HAZARDOUS AREA MOTOR/DRIVE PROTECTION PRINCIPLES AND OPTIMUM SELECTION CRITERIA

Abstract - This paper will provide an overview of hazardous area classifications including the implications of the latest IEC standards and the LV/HV motor & drive protection principles of ‘non-sparking’, ‘increased safety’, ‘flame proof’ and ‘pressurised’. The relative advantages for each technique will then be discussed for different scenarios such as atmosphere, overload, starting, inverter operation, size, weight, flexibility and cost.

Index Terms – Hazardous Area, Protection, Motors, Increased Safety, Flame Proof, Non-Sparking, Purge.

I. INTRODUCTION

This paper will cover hazardous area basics, a description and comparison of motor Ex protection types followed by advice on matching drives to Ex motors and a cost evaluation.

II. HAZARDOUS AREA MOTORS & DRIVES

A. Ex-protection in Electrical Apparatus

Three components are required to make a hazardous situation: - flammable material, oxygen and an ignition source.

B. Definition of Zones

Fig 2 Hazardous Area Zones

Zones are defined on the probability of a hazard occurring in that area. Zone 0 which has a permanent threat of an occurrence is generally not suitable for any sort of electrical machine.

C. Precautions

Risk minimization – basic principles according to EN 1127-1. Protection measures have to be undertaken in the following sequence:

Primary Ex-protection
Prevent hazardous atmospheres
  - Limit concentration of flammable material
  - Inertization (add Nitrogen, Carbon Dioxide)

Secondary Ex-protection
Avoid every potential ignition source

Tertiary Ex-protection
Limit the consequences of an explosion to a harmless degree.

Protection methods for electrical machines are part of the secondary precaution to avoid every potential ignition source.
D. Classification of Electrical Equipment

In the Equipment Category designations M means Mines, G means Gases and D means Dust. This paper will only focus on the G Gases category.

In approximate terms the Explosion Protection Levels (EPL) Ga, Gb, Gc correspond to the Equipment Categories 1G, 2G and 3G which align with the Zones 0, 1 and 2. The latest IEC standards mean that nA (non sparking) will become ec (for EPL increased - zone 2); e (increased safety) will become eb (for EPL high - zone 1) and d (flameproof) will become db (for EPL high – zone 1). This terminology is mandatory from 2018.

E. Classification of Gases and Vapours

Hydrogen is a very combustible gas but has a high ignition temp. The higher the gas combustibility the lower the Minimum Ignition Energy (MIE) and the lower the Minimum Ignition Current (MIC) for intrinsic safety circuits; and the smaller the Maximum Experimental Safe Gap (MESG) for Ex d machines. The higher the ignition temperature; the higher the allowable surface temperature; and the lower the permissible temperature class.

F. Protection Classes

Electrical machines use different protection methods than monitoring devices. However motors may have installed monitoring devices that require separate protection.

G. Non Sparking “nA” in future “ec”

According to EN 60079-15 this is an explosion protection type in which the risk of ignition sources occurring during normal operation is minimised by utilising additional methods which can be:

- nA – non-sparking
- nC – enclosed break
- nL – limited energy
- nR – restricted breathing

IIB gas group and T3 (200°C) temperature class motors are by far the most common.

Ingression protection to IP55 - dust protected and water jets is standard for all types of Ex motors which is equivalent to NEMA 3. IP56 - dust protected and heavy seas are also common. Dust tight IP65 is required for IIC conductive dust and is possible for roller bearing HV motors.
nA is the most appropriate method of protection for electrical machines. In future nA (non sparking) will become ec for Equipment Protection Level (EPL) - increased - zone 2. That is Ex n motors can only be used in zone 2.

A rotor design ignition risk assessment is required for Ex n motors >100kw and other than S1 or S2 operating modes. A stator winding ignition risk assessment is required for motors >1kV and other than S1 or S2 operating modes. (EN 60079-15)

**H. Increased Safety “e” in future “eb”**

<table>
<thead>
<tr>
<th>Ex-protection</th>
<th>Construction standards</th>
<th>Basic principle</th>
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<tbody>
<tr>
<td>Increased safety</td>
<td>EN 60079-0 60079-7</td>
<td>Equipment is designed to prevent hazardous temperatures, sparks and arcs during normal operation. Ignition during breakdown is prevented by additional mechanical, electrical and thermic safety measures.</td>
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</table>

Ex e motors are always de-rated to prevent hazardous temperatures, sparks and arcs during normal operation including start-up. This de-rating makes Ex e motors unpopular and not widely used. In addition Ex e motors typically can only handle a T3 temperature class.

A stator winding ignition risk assessment is required for motors >1kV. (EN 60079-14) also anti-condensation heaters must be fitted and additional protection during start-up maybe required (purging, measure gas concentration etc.)

In future e (increased safety) will become eb for EPL high - zone 1.

**J. Flameproof “d” in future “db”**

A flameproof motor must fulfil three prime requirements. Firstly the design must limit the outside surface temperature not to exceed the permitted temperature class. Secondly the explosion resistance must ensure that an explosion cannot spread to the external surroundings. Lastly the pressure resistance prevents any lasting damage or deformation to the protection of the motor following explosions within the enclosure.

Ex d motors typically can handle up to a T4 temperature class and with special designs even T5 and T6 can be achieved. In future d (flameproof) will become db for EPL high – zone 1.

An Ex d motor may have withstood many internal explosions during its’ lifetime without affecting operation.

**K. Protection Comparison for Low Temps**

<table>
<thead>
<tr>
<th>Ex-protection</th>
<th>Construction standards</th>
<th>Basic principle</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flameproof</td>
<td>EN 60079-0 60079-1</td>
<td>All parts capable of igniting flammable gases are placed inside a flameproof enclosure. An explosion inside is not propagated outside the enclosure. The outer parts of the flameproof enclosure do not exceed permissible surface temperatures.</td>
</tr>
</tbody>
</table>

The range of ambient temperatures is 40°C down to -20°C. This temperature range may be extended to 60°C down to -40°C with a special electrical or thermal design in which suitable terminal boxes, materials and components are used, or with the data for the electrical ratings.

Leakage Loss Compensation is generally used for electrical machines rather than a continuous purge.

**Fig 7 Increased Safety Motor**

**Fig 8 Flameproof Motor**

**Fig 9 Pressurized Motor**

The “px” system where a pressurised enclosure reduces the device protection level inside the pressurised enclosure housing from Gb (zone 1) to “not at risk of explosions” is the most common. The “py” system is not suitable for motors and the “pz” method can be used for zone 2 but is not popular.

**Fig 10 Low Temp Protection Comparison**
Motors in all explosion protection types are available for low temperatures down to -40°C and below. However, often supplementary measures must be utilized for low temperature operation. It should also be noted that at low temperatures, the strength values of the motor materials decrease, especially plastics.

**L. Protection Comparison for Inverter Use**

Non-sparking machines must, as a minimum, first be type tested as a system with the actual inverter to be used or a comparable one. For Ex nA it must be ensured that the permissible inner as well as outer temperature does not exceed the temperature class limit during operation, particularly at low speeds when the cooling fan may also be running slowly.

Ex e motors must always be tested and certified as a complete system together with the actual inverter to be used (the only exception is PTB certification with significant power de-rating – taking into account the thermal reserves – and only for a square law load torque).

Ex p motors can always be operated with an inverter. However if the purge system fails it must be ensured that the inner temperatures do not exceed the permissible temperature class limit. This also applies to mounted/installed components, for example heating systems.

For all Ex e, Ex nA and Ex p motors, the permissible inverter must be specified on the certificate, and the necessary tripping device on the manufacturer's declaration or on the Ex certificate.

The inner components of Ex d motors e.g. heating system, do not generally require an Ex version. The installed temperature sensors are selected and located so that they trip earlier before the motor surface reaches the temperature limit. This is the reason that other inverters can be used with Ex d motors, assuming that the company operating the drive system complies with the regulations specified by the motor manufacturer.

Thermal sole protection test means that the temperature sensor trip (PTC in winding) is tested because it is the sole (only) means of protection to prevent the outside surface exceeding the temperature class limit.

**M. Protection Comparison by Weight**

Ex nA and Ex p motors have the lowest weight. Generally Ex e motors with the same power rating are at least one or two frame sizes larger (especially for 2 and 4-pole motors) and are therefore heavier. The higher the power rating, the more significant the differences in the corresponding shaft heights.

Generally, an Ex d motor has the same active part as an Ex nA or Ex p motor. However, the enclosure and the end shields are significantly bigger and therefore also heavier as they must withstand high explosion pressures.

**N. Protection Comparison for Large Power**

Output power limits 6kV/50Hz air cooled.

**Fig 12 Monitoring Investment Comparison**

**Fig 13 Weight Protection Comparison**

**Fig 14 Large Power Protection Comparison**
HV Ex d motors, as a result of the necessary explosion protection, can only have higher power ratings in IC511/IC516 (tube cooling, tubes concentrically arranged around the stator core); a mounted cooler is not possible. 1000mm is the maximum shaft height that can still be tested in the worlds largest Ex d test laboratory. As a consequence, the maximum power for a 4-pole motor with 6kV is approx. 8 MW.

2 and 4 pole Ex e motors, with power ratings above approx. 2.5 MW are no longer practical because achieving a reasonable (long) safe locked rotor time (te) it is necessary to reduce the starting current, which leads to a low starting torque.

When it comes to higher power ratings, there are no restrictions for Ex nA and Ex p motors.

O. Protection Comparison for Flexibility

<table>
<thead>
<tr>
<th>LV-Motors</th>
<th>HV-Motors</th>
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<tbody>
<tr>
<td>Ex nA</td>
<td>Ex e</td>
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<td>0</td>
<td>+</td>
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<tr>
<td>Flexibility for applications</td>
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</table>

Fig 15 Flexibility Protection Comparison

Ex d motors have the best flexibility, because in principle, they can be designed for normal line operation, intermittent duty, inverter operation as well as heavy-duty starting. For an Ex nA motor, intermittent duty is no longer considered normal operation; as a consequence, starting must also be taken into account in the explosion protection assessment, which makes it similar to an Ex e motor.

Intermittent duty is only possible for an Ex p motor if it is continually purged (also at standstill).

An essential advantage of Ex d high-voltage motors, when compared to Ex p and Ex e motors (which must be purged before starting) is that following a power failure or after the motor has been switched off, it can be immediately restarted.

P. Protection Comparison by Ops Costs

As a result of the lower thermal utilization, an Ex e motor has lower copper losses, and therefore in comparison, a higher efficiency.

For Ex p motors, the costs associated with the purging air supply (purchase, installation and operating costs) is an additional cost, which depending on the motor size and bearing design, can amount to several thousand Euros per year.

Q. Protection Comparison Summary Table

Evaluation Key:
++ Very well suited
+ Well suited
0 Suited
- Less suited
-- Not suited

R. Cost Comparison

Fig 18 Cost Comparison
Ex na motors are always the most cost effective but are only suitable for zone 2 operation. Ex e motors are always expensive because they are de-rated. Ex p are the most expensive when small but become cheaper the bigger the motor size because the purge system becomes less as a proportion of the total motor cost. Ex d becomes the most expensive as the explosion proof enclosure becomes a larger proportion of the total motor cost.

S. Info required for Ideal Motor Selection

Fig 19 Motor Selection Info Required

It is easier to optimise the proposed motor/drive solution when more information can be specified at the quotation stage.

III. CONCLUSION

Flameproof Ex d motors provide the best flexibility across LV and HV ranges; they can also be used with any manufacturer’s inverter without special testing. However, Ex d motors become increasingly expensive & heavy with a maximum limit of circa 8MW, so Ex p is better for larger sizes.

IV. ACKNOWLEDGEMENTS

The authors acknowledge the contributions made to this paper over the years by such hazardous area motor luminaries as Helmut Hasch, Karl Hofbauer, Klaus Neupert, Thomas Mutzl, Thomas Fuchs and Ulrich Schanzer.

V. REFERENCES


VI. VITA

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Hugo Stadler graduated from the Fachhochschule Regensburg with an Electrical Engineer Dipl.-Ing. (FH). After six years in the development department for variable speed drives at SIEMENS (Loher) he moved into the sales department and served key customers in the Oil & Gas and Chemical industry. Hugo’s competence is electrical motors, frequency inverters and ex-protection with over 40 years service and experience with the SIEMENS (Loher) company. Today Hugo Stadler is responsible for the SIEMENS sales of LV drive systems to the Oil & Gas industry.

Eur Ing Steve Jackson MA BSc CEng

Steve Jackson graduated from the University of Bath Chemical Engineering School with a BSc (Hons) in 1982. During 2016 he enhanced his academic qualifications with a Masters in Sales Management from the University of Portsmouth. In 1987 Steve became a Chartered Engineer and in 1994 a European Engineer. He has been a Member of the Institute of Measurement and Control for nearly 30 years. Over the course of his career Steve has worked for Fisher Controls, Elsag Bailey, ABB, Endress+Hauser and for the last 12 years SIEMENS – in the fields of automation, instrumentation, process analytics and electrical engineering. Steve is also a committee member for the Energy Industries Council (EIC).
### Directive 94/9/EC EN 60079-0

<table>
<thead>
<tr>
<th>Equipment group</th>
<th>Equipment category</th>
<th>Types of protection examples</th>
<th>Equipment group</th>
<th>EPL Equipment Protection Level</th>
<th>Level of protection</th>
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<tr>
<td>I</td>
<td>M1</td>
<td>Ex ia</td>
<td>Ma</td>
<td>Ma</td>
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<tr>
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<td>M2</td>
<td>Ex d, Ex e</td>
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<td>high</td>
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<td>Ga</td>
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<tr>
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<td>Ex d, Ex e, Ex px</td>
<td>Gb</td>
<td>Gb</td>
<td>high</td>
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<td>Z2 ~ 3G</td>
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<td>Db</td>
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<td>Z22 ~ 3D</td>
<td>Ex tc, pD, mD</td>
<td>Dc</td>
<td>Dc</td>
<td>increased</td>
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</table>

**Gas groups:**
- IIA - Methane, ammonia, ethyl alcohol, etc.
- II B - Town gas, ethylene, hydrogen sulfide, etc.
- IIC - Hydrogen, acetylene, etc.

**Dust groups:** (IP55)
- IIIA - Combustible flyings
- IIIB - Non-conductive dust
- IIIC - Conductive dust (IP65)

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**Fig 3 Electrical Equipment Classification**

<table>
<thead>
<tr>
<th>LV-Motors</th>
<th>Ex nA</th>
<th>Ex e</th>
<th>Ex d</th>
<th>Inverter operation</th>
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<tbody>
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<thead>
<tr>
<th>LV-Motors</th>
<th>Ex nA</th>
<th>Ex e</th>
<th>Ex d</th>
<th>Ex px</th>
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<th>HV-Motors</th>
<th>Ex nA</th>
<th>Ex e</th>
<th>Ex d</th>
<th>Ex px</th>
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**Additional effort for testing and certification**

- Limited initial test
- Prototype
- Regulatory test
- Thermal stability test
- Safety test

**DOL operation**

<table>
<thead>
<tr>
<th>Non sparking</th>
<th>Ex nA</th>
<th>x</th>
<th>x</th>
<th>n.a.</th>
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<tr>
<td>Increased safety</td>
<td>Ex e</td>
<td>x</td>
<td>x</td>
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<tr>
<td>Flame proof</td>
<td>Ex d</td>
<td>x</td>
<td>x</td>
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<tr>
<td>Pressurised</td>
<td>Ex p</td>
<td>x</td>
<td>x</td>
<td>n.a.</td>
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**Inverter operation**

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<tr>
<th>Non sparking</th>
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<th>x</th>
<th>x</th>
<th>x</th>
<th>n. a.</th>
<th>*</th>
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<tbody>
<tr>
<td>Increased safety</td>
<td>Ex e</td>
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<td>x</td>
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Thermal sole protection means that the PTC is the **ONLY** temperature protection device.

* dependent on inverter type, counter torque characteristic and speed range
Fig 13 Weight Protection Comparison

<table>
<thead>
<tr>
<th>Ex nA</th>
<th>Ex e</th>
<th>Ex d</th>
<th>Weight</th>
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<tbody>
<tr>
<td>++</td>
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LV-Motors

<table>
<thead>
<tr>
<th>Ex nA</th>
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<th>Ex d</th>
<th>Ex px</th>
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HV-Motors

Comparison based on experience from Service and Engineering information

Fig 17 Comparison Summary Table

Fig 20 Gas Hazard Marking – in future the EPL will be added to the end eg ‘………………Ex d IIC T4 Gb’