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EVALUATION FOR TYPE OF PROTECTION OPTICAL RADIATION "op"

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Abstract: This paper proposes the analysis, evaluation and highlighting of the essential requirements for equipment and transmission systems that use optical radiation in areas with a potentially explosive atmosphere. The first part of paper deals with the risk of explosion and presents fundamental characteristics regarding the protection against explosions applied to technical equipment. The systematized presentation of applicable requirements to the equipment and transmission systems that use optical radiation is presented in second part of the paper. Among the conclusions, it is mentioned that, although the testing in explosive atmospheres is relevant, ensured by the specific standards, it is important to comply with the required conditions, still in the design faze and also, later in the production, installation and maintenance faze.

Keywords: explosive atmosphere, explosion protection; electrical equipment, type of protection, optical radiation, explosion risk.

1. INTRODUCTION

In the industrial field such as production, transport, extraction, processing, storage of petroleum products, interaction with various substances, mostly fuels and explosives, is predominant. The use of technical equipment in activities related to the

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storage, transfer and / or processing of this type of substance involves the formation of a specific area with a significant risk of explosion. [27], [3], [31]

Explosion prevention and protection are of major importance for health and safety at work. For an atmosphere to become explosive, the flammable substance must be present in certain concentrations. Therefore, the explosion can only occur if there is a source of ignition and only if the concentration falls within the flammability (explosive) limits of the substance, i.e., between the lower flammability limit and the upper flammability limit. The limits of flammability (explosiveness) of the substance depend on the pressure and concentration of oxygen in the air. Thus, the mechanism of an explosion generated by a mixture of flammable gases, vapours or vapours with air can be expressed by the well-known explosion triangle shown in Figure 1 (a) and the explosion pentagon for or dust, lint and fibres, Figure 1 (b). [5], [4], [15]

a) b)

Fig.1. a) explosion triangle (for gases, vapours, mists); b) explosion pentagon (for dusts, lint and fibres)

The dust explosion has different characteristics from the gas explosion and can be in many cases more devastating. If, for example, a stream of air swirls a layer of dust, in a small space, dust along the oxygen generates a flammable mixture of air-dust. If this mixture is ignited by a source of ignition, it will explode. The force of explosion swirls more dust in the air, being ignited in turn, like a chair reaction. [6]

Consideration must also be given to the fact that in order to be considered a combustible dust, the dust must be explosive - it must be suspended in the air, in order to have a distribution of particles capable of propagating combustion and a concentration, between explosion limits. Therefore, the explosion pentagon shown in figure 1 (b) can be defined by adding to explosion triangle aspects related to mixture or dispersion of combustible substances and oxidant, as well as those related to mixture suspensions. [8], [2], [10]

New concepts for explosion prevention and protection develop new strategies to prevent the propagation of explosions or to limit their effects, by taking into account specific related to the explosive mixture (limitation, containment, etc.). This representation provides a clear picture of the explosion conditions and allows identification of safety measures for design, manufacture, installation and repair of installations in order to prevent an explosive atmosphere, to eliminate sources of ignition or to reduce the effects of explosions by using protective systems. [11], [29]

2. THE EXPLOSION PROTECTION

All equipment used in installations operating in potentially explosive atmospheres must meet the following requirements:

• be adequately protected to explosion;

• maintain degree of protection to environmental conditions for which they were built;

• be able to withstand all the stresses to which they are subjected during storage, transport, installation and operation of installation. [12], [16]

All constructive solutions applied to electrical or non-electrical equipment that are used in potentially explosive atmospheres, in order to avoid the ignition of the surrounding explosive atmosphere, are included in specific types of protection. Constructively, electrical equipment may be designed using two or more types of protection, specified by manufacturer on the label, in accordance with the requirements of applicable standards. Each type of protection is based on a specific technical solution in order to implement explosion protection, Table 1. [2]

Table 1. ***Technical solutions and types of protection***

Types of protection to explosion		**Technical solution used**
Symbol	**Name**	
Ex m	Encapsulation „m”	Separates electrical equipment or parts that are likely to cause explosive atmospheric ignition
Ex p	Pressurized enclosure „p”	
Ex q	Powder filling „q”	
Ex e	Increased safety „e”	Eliminates the ignition source
Ex n	Type of protection „n”	
Ex d	Flameproof enclosures „d”	Prevents the ignition from spreading throughout the mixture in hazardous area
Ex i	Intrinsic safety „i”	It limits electric energy in circuits that can be a source of ignition
Ex op	Optical radiation	Energy limitation (is), blocking of optical radiation in equipment with other types of protection (pr), interlocking (sh)

The correlation of the types of protection with EPL (Equipment Protection Level) and the area in which they can be used is presented in figure 2.

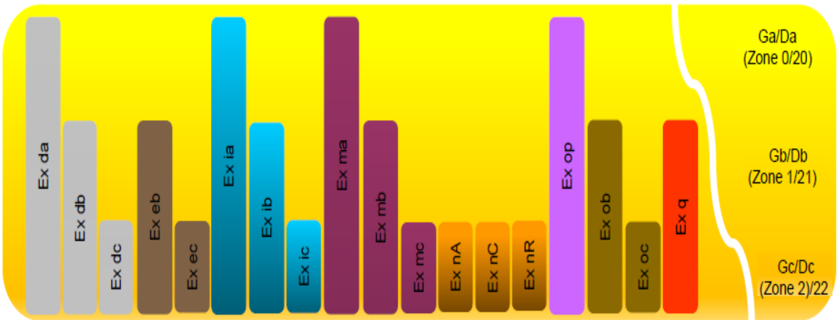

Fig.2. Correlation between the types of protection and the equipment EPL/ corresponding area

The use of technical equipment in areas where explosive atmospheres may form is clearly regulated, so preventive methods and solutions have been proposed to meet these requirements in order to minimize the risk of undesirable events. [13], [24]

3. TYPE OF PROTECTION OPTICAL RADIATION "*op*"

Optical equipment in the form of lamps, lasers, LEDs, optical fibers is increasingly used for communications, surveying, monitoring and measurement. In material processing, optical radiation of high irradiance is used. Where the installation is inside or close to explosive atmospheres, the radiation from such equipment may intersect with these atmospheres. [9], [28]

Depending on the characteristics of the radiation it might then be able to ignite a surrounding explosive atmosphere, and the presence or absence of an additional absorber, such as particles, significantly influences the ignition. [14], [26]

There are two possible ignition mechanisms:

a) Optical radiation is absorbed by surfaces or particles, causing them to heat up;

b) Direct laser induced breakdown of the gas or vapour at the focus of a strong beam, producing plasma and a shock wave both eventually acting as ignition source. These processes can be supported by a solid material close to the breakdown point.

Three types of protection can be applied to prevent ignitions by optical radiation in explosive atmospheres. These types of protection encompass the entire optical system.

These types of protection are:

a) inherently safe optical radiation, type of protection "*op is*",

b) protected optical radiation, type of protection "*op pr*", and

c) optical system with interlock, type of protection "*op sh*".

Where the ignition hazard assessment, shows that ignition due to optical radiation may be possible, the principles of using the types of protection shown in Table 4 shall be applied.

Table 4. ***Relationship between EPL and the probability of an ignition source***

EPL	Protection required
Ga	Ignition not likely with one fault and two independent faults or in the case of rare malfunctions
Gb	Ignition not likely with one fault or in the case of expected malfunctions
Gc	Ignition not likely in normal operation

3.1 Type of protection inherently safe optical radiation, "*op is*"

Inherently safe optical radiation means that the visible or infrared radiation is incapable of supplying sufficient energy under normal or specified fault conditions to ignite a specific explosive atmosphere. The concept is a beam strength limitation approach to safety. Ignition by an optically irradiated target absorber requires the least amount of energy, power, or irradiance of the identified ignition mechanisms in the visible and infrared spectrum. The inherently safe concept applies to unconfined radiation and does not require maintaining an absorber-free environment. [18], [22]

3.2 Type of protection protected optical radiation "*op pr*"

This concept requires radiation to be confined inside optical fibre or other transmission medium based on the assumption that there is no escape of radiation from the confinement. In this case the performance of the confinement defines the safety level of the system, "*op pr*". Safety levels that are applicable include EPL Gb or Gc and Db or Dc and Mb. All optical components shall be suitable for the ratings and temperature range for which they are used [19], [25].

3.3 Type of protection optical system with interlock "*op sh*"

This type of protection is also applicable when the radiation is not inherently safe. The concept requires radiation to be confined inside an optical fibre or other transmission medium based on the assumption that there is no escape of radiation from the confinement under normal operating conditions.

4. EVALUATION OF EQUIPMENT AND TRANSMISSION SYSTEMS USING OPTICAL RADIATION

Electrical equipment and electrical Ex components (e.g., fibre optic terminal devices) shall comply with one or more of the specific electrical equipment protection technique standards listed in SR IEC EN 60079-0, [17], suitable for the application if intended to be installed inside the hazardous area. [1], [7], [23] Optical equipment shall be subjected to a formally documented ignition hazard assessment using the principles stated in figure 3. This assessment shall be made to determine which possible optical ignition source can arise in the equipment under consideration, and which measures may need to be taken to mitigate the risk of ignition.

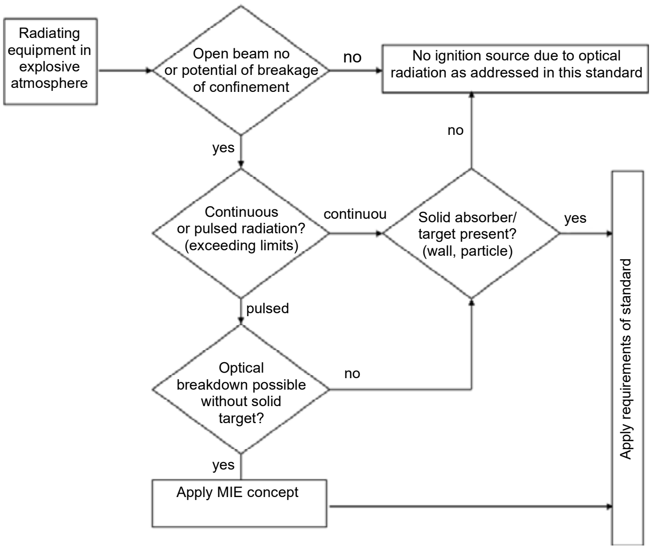

Fig.3. Ignition hazard assessment

In all cases, where optical radiation is to be considered, the ignition hazard assessment shall be the first step. If the assessment shows that no ignition is to be expected, the further application of this standard is not necessary.

An explosive atmosphere can be ignited by optical radiation provided that the beam strength exceeds an inherently safe level and an absorbing solid exists in the beam that can cause a hot spot and an ignition source accordingly, or in case of pulses the conditions for a break down apply (threshold irradiance exceeded).

4.1 Requirements for inherently safe optical radiation "*op is*"

Either optical power or optical irradiance shall not exceed the values listed in Table 5, Table 6 and Table 7, categorized by equipment group and temperature class.

As an alternative to compliance with Table 5 the following options are available:

- For irradiated surface areas above *400 mm²*, the maximum temperature measured on the irradiated surface shall be used to establish the temperature class, with no limit on irradiance. The temperature measurement shall consider the possibility of nonhomogeneous beam strength.

- For limited irradiated areas not greater than *130 mm^2*, maximum radiated power values other than those as permitted by Table 2 for temperature classes *T1*, *T2*, *T3* and T4 and Groups *IIA*, *IIB* or *IIC* are detailed in Table 7.
- Passing the ignition tests.

Table 5. ***Safe optical power and irradiance for Group l and 11 equipment, categorized by Equipment Group and temperature class, [28]***

Optical radiation sources with		**Can be used for the following atmospheres (temperature classes in combination with equipment groups)**	**Remarks**
Radiated power (no irradiance limit applies) mW	**Irradiance (no radiated power limit applies)** mW/mm^2		
≤ 150		IIA with T1, T2 or T3, and I	No limit to the involved irradiated area
≤ 35		IIA, IIB independent to T-class, IIC with T1, T2, T3 or T4, and I	No limit to the involved irradiated area
≤ 15		All atmospheres	No limit to the involved irradiated area
	≤ 20	IIA with T1, T2 or T3, and I	Irradiated areas limited to ≤ 30 mm^2
	≤ 5	All atmospheres	No limit to the involved irradiated area

Table 6. ***Safe optical power and irradiance for Group III equipment [28]***

Equipment Group	**IIIA, IIIB and IIIC**		
EPL	**Da**	**Db**	**Dc**
Radiated power (no irradiance limit applies) mW	≤ 35	≤ 35	≤ 35
Irradiance (no radiated power limit applies) mW/mm^2	≤ 5	≤ 5	≤ 10

Table 7. ***Safe limit values for intermediate area, Group I or 11, constant power, T1 - T4 atmospheres, equipment Groups IIA, IIB or IIC, [28]***

Limited irradiated area mm2	Maximum radiated power value mW
< 4 * 10–3	35
≥ 4 * 10–3	40
≥ 1,8 * 10–2	52
≥ 4 * 10–2	60
≥ 0,2	80
≥ 0,8	100
≥ 2,9	115
≥ 8	200
≥ 70	400
For irradiated areas equal to or above 130 mm2 the irradiance limit of 55 mW/mm2 applies	

For optical pulse duration of less than *1 ms*, as determined in accordance with the applicable equipment protection level, the optical pulse energy shall not exceed the minimum spark ignition energy (MIE) of the respective explosive gas atmosphere.

For optical pulse duration from *1 ms* to *1 s* inclusive, as determined in accordance with the applicable equipment protection level, an optical pulse energy equal to 10 times the MIE of the explosive gas atmosphere shall not be exceeded.

For a single pulse, optical pulse energy is equal to the product of the average power and the optical pulse duration of that single pulse.

The MIE values for the application of this standard, [30], are:

- Group IIA: *240 μJ;*
- Group IIB: 82 *μJ;*
- Group IIC: 17 *μJ.*

4.2 Requirements for protected optical radiation "*op pr*"

This concept requires radiation to be confined inside optical fibre or other transmission medium based on the assumption that there is no escape of radiation from the confinement. [20]

In this case the performance of the confinement defines the safety level of the system, "*op pr*". Safety levels that are applicable include EPL Gb or Gc and Db or Dc and Mb.

All optical components shall be suitable for the ratings and temperature range for which they are used. [21]

The optical fibre, figure 4, or cable protects the release of optical radiation into the atmosphere during normal operating conditions. For EPL Gb, Db or Mb protected optical fibre cables shall be used provided by additional armouring, conduit, cable tray, or raceway.

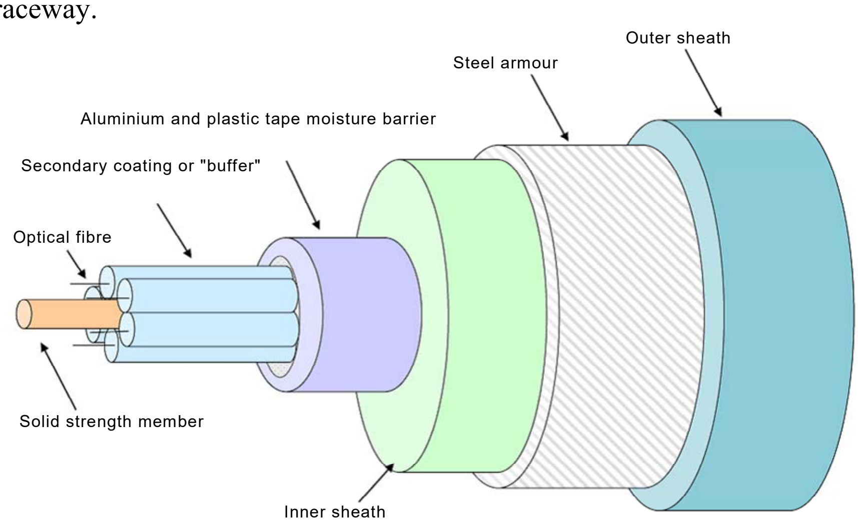

Fig.4. Example multi-fibre optical cable design for heavy duty applications, [28]

Internal or external cables can be terminated/ spliced from one fibre (from a cable) to another fibre (in a new cable) by using dedicated coupler or joining kits giving a fixed termination. For external termination/splicing, the cable connection shall provide equivalent mechanical strength to that of the cable.

For EPL Gc or Dc optical fibre or cables and internal pluggable factory connections that comply with the applicable industrial standard are suitable.

Ignition capable radiation inside enclosures is acceptable if the enclosure complies with recognised types of protection for electrical equipment designed to contain an internal ignition (flameproof "d" enclosure), or where it is not to be expected that there are absorbing targets inside the enclosure according to the ignition hazard assessment (such as an IP ox enclosure, pressurized "p" enclosure, restricted breathing "nR" enclosure, dust ignition protection by enclosure "t" etc.).

4.3 Optical system with interlock "*op sh*"

This type of protection is also applicable when the radiation is not inherently safe. The concept requires radiation to be confined inside an optical fibre or other transmission medium based on the assumption that there is no escape of radiation from the confinement under normal operating conditions.

Depending on the EPL, "*op sh*" requires the application of "*op pr*" principles, along with an additional interlock cut-off, as follows:

- For *Ga*, *Da* or *Ma* "*op sh*" applications, protected fibre optic cable "*op pr*" for *Gb/Db/Mb*, along with a shutdown functional safety system based on ignition delay time of the explosive gas atmosphere, is required.
- For *Gb*, *Db* or *Mb* "*op sh*" applications, protected fibre optic cable "*op pr*" for *Gc/Dc*, along with a shutdown functional safety system based on eye protection delay times, is required.
- For *Gc* or *Dc* "*op sh*" applications, unprotected fibre optic cable (not "*op pr*"), along with a shutdown functional safety system based on eye protection delay times, is required.

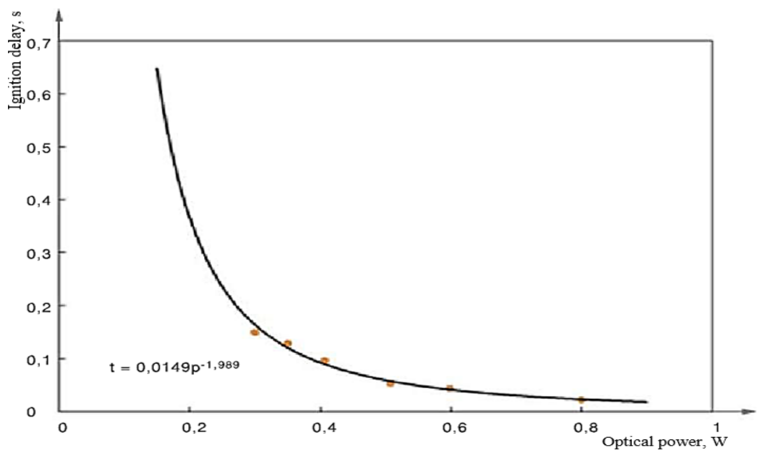

Fig.5. Optical ignition delay times and safe boundary curve with safety factor of 2, [28]

The interlock cut-off shall operate if the protection by the confinement fails and the radiation becomes unconfined on time scales shorter than the ignition delay time or the delay time for eye protection.

The interlock cut-off delay time of equipment for use for Group *I*, Group *IIA* temperature class *T1* and Group *IIA* temperature class *T2* shall be less than the boundary curve of figure 5 represented by the curve fit to minimum ignition delays with a safety factor of *2* included.

The interlock cut-off shall be required to perform according to the requirements defined by the risk analysis.

5. CONCLUSIONS

The risk of ignition of an explosive atmosphere may be reduced by the use of equipment, components and protective systems designed in accordance with the provisions of the technical standards for protection against explosions in force. The explosion risk assessment shall also take into account the determinations and interpretations of the parameters of the flammable substance. The importance of determining, identifying the factors influencing and the measures to be taken to determine as accurately as possible the parameters of influence are necessary for explosion prevention and explosion protection, of major importance for health and safety at work and to minimize losses (both human and materials).

The paper presents relevant aspects for the evaluation of technical equipment and transmission systems that use optical radiation in potentially explosive environments, useful aspects in the choice of materials, components of the equipment manufacturing process, all in order to minimize the risk of initiation atmospheres in which it is used. This equipment must comply with the requirements briefly presented in this paper and correspond in terms of protection against the initiation of the Ex atmosphere in which it is used, as a result of the tests to be performed depending on the type of protection.

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