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Performance analysis of the ‘d’ explosion-flameproof enclosure type of protection for electrical equipment used in hazardous explosion areas

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Abstract. In many industries such as petrochemicals, natural gas extraction, food, and pharmaceuticals, potentially explosive atmospheres can occur due to the presence of flammable gases, vapours, or combustible dust. These environments require the adoption of rigorous safety measures to prevent explosions and protect personnel and infrastructure. Explosion protection is regulated at the European level by the ATEX Directive 2014/34/EU and a series of international standards, such as the IEC/EN 60079 series. Equipment used in these environments must be designed so that it does not become a source of ignition. One of the most widespread and effective types of protection is protection by means of a flameproof enclosure, marked with the Ex d symbol. This involves enclosing the electrical components in an enclosure capable of withstanding an internal explosion and preventing its propagation into the environment. The purpose of this paper is to analyse the performance of the Ex d protection type from a constructive, functional, and application point of view. The paper will address the operating principles, design criteria, equipment testing, and concrete applications in industry. This analysis aims to highlight the essential role of Ex d protection in the current context of industrial safety and to identify the limitations or challenges associated with the use of this type of protection.

1 Introduction

Type "d" flameproof enclosure protection applies to all electrical apparatus which, in normal operation, may produce electric arcs and sparks. This protection consists of placing parts that could ignite an explosive atmosphere inside an enclosure capable of withstanding the pressure developed during an internal explosion of an explosive mixture and preventing the transmission of the explosion to the surrounding explosive atmosphere.

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In order to use this type of electrical equipment in potentially explosive atmospheres, it must undergo a certification process in accordance with Directive 2014/34/EU.

To certify electrical equipment with explosion protection type "d" enclosure, it is necessary for the equipment to undergo type testing. This category of type tests includes tests carried out in specialized laboratories, such as tests in explosive mixtures. The type tests in explosive mixtures to which the explosionproof encapsulated equipment must be subjected are:

(a) determination of explosion pressure (reference pressure);

(b) overpressure test

c) internal ignition non-transmission test.

These tests also apply to lighting fixtures with flameproof encapsulated protection. Such fixtures are most commonly used for illuminating areas where an explosive atmosphere is likely to occur.

2 Explosive atmospheres

An explosive atmosphere is a mixture of flammable gases, vapors, fumes, mists, or dusts with air under normal atmospheric conditions of temperature and pressure, which may ignite from an ignition source. The occurrence of such explosive atmospheres is common in industrial installations where flammable substances are used, processed, or stored.

The classification of hazardous areas is based on the frequency and duration of the presence of an explosive atmosphere. For gaseous or vaporous explosive areas, there are three zones: Zone 0, Zone 1, and Zone 2. For combustible dusts, the corresponding zones are Zone 20, Zone 21, and Zone 22. The selection of electrical or electronic equipment for these zones is made in accordance with the minimum level of protection required for each hazardous area. [1]

To ensure explosion protection, the European Union has issued Directive 2014/34/EU, known as the ATEX Directive, which regulates the essential requirements for equipment and protective systems intended for use in potentially explosive atmospheres. This is complemented by Directive 99/92/EC, which sets out minimum requirements for the protection of workers' health and safety. [2]

At the international level, the IEC/EN 60079 series of standards provides detailed guidelines for the design, certification, and use of equipment in explosive environments. The IEC 60079-0 standard defines the general requirements for all electrical equipment used in potentially explosive atmospheres, while IEC 60079-1 deals specifically with the flameproof enclosure type of protection "d".

Compliance with the legislative framework is essential to ensure safety and to obtain the necessary certifications for placing equipment on the market. In addition, the correct application of these regulations and standards helps reduce the risk of explosion and protects both personnel and industrial installations.

3 Types of Ex protection - overview

This type of protection emerged as a technical solution for safeguarding electrical equipment used in surface or underground areas where explosive atmospheres may occur.

The oldest types of protection are flameproof enclosure "d" (which appeared at the end of the 19th century), oil immersion "o", sand filling "q", pressurization "p", and intrinsic safety "i", which emerged around 1930. The development and implementation of standards for these protection types began in the first half of the 20th century.

In the second half of the 20th century, protection types such as increased safety "e" (standardized in 1969) and encapsulation "m" (standardized in 1988) began to be used.

By the end of the 20th century, the oil immersion (o) and sand (powder) filling (q) protection types were increasingly phased out, being replaced by a newer type of protection known as non-incendive (n), which includes several subtypes such as nA, nL, nC, and nR.

4 Type "d" protection - explosion-proof enclosure

The protection of electrical equipment using the explosion-proof enclosure type "d" consists of enclosing the electrical components in an enclosure that can withstand an internal explosion and prevent its propagation into the surrounding environment. The operating principle assumes that any explosion occurring inside the enclosure is contained and safely dissipated into the surrounding environment, which may itself be explosive.

To fulfill this function, the enclosure must be designed to withstand the maximum internal pressure that could result from an explosion of the explosive mixture inside. It must be provided with flame-exhaust paths in the form of either threaded or flat (flange-type) joints, which allow the dissipation of thermal energy without igniting the external explosive mixture. The casing is made of durable materials such as grey cast iron, cast aluminum, or stainless steel, which provide both mechanical strength and corrosion resistance. [3]

Flameproof enclosure joints must comply with strictly regulated dimensions and tolerances, as specified in standard 60079-1. For example, the minimum thread lengths and clearances between parts are defined to minimize the velocity and temperature of the flame at the outlet. A thread length of 5–10 mm, precisely executed, may be sufficient to prevent flame propagation to the outside. [3]

At the same time, type "d" protection requires periodic checks of the enclosure's tightness and integrity.

Personnel working on this equipment must be trained accordingly: opening an Ex d enclosure requires strict procedures to be followed, as specified in standard 60079-17. These include turning off the power and ensuring that the area is free from explosive atmosphere. [4]

In practice, equipment protected by type "d" enclosure includes electric motors, command and control apparatus, lighting fixtures, junction boxes, and process sensors. This equipment is used in areas where operational safety is essential.

5 Testing electrical equipment with type of protection Ex d

In order to certify electrical equipment with the type "d" flameproof enclosure protection, it must undergo type testing. These type tests include tests in explosive mixtures. The specific tests in explosive mixtures to which this type of electrical equipment must be subjected are:

(a) determination of explosion pressure (reference pressure);

(b) overpressure test;

(c) internal ignition non-transmission test.

Among these type tests, the determination of explosion pressure (reference pressure) and the overpressure test (second method – dynamic test) require the measurement and recording of the burst pressure. [3]

5.1 Determination of reference pressure

The reference pressure is the highest value of the maximum pressure, relative to atmospheric pressure, observed during the tests.

Each test consists of igniting an explosive mixture inside the enclosure and measuring the pressure developed by the explosion.

The number of tests to be carried out, and the explosive mixture to be used (in volumetric ratio with air and at atmospheric pressure), are as follows:

- for Group I electrical equipment: three tests with (9.8 ± 0.5)% methane;
- for electrical equipment in Group IIA: three tests with (4.6 ± 0.3)% propane;
- for electrical equipment in Group IIB: three tests with (8 ± 0.5)% ethylene;
- for electrical equipment in Group IIC: three tests with (14 ± 1)% acetylene and three tests with (31 ± 1)% hydrogen. [3]

If compression occurs during testing, it shall be performed at least five times with each gas applicable to the respective gas group.

For the overpressure test any of the following methods, which are considered equivalent must be performed.

5.2 Overpressure test - First method, static method

The relative pressure applied shall be 1,5 times the reference pressure, with a minimum of 3,5 bar; or 4 times the reference pressure for housings not subject to routine overpressure testing or at the following pressures given in Table 1, where determination of the reference pressure was impracticable. [3]

Table 1. Testing pressures.

Volume cm^3	Group	Pressure bar
≤10	I, IIA, IIB, IIC	10
>10	I	10
>10	IIA, IIB	15
>10	IIC	20

5.3 Overpressure test - Second method Dynamic method

The dynamic test shall be carried out in such a way that the maximum pressure to which the enclosure is subjected is 1.5 times the reference pressure, with a minimum of 3.5 bar. When the test is performed using the mixtures specified for the determination of the reference pressure, they may be pre-compressed to produce a burst pressure equal to 1.5 times the reference pressure. The test shall be carried out only once, except in the case of electrical equipment in Group IIC, for which each test shall be performed three times with each gas. [3]

Burst pressures resulting from tests in explosive mixtures shall be measured and recorded. Pressure curves shall also be visualized and analyzed.

6 Analysis of equipment with flameproof enclosure type of protection

The most important performance feature of this type of protection is its operating principle: the "d" flameproof enclosure does not prevent explosive gases from entering the equipment but is designed in such a way that, in the event of an internal explosion, it prevents the explosion from being transmitted to the external explosive atmosphere. [5]

The enclosures are constructed from resistant materials (cast iron, steel, aluminum, and sometimes stainless steel) to withstand the high pressures generated by an internal explosion.

This protection type is suitable for components that can produce sparks, arcs, or high temperatures, such as motors, contactors, lamps, and relays. [5]

Standard (not necessarily Ex) equipment can be mounted inside the enclosure as long as it is certified for use within an explosion-proof enclosure.

One of the main disadvantages is the weight and large size of the enclosures, which must be thick and robust enough to withstand blast pressure, making them bulky and harder to handle or install.

In service, equipment with flameproof enclosures must be correctly installed and maintained: bolts tightened to the prescribed torque, joint surfaces free from corrosion or deformation. Any slight non-conformity may compromise the protection type.

No intervention should be made inside the enclosure in Ex areas without switching off the power, venting the area, and following strict procedures.

Being a sealed enclosure, heat dissipation occurs only through convection and external radiation, which limits its use to low-loss equipment.

It is particularly used in Zone 1, where there is a frequent risk of explosive atmospheres.

The gas characteristics (explosion group, auto-ignition temperature), which influence the design (e.g., joint length and clearance, mechanical strength), must also be considered. [6]

In some cases, this protection is combined with other types (e.g., Ex e terminals inside an Ex d enclosure).

The most common combination is found in lighting fixtures.

In a lamp, electrical components can generate sparks or overheating—particularly contacts, sockets, starters, or ballasts. Type "d" flameproof protection allows these components to be placed inside a robust enclosure that contains any internal explosion and prevents its propagation to the outside explosive atmosphere. [3]

Explosion-proof encapsulated lighting fixtures typically have a robust body—cast or machined aluminum or stainless steel—thick treated glass, mechanically sealed or gasketed, capable of withstanding internal blast pressure, and threaded or flat joints with precise dimensions as per standard 60079-1 to cool and extinguish the flame before it exits. They use standard internal parts such as LED, halogen, or discharge bulbs—selected according to spatial compatibility and thermal behavior—and special Ex d cable glands, properly threaded and sealed. [3]

Lighting fixtures with explosion-proof enclosures offer internal explosion resistance, reliability in harsh environments, and housing robustness that makes them suitable for aggressive industrial conditions (corrosive, high vibration, etc.). They are clearly certified for use in Zones 1 and 2, including for Group IIC gases (e.g., hydrogen, acetylene), and have long service life, especially if properly maintained. [2]

Main disadvantages include weight—an Ex d lamp can weigh several to dozens of kilograms depending on size and protection level—difficult access for light source replacement (which involves disassembly, disconnection, venting, and reassembly per manufacturer specs). For high-power LED lamps, proper thermal sizing is crucial to prevent overheating inside the enclosure. The high cost is also a drawback, due to the level of engineering and certification required.

Ex d lamps are the robust and safe choice for hazardous areas, especially where spark-generating lighting sources are used or where stringent protection requirements apply (Zone 1, gas Group IIB or IIC), for general lighting in refineries, pumping stations, LPG tanks, or areas with IIB (e.g., propane, ethane) or IIC (e.g., hydrogen, acetylene) gases, as well as Ex-rated street lighting in oil terminals or harbors. [5]

One of the most widely used types of equipment with explosion-proof enclosure protection is the electric motor.

Electric motors with flameproof enclosure type "d" protection (according to IEC/EN 60079-1) are specifically designed to operate in potentially explosive atmospheres. In terms of performance, they are comparable to standard motors, but with some particular differences in efficiency, size, heat dissipation, starting current and torque, maintenance, and reliability.

Ex d electric motors may have lower efficiency than standard motors due to the robust enclosure and additional thermal losses, but many manufacturers offer Ex d motors in IE2, IE3, and even IE4 efficiency classes, depending on application and construction. [6]

For the same power rating, an Ex d motor is heavier and larger than a standard motor, as the casing must withstand the pressure of a potential internal explosion. This also affects mounting and handling methods. Most Ex d motors are TEFC (Totally Enclosed Fan-Cooled). Due to the sealed housing, heat transfer is more difficult, which can limit their overload capability compared to standard motors.

In demanding applications, temperature monitoring or the use of thermal sensors is important.

There are generally no major differences in starting current and torque compared to standard motors of the same class. The starting torque remains similar, although some Ex d models are optimized for soft starting—especially useful in hazardous areas where sudden starts may generate sparks.

Ex d motors are built to be robust and generally offer high reliability. However, maintenance is more demanding: any opening of the enclosure must be done in strict accordance with procedures outlined in standard 60079-17. Seals, gaskets, and fasteners must be inspected periodically to maintain explosion-proof integrity. [5]

Maximum surface temperatures are strictly regulated (temperature class T1–T6), which may limit load regimes. Maintenance and operation practices have a significant impact on the performance and service life of explosion-protected motors. [2]

Although these motors are robust by design, they are not immune to degradation if not properly inspected and maintained.

The performance of Ex d motors can remain excellent if they are operated within their rated parameters, periodically maintained, opened and reassembled only by authorized personnel, and if key parameters such as temperature, vibration, and bearing condition are regularly monitored.

Table 2. General performance analysis of electrical equipment with Ex d

Criterion	**Flameproof (Ex d)**	**Increased Safety (Ex e)**	**Pressurization (Ex p)**	**Encapsulation / Intrinsic Safety (Ex m / Ex i)**
Mechanical strength	Very high (robust enclosure)	Medium	High (depends on pressurized enclosure)	Low – no mechanical protection
Construction complexity	High	Medium	High (requires auxiliary systems)	Low (but sealed units cannot be opened)
Cost	Medium to high	Medium	High (pressurization + purge control systems)	Low (but components often non-repairable)
Maintenance accessibility	Low (opening the enclosure requires full procedure)	Good	Low – requires depressurization	None – sealed, maintenance not possible
Thermal efficiency	Poor (enclosure retains heat)	Good	Good	Variable (depends on compound and installation)

Use in dynamic applications	Excellent (suited for motors, switching, etc.)	Limited	Possible but complex	Limited to small-scale, low-energy devices
Zone 1 applicability	Yes	Yes	Yes	Only Ex ma / Ex ia rated devices
Fault containment capability	Very good – contains internal ignition	Low – does not contain internal faults	Good – maintains safe conditions internally	Excellent (Ex i limits energy below ignition threshold)

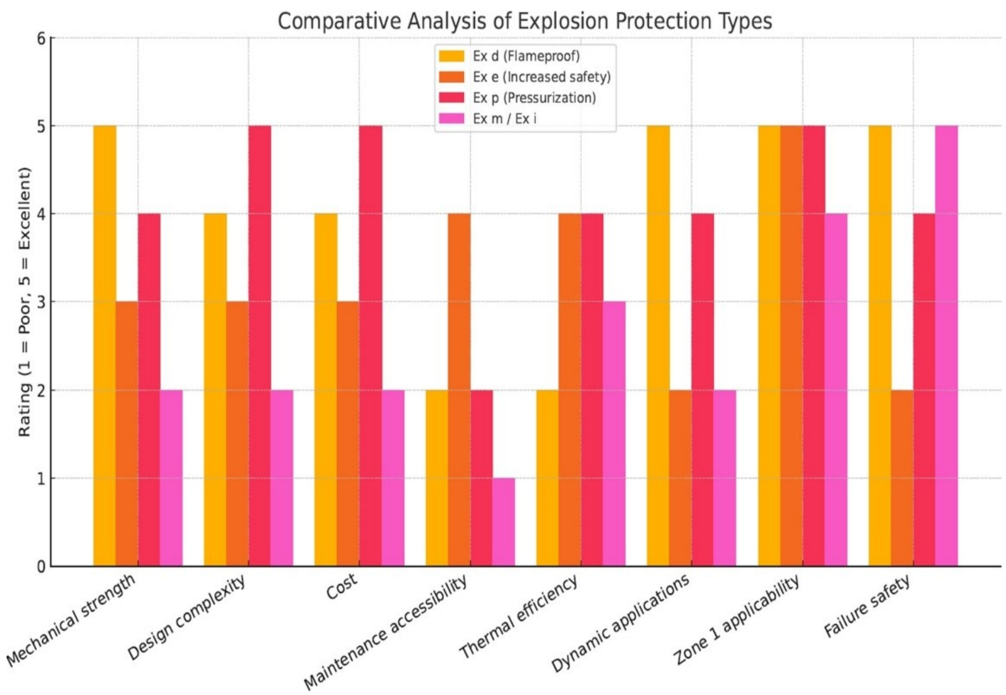

Fig. 1. Graphical representation of the comparative analysis according to the type of protection

7 Conclusions

Electrical equipment with flameproof enclosure type of protection is designed to operate in hazardous environments where there is a risk of explosive atmospheres (gases, vapor's, flammable mists). By design, this equipment can withstand an internal explosion without allowing it to propagate outside.

The performance, safety, and lifetime of such equipment are not fixed once and for all, but depend heavily on how it is maintained and operated.

Proper maintenance is essential.

Any work on the equipment (opening, repairing, connecting) must only be carried out by trained personnel, in strict compliance with the Ex d requirements.

Threaded joints, flat contact surfaces, and sealing components must be kept in good condition. If mechanical integrity is compromised, explosion protection is lost—regardless of how well the electrical parts function.

Periodic checks, as required by IEC 60079-17 and the manufacturer's instructions, are mandatory for personnel servicing such installations and equipment.

The operating environment directly influences performance and reliability.

Equipment may be affected by extreme temperatures (which can cause enclosure temperature limits to be exceeded), dust, corrosive vapors, moisture (which can attack both external and internal components), as well as shock and vibration (which can cause mechanical damage or loosen connections).

In harsh environments (e.g., oil platforms, chemical industry, refineries), continuous monitoring of equipment is essential.

Overloading or operating the equipment outside of the manufacturer's specifications will reduce performance. If the equipment is used above its rated current, in intermittent operation, without proper cooling, with unsuitable mechanical loads, or in an atmosphere different from the one it was certified for (e.g., IIA instead of IIC), then not only is performance reduced, but safety is also compromised.

Although the equipment is certified and rigorously tested by manufacturers, operational responsibility lies with the user.

It is essential that:

- Ex equipment is properly selected for the classified area (Zone 0, Zone 1, Zone 2, gas group, temperature class);
- personnel are trained in Ex procedures;
- there is a preventive maintenance plan and regular inspection schedule.

The performance of explosion-proof electrical equipment is not based solely on its robust construction. It is the result of a balanced approach: compliant design, correct application, rigorous maintenance, and operation under proper conditions.

Neglecting any of these aspects may lead not only to performance degradation, but also to compromised explosion protection—posing serious risks to personnel, facilities, and the environment.

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