Research on the possibilities of reducing the effects of shock waves in case of explosions in environments with dust and textile suspended particulate matter

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OLIMPIU STOICUTA
MARIN SILVIU NAN
DĂNUŢ GRECEA
CĂTĂLIN PLOTOGEA
DORINA POPESCU
ALEXANDRU LAURENTIU CHIOTOROIU
GABRIEL ŢUŢUIANU

REZUMAT – ABSTRACT

Cercetări privind posibilitățile de reducere a efectelor produse de undele de șoc în cazul exploziilor în medii cu praf și particule textile în suspensie

În cadrul acestui articol se prezintă un sistem automat destinat reducerii undelor de șoc ce se obțin în urma unei explozii interioare într-un spațiu închis unde amestecul cu aerul, în condiţii atmosferice, al substanţelor inflamabile sub formă de praf sau fibre, după aprindere, arderea se propagă în tot amestecul neconsumat.
Sistemul automat realizează aerisirea spațiului închis în vederea reducerii efectelor produse de explozie. Sistemul este dezvoltat în jurul unui microcontroler și se bazează pe un algoritm predictiv. Alimentarea cu energie electrică a dispozitivelor de automatizare, utilizate în cadrul sistemului, se face de la un sistem fotovoltaic autonom cu stocare de energie electrică, situat în exteriorul spațiului închis.

Cuvinte-cheie: sistem automat, sisteme protectoare, algoritm predictiv

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This article presents an automatic system designed to reduce shock waves resulting from an internal explosion in a closed space where mixing with air under atmospheric conditions of flammable substances in the form of dust or fibers after ignition, is propagated in the whole unconsumed mixture.
The automatic system provides ventilation of the enclosure in order to reduce the effects of the explosion. The system is developed around a microcontroller and is based on a predictive algorithm. The power supply of the automation devices used in the system is made from a stand-alone photovoltaic system with electrical storage located outside the closed space.

Keywords: automatic system, protective systems, predictive algorithm

GENERAL CONDITIONS

Industrial installations where flammable and/or combustible materials are processed, transported or stored are likely to have an explosive atmosphere.
Explosive atmosphere is defined as a mixture with air, under atmospheric conditions, of a flammable material in which, after ignition, the burning propagates throughout the whole unconsumed mixture.
Flammable and/or combustible materials must be considered creating/able to create an explosive atmosphere unless the situation where investigation of their properties has shown that they are incapable of spreading a self-sustained explosion in air mixtures.
Depending on the nature of the flammable material, explosive atmospheres can be:
– explosive gas atmospheres when the flammable material is in the form of gas or vapors;
– explosive dust atmospheres when the flammable material is in the form of dust or fibers.
In order for an explosion to occur, it is necessary to coexist with an explosive atmosphere and a source of ignition. Therefore, to reduce the risk of explosion, precautions must be taken to prevent explosions through:
– avoiding explosive atmospheres. This purpose can be achieved mainly by either changing the concentration of the flammable substance to a value that is outside the range of explosion or by bringing oxygen concentration to a value below the concentration limit of oxygen (LOC);
– avoiding any possible sources of ignition.
Measures may also be taken by limiting the effects of explosions to an acceptable limit by constructive protection measures.
Elimination or minimization of risk can be achieved by applying only one of the above prevention and protection measures. However, this is often not possible and therefore, in practice, we apply a combination of these.
In most cases, combustible dusts and vapors are a fire hazard, but mixed with air at certain concentrations and in the presence of a source of ignition are also an explosion hazard. The existence of this real danger was confirmed by the events that took place in economic units, for example: textile industry, forage factories, steel industry, etc.
Because in most cases fires and explosions cause damage with significant economic and social effects,

it is absolutely necessary to take appropriate measures to prevent such a hazard.

The risk of fire and explosion due to dust is less known than the one produced when using flammable gases or liquids. That is why, an erroneous assessment of the hazard might be obtained.

Regarding the explosion, it can only occur if the following conditions are met simultaneously:

– the existence of sufficient amounts of lint or combustible dust;
– their concentration combined with air should be at least the minimum explosive concentration;
– the existence of a dangerous potentially explosive mixture;
– the existence of a source capable of ignition.

To prevent the risk of explosion and/or fire, the following protective measures are recommended:

– avoiding or diminishing the flammable and combustible substances that may form explosive mixtures with air;
– prevent or reduce the possibility of forming explosive mixtures around electrical installations.

The ignition and explosion of dust requires simultaneous existence in the same place:

- of the oxidizable substances to the outside;
- of the oxidant (sufficient oxygen);
- of the efficient ignition source.

The explosion of dust only occurs if, in addition to the above conditions, the following are added:

- the fine grain size of the dust is less than 200 μm;
- the concentration of dust in the cloud is within the explosive limits.

According to industrial practice, ignition and explosion of dust can occur during the following technological operations:

- the mechanical transport of organic substances and their spillage;
- grinding and drying organic dust;
- suction and pumping of dust into separation and filtration installations;
- dry spraying of organic products;
- polishing light metals and their alloys.

Zoning needs to be done for both new and existing installations. In the first case, the responsibility lies with the technological specialists from the design institutes, in the latter case the plan can also be set up by technological specialists from the industrial units.

Zoning must be reviewed and updated whenever changes occur in installations and/ or technological process.

Electrical installations and equipment, located in areas with explosive atmosphere which may be a potential source of ignition, must meet certain conditions both in terms of construction and use.

FACTORS DETERMINING THE EXPLOSION RISK IN DANGEROUS AREAS WITH COMBUSTIBLE DUST AND LINT

Combustible dust and lint may be ignited by the following sources:

– by having contact with the surfaces of electrical devices which have a temperature above the ignition temperature of the dust;
– by arches or sparks produced by the electrical parts of electrical equipment (eg brushes, contactors, switches, etc.);
– by discharging an accumulated electrostatic charge;
– by radiant energies (eg electromagnetic waves, ionizing radiation, ultrasound, etc.);
– through mechanical friction and impact sparks or heating of the equipment.

THE PROPERTIES OF COMBUSTIBLE DUST

The nature of the dust is a decisive factor in the explosions, the characteristics of the dust (particle size, humidity, ignition temperatures in the cloud and in the layer, resistivity) influence both its dispersion in the medium, the particles size and also the explosive parameters.

In order to achieve security against combustible dust and lint, it is necessary to know the main explosive parameters of dust and lint which in combination with the air can generate explosive atmospheres. These features for the main combustible dust and lint are presented in literature [11–13].

THE QUANTITY OF DUST AND LINT EXISTING IN THE TECHNOLOGICAL FIELD

Dust and lint exist in the technological fields in two forms: dust and lint in suspension and dust and lint deposited.

Dangers due to dust and lint deposits occur in two closely related ways:

– Dust and lint deposited on/ in electromechanical devices and equipment having hot surfaces, as well as other hot surfaces such as heat-conducting pipes with improper insulation, etc., form a heat-insulating layer which prevents the dissipation of heat in the environment.
– Accumulation of heat in the layer of dust and lint leads to the sudden acceleration of the exothermic oxidation reactions, which end with the phenomenon of smolder, on the surface of dust and lint layer leading eventually to fire spots. These fire spots can migrate through a layer of dust at tens of meters distance and when they encounter a flammable substance they can trigger fires.

Most causes that determine whirling of the deposited dust also ensure the ignition source of the formed suspension.

Deposits of dust and lint that smolder represent a great danger. These, usually have a very low humidity around the fire spots, and at any movement they rise in suspension.

CHARACTERISTICS OF THE TECHNOLOGICAL FIELD

Being a factor that influences the danger of explosion, the technological space intervenes first of all through its volume. It is well-known from the research

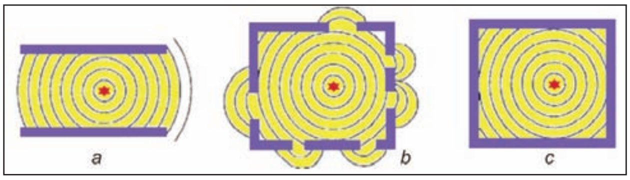

Fig. 1. Types of internal explosions according to the degree of ventilation [1]: *a* – complet ventilated; *b* – partially ventilated; *c* – fully closed

studies that a certain volume of explosive mixture of dust, lint and air produces effects on a 10 times higher volume.

This way results one of the security measures which requires removal of deposited dust and lint so that in the case of total whirling of the deposits, the concentration of the resulting mixture is less than the minimal explosive concentration. The volume of this mixture must not exceed 1/10 of the technological room volume.

When the explosion occurs inside a building, the pressures associated with the initial shock wave will be much higher than in the case of an explosion that occurs outside the building.

High temperatures as well as the accumulation of gases produced by chemical reactions make the explosions produced inside buildings require structural resistance over a longer period of time, depending on the degree of ventilation of buildings. This situation can be easily encountered in textile units that process and handle combustible materials such as raw material for yarn production, textile thread, dye solvents, combustible chemical substances used in technological processes, lubricants, textile dust.

Figure 1 illustrates the three types of interior explosions, depending on the ventilation degree of the building.

Internal explosions are characterized by three effects [2]:

- The effect of air compression around the explosion, the so-called "air shock wave" effect;
- Dynamic air pressure;
- Ground compression effect, the so-called ground shock wave effect.

After the explosion, the shock wave produces an instantaneous increase in air pressure (overpressure) over ambient atmospheric pressure at a certain distance from the source of the explosion (the positive phase of the explosion). Consequently, there is a difference in pressure between the combustion gases and the atmosphere, which causes a reversal of the flow direction (from a certain point to the center of the explosion). This stage is known as the negative phase of the explosion. The equilibrium point is reached when the air pressure returns to its original state. The above mentioned are highlighted in figure 2.

In figure 2, with t_d was noted the duration of the positive phase of the explosion, and with t_0 was denoted the initial time when the detonation took place. From figure 2 it is observed that the explosion has three phases: detonation, positive phase and negative phase. As a result of the practical experiments it was shown that the time variation of the air pressure within an enclosure after an explosion is described by an exponential function, given by the Friendlander equation [3].

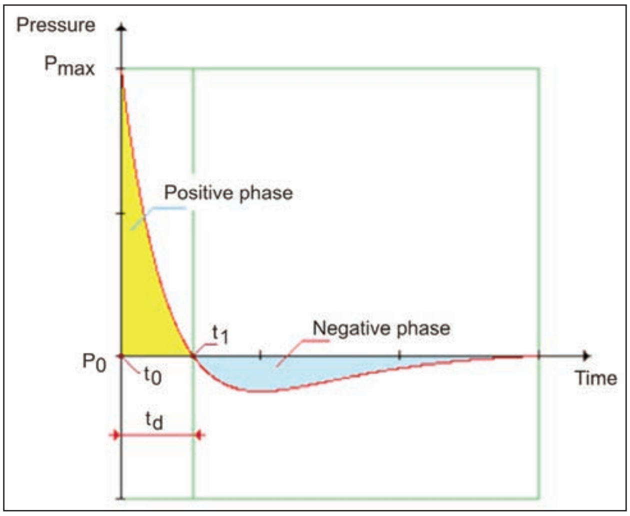

Fig. 2. Blast wave pressure plotted against time

$$p(t) = p_{max} \cdot \left(1 - \frac{t - t_0}{t_d}\right) \cdot e^{-\alpha \cdot \frac{t - t_0}{t_d}} \qquad (1)$$

Where $t_d = t_1 - t_0$, and α is a parameter of the waveform.

Based on the above-mentioned relationship, we can calculate the value of the shock wave pulse, which is defined by the area of function (1) in the positive phase of the explosion.

$$i_s = \int_{t_0}^{t_0 + t_d} p(t)\, dt = \frac{p_{max} \cdot t_d}{\alpha^2} \cdot (\alpha - 1 + e^{-\alpha}) \qquad (2)$$

From relations (1) and (2) it is observed that with the decrease of the maximum pressure, the value of shock impulse decreases. A widespread method for reducing the effects of an explosion (reduction of maximum pressure) within a building is the method of aerating the space where the explosion occurred. The ventilation must be made to a safe location where combustion can not be sustained, away from crowded areas, other facilities or other buildings.

Among the most well-known venting devices in the spaces where explosions occur, we mention the following [4]:

- ventilation ducts covered with membranes made of weak material that breaks gently at contact with the explosion air flow (figure 3, *a*). These holes are designed according to NFPA 68 [5] and are designed to reduce overpressure and flame directional firing;
- ventilation devices that do not allow flame and dust particles to escape outward (figure 3, *b*). These devices have been able to evacuate excess pressure and hot gas from the explosion, consisting of a membrane and a filter. The ventilation design using these devices is based on the NFPA 68 standard.

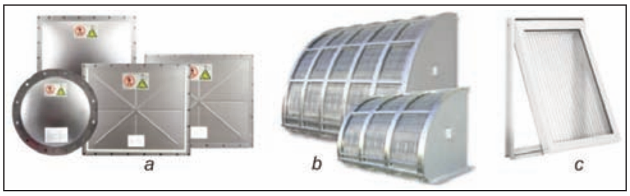

Fig. 3. Passive ventilation devices for spaces where explosions occur [6], [7], [8]

- steel hinged doors (figure 3, *c*). According to standard NFPA 68, the mass of the door should be less than 12.2 kg/m^2.

The ventilation devices in figure 3 are some passive ones being driven by the explosion air flow. The main concerns of researchers in recent years with regard to ventilation devices are largely intended to increase their effectiveness in the event of an explosion [9]. In view of the above, the primary objective of the article is to propose a new type of device designed to vent a space in which an explosion occurred. The proposed ventilation device is an active device, driving the device by means of an automatic system. The control system consists of one or more automatic transducers used in explosion detection (pressure transducers, flame transducers) whose information is transmitted to a performing microcontroller which, based on a program based on a predictive algorithm, performs the command the execution element conducting the ventilation of the space in which the explosion occurred.

AUTOMATIC SYSTEM AND VENTILATION DEVICE

The proposed ventilation device is shown in figure 4. The ventilation device consists of the following elements: 1 – steel panels (4 pieces); 2 and 3 – steel fastening bars; 4 – way, rigid, steel, clamp connectors (4 pieces); 5 – tension spring hinge and electromagnet (4 pieces).

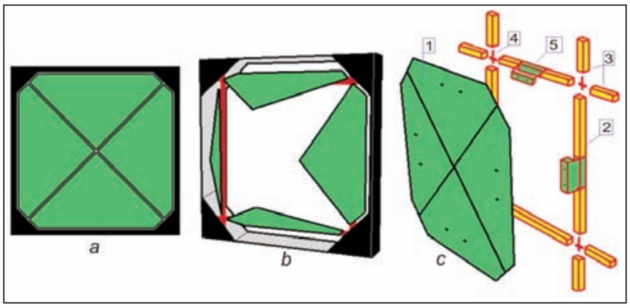

Fig. 4. Ventilation device

Each panel is hinged to the hinge by means of two screws.

The hinge of the hinge component can be adjusted manually, which is used to open the panel. The hinge is made up of an electromagnet used to hold a panel in a closed position.

The four panels of the ventilation device are closed as long as the coils of the 4 electromagnets are run-in. When powering the electromagnets is interrupted, the tensile springs in the four hinges will open the four steel panels very quickly.

The scheme of the ventilation control system is shown in figure 5.

In figure 5, have been using the following electronic devices:

- Resistances (denoted with R, R_1 and R_2). Resistance values are: R = 1 kΩ; R_1 = 220 Ω; R_2 = 10 kΩ.
- Protection diodes 1N4004 (denoted with D).
- BC301 transistors (marked with T).
- An opt coupler 4N25.
- Four PML-080AB electromagnets with a 45 kgf retaining force at 12 Vdc / 60 mA.
- A MEX-3.2HT pressure sensor.
- A processing unit with microcontroller, FAB-4.

An autonomous photovoltaic system, used in the power supply of consumers, of the control system component of figure 5.

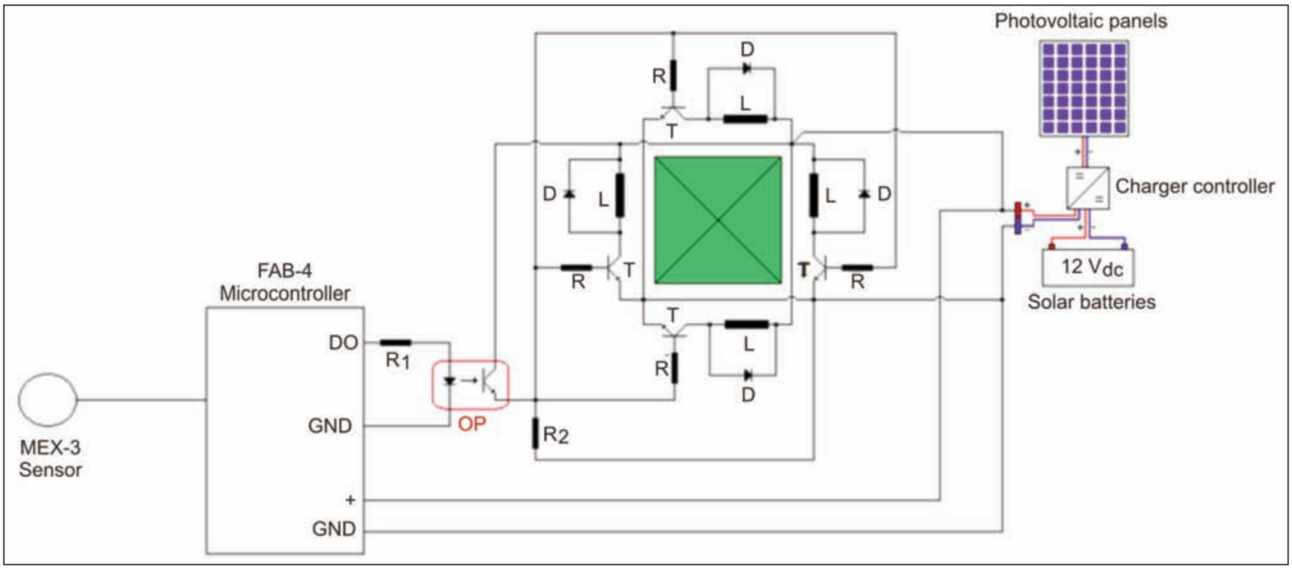

Fig. 5. Ventilation control system

In the scheme of figure 5, dynamic pressure is measured using the MEX-3.2HT sensor, manufactured by Germana, IEP Technologies GmbH [10]. This sensor is capable of measuring dynamic pressures ranging between 0 and 2 bar, under temperature conditions between –20 and 160 degrees Celsius. The MEX-3.2HT sensor is shown in figure 6.

Fig. 6. Pressure sensor MEX-3.2HT [10]

The sensor is KEMA 03 ATEX 1480 certified, protected by a stainless steel casing. The MEX-3.2HT sensor must be mounted inside the building. Data acquired by the MEX-3.2HT pressure sensor is processed by the FAB-4 microcontroller unit [10]. Within the microcontroller are implemented three predictive algorithms, working in parallel, to determine the rate of increase of the dynamic pressure from the positive phase of the explosion. The FAB-4 processing unit is manufactured by the same firm as the MEX-3.2HT pressure sensor. The FAB-4 processing unit connected to the MEX-3.2HT sensor is shown in figure 7.

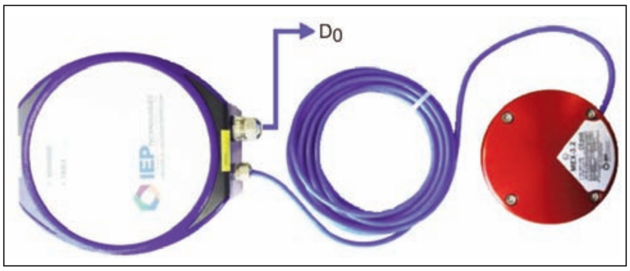

Fig. 7. FAB-4 Processing Unit [10]

The FAB-4 processing unit connects outside the building, powered by a stand-alone photovoltaic system with a 12 Vdc voltage. The FAB-4 processing unit has a 1.5 W power consumption and can operate in the following temperature range: –25 ... + 75 degrees Celsius.

The FAB-4 processing unit is certified SEV 15 ATEX 0120. This unit allows for the recording of the acquired values of the pressure and can thus carry out post-explosion analyzes. With the evaluation software, you can download event logs from the FAB-4, either in the short or long term.

On the other hand, it is known that the rate of pressure increase depends on concentration, explosive material and room volume. For this reason, the FAB-4 processing unit allows you to program and adapt the software to the process conditions.

CONCLUSIONS

In order to avoid the risk of ignition, it is necessary:

- the temperature of the surfaces to which dust, lint may deposit or may come in contact with dust and lint cloud, to be hold below the ignition temperature of the dust and lint taken into account.
- all electrical parts capable of producing sparks or all parts having a temperature above the ignition temperature of the considered dust and lint;
- to be contained in a capsule that conveniently prevents the penetration of dust and lint or has electric networks with limited energy in order to avoid arches, sparks and temperatures capable set fire to combustible dust and lint;
- all other sources of ignition should be avoided.

In order to prevent the explosion hazard, the essential security requirements are targeted to two basic directions, namely:

- preventing the accumulation of combustible dust and lint and maintaining their contents, in mixture with air, below the limit value considered as non-dangerous;
- limitation of ignition sources by using equipment and specifically constructed installations (all electrical parts capable of producing sparks or all parts which have a temperature above the dust and lint temperature must be protected or totally enclosed in capsules or must have electrical circuits with limited energy).

Preventive measures may be used to eliminate the risk of simultaneous occurrence of a source of ignition and an explosive atmosphere in the considered area. The problem can be addressed in one of the following ways, each having its own field of application:

a) suppressing or avoiding dangerous conditions;
b) the use of electrical equipment which is protected from explosion;
(c) control conditions applied to manual, automated or procedural means through which we prevent the simultaneous occurrence of an explosive atmosphere and a source of ignition.

Although each method of prevention can be a complete solution to a particular problem, it is allowed to use a combination of techniques to achieve the required degree of security.

In case the explosion cannot be avoided, a series of technical means can be introduced to alleviate the effects of shock waves from explosions produced in environments with dust and suspended particulate matter.

Both the proposed automatic system and the ventilation device require a comparative analysis with existing exhaust systems in terms of explosion efficiency.

The hinges of the ventilation device require careful maintenance in operation (they must not be blocked, corroded, the spring should not be broken).

The automatic system together with the ventilation device reduces the maximum burst pressure as well as the effects of the shock waves both on the structure of the building and on the people.

The automated system together with the proposed venting device considerably reduces the disadvantages of membranes in the existing ventilation systems. Among the most important drawbacks are: fatigue damage, heat damage, damage due to bending of the membranes due to pulsating pressures.

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Authors:

Assoc. prof. dr. eng. OLIMPIU STOICUTA[1]
Prof. dr. eng. MARIN SILVIU NAN[2]
drd. eng. DĂNUŢ GRECEA[2]
drd. eng. CĂTĂLIN PLOTOGEA[2]
drd. eng. DORINA POPESCU[2]
MD, PhD ALEXANDRU LAURENTIU CHIOTOROIU[3]
drd. eng. GABRIEL ŢUŢUIANU[2]

[1] University of Petrosani, Faculty of Mechanical and Electrical Engineering, Department of Control Engineering, Computers , Electrical Engineering and Power and Power Engineering

[2]University of Petrosani, Faculty of Mechanical and Electrical Engineering, Department of Mechanical Engineering, Industrial Engineering and Transportation

Petrosani – 332006
Str. Universitatii, No. 20, jud. Hunedoara, Romania

[3]Emergency Hospital Bucharest

e-mail: stoicutaolimpiu@yahoo.com, nan.marins@gmail.com, greceadanut@gmail.com, catalin.plotogea@gmail.com, popescu_doris@yahoo.com, chiotoroiu@yahoo.com, gabriel.tutuianu@yahoo.com

Corresponding author:

MARIN SILVIU NAN
e-mail: nan.marins@gmail.com