Fact sheet

Sensor malfunction

By virtue of transmitting the information required to conduct a situation analysis and the ensuing action plan, sensors are critical components in ensuring the good working order of automated control and safety systems. As such, the role of sensors has become increasingly important in providing for the safety of industrial sites and the quality of their production. This greater emphasis placed on sensors in the field of industrial safety has naturally been accompanied by a higher frequency of accidents involving sensor malfunctions. A study[1] focusing on 345 accidents occurring at French classified facilities through 2011 has revealed a doubling in the average number of "sensor accidents" per year over the periods 1992-1999 and 2000-2008 for the 4 most highly automated sectors of activity (see Fig. 1).

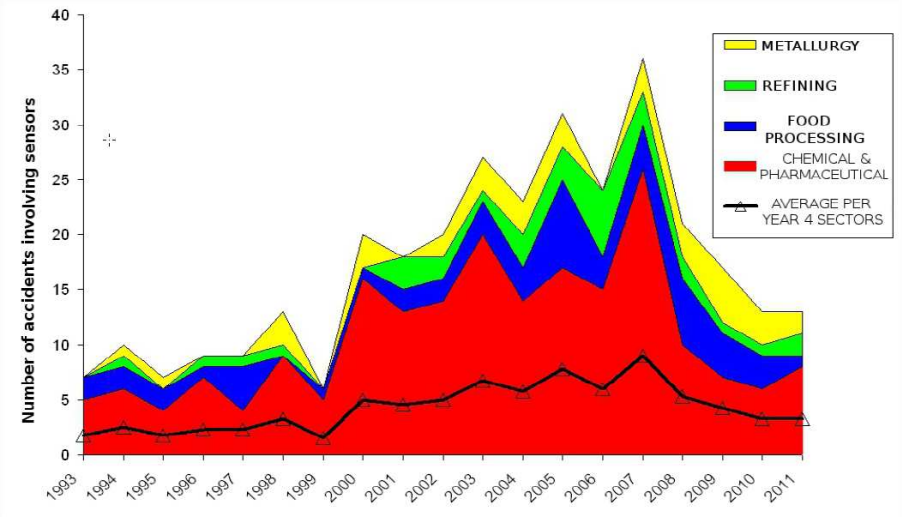


Fig. 1 : Annual number of accidents involving sensors for the most highly automated industrial sectors (ARIA base - 345 accidents)

1. Phenomena caused by accidents involving sensors

Industrial sensors offer the potential to remotely monitor facilities that operate with hazardous substances or processes, thus making it possible to remove technicians from these sources of danger. The accidents recorded as resulting from sensor malfunctions reveal the benefits offered by sensor use through a reduction in the most serious accident types, e.g. explosions and fires, since the majority of these accident records indicate a loss of hazardous materials, and in many instances remaining confined within the given unit or site (Fig. 2).

[1] « Sensors, compliant with safety ? », BARPI, 2012, 30 pages, free download on www.aria.developpement-durable.gouv.fr.

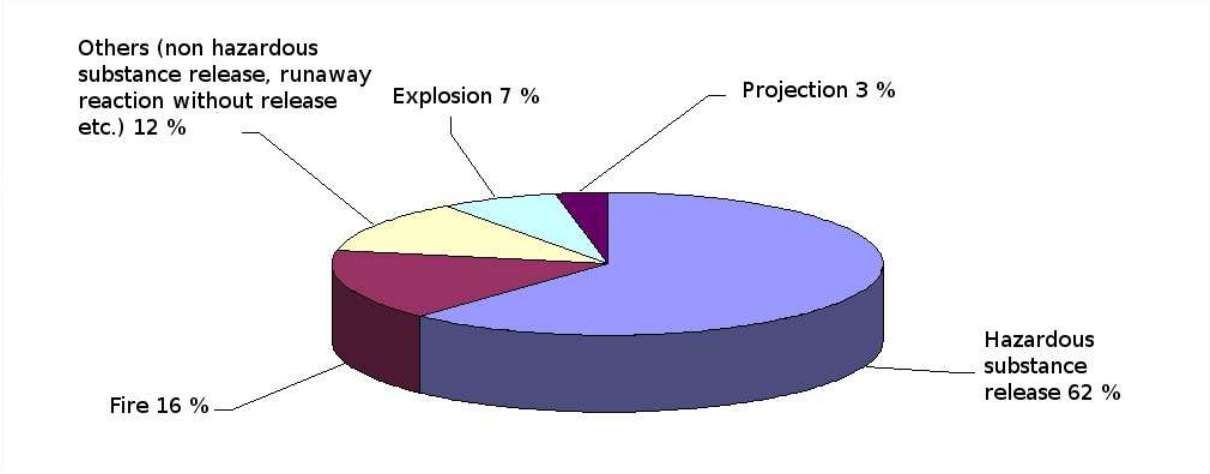


Fig. 2 : Breakdown of phenomena caused by accidents involving sensors (ARIA base)

The violent explosion that occurred on 8 June 2007 at a steel mill provides an effective illustration of the potential seriousness resulting from inadequate sensor equipment for process monitoring and safety functions:

ARIA 33059 - 08/06/2007 - 78 - PORCHEVILLE

24.10 - Manufacture of basic iron and steel and of ferro-alloys

In an electrical steel mill around 7:10 pm, the (70-tonne) melting furnace control operator noticed blue flames on the surveillance camera feed, which was an indication of the presence of water in the furnace. He proceeded by closing the safety guard in front of the window separating the control booth from the furnace wall and then ordered personnel to evacuate. A violent explosion occurred shortly thereafter, once water had come into contact with molten metal. During that afternoon, a water leak had been detected on 2 coolant return hoses at the furnace roof. One was replaced, and then it was decided to start the backup return circuit in order to compensate for the deficient second hose. Since the circuit water valve had not been opened, the cooling system malfunction caused a tube to be perforated and water to enter the furnace [...] The investigation exposed a substandard organisation of maintenance works performed on water supply hoses at the furnace roof (procedures, task management, supervision, etc.), in addition to **instruments incapable of controlling furnace roof cooling efficiency or water circuit integrity (i.e. no measurement of temperature and pressure variation) and a lack of instrumentation on the backup cooling circuit**. The mill operator commissioned an independent body to identify the causes of this accident and establish a set of technical and organisational measures to adopt so as to avoid recurrence. **The operator also specified: the backup circuit instrumentation to be introduced, installation of a hydrogen detector**, revision to the overall maintenance organisation, and a design study devoted to cooling circuit instrumentation for improved efficiency monitoring.

2. Functions performed by sensors involved in accidents

Some types of sensors involved in accidents stand out from the rest (Fig. 3). Depending on the extent of their use in industrial processes, especially chemical processes, temperature and pressure sensors are implicated in nearly half of all studied accidents. Sensors responsible for detecting an abnormal phenomenon (e.g. fire, toxic gas) were cited in the 2nd highest number of accidents, as a result of their role in exacerbating conditions in the event of malfunction. Lastly, level sensors are involved, on average, in over 20 % of all accidents inventoried and in up to 80 % of accidents recorded in the refining sector, where their operability is essential to ensuring process control.

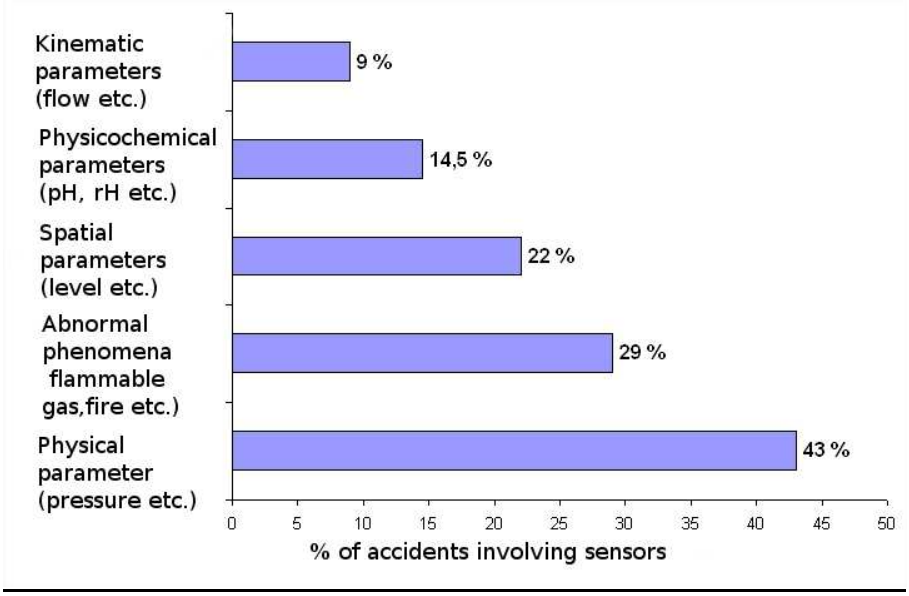


Fig. 3 : Breakdown of the functions performed by sensors involved in the analysed sample of accidents (ARIA base)

The accident that occurred in May 2005 in a French refinery clearly demonstrates the importance of level sensors for processes carried out in this sector :

ARIA 29903 - 26/05/2005 - 77 - GRANDPUITS-BAILLY-CARROIS

19.20 - Manufacture of refined petroleum products

Fire broke out in a refinery on an atmospheric distillation unit. The blaze was triggered by an ignited leak on the exhaust of a safety valve associated with a gasoline stabilisation column (i.e. a debutaniser) whose function was to separate gasoline from gas. The internal emergency plan was activated at 6:56 pm and the unit was shut down as per an emergency procedure. The refinery's internal responders extinguished the fire at 7:49 pm. Smoke from the blaze was dissipated by the south-easterly winds. The extinction water was channelled towards the refinery's treatment plant [...] The atmospheric distillation unit had been restarted a few days prior and its operations had not yet stabilised. Just a few hours before the incident, console operators and technicians had experienced difficulties on a vacuum distillation pump. **The stabilisation column was re-boiled at its base by an exchanger fitted with a column base level setting device. As of 3:30 that afternoon, a drift appeared on the corresponding measurement, leading to the partial, then complete, closure of the bottom valve and hence to the column filling with gasoline.** A mix of gasoline and gas spilled out via the overhead valve, formed a stream and ignited at a hotspot at the column base. The flame front rose to the outfall, thus sending a flame above the main atmospheric distillation column. The pressure sensor had been servo-controlled to allow turning off the heat, thus avoiding insufficient condensation at the top, which constitutes the typical cause of pressure surges. **This incident underscored the need for a new sensor locked loop on the column bypass, in order for the safety diagram to incorporate the risk of column overfilling.**

3. Accident circumstances

Installation shutdown or start-up constitutes a transitional phase capable of causing malfunction of the sensors, which often operate under atypical conditions not given full consideration at the time of sensor selection, installation or adjustment. This observation is also applicable to system maintenance phases

when it is more frequent, for example, to overlook connections or encounter shunts, damage and sensor fouling. The accident that occurred at a Paris Region chemical site in August 2009 illustrates this concern :

ARIA 36660 - 13/08/2009 – 77 - GRANDPUITS-BAILLY-CARROIS

20.15 - Manufacture of fertilisers and nitrogen compounds

Ammonia (NH_3) was released around 10:50 am through a vent in the carbon dioxide (CO_2) liquefaction workshop at a chemical plant. A watchman observed the discharge and sounded the alarm. The shop was shut down and the internal emergency plan triggered […] The workshop was liquefying CO_2 by means of a refrigeration circuit using 5 tonnes of ammonia. **Since the workshop was idle, a pressure transmitter had been disassembled the day before to perform maintenance on the high-pressure ammonia compression circuit. This transmitter was providing a double function: regulating refrigeration circuit pressure at a recommended value of 13 bar, and ensuring installation safety by setting a 14-bar threshold. The workshop reopened the next morning while the transmitter was still undergoing repairs. Without any regulation or safety, the system diverged and the ammonia circuit experienced a temperature and pressure rise.** The circuit valve was tripped and 200 kg of ammonia were discharged via a 17-m high vent.

4. Focus on a few recurrent accident causes

Among the causes giving rise to sensor malfunctions, two are easily distinguished by their frequency in accidents catalogued for the 4 sectors of activity examined herein. The leading cause occurs early on and is tied to incorrect sensor installation. In many cases, the sensor is poorly connected or its location not suited to its assigned function. A survey[2] conducted among 119 French industrial sites equipped with 2,000 sensors on average has shown that 52 % of observed causes of malfunction stem from assembly or cabling errors. A recent accident at a chemical facility in the Isère department directly relates to this issue :

ARIA 43042 - 16/11/2012 - 38 - SALAISE-SUR-SANNE

20.14 - Manufacture of other organic basic chemicals

On an upper-tier Seveso petrochemical platform, a temperature rise vacuum test of a new reactor was underway when an explosion occurred at 9:15 am. The explosion took place on a heat-insulated tank used to melt salt by exposing it to water vapour at 180℃ and electrical resistances, before injecting it into the reactor's double containment as a heat transfer fluid [...] The investigation conducted by the site operator and an expert body confirmed ignition during the gaseous phase of an organic fuel, along with the presence of a combustible (NO_x) originating from the thermal decomposition of the heating salts, given that the tank vapour space was voluminous due to a low filling level (10 m³ of melted salt). This fuel contained as an ingredient either an anti-caking agent (organic product) in the salts, a foreign substance, or else a component stemming from a degradation reaction involving both these substances. This ingredient accumulated in the confined atmosphere of the tank until reaching its lower explosive limit and then burned once in contact with an ignition source (product temperature > 370℃?) [...] **The probe measuring temperature of the salt mix in the tank had been positioned too high relative to the low operating level and was insufficiently immersed in the liquid at the time of the accident, which led technicians running the test to underestimate the actual temperature of the mix.** The operator adopted several remedial measures, including **repositioning the temperature probe to ensure its immersion at the lower level** [...].

Fig. 4: The fouling of vibrating fork level probes caused a runaway reaction (ARIA 18339, Source: DREAL)

During the phase of normal facility use and operations, a 2nd very frequent cause of sensor malfunction pertains to deficient maintenance and cleaning. Since sensors are often in contact with the product(s) being monitored, the physicochemical characteristics of such products could on occasion quickly foul the main sensor parts (Fig. 4), or lock/clog/seize its operating mechanism, or even degrade its component materials (mechanical or electronic components).

[2] "Industries and their process instruments", MESURE magazine, issue no. 744, April 2002.

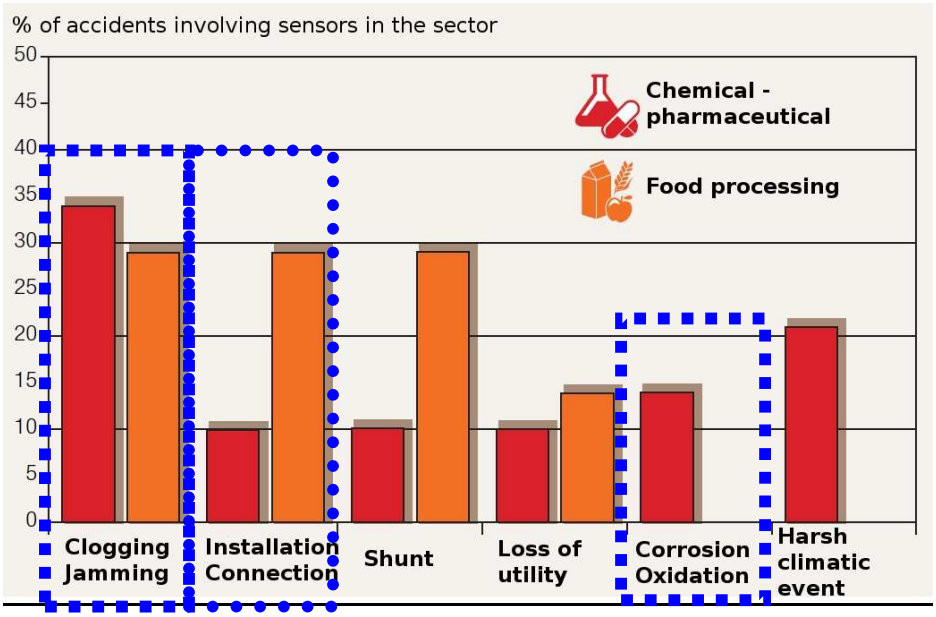
The July 2005 accident[3] at a chemical facility in France's Lorraine Region illustrates the consequences of improper sensor cleaning:

ARIA 30920 - 21/07/2005 - 57 - SAINT-AVOLD

20.16 - Manufacture of plastics in primary forms

In a plastics plant, a rupture disc burst on the medium-pressure circuit of a compressor; 3.2 tonnes of ethylene were released into the atmosphere. The incident occurred following a pressure rise at the primary compressor discharge. On 10 July, a leak was detected at the bleed valve of a grease bottle on the medium-pressure return line of the polyethylene unit. The bottle was refrigerated while awaiting its repair; the line was subsequently shut down on 20th July at 4 am for maintenance works and then started back up at 6 pm the same day. The technician turned on the primary compressor according to normal procedure, with the pressure rise being monitored in automatic mode. The pressure measurement at the secondary compressor inlet indicated a value above 300 bar, even though a discharge valve on the primary compressor should have opened at 284 bar. Moreover, the automatic mode switch on the primary compressor, designed to activate as of 270 bar, did not engage. The technician recorded an abnormal pressure increase and entered manual mode; this delayed action was unable to avoid a pressure rise to 310 bar, causing the disc to rupture**. The failure of the primary compressor to switch modes resulted from partial clogging of the pressure increase regulator gauge (i.e. measurement < actual pressure)**, and the valve did not open due to faulty maintenance; a noncompliant valve (calibration pressure > 310 bar) had been installed during a replacement step. Furthermore, fouling of the medium-pressure return section, correlated with several days of operations without bleeding the grease, only enhanced the pressure rise kinetics. After this accident, the check valve obstructed by polymers was cleaned and inspected, plus **a test enabled verifying the good working order of the automated safety mechanisms and automatic switching sequence for the primary compressor** [...] Both the rupture disc and check valve were replaced. Several remedial measures were adopted: mode-switching function installed on the compressor whether in automatic or manual mode, pressure measurement activating the backup function, revision to rules for using grease bottles in order to avoid fouling on the medium-pressure return lines, additional personnel training, and inclusion of this fouling phenomenon in the site's safety report.

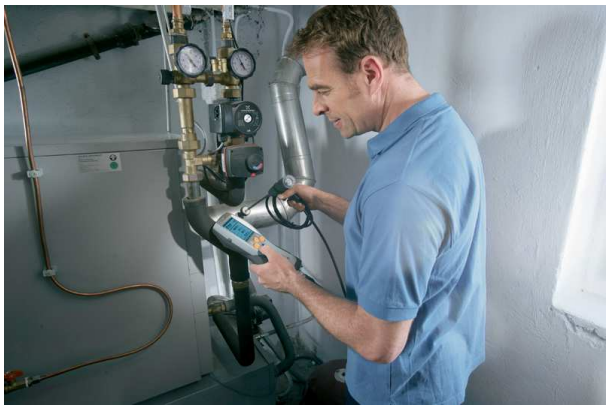
An analysis of accidents caused or exacerbated by sensor malfunction has revealed that the problems of fouling, seizing and corrosion account for nearly half of all sensor-related accidents in the chemical - pharmaceutical sector, with almost one-third of those occurring in the food processing sector. Food processing also stands out by the frequency of causes related to sensor installation and connection, no doubt reflecting less rigorous supervision of instruments here than in the chemicals sector (Fig. 5).



[3] Accident presented during the IMPEL seminar on feedback from industrial accidents, 30 th and 31st May 2007 (Paris).

Fig. 5 : Primary causes of sensor malfunction for the chemical and food processing sector (ARIA base)

5. Conclusion and recommendations



A procedure of regularly calibrating sensors is mandatory !

The purchase of an "off the shelf" sensor does not necessarily mean that it can be forgotten once installed ! The efficiency of a sensor as a means of mitigating risks is not solely dependent on its performance, since use conditions also prove to be determinant. If these conditions are unsuitable, they may undermine efficiency and even raise the possibility of an accident should the sensor malfunction be difficult for technicians to detect.

During the preliminary phase, special attention needs to be paid to the chosen sensor location, in accounting for the various process steps or product states to be monitored, including infrequent or exceptional operating phases (e.g. extended down periods, emergency shutdowns, and scheduled maintenance).

During the operating phase and as is the case for any so-called "active" equipment, the good working order of a sensor over time depends on the efficiency of on-site control and maintenance measures, in order to avoid:

- malfunctions tied to operating errors committed by personnel or subcontractors (damage, absent or poor-quality connections at the time of initial installation or during the maintenance phase) : availability and compliance with supplier documentation, respected works schedule, awareness of sensor importance amongst maintenance teams, physical protection of sensors, consignment labelling, system of authorisation and traceability for all bypasses introduced;
- malfunctions tied to sensor operations under normal working conditions: calibration procedure in accordance with supplier recommendations for the purpose of guaranteeing measurement accuracy; and regular inspection and cleaning procedure whenever the sensor enters into contact with the product or an aggressive environment.