Considerations on the type of protection increased safety "e"

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Abstract. Increased safety "e" represents a type of protection applied to electrical equipment or Ex Components in which additional measures are applied so as to give increased security against the possibility of excessive temperatures and against the occurrence of arcs and sparks. This type of protection cannot be applied to equipment producing electrical arcs and sparks in normal operation. This paper aims to underline some specific aspects regarding the equipment with type of protection increased safety.

1 Generalities

The type of protection increased safety "e" can be applied only to equipment not producing electrical arcs and sparks in normal operation. Supplementary measures are taken so that excessive temperatures, arcs and sparks not to occur even in specific abnormal operating conditions [1].

The type of protection increased safety "e" is based on the proper selection of insulating materials, providing a suitable IP (ingress protection) for the enclosure and maintaining adequate insulation distances between the conductive parts subjected to electrical voltages.

The applicable requirements for equipment with type of protection increased safety "e" are included in the specific standards, SR EN 60079-0 (that contains the general requirements for equipment designed for use in explosive atmospheres) and SR EN 60079-7 (that contains the general requirements for the type of protection increased safety "e") [1, 2].

In the last edition of the specific standard [1], the requirements for non-incendive "n" equipment, type of protection "nA" were translated from the non-incendive specific standard [3] to the increased safety standard [1]. From this movement of prescriptions from one standard to another, the type of protection increased safety received a new level of protection "ec".

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2 Specific requirements for equipment with type of protection increased safety "e"

Following the last edition of the specific standard [1], increased safety "e" electrical equipment and components are included in one of levels of protection presented below [1]:

– "eb" (EPL "Mb" or "Gb"); or

– "ec" (EPL "Gc").

Increased safety "eb" can be applied in case of equipment or Ex Components, including their connections, conductors, windings, lamps, and batteries. In the level of protection "eb" are not included semiconductors or electrolytic capacitors [1]. Examples of equipment to which the type of protection increased safety level of protection "eb" can be used: junction boxes, electric motors, luminaires, resistance heaters etc.

Increased safety "ec" can be applied in case of equipment or Ex Components, including their connections, conductors, windings, lamps, and batteries. In the level of protection "ec" are also included semiconductors or electrolytic capacitors [1]. Increased safety "ec" can be applied to the same equipment like level of protection "eb" and, in addition to electronic equipment, led luminaires etc.

In level of protection "eb", the maximum rated voltage shall not exceed 11 kV r.m.s., a.c. or d.c. and in level of protection "ec", the maximum rated voltage shall not exceed 15 kV r.m.s., a.c. or d.c. [1].

2.1 Requirements for electrical connections

Electrical connections made inside the equipment enclosures are divided in connections for field-wiring and for factory wiring (and into permanent types and reconnectable/rewireable types) [1]. Connections shall be made in such way not to increase the possibility of occurrence for electrical arcs, sparks or excessive temperatures [1].

Electrical connections must meet the applicable technical requirements. Connections must be designed and constructed so that conductors not to slip out from their location (during tightening or after insertion). Loosening of the connection in service must be avoided [1].

A positive compression force (to maintain contact in service) shall be provided and the contact shall be ensured and maintained without damaging the conductors. The contact provided shall not be appreciably impaired by temperature changes occurring in normal service. The pressure contact shall not be transmitted by insulating materials. In case of stranded conductors, the contact pressure shall be distributed evenly. A specific torque has to be specified (by the manufacturer) in case of screw connections (terminals) [1].

2.1.1 Field wiring connections

Terminals must be designed so as to accept conductors having the cross-section at least the corresponding one for the rated current of the electrical equipment. Connections shall be made so as to be easily inspected in service [1].

The number, size, and type of conductors shall be specified [1].

The following methods are accepted for field wiring connections [1]:

- Connections made using terminals conforming to IEC 60947-7-1, IEC 60947-7-2, IEC 60947-7-4, IEC 60999-1, or IEC 60999-2;
- Integral field wiring connection facilities;
- Connections designed to be used with cable lugs and similar devices;
- Connections using permanent arrangements.

2.1.2 Factory connections

Factory connections must provide means to meet the creepage and clearance requirements or to be fixed in a specific location [1].

The connection methods used for field wiring connections is accepted for factory connections. In addition to these methods, the following are also accepted for factory connection [1]:

- Twist-on connectors (only for Level of Protection “ec”);
- Permanent connections (crimping; brazing; welding; soldering - with mechanical support of the completed connection, in addition to the solder; only for “ec”, printed circuit board mounted components, without additional mechanical support);
- Pluggable connections for Level of Protection “eb” or “ec”;
- Pluggable terminal bridging connections;

2.1.3 Clearance and creepage distances

Clearances are dependent to the working voltage. If more rated voltages (or a range of rated voltages) are specified, the working voltage represents the highest value of rated voltage [1].

The creepage distance is dependent on the working voltage, the resistance to tracking of the electrical insulating material and its surface profile [1]. The effect of ribs and grooves shall be considered when determining the clearances and creepage distances [1].

Electrical insulating materials are classified according to the CTI - comparative tracking index as presented in table 1 (inorganic materials like glass and ceramics, do not track and are classified, conventionally, in material group I) [1, 4].

Table 1. Tracking resistance of insulating materials [1, 4]

Material group	Comparative tracking index (CTI)
I	600 ≤ CTI
II	400 ≤ CTI < 600
IIIa	175 ≤ CTI < 400
IIIb	100 ≤ CTI < 175

In case of printed wiring boards with conformal coating are accepted only in level of protection “ec” and the reduced distances under coating are permitted in case of a working voltage not exceeding 1100 V. The solder mask is not considered conformal coating, but may be accepted as a coat (when an additional coat is applied, and the solder mask is not damaged during soldering) [1].

In table 2 are presented the minimum creepage distances, clearances and separations.

Table 2. Minimum creepage distances, clearances and separations [1]

Voltage $U_{val\ ef}$ c.a. or c.c. V	**Minimum creepage distance** mm								**Minimum clearances and separations mm**		
	Material group								**Clearance**		**Distance under coating**
	I		**II**		**IIIa**		**IIIb**				
	“eb”	“ec”	“eb”	“ec”	“eb”	“ec”	“eb”	“ec”	“eb”	“ec”	“ec”
≤ 10	1,6	1	1,6	1	1,6	1	-	1	1,6	0,4	0,3
≤ 12,5	1,6	1,05	1,6	1,05	1,6	1,05	-	1,05	1,6	0,4	0,3
≤ 16	1,6	1,1	1,6	1,1	1,6	1,1	-	1,1	1,6	0,8	0,3
≤ 20	1,6	1,2	1,6	1,2	1,6	1,2	-	1,2	1,6	0,8	0,3

≤ 25	1,7	1,25	1,7	1,25	1,7	1,25	-	1,25	1,7	0,8	0,3
≤ 32	1,8	1,3	1,8	1,3	1,8	1,3	-	1,3	1,8	0,8	0,3
≤ 40	1,9	1,4	2,4	1,6	3,0	1,8	-	1,8	1,9	0,8	0,6
≤ 50	2,1	1,5	2,6	1,7	3,4	1,9	-	1,9	2,1	0,8	0,6
≤ 63	2,1	1,6	2,6	1,8	3,4	2	-	2	2,1	0,8	0,6
≤ 80	2,2	1,7	2,8	1,9	3,6	2,1	-	2,1	2,2	0,8	0,8
≤ 100	2,4	1,8	3,0	2	3,8	2,2	-	2,2	2,4	0,8	0,8
≤ 125	2,5	1,9	3,2	2,1	4,0	2,4	-	2,4	2,5	1	0,8
≤ 160	3,2	2	4,0	2,2	5,0	2,5	-	2,5	3,2	1,5	1,1
≤ 200	4,0	2,5	5,0	2,8	6,3	3,2	-	3,2	4,0	2	1,7
≤ 250	5,0	3,2	6,3	3,6	8,0	4	-	4	5,0	2,5	1,7
≤ 320	6,3	4	8,0	4,5	10,0	5	-	5	6,0	3	2,4
≤ 400	8,0	5	10,0	5,6	12,5	6,3	-	6,3	6,0	4	2,4
≤ 500	10	6,3	12,5	7,1	16	8	-	8	8,0	5	2,4
≤ 630	12	8	16	9	20	10	-	10	10	5,5	2,9
≤ 800	16	10	20	11	25	12,5	-	-	12	7	4
≤ 1 000	20	11	25	11	32	13	-	-	14	8	5,8
≤ 1 250	22	12	26	12	32	15	-	-	18	10	
≤ 1600	23	13	27	13	32	17	-	-	20	12	
≤ 2 000	25	14	28	14	32	20	-	-	23	14	
≤ 2 500	32	18	36	18	40	25	-	-	29	18	
≤ 3 200	40	22	45	22	50	32	-	-	36	22	
≤ 4 000	50	28	56	28	63	40	-	-	44	28	
≤ 5 000	63	36	71	36	80	50	-	-	50	36	
≤ 6 300	80	45	90	45	100	63	-	-	60	45	
≤ 8 000	100	56	110	56	125	80	-	-	80	56	
≤ 10 000	125	71	140	71	160	100	-	-	100	70	
≤ 12 500	-	90	-	90	-	125	-	-	-	89	
≤ 13 640	-	98	-	98	-	138	-	-	-	97	
When determining the required values for creepage and clearance, the working voltage may be higher than the voltage in the table by a factor of 1,1.											

In case of solid electrical insulating materials, the long-term thermal stability shall be verified (it must be at least 20 K above the maximum service temperature but at least 80 °C for “eb”; and at least the maximum service temperature for “ec”) [1].

2.1.4 Windings

For level of protection “eb” the conductors used for windings shall have at least two layers of insulation (only one layer may be enamel) or in case of round winding enamelled wires shall be according grade 1, 2 or 3 according specific standards. Not all methods of impregnation are accepted for type of protection increased safety (dipping, trickling or vacuum pressure impregnation methods are accepted, but painting or spraying are not accepted). The minimum nominal dimension of windings wires is 0,25 mm. Sensing elements of RTDs shall be impregnated (or sealed) with the windings (by the manufacturer). The maximum temperatures admitted for insulated windings are dependent of the insulation class (thermal class), level of protection and method of measurement [1].

2.2 Temperature limitations

The temperature attained on solid insulating materials shall not exceed the long-term thermal stability (tested under rated conditions) [1].

Temperature limitations applies also for internal surfaces of equipment (no internal parts of increased safety equipment shall be at temperature exceeding the maximum surface temperature) except for some specific cases of lamps in luminaires (even in this case the highest lamp surface temperature inside the luminaire shall be at least 50 K below the auto-ignition temperature of the specific explosive gas atmosphere for which the luminaire is intended. This dispensation is applied only for the specific marked explosive gas atmospheres). Determination of the maximum surface temperature considers also the additional overload or malfunction conditions [1].

2.3 Degrees of protection provided by enclosures

A minimum IP54 degree of protection shall be provided in case of enclosures containing bare conductive live parts and a minimum of IP44 in case of enclosures containing only insulated conductive live parts. A reduced degree of protection (IP23 for Group I, or IP20 for Group II) can be applied for enclosures containing only insulated conductive live parts, when solid objects are prevented from falling vertically (through any openings into the enclosure) and operation in a clean environment is ensured (the symbol "X" shall be included as a suffix to the certificate and the specific conditions of use details the degree of protection provided by enclosure and provides guidance on the required location requirements) [1].

2.4 Requirements for electrical rotating machines

Increased safety rotating electrical machines shall be designed considering also the provisions of SR EN 60034-1 [1].

A minimum air gap shall be provided so as to avoid contact between rotor and stator. Compliance is demonstrated by [1]:

- Air gap measurement (on the test sample); or
- Minimum air gap calculation; or
- The minimum radial air gap (in case of machines with a radial flux path may) is calculated (in mm) by equation (1):

$$\left[0{,}15+\frac{D-50}{780}\left(0{,}25+\frac{0{,}75\cdot n}{1000}\right)\right]\cdot r\cdot b \tag{1}$$

where

D – rotor diameter (mm);
n – maximum rated speed (rpm);
b – bearing coefficient (it is 1 for rolling bearings and 1,5 for plain bearings);
r – coefficient given by the equation (2)

$$r=\frac{\text{core length (in mm)}}{\text{1,75 x rotor diameter, D(in mm)}} \tag{2}$$

The bars of cage rotors shall fit tightly in the slots and the joints between bars and short-circuiting rings shall be brazed (or welded). Compatible materials shall be used to enable high quality joints to be made [1].

Pressure die-casting and centrifugal casting (or other equivalent techniques) shall be used in case of cast rotor cages [1].

Rotating electrical machines shall be assessed for possible air gap sparking. The assessment is made for all electrical machines in level of protection "eb" and for level of protection "ec" only for machines exceeding 100 kW rated output, with duty types S3, S4, S5, S7, S8, or S10. If the total sum of the factors determined (according SR EN 60079-7) is higher than 6, additional protective measures must be applied (one of the following) [1]:

a) The machine or a representative sample shall be tested for aging of rotors and subjected to tests in explosive mixtures.

b) The machine design shall allow special measures to be applied during starting, to ensure that its enclosure does not contain an explosive gas atmosphere at the time of starting (measures detailed in the certificate at Specific Conditions of Use).

c) Limiting the starting current of the machine to maximum 300 % of rated current, I_N. (this must be specified in the Specific Conditions of Use listed on the certificate).

In case of rotating electrical machines in level of protection "eb" and level of protection "ec" (duty types S3, S4, S5, S7, S8, or S10) with cage rotors (including synchronous machines with "cage rotor" starting or damping windings) the limiting temperature of the rotor shall not exceed 300°C for uninsulated rotor cage constructions (or the temperature limitation determined by for insulated rotor cage constructions). The limiting temperature shall not be exceeded even under starting conditions [1].

For rotating machines intended for line starting, in Level of Protection "eb", protected by current-dependent safety devices against exceeding the limiting temperature, the starting current ratio I_A/I_N and the time t_E shall be determined and inscribed on the marking label. The current dependent safety device shall be chosen so that it can disconnect the machine before exceeding time t_E (even when the machine is stalled). The minimum values of time t_E are dependent of the current ratio I_A/I_N. In Figure 1 are presented the minimum values of time t_E according the current ratio I_A/I_N. The time t_E shall not be less than 5 s and the starting current ratio I_A/I_N shall not exceed 10 [1].

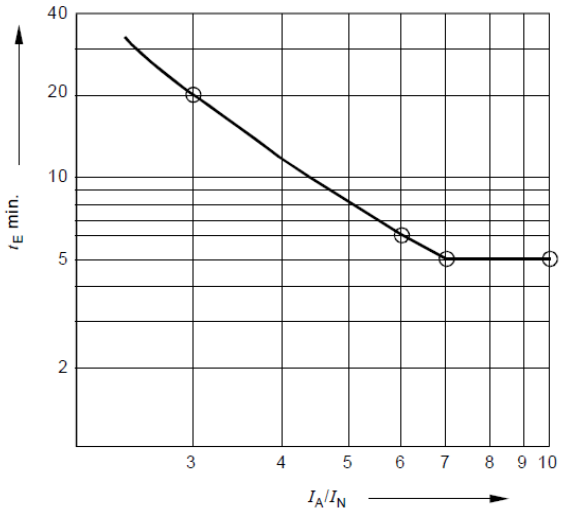

Fig. 1. Minimum values of time t_E (in seconds) of motors in relation to the starting current ratio I_A/I_N

When using temperature sensors located in windings these must be associated with safety devices to protect against exceeding the limiting temperatures [1].

When electrical machines are intended to be operated with a frequency converter, it shall be tested with the specified converter or with a comparable converter (for output voltage, output current, and switching frequency specifications) to confirm that the machine limiting temperatures are not exceeded. The descriptive documentation must include all the required parameters and conditions for use [1, 5]. Alternative verification by calculation of limiting temperature when using a converter may be used only when data resulted from previously performed tests exists [1].

In case of electrical rotating machines supplied at voltages exceeding 1000 V, tests in explosive mixtures shall be performed [1]:

- For level of protection "eb", impulse ignition test for stator insulation systems and steady state ignition test for stator insulation systems;
- For level of protection "ec", steady state ignition test for stator insulation systems.

2.5 Requirements for luminaires

Lamps operating with internal ignitors are not accepted for use with luminaires in levels of protection "eb" or "ec" (because these can cause high-voltage transients which can damage ballasts or electronic ignitors) [1].

The lamps accepted for use in luminaires with type of protection increased safety are [1]:

- fluorescent lamps with cold starting and single-pin caps, for level of protection "eb" and "ec";
- tubular fluorescent bi-pin lamps in accordance with pins made of brass (connected in a circuit where they start and run without preheating of the cathodes) for level of protection "eb" or "ec". Only T8, T10, or T12 lamps are accepted, together with T5 lamps up to 8 watts.
- tubular fluorescent bi-pin lamps with pins made of brass (connected in a circuit where they start and run with preheating of the cathodes) for level of protection "ec". Only T8, T10, or T12 lamps are accepted, together with T5-HE lamps (14, 21, 28 and 35 W).
- tungsten filament lamps for level of protection "eb" or "ec";
- tungsten-halogen lamps restricted to max. 100 W for level of protection "eb";
- tungsten-halogen lamps for level of protection ec".
- discharge lamp for level of protection "ec".

LEDs and combination of LEDs (LED packages and LED modules) are accepted only for level of protection "ec" [1, 5].

The distance between the lamp and the protective cover, for fluorescent tubes, shall be greater than 5 mm (except when the protective cover is a concentric cylindrical tube and the minimum distance is 2 mm). For other type of lamps, the minimum distance between the lamp and the protective cover is given in table 3, according to the lamp wattage [1].

Table 3. Minimum distance between lamp and protective cover [1]

Lamp wattage, P W	**Minimum distance mm**	
	Level of Protection "eb"	**Level of protection "ec"**
$P \leq 10$	1	1
$10 < P \leq 60$	3	3
$60 < P \leq 100$	5	5

100 < P ≤ 200	10	7,5
200 < P ≤ 500	20	10
500 < P	30	20

3 Aspects regarding installation of increased safety "e" equipment

In case of equipment with type of protection increased safety there are some specific requirements which must be considered when performing the installation of such equipment.

In installations operating in potentially explosive atmospheres are accepted for installation only Ex "e" equipment accompanied by a complete certificate. If Ex "e" enclosures and components are provided with a component certificate (i.e. marked with symbol "U" as a suffix to the certificate), these are not to be installed in the hazardous area (unless part of an equipment covered by a full Ex certificate, with the suffix "X" or without any suffixes) and the equipment marking label is provided with the full Ex marking (including temperature class) [5].

In case of terminal box enclosures, it must be ensured that the heat dissipated by power loss within the enclosure does not result in exceeding the temperature associated to the required temperature class. The length of conductors should be kept as short as practicable according to the calculations and type tests. The manufacturer's documentation shall comprise for each terminal size, the permissible number of terminals, the conductor size and the maximum current. Some terminals, may permit the entry of more than one conductor (in this case care shall be taken to ensure that each conductor is adequately clamped). The insulation of each conductor shall be maintained up to the metal of the terminal (to avoid the risk of short-circuits) [5].

In case of increased safety "e" motors the inverse-time delay overload protective device shall monitor the current and disconnect the motor within the time t_E stated on the marking plate (even when the motor is stalled). The user must be in the possession of the current-time characteristic curves (giving the delay time of the overload relay) indicating the value of the delay time from the cold state at an ambient temperature of 20 °C and for a range of starting current ratios (I_A/I_N) of at least 3 to 8 (the tripping time shall be equal to these values of delay ±20 %) [5].

For delta wound motors, phase imbalance shall be considered and protection be provided (to detect motor imbalances before resulting in excessive heating effects) [5].

Inverse-time delay overload protection is applied to motors designed for continuous operation (involving easy and infrequent starts not producing additional heating). When arduous starting conditions are considered (or when frequently started) for electrical motors suitable protective devices have to be used to ensure the limiting temperature is not exceeded. Arduous starting conditions exists if the electric motor is disconnected by an inverse-time delay overload protective device, before it reaches its rated speed (generally, this will happen if the total starting time exceeds 1,7 t_E). Automatic reclosing (automatic restarting) is not recommended due to the increased risk of rotor sparking or insulation system sparking during the reclosing. Motors may be limited to a fixed number of start attempts [5].

When motors are supplied by a converter at varying frequency and voltage the configuration converter – motor - protective device shall be type tested [1, 5].

Luminaires with fluorescent lamps and electronic ballasts are not accepted for use in temperature class T5 or T6 or where the ambient temperature exceeds 60 °C [5].

In case of cable glands, these shall be selected to match the cable diameter. The use of sealing tape, heat shrink tube or other materials is not permitted to make the cable fit to the cable gland. Regarding ingress protection, it may also be necessary to seal between cable glands, adapters and blanking elements and the enclosure (for example by means of a sealing washer or thread sealant). In case of increased safety equipment, only cable gland providing type of protection increased safety "e" or flameproof enclosure "d" can be used [5].

4 Particularities of increased safety "e" equipment

4.1 Equipment using increased safety "e"

Increased safety "e" can be applied only for electrical equipment not generating arcs and sparks [1]. Because increased safety "e" assumes that explosive atmosphere can enter inside the equipment, both internal and external surfaces shall be monitored and measured to determine the maximum surface temperature. In case of equipment with type of protection flameproof enclosure "d" (that can be applied on electrical equipment producing electrical arcs and sparks and as a consequence also to equipment not producing electrical arcs and sparks), because the principle of this type of protection assumes that an explosion can occur inside the enclosure of the equipment [6], only the temperature on external surfaces is monitored when determining the maximum surface temperature [7]. If we compare the type of protection increased safety "e" with the type of protection flameproof enclosure "d" (where an explosion can occur inside the enclosure of the equipment) from the maximum surface temperature point of view, for an equipment having the same characteristics we can conclude that the higher values regarding the maximum surface temperature will be recorded for the increased safety "e" equipment.

Another comparison of the type of protection increased safety "e" and flameproof enclosure "d" can be made relative to the weight of equipment. Due to the fact that an enclosure of a flameproof "d" equipment must withstand an internal explosion without the transmission of the explosion to the explosive gas atmosphere surrounding the enclosure, it will require a more resistant construction (heavy and resistant materials will be used to satisfy the requirements). Because the increased safety "e" enclosures do not require to withstand an internal explosion, more light materials may be used (even plastic materials in many applications like junction boxes, luminaires etc.).

The type of protection increased safety "e" may be used together with other types of protection in order to provide explosion protection to equipment designed for use in potentially explosive atmospheres. Some common situations are related to using the type of protection increased safety "e" together with the type of protection flameproof enclosure "d", encapsulation "m" or optical radiation "op". Examples of equipment with multiple types of protection, using also the increased safety type of protection are push buttons ("d" + "e"), electric motors ("d" + "e"), luminaires ("e" + "d", "e" + "m", "e" + "m" + "op"), electromagnets ("m" + "e"). In figure 2, 3, 4 and 5 are presented examples of equipment using the type of protection increased safety "e" together with other types of protection.

Fig. 2. Fluorescent luminaire Ex d e IIC T4 Gb

Fig. 3. Push button Ex db eb IIC T6 Gb

Fig. 4. Electromagnet Ex e mb IIC T5/T6

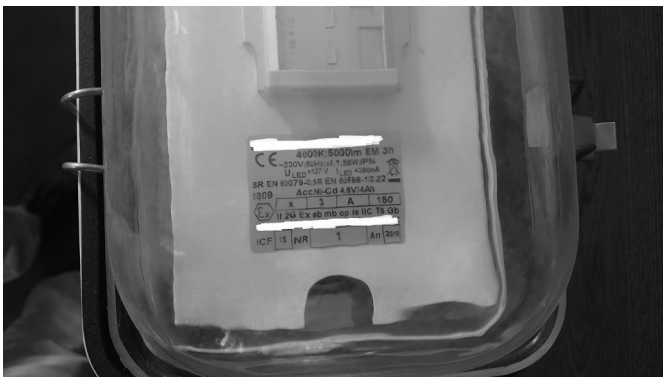

Fig. 5. LED luminaire Ex eb mb opis IIC T6 Gb

4.2 Practical examples of deficiencies met on increased safety “e” equipment

When installing equipment with type of protection increased safety “e” the manufacturer instructions, together with the project of installation and hazardous area plan shall be observed [5, 8, 10, 11]. No alteration/modification of the certified equipment shall be made because it can compromise the explosion protection, and the equipment no longer meets the requirements of ATEX Directive [9].

In the process of assessment of installations operating in potentially explosive areas [8, 12] some deficiencies influencing the explosion protection were met. Some examples are presented below:

- inadequate cable glands (inappropriate size) used for the cables entering the enclosure and using duct tape “to optimize” the cable diameter;
- two (or more) cable were introduced to a cable gland capable of accepting only one cable [12] – compromising the degree of protection of the equipment (Fig. 6)

Fig. 6. Two cable entering a cable gland designed for a single cable

- installation of equipment in enclosures certified only as Ex components without a further certification of the assembly as a whole equipment (Fig. 7). This represents an incorrect practice for multiple reasons (incompatibility with the type of protection of the enclosure, maximum surface temperature is not determined, no certificate is issued for the assembly etc.);

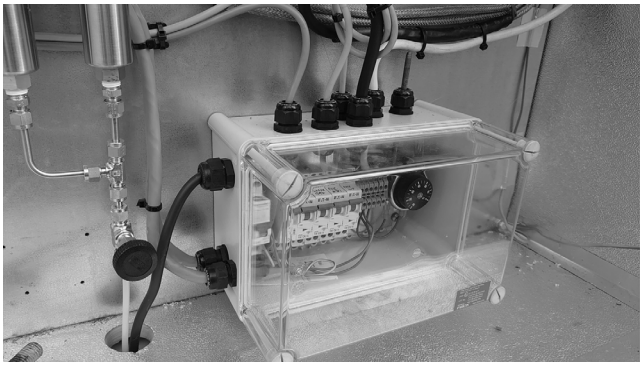

Fig. 7. Electrical apparatus generating electrical arcs and sparks installed into an increased safety "e" enclosure certified only as an Ex component

- incompatible light source replaced in luminaire with type of protection increased safety "e" (fig. 8)

Fig. 8. Compact fluorescent lamp (economic) used for an increased safety luminaire (in Ex "eb" compartment)

5 Conclusions

The first and second part of the paper presented some of the most important specific requirements for electrical equipment with the type of protection increased safety "e" (connections, degree of protection, rotating electrical machines, luminaires, temperature limitations).

The third part of the paper focused on some important aspects to be considered when installing equipment with type of protection increased safety "e".

The last part of the paper concentrated on some practical examples of deficiencies found on increased safety equipment, when performing on-site inspections.

This paper is considered to be very important both for the manufacturers and users of increased safety equipment. The paper is also important for the personnel performing the erection and site inspections of installations comprising equipment with type of protection increased safety "e".

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