

About dependence of parameters of internal explosion on the device of safety designs in apertures of the protecting walls of the production and residential buildings

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Abstract. Protection of buildings against consequences of gas explosion indoors by means of the safety designs (SD) is widespread. In a number of the regulating documents requirements to these designs are imposed. It agrees, the regulating documents are allowed to carry out calculation of system of protection against internal explosion by means of the safety designs. The key sizes determining the area of apertures of the blocked safety designs are: speed of explosive combustion, most allowed explosion pressure, unit weight (per acre) the safety designs and pressure of opening of the safety designs. Under pressure openings it is meant pressure with which communications of the safety designs with walls of the building collapse and the safety designs starts moving. Depth of seal of the safety designs in an aperture remains out of sight and is supposed what influences the end result a little. In the real article an attempt to deal with this question is made. As a result of the conducted researches it was established that depth of seal of the safety designs in an aperture has to be considered when calculating system of protection of buildings against internal explosion by means of the safety designs. Especially it is important for rooms of small volume of $V_0 \leq 120$ of m^3 . For the analysis of explosion in the production buildings it is necessary to consider the volume of these rooms and a possibility of increase in burning rate because of existence of barriers indoors.

1 Introduction

Explosions of household gas in residential buildings became the real national problem. Frequent reports from the place of events, messages about a death toll and the reasons of the incident are alarming and will mobilize to carrying out the analysis of the reasons and consequences of explosions of gas in premises. The safety designs (SD) are without fail applied to protection against action of an overpressure at internal emergency explosion on the industrial facilities if these objects are referred to category explosive [1]. At the same time the area of apertures which have to be blocked [2,3] is regulated. Also requirements to

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the safety designs, namely, to their area, in case of the collapsing glasses, and to weight on 1 m², in case of the safety designs located in a covering are regulated.

Destruction of glasses depends on a form, and thickness of sheets of glazing [3] and also on quantity of glazing [4]. For the safety designs located in a covering it is required that their average weight on 1 m² did not exceed 70 kg/ m².

Residential buildings and kitchen rooms are not characterized as explosive, and special events to their protection against explosion are not provided. Frequent explosions of household gas in houses force to pay an attention to this problem, in particular, to raise a question of use of the safety designs in kitchen rooms. For more fruitful consideration of a question it is necessary to remember the highlights taking place at internal explosion. Further the quasistatic nature of explosion is supposed [5-6].

2 Methods and technique

Explosive combustion is deflagration and begins in pressure-tight volume. Change of pressure at the same time is described by expression [7-8]:

$$\frac{P_{(t)} - P_0}{P_M - P_0} = \frac{m_{(t)}}{m_0} \tag{1}$$

Here P_(t) - the current pressure indoors, P_M – the maximal pressure of explosion in completely pressure-tight volume.

P_M – depends on properties of original gas mixture in completely gas-polluted volume. If to accept that design admissible pressure ΔP_d is, approximately, ΔP_d=7 kPa, of P_M =800 kPa, then from (1) assessment follows:

$$\frac{\Delta P_d}{\Delta P_M} = \frac{m_{(t)}}{m_0} = 10^{-2}$$

This assessment shows that even at gas contamination of 1% pressure of explosion will already reach the design allowed value. Estimated values of admissible pressure are defined by calculation on a carrying capacity for the first group of the limiting conditions [4,9-12].

Follows from expression (1):

$$\frac{\Delta P_{(t)}}{P_0} = \Delta P_M \frac{4\pi(\sigma-1)\sigma^3 U_{g1}^3 t^3}{3V_0} = \gamma \frac{\sigma-1}{\sigma} \frac{V_{(t)}}{V_0} \tag{2}$$

In expression (2) $\gamma = \frac{C_p}{C_v}$ for products of combustion. At $\gamma=1,27$ and $\frac{P_M}{P_0} = 8$,

$\sigma=6,5$.

From (2) it is visible that pressure on an incipient state of explosion grows in proportion up $U_{g1}^3 \sigma^3 t^3$ to the pressure ΔP_{0T} and until t=t_{0t} (Fig. 1).

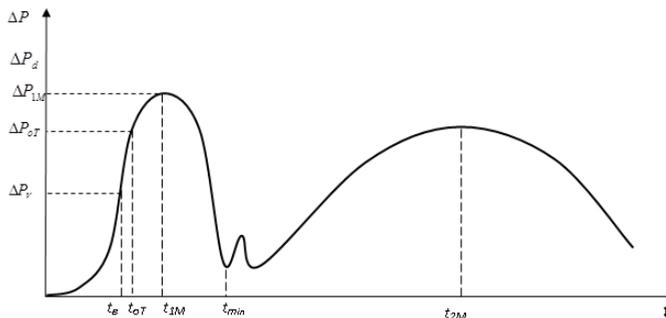


Fig. 1. The nature of change of pressure at explosion in volume with the opened apertures.

In fig. 1 – ΔP_v – pressure of opening of the safety designs, corresponds to an instant of destruction of fastening of the safety designs to a building framework, ΔP_{0T} – pressure with which apertures open for the expiration of gases in t_{0T} instant. From t_v moment until t_{0T} safety designs moves in an aperture, without opening space for the expiration of gases, Fig. 2.

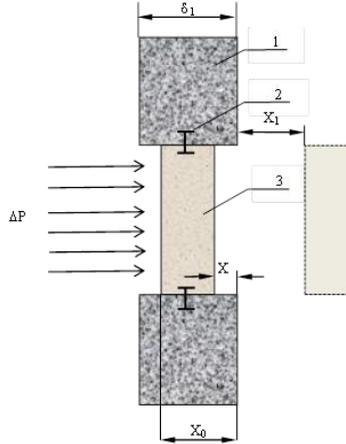


Fig. 2. The movement safety designs in an aperture.

It means that volume during time 0 - t_{0T} remains pressure-tight though in an interval of time from t_v to t_{0T} safety designs are in driving. We neglect increase in volume during driving. After the beginning of opening of space for the expiration of gases pressure grows in volume up to the size ΔP_{1M} during time $\Delta t_1 = t_{1M} - t_{0T}$.

At the same time the area (S) of open space for the expiration of gases at the time of t_{1M} is equal:

$$S_{1M} = X_{1M} \Pi$$

3 Results

So, after destruction of fastenings of the safety designs to walls they begin to move in an aperture. The equation of motion of the safety designs has an appearance:

$$M \frac{d^2 X}{dt^2} = ab * \Delta P(t) \tag{3}$$

$X=0, dX/dt=0$ at $t=0$; $\Delta P(0)=\Delta P_{0T}$, M – the mass of a safety design, a * b – the area of the personal computer, $\Delta P(t)$ – pressure operating on the safety designs from the moment of t_v until t_{0T} when the safety designs passes a path of X_0 and begins to open space for the gas expiration. The solution of the equation (3) on site 0 – X_0 or from t_v to t_{0T} , has an appearance:

$$\bar{X} = \frac{B}{4} \left[\frac{(1+\theta)^5}{5} - \theta - \frac{1}{5} \right] \tag{4}$$

$$B = \frac{abt_v^2 \Delta P_v}{MX_0}; t_B = \frac{1}{U_{g1} \sigma} \left[\frac{3\Delta P_v V_0 \sigma}{P_0 4\pi \gamma (\sigma - 1)} \right]^{1/3}; \bar{X} = \frac{X}{X_0}; \theta = \frac{t - t_v}{t_v}.$$

After achievement of value $\bar{X} = 1$ the space for the expiration of gases begins to open. The first passage time of the moment of opening $\theta_0 = \frac{t_{oT} - t_V}{t_V}$ is defined from a condition

from $\bar{X} = 1$ (4):

$$\frac{4}{B} = \left[\frac{(1 + \theta_0)^5}{5} - (1 + \theta_0) + \frac{4}{5} \right] \tag{5}$$

Traveling speed of the safety designs at the time of the beginning of opening of an aperture at, $\bar{X} = 1, t=t_v, \theta=\theta_0$ is defined by expression:

$$\left. \frac{d\bar{X}}{d\theta} \right|_{\substack{\bar{X}=1 \\ \theta=\theta_0}} = \frac{B}{4} \left[(1 + \theta_0)^4 - 1 \right] \tag{6}$$

Results of calculation of time of opening of t_v , and time of the beginning of opening of t_{oT} depending on the volume of the room and the size ΔP_V or ΔP_{oT} are presented in table 1. Calculations are given for the size of $U_{c1} = 3,1 * U_n = 3,1 * 0,35 = 1,085$ m/s and $\sigma=6,5, \gamma=1,27$.

Table 1. Results of calculation of time of opening of t_B , and time of the beginning of opening of t_{ot} depending on the volume of the room and the size ΔP_V .

V, m ³ ΔP_V , kPa	30	40	50	60	100	120	150
2	0.0725	0.08	0.086	0.091	0.108	0.115	0.124
5	0.0984	0.109	0.117	0.123	0.147	0.156	0.167
7	0.11	0.121	0.13	0.138	0.164	0.174	0.188
10	0.124	0.137	0.147	0.156	0.185	0.197	0.21
15	0.142	0.156	0.168	0.178	0.21	0.2255	0.243

In table 1 time in seconds by the time of achievement of the corresponding pressure of explosion in the pressure-tight volume of V_0 is given, to m³. The difference of valium in lower line and in the line located above in the same column gives time of the movement safety designs in an aperture from the moment of destruction of fastenings of the safety designs – t_v , until opening of an aperture of t_{ot} . Follows from the analysis of table 1 that at a slight difference of times of opening – t_v and t_{oT} , pressure in volume changes many times and can exceed the allowed pressure before opening of an aperture. Thus, the strict conditions are imposed to the safety designs, that is they have to pass a way in an aperture

before its opening in time $\theta_0 = \frac{\Delta t_{oT} - \Delta t_V}{\Delta t_V} \ll 1$.

After the beginning of opening of an aperture for the expiration of gases we will present an equation of motion of the safety designs in the form:

$$M \frac{d^2 X_1}{dt_1^2} = ab \frac{\Delta P_{oT} + \Delta P_{IM}}{2} \tag{7}$$

The datum of movement and timing begins with 0, and initial value of speed

$$\left. \frac{dX_1}{dt_1} \right|_{t_1=0} = \left. \frac{dX}{dt} \right|_{t=t_{oT}}$$

That is at the time of opening of an aperture of the safety designs has already sufficient speed, and further opening of an aperture is defined by the value of this speed. In $X_1(t_1)$ and t_1 respectively the shift of the safety designs and time of the movement safety designs later began opening of an aperture of t_{0T} .

In the equation (7) ΔP_{1M} - the maximal pressure in volume after opening of an aperture, it should not be more admissible $\Delta P_d \geq \Delta P_{1M}$.

The decision (7) has an appearance:

$$X_1 = \frac{ab}{m} \frac{(\Delta P_{or} + \Delta P_{1M})}{4} t_1^2 + B_1 t_1 \tag{8}$$

$$B_1 = \frac{BX_0}{4t_v} [(1 + \theta_0)^4 - 1] \text{ или } \bar{B}_1 = \frac{B}{4} [(1 + \theta_0)^4 - 1] \tag{9}$$

Size \bar{B}_1 is a dimensionless speed of safety designs at the time of a departure from an aperture.

Time of opening of an aperture is defined from (5) for different B. Size B changes over a wide range and defines time from the beginning of opening before opening. The it is less the larger time moves a safety design before opening of an aperture and higher than pressure in volume at the time of opening.

In the analysis of decisions (8) and (9) $\Delta P_{0T} \approx \Delta P_{1M}$ is accepted that is fair for mild safety designs. At the same time it turns out:

$$\bar{X}_1 = B\theta_1 \left[\frac{(1 + \theta_0)}{2} \theta_1 + (1 + \theta_0)^4 - 1 \right] \tag{10}$$

The dependence of time $t_{01} = t_v (1 + \theta_0)$, the relation $\frac{\Delta P_{or}}{\Delta P_v} = (1 + \theta_0)^3$ and sizes \bar{B}_1 on parameter B is presented in table 2.

Table 2. The dependence of time $t_{01} = t_v (1 + \theta_0)$, the relation $\frac{\Delta P_{or}}{\Delta P_v} = (1 + \theta_0)^3$ and sizes \bar{B}_1 on

parameter B.

B	1.0	2.0	4.0	8.0	16
$t_{0T} / t_B = (1 + \theta_0)$	1.91	1.71	1.54	1.41	1.31
$\Delta P_{or} / \Delta P_B = (1 + \theta_0)^3$	7	5	3.65	2.8	2.25
\bar{B}_1	3.1	3.75	4.65	5.86	8.25
$\Delta P'_m$	0.027	0.035	0.065	0.08	0.085
$\Delta \bar{X}_{1M}$	0.45	0.424	0.48	0.39	0.36
θ_{1M}	0.033	0.04	0.075	0.08	0.086
ρ_M	37.2	29.5	30	25	18.5
X_{0M}	0.4	0.25	0.125	0.074	0.05

The sizes presented in the table №. 2 are received for $V_0=50 \text{ m}^3$ conditions $S_0=2.1 \text{ m}^2$, $\Delta P_v = 2 \text{ kPa}$, $\Pi=5.9 \text{ m}$, $U_g=1.035 \text{ m/c}$, $\sigma=6.5$.

At assessment of the valium $S_0 \Delta P_d = 9$ kPa and burning rate on the second maximum of ΔP_{M1} taking into account was accepted [15-18]. Burning rate of U_{g1} was defined on the basis of [19,20].

At the opening aperture from volume gases begin to expire, and pressure in volume is described by expression:

$$\frac{d\Delta \bar{P}_1(\theta_1)}{d\theta_1} = A - F\theta_1 \tag{11}$$

$$A = \frac{3}{1+\theta_0}; F = 0.266v_1 \frac{\Pi \Delta P_v^{3/2}}{\sigma^2(\sigma-1)U_g^3 \rho_0^{1/2} \rho_n(1+\theta_0)^{3/2}} \tag{12}$$

Factor $0,266 = \frac{3 \cdot 2^{1/2}}{4\pi \cdot \gamma}$, $\rho_{II} = \frac{M}{ab}$ kg/m³, $v_1=0,8$, ρ_0 – density of reactant.

Π – the perimeter of an aperture is defined after establishment of the required area of open apertures [4, 13-14].

The solution of the equation (11) has an appearance:

$$\Delta \bar{P}_1 = A\theta_1 - \frac{F\theta_1^2}{2} \tag{13}$$

From this decision it is visible that pressure after the beginning of opening of an aperture grows, at $\theta_{1M} = \frac{A}{F}$ the maximum is implemented.

$$\Delta P_{1M} = \Delta P_v (1+\theta_0)^3 \left(1 + \frac{A}{2F}\right) \tag{14}$$

By the time of achievement of the maximal pressure of ΔP_{1M} the aperture is open not completely. It means that the distance passed by the safety designs after opening of an aperture in time $\Delta t_M = \theta_{1M} t_v$ is less than distance of X_2 corresponding to a full opening aperture: $X_2 = \frac{S_0}{\Pi}$.

4 Discussion

The analysis of the data presented in table 2 shows that at values of the parameters B=1 and B=2 explosion pressure before opening of an aperture increased to value of 14 kPa and 10 kPa respectively, and exceeds admissible value. It means that an object does not conform to requirements for a carrying capacity. It is possible to reduce explosion pressure increase in parameter "B", reducing of the result ($\rho_{II} \cdot X_0$). It is useful to consider the possibility to reduce explosion pressure by the time of opening of an aperture ΔP_{OT} . reducing opening pressure ΔP_v ,

Decrease opening pressure ΔP_v from 2 kPa of from of 1 kPa reduces parameter "B" 1,67 times.

For B=2 case the value of this parameter reaches B=0,63 value.

Despite decrease of parameter "B" due to decrease of pressure of opening, terminal pressure of explosion in pressure-tight volume ΔP_{OT} decreases due to decrease ΔP_v . At B=0,63 $(1+\theta_0)=2,07$ so $\Delta P_{OT} = 8,87$ kPa that it is less, than $\Delta P_{OT} = 10$ kPa at B=2 and $\Delta P_v = 2$ kPa follows from expression (5).

Pressure boost later began the expirations of gases from volume slight and makes usually no more than 10%. Such situation is a direct consequence of dispersal of the safety designs the initial site of driving on the way of X_0 .

Increase in parameter "B" leads to decrease of terminal pressure of explosion only in case of decrease of the result ($\rho_{II} * X_0$). Decrease of size ρ_{II} is limited. Size $\rho_{II} = 10 \text{ kg/m}^3$ at $B=30$ value is already close to the limiting. Decrease of the size X_0 to 0, is possible and is reached by fastening of the safety designs to an external wall of a protection or profiling, the corresponding expansion of an aperture.

As as it was shown, seal of the safety designs in an aperture leads to noticeable, and sometimes and to the significant increase in pressure of explosion during process of an unclosing of an aperture, there is a need to analyse influence of various parameters on pressure boost. The greatest growth rate of pressure at internal explosion is observed before opening of apertures. The maximal rise in pressure in this case is controlled by parameter "B". The parameter "B" the more pressure in volume before opening of an aperture are less. It is possible to regulate the size of parameter "B" by means of four sizes: a specific surface density of the safety designs (ρ_{II}), depth of seal of the safety designs in X_0 aperture, ΔP_v – the opening pressure (destruction of communications of the safety designs with the protecting designs), perimeter of apertures through which gases expire. At decrease of the result ($\rho_{II} * X_0$) parameter "B" increases and pressure of opening of an aperture decreases. At increase in pressure of opening ΔP_v parameter "B" increases and the dimensionless pressure of opening also decreases, but absolute pressure increases. Therefore if opening pressure ΔP_v decreases, then explosion pressure decreases despite body height of parameter "B" too. As at discovery of the area for the expiration of gases of at most pressure ΔP_{IM} it is reached not at the complete opening of an aperture of X_{IM}

In work the most typical and possible values of parameter "B" are considered. At these values of the movement safety designs it is possible to break into two periods: driving in an aperture and driving after opening of an aperture. When driving in an aperture of the safety designs accelerates and by the time of escaping of an aperture has the sufficient speed of $X_1 \approx B_1 \Delta t_1$ shift the providing expiration of gases is defined by this speed.

5 Conclusion

In the conclusion it should be noted that before the real work due attention was not paid to a question of seal of the safety designs in apertures. Such situation needs to be reconsidered also at projection of ways of fastening of the safety designs to consider depth of seal of the safety designs in an aperture. At tests of apertures of the safety designs on model installations also often do not consider a possibility of deepening of fastening, believing that the mass of the safety designs and property of clusters of fastening of the safety designs completely resolve an issue of effectiveness of the safety designs. The results received in work unambiguously show that it is necessary to consider depth of seal of the safety designs. Tests of the safety designs on model installations happen at high values of parameter "B" as the speed of explosive combustion at the initial moment of explosion at tests corresponds to laminar flame propagation. Therefore test data often yield excessively optimistic results.

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