Optical sources of ignition in hazardous areas

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Interest in the possibility of igniting flammable gases and dust by using light gained momentum some twenty-five years ago when the use of fibre optic transmission and laser techniques began to be explored. Since that time, there has been a considerable amount of work studying the various mechanisms for ignition, which can occur. Inevitably the challenge has been to find the minimum light levels which can cause ignition and some generally accepted results have emerged. The remaining task is to convert these results into a code of practice, which will allow the techniques to be used safely.

Data transmission by fibre optics has some advantages in process industries and is becoming more widely used as the economics and installation practice changes. A major advantage for process industries using flammable materials is the comprehensive electrical isolation. This removes concerns about variations in plant potentials during electrical faults or lightning induced surges, or the inadvertent interconnection of supply systems, which are intended to remain separate. The increased use of distributed systems and the emerging higher speed fieldbus systems lead themselves to fibre optic transmission techniques. Adequately isolated electrical transmission systems exist but the isolation and freedom from interference offered by fibre has a fundamental appeal.

As an example - a very simple interconnection between two equipotential islands - inevitably the islands are interconnected but not so as to prevent potential differences. As networks and interconnections become more complex the desirability of a well-defined isolation between electrical systems becomes even more important. It is possible that the lack of a clear code of practice has delayed the introduction of these techniques, which can be demonstrated to improve operational reliability and safety. The use of lasers in flammable atmospheres is principally, but not exclusively, for analytical purposes. This article only briefly touches on this subject because the range of powers and the applications vary widely.

Mechanism of ignition

The generally accepted most sensitive mechanism for igniting gases by light, is for light to be concentrated on a small highly absorbent particle, which then becomes hot and ignites the gas air mixture. The probability of this combination existing has inspired a great number of debates but is arguably a more severe test than that required by electrical protection. The nearest parallel is with spark test apparatus used for intrinsic safety testing, which uses specifically conditioned cadmium discs and tungsten wires in an ideal mixture of gas and air. The requirement of a well-focused beam on a stationary particle of a specific size and almost perfect absorbing ability is possibly several orders less probable. It is almost impossible to calculate this type of probability and even if it is possible there is no defined acceptable risk against which to measure it. The recent ATEX directives advocate the use of risk analysis without defining the targets to be achieved.

An alternative technique, which is frequently used for testing, is to affix the absorbent particle to the end of the fibre thus ensuring maximum energy transfer. This situation is possibly slightly more probable than successfully heating up a mobile particle.

The early work on this subject concentrated on the use of continuous light, bombarding particles of various sizes. A very large number of tests was done and work from various research projects was brought together to create a proposal to be made to both CENELEC and IEC committees. The resulting proposal was that figures of 35 mW and 5 mW/mm^2 should be used to ensure safety.

The 35 mW has a factor of safety of '2' on the most sensitive experimental result and seems excessive if the improbable coincidence of factors to achieve the results are considered. However, these proposals are quite old (1995) and have become a de facto standard and hence are unlikely to be successfully challenged. More recently EN50303 [1], which defined Group I Category MI apparatus, proposes values of 150 mW and 20 mW/mm^2 for use in atmospheres of methane/ air mixtures and coal dust. The standard has a note warning: 'If the optical radiation can impinge on a coal dust layer and cause local heating in excess of 150°C' - then these values have to be modified. The full implications of this note are difficult to understand.

Different gases are more or less sensitive to ignition by light. Recent work confirms that there is no close correlation between this energy and electrical ignition energy or ignition temperature. There is a degree of correlation with ignition energy (gas classification) but the pattern is modified by the thermal and other characteristics of the gas. Some of the experimental evidence goes some way to explaining the reaction of small hot electronic components and gases and may also be relevant to hot spots on all electrical apparatus. There is sufficient knowledge to characterise some particular gases such as methane but it will be some considerable time before an agreed list of the sensitivity of gases is available. Meanwhile, the conservative

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figures 35 mW and 5 mW/mm^2 are likely to form the basis for the majority of safety assessments.

Some feeling for the level of light being considered can be derived from the fact that bright sunlight is 1 to 2 mW/mm^2 at the earth's surface. The level of light considered safe for direct optical viewing is a few milliwatts and frequently this is the power limitation for most fibre optic links. Some forms of lighting such as high power floodlighting exceed the permitted limits in the immediate vicinity of the lights and light emission from the more powerful photographic flash equipment can cause ignition.

Further research, particularly on some forms of pulse power has been carried out. It has been known for some time that there was a time delay as the target particle warmed up. This effect together with a variable rate of cooling means that the analysis of pulse chains with different pulse lengths and intervals between pulses is complex but sufficient experimental work has been done to enable informed assessments of the ignition capability of commonly occurring pulse chains to be made.

The use of fibre optics

Within Europe the ATEX directives decide the level of safety to be achieved and the requirements in the rest of the world are similar. The usual translation of the requirements is that apparatus used in Zone 0 has to be safe with two faults (Category 1), for Zone 1 safe with one fault (Category 2) for Zone 2 safe in normal operation (Category 3). Since light is not an electrical phenomenon, then third party certification of a fibre optic link will only be legally required for installations in Zone 0. It may emerge that end users will insist on third party certification and when the light source itself is in a Zone 1 hazardous area then the electrical circuit will have to be third party certified. A solution, which is acceptable to the market, will emerge.

Where the level of 35 mW is operationally satisfactory it is reasonable to use this approach which is similar to intrinsic safety. This has the advantage that there is no requirement to isolate the circuit when doing maintenance and damage to cables cannot produce an incendive situation. The fibre optic link when used for communication purposes operates at a relatively lower power (1 mW) and the initiating diode is not capable of inserting 35 mW into the fibre. Some testing done by Physikalisch Technische Bundesanstalt (PTB) suggests that if a diode which is normally used in the 1 - 2 mW range is overdriven by an excessive current the output power peaks at less than 15 mW before failing.

The diode itself is effectively an infallible interface for this purpose and provides an ideal solution. Such a diode would be sufficient protection in itself but would have to cope with the definition of its location, marking and certification obstacles. The diode located within the Zone 1 hazardous area would require the drive circuitry to be certified. The usual low voltage relatively high current circuitry is not difficult to make intrinsically safe but ignition temperatures under fault conditions require some ingenuity.

The Zone 2 requirements are readily met since the normal operating temperatures are less than the 135 C of T4. Provided that the power is limited to less than 35 mW the circuit can be maintained in the same manner as an energy limited Type n circuit. If advantage is taken of the opportunity to use increased power in a pulsed mode in Zone 2 then no appreciable problem should arise. However, the problem of what power would be available under fault conditions is quite complex and might cause difficulties in Zone 1 installations.

Where higher power transmission is thought to be desirable then a method of protecting the cables equivalent to that used by power cables must be considered as adequate for Zone 1 and Zone 2 installations. If cables are armoured or protected by conduit then the isolation is bridged and one of the major advantages of fibre optics is lost. The recommended practice is therefore to use cable with a toughened outer sheath and mount it so that it is mechanically protected. Any interconnections have to be secure so as to ensure that no hot spots are generated by a mismatch and there will be a considerable amount of haggling over temperature classification of accessories. No doubt a comprehensive range of accessories will emerge but early applicants may find that certification by a third party is time consuming and expensive while some of the problems are resolved. Before any disconnection is made the light sources must be switched off and this will usually mean isolation of both ends of the fibre which is inconvenient. In Zone 2 the normal operation requirement eases the problem considerably and apart from the requirement to isolate before disconnecting there should be no difficulty. It would seem wise to avoid these problems by using the low power solution except in exceptional circumstances.

The use of lasers

There are a number of analytical processes which use lasers and the available techniques increase because of the well-defined application. In a few cases it is possible to remove the possibility of a particle target by filtering the sample. This would permit higher power but the permitted power would have to be determined experimentally and possibly a safety factor applied.

The permitted power for short single pulses has been the subject of some experimental work and the pulse energy varies with the pulse width because the mechanism of ignition becomes more complex as the time decreases. With microsecond pulses, the ignition is not entirely caused by hot surfaces, but occurs as a plasma spark, generated on the target material. Hydrogen, which has a high ignition temperature but low ignition energy, requires a relatively small amount of power for ignition by a light pulse. (2,3 mJ for a 70 S pulse). If advantage is to be gained from this higher level of power then the method of generating the pulse must be controlled to a safe level with two possible faults if the laser is intended to impinge on a flammable gas/ air mixture. The resultant discussion on system reliability is likely to be long and expensive.

The short time higher power characteristic can theoretically be used to remove the power in the event of a malfunction. Provided that the malfunction can quickly be detected the time for taking corrective action is much longer than that required to prevent spark ignition in electrical circuits. The reliability of this type of protection would have to achieve an acceptable level. In some applications the size of the beam can be well controlled and the light equally distributed across it. In these circumstances advantage can be taken of the 5mw/mm^2 radiant power to permit higher powers. Where this requirement has to be met under fault conditions it is not always easy to satisfactorily demonstrate that safety is maintained. The use of lasers for survey purposes and position guidance in hazardous areas arises from time to time. However, the power level is usually below the 35 mW requirement and only causes difficulties if safety under fault conditions becomes a requirement. The inevitable conclusion is that if 35 mW is sufficient power for operational reasons then it makes demonstrating that adequate safety has been achieved much easier. In the CENELEC dust standard EN50281 [2] an energy level of: '0,1 mJ/mm^2 for pulse laser or pulse light sources with pulse intervals of at least 5s' is proposed.

Optical ignition of dust atmospheres

The amount of power to ignite a dust cloud is dependent on so many factors, that it is almost impossible to evaluate the risk. A cloud, which can be ignited, is very dense and is unlikely to be composed of particles of ideal size and absorbivity which will obligingly remain stationary within the light beam. The literature on the subject suggests that powers of the level of 10 W are necessary to cause ignition in some dusts. EN50281-1-1 [2] contains a requirement:

The energy levels of radiation generating equipment shall not exceed the values given below (see EN50281-1-2 [2], clauses 8 and 9).

For lasers and other continuous wave sources:

- - 5 mW/mm^2 for continuous wave lasers and other continuous wave sources
- 0,1 mJ/mm^2 for pulse lasers or pulse light sources with pulse intervals of at least 5 s.
- Radiation sources with pulse intervals of less than 5 s are regarded as continuous light sources in this respect.

This is an ultra conservative approach and unfortunately does not include the 35 mW power level as an option. This is a curious omission, which causes some problems with standard fibre optic practice. For example a 250 m fibre is restricted to a power level of 0,25 mW if it must meet the 5 mW/mm^2 requirement. The reason for the omission is not known to the author. Possibly because of the debate about dust layers only being a source of ignition, the problem of a light beam impinging on a layer of dust is not considered in this standard, which makes the reference in the M1 standard even more difficult to understand. There is some evidence that an energy level in excess of a specific amount is necessary to initiate smouldering. Unfortunately the value is not well defined but there is sufficient evidence to suggest that the figures of 35 mW and 5 mW/mm^2 are unlikely to cause a problem. At the present time, the figures of 35 mW and 5 mW/mm^2 are likely to be used when certifying apparatus for use in dusts. There is no doubt they are very conservative in almost all situations but there are no proposed alternative figures which have an adequate level of acceptancy and hence these will be used.

Conclusion

There is available a considerable amount of information about ignition from optical sources, which can be utilised to solve problems relating to specific applications with specific hazardous materials. Wherever possible using the limits of 5 mW/mm^2 and 35 mW is the most acceptable solution and is likely to be internationally acceptable and more widely applicable. The application of the fault count to apparatus used in Zones 0 and 1 inevitably means that the useable power is lower than these values. It is not easy to anticipate how the light pattern may be distorted under fault conditions and hence the 35 mW limit becomes the principal useable restriction. However, fibre optic links and some laser analysis techniques can all achieve solutions with operational integrity at this power level with an adequate margin of safety.

References

[1] EN 50303: 2000. Group I, Category M1 equipment intended to remain functional in atmospheres endangered by firedamp and/or coal dust.

[2] EN 50281-2-1: 1999. Electrical apparatus for use in the presence of combustible dust. Test methods. Methods of determining minimum ignition temperatures.

Bibliography

[1] EUR 16011 EN. 1994. Optical Techniques in Industrial Measurement: Safety in Hazardous Environments

[2] EUR 19617 EN. 2000. Pre-normative research on the use of optics in potentially explosive atmospheres.

[3] European (CENELEC) standards: http://www.cenelec.be.

[4] International (IEC) standards: http://www.iec.ch.

[5] European (ATEX) directive: http://www.europa.eu.int/comm/dg03/index_en.htm.

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