New protecting structures on buildings of explosive production

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Abstract. The protective structures must be installed in the enclosing structures of explosive production buildings. Protective structures, when an explosion pressure reaches a certain value, caused by the pressure opening, release a square for the expiration of gases from the volume of the room where the explosion occurs. In the proposed work, new protective structures were considered. The process of opening and movement of the panel with the release of the area for depressurization is studied in the process of explosion development. The movement of the panel begins with the destruction of its attachment to the building frame. In this paper, the laws of change in the pressure of the explosion were considered, taking into account the inertia of the movement of the panel.

1. Introduction
Explosions of household gas in the premises of residential buildings occur with alarming frequency, lead to significant human casualties, material losses, strongly excite the public. The causes of explosions are uncontrolled gas leaks with subsequent ignition of the gas-air mixture. The destructive effect of the explosion is determined by the level of overpressure.

The explosion of household gas in a residential area can usually be considered as quasi-static, that is, there are no pressure gradients inside the volume, and its change over time occurs equally at all points [1-5]. With this development of the explosion, the change in pressure inside the volume is determined by the competition of the two processes. The increase in pressure occurs as a result of the conversion of chemical energy into thermal energy during combustion, and the expansion of the explosion products by 6÷8 times relative to the initial mixture. The pressure reduction occurs as a result of the flow of gases from the volume through the opening openings. Industrial buildings and premises with handling of explosive gases are classified as explosive [6-8], and for their protection it is necessary to use safety structures (SS) [4,7,8]. In Russian literature, they are often referred to as pressure-relief structures (PRS). These structures are subject to certain requirements, the implementation of which should provide effective pressure relief of the explosion and the protection of the object.

The formal transfer of quantitative criteria for protection against explosion of production facilities to residential ones can lead to significant errors, and in the direction of reducing safety, which is unacceptable. It is necessary to take into account features of development of explosion in premises, in particular features of pressure relief. In residential areas, but most often it is the kitchen, the explosion develops faster than in industrial premises. So if the permissible overpressure of the explosion in the living room \( \Delta P_1 \), and its volume \( V_{01} \), and for the production room, these values, respectively \( \Delta P_2 \) and
\( V_{02} \), the ratio of the time of development of the explosion before reaching the permissible pressures will be such as:

\[
\frac{\tau_1}{\tau_2} = \left( \frac{\Delta P_1 \times V_{01}}{\Delta P_2 \times V_{02}} \right)^{\frac{1}{3}}
\]

Because residential buildings are not calculated on the explosive load, then at least you can take \( \Delta P_1 \leq \Delta P_2 \). The volume of kitchen facilities is much less than the volume of production facilities, so the time of the explosion in them several times, and even an order of magnitude less. As a result, SS designed for the protection of residential premises should be subject to more stringent requirements, the implementation of which will provide pressure relief in a shorter period of time. In residential areas as a SS is always assumed to use Windows. Due to the limited size of the glazing sheet in the kitchen and the small distance between the Windows in the Windows, the destruction of the glass in the explosion does not provide an effective pressure relief [5], so the calculation is made for the release of the entire window together with the frame. The Windows are fixed inside the openings and before the space for the expiration of gases opens, the explosion develops in a closed volume until the window array is shifted at a distance at which the gas begins to flow. Thus, at explosion in premises time of development of explosion decreases in comparison with explosion in the big production room, and time of opening of the SS increases. As a result, the explosion pressure can reach the permissible value before the gas flows out during the movement of the SS in the opening [9-11]. In this paper, we consider the option of expanding the opening to the gas flow began immediately after the beginning of the movement of the LSC as a result of the destruction of the fasteners connecting the window frame with the frame of the building.

2. Research methods

It was previously shown [9-11] that the pressure rise \( \Delta P_{\text{open}} \) during the movement of the SS inside the expanding opening is determined by the time elapsed from the beginning of the explosion to the moment of the SS exit from the opening (\( t_{\text{open}} \)). In this case, the explosion occurs in a sealed volume.

\[
\frac{\Delta P_{\text{open}}}{P_0} = \frac{4}{3} \pi \gamma \frac{U_b (\sigma - 1) \sigma^2}{V_0} \tag{1}
\]

This pressure is due to the pressure \( \Delta P_{\text{break}} \), in which the SS attachment points to the building are destroyed, the ratios:

\[
\Delta P_{\text{open}} = \Delta P_{\text{break}} \left( \frac{t_{\text{open}}}{t_{\text{break}}} \right)^3 \tag{2}
\]

Expressions (1) and (2) written for the case of the explosion at the initial stage of the explosion in a sealed volume, when the volume of the explosion products is spherical, and it is less than the free volume of the room. In (1) and (2) \( U_b = \chi U_l \) - rate of explosive combustion, \( U_l \) - speed of propagation of laminar flames, \( \chi \) – coefficient taking into account the intensification of combustion [12-16], \( \gamma = 1.28 \) – isentropic index, \( V_0 \)–free volume of the room. With an expanding opening after the beginning of the movement of the SS gases flow through the opening space and the ratio (1) and (2) acquire a different form.
Consider the expanding aperture of Fig. 1. When the SS moves inside such an opening, an area for the expiration of gases opens:

$$S_x = X \Pi \sin \alpha$$

(3)

In (3) $X$ – movement SS, $\Pi$ - perimeter of the aperture SS. At the exit from the opening ($X=X_0$) the area for the gas flow is still described by the expression (3) reaching the maximum value.

$$S_{X(M)} = X_0 \frac{\sin \alpha}{\cos^2 \alpha}$$

(4)

Another limit value for the gas flow area at $S_x = X \Pi \sin \alpha$ is the area of the opening at the narrowest point $S_0$. Thus, we obtain a limit on the amount of displacement $X$, when the area of the expiration is described by the expression (3)

$$X \leq \min \left\{ \frac{X_0}{\cos^2 \alpha} (a), \frac{S_0}{\Pi \sin \alpha} (b) \right\}$$

(5)

In further analysis, the condition (5b) is used, which corresponds to the formation of the pressure peak when the SG moves with the condition that the area of the flow does not reach the value $S_0$. The change in pressure inside the room, taking into account the flow of gases and the movement of the SS under the condition (5b) is described by the equation.

**Figure 1.** The layout of the SS in widening the opening. 1a - SS in the initial state, 1b – SS in the final state when $S_x = X \Pi \sin \alpha$. 2. Mount the SS, destroyed by $\Delta P = \Delta P_{break}$. 3. The scheme of the building. 4. Opening with an area $S_0$ and perimeter $\Pi$, $X_0$ - distance traveled to the exit of the opening, $\frac{X_0}{\cos^2 \alpha}$ - distance traveled SS.
\[
\frac{d\Delta P}{P_0 \, dt} = \frac{4\pi y(\sigma - 1)\sigma^2 U_b^3 t^2 - K_U S_X \sqrt{2\Delta P/P_0}}{V_0}
\] (6)

The expression (6) is written for the condition \(\Delta P < 0,2P_0\). Other approximations are discussed in [17-20].

In the following equation (6) is reduced to a dimensionless form and the condition of achieving the maximum pressure during the motion of the SS in the expanding opening is considered. The maximum condition is specified by the requirement \(\frac{d\Delta P}{dt} = 0\). The result is an expression:

\[
3(1 + \bar{t}_M)^2 = AX_M \left(\frac{P_0}{\Delta P_{\text{break}}}\right)^{2/3}
\] (7)

In equation (7) \(\bar{t}_M = \frac{t_m - t_{\text{break}}}{t_{\text{break}}}\) – time to reach maximum pressure, \(\bar{X}_M\) – displacement of the SS to the moment of reaching the maximum pressure \(\Delta P_m\), \(t_B = \left(\frac{P_{\text{break}}V_0}{P_0^2 \pi y U_b^3 (\sigma - 1)\sigma^2}\right)^{1/3}\) - the start time of the SS movement due to the destruction of SS connections with the frame of the building.

\[
A = \frac{K_0(\sigma - 1)^{2/3}}{\left(\frac{4}{3}\pi y\right)^{1/3} \sigma^{7/6}}
\] (8)

The motion of the SS is described by the equation:

\[
\frac{d^2 \bar{X}}{dt^2} = \frac{\Delta P}{\Delta P_{\text{break}}} \times B \times \bar{X}_0
\] (9)

\[
\bar{X} = \frac{S_X}{S_0}; \quad \bar{t} = \frac{t - t_{\text{break}}}{t_{\text{break}}}; \quad B = \frac{\Delta P_{\text{break}} \times t_{\text{break}}^2}{\rho_0 \times S_0}; \quad \bar{X}_0 = \frac{X_0 \Pi \sin \alpha}{S_0};
\]

\(\rho_0 = \frac{M}{S_0}\) – SS area unit mass (kg/m²).

Initial conditions \(\bar{X}(0) = 0; \frac{d\bar{X}}{dt}(0) = 0\). The relation between equation (9) and maximum pressure condition is obtained

\[
\bar{X}_M = B\bar{X}_0 t_M^2 (0,15m + 0,35 + 0,3t_M)
\] (10)

As a result, an expression is obtained from (10) and (7) to determine the time to reach the maximum pressure during the opening process of the expanding opening:

\[
\frac{(1 + \bar{t}_M)^2}{t_M^2 (0,15m + 0,35 + 0,3t_M)} = \frac{K_{\text{flow}} 2^{1/2}m^{1/2} \Delta P_{\text{break}}^{3/2} \Pi \sin \alpha}{\rho_0^{1/2} \rho_0 4\pi y U_b^3 (\sigma - 1)\sigma^2}
\] (11)

\(K_{\text{flow}}\) – flow coefficient takes into account the reduction of the section of the expiring gas jet, \(m = \frac{\Delta P_M}{\Delta P_{\text{break}}}\) – ratio of the maximum explosion pressure to the pressure opening SS.

3. Discussion of research results

In the expression (11) all values except \(\bar{t}_M\) are given: \(\Delta P_M\) – is given from the conditions of preservation of the bearing capacity, \(\Delta P_0\) – is selected from the condition that at the maximum area \(S_0\) of the expiration of the pressure \(\Delta P_M\) does not exceed the permissible or in our case, that the resulting
area of the expiration \( S_x = \pi \cdot \sin \alpha \) does not exceed \( S_0 \) at \( \Delta P_M \). II - perimeter of the opening area \( S_0 \), \( S_0 \) – are determined from the condition of preserving the bearing capacity at the maximum rate of allocation of additional volume during combustion. This condition often coincides with the condition of the maximum burning area \( F_M = K_f V_0^{2/3} \) during the explosion. The coefficient of a form \( K_{form} \) depends on the form of the room and the location of the discharge opening. For residential premises of rectangular form \( K_{form} = 4\div6 \) [5]. In the estimates below, the value of \( K_{form} = 4,5 \) and then

\[
S_0 = \frac{K_{form} V_0^{2/3} U_r (\sigma - 1) \rho_0^{1/2}}{K_{flow} 2^{3/2} \Delta P_M^{1/2} \sigma^{1/2}} \quad (12)
\]

In tables 1 and 2 presents the results of calculations of the parameters of opening the SS in the expanding openings. Table 1 shows the dimensionless time \( \bar{t}_M \) to reach the maximum pressure \( \Delta P_M = 12,5 \text{ kPa} \) in an expanding opening with an angle \( \alpha = 45^\circ \), depending on the opening pressure \( \Delta P_{break} = 10 \text{ kPa}; 8,33 \text{ kPa}; 6,25 \text{ kPa}; 4,17 \text{ kPa} \) и 2,5 \text{ kPa}.

**Table 1.** The main parameters characterizing the process of opening the SS for the case \( \Delta P_M = 12,5 \text{ kPa} \), \( \alpha = 45^\circ \).

| \( \Delta P_{break} \) (M), kPa | 10 (1,25) | 8,33 (1,5) | 6,25 (2) | 4,17 (3) | 2,5 (5) |
|---|---|---|---|---|---|
| \( \bar{t}_M \) | 0,28 | 0,306 | 0,34 | 0,4 | 0,45 |
| \( t_{break} \) sec | 0,134 | 0,126 | 0,106 | 0,0929 | 0,0784 |
| \( X_M \) | 1,08 | 0,996 | 0,854 | 0,71 | 0,55 |
| \( X_0 \) (M) | 0,35 | 0,32 | 0,273 | 0,227 | 0,176 |
| \( \Delta P_{open} / \Delta P_M \) | 1,4 | 1,22 | 1,01 | 0,74 | 0,592 |

**Table 2.** The main parameters characterizing the process of opening the SS for the case \( \Delta P_M = 6 \text{ kPa} \), \( \alpha = 45^\circ \).

| \( \Delta P_{break} \) (M), kPa | 4,8 (1,25) | 4 (1,5) | 3 (2) | 2 (3) | 1,2 (5) |
|---|---|---|---|---|---|
| \( \bar{t}_M \) | 0,52 | 0,565 | 0,65 | 0,77 | 0,94 |
| \( t_{break} \) sec | 0,105 | 0,0996 | 0,0897 | 0,079 | 0,066 |
| \( X_M \) | 0,93 | 0,877 | 0,804 | 0,706 | 0,6 |
| \( X_0 \) (M) | 0,397 | 0,374 | 0,343 | 0,3 | 0,236 |
| \( \Delta P_{open} / \Delta P_M \) | 2,025 | 1,83 | 1,6 | 1,33 | 1,1 |

**Table 3.** The main parameters characterizing the process of opening the SS for the case \( \Delta P_M = 6 \text{ kPa} \), \( \alpha = 30^\circ \).
The opening time is also presented $t_{\text{break}}$, dimensionless $\bar{x}_M$ and dimension $X_M(M)$ SS displacement to the moment of reaching the burst pressure of magnitude $\Delta P_M$. Value $X_0(M)$ – means depth of sealing of the SS in an aperture less than which it is necessary to pass to a condition 5A, and the area of the expiration of gases at $X > \frac{x_0}{\cos^2 \alpha}$ will grow faster than (3), and pressure relief will be more effective. The lower graph shows the ratio of the pressure, which is realized in the case under consideration at the beginning of the gas flow from the non-expanding opening ($X = X_0$) to the maximum pressure $\frac{\Delta P_{\text{open}}}{\Delta P_M}$. Table 2 contains the same values for maximum pressure only $\Delta P_M = 6$ kPa, $\alpha = 45^0$, and table 3 for $\Delta P_M = 6$ kPa, $\alpha = 30$ Analysis of the calculation results shows that the lower the opening pressure and the greater the opening angle, the more effective the pressure relief. The last line of all three tables shows the effectiveness of the device expanding openings. At small angles of expansion of the opening, the final pressure relief occurs at a long distance $X_M$, in particular, at high opening pressures $m = 1.25$ and $m = 1.5$ explosion safety is not provided, since $\bar{x}_M > 1$. To provide protection in these cases, if it is impossible to reduce the opening pressure $\Delta P_B$ can be achieved by reducing the weight of the SS, reducing the sealing depth ($X_0$) SS.

| $\Delta P_{\text{break}}(M)$, kPa | 4,8 (1,25) | 4 (1,5) | 3 (2) | 2 (3) | 1,2 (5) |
|---------------------------------|------------|--------|-------|-------|--------|
| $\bar{t}_M$                     | 0,65       | 0,715  | 0,82  | 1     | 1,25   |
| $t_{\text{break}}$, sec         | 0,105      | 0,0996 | 0,0987| 0,079 | 0,066  |
| $\bar{x}_M$                     | 1,1        | 1,05   | 0,98  | 0,9   | 0,81   |
| $X_M(M)$                        | 0,664      | 0,634  | 0,592 | 0,544 | 0,489  |
| $X_0(M)$                        | 0,5        | 0,475  | 0,444 | 0,408 | 0,367  |
| $\frac{\Delta P_{\text{open}}}{\Delta P_M}$ | 2,87       | 2,65   | 2,4   | 2,1   | 1,88   |

The device of expanding window openings for SS sealing and reducing the depth of SS sealing in these openings are unused and effective methods to improve the reliability of protection of buildings from internal explosion. The obtained results require experimental refinements.

4. Conclusions

The device of expanding window openings for SS sealing and reducing the depth of SS sealing in these openings are unused and effective methods to improve the reliability of protection of buildings from internal explosion. The obtained results require experimental refinements.

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