Intrinsically safe acoustic emission equipment opens the door to permanent monitoring applications in the oil and gas industry

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Abstract

The oil and gas industry is a very prospective target group for the permanent installation of acoustic emission (AE) instrumentation for monitoring various test objects for crack growth or active corrosion. According to directives and standards, electrical instrumentation installed in a potentially explosive atmosphere must be certified intrinsically safe. The development and certification process of intrinsically safe instrumentation needs great effort, which is not economical for the relatively small market for intrinsically safe AE instrumentation, nowadays. On the other hand, the non-availability of suitable intrinsically safe AE instrumentation could be a hindrance for the potential market growth. European Commission helps to overcome the problem: In the European research project titled "Cost effective corrosion and fatigue monitoring for transport products (CORFAT)" (www.corfat.eu), the German company Vallen Systeme GmbH is responsible for developing an intrinsically safe AE sensor system (ISAFE3). The ISAFE3 system is employed for detection of corrosion and fatigue crack of storage tanks used in surface transportation means like ships, mainly oil tankers, trucks and rail wagons. ISAFE3 is intended to be ATEX certified for use in most dangerous explosion zone 0 (where an explosive atmosphere can permanently be present) and for gas group IIC (where lowest spark energy can ignite an explosion). The sensor system must be sealed for immersion into oil at peak pressure up to 12 bar (caused by sloshing forces in an oil tanker ship).

This paper presents basics about the requirements of the applicable standards and the applications and an overview of the realization of ISAFE3.

Keywords: Acoustic emission; intrinsic safety; corrosion monitoring; fatigue crack detection

1. Introduction

Today, acoustic emission testing (AT) is well established as a non-destructive testing (NDT) method in many applications, where test objects are under mechanical load, e.g. pressure vessels, chemical reactors, pipelines, but also racing cars, sailing masts, aerospace components, bearings, bridges, dams, and many more.

Most of these applications are temporary tests under mechanical load that exceeds the normal work load. The higher load is needed to stimulate crack growth or crack face rubbing, if a flaw exists. Both occurrences emit elastic waves called acoustic emissions (AE).

In recent years, needs came up for permanent monitoring of test objects. As it turns out, AE testing is the only NDT method which can be applied cost efficient 24 hours a day, 7 days a week [1]. The need for permanent monitoring of objects shall be explained by the following three examples:
A) A test object with known flaw is monitored permanently in order to warn the operator when the flaw is growing.

B) In case of tank floor testing for detecting leakage or active corrosion, external conditions like wind, temperature change, traffic, etc., influence the acoustic behaviour and may cause incorrect testing results and false alarms. Additionally, AE activity caused by corrosion depends also on storage medium composition, which in some cases may change over time and is out of control of an operator. With a permanently installed AE system, the optimum time period for gathering and analysing AE data could be automatically selected and the quality of test results improved.

C) Test applications in which the maximum mechanical load occurs at a non-predictable moment in time. For example: existing flaws in a ship’s structure may only grow when sea is rough, i.e. at high load regimes. Acoustic emission of these flaws can only be detected by a permanently installed acoustic emission measurement system.

Applications concerning example C) are in the scope of the European research project "Cost effective corrosion and fatigue monitoring for transport products" (CORFAT, www.corfat.eu). This project lays the ground for the development of a permanent AE system installation on tank ships, where potential locations of flaws are known. Safety could be improved, if those locations are monitored permanently. Other test objects addressed in that project are road tankers and railway tank cars.

A location, where an explosive atmosphere could occur, is called a "hazardous area". On tanks ships, beside of a few non-hazardous rooms, all areas are classified as hazardous and any instrumentation installed must be certified explosion proof. Also in European refineries, permanently installed instruments must be certified explosion proof.

In our view, the AE test market can be tremendously expanded, when suitable, certified explosion proof instrumentation becomes available.

Within the CORFAT project, Vallen Systeme from Germany, is responsible for designing and providing explosion proof prototype instrumentation to validate newly developed AE monitoring procedures e.g. for use in the hazardous area inside a crude oil cargo tank of a tank ship.

2. Applicable Standards for intrinsically safe electrical instrumentation used in explosion hazardous spaces

2.1 General

A complete overview of the many standards applicable for the design of instrumentation for use in explosion hazardous areas would go beyond the scope of a conference paper. “Understanding global explosion protection” [2] gives a good overview about global standardization systems like

- CLASS and DIVISION system, (NEC and CEC)
- CLASS and ZONE system, (NEC and CEC)
The current paper concentrates on the special requirements of an intrinsically safe AE sensor system suitable for detecting acoustic emissions when AE-sensors are installed inside a crude oil tank. Such instrumentation must fulfill the highest standards put forward by ATEX/CENELEC/IEC. Hence this paper deals only with explosive above-ground gas atmospheres (no mines, no dust) and the protection type "intrinsic safety". For this limited application range all mentioned systems follow the same standard: IEC 60079.

The standards of the IEC 60079-series apply for the design and installation of devices in explosive atmospheres. IEC 60079-0 defines general requirements. IEC 60079-11 defines the requirements on intrinsically safe instrumentation. Intrinsic safety is one of 11 different protection types defined in 60079-0, but the only one applicable for an AE sensor located inside a crude oil tank and connected to a cable running several 100 m through hazardous area up to a safety-barrier in a non-hazardous area. Therefore, following sections deal with protection type of intrinsic safety, only.

Several classifications and groupings need to be considered when selecting a suitable ex-proof device for a certain application. These are defined in the IEC 60079-xx standard series. Fig. 1 shows an overview, where terms with green background indicate the classification of the described intrinsically safe AE-sensor system under development.

**2.2 Grouping apparatus by place of installation**

An apparatus can be installed either in a mine, then it is classified Group I, or somewhere else, then it is classified Group II.
2.3 **Group II subdivisions**

This classification concerns the minimum spark ignition energy needed to ignite an explosive atmosphere. A gas atmosphere classified IIC ignites at much less energy than a gas of group IIB or IIA. Accordingly, the design of a device must ensure that any spark that might occur will not have enough energy to ignite an explosion. The energy values in µJ shown in Fig. 1 for each gas group correspond to the maximum electrical pulse energy allowed for intrinsically safe circuits.

2.4 **Explosion zone classification by risk of occurrence of explosive atmosphere**

A hazardous area must be classified into one of three zones. An area is of zone 0, if an explosive gas atmosphere is present continuously or for long periods of time or frequently in time. This condition is also defined in numbers: if the cumulated presence of explosive atmosphere is 1000 hours per year or longer, an area is rated zone 0 [2]. For example, this is the case above an oil- or gasoline surface in a closed container. In such an environment explosive vapour may exist continuously. Equipment used within zone 0 must fulfil requirements defined as Equipment Protection Level (EPL) "Ga" [3] such as: The design must assure intrinsic safety even at two simultaneous worst case faults [4]. Faults that have to be considered are, for example, defective electronic components or short cuts that could cause overheating or increase the spark energy.

An area is classified zone 2, if the occurrence of an explosive atmosphere is very rare, between 1 and 10 hour per year. Equipment used within zone 2 must fulfil requirements of EPL "Gc". The design must assure intrinsic safety without consideration of a fault.

All other areas, where an explosive atmosphere may occur, are classified zone 1. Equipment used in zone 1 must comply with EPL "Gb". One worst case fault must be considered.

2.5 **Temperature classification**

This classification deals with the surface temperature that can ignite an explosive gas atmosphere. Equipment of e.g. temperature class T6 shall never heat a surface above 80°C at a specified maximum ambient temperature.

2.6 **Classification of protection types**

IEC 60079-0 defines 11 protection types. Intrinsic safety is the only protection type suitable for an AE-sensor system that is installed inside a crude oil storage tank. Intrinsic safety means limitation of electrical voltage, current, power and pulse energy to a safe level in any electrical circuit inside a hazardous area. "Limitation to a safe level" means, that energy of a spark, e.g. by a short-cut or interruption of a circuit, must be lower than required to ignite an explosive atmosphere. Before a cable enters a hazardous area, a device in a non-hazardous area must ensure that limitation. The sensor located in the hazardous area must also ensure by design, that neither a hot surface, nor the possible energy of a spark can ignite the explosive gas atmosphere.

There are three levels of intrinsic safety:

- "ia" provides EPL "Ga" and is acceptable for zone 0, 1 and 2.
- "ib" provides EPL "Gb" and is acceptable for zone 1 and 2.
"ic" provides EPL "Gc" and is acceptable for zone 2.

For types "ia" and "ib", the different standardization systems (IEC/ATEX, NEC, CEC) are based on same standards: The type "i" with NEC 504 and "ia" with NEC 505 and ATEX are identical, because both are based on IEC60079-11. Both are the only acceptable protection type of an AE-sensor system for zone 0 areas.
Type "ib" (NEC 505 and ATEX) are acceptable in zone 1 and 2 areas. Differences concerning zone 2 are not relevant here.

3. Requirements

The sensor under development (ISAS3) shall be certified according to the European ATEX directive for installation in zone 0 and gas group IIC. This covers the installation in zone 1 and 2 and gas groups IIB and IIA [5]. The temperature class is T6 what means that no component surface will exceed 80 °C, even if two worst case faults exist simultaneously. According to [2], this covers the requirements of the North American standards, too.

For a permanent installation, a sensor holding device shall be welded or bonded to the test object. The sensor must be mounted in a reliable manner, although in case of a defect, it must be replaceable. For a temporary installation, sensors can be fastened by use of magnetic holders which are mechanically compatible with the permanent sensor holder.

Sensor and cable connection must be water tight (IP68), withstand crude oil and sloshing forces causing a peak pressure of up to 12 bar.

Since the electric energy must be limited already in the cable to the sensor, a limiting device (safety barrier) is required outside of the hazardous area. It shall be of isolating type (signal isolator SISO3). The isolation improves the signal-to-noise ratio, particularly with long sensor cables, by eliminating a screen-to-earth connection of the signal cable at SISO3 side. In addition it avoids the need of inserting safety transformers between mains supply and AE system as required by [7].

For use on a ship, the signal isolator can be installed in a non-hazardous control room but for use on a tank car, it must be installable in the driver cabin of a tank car which is classified to zone 2.

The signal isolator shall be powered like a standard 28V preamplifier.
4. Realization

4.1 Block diagram of tank ship application

Fig. 2 Block diagram of an AE system for a tanker application

Fig. 2 shows an application example where PC, AE-system and signal isolators are located in a non-hazardous area and the sensors in a hazardous area rated zone 0 (inside a tank or on tanker ship deck in less than 3 m distance from a man hole), or in zone 1 (other areas on deck).

The ISAFE3 product family consists of five variants of intrinsically safe AE sensors ISAS3 covering the frequency range from 23 to 910 kHz, the signal isolator SISO3 and - as accessories - a magnetic sensor holder and an enclosure for up to 8 or 20 signal isolators. ISAS3 variants differ only in the geometry of the piezo-electric element, hence in the frequency response.

SISO3 gain can be defined by jumpers to 14, 20 or 26 dB, with 14 dB as default. The total gain is 20 dB higher due to an integral preamplifier in the sensor.

4.2 Intrinsically safe sensor ISAS3

Purpose of ISAS3 is to
1. pick up the surface movement of a test object caused by an AE-source, e.g. corrosion, crack growth or crack closure
2. convert the surface movement into an electrical AE signal
3. amplify the AE signal within a certain frequency range and transmit it over a coaxial cable to the signal isolator (SISO3)
4. convert the AST control pulse from SISO3 into an artificial AE event for a sensor coupling check.

Fig. 3 shows ISAS3 with its sensitive face pointing upward. Within the piezo cup is the piezo element. The face of that cup must be pressed against the test object. Fig. 4 shows the sensor cover (46,5mm diameter) with Ex-labelling. Fig. 5 shows the SMA connector of the intrinsically safe circuit, embedded in the sealing adapter, where a heat shrink or flexible tube can be clamped on for protecting the connector from up to 12 bar peak pressure.
Fig. 3  View onto piezo-cup of AE sensor ISAS3

Fig. 4  View on cover of ISAS3 with Ex-label

Fig. 5  SMA-Connector & Sealing adapter

Fig. 6  Magnetic holder MAG4IS

Fig. 7 ISAS3 on magnet holder MAG4IS
Fig. 6 shows the magnetic holder MAG4IS. ISAS3 is fastened to MAG4IS by 3 screws M4 through spacers labelled "A" in Fig. 3 into the threads labelled "A" in Fig. 6. Fig. 7 shows an ISAS3 mounted onto MAG4IS and a heat-shrink cable-to-sensor transition sealed and clamped.

ISAS3 carries the following label based on ATEX/CENELEC standards:

\[ \text{Ex II 1G Ex ia IIC T6 Ga Tamb: -20°C ... +60°C IP68} \]

**Meaning of the label elements:**

- **Ex** indicates the following symbols as terms defining the area of use according to ATEX
  - **II** group of device which can be used in explosive areas but not in mines
  - **1** this is a device of category 1 from the group of device (II) useable in zone 0
  - **G** for use in explosion hazardous gas (not dust)
  - **Ex** label indicating the following symbols are terms defining the protection of devices according to CENELEC standards
  - **ia** this is an intrinsically safe device "ia" (useable in zone 0), safe at even two simultaneous worst case faults
  - **IIC** explosion group; for gases needing the lowest amount of ignition energy (\(< 60\mu J,\) hydrogen) to ignite an explosion.
  - Group IIC specification covers also IIB and IIA, since these groups are for gases of higher ignition energy (60 to 180 \(\mu J\) with IIB, e.g. for ethylene, and \(> 180 \mu J\) with IIA, e.g. for propane)
  - **T6** temperature class, defining the maximum surface temperature a gas can reach at or in the device. The surface temperature of the device will stay at least 5 K below 85 °C at any time, even in the presence of two worst case faults.
  - **Ga** equipment protection level (EPL) "Ga": Equipment with very high level of protection for explosive gas atmospheres. It cannot be a source of ignition in normal operation, expected malfunction or even when subject to rare malfunction. Such equipment will have a form of protection which will remain effective even in the presence of two potential faults.
  - **-20/+60°C** this is the range of ambient temperature this apparatus can be operated in. For maintaining intrinsic safety, the upper limit is essential. The lower limit is more a functional specification.
  - **IP68** degree of protection against ingress of dust and liquid.
    - First digit "6" means completely protected against ingress of dust.
    - Second digit "8" means suitable for continuous immersion in water under conditions which shall be specified by the manufacturer. The connector used is specified for IP68, however, for use in crude oil or salty water, the user guide describes how to protect the cable-to-ISAS3-transition shall be protected.

**4.3 Signal Isolator SISO3**

SISO3 is a so-called associated apparatus. That means it is an electrical apparatus which contains both, intrinsically safe circuits and non-intrinsically safe circuits, and is constructed in a way that the non-intrinsically safe circuits cannot adversely affect the intrinsically safe circuits [6] (IEC60079-0:2007 / 3.2). SISO3 is a module to be snapped-on a DIN rail.
The purpose of signal isolator SISO3 is to
1.) electrically isolate the intrinsically safe sensor circuit from the AE system
2.) provide isolated DC-voltage for ISAS3 over the combined coaxial power/signal cable
3.) amplify the AE signal from the sensor and transfer it to the AE system
4.) transfer an Auto Sensor Coupling Test (AST) control pulse from the AE system to the
   sensor
5.) limit the voltage, current, power and pulse energy on the intrinsically safe circuit in
   accordance with EN60079-11:2007 for use in zone 0, even in the presence of two
   simultaneous worst case faults in SISO3.
6.) ensure electro-static discharge of intrinsically safe cable over 220 kΩ to earth at DIN
   rail, when cable is interrupted.

SISO3 carries the following label based on ATEX/CENELEC standards:

II 3 (1) G, Ex nA [ia Ga] IIC T4 Gc Tamb: -20°C ... +60°C IP30

Meaning of the label elements:

see ISAS3
II see ISAS3
3 this apparatus is of category 3 useable in zone 2 (or in non-hazardous area)
(1) this is an associated apparatus for a device of category 1 which is useable in zone 0
G for use in explosion hazardous gas (not dust)
Ex Label indicating the following symbols are terms defining the protection of devices
according to CENELEC standards
nA this is a non-sparking apparatus for use in zone 2
[ia Ga] this is an associated apparatus of an intrinsically safe device "ia" and in accordance
with Equipment Protection Level (EPL) Ga
IIC see ISAS3
T4 temperature class, defining that the maximum surface temperature a gas can reach in
this apparatus stays always below 135 °C, even in presence of two worst case faults.
Gc Equipment for explosive gas atmospheres, having a normal level of protection, which is not a source of ignition in normal operation. That means, SISO3 can be located in zone 2 or non-hazardous area -20...+60°C this is the range of ambient temperature this apparatus can be operated in IP30 degree of protection against ingress of dust and liquid according to EN60529. First digit "3" means protected against objects larger than 2.5 mm diameter. Second digit "0" means no protection against ingress of water

4.4 Housing for SISO3

Fig. 10 and 11 show a HISO3-08 housing with 8 SISO3 fully cabled. Ready-made cables with BNC and SMA connectors can be inserted into the cable entry system.

5. Conclusions

The availability of the new intrinsically safe sensor ISAS3 and signal isolator SISO3 shall open the door for permanent monitoring application in the oil and gas industry and the transportation industry in order to identify e.g. fatigue cracking in an early state. This shall avoid the need for sudden repairs and contribute to a safer environment.

Fig. 10 Top view into opened HISO3-08

Fig. 11 Front view on cable entry system

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