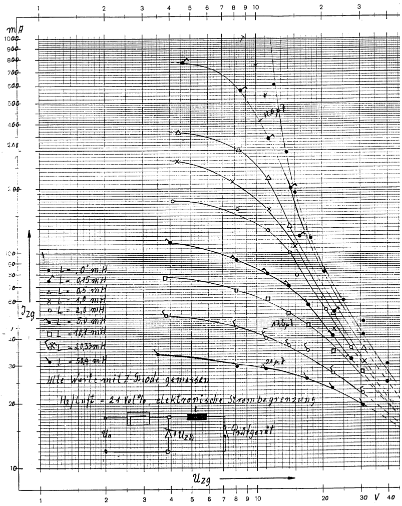
Voltage range is from about ten to 40 V, inductances are between (0 mH) 0.15 mH and 50 mH.

Obviously all the curves of different inductances tend to the same hyperbolic shape for higher voltages and to an individual merely constant current if voltage is lower.

The latter obviously is based on some ignition energy; the hyperbolic part will later be explained by the imagination of a certain ignition power.

2.2 Rectangular inductive circuit

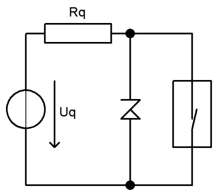


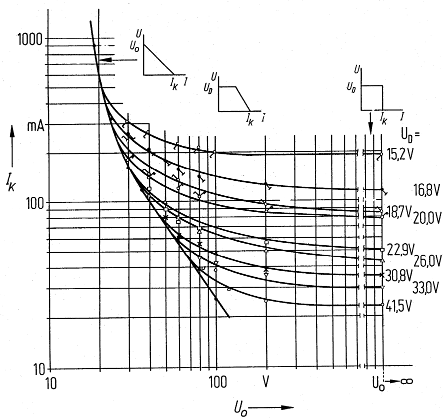


When the operability of an apparatus suffers from voltage loss under load condition, often supply circuits incorporating electronically limiting means are used, resulting in a rectangular shape of the electrical characteristic. Compared to a linear source of the same U_o and I_o, the available power is four times greater here and naturally the formerly known limits of linear circuits obviously can not be applied in those cases. At the left, the results of testing those circuits experimentally are shown as a diagram. Voltage range is from about four to 40 V, inductances are between (0 mH) 0.15 mH and 50 mH.

Curves' shapes are similar to those of linear circuits but permissible short circuit current is significantly lower with the same open loop voltage

2.3 Trapezoidal ohmic circuit





Further research work was carried out in PTB with respect to the transition from linear, passing trapezoidal source characteristics finally to rectangular ones.

The transition is obviously very smooth and leads to expect very similar spark properties.

Later will be shown, that all inductive sparks belong to one and the same generic spark type with contact opening out of a short circuit.

2.4 Circuits comprising both, inductances and capacitances

One special weakness with international standardized assessment procedures is the item, that they do not at all take into account any interaction of capacitances and inductances, neither by data nor by procedures. This is, although most real electrical circuits reveal capacitive and inductive aspects together.

Contrary to pure inductive (ohmic) and capacitive sparks, which are characterized by contact opening resp. closing only, with circuits including capacitance and inductance, a short transient close/open sequence is of great interest. One may at first have objections against this statement, perhaps referring to contact's inertia making a make and break within sparks lifetime impossible. But it is. Please see Annex A also.

PTB carried out experiments with respect to circuits comprising both, inductances and capacitances. Results are published by PTB Report W-11 and W-16 and an according assessment method was offered.

This method (the first one known, which uses computational means) was based on a "maximum arithmetic mean current" versus time as criterion to be compared with the ignition data of the linear inductive circuit.

Later investigations showed however, that this method does fit if voltages are low, but leads to excessive restrictions for higher ones. Nevertheless this was the first attempt to include advanced methods to intrinsically safe circuits evaluation.

2.5 Circuits with cables

Up to now, acknowledged standards serve for very weak information about special ignition properties of cables.

Introduced practice and surely on the safe side is, to treat distributed reactances like their lumped counterpart and, if the latter are present also within the circuit, to summarize them all together.

But there is a closer approach to the physical behavior of cables alone:

PTB investigated special ignition properties of cables with the results published via PTB report W-3. Unfortunately most of the experiments refer to long lines and high source resistances, but some of them fit to the target of commonly used parameters. A comparison with *ispark's* results is given in chapter 8.3.2.

Further, the FISCO model was established by PTB and adopted by international standards.

With spark ignition, the FISCO concept in essential places two statements to ensure intrinsic safety:

- the one and only present power source shall be intrinsically safe itself and does not exceed the open loop voltage range from 14 V to 17.5 V nor a short circuit current of 380 mA
- cables shall have distributed parameters not exceeding 15 Ω/km up to 150 Ω/km, 0.4 mH/km up to 1 mH/km and 0.045 µF/km up to 0.2 µF/km
- lumped inductances and capacitances have to be negligibly small

An *ispark* example within the FISCO range is reported in 6.5.5.2.

3 Some reflections about uncertainties with ignition data

The primary attempt of standardized spark test apparatus' design is to create a versatile equipment, suitable without any special adjustment for all practically appearent circuits. For this purpose a lot of quite different sparks is generated consecutively. An unavoidable main draw back is the consequence, that any experiment will take some time because one has to continue to have an appropriate chance for every relevant spark type to occur.

Unfortunately from this constructional idea directly follows an enormous disadvantage:

spark test apparatus' results are not deterministic but stochastic

Anyhow, operating conditions of the spark test apparatus do imperatively imply, that test conditions are arranged in a strict way and are kept constant from the beginning to the end of the experiment. Thus the probability of each spark characteristic to appear is intended to be time independent:

ignition probability is intended to be constant over time

The direct mathematical conclusion is:

contact (revolution) counts between ignitions form an exponential distribution

This is the main reason for the known insufficient reproducibility of single pass experiments with the standardized spark test apparatus.

For those technicians who normally are used to imply a slim Gaussian distribution with their experimental results, a very strange behavior occurs when using the spark test apparatus.

Let's imagine a test sequence using one and the same electrical circuit, but extended to ten separate experiments, each until ignition is encountered. Contact counts until ignition occurs are forming an exponential distribution, for example:

598, 163, 1050, 2996, 288, 53, 1897, 431, 1386 and 799

and arranged in increasing order:

53, 163, 288, 431, 598, 799, 1050, 1386, 1897 and 2996

Mean value of all is about 966 counts, according to an ignition probability of about $w \approx 10^{-3}$, which is considered to be equivalent to the standardized ignition boundary.

If only one experiment is performed, it accidentally tends to result in a value near anyone of those listed above, may be the smallest but the largest also. Using the standard assessment procedure, this circuit therefore would be refused six times and accepted four times. And moreover: the circuit may be deemed even to be far away from the limiting value $w = 10^{-3}$ what's surely not fact.

As a summarization one should be aware, that results of experiments using the spark test apparatus always are stochastic and can give some precision only when are conducted several times.

Here's a great benefit of analytical assessment methods like boundary curves and -data (and consecutively *ispark's* results also), as they in principal are free from statistical influences.

4 A physical view on sparks with the standardized test apparatus

Because of the (intended) dirty environment of sparks with the standardized spark test apparatus and very small resources in this field, an analytical progress as it can be encountered for example with respect to investigations of discharging lamps or welding arcs can not be expected even in future. Nevertheless is was found to be useful, trying to insert some physical considerations into the reflection of sparks in the field of intrinsic safety too.

For best efficiency in evaluating the model, known general effects with sparks were identified in literature and observations for example in PTB, resulting in a suitable model **structure**, while model's **parameter quantities** are obtained by analyzing known ignition data yielded by use of the standardized spark test apparatus.

Naturally it’s expected, that found parameters are dependant on gas mixture of course and may be different for break and make sparks. But for pure electrical effects there could be a chance for independency from gas mixture because of some kind of separation between the electrical world and the calorical one.

The spark test apparatus reveals a very uneven contact behavior because of it's striving motion and all sorts of pollution on the surface including conductive ones. One should know that both, the amount of energy required to start an electrical spark and the quantity to explode a tiny metallic particle, are much smaller than gas ignition energy. It will therefore not clearly appear within the quantity of the latter. In the same way, time spans for electrical effects are magnitudes smaller then for gas ignition related ones.

Therefore a spark can meet a very great variability of circumstances influencing its ignition capability. As a result, exactly those sparks will jump into the foreground with effective ignition, who accidentally find the most fortunate conditions. Every ignition capable spark needs a sensitive sequence of occasions to occur, which property directly leads to the conclusion, that ignition capable sparks must be solitary events separated in time and normally not superposing together.

4.1 Cathode spot and loss voltage

There is a lot of publications dealing with the phenomenon of cathode spots. All to extract here is the imagination of a certain (nearly constant) voltage which is necessary and sufficient to maintain current flow and to accept the hypothesis that the associated power mainly heats up the cathode material but not significantly the surrounding gas mixture.

In effect, with gas ignition, this voltage is a loss voltage here because it does not essentially contribute to ignition.

The most straight forward way to get a numerical impression of the loss voltage is to look into ignition data of those circuits, where no voltage rising means like inductances are present; figure A.1 of IEC 60079-11 is an example. It's clearly to be seen, that below a voltage of about 10 V there is no ignition even with high currents. The experimental results of PTB with varied voltages in ohmic circuits presented above do support this quantity.

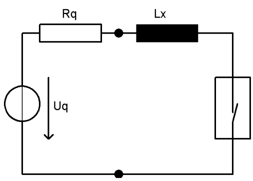
Figure A.3 'capacitive circuit' does not coincide fully; here ignition is encountered although voltage is somewhat below 10 V. This contradiction will be solved later in this paper when considering parasitic reactances.

As a first idea one should remember the quantity 10 V if the item loss voltage is talked about.

It's known from literature, that maintaining a cathode spot requires a minimum current mainly depending on electrode's materials. Cadmium with relatively high vapor pressure and low thermal conductance reveals a very low minimum limit current. No exact value is actually known here, but it will be at some mA only. If spark's current decreases below this boundary, it extinguishes instantly. As explained before, normally there is no chance for reignition, even if significant recurrent voltage exists, because the required sensitive contact situation is normally no longer present.

4.2 Characteristic (inductive) ignition energy

IEC 60097-11 reports an ignition energy of 40 µJ in figure A.4 for a linear inductive circuit; this amount of energy was found to be necessary to be stored within the magnetic field of the inductance at the start of the spark.



At the second glance the question arises, whether or not the charged energy is really the same as this one, which is dissipated in the spark. Obviously one part must be dissipated in the current limiting resistance because it is arranged in series with inductance and spark.

Investigations of spark's evolution with time show an amount of up to 75% to be dissipated within the resistance of those linear circuits in some circumstances.

The quantity of 40 µJ therefore must be much too high if reference to net spark energy is taken.

PTB's diagram for rectangular circuits is of some interest here (please see chapter 2.2). If an open loop voltage of about 10 V is chosen (equal to the loss voltage mentioned above) the latter is compensated totally, resulting in a possible clearer view on ignition energy. For the 0.15 mH branch at 10 V, a stored energy of 13.9 µJ can be calculated as a net value with respect to energy input into the mixture. Because even this small inductance reveals a significant spark time for a real eruptive short spark, ignition energy may be somewhat lower.

4.3 Characteristic ignition power with opening sparks

A lot of years ago already, it was supposed, a complement is existing to the characteristic ignition energy in form of a characteristic power. Taking figure A.1 of IEC 60079-11, there is a characteristic power of about 0.5 W, which in conjunction with a loss voltage of 10 V reproduces the curve nearly perfectly.

Unfortunately there is no direct conclusion possible with respect to a maximum permissible available power of an electrical source:

> **because of the time dependence of spark's voltage, some circuits may match better than others.**

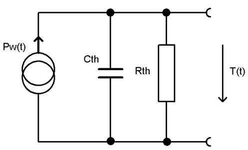
Nevertheless, an available power smaller than about 0.5 W is deemed to be not ignitable with electrical sparks at all.

4.4 Characteristic voltage rise with opening sparks

Investigations of opening sparks using an oscilloscope, very often reveal a starting voltage equal to the known loss voltage and some voltage increase over time. The increase may be caused by depletion of charge carriers or some increase of spark impedance while opening. Whatever the cause really may be, it's possible to establish one voltage rise time constant for each gasgroup for an appropriate fit of ispark's results to known ignition data.

4.5 Thermal ignition properties with opening sparks

Combining the found characteristic ignition energy and typical ignition power, a structure can be created like a calorical low pass filter of first order: Input parameter is the net power value over time, the output an actual temperature.



It's only a small step, to identify the exceeding of a given limit temperature with ignition of a surrounding gas mixture.

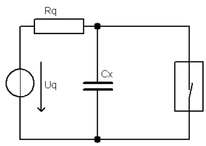
Unfortunately the parameters C_{th} and R_{th} are only defined in an implicit manner, as electrical limiting energy and power; there is no known recursion to the corresponding calorical quantities thermal capacitance and thermal transfer resistance into the surrounding.

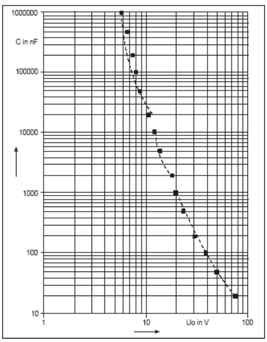
Therefore any trial of comparison with known ignition temperatures must fail. But a rough estimation of an effective thermal time constant is possible, resulting in the value of 13.9 µJ/0.5 W = 27.8 µs.

When a spark is much shorter, the characteristic ignition energy will dominate the situation, if very enduring the typical ignition power gains control. Within the broad region between these extremes, a suitable calculation is necessary and possible.

Already now it can be seen, that referencing to ignition energy limits only must fail if sparks are of significant lengths.

4.6 Quantities of capacitive closing sparks





Taking a loss voltage of about 10 V into account and restricting to higher voltages (≥ 20V), the capacitive limiting curve of IEC 60079-11 is very good approximated for a characteristic ignition energy of 40 µJ.

But this value does not fit at all with lower voltages and ignitions are even encountered at voltages below the loss voltage. As explained before, the latter requires any voltage rising component to be present within the circuit.

It seemed to be a good idea to apply the imagination of closing/opening sparks to this problem. Indeed IEC 60079-11 defines maximum values of permissible inductances for the standardized spark test apparatus.

Assuming 1 µH additional only within the "capacitive" circuit in series, reveals the problem to be apparent only (please see chapter 6):

> **In reality, the standard's capacitive limit curve presents a mixture of different spark types within the same diagram. In the area exceeding about 20 V, simple closing sparks are dominant; while lowering voltage, at first spark type s/o-2 gains control, followed by sparks of type s/o-1.**

Maybe the great influence of the stray inductance as a formerly unknown and therefore not governed effect on ignition properties while experimenting, has led to the fluctuations of capacitive limiting curves for lower voltages in different standards and different editions.

Nearly no information is available about the enhancing influence of additionally delivered energy by the electrical source, if R_q is smaller than the used value of 100 kΩ. But it can be expected, that it's not very great because closing sparks are short in time, so there is only a poor chance to contribute to ignition.

Note: See annex A also.

5 *ispark's* working in principal

The most severe problem in assessing intrinsically safe circuits is in the enormous variability of parameters. Variations may concern for example:

- several types of gas mixture
- nearly arbitrary shapes of source characteristic, including maximum values of current and voltage, every item varying over decades
- capacitance and inductance in various arrangements, each covering a lot of decades

Reported ignition data thus can only form single points or spurs in a multidimensional continuum. A first idea would be trying a pure mathematical interpolation to cover the problem. But without any nature related basic assumptions this trial will degenerate to a more ore less sophisticated but unfounded system of formal rules.

With *ispark*, the opposite way is been gone:

- observations of sparks by oscilloscopic means and similar allowed **detection of typical effects** like loss voltage and definition of some more abstract ignition related parameters
- ignition data bundled in curves and diagrams for example were used for control of the relevance of defined parameters and more **quantitative fixing**

As a result a method is created, which is able to carry out the **quantitative** task of interpolation of known ignition data, but using a **physically reasonable interpolation function**, represented by its model structure. Its outstanding property is the ability to pick up further findings in a straight and easy manner.

ispark uses a modeling method which combines some parameters concerning the standardized spark test apparatus‘ **electrical** response while sparking, arising from the properties of the connected electrical source and reactances, and some additional, which are found to be typical for the standardized spark test apparatus‘ **thermal** properties affecting ignition.

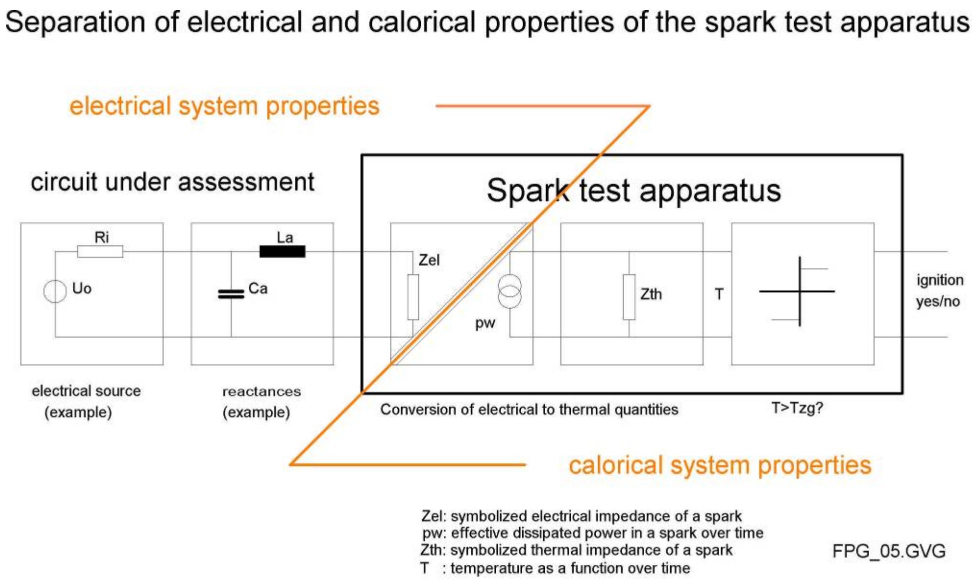
Suitable differential equations are used to take account of the electrical properties and an increment/decrement method for the thermal PT_1 modeling, all from a starting situation according to the type of the actually examined spark type.

Because of the overall non linearity of this modeling system, results can not be obtained by a formula expression. Beneath the computer's principal need to make use of discrete data, there must be performed a recurring procedure until a characteristic limiting value is reached. This is the essential and only reason for *ispark's* required amount of computer‘s calculational power.

Please note: The calculated spark with its current, voltage and calorical properties is an idealized one, you hardly will encounter exactly within an experiment. It merely is a superposition of a collective to constitute a unique representative leading to the same overall ignition probability.

5.1 *ispark's* model structure

Firstly, *ispark* divides the world into an electrical and a calorical one:



The electrical one comprises an electrical source, a network of reactances and a symbolized electrical input impedance of the spark test apparatus. Nearly arbitrary electrical source characteristics can in principal be evaluated; in this respect, the figure above does illustrate an example only. The arrangement of the reactances C_a and L_a is reported here as an example too. *ispark* regards the effects of a loss voltage and spark's voltage rise with a certain time constant and an ending spark when current falls to zero in form of Z_{el}.

The calorical world picks up the effective power from the electrical one and passes it to a symbolic thermal impedance. Distinct calorical quantities of characteristic ignition energy and characteristic power are used, represented by Z_{th}. The comparator shown, shall indicate if an ignition will occur.

It may be of some interest, that there was no indicator found for repercussion from the calorical world into the electrical one. This seems to be caused mainly by the very great distance between the internal temperatures of sparks, compared to ignition temperatures of mixtures. Nevertheless it makes the evaluation much simpler.

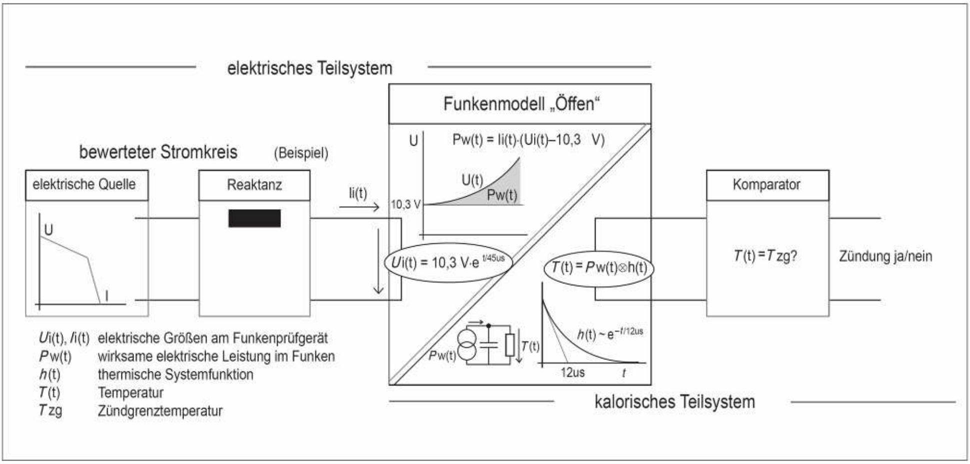
5.2 Characteristic ignition quantities used by ispark

The parameters, ispark uses, can't be fundamental physical constants as explained above, but characteristic values only, which are justified by the best possible overall compliance to known ignition limiting data.

For gasgroup IIC and opening sparks, the best fitting is received using the following parameters:

- loss voltage: 10.3 V
- spark voltage rise time constant: 45 µs
- ignition energy: 5 µJ
- ignition power: 0.42 W
- thermal time constant: 12 µs

and incorporated in system's model:



While loss voltage could be confirmed to be constant independent of gas mixture, ispark uses somewhat different spark voltage rise time constants for best overall matching to known ignition data. For the latter, however, it's not clear up to now if this mirrors really existing physical phenomena or is related to a best-fit technique only.

Stated ignition energy and power both are somewhat smaller than the rough estimations revealed above. This must be expected, because known fundamental experiments do not comprise the extremes **either** instantaneous **or** long lasting power consumption, as would be required to get these parameters purely. In reality there is always a superposition effective.

A consequence of the thermal time constant is some separation between succeeding sparks if there is a time delay.

This may be interesting in future for applications using successive pulses.

The encountered spark loss voltage and rise time constant reveal possibilities for advanced protection methods with intrinsic safety. Because the starting spark is far away from being matched to the effective source in the beginning, one may detect the spark just in time and force the current flow down by switching off the power supply for example or insert an artificial load within the circuit.

As a result, greatly more power may be supplied intrinsically safe. This will work ideally when no delay is present within the system but may be beneficial with short lines also.

For details, please see Annex B also.

5.3 Basic modeling principles

a) Instead of the varying properties of real sparks, *ispark* uses a ‚model spark' as representative, revealing the same igniton probability as the really existent collective.

b) *ispark* treats all sparks as singular events.

c) All sparks are considered to start out of a static situation and usually end with vanishing spark current.

d) For each basic spark type, matched electrical and calorical parameters are used.

e) Instead of calculating all theoretical possible arrangements of basic spark types, failure assumptions and circuit topologies, *ispark* dispenses those, which are proved to be less ignition capable than any one which is considered already.

f) *ispark* always includes the necessary failure assumption with respect to capacitances and inductances to lower values and interruption and short circuit too. As a result, the common maximum theorem is kept, that all reported data are maximum ones and smaller values are permissible.

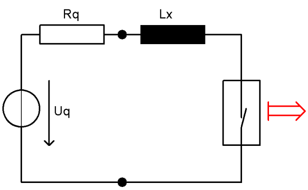
5.4 *ispark's* working in detail

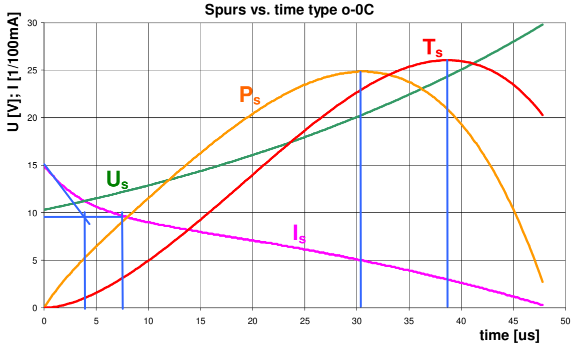
5.4.1 Microscopic procedures

There is a basic microscopic procedure which, according to the target of actual calculations, is loop wise repeated until a given boundary condition is satisfied:

At first, depending on the spark type, electrical start conditions are determined. Then, according to the source characteristic, the reactance network and the non linear spark voltage, step by step, the current versus time is calculated using appropriate differential equations. The product of this current and the actual effective (minus loss voltage) spark voltage gives an actual spark power. This is passed over to the calorical system part, consistent of thermal capacitance and thermal resistance and giving an equivalent for an actual temperature.

Please see the following example with an opening spark produced by a linear source with an open loop voltage of 28 V, a short circuit current of 150 mA and a reactive load of 0.7 mH.





Four spurs are to be seen:

Spark's voltage in U_s green and its current I_s in magenta (scaled *100). Actual effective power P_s (orange, scaled *50) and resulting temperature T_s (red, scaled 1/20).

Voltage follows the stated exponential increase.

Current starts with source's short circuit current. For the first moment, its decrease is given by the time constant L_x/R_q, (keeping in mind a lasting current of 150 mA * [(28-10.3)/28] = 94.8 mA).

Please note, that the in the inductance originally stored energy of 7.88 µJ decreased within a time of 7.5 µs to 3.15 µJ without having a significant influence on the resulting temperature.

With spark's progress, it's voltage rises and current went down, but the net power consumption increases because of the prevalence of the former. At about 30 µs duration, spark's power reaches a maximum here of 50 mA * (20 -10.3) V = 485 mW. That's a little bit more than the characteristic ignition power of 0.42 W as stated before.

Consequently the temperature rises further and reaches a value of 520 at a time of 38 µs, which is the stated boundary for ignition. This naturally is identical with the moment, when the effective power equals the characteristic ignition one.

Within the most effective sparking time span from 7.5 µs to 48 µs, the current falls with about 2.47 10^3 A/s causing an inductive voltage addition of 0.7 mH * 2.47 10^3 A/s = 1.73 V. This can be used to calculate inductance's contribution to ignition as: 1.73/(28 - 10.3) = 0.0977 ≈ 10 %

Despite a significant originally stored energy, the inductance does contribute only very little to ignition here.

As the maximum temperature is about 520, this example represents a situation of a safety factor 1.0.

5.4.2 Macroscopic procedures

Repeatedly using the basic process of the preceding chapter, ***ispark*** can adjust inductance and/or capacitance (or some other parameters) until they suit the boundary between ignition / no ignition.

The traditional proceeding of ***ispark*** is based upon four principal steps (besides initially testing the source without any reactances at all):

Firstly, an absolute maximum inductance L_{pms} is determined with respect to opening sparks in serial connection.

Secondly, (additionally) permissible capacitances are determined, depending on several models of closing/opening and closing sparks and serial resp. parallel connection.

Thirdly, the need of failure assumption is met by reducing, if necessary, calculated capacitances to a certain value in the way that failures of both, inductances and capacitances to lower values do not impair safety (the maximum theorem).

Remark: Investigations of the effect of combined capacitance and inductance within the same circuit don't show the trivial result of independent maximum permissible values for both as traditional assessment methods are dealing with. Usually a larger inductance leads to a smaller capacitance. But the possibility exists, that smaller inductances may be more critical than larger ones, yielding smaller permissible capacitances too. ***ispark*** *meets this effect in calculating permissible capacitances according to smaller L (than detected with the spark type o-0C, L_{pms}) systematically also.*

Fourthly, the received calculational results, for more acceptability, are cropped to capacitance data reported by IEC 60079-11.

Note: With cables, the macroscopic procedures do differ somehow because inductance can be taken to be predetermined and needs not to be adjusted.

6 Spark types, failure aspects and circuit topology

6.1 General

ispark has to investigate sparks and their ignition capability taking into account some basically different backgrounds combined with their necessary consequences:

a) Sparks may occur while contacts are closing, opening and additionally as a sequence of both; this may be called the „**contact aspect**“:

spark type	contact aspect
o	opening
s/o-1	closing and opening at peak current
s/o-2	closing and opening instantly
s	closing

Please note, that this basic distinction is in **contact transients** and not in the existence of capacitances or inductances as the classical reflections do.

b) For general convenience, *ispark* should take account of the failure assumptions of IEC 60079-11 (otherwise the operator has to do). Therefore the spark type classification is amended by the idioms 0C and/or 0L for component‘s failure to short circuit resp. open circuit. This is a „**failure aspect**“.

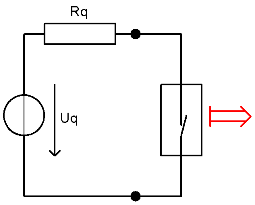
This aspect sometimes has to be appended further by scanning to lower values instead of taking a short only.

c) Because C_o and L_o in principal must be valid including arbitrary network topologies, these reactances may be arranged in a lot of different sets. It can be shown, that these can be reduced to a serial or parallel connection of the network to the considered electrical source and the spark test apparatus. This property is stated by the parameter „s“ or „p“ in the spark classification; it‘s a „**topology aspect**“.

6.2 Generic spark types and procedures

A suitable way to assess all those properties practically and effectively is implemented by *ispark* following the best efficient known order of spark investigations and leaving out those configurations, which can be shown to be less critical than others which are calculated. Thus, the following spark types remain, which include contact, failure and topology aspects. Bundled with the spark type itself sometimes is an association, if a procedure may carry out an approximation or simply can detect suitability with the predetermined safety factor only:

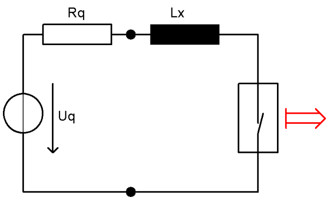
1) spark type **o-0L-0C** procedure:



is used to detect, if the actual electrical source itself is intrinsically safe with respect to opening sparks and no reactive load at all.

Note: otherwise no further investigation is necessary; the program then returns to a new input request.

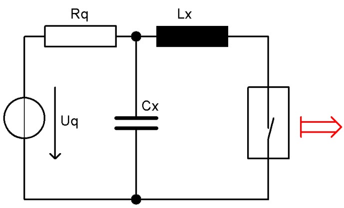
2) spark type **o-0C** procedure:



approximates a maximum permissible inductance „L_{pms}“. Serial connection and no capacitance at all is the overall worst case with respect to any inductance.

Note: this calculated L_{pms} forms the basic and maximum inductance for determining maximum permissible capacitances.

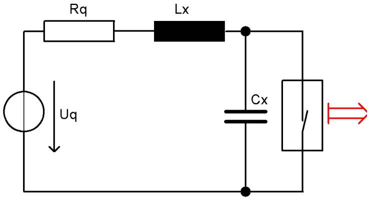
3) spark type **o** procedure:



detects, if the given source with predetermined C_x and L_x complies with ignition limits.

Note: because moderating, C_x must be infallible here.

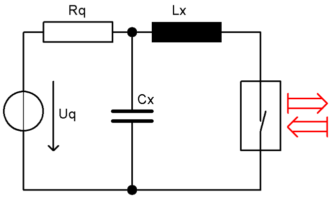
4) spark type **o-Cl** procedure:



detects, if the given source with predetermined C_x and L_x complies with ignition limits.

Note: because moderating, C_x must be infallible here.

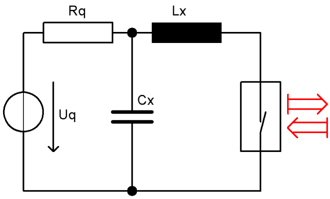
5) spark type **s/o-1-s** procedure:



approximates a maximum possible C_x. This spark type is characterized by closing the spark test apparatus' contacts and open them when a maximum current is encountered. L_x is predetermined as L_{pms}.

Note: predetermination of L_x is controlled by step ‚firstly' of chapter 5.4.2.

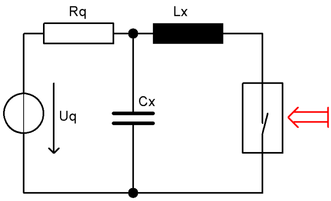
6) spark type **s/o-2-s** procedure:



approximates a maximum possible C_x. This spark type is characterized by closing the spark test apparatus' contacts and open them instantly. L_x is predetermined as L_{pms}.

Note: predetermination of L_x is controlled by step ‚firstly' of chapter 5.4.2.

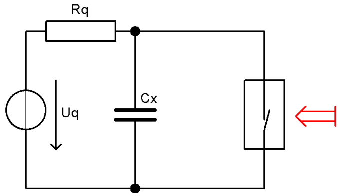
7) spark type **s-s** procedure:



approximates a maximum possible C_x. This spark type is characterized by closing the spark test apparatus' contacts. L_x is predetermined as L_{pms}.

Note: predetermination of L_x is controlled by step ‚firstly' of chapter 5.4.2.

8) spark types **s-0L-s** procedure:



approximates a maximum possible C_x. This spark type is characterized by closing the spark test apparatus' contacts with an actual L of zero.

9) spark type **s/o-1-p**, **s/o-2-p**, **s-p** and **s-0L-p** procedures:

These spark types conform in principal to the spark types ‚serial' mentioned above, with the difference of a ‚parallel' connection of the spark test apparatus **between** the electrical source and the reactance network. The type s/o-1-p was found to go under with respect to type s/o-1-s and isn't incorporated any more.

*Note: the parallel connection attribute makes a consideration of all serial types (**o-x-x**) of sparks obsolete, because reactances play the role of a load here but cannot contribute to the spark.*

6.3 Spark type procedures with circuits comprising lumped reactances only

6.3.1 General

Ignition properties doubtlessly are influenced by the presence of reactances. Unfortunately there is no easy made and reliable preview possible if they actually reinforce the ignition capability of a spark or do moderate it.

To go out the necessity to evaluate all variations with respect to basic spark types, values of reactances and topology, ispark uses a rather sophisticated sequence of procedures.

A reflection of a more simple kind for example is, that with parallel connection no opening sparks have to be considered because of the unloaded start conditions.

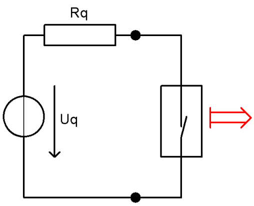
For some more insight, this chapter shows all serial spark type procedures used by ispark today as examples using:

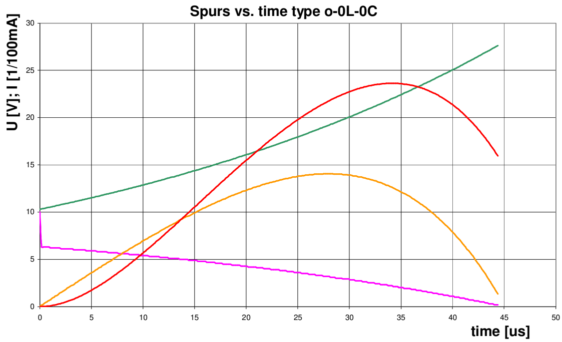
- a linear source of 28 V and 100 mA
- calorically weighted for IIC and safety factor 1.5
- if relevant, an inductance of 0.5 mH and/or a capacitance of 0.03 µF
- scales: U*1; I*100; P*50; T/20

The presentation is completed by comments.

6.3.2 spark type o-0L-0C

The circuit arrangement spark type o-0L-0C doesn't comprise any reactance. Contact's motion is of simple opening.





Considering the spurs:

At spark's start, the loss voltage is about 10 V and spark current jumps initially from short circuit current down to about 63 mA, which is the result of the upcoming loss voltage. At this moment the calorical spark power is zero because spark's voltage is totally consumed by the loss voltage and consequently temperature and it's rise is zero also.

Spark type o-0L-0C cannot exist within circuits with voltages below 10.3 V.

Because of increasing spark voltage, current decreases further, while power reaches a maximum and reduces further. Temperature follows power with some kind of delay caused by the PT_1 behavior of the calorical model part.

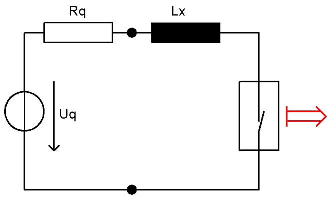
Maximum temperature is about 23.5 * 20 = 470 here.

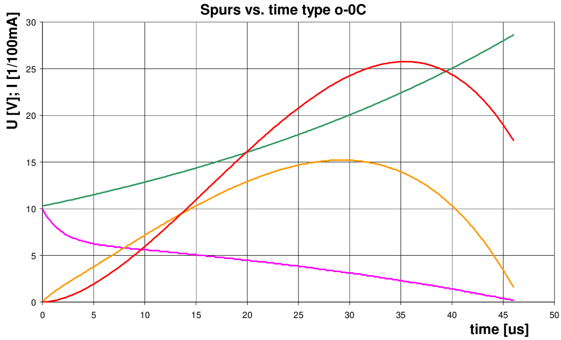
ispark uses this spark type procedure for determination if the source itself is intrinsically safe. Because the required failure assumptions include zero values for reactances, no further evaluation is possible if this investigation fails negative. This spark type procedure represents the worst case with missing reactances. Because of importance and easy carrying out it's the first procedure of ***ispark***.

Remark: As the circuit doesn't comprise any reactances at all, one should believe, closing sparks may have the same ignition properties. But all observations show, that ignitions always occur with opening. Reason is, that opening sparks require an origination from a current carrying state.

6.3.3 spark type o-0C

The circuit arrangement includes an inductance only and contacts movement is opening.





Considering the spurs:

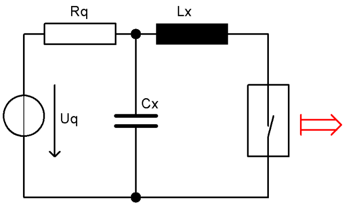
The spurs conform to those of spark type o-0L-0C except an inductively weakened step at the beginning. For the most part of the course, the inductance adds a small amount of voltage, thus increasing current a little bit and serving for a slightly longer spark duration. Accordingly the maximum temperature is somewhat higher.

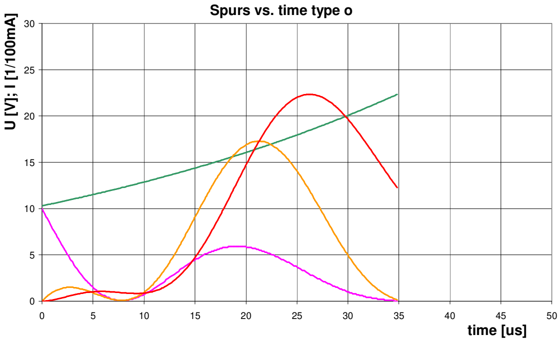
Maximum temperature is about 26 * 20 = 520 here.

ispark uses this spark type procedure for approximation of an overall maximum possible inductance L_{pms}. This approach is feasible, because the relation of inductance and maximum temperature is monotonous here and all other variations of topology and failure assumptions can be proved to be less critical. Because of this simple and strict behavior, *ispark* carries out this procedure directly following the type o-0L-0C one.

6.3.4 spark type o

The circuit arrangement includes an inductance and a capacitance in parallel to the source and contacts movement is opening.





Considering the spurs:

The spurs resemble a little bit those of the o-0C type, but the initial step there is replaced by an oscillation and the current depletion runs to nearly zero.

Maximum temperature is about 22.5 * 20 = 450 here.

Referring to type o-0L-0C and o-0C sparks the ignition capability is observably lower, confirming the statement concerning the influence of capacitances on opening sparks.

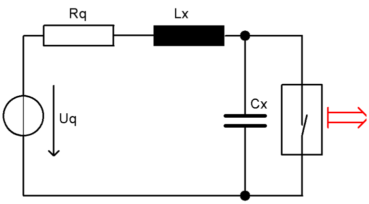
Remark: C_x acts in some kind of separation between source and spark test apparatus. If high enough sources voltage doesn't play any role at all.

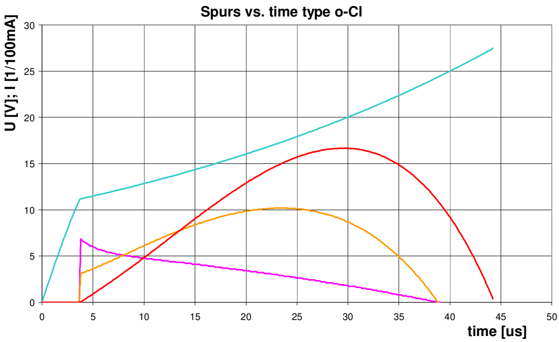
Further: increasing the capacitance, spark's current will ‚untimely' reach zero value, forcing the spark to cease. The relation ‚temperature over C' isn't smooth, but stepwise in this case.

Therefore: spark type o procedure may be suitable for detection of an actual safety factor of an integer circuit but will not stand the required failure assumption. This spark type is used by *ispark* with cables only.

6.3.5 spark type o-CI

The circuit arrangement includes an inductance and a capacitance directly in parallel to the spark test apparatus and contacts movement is opening.





Considering the spurs:

The spurs resemble a little bit those of the o-0C type, but the initial spark current is zero, as well as the effective power because, when the contact opens, the current will instantly commutate from the spark test apparatus over to the capacitance as its voltage is lower than the loss voltage. The zero state lasts until the voltage of C_x reaches the ‚normal' growth of the spark voltage; just in that moment a current flow starts.

Note: The strict presumption of spark ending with vanishing current, as common with former spark evaluation, is dropped down here. As no real circuit is exactly without any capacitive effect, it must be concluded, a certain bridging time exists, which allows spark prosecution even after a short expiration.

Maximum temperature is about 17 * 20 = 340 here.

Referring to type o-0L-0C and o-0C sparks, the ignition capability is extremely lower. This is due to the direct energy consumption in concurrence to the spark.

Further: increasing the capacitance, a situation will be reached, where capacitor's voltage at no moment reaches the necessary value to cause a current flow. In this case, no spark occurs at all.

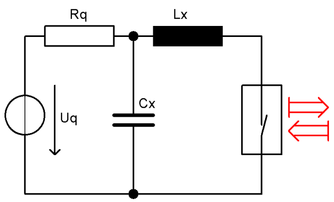
Therefore: spark type o-CI procedure may be suitable for detection of an actual safety factor of an integer circuit but will not stand the required failure assumption. This spark type is used by ispark with cables only.

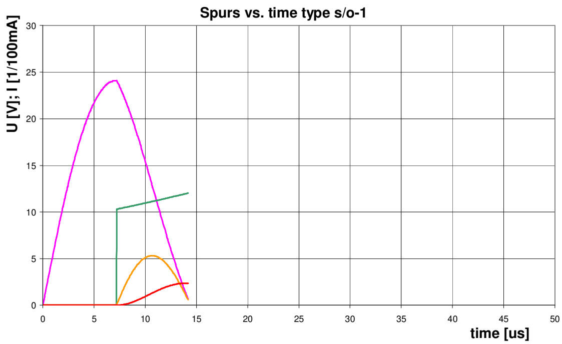
Remark: This method of spark suppression widely is used in techniques; application with intrinsic safety normally fails because of failure considerations (opens of capacitors) and the fixed location in parallel to the spark.

6.3.6 spark type s/o-1-s

The seriousness of closing/opening sparks was discovered relatively late. Its major effect consists in an transformation of originally capacitively stored energy to an inductive one, thus decreasing the often moderating influence of the loss voltage.

The circuit arrangement includes an inductance and a capacitance in parallel to the source and contacts movement is close/opening.





Considering the spurs:

Spark starts short circuiting out of an open loop condition. Because of the inductance, current begins to flow by and by. At that moment, when ispark encounters a current maximum, spark's voltage is switched on and power is introduced to the calorical system. The power dissipating part in principal is similar to opening sparks in pure inductive circuits with the difference of a capacitively enhanced maximum current (240 mA vs. 100 mA).

Remark: Formerly the type s/o-1-s was considered to describe mixed circuits wholly (see PTB reports W-11 resp. W-16) and its ‚maximum arithmetic current mean value' was rated with reference to inductive circuits. But inspection of experimental data can show, that the spark type s/o-2-s covers situations with higher voltages better.

Maximum temperature is about 5 * 20 = 100 here.

Although the higher current with respect to type o-0C sparks, temperature is much lower here (100 vs. 520). That's because of a current zero-crossing forced by the natural oscillation of the reactances causing the effective spark duration to be much shorter (7 µs vs. 46 µs).

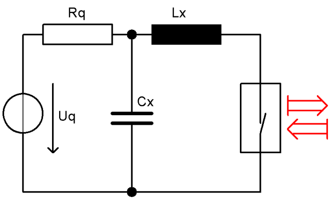
Remark: this spark type mirrors the low voltage range of A.3 of IEC 60079-11.

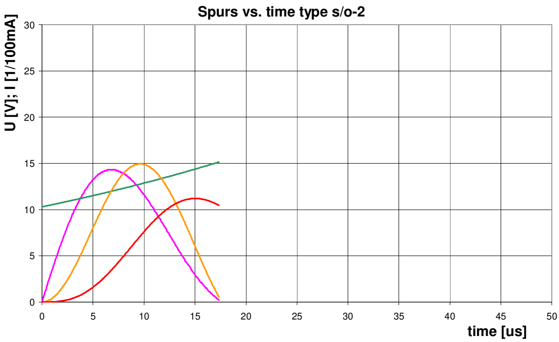
This spark type only partly reveals a brave behavior, as maximum temperature is monotonous with the capacitance but it's not with the inductance. Thus ispark can approximate a maximum permissible capacitance but must check stepwise with lower inductances.

Remark: Although ignition capability here is rather weak, exactly this spark type is responsible for hazardous situations with low voltages allowing very big capacitances, if even very small inductances are left out of consideration. See annex A also.

6.3.7 spark type s/o-2-s

The circuit equals the s/o-1-s one. The only difference is the moment, the spark voltage appears, which is predetermined as at once here.





Considering the spurs:

Spurs resemble pure oscillations here. The obvious ‚time shift' in case of the temperature versus effective power is founded in the PT_1 model, with power versus current it's pretended only and a result of the increasing voltage.

Maximum temperature is about 12 * 20 = 240 here, which is significantly superior with respect to type s/o-1-s. Among others, the reason is the more than doubled effective time duration.

Remark: the dominance region with type s/o-1-s is the area of low voltages, those of type s/o-2-s rather higher ones.

Remark: this spark type mirrors the medium voltage range of A.3 of IEC 60079-11.

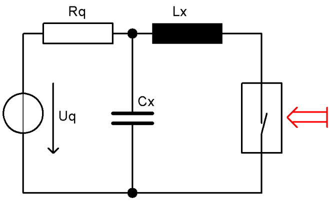
Spark type s/o-2-s cannot exist within circuits with voltages below 10.3 V.

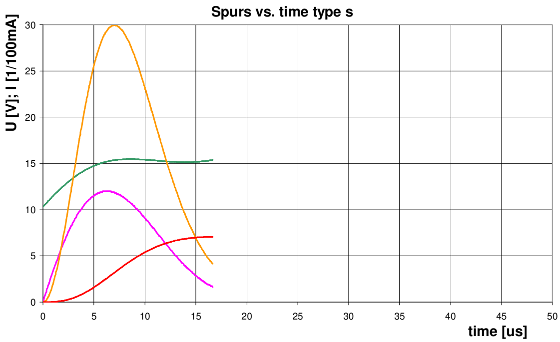
This spark type only partly reveals a brave behavior, as maximum temperature is monotonous with the capacitance but it's not with the inductance. Thus *ispark* can approximate a maximum permissible capacitance but must check stepwise with lower inductances.

6.3.8 spark type s

This circuit arrangement comprises capacitance and inductance, contact movement is closing.

While all spark types mentioned up to here are only characterized by an exponentially increasing spark voltage, whose effective calorical spark power inducing part must consider a loss voltage, for types s-x an additional power consumption is modeled in terms of a characteristic resistivity. This serves for compliance with higher voltage situations.





Considering the spurs:

There is some similarity to type s/o-2-s sparks. Spark time span is about the same, but because of the ‚additional' resistivity, maximum power is approximately doubled here. Nevertheless *ispark* states a maximum temperature of about 7 * 20 = 140, which is less than with type s/o-2-s. Reason is a difference in the model conform characteristic ignition energy with different spark types.

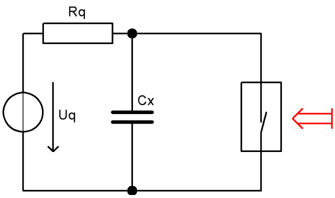
This spark type only partly reveals a brave behavior, as maximum temperature is monotonous with the capacitance but it's not with the inductance. Thus *ispark* can approximate a maximum permissible capacitance but must check stepwise with lower inductances.

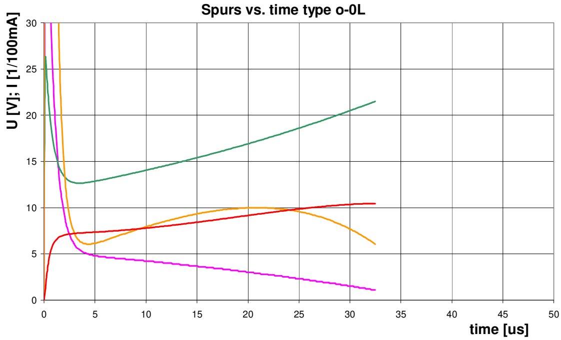
Spark type s cannot exist within circuits with voltages below 10.3 V.

Remark: the dominance region with type s is the area of higher voltages, exceeding those of characteristic type s/o-2-s.

6.3.9 spark type s-0L

This circuit arrangement comprises a capacitance only, contact movement is closing. ***ispark's*** treatment is similar to the type s spark model.





Considering the spurs:

Here clearly can be differed between an impulsive energy insertion and a prolonged one. The initial discharge of the capacitance forces the temperature nearly stepwise up to 7 * 20 = 140.

Source's contribution, within a while, adds a little bit up to about 10 * 20 = 200.

Remark: this spark type mirrors the high voltage range of A.3 of IEC 60079-11.

Spark type s-0L cannot exist within circuits with voltages below 10.3 V.

6.4 Introduction to distributed reactances (cables)

There are two main differences between lumped and distributed reactances (cables) with respect to circuit evaluation and spark ignition:

Firstly, distributed reactances (cables) carry some kind of elevated damping with themselves, normally declared by a resistance per length R', while lumped reactances may have negligible electrical loss.

Note: Actual standards try to take this effect into account for example by picking up an L/R ratio. But a detailed review shows other effects to dominate the situation often.

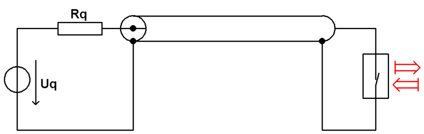
Secondly, with cables, the relation of L', C' and R' is infallible in that sense, that it's the same for all cable lengths independent of failure assumptions. For constellations where, for example, an inductive effect will compensate a capacitive one or vice versa, both do not act the same way a circuit consisting of lumped reactances does, if one or both of them fail.

A general remark shall be made here:

It wasn't possible up to now, to include in *ispark's* procedures the transport properties of cables like delay times, nor the influence of skin effects or others. The first is overridden by calculating a maximum permissible capacitance (which serves for a sufficient time constant), the latter are supposed to tend to a safer side. Therefore a situation like FISCO/-FNICO will not be exactly represented by *ispark* up to now. On the other hand side, *ispark* is able to calculate additional lumped inductances and capacitances not covered by the aforementioned field bus standard.

6.4.1 A trivial case with cables

Cables carry electrical and magnetic fields while operating according to C' and L'. As far as the cable is of homogenous construction, the relation L'/C' is a characteristic number, which square root has the dimension of a resistivity, the characteristic cable impedance called Z_w.



If R' is equal to zero, Z_w (and length) are the remaining set of significant parameters. A special most simple case arises, if additionally Z_w equals R_q. For this situation, the spark test apparatus arranged at the end of the cable does recognize only an electrical source resistance like R_q.

The cable appears completely transparent. Any transient generated at the end does traverse the line and is consumed without reflection within R_q.

> **Thus there is (despite the traditional method of taking into account cables) no possibility to get other ignition data then those received without any cable.**

For example with gasgroup IIC, at the ohmic boundary, an U_o of 25 V is permissible with a current limiting resistor of 100 Ω (safety factor 1.0). Choosing a cable with Z_w = 100 V/A, the latter is wholly hidden and cannot influence spark ignition; no consideration of cable is required at all.

In general, cables with a characteristic impedance lower than R_q tend to react like inductances, if higher, merely as capacitances. For medium values, FISCO reports a total hiding effect for source voltages of about 14 V up to 17.5 V.

Unfortunately, faults with cables may occur at other cable positions than the end only. In this cases indeed electrical fluctuations arise, which are comparable to oscillations with circuits comprising lumped reactances. The dimension of those transients depends widely on the reflection properties at the cables' ends and may reach the values which occur with lumped reactances; but they demonstrably cannot be more severe than the latter.

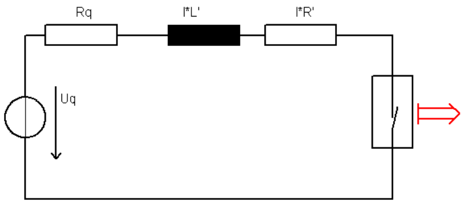
That's the reason, why in doubt, distributed reactances are taken for lumped ones.

Note: Some more details with cables are presented in Annex B.

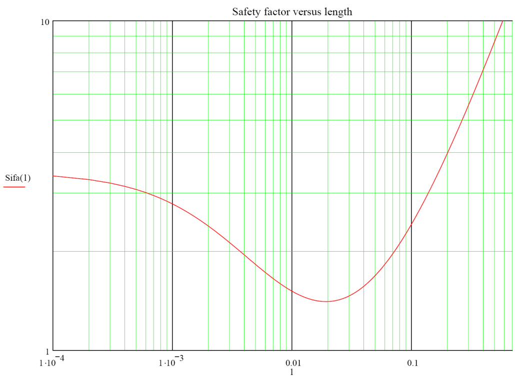
6.4.2 What an infallible distributed cable resistance serves for with opening sparks

With opening sparks, a distributed resistance reacts twice:

Firstly it takes part in stationary short current limitation like an ‚additional source limiting resistance' and secondary it does dissipate stored energy extra.



For some more insight, let's have a brief glance on the safety factor of opening sparks in a circuit comprising a linear source and a cable with a distinct L'/R' ratio but of variable length (C' shall be neglected).



A quantitative (short cable) example shall be presented here:

A linear source of U_o = 4.2 V and I_o = 4.8 A is connected to a cable with
R' = 35 Ω/km and L' = 0.35 mH/Ω (L'/R' = 10 µH/Ω).

The diagram besides shows the safety factor versus cable length on the base of a minimum ignition energy of 40 µJ, taking into account an inductance of the spark test apparatus itself of 0.001 mH.

Note: Despite ispark uses a more sophisticated method, for demonstration purposes it's sufficient to assume an ignition energy of 40 µJ here and the safety factor to be inverse proportional to inductances stored energy.

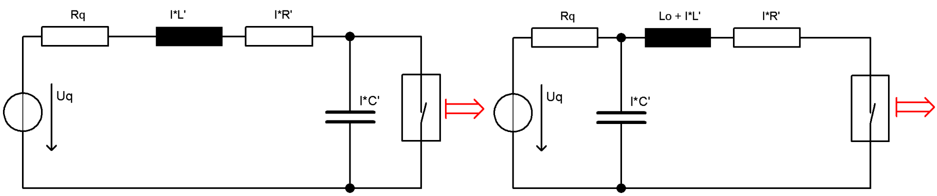
With this example a minimum is clearly to be seen, occurring at the 'critical cable length', where the source resistance equals l*R' and is located at about 1 km * 4.2/4.8/35 = 25 m here; the minimum safety factor reaches the required value of 1.5. But raising L' up to 0.5 mH/Ω (L'/R' = 14.3 µH/Ω) would minder the safety factor nearly down to 1.0, which clearly isn't sufficient for zone 1/0.

Please notice, that the relations of yielded safety factors and L'/R' conform to those with lumped inductances; cables with this respect do not play a special role. This is not surprising when taking into account the very small delay times of those short cables of about 0.1 µs per 10 m. Additionally please see an absolute short cut: when the function equals the required safety factor then the property unlimited long cable length alters abruptly to only a certain one.

The knowledge, that there is a minimum safety factor with this spark type at a special length is extremely important because valid experiments have to include especially this length; greater ones will pretend a safety factor which doesn't represent the worst case and doesn't stand the required failure assumption (breakage of cable).

6.4.3 How an infallible distributed capacitance can influence opening sparks

A further effect associated with cables and opening sparks results out of cable’s capacitance l*C’, which is inseparably bound to it's inductance and therefore stands the failure considerations. Because with opening sparks, the spark voltage significantly increases from zero to a certain value, the capacitance must consume some amount of the energy originally stored within the inductance and power flow from the source. As a result, opening sparks will exercise less electrical power than without l’C’ and L_o limiting values often are considerably higher than without cables’ capacitance.



According to the actual circuit parameters, current return even stays away totally; the initially stored energy will cause oscillations only, which are depleted by circuit resistances, no spark is generated at all.

6.4.4 Pure cables and the mixed circuit consideration

Nowadays it's an accepted judgement, that mixed circuit configurations with lumped reactances can have excessive ignition properties than one of the participating reactances itself. With distributed reactances, for example of cables, it’s only known, that the risk is less, but a reasonable quantitative approach, other than presented here, isn’t to be seen until today.

The new methods of ***ispark*** now can serve for detecting and quantifying ignition risks including both, mixed configurations of only lumped reactances and such, where cables are taking part of in a consistent manner.

For a detailed demonstration please see Annex A also.

6.4.5 Typical cable parameters

Contrary to lumped reactances, which may vary over several decades, cable parameters differ much less. Usually used cables may keep the following limits:

distributed inductance	L’:	0.35	mH/km	to	0.7	mH/km
distributed capacitance	C’:	0.035	µF/km	to	0.12	µF/km
distributed resistance	R’:	10	Ω/km	to	100	Ω/km

The widest variation (naturally) is with distributed resistance, because copper material has some cost.

Note: Please be aware of two facts: firstly that with galvanically isolated circuits normally two similar conductors take part in R’ and secondly, considering earthed circuits, L’ and C’ are defined very weakly only.

For a better overview, in this document the following common cable types are defined:

Standard installation cable (StdInstCb):	0.7	mH/km;	0.06	µF/km;	35	Ω/km
Standard bus cable (StdBusCb):	0.35	mH/km;	0.035	µF/km;	70	Ω/km

Remark: Please note, that the variation of L’ and C’ are of the factor 2 to 4, while R’ varies by the factor 10.

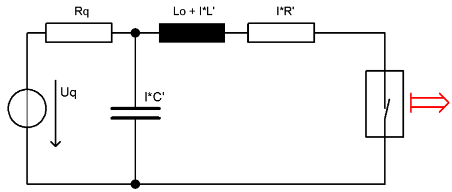
6.5 Spark type procedures with circuits comprising lumped and distributed reactances

6.5.1 Procedures with opening sparks

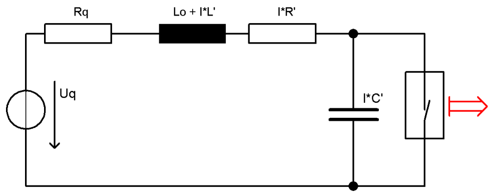
All capacitances parallel to the circuit always have a moderating effect upon opening spark's ignition capability. All lumped ones have to be omitted because of the required failure assumption, leaving operative only distributed cable capacitances l*C'. Although exact cable representation isn't possible up to now, considering both, l*C' arranged between source and reactances and directly parallel to the spark test apparatus, and taking the worst case for valid, seems to be a convincing approach.

Cables' damping is taken into account by including l*R' in series to L_o + l*L'.

The first arrangement to be evaluated conforms with spark type o:

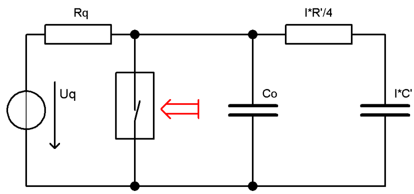


The second arrangement to be evaluated conforms with spark type o-Cl:



From both arrangements, *ispark* determines maximum permissible L_o combined with l*L' as a function of cable's length, taking l*R' into account.

6.5.2 Procedures with closing sparks

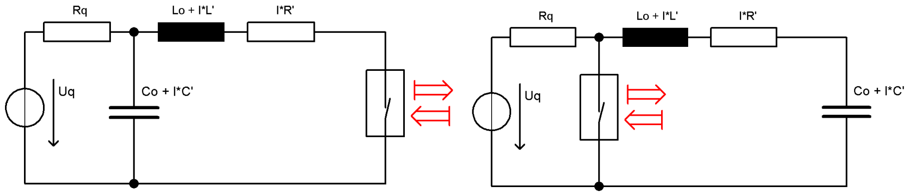


With closing sparks, type s normally is the most denotative as well as circuit's parallel connection. *ispark* therefore picks up a configuration taking into account C_o as it is and a quarter of l*R' as a decoupling device with respect to l*C'. The term 1/4 is explained by the imagination of a short circuit in the middle of the line and considering the fact, that cable's charge not wholly has to pass the half of the cable.

6.5.3 Procedures with closing/opening sparks

With closing/opening sparks, there is nearly no specialty in the treatment by *ispark* compared to the traditional way: The only difference consists in the inclusion of l*R' as the only dependable effective resistance beneath R_q.

All capacitances and inductances are summarized and series and parallel connections are evaluated.



As mentioned before, the effiency of l*R' widely depends on the characteristic impedance constituted by L_o + l*L' and C_o + l*C'.

As with lumped reactances, the evaluation of closing/opening sparks is of interest only concerning s/o-1 type in serial connection, but s/o-2 type in serial and parallel arrangement.

6.5.4 Merging local results for integrated tabulated ones

For creation of the final matrix of lumped C_o versus L_o and cables length *ispark* uses the following steps:

a) for all individual cells, according to all opening spark types, is calculated whether or not the required safety factor is kept

b) for all positively confirmed cells all other spark types are evaluated and a summarized permissible capacitance is determined for each

c) to cover the minimum theorem, these capacitive values are smoothed in the way, that they monotonously decrease with increasing L_o as well as with a longer cable

6.5.5 Examples

6.5.5.1 General

Because of the complex behavior of superposition of lumped reactances and cables, examples are presented here to clarify the relations.

Note: When without notice, all the following examples are based upon linear sources and gasgroup IIC, safety factor 1.5.

6.5.5.2 A „midrange source“

Within the middle of ‚i’ sources, concerning open loop voltage, may reside the following active data:

```
open loop voltage         [V]:      17.500
short circuit current    [mA]:     300.000
```

ispark's calculation with lumped reactances gives within the first step:

```
Cpms summ. acc. to type s/o-2-s           in uF :     0.152
Lpms                                      in mH :     0.208
```

Using a StdBusCbl:

```
inductance/km          [mH/km]:       0,35
capacitance/km         [uF/km]:       0,035
resistance/km         [Ohm/km]:      70,000
```

ispark reports the following results:

```
 0.000     -       -       -     0.210   0.200   0.100   0.050   0.020   0.010

 0.000     -       -       -     0.150   0.150   0.210   0.270   0.339   0.339

 0.010     |       |       |       |       |       |       |       |       |
 0.020     |       |       |       |       |       |       |       |       |
 0.050     |       |       |       |       |       |       |       |       |

 0.100     |       |       |       |       |       |       |     0.339     |
 0.150     |       |       |       |       |       |       |     0.330     |
 0.200     |       |       |       |       |       |     0.270   0.320   0.339

 0.300     |       |       |       |       |       |     0.260   0.300   0.310
 0.400     |       |       |       |       |       |     0.250   0.280   0.290
 0.500     |       |       |       |       |       |     0.240   0.270   0.280

 0.700     |       |       |       |       |       |     0.230   0.250   0.260
 1.000     |       |       |       |       |       |       |       |       |
 1.500     |       |       |       |       |       |       |       |       |
 2.000     -       -       -     0.150   0.150   0.210   0.230   0.250   0.260
```

Interpretation: With this cable parameters, cable’s distributed inductance and capacitance will really have a very small effect upon ignition properties (within 2 km length); the primary results of ***ispark*** referring to lumped reactances only nearly stay valid and the cable reactances present do not require any further consideration.

With this situation, source resistance R_q is 46.1 Ω and cable’s characteristic impedance Z_w of the same order (100 V/A). Thus L’ / C’ compensation is significantly effective with opening sparks further to the damping impact of R’.

ispark's results including cables here do grant a lot more of space for dimensioning than the standard’s procedures as well as ***ispark's*** procedures referring to lumped reactances only.

This situation in principal is the origin of FISCO/FNICO evaluation, claiming that a cable doesn't has any aggravating influence on ignition within the therein stated electrical source boundaries. ***ispark*** does not perfectly quantitatively follow this statement because it cannot take into account special loss factors and must refer to its own necessarily simplified models. Nevertheless the difference isn't too big and ***ispark*** can serve for information about additional lumped reactances while FISCO/FNICO doesn't. The fact, that there is a significant amount of (additional) lumped capacitances permissible allows the conclusion. that within the FISCO/FNICO area opening sparks do dominate the scenario.

Using a StdInstCbl:

```
inductance/km          [mH/km]:       0.700
capacitance/km         [uF/km]:       0.060
resistance/km         [Ohm/km]:      35.000
```

ispark reports the following results:

```
 0.000     -       -       -     0.210   0.200   0.100   0.050   0.020   0.010

 0.000     -       -       -     0.150   0.150   0.210   0.270   0.339   0.339

 0.010     |       |       |       |       |     0.200   0.260   0.339     |
 0.020     |       |       |       |       |     0.200   0.250   0.320   0.339
 0.050     |       |       |     0.150   0.150   0.190   0.230   0.280   0.300

 0.100     |       |       |     0.140   0.140   0.170   0.210   0.230   0.250
 0.150     |       |       |     0.130   0.130   0.160   0.190   0.210   0.220
 0.200     |       |       |     0.120   0.130   0.150   0.170   0.190   0.190

 0.300     |       |       |     0.110   0.110   0.130   0.150   0.160   0.160
 0.400     |       |       |     0.100   0.100   0.120   0.130   0.140   0.140
 0.500     |       |       |     0.092   0.093   0.110   0.120   0.120   0.120

 0.700     |       |       |     0.075   0.076   0.085   0.091   0.095   0.097
 1.000     |       |       |     0.054   0.055   0.061   0.065   0.067   0.068
 1.500     |       |       |     0.028   0.029   0.032   0.034   0.035   0.036
 2.000     -       -       -     0.015   0.015   0.016   0.017   0.017   0.017
```

Interpretation: With this cable parameters, cable's distributed inductance and capacitance will have some effect upon ignition properties.

While L' / C' compensation is nearly the same as with StdBusCbl, reactances are about double as high and R' is only the half. As a result, l*C' and l'R' are too small for compensation with high lumped inductances L_o (0.1 mH) and opening sparks. For smaller inductances, spark types of the closing/opening type gather control, which get more intensive with growing L' as well as C'. But permissible cable length isn't restricted (apart from the scope of 2 km).

ispark here also extends permissible cable length beyond there lumped counterpart.

6.5.5.3 An „upper range source“

The following electrical parameters are common with (often used) safety barriers:

```
open loop voltage         [V]:      28.000
short circuit current    [mA]:     100.000
```

ispark reports the following results for lumped reactances only:

```
Cpms summ. acc. to type s/o-2-p          in uF :    0.064
Lpms                                     in mH :    0.686
```

Using a StdBusCbl:

```
inductance/km          [mH/km]:       0.350
capacitance/km         [uF/km]:       0.035
resistance/km         [Ohm/km]:      70.000
```

ispark reports the following results:

```
 0.000     -       -     0.690   0.500   0.200   0.100   0.050   0.020   0.010

 0.000     -       -     0.064   0.072   0.083   0.083   0.083   0.083   0.083

 0.010     |       |       |       |       |       |       |       |       |
 0.020     |       |     0.064     |       |       |       |       |       |
 0.050     |       |     0.063   0.072     |       |       |       |       |

 0.100     |       |     0.062   0.071     |       |       |       |       |
 0.150     |       |     0.061   0.070     |       |       |       |       |
 0.200     |       |     0.060   0.069     |       |       |       |       |

 0.300     |       |     0.057   0.067     |       |       |       |       |
 0.400     |       |     0.055   0.065     |       |       |       |       |
 0.500     |       |     0.052   0.062     |       |       |       |       |

 0.700     |       |     0.047   0.057   0.083     |       |       |       |
 1.000     |       |     0.038   0.047   0.073   0.083   0.083   0.083   0.083
 1.500     |       |     0.021   0.029   0.049   0.059   0.064   0.067   0.069
 2.000     -       -     0.003   0.010   0.025   0.032   0.036   0.038   0.039
```

Interpretation: With this situation, the standard's capacitance boundary of 0.083 µF dominates mostly in the whole field, but at the boundaries there is some relief.

Comparing these data to the results of only lumped reactances, there are to be mentioned mainly two properties:

The permissible maximum sum of inductance is significantly greater, for example 0.5 mH (lumped) + 2*0.35 mH (distributed) = 1.2 mH at two kilometers length, while lumped alone were 0.69 mH at maximum. This is mainly due to the ‚double' effect of I*R' concerning opening sparks. L' - C' compensation is rather weak because of the unfortunate relation of R_q (280 Ω) to Z_w.

With respect to closing/opening and closing sparks, the effect of I*R' is smaller. Nevertheless the damping is high enough to allow at two kilometer length and up to 0.02 mH lumped inductance a pure sum of 0.038 µF (lumped) + 2*0.035 µF (distributed) = 0.108 µF.

Using a StdInstCbl:

inductance/km	[mH/km]:	0.700
capacitance/km	[uF/km]:	0.060
resistance/km	[Ohm/km]:	35.000

ispark reports the following results:

<table>
<tr><td>0.000</td><td>-</td><td>-</td><td>0.690</td><td>0.500</td><td>0.200</td><td>0.100</td><td>0.050</td><td>0.020</td><td>0.010</td></tr>
<tr><td>0.000</td><td>-</td><td>-</td><td>0.064</td><td>0.072</td><td>0.083</td><td>0.083</td><td>0.083</td><td>0.083</td><td>0.083</td></tr>
<tr><td>0.010</td><td>|</td><td>|</td><td>0.063</td><td>0.072</td><td>|</td><td>|</td><td>|</td><td>|</td><td>|</td></tr>
<tr><td>0.020</td><td>|</td><td>|</td><td>0.063</td><td>0.071</td><td>|</td><td>|</td><td>|</td><td>|</td><td>|</td></tr>
<tr><td>0.050</td><td>|</td><td>|</td><td>0.060</td><td>0.068</td><td>|</td><td>|</td><td>|</td><td>|</td><td>|</td></tr>
<tr><td>0.100</td><td>|</td><td>|</td><td>0.057</td><td>0.065</td><td>|</td><td>|</td><td>|</td><td>|</td><td>|</td></tr>
<tr><td>0.150</td><td>|</td><td>|</td><td>0.053</td><td>0.061</td><td>0.083</td><td>|</td><td>|</td><td>|</td><td>|</td></tr>
<tr><td>0.200</td><td>|</td><td>|</td><td>0.050</td><td>0.057</td><td>0.078</td><td>0.083</td><td>|</td><td>|</td><td>|</td></tr>
<tr><td>0.300</td><td>|</td><td>|</td><td>0.043</td><td>0.049</td><td>0.068</td><td>0.079</td><td>0.083</td><td>0.083</td><td>0.083</td></tr>
<tr><td>0.400</td><td>|</td><td>|</td><td>0.036</td><td>0.042</td><td>0.058</td><td>0.067</td><td>0.073</td><td>0.078</td><td>0.079</td></tr>
<tr><td>0.500</td><td>|</td><td>|</td><td>0.029</td><td>0.034</td><td>0.049</td><td>0.057</td><td>0.062</td><td>0.066</td><td>0.067</td></tr>
<tr><td>0.700</td><td>|</td><td>|</td><td>0.015</td><td>0.020</td><td>0.032</td><td>0.038</td><td>0.042</td><td>0.044</td><td>0.045</td></tr>
<tr><td>1.000</td><td>|</td><td>|</td><td>-</td><td>-</td><td>0.008</td><td>0.013</td><td>0.015</td><td>0.017</td><td>0.017</td></tr>
<tr><td>1.500</td><td>|</td><td>|</td><td>|</td><td>|</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td></tr>
<tr><td>2.000</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td></tr>
</table>

Interpretation:

Because of the higher cable reactances and lower R’, the overall damping is smaller than with the example before. Thus the advantage with respect to pure lumped circuit evaluation goes missing for the most part. Merely with heavy inductive loading there is an advantage from 0.69 mH lumped max to 0.69 mH lumped plus 0.7*0.7 mH distributed = 1.18 mH overall.

6.5.5.4 A „high voltage source“

Using a StdBusCbl:

ispark reports the following data file:

```
program ispark, version 7.1, 29.03.2015 ***************** copyright @ PTB 2002

EPL          :  b
gasgroup     :  IIC
source       : linear
Uo       [V]=   44.000
Io      [mA]=   39.000
freewheeling: without

SafetyFactor:    1.90

inductance/km         [mH/km]:    0.350
resistance/km        [Ohm/km]:   70.000
capacitance/km        [uF/km]:    0.035

info: L`/R` [uH/Ohm]:   5.000;   Sqrt(L`/C`) [V/A]:  100.000

0.000   5.000   2.000   1.000   0.500   0.200   0.100   0.050   0.020   0.010

0.000   0.024   0.027   0.027   0.027   0.027   0.027   0.027   0.027   0.027

0.010   0.023     |       |       |       |       |       |       |       |
0.020   0.023     |       |       |       |       |       |       |       |
0.050   0.022     |       |       |       |       |       |       |       |

0.100   0.020     |       |       |       |       |       |       |       |
0.150   0.019     |       |       |       |       |       |       |       |
0.200   0.017   0.027     |       |       |       |       |       |       |

0.300   0.014   0.024     |       |       |       |       |       |       |
0.400   0.010   0.021     |       |       |       |       |       |       |
0.500   0.007   0.018   0.027     |       |       |       |       |       |

0.700     -     0.011   0.022   0.027     |       |       |       |       |
1.000     |     0.002   0.013   0.026   0.027     |       |       |       |
1.500     |       -       -     0.010   0.024   0.027   0.027   0.027   0.027
2.000     -       -       -       -     0.005   0.010   0.012   0.014   0.015
```

Interpretation:

With this high voltage circuit and cable, closing sparks dominate the available cable length mostly. And here the damping effect of l*R’ on capacitances can be encountered. While, for example, l*C’ grows from 1 km to 2 km by 0.035 µF, stated C_o is lessened by 0.012 µF only.

And instead of lumped 0.027 µF, for 2 km a sum of 0.085 µF is possible.

Using a StdInstCbl:

ispark reports the following data file:

```
program ispark, version 7.1, 29.03.2015 ***************** copyright @ PTB 2002

EPL          :  b
gasgroup     :  IIC
source       : linear
Uo        [V]=   44.000
Io       [mA]=   39.000
freewheeling: without

SafetyFactor:    1.90

inductance/km          [mH/km]:    0.700
resistance/km         [Ohm/km]:   35.000
capacitance/km         [uF/km]:    0.060

info: L`/R` [uH/Ohm]:  20.000;   Sqrt(L`/C`) [V/A]:  108.012

0.000   5.000   2.000   1.000   0.500   0.200   0.100   0.050   0.020   0.010

0.000   0.024   0.027   0.027   0.027   0.027   0.027   0.027   0.027   0.027

0.010   0.023     |       |       |       |       |       |       |       |
0.020   0.022     |       |       |       |       |       |       |       |
0.050   0.021     |       |       |       |       |       |       |       |

0.100   0.018   0.027     |       |       |       |       |       |       |
0.150   0.015   0.024     |       |       |       |       |       |       |
0.200   0.012   0.021   0.027     |       |       |       |       |       |

0.300   0.005   0.015   0.023   0.027     |       |       |       |       |
0.400     -     0.009   0.016   0.024   0.027     |       |       |       |
0.500     |     0.003   0.010   0.018   0.026   0.027   0.027   0.027   0.027

0.700     |       -       -     0.004   0.012   0.015   0.017   0.019   0.019
1.000     |       |       |       -       -       -       -       -       -
1.500     |       |       |       |       |       |       |       |       |
2.000     -       -       -       -       -       -       -       -       -
```

Interpretation:

With this arrangement, C’ is too big to reach a cable length, which can have significant profit from R’ with respect to closing sparks.

For opening sparks, l * R’ and Z_w are weak against the large R_q here.

As a result, the lumped consideration deviates only slightly from the combined assessment.

6.5.5.5 A „lower range source“

Since several years an intrinsic safety assessment for a special RS 485 field bus is known with the following summarized electrical data.

```
open loop voltage          [V]:       4.200
short circuit current     [mA]:    4800.000
```

Resulting from those data, *ispark* reports the following results for lumped reactances:

```
Cpms summ. acc. to type s/o-1-s           in uF :   17.428
Lpms                                      in mH :     0.008
```

Using a StdBusCbl:

```
inductance/km          [mH/km]:       0.350
capacitance/km         [uF/km]:       0.035
resistance/km         [Ohm/km]:      70.000
```

ispark reports the following results for circuits with lumped reactances and cable reactances:

```
 0.000   5.000   2.000   1.000   0.500   0.200   0.100   0.050   0.020   0.010   0.008

 0.000     -       -       -       -       -       -       -       -       -    17.000

 0.010     |       |       |       |       |       |       |       |       |       |
 0.020     |       |       |       |       |       |       |       |       |       |
 0.050     |       |       |       |       |       |       |       |       |       |

 0.100     |       |       |       |       |       |       |       |       |       |
 0.150     |       |       |       |       |       |       |       |       |       |
 0.200     |       |       |       |       |       |       |       |       |       |

 0.300     |       |       |       |       |       |       |       |       |       |
 0.400     |       |       |       |       |       |       |       |       |       |
 0.500     |       |       |       |       |       |       |       |       |       |

 0.700     |       |       |       |       |       |       |       |       |       |
 1.000     |       |       |       |       |       |       |       |       |       |
 1.500     |       |       |       |       |       |       |       |       |       |
 2.000     -       -       -       -       -       -       -       -       -    17.000
```

Interpretation: There is no restriction of cable length and (additional) summarized lumped values of capacitances and inductances of 17 µF resp. 0.008 mH are permissible. The most significant effect here is the moderating I*R'; this additional current limitation is the most effective and overrides both, the additional cable inductance and source properties of C_o.

Note: Because of new parameters, an L_{pms} of 0.01 mH isn't reached any more. To keep the original intention, a developper version of ispark is used here.

Using a StdInstCbl:

```
inductance/km          [mH/km]:       0.700
capacitance/km         [uF/km]:       0.060
resistance/km        [Ohm/km]:       35.000
```

ispark reports the following results for circuits with lumped reactances and cable reactances:

```
 0.000   5.000   2.000   1.000   0.500   0.200   0.100   0.050   0.020   0.010   0.008
                                                                                17.400
 0.000     -       -       -       -       -       -       -       -       -       -

 0.010     |       |       |       |       |       |       |       |       |       |
 0.020     |       |       |       |       |       |       |       |       |       |
 0.050     |       |       |       |       |       |       |       |       |       |

 0.100     |       |       |       |       |       |       |       |       |       |
 0.150     |       |       |       |       |       |       |       |       |       |
 0.200     |       |       |       |       |       |       |       |       |       |

 0.300     |       |       |       |       |       |       |       |       |       |
 0.400     |       |       |       |       |       |       |       |       |       |
 0.500     |       |       |       |       |       |       |       |       |       |

 0.700     |       |       |       |       |       |       |       |       |       |
 1.000     |       |       |       |       |       |       |       |       |       |
 1.500     |       |       |       |       |       |       |       |       |       |
 2.000     -       -       -       -       -       -       -       -       -       -
```

Interpretation: With this cable, permissible cable length equals zero. The weakening effect of I*R' isn't sufficient for any cable addition.

Note: At the first glance it may be surprising, that there is a relatively sharp transition between cable parameters allowing unlimited cable lengths and those do not permitting any cable. This behavior is because of the very short critical cable length as discussed in chapter 6.4.2.

Note: Because of new parameters, an L_{pms} of 0.01 mH isn't reached any more. To keep the original intention, a developper version of ispark is used here.

6.6 How to communicate data with operating instructions

While *ispark* via (l)ist creates a linear list of associated Lo/Co pairs (which is just a little bit more voluminous than the standards ‚single Lo/Co'), per (i)nclude cables, a two dimensional matrix is evaluated which, moreover, additionally depends on certain cable parameters.

As a result, there is normally no real chance to press this huge amount of information into operating instructions or certificates.

The overall best seems to be, to declare Electrical Data exactly and let the installer calculate the requirements with its special interconnection and cables intentions. If a method like *ispark* isn't available there, manufacturers may serve for assistance.

7 Data to be declared

ispark naturally needs the declaration of the claimed gas group (group I, IIA, IIB or IIC) and the intended zone ('i' for zone 0 / 1 according to a safety factor of 1.5, resp. 'n' for zone 2 according to 1.0).

All further called inputs reflect the characteristic of the effective active electrical source which must be a two wire gate. The wording ‚effective' is used here to make obvious that this source may have its base also in an arbitrary interconnection of active sources and must include any dynamic response.

It should be emphasized, that *ispark* is especially useful in assessing source characteristics arising from interconnection of more than one electrical source in the same circuit, which may be of very curious shapes never having any chance to be evaluated based on data given in IEC 60079-11.

Even the most general active electrical source may then exactly be defined within a single rectangular diagram with the two axes U and I. Usually of interest is the first quarter of this diagram but with spark types s/o-x the fourth may have a slight influence because reactances can in principal force an inverted voltage to the source. This topic here is covered by the term „freewheeling".

For easy use, *ispark* presents often used and simple source characteristics like linear, rectangular and trapezoidal per single click but can handle more complex „angular" ones up to nine angle points.

Especially when assessing circuits comprising more than one active source, the „angular" capability of *ispark* is of significant benefit. This problem often arises in the area of installation planning.

Input parameter range is restricted to source voltages of 1 ... 50 V and short circuit currents of 1 ... 5000 mA; this should cover nearly all realistic applications, does not overstress the implemented algorithm and is well verified against known experiment's results. If your task exceeds this range please contact PTB for assistance; with experts knowledge *ispark's* method can be used in an extended manner.

Depending upon the actually chosen source characteristic, *ispark* requires the following input:

		required input vs. source characteristic			
parameter	**input range**	**linear**	**rectangular**	**trapezoidal**	**angular**
U_o	1 ... 50 V	X	X	X	X
I_o	1 ... 5000 mA	X or	X	X	X
R_i	0.1 Ω ... 100 kΩ	X	-	X(1Ω) or	-
dU	0.1 V ...	-	X[1)]	-[3)]	-
U_e	1 ... 50 V	-	-	-	XXX[4)]
I_e	1 ... 5000 mA	-	-	X[3)]	XXX[4)]
freewheeling	-	X[2)]	X	-	-[5)]

Notes:

1) a commonly used value is 0.5 V; this will be accepted without further justification

2) normally no freewheeling is effective with linear sources but may be

3) *ispark* here automatically uses a value of 0.5 V for the difference between open loop voltage and the voltage at Ie; please note, that dU will alter the effective I_e to a value above the one calculated simply from zener diode's voltage. Declaring R_i instead of Ie may be the alternative easier to use

4) *ispark* can't handle exactly horizontal or increasing parts of source characteristics at all; therefore all U_e and I_e must be at a minimum distance of 0.1 V respectively 1 mA referring to the neighbored angles

5) with angular characteristics *ispark* always assumes freewheeling directly with output; otherwise for each angle an input would be necessary; this seems not to be practical

All mentioned restrictions apply for ‚multiple sources' in an equivalent way. Especially the sum restriction of 50 V and 5000 mA may be the most obvious.

The presetting of cable parameters is restricted by *ispark* to rational ones; for exceeding values please contact me.

The range of accepted cable parameters is:

0.3	mH/km	≤	L'	≤	1.4	mH/km
0.025	µF/km	≤	C'	≤	0.2	µF/km
10	Ω/km	≤	R'	≤	100	Ω/km

While with R' the lowest value (at the most unfortunate temperature) has to be stated, C' and L' must normally be values with an uncertainty of ± 5 % at maximum. The latter is, because especially C' may have both, a moderating or an aggravating influence on spark ignition.

8 Comparing *ispark's* results to experimental data

All methods, claiming to present a suitable view upon reality, naturally must be checked against original data to prove their validity and reliability. In the following only the most essential shall be pointed out but further exist.

8.1 General

Modeling methods never can fit real data exactly; they always are some kind of approximation. So the question arises about the precision reasonably should be strived for.

The first obstacle for an exact matching lies in the original data themselves. If there are stochastic effects, they will inherently carry a quantitative uncertainty. A lot of comparisons were made before evaluating *ispark's* model in detail and it was found, that original data are correlated only with a common deviation of up to ± 20 % in a parameter of primary significance.

Thus the question arises, how to grade available data when introducing them into the model's parameter consideration.

An immediate choice would be to calculate a simple mean value out of all known collected data concerning one and the same physical situation. But this way doesn't take into account a diverse gravidity of data, which will really exist because of the number of tests carried out to get them.

It was concluded to be reasonable, to give the standard's data a primary weight and further ones, like PTB's and others, only a secondary.

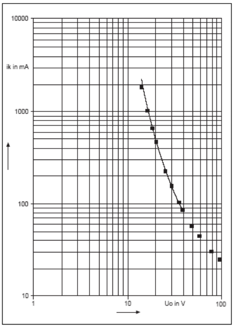
The second problem for exact fitting is, that obviously not all effects taking part in spark ignition can be identified clearly. If so, then they could be quantified even harder. Because it was strictly intended, to keep the model within an area of direct physical representation, only those parameters were picked up which could clearly be identified.

The way of a simple mathematical interpolation of data, as some other methods present, was not picked up because the lost of real information would make any further improvement impossible and demonstrating the suitability of the used interpolation functions would arise exactly the same problem as building up a model structure.

8.2 Comparison to IEC 60079-11

Please note: in the following, original data got from IEC 60079-11 are represented by dots, ***ispark's*** results by continuous resp. dashed lines.

ohmic limiting curve:



There are obviously no significant deviations between original data and calculated ones.

Two things can be concluded therefore:

firstly, that ***ispark's*** **structure** indeed mirrors the effects taking part globally and

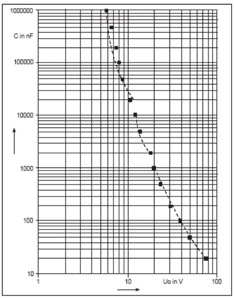
secondly, that ***ispark's*** **parameters** are set correctly.

The latter is less surprising, because ***ispark's*** parameters are primarily rated just to fit best here.

From a physical point of view, this limit curve delivers a good approximation to a characteristic ignition power of opening sparks, which is a direct indicator for long spark duration compared to the thermal time constant.

Additionally the curve helps to determine the loss voltage quantitatively. Valid spark type is o-0L-0C.

capacitive limiting curve:



As discussed before, three different types of sparks are taking part in this diagram: types s/o-1, s/o-2 and s.

All together the standard's data are mirrored in an obviously suitable manner.

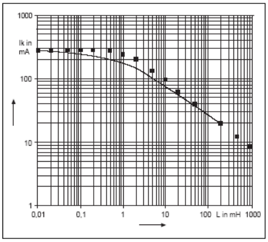
Above about 20 V, type s sparks are dominant; this region is valuable for determining a characteristic limiting energy for pure closing sparks.

Below, the mixed types of spark are emphasized, where a parasitic inductance has a great influence. Here can be found a measure for a characteristic ignition energy of s/o-1 and s/o-2 sparks.

Additionally the estimated model loss voltage is confirmed here.

inductive limiting curve:

While for big inductances and small ones there is a good matching of standard's data and *ispark's* calculated results, in the middle obviously a deviation exists.



From physical insight, this is the region where ignition is supported by both, inductively stored energy and power delivered by the electrical source also, while at the outer branch parts one of them is negligible against the other.

The horizontal branch is determined by nearly ohmic relations and must be of the same value as the ohmic limiting curve describes. The falling one represents a constant energy of 40 µJ. Maybe the validity of a characteristic ignition energy and the known ohmic limits are extended a little bit to far "constructing" this curve yielding a too sharp bend?

A different explanation may lie in the reported circumstance, that with experimental approach towards the ohmic limit, the used voltage was somewhat reduced.

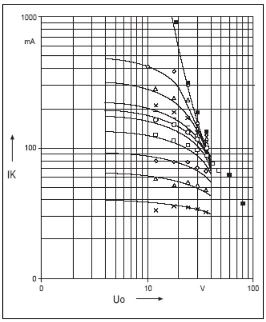
Perhaps a more abstract consideration is of any interest?

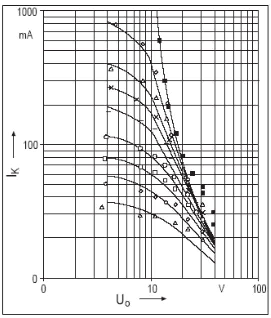
If so, then imagine, that two quantities affect spark igniton here: a typical energy and a typical power. In an area where both are significant only one single question arises. That's about the way they superpose. If they do not at all, the resulting curve will degenerate to two independent straight lines. But they really must superpose, because they reveal their effects of heating within the same short time span, as can be seen directly observing sparks by an oscilloscope. Estimating a linear superposition, the resulting curve must lie at the factor 1/2 below the point of intersection, assuming a mean square one, at 1/√2.

8.3 to PTB's

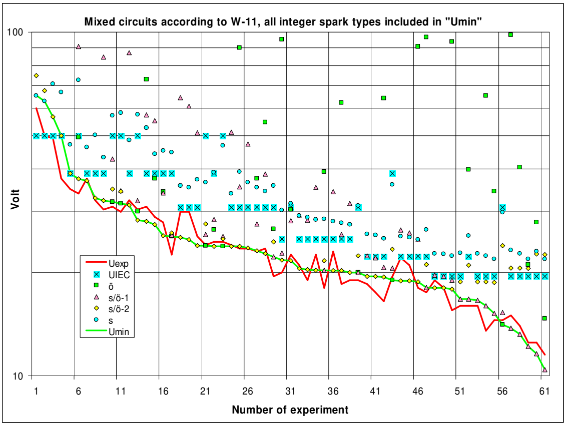
8.3.1 Lumped reactances

Here are shown *ispark's* results with respect to the linear and the rectangular inductive circuit with variable voltage. Despite the broad range of parameters over some decades of inductance in magnitude, the correspondence is demonstrated to be quite good.





Some more sophisticated is the comparison to mixed circuits containing both, inductances and capacitances. The plot reported here therefore needs some more explanation.



The diagram's vertical axis is in voltage, the horizontal one marks the number of the experiment, arranged in an order of decreasing calculated voltage.

The following items are emphasized by solid lines:

red: the experimental results

green: the overall result of ispark's calculations, as the minimum value of all spark types of integer circuits (no failure)

Inspecting the plot, one can recognize:

a) Various spark types are of tremendous difference in ignition capability (see the wide vertical spread of singular symbols for one and the same circuit).

b) The values UIEC obtained by the IEC 60079-11 method are partly significantly higher than reported experiments' data; obviously they do not comply with mixed circuits at all.

c) ispark mirrors experimental data satisfactorily by taking the calculated minimum value. This is reasonable because while experimenting, all types of sparks are permanently generated and the most igniting type will dominate the situation; others practically are resting hidden.

d) The most competing spark type typically varies with voltage level in a certain order: at low voltages type s/o-1 is in the foreground, with increasing voltage type s/o-2 takes over and if even higher type s is dominant. Unfortunately the transition voltages depend on the circuits themselves and no simplification can be seen.

8.3.2 Distributed reactances

PTB report W-3, issued in 1974, deals with experiments referring to the ignition properties of cables. Unfortunately there are some specialties, whose impact on comparability to other known ignition data isn't quite clear. Because W-3 yet, is the only common known seemingly complete report, it shall be picked up here despite it's specific course of action.

Main specialties with W-3:

- The experimental approach uses a compressing technique to manage with much less experiments than usually performed, consisting in a significantly stepwise variation of circuit's voltage.
- All individual experiments are targeted on an ignition probability of 10^{-4}.
- There partly were cable models used instead of real cables, consisting of lumped capacitances, inductances and resistances, each representing 100 m cable length.

It's impossible, to deduce out of these peculiarities, to which extent a comparability to standard procedures is given. Nevertheless, some quantitative relations of *ispark* and W-3 shall be demonstrated here.

Within the scope of *ispark*, only the data reported for 1 km length and for 240 Ω resp. 1330 Ω are of interest. Cable data for type 1: L' = 0.7 mH/km, C' = 0.06 µF/km, R' = 35 Ω/km; all others derived by multiplication as stated in table's headlines.

Here is the direct confrontation of data:

1330 Ohm	Typ1	2R	0,5R	2C	0,5C	2L	L=0
0 km	43,00 V	49,00 V	42,00 V	33,00 V	58,00 V	48,00 V	43,00 V
0,5 km	41,00 V	43,00 V	40,00 V	33,00 V	54,00 V	43,00 V	35,00 V
1 km	43,00 V	49,00 V	42,00 V	38,00 V	58,00 V	48,00 V	43,00 V
W-3 min	41,00 V	43,00 V	40,00 V	33,00 V	54,00 V	43,00 V	35,00 V
ispark min	52,45 V	56,82 V	50,00 V	36,11 V	69,18 V	47,60 V	52,54 V
spark type	s-0L-p	s-0L-p	s-0L-p	s/o-2-p	s-0L-p	s/o-2-p	s-0L-p
ispark/W-3	1,279	1,321	1,250	1,094	1,291	1,107	-

240 Ohm	Typ1	2R	0,5R	2C	0,5C	2L	L=0
0 km	32,50 V	37,50 V	37,00 V	32,50 V	37,50 V	37,00 V	42,00 V
0,5 km	32,50 V	37,50 V	37,00 V	27,00 V	37,50 V	37,00 V	34,00 V
1 km	32,50 V	37,50 V	37,00 V	32,50 V	37,50 V	37,00 V	42,00 V
W-3 min	32,50 V	37,50 V	37,00 V	27,00 V	37,50 V	37,00 V	34,00 V
ispark min	35,88 V	37,85 V	34,48 V	29,96 V	35,04 V	33,78 V	41,19 V
spark type	o	o	o	s/o-2-p	o	s/o-2-p	s/o-2-p
ispark/W-3	1,104	1,009	0,932	1,110	0,934	0,913	-

Leaving out the suspicious values for L=0, with a source resistance of 1330 Ω a mean relation of *ispark's* values (safety factor 1.0) to W-3's is calculated to be 1,22, with a standard deviation of 0,1 resp. 8,1%. Analogously for 240 Ω; 1,0, 0,09 and 8,9%.

8.4 To further acknowledged experimental data

Without detailed report some further experimental data sets shall be mentioned, which *ispark* was compared with and sufficient compliance was found:

I) Transition from linear via trapezoidal to rectangular sources

II) Capacitive circuits including damping resistance

III) PTB report W-16, mixed circuits with rectangular shaped sources

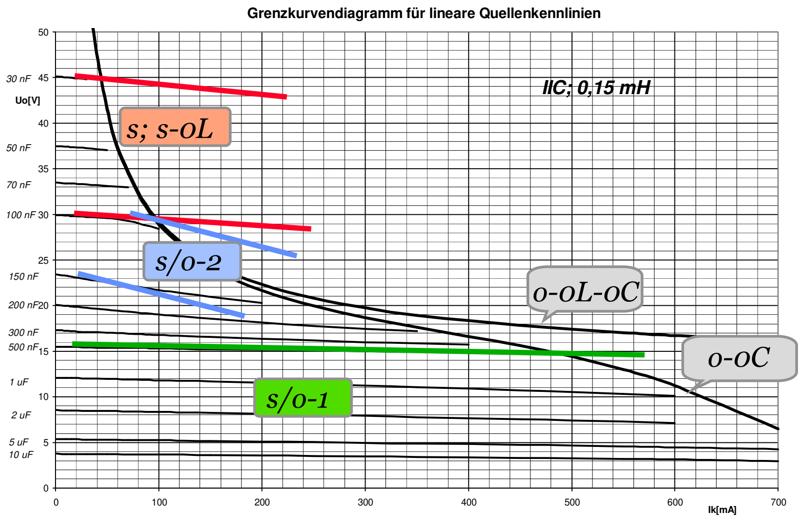
IV) Diss. Johannsmeyer, short closing sparks

V) Diss. Gerlach, ohmic sparks with current interruption

9 Examples and explanations

9.1 Overview about spark dominance regions

As described in *ispark's* operating instructions already, a distinction is made between different spark types. The following figure is intended to achieve some more understanding of ignition basics. Its appearance is like a diagram of the PTB Report ThEx-10 for gasgroup IIC and 0.15 mH, but additionally there are several areas classified according to spark type.



The line for spark type o-0L-0C segregates the regions where a source itself is intrinsically safe or not when no reactive load at all is present.

Clearly to be seen is the smooth transition from the line representing spark type o-0C to that of type o-0L-0C, especially with decreasing current. It's possible to make a distinction between a region where inductively stored energy significantly contributes to (above about 300 mA) and a different one where simply the sources' available power solely is sufficient for ignition (below 300 mA). With higher inductances this transition will be at lower currents.

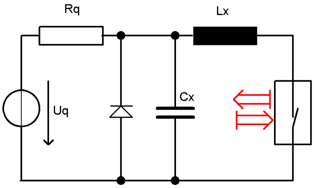
For sources of high voltage and low current the spark type s resp. type s-0L dominates the situation. Because of very short spark durations in this area the source does not contribute significantly and the curves are flat like the red enhanced colored lines.

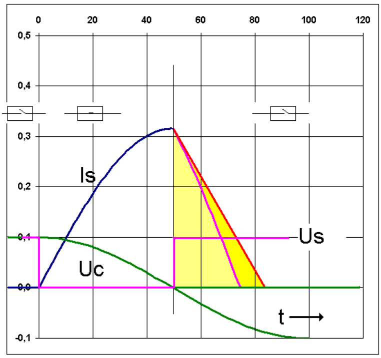
If currents are higher, the most essential spark is of type s/o-2. Here the sources' influence is not negligible at all; the slope is steeper with increasing current (blue lines). Reason is the longer duration of the spark giving the source enough opportunity to contribute to ignition.

If voltages are relatively small, in principal big capacities are allowed. But in conjunction with inductances they build up a circuit which is able to transform capacitively stored energy to an inductive one as it's typical for sparks of type s/o-1. In this area the source's current often is of small influence and the peak current through capacitance and inductance will dominate. The green line therefore is rather flat.

9.2 The freewheeling effect

One of the most frequently asked questions with *ispark* is about the effect of freewheeling.





It will occur only with mixed circuits and especially if the damping influence of R_q is relatively weak. The according spark type is s/o-1.

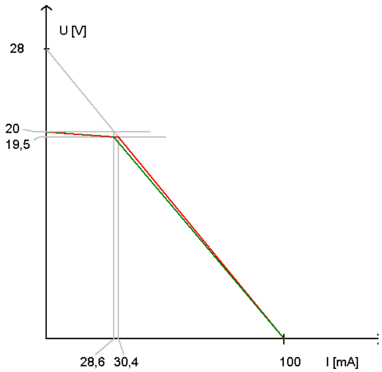
On the left, there is demonstrated a quantitative example using an U_q = 10 V, R_q = 100 kΩ, C_x = 1 µF and L_x = 1 mH (time axis is in µs).

For $t \leq 0$, I_s is identical to 0 and U_c to U_q (1/100 scaled). Closing the contacts starts phase two with sine shaped increasing current through the inductance as the spark test apparatus as well. As modeled with the spark type s/o-1, contact opens at the maximum encountered current revealing the effect of a spark voltage of about 10 V, which reinforces the falling rate of Is.

In this situation the role of the freewheeling diode becomes clear: if present, it will clamp the capacitor's voltage to nearly 0 V, if not, the capacitor is charged to a negative voltage thus hindering further current flow somewhat more.

In effect, the power dissipation and ignition capability of the spark is greater when freewheeling occurs. According to the plot one would estimate an enhancement factor of about 30%. In reality it can be greater (up to about 50%) because spark voltage isn't constant over time as assumed for this example but increases significantly. Even neglecting an existing freewheeling effect only, the standard safety factor 1.5 may totally be consumed.

9.3 Trapezoidal source characteristics



source characteristic

With trapezoidal source characteristics there are implemented two different ways to declare quantities: referring to a current limiting resistor (r) or to an angle current value (i).

Because of historical reasons *ispark* always assumes a voltage drop of 0.5 V from open circuit voltage to the state where zener's effect disappears.

As an example, a source is assumed with an internal voltage of 28 V, limited by a resistor of 280 Ω in series and clamped by a zenerdiode rated 20 V. If you choose the option (r)esistance *ispark* calculates an effective angle current of 30.4 mA on the base of (28 V - 8.0 V - 0.5 V) / 280 Ω.

If one wants to use the option to declare Ie (instead of R) and ignores the gap of 0.5 V, he will get an incorrect value 28,6 mA.

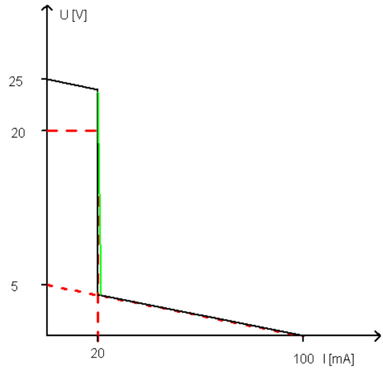
Normally the difference is small but in the proximity of the ohmic boundary permissible inductances do significantly change with Ie.

Generally it's recommended to use the option defining R and not I_e.

Please note also that the dependency of L_o from R (all other parameters fixed) seems to be strange at the first glance, because an increasing R will turn the situation into an unfavorable direction. Looking at the figure above, it becomes clear, that an increasing R will give a more rectangular shape of the source characteristic, thus more available power and more ignition capability.

9.4 Angular source characteristics

ispark doesn't handle real vertical or horizontal parts of source characteristics, because the implementation uses one set off differential equations only, which would degenerate in those cases producing a division by zero error. With real circuits those vertical/horizontal branches normally are not achieved and it was found unnecessary to cover them exactly.



source characteristic

The first choice to govern this problem would be an investigation of the really effective slopes. If they comply with the minimum steps of 0,1 V and 1 mA, *ispark* can handle this source without additional effort by the user.

If not, with respect to U_e and I_e, substitutions of values on the safe side must be made by the user himself.

At the left an example is presented resulting out of a superposition in voltage of an exact rectangular (20 V & 20 mA) and a linear source (5 V & 100 mA).

Calculated values are: U_o = 25 V; U_{e1} = 24 V; I_{e1} = 20 mA; U_{e2} = 4 V; I_{e2} = 20 mA; I_o = 100 mA.

The conflict mentioned above arises with $I_{e1} = I_{e2}$.

Simply setting I_{e2} to 21 mA solves the problem. The calculated maximum permissible inductance L_o and capacitance C_o do not significantly suffer from this slight alteration.

9.5 Rectangular source characteristics

As pointed out above, *ispark* doesn't handle real vertical parts of source characteristics. Therefore, if rectangular source characteristic is chosen, the vertically falling part of the shape in an U over I plot is substituted by a slightly different one, keeping the stated short circuit current but drawing back the angle current just like a resistance of 10 kΩ would do.

Although the difference is small, it can be encountered by comparing the calculated results of "rectangular" declared sources with those achieved declaring a "one angle source", where the angle point's values are defined similarly.

Because the influence on the yielded safety factor is restricted (about 10%), nowadays it's not planned to make an adjustment with *ispark* to cover this small incoherency, but will be done if more serious problems are experienced.

10 Some delicate considerations

With safety related regulations, the psychological problem arises, that one must have a critical look at a more ore less severe incident. Many people and experts too tend to avoid considerations of this aspect, pretending a certain set of measures does yield perfect safety. A realistic quantification of risks often is neither done nor welcome.

This seems to be the same with the common interpretation of the effectiveness of measures concerning intrinsic safety. On your own risk some reflections are presented here in the following.

10.1 How to interpret and include the safety factor?

Including the required safety factor 1.5 according to the IEC 607097-11 procedure is a simple task. Obviously, appliance of a safety factor should increase safety, in this case by means of a kind of over dimensioning. But it's a real challenge to find out what it's worth to do so.

Some facts:

a) IEC 60079-11 makes no difference between safety level ia and ib and does not distinct between permanently sparking contacts from those which only spark when failures have occurred.

b) Including the safety factor of 1.5 into a firstly significant parameter (for example the voltage with a capacitive circuit) decreases the ignition probability usually by about two to three decades. Vice versa the inverse inclusion while carrying out an experiment will decrease the amount of time needed in the same magnitude.

c) Including the safety factor 1.5 into the short circuit current will decrease inductively stored energy by the factor 2.25. In an ohmic circuit, where the power is expressive, the original value 1.5 is valid. It seems not to be possible to determine the effect of safety factor application anywhere with mixed circuits which include capacitance and inductance.

d) The encountered loss voltage is of a strict physical property with respect to spark's effective power consumption. There is no need to incorporate this voltage into safety factor conclusions.

Some statements according to the facts above:

a) The only encountered possible explanation for these missing distinctions is, that the standard assumes the application of the safety factor to be sufficient for reduction of ignition probability to zero. If so, then indeed the count of and necessary circumstances for the occurrence of sparks make no difference at all. But see b).

b) The reason for applying the safety factor while conducting the experiments is expected to be the need for speeding up the procedure. The decisive problem results from the lack of knowledge about the validity of the chosen safety factor related parameter. If the chosen parameter is of a first order significance, the proved circuit originally may have an ignition probability of about 10^{-5} to 10^{-6}, otherwise perhaps only 10^{-3}. This difference may be tolerable with sparks during failures only but with permanently sparking devices a real problem can arise.

c) With *ispark*, the problem of associating the safety factor is solved in a somehow sophisticated way. Because *ispark* encounters a certain temperature as criterion of ignition, the task of a safety factor has to be denoted to an appropriate distance to this temperature. This will work without the need, to detect a parameter of first order significance.

   To beware a maximum compliance with the traditional method, incorporation of a safety factor 1.5 is implemented by multiplying the thermal resistance to ambient by 1.5, thus decreasing the required power for ignition by just this quantity. The thermal capacitance is divided by 2.25, the square of 1.5, which results in an accordingly smaller energy for ignition.

   This works exactly when either ignition energy is dominant or ignition power. Other circumstances underlie some kind of interpolation.

d) The loss voltage in *ispark* is really treated as not contributing to ignition; a safety factor has no influence here. Therefore *ispark* itself, if 10 V are a certain amount, calculates higher permissible capacitances as IEC 60097-11 allows. For not to come into conflict, these values actually are cropped to IEC ones.

10.2 Power down circuits

Standardized ignition probability is about 10^{-3} per $1/4^{th}$ revolution, tested after having applied the required safety factor.

Thus the question arises, how to act with circuits, which alter their properties with the first or within a certain number of experienced sparks in a more safe direction. In other words: are single sparks allowed, having an ignition probability exceeding 10^{-3}, if they just are accompanied by a collective of minor ignition capable sparks, lowering the overall mean down to the permissible value?

As discussed in chapter 10.1, the standard does not distinct between single and multiple sparking arrangements, and further gives hints to cover circuits with large time constants. It's to be concluded, that all sparks, even the worst the circuit can deliver, must not exceed an ignition probability of 10^{-3}.

For testing those dynamically acting circuits using the standardized spark test apparatus suitable means are required for counting contacts only while the circuit is alive.

10.3 Criticality of parameter uncertainties and sensitivities

10.3.1 General

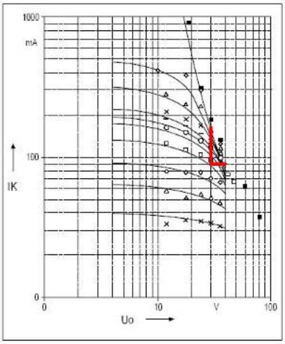
A suitable model realization allows investigation of criticality and sensitivity. Especially the stochastic properties of the spark test apparatus would make it impossible to obtain dependable results by experiments.

10.3.2 Sensitive effects

In some circumstances, a certain parameter is surprisingly heavily influenced by slight variations of another one. This is usually the case, when the first is only weakly involved in ignition. The effect seems to be great but the safety factor may be affected only much less significantly.

Example: Permissible inductances in the vicinity of the ohmic limit

There is a more or less slight transition from inductively enhanced sparks to pure ohmic ones. Approaching the ohmic boundary, permissible L decrease rapidly.



Please consider the red angle in the diagram at the left (concerning linear inductive circuits here).

Within the highlighted area, currents have a ratio of about 2:1, voltages of 4:3 but inductances will vary from 5 mH to zero.

Inductance is very sensitive, when approaching the ohmic boundary. For practical appliances, the amount of permissible cable length, for example, will rapidly decrease down to zero. Vice versa a small reduction in source's current and/or voltage will reestablish useful permissible inductances.

In a physical view, this behavior is a result of a minor contribution of inductance to ignition compared to the one of the electrical source itself.

As an example, the following table is presented, showing the great effect of increasing voltage on permissible inductances. It is demonstrated also, that the achieved safety factor does not suffer in the same way. If ispark calculates a circuit to be not intrinsically safe even without any external inductance, a relatively small reduction in safety factor requirement does allow some inductance.

	L_{pms} [mH]		
U_o [V]	safety factor 1.0	safety factor 0.95	safety factor 0.9
33	1.722	2.154	2.608
34	1.286	1.728	2.211
35	0.841	1.289	1.779
36	0.392	0.844	1.339
37	#	0.394	0.892
38	#	#	0.443
Electrical Data: I_o = 100 mA; linear source; IIC			

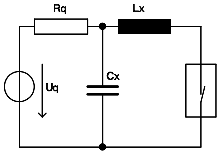
Thus a possibility arises, to "rescue" older designs by tolerating a small deviation in safety factor. ispark now includes the option to apply a safety factor lessen by 10% for zone 1.

10.3.3 Critical effects

Attention here is drawn to those situations, where the native imagination of some sort of proportionality between a chosen parameter and ignition probability fails in such excess, that the applied safety factor has nearly no chance to cover the effect.

Examples:

a) Adding a "small" amount of inductance to a circuit comprising big capacitances:



According to IEC 60079-11, at 5.6 V a capacitance of 1000 µF is stated to be intrinsically safe. *ispark* calculates a safety factor of 1.12 for this combination if the inductance within the circuit is 1 µH.

The dependence of an actual safety factor on the "parasitic" inductance according to *ispark* is reported below:

L [mH]	0.0005	0.001	0.002	0.003	0.004	0.005
safety factor	3.79	1.12	0.36	0.2	0.13	0.10
Electrical Data: U_q *= 5.6 V;* R_q *= 100 kΩ;* C_x *= 1000 µF; IIC*						

It is of great importance to understand, that with such a circuit the main parameter in common considerations C_x is much less effective than another, which may often be overlooked and which isn't mentioned at all in the standard within this context.

The effect is moderated somehow because any inductor has a resistance too. Especially with cables it can be shown, that there is a suitable maximum L'/R' relation to sufficiently control the situation. *ispark* versions above and including 6.0 will cover this complication.

b) Erroneously treating a rectangular shaped source like a linear one:

A few years ago, known standards did not expressively explain, that reported ignition data do only belong to linear sources. If a rectangular shaped source erroneously is taken for a linear one and assessed according to IEC 60079-11 the yielded safety factor does suffer a lot.

Example:

U_o is assumed to 28 V and I_o to 20 mA. If linear source shape is selected, L_o resp. C_o is calculated by *ispark* to 94 mH resp. 0.041 µF; a rectangular one results in 4.1 mH resp. 0.037 µF.

If, per confusion, the values 94 mH resp. 0.041 µF are associated to a rectangular source, the yielded safety factor is about 0.7 instead of 1.5. Such a weak safety factor nearly is of no worth because the effective ignition probability is about 10^{-2} to 10^{-1} in such situation.

Unfortunately, indeed, appliances are known where exactly this mistake has happened.

10.4 ‚Artificial' spark test apparatus

The standardized spark test apparatus reveals some severe shortcomings:

- Thoroughly trained staff is required.
- The apparatus itself and suitable operating environment is needed.
- Hazardous materials are used like cadmium and explosive gas mixtures.
- Experiment's results are of stochastic nature and dependable only if executed several times.
- Experiments state a binary pass / fail verdict only.
- Inclusion of the required safety factor is challenging with certain circuits.
- Dynamically acting circuits sometimes can be tested only using additional control means.
- Operating range especially with higher currents is restricted.

The only item to be overcome by a slight alteration of the standardized spark test apparatus is the operating range. If, for example, elevated currents are the target, one may have a better approach to pure spark ignition, using wires of larger diameter, which do not heat up as much as the standard wires do. Or the apparatus and the source are run in duty cycles, allowing the wires to cool down.

Simulation can be a powerful method to overcome all of the mentioned drawbacks.

While *ispark* solves these problems on the base of pure software modeling, some attempts came up since about 2008, to develop an alternative spark test apparatus using some hardware means besides software also.

A recent example for such a trial is described in the patent WO 2013/010221 A1 (CMTE DEVELOPMENT LIMITED, Australia). It's called electronic spark Tester (EST) further.

(54) Title: SPARK TESTING APPARATUS

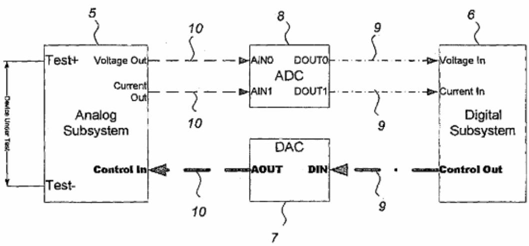


Figure 2

(57) Abstract: The invention provides a method and apparatus for electronically testing the safety of sources of energy such as electrical circuits, in explosive atmospheres such as high risk mining situations, using an electronic spark tester (EST) in place of the known mechanical spark test apparatus (STA). The EST typically uses an analogue subsystem (5) and a digital subsystem (6) connected by a digital to analogue converter (7) and an analogue to digital connector (8) to apply a simulated spark load to the energy source and measure the time varying current response to that load.

The drawing demonstrates nothing further than a time dependant variable load to the test object accompanied by digital analog interfaces for control and measurement purposes.

Note: Challenging items like an electro-thermal model in structure or parameters are not qualified within this patent.

The original idea of this EST is to connect the electrical source to the test apparatus, stimulate the device under test by an electrical control sequence and simultaneously measure its electrical response.

Firstly the arrangement shall check spark ignition relevant properties of the source by using some load sweep methods.

Secondly these properties are combined with operator declared parameters and both are calculatively assembled to an electrical worst case load “stimulus”.

Thirdly, the electrical source is subjected to this stimulus; the resulting electrical response in voltage and current courses over time is measured and analysed and submitted some calculational means.

Outcome shall be a numeral quantity characterizing an actual distance to ignition, which seems to be something like the commonly used safety factor.

Actually the following systematic differences of such an EST to *ispark* can be seen:

- The EST can perform in-situ testing because of its hardware analog “frontend”. This can be used to detect some abnormal / defective states in existing installations. But the expressiveness of such a check is highly compromised if the actual fault status isn’t known, what’s usually the fact.
- *ispark* handles a comprehensive set of failure assumptions required by the standard autonomously. Using an EST, each of them has to be incorporated individually into the hardware of the device under test.
- Using an EST, a physical representation of the test device is required for assessment.
- An EST must be manufactured as a hardware device, deployed and maintained, eventually updated/-graded also.
- Verification of an EST against acknowledged ignition data is deemed to be achieved harder than with a totally software based method.

As an abstract, neither *ispark* nor an EST is able to perform an expressive integrity check of existing installations and for apparatus’ development and certification purposes a pure software method like *ispark* requires significant less effort.

11 Errata

6.3.9 spark type s-0L: With diagram title read s-0L instead of o-0L.