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Flexible Method for Corrective Actions Ranking in the Field of Protection Against Explosion

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In the European Union, assessing the hazard of the explosion in a plant of a dust or gas atmosphere is mandatory for its manager (European directive 1999/92/EC). This assessment relies on three different steps:
- the identification of the position of explosive areas and their frequency (appear during normal process, appear rarely during normal process, do not appear during normal process, do not appear at all) based on the standards IEC 60079-10-1 for gas atmospheres and IEC 60079-10-2 for dust atmospheres
- the identification and the assessment of the frequency occurrence of ignition sources based on the standard EN 1127-1
- the assessment of the plausible consequences of an explosion based on the standard ISO 14121-1.
When the assessment highlights that the hazard of explosion is too high, some corrective measures must be implemented to decrease this hazard to a reasonably value. It is common that for a large plant, several dozens of actions need to be implemented.
To the authors' knowledge, there is a lack of method in the literature to help HSE engineers to rank the actions to be taken. What should be corrected first? A very rare deviation that could severely injure or even kill an operator or a less dangerous but more frequent one?
This paper proposes a method derived from the determination of a SIL level (standard IEC 61511-3). A similar decision tree is build which is based on the consequences of the explosion defined in ISO 14121-1. It takes into account the probability of attendance of an operator in the hazardous area and the frequency of occurrence of an ignition source and of an explosive atmosphere.
This method gives an index for each couple of [consequence of an explosion/ frequency of occurrence of an explosion]. It thus permits to compare each situation and correct the one with the highest index first. This method is very flexible and can be adapted to every situation. It allows emphasizing one or two of the used parameters according the safety policy of the firm who uses it. It is thus possible to justify to the authorities the choice of the prioritized actions. This method will be illustrated with two case studies.

1. Introduction

The protection against an explosion is a hot topic since decades with still improving results. Tools were developed to accurately define the position of a flammable atmosphere and to remove the possible ignition sources (R. L Rogers, Broeckmann, & Maddison, n.d.; Tixier, Dusserre, Salvi, & Gaston, 2002). The European directive 1999/92/EC (European parliament, 1999) so called ATEX 137 requires an explosion protection document for each plant handling flammable substances. Every equipment must be considered and depending on the frequencies of a flammable atmosphere and of an ignition source, it is determined whether or not corrective actions must be implemented (part 2) without taking into account the possible effects of an explosion on the operator. It means that an explosion taking place in a place exempt from people will be considered as dangerous as one taking place when an operator himself ignites it. Even though the consequences of the two explosions differ, a standard ATEX assessment considers the two incidents with the same criticality. In order to improve that point, some countries such as Germany started to integrate parts of classic risk analysis (FMEA and risk matrix method) but out of the scope of the designed classes defined during an ATEX assessment (part 3).

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This paper presents a method (part 4) derived from the Safety Integrated Level determination method (IEC, 2003) in order to refine the criticality of an explosion. It permits:

1. to accurately assess the criticality of an explosion thanks to the assessment of the consequences of the explosion, the frequency of attendance of the operator in the dangerous area, the possibility for the operator to avoid an explosion and the frequency of occurrence of a hazardous situation based on ATEX assessment criteria
2. to rank the situations and clearly and easily define what are the most critical situations.

2. ATEX risk assessment

Since 2003, the ATEX directive requires that an explosion protection document needs to be prepared in any plant where a flammable atmosphere could appear using an ATEX risk assessment. An ATEX risk assessment is a four steps process:

1. Identify where a flammable atmosphere could occur and estimates its frequency of occurrence,
2. Estimate the frequency of occurrence of 19 different ignition sources for each identified flammable atmosphere
3. Define if each configuration (flammable atmosphere – ignition source) represents a hazard
4. Propose different corrective measures to sustain a sufficient level of safety.

The frequency of occurrence of a flammable atmosphere can be defined knowing the duration of the process during a year (Table 1).

Table 1: Ex-zoning (IEC, 2008; IEC, 2015)

Ex-zone	Duration of occurrence of a flammable atmosphere	Signification
Zone 0	More than 1000 h/year	Flammable atmosphere made of gas
Zone 1	More than 10 h/year and less than 1000 h/year	Flammable atmosphere made of gas
Zone 2	More than 1 h/year and less than 10 h/year	Flammable atmosphere made of gas
Zone 20	More than 1000 h/year	Flammable atmosphere made of dust
Zone 21	More than 10 h/year and less than 1000 h/year	Flammable atmosphere made of dust
Zone 22	More than 1 h/year and less than 10 h/year	Flammable atmosphere made of dust
No zone	Less than 1h/year	No flammable areas

The relevant ignition sources are defined in the EN 1127-1 standard (CEN, 2011). Their frequency of occurrence depends on the different equipments and must be assessed case by case.

		A flammable atmosphere…			
		… is not expected to be present in quantities such as to require special precautions for the construction, installation and use of equipment	is not likely to occur in normal operation but, if it does occur, will persist for a short period only	… is likely to occur in normal operation occasionally	… is present continuously, or for long periods or frequently.
The ignition source…	Zone	HZ	2 / 22	1 / 21	0 / 20
	A… happens frequently under normal conditions				
	B… happens during rare deviations				
	C… happens during very rare deviations				
	D… can be ruled out or is not an effective ignition source				

Figure 1: Hazard matrix, the configuration in the grey area must be improved.

Each couple “Flammable atmosphere – Ignition source” is placed in a 4 x 4 matrix (figure 1). If the studied configuration lies in the upper part of the matrix (grey area), the configuration is too hazardous and the frequency of occurrence of either the flammable area or the ignition source must be lowered.
This method does not provide any ranking. An ungrounded twenty litres drum will be considered as dangerous as a reactor containing flammable vapours where a flammable powder is manually introduced. This point must be improved in order to increase the efficiency of the plant management.

3. Overview of the existing methods

Several European countries have enforced additional rules, especially in Germany. Overviews of three different countries are given below.

3.1 Swiss method

The Swiss authorities follow the European standards. No additional method is emphasised and the criticality of an explosion on an operator does not influence the importance of a configuration.

3.2 French method

The French authorities follow the European standards but sometimes require a deeper study taking into account the effects of an explosion on an operator. In that case there is a lack of methods. The only scale in terms of injuries or death of people is used for the assessment of the consequences of an accident outside the plant (Ministre de l’écologie et du développement durable, 2005) but cannot be used as it is for the assessment of an explosion on site since the overall method aims quantitatively to estimate the frequency of occurrence of an accident. Since the frequency of an explosion depends on both of the frequencies of flammable atmosphere and ignition sources, the usage of the previous matrix is thus difficult since a third parameter must be added.

3.3 German method

Some German associations like the Association of German Engineers (VDI) propose in different German standards and recommendations (e.g. VDI, 2013a) the use of either a risk matrix method or an FMEA risk analysis. These two methods differ from an ATEX risk assessment in the sense that the probability of an explosion needs to be assessed.
FMEA and risk matrix method are semi-quantitative methods. An FMEA assessment is based on frequencies of occurrence of an event and the distinction between normal operation, frequent fault or infrequent fault as described in EN 1127-1 (CEN, 2011) disappears. Two other parameters, the detectability (the index ranges from 1 to 10) and the severity (the index ranges from 1 (harmless incident) to 10 (loss of life or irreparable damage to health)) are taken into account. The product of the 3 indexes gives an estimation of the hazard level. The frequency of attendance of an operator is not taken into account. This method permits to rank the situations one to another. The German guidelines recommend to install some constructive measures to protect the operators from an explosion if the product of the three index is higher than 150.
The risk matrix method differs from the FMEA method in the sense that the probability of an explosion depends on the zone defined and on the occurrence of the ignition source. In that sense, this method really corresponds to the ATEX policy. The severity presents the same boundaries as the FMEA method. It is thus not possible to take into account the probability of attendance of an operator in the vicinity of the explosion. The absence of index does not allow a clear ranking between the different actions to be taken.

4. Proposed method

An ATEX assessment aims at protecting the operators from the effects of an explosion. Obviously, an explosion must be avoided as far as possible but the different presented methods can perhaps be improved by putting together the two main assets of the FMEA and risk matrix methods:

- easy ranking of the hazardous configurations
- matching of the method with the ATEX definition of frequency of occurrence of an ignition

This goal can be achieved by adapting the SIL determination method.

4.1 SIL determination method

The IEC 61511-3 (IEC, 2003) proposes a method of determination of the required SIL level based on a risk graph and on the following parameters:

- Consequences on the operator of the explosion (C parameter) from an harmless accident (C1) to the death of an operator)
- Exposure time parameter (F parameter), often or not
- Probability of avoiding the hazardous event (P parameter), yes or no
- Frequency of occurrence of the hazardous event (W parameter) from rare (W1) to often (W3)

The approach can be summarized in the following tree (Figure 2):

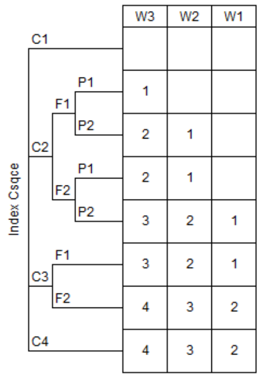

Figure 2: Decision tree for SIL level determination.

Depending on the chosen values for each parameter, the user easily defines the required SIL level for the configuration that he studies. The number of possible options decreases with the consequences on the operator since the protection of an operator must less rely on human factors as the hazard increases. When the C3 (severe injuries) and C4 (death of an operator) cases are considered, the highest possible value should be chosen for the missing parameters. On the other hand, when using the C1 parameter (harmless accident) F1 and P1 values can be used. This approach can be adapted for an ATEX assessment.

4.2 Adaptation to an ATEX assessment

Some bonds exist between SIL and ATEX assessments. The German VDI/VDE 2180 Part 6 (VDI, 2013b) proposes a method to define the proper SIL level of a protective equipment in order to decrease the defined Ex zone. On that basis, we propose a qualitative approach to rank the explosion hazard based on the same two parameters as a SIL assessment. The first parameter is focused on the operator (OI) and the second is focused on the possibility of an explosion (W). To do so, the sub parameters C, F, P and W are adjusted and weighted in order to set up the priorities or to cope with the safety policy of the plant where the ATEX assessment is carried out. Tables 2 to 4 propose values for the sub-parameters C, F and P. In these tables it is considered that and accident where an operator is slightly injured (C2 in table 2) is twice more severe than a harmless one (C1 in table 2) and that the frequency of presence of an operator (sub parameter F in table 3) is as important as the possibility to anticipate the explosion (sub parameter P in table 4). The parameter focused on the operator (OI) can be computed by multiplying the sub parameters C, F and P.

Table 2: Allocation for risk scores for consequences (C sub-parameter)

Parameter C	Significance	Index value
C1	No personal injuries	1
C2	Slight injuries	2
C3	Severe injuries	4
C4	Death of one operator	16

Table 3: Allocation for risk scores for exposure time parameter (F sub-parameter)

Parameter F	Significance	Index value
F1	The operator is not usually in the vicinity of the equipment	1
F2	The operator stays near the equipment or is the cause of the explosion	2

Table 4: Allocation for risk scores for the possibility of detection (P sub-parameter)

Parameter P	Significance	Index value
P1	The operator can detect the malfunction (noise, odour, …)	1
P2	The operator cannot detect the malfunction leading to the accident	2

The parameter W is modified in order to take into account all the possible combinations of Ex - zones and ignition sources. This parameter can be expressed as a function of the classes of frequency of occurrence of a flammable atmosphere (from zone 2 or 22 to zone 0 or 20) and of an ignition source (from occurs during very rare malfunction to occurs under normal conditions). If both of these criteria are considered of the same importance, six different classes appear and the explosion parameter ranges from 1 to 9 (Figure 3). This number would be different if one parameter is considered as more important than the other

Frequency of occurence of an ignition source		Ex - Zone	Zone 0 - 20	Zone 1 - 21	Zone 2 -22
		Index	3	2	1
Under normal conditions	3		9	6	3
Under predictable malfunction	2		6	4	2
Under rare malfunction	1		3	2	1

Figure 3: Definition of the W sub parameter.

With this method, all the information related to the ignition sources and the Ex zoning is preserved. The final criticality index is expressed as:

$$IC_{ij} = \frac{OI_i \times W_j}{\max_{i,j}(OI_i \times W_j)} \times 100 \quad (1)$$

A new criticality matrix can be built (figure 4) where an explosion index is defined for each case.

			OI	Zone index 9	6	4	3	2	1
C1			1	1.56	1.04	0.69	0.52	0.35	0.17
C2	F1	P1	2	3.13	2.08	1.39	1.04	0.69	0.35
C2	F1	P2	4	6.25	4.17	2.78	2.08	1.39	0.69
C2	F2	P1	4	6.25	4.17	2.78	2.08	1.39	0.69
C2	F2	P2	8	12.50	8.33	5.56	4.17	2.78	1.39
C3	F1		8	12.50	8.33	5.56	4.17	2.78	1.39
C3	F2		16	25.00	16.67	11.11	8.33	5.56	2.78
C4			64	100.00	66.67	44.44	33.33	22.22	11.11

Figure 4: Criticality matrix.

5. Case studies

This method will be applied to rank two classic examples in the chemical industry: an explosion due to the unloading of a bag from a centrifuge and an explosion of a mixer due to an electrostatic discharge.

5.1 Extraction of a bag from a centrifuge

An operator is involved to empty a centrifuge. The product inside is an electrical resistive paste whose solvent concentration is higher than 0.5%. A zone 1/22 is defined 1 meter around the centrifuge. Due to a deviation in the filling procedure, the amount of powder is lower than usual, the process generated more electrical charges than usual and the paste is still charged with static electricity when the operator unload the centrifuge. A brush discharge occurs between the bag and the centrifuge and the cloud of solvent ignites. The operator is slightly injured but manages to stop the fire.

Using a standard risk assessment (figure 1), some corrective measures should be carried out (zone 1 / ignition source occurs under normal conditions). Using the proposed method, the following indexes are defined: the operator is slightly injured, a C2 value is defined. The hazard of ignition is only present while the operator works, a F2 factor is defined. The operator is not aware that the product still contain electric charges, a P2 factor is defined. Using the coefficients in the tables 2 to 4 and in the figure 3, the Operator Index is worth 8. The area around the centrifuge during its emptying is a zone 1 and a brush discharge does not usually appear under normal conditions. The W parameter is set at 4. The criticality index of this accident is 5.56

Table 5: Summary of the chosen values and Criticality Index

C	F	P	OI	W	CI
C2	F2	P2	8	2	5.56

5.2 Explosion of a mixer

An operator notices that the manhole of a mixer is opened while working. An ignition occurs when he approaches the lid. He is severely burned at his back.

Using a standard risk assessment (figure 1), this situation would also need improvements (zone 2 around the manhole and ignition source occurring under normal operation). Using the proposed method, a C3 and a F1 coefficients are defined since the operator is severely injured and that he just walks near the equipment when the explosion occurs. Since he is severely burned, a P2 factor is considered. Besides, the W parameter is set at 3. The criticality index of this accident is also 4.17.

Table 5: Summary of the chosen values and Criticality Index

C	F	P	OI	W	CI
C3	F1	P2	8	3	4.17

5.3 Summary

These examples present two situations that need corrective actions according to the standard procedure of an ATEX assessment. Thanks to this new method, it is now possible to define that the first situation should be solved first. It is shown that with the describe method a ranking of actions can be provided.

6. Conclusion and outlooks

This paper presents a qualitative method aiming to improve an ATEX assessment. This method is based on the SIL determination procedure and uses the same basis: a parameter focused on the operator and another one focused on the possibility of an explosion. A criticality index is defined for each considered situation depending on the value of each parameter and permits to rank them one another. The expression of the different parameters can be adjusted according the safety policy of the firm and can lead to different ranking for the same scenarios. This method a real improvement towards an FMEA and a risk matrix method in an ATEX assessment since the accurate frequency of the ignition source does not need to be assessed as it is for an FMEA while ranking between the different situations clearly appears unlike a risk matrix method analysis.

References

Chapter 2 CEN, 2011, Explosive atmospheres - Explosion prevention and protection - Part 1

European parliament, 1999, Directive 1999/92/EC of the European parliament and of the council of 16 December 1999 on minimum requirements for improving the safety and health protection of workers potentially at risk from explosive atmospheres

IEC, 2008, Explosive atmospheres - Part 10-1: Classification of areas - Explosive gas atmospheres

IEC, 2015, Explosive atmospheres - Part 10-2: Classification of areas - Explosive dust atmospheres

IEC, 2003, Functional safety – Safety instrumented systems for the process industry sector – Part 3: Guidance for the determination of the required safety integrity levels

ISO 14212-1, 2007, Safety of machinery – Risk assessment – Part 1 : Principles

Ministre de l'écologie et du développement durable, 2005, Arrêté du 29/09/05 relatif à l'évaluation et à la prise en compte de la probabilité d'occurrence, de la cinétique, de l'intensité des effets et de la gravité des conséquences des accidents potentiels dans les études de dangers des installations classées soumises à autorisation

Rogers, R. L., Broeckmann, B., & Maddison, N. (n.d.). A RISK ASSESSMENT STANDARD FOR EQUIPMENT FOR USE IN POTENTIALLY EXPLOSIVE ATMOSPHERES: THE RASE PROJECT. *Symposium Series*, *147*.

Tixier, J., Dusserre, G., Salvi, O., & Gaston, D. (2002). Review of 62 risk analysis methodologies of industrial plants. *Journal of Loss Prevention in the Process Industries*, *15*(4), 291–304.

VDI, 2013a, Dust fires and dust explosions – Part 7.1

VDI, 2013b, Safeguarding of industrial process plants by means of process control engineering (PCE) – Part 6