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CURRENT CHALLENGES FOR OPERATION AND MAINTENANCE OF ELECTRICAL EQUIPMENT IN SHIPS' HAZARDOUS AREAS

Appearance of hazardous areas on ships and other mobile sea units is a result of use of combustible materials for propulsion systems and ongoing ships' maintenance, but also because of the load transported or processed. Safety associated with it depends not only on the proper operation of devices installed in the potentially explosive areas, but also on their proper maintenance. Crews are trained on compulsory courses mainly focused on operation. ETO, who is responsible for the technical efficiency of electrical explosion-proof equipment, should complete a dedicated compulsory training program.
Another purpose of the article is to draw attention to obsolescence and stiffness of the current regulations with regards to hazardous areas on ships and other mobile sea units. Updating marine regulations in compliance with the global IECEx system will eliminate the existing drawbacks.
Keywords: *ship's hazardous areas, ETO model course, IECEx system.*

INTRODUCTION

There are hazardous areas on each ship or a mobile or fixed offshore unit. Risk of explosion exists due to the use of combustible fuels necessary for sailing a ship as well as use of flammable materials for ongoing maintenance and repairs. Oil exploration, production and transport are an additional and even much more significant hazard. The above concerns also oil or gas processed products. There are two types of hazards: the first one arising from presence of mists, vapours and flammable gases in the air, the second one from presence of flammable dust. Sometimes both hazards are combined.

It is worth emphasizing that there are substances and materials which are generally considered as non-flammable, but in certain forms pose a hazard of explosion. These may include hydraulic oils, which under very high pressure and in case of small leaks can create mist that may pose a very high risk of explosion. The same applies to some metals in form of dust.

Safety in hazardous areas depends on many factors. At the beginning it requires suitable design and implementation of the installation. The next challenge is the proper long-term operation. This stage is connected with two issues. One is the correct safe operation of the installation during loading, care in transit, handling of cargo, tank clearing etc. The second, parallel issue is the maintenance of the electrical facilities in technical efficiency preserving their explosion proof properties. However, it should be emphasized that electrical systems or devices, even though functionally efficient, may lose explosion proof properties under interaction of various factors.

Safe exploration, process and transport at sea of the dangerous products require systems, which are more developed and adequately designed for realising the monitoring, control engineering and electrical power supply in hazardous areas.

1. STATUTORY DEMANDS FOR ETO COMPETENCE CONCERNING SHIPS' HAZARDOUS AREAS

Assuming that the appropriate explosion proof equipment is used, safety depends mainly on skills of the crew. For that purpose all the crew members have to pass the adequate courses depending on their rank and the kind of the ship.
The STCW Convention 1978 as amended in 1995 and in 2010 in Manila (chapter V) defines corresponding competency requirements for the crew members [1]. Unfortunately, all the competence courses are focused only on safe handling of dangerous cargo [2–5].

The ship electrician or ETO on board is the person who has to maintain all the electrical equipment, including the one dealing with the hazardous areas [6]. Knowledge available on the currently required courses (both on the familiarization one and on the advanced one for oil, chemical and gas tankers) is not sufficient for proper maintenance of the equipment under consideration. To ensure safety this job requires special skills, which should be trained not only on separate, voluntary courses, but they should be included into mandatory minimum requirements for certification of electro-technical officers (ETO).

Currently the Manila Amendments to the STCW convention contain mandatory requirements at the section A-III/6, table A-III/6 for the function “Maintenance and repair at the operational level” in two competences [1]:

“Maintenance and repair of bridge navigation equipment and ship communication systems”, and

“Maintenance and repair of control and safety systems of hotel equipment”.

For the above competences in the fields of “Knowledge, understanding and proficiency” the requirements concern only theoretical knowledge in the field “Electrical and electronic systems operating in flammable areas”.

In practice, navigation’s and hotel’s equipment are not placed in hazardous areas and because of that they are not produced as explosion proof so those requirements should be removed.

For the same function, requirements for "Electrical and electronic systems operating in flammable areas", not only as theoretical knowledge, but also as practical one should be added in relation to the following competences:

- "Maintenance and repair of electrical and electronic equipment", and
- "Maintenance and repair of electrical, electronic and control systems of deck machinery and cargo-handling equipment".

These competences cover almost the all explosion-proof electrical equipment occurring on ships.

It is worth mentioning that in the model course 7.08 for electro-technical officer the problem raised above was spotted and a program for electrical and electronic systems operating in flammable areas was placed for competence: "Maintenance and repair of electrical, electronic and control systems of deck machinery and cargo-handling equipment" [7].

Similar approach concerning electrical explosion proof equipment was presented in a model course for electro-technical officers developed for International Association of Maritime Universities. IAMU Project FY2012-3 [8].

Also, the knowledge and the practical skills mentioned in this article are included in a course mandatory for ETO in Gdynia Maritime University. It is worth underlying that the course is especially dedicated to address these requirements, while in other cases mentioned above, the topics are covered only as a part of a wider subject.

2. SOME ASPECTS OF EXPLOSION PROTECTION

All the problems concerning explosion protection are well described in the ashore industry. Historically, there have existed two different approaches to certification of electrical explosion-proof equipment and systems in the world. One is specific to North America and the countries associated with it economically – Article 500 NEC (National Electrical Code) and CEC (Canadian Electrical Code).

The second one is a worldwide accepted approach defined by IEC (International Electrotechnical Commission) standards. An approach similar to IEC standards, Article 505 NEC and CEC, has run in parallel in North America since 1996.

In European Union (EU) and European Economic Area (EEA) the ATEX (ATmosphères EXplosibles) directive 2014/34/EU on the harmonisation of the laws of the Member States relating to equipment and protective systems intended for use in potentially explosive atmospheres is currently in force [9]. It is worth to emphasizing that strong technical cooperation between CENELEC (European Committee for Electrotechnical Standardization) and IEC on the new standards has been established under Dresden Agreement since 1996. Therefore, almost all the standards harmonised with the directive 2014/34/EU EN are the same as the IEC standards. It needs to be highlighted that the ATEX approach is still only a regional solution.

Everything corresponding to electrical equipment installed on ships and mobile offshore units is a subject to requirements of IMO, flag administration, classification societies and other international organizations. In the field of explosion-proof technology almost all the compulsory IMO requirements are based on the IEC standards. Nevertheless, explosion-proof certificates for electrical equipment are issued mainly on the basis of the regional and state rules. Such a situation creates various problems with recognition of these certificates.

To solve the above mentioned issues, IEC introduced a certification system for standards relating to equipment used in explosive atmospheres (IECEx System) in1996 [10]. The IECEx system is currently a global one and it is very similar to the approach used in EU and EEA. A lot of explosion-proof electrical equipment is certificated not only according to the state or regional rules but in line with the IECEx requirements as well. Laboratories have to pass restricted accreditation procedures to obtain the right certification according to the IECEx system. This approach gives a lot of benefits in comparison to the ones used till now. From the end users' perspective, one of such advantages is that the issued IECEx certificate is published on the IECEx website and it is withdrawn from there in case of any problem with the certificated explosion-proof equipment.

The current challenge is to recognise and to introduce the IECEx system into all the conventions, codes and rules in all the fields supervised by IMO. However, the above processes create a possibility to review, correct and remove many inaccuracies and ambiguities in the current conventions, codes, standards and other regulations concerning the sea. IACS' (International Association of Classification Societies) interpretation of SC274 (Dec 2015) concerning "hazardous area classification in respect of selection of electrical equipment, cables and wiring and positioning of opening and air intakes" can serve as an example [11]. In the annex 1 there is presented a "summary of discrepancies on the hazardous classification issues among SOLAS/IBC/IGC and IEC 60092-502-1999". The fact that the standard *IEC 60092-502-1999, Electrical installations in ships – Part 502: Tankers – Special features* is still in force, while the similar standards for ashore industry have changed significantly in the last seventeen years, illustrates difficulties in progress of updating the rules concerning hazard of explosion at sea [12]. The forecast publication date for the next 6.0 edition of IEC 60092-502 is 1st January of 2017.

Summarizing, the ship crew involved in operating and maintenance of explosion-proof electrical equipment have to understand all those legislative and technical problems to work in a safe and effective way.

3. ELECTRICAL EQUIPMENT IN THE HAZARDOUS AREAS

With regards to the explosion-proof electrical equipment and installations there are two different concepts relating to electrical equipment and plant design and operation.

The first concept is symbolically presented in Fig. 1. The explosion-proof electrical devices are placed in the hazardous area. All of them are directly connected by cables with standard electrical devices placed in the safe area. Connecting cables are partly placed both in the hazardous and safe areas. There exists high electrical energy in such electrical circuits. If that energy is released in any form like sparks, arcs, discharges or high temperature it will be sufficient to ignite an explosive mixture. In this concept the entire effort for designing, construction, installation, operation and maintenance focuses on such solutions and procedures that do not discharge energy in any form into the hazardous area that would be able to ignite a dedicated explosive mixture.

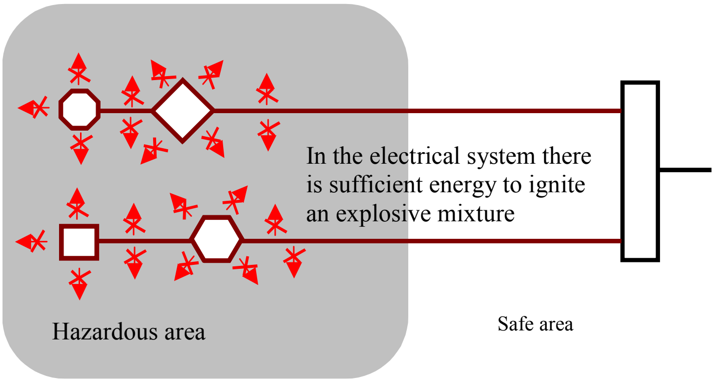

Fig. 1. The concept of electrical explosion-proof equipment and its installation, in which the existing energy may be capable to ignite an explosive mixture

The second concept is based on the inverse approach symbolically shown in Fig. 2. In electrical explosion-proof devices and their cables located in the hazardous area, there is electrical energy, which, when released, is not sufficient to ignite a dedicated explosive mixture.

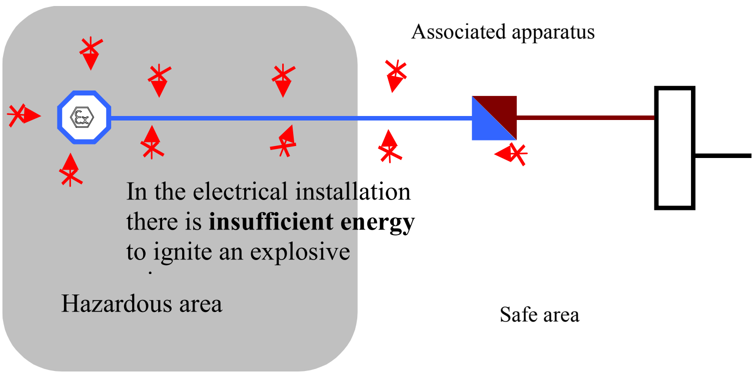

Fig. 2. The concept of electrical explosion-proof equipment and its installation, in which the existing energy will not be capable to ignite an explosive mixture

This is achieved through the use of two appropriately designed explosion proof devices. One of them is placed in the hazardous area and the second one is placed in the safe area. Both are connected by a cable. The second one is a special device named an associated apparatus which limits the electrical energy originating from the safe area.

In this case, the entire processes of designing, construction, installation, operation and maintenance are based on solutions and procedures where energy in the electric circuits is limited to the level that cannot ignite an explosive mixture in case of its release as well as additional energy from outside cannot reach the explosion-proof circuits.

There exist situations where both concepts are used simultaneously in the industry.

3.1. Conditions concerning hazard of explosion according to the IEC standards approach

The process of ignition and finally explosion results from three factors, which have to be present in adequate proportions in the same place and time. These are: flammable substance, oxygen in atmospheric air and energy for ignition. It is enough to remove or limit one of the factors to create a safe situation. This is the main principle of explosion protection.

Based on the relations among the factors causing ignition it was possible to recognize selected parameters, dependencies or standards which are useful for designing, construction and wiring as well as final maintenance (especially checking, diagnostics, repairing and inspections) of explosion-proof equipment and installations.

Flammable materials which may create explosive mixtures together with air were classified into three groups. The group I concerns coal mining industry, the group II concerns all flammable gases and the group III concerns hazard caused by dust that may occur in all the industries excluding mining [13–14].

Flammable gases which create explosive mixtures together with air are divided into subgroups with their representative gases accordingly: IIA (propane), IIB (ethylene) and IIC (hydrogen). The most important parameters of explosive mixtures in a form of gas, vapour or mist are: flash point, ignition temperature (auto-ignition temperature), minimum ignition energy, lower flammable limit (LFL), upper flammable limit (UFL) and specific gravity [13].

Dusts are divided into subgroups: IIIA (combustible fibres and lint), IIIB (non-conductive dusts) and IIIC (conductive dusts) [14].

It is natural that explosive mixture based on the atmospheric air creates an explosive atmosphere where hazard can appear with a various probability (the case when the explosive atmosphere is continuously present is the most dangerous). Because of that hazardous areas are divided into three hazardous zones for gas and dust explosive mixtures respectively.

Table 1. Zones for gas and dust hazard [13–14]

Gas zones	Dust zones	Likelihood of hazard
Zone 0	Zone 20	the explosive atmosphere is continuously present or present for long periods
Zone 1	Zone 21	the explosive atmosphere is likely to occur during normal operation
Zone 2	Zone 22	the explosive atmosphere is not likely to occur during normal operation and, if it occurs, it exists only for a short time

The classification of zones is very important and it is necessary to consider many factors for risk assessment, such as physical property of the flammable substance, room ventilation, source and efficiency of emission. In case of dust it is also required to take layers of dusts into consideration. Additionally, depending on the ship's or other sea unit's construction, corresponding support in assessment of the zones is given in codes [15–17], classification's rules [18–19] and standards [12–14]. The plan of zones has to be available on all the ships and it has to be approved by the classification society.

3.2. Methods of the electrical equipment explosion protection

Installation of the adequate equipment or carrying it into the hazardous area depend on the assigned zone. The equipment and its production process have to be checked by a certification body according to the approach recognized by the classification societies.

Different methods complying with IEC standards are used for explosion protection of the electrical equipment. Each method is marked with the relevant letters, namely:

- for gas hazard: d – flameproof enclosures, p – pressurized enclosures, q – powder filling, o – oil immersion, e – increased safety, i – intrinsic safety, n – protection n, m – encapsulation, op – optical radiation, s – special [12];
- for dusts hazard: tD – protection by enclosure, pD – pressurisation, iD – intrinsic safety and mD – encapsulation [13].

To be more detailed, some types of protection are further divided into more granular safety levels, which is marked by additional letters: a, b and c. Safety level for each certificated electrical equipment is appointed by EPL.

Each protection method is unique and some from them can be used together.

3.3. Selection of explosion-proof equipment

Basing on the zones appointment, the adequate explosion-proof equipment is required. Statutory IMO codes, classification society rules such as standard IEC 60092-502-1999 (which is still in force) require selection of explosion-proof equipment for the zones according to the applied explosion protection methods. An example of such a selection for gas hazard is the MODU Code (Code for the Construction and Equipment of Mobile Offshore Drilling Units) where for [17]:

- zone 0 – only equipment intrinsically safe of category i_a can be applied;
- zone 1 – equipment adequate for zone 0 and additionally d, p, m, e, i_b, o, q, s can be applied;
- zone 2 – equipment adequate for zone 0, zone 1 and additionally n, s can be applied.

The above selection is stiff and does not follow current progress in explosion protection technology.

The IEC standards concerning protection methods introduce another more flexible way. A safety level named EPL (Equipment Protection Level) is assigned for all the electrical explosion-proof equipment. Safety level is marked by letters: a, b and c which are equivalent to the equipment categories used in the EEA (ATEX directive). Selection of explosion-proof equipment for the zone is done by EPL according to the Table 2.

Table 2. Selection of explosion-proof equipment by EPL [12–13]

<table>
<tr><th>Protection afforded</th><th>EPL IEC</th><th>Category ATEX</th><th>Performance of protection</th><th>Group</th><th>Condition of operation</th></tr>
<tr><td rowspan="2">Very high</td><td>Ga</td><td>1D</td><td rowspan="2">Two independent means of protection or safe even when two faults occur independently of each other</td><td>II</td><td>Zone 0, 1, 2</td></tr>
<tr><td>Da</td><td>1G</td><td>III</td><td>Zone 20, 21, 22</td></tr>
<tr><td rowspan="2">High</td><td>Gb</td><td>2D</td><td rowspan="2">Suitable for normal operation and frequently occurring disturbances or equipment where faults are normally taken into account</td><td>II</td><td>Zone 1, 2</td></tr>
<tr><td>Db</td><td>2G</td><td>III</td><td>Zone 21, 22</td></tr>
<tr><td rowspan="2">Enhanced</td><td>Gc</td><td>3D</td><td rowspan="2">Suitable for normal operation</td><td>II</td><td>Zone 2</td></tr>
<tr><td>Dc</td><td>3G</td><td>III</td><td>Zone 22</td></tr>
</table>

G, D – safety level dedicated to gas or dusts risk respectively.

The EPL safety levels are part of IECEx systems as well as an example of a flexible solution accepted worldwide in offshore industries. Again, similar approach would simplify designing, implementation and maintenance of explosion-proof equipment and installations on the ships and mobile sea units.

CONCLUSIONS

In the article the focus is placed on two challenges concerning maintenance of electrical explosion-proof equipment in ships' hazardous areas.

The first one is proper training of the crew members, mainly ETO. The crew is usually trained on handling dangerous cargo, while ETO is responsible for proper maintenance and repair of electrical equipment, therefore this job requires special training. In particular, ETO should be familiar with explosion protection methods used for electrical equipment and how they are described in various standards.

The second challenge is too slow pace of updating the regulations concerning ships and other mobile sea units, which do not reflect changes in the current explosion protection technology. At present, there is a number of explosion protection approaches commonly used in various regions, while IECEx system would be the most appropriate due to its flexibility and global reach.

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