https://doi.org/10.1051/e3sconf/202341002042

Processing of experimental data describing internal deflagration explosions

Alexander Komarov[*], *Jahongir* Azamov

Moscow State University of Civil Engineering, Yaroslavskoye shosse, 26, 129337, Moscow, Russia

Abstract. This article is devoted to issues related to experimental studies of internal deflagration explosions or emergency explosions occurring inside buildings and premises. In internal emergency explosions, the main role in reducing the explosive pressure to a safe level is played by discharge openings blocked by safety structures (SS). As discharge openings, windows are often used, covered with glazed window blocks, or opened explosion venting structures (EVS).

The article deals with processing experimental data obtained in the study of deflagration explosions occurring inside buildings and premises. The main features and difficulties that arise while analyzing experimental materials are described. The article considers the general methodology for processing experimental data to study deflagration explosions inside buildings and premises. Examples of processing materials from experiments performed in chambers equipped with a transparent edge allow high-speed filming of the explosive combustion process inside the chamber.

The article presents a technique that allows, based on data processing on the overpressure in the explosion chamber, to obtain complete characteristics of the loads that occur in the experimental chamber during an internal deflagration explosion. The proposed technique makes it possible to abandon the transparent edge of the explosion chamber and obtain data on the explosion process based on the numerical processing of the excess pressure created in the explosion chamber. An example of processing a full-scale experiment to determine the effectiveness of a real explosion venting structure (EVS) is given.

1 Introduction

To ensure safety in emergency explosions, specialists design explosive production buildings in an explosion-proof design. In this case, the bearing capacity of the main structural elements of the building must exceed the possible explosive loads. To ensure acceptable loads arising from emergency explosions inside buildings and premises, they provide discharge openings equipped with safety structures (SS). The primary function of safety structures is their ability to open under the action of internal overpressure created by an emergency explosion and release the opening blocked by the structure to discharge the

---

[*] Corresponding author: komarovaa@mgsu.ru

explosion products into the atmosphere. In this case, the maximum explosion pressure mustn't exceed the bearing capacity of the main building structures of the building or premises. To determine the necessary parameters of safety structures and the required area of discharge openings, experimental studies are carried out to determine the effectiveness of safety structures. A specific methodology for conducting experiments is required for a reliable assessment of the effectiveness of a particular safety structure and the possibility of its use in a particular room. This article discusses the basic principles of researching to study internal emergency explosions and describes the methodology for processing experimental data obtained during the experiments.

2 Methods

Accidental explosions that occur indoors are called internal explosions. Explosive combustion of a mixture prepared for an explosion during internal emergency explosions occurs in a deflagration mode. The spread of a chemical reaction (oxidation reaction of a combustible substance) over space in the deflagration regime of explosive combustion occurs due to the thermal conductivity of the medium. In this case, the apparent speed of the flame is much less than the speed of sound in the medium with which the explosive pressure propagates. Therefore, during deflagration explosions of combustible mixtures in rooms, the principle of quasi-static excess pressure is realized, when the excess pressure depends on time but practically does not depend on the spatial coordinate.

Considering this feature of explosive load formation in a room, a computational algorithm is constructed that describes the process of pressure build-up in a room and the depressurization of the room volume as a result of an internal explosion. The computational scheme in this approximation is a system of differential equations describing the time dependence of the explosive pressure and the parameters of the safety structure blocking the discharge opening.

To determine the dynamics of explosive pressure in a room equipped with a safety structure, it is necessary to solve the following ordinary differential equation [1-4]:

$$\frac{dP}{dt} = \frac{S(t)\cdot\frac{(\varepsilon-1)}{\varepsilon}\cdot U - \mu\cdot\sqrt{\frac{2\cdot\Delta P}{\rho_j}}\cdot S_W\cdot f(t)}{\frac{V_1}{\gamma_1}+\frac{V_2}{\gamma_2}}\cdot P(t), \qquad (1)$$

where $P(t)$ - the current pressure value; ΔP - excess pressure; $S(t)$ - the current value of the flame front surface area; S_W - the total area of discharge openings; ρ_j - density of cold mixture (ρ_1) or combustion products (ρ_2); ε - the degree of expansion of the mixture during combustion; γ_j - adiabatic index of a fresh mixture (γ_1) or combustion products (γ_2); U - the apparent speed of flame propagation; V_j - a current volume of a fresh mixture (V_1) or combustion products (V_2); μ - coefficient of consumption of gases flowing through the discharge opening; $f(t)$ - functional dependence of the degree of release of discharge openings from safety structures.

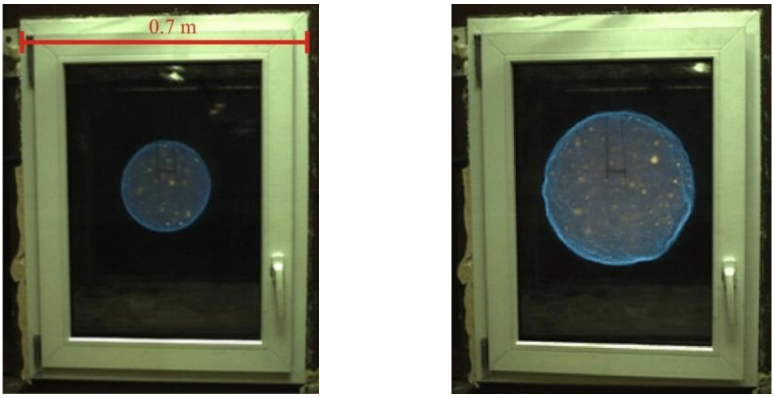
The sphericity of the flame at the stage of operation (opening) of the safety structure greatly simplifies the design scheme.

Figure 1 illustrates the sphericity of the flame at the moment of opening the safety structure. Figure 1 shows instant photographs of the deflagration explosion process in a cubic volume (cube edge 0.7 m) equipped with a hinged window or an explosion venting structure (EVS).

Considering that the flame front at the initial stages of the development of a deflagration explosion has a spherical shape, and the discharge openings are closed by safety structures, equation (1) can be significantly simplified. In this case, the pressure growth rate at the initial stages of explosion development can be determined from the following relationship:

$$\frac{dP}{dt}=\gamma\cdot\frac{4\pi\cdot(U\cdot t)^2\cdot U\cdot\frac{(\varepsilon-1)}{\varepsilon}}{V}\cdot P_0=\gamma\cdot\frac{4\pi\cdot R^2\cdot U\cdot\frac{(\varepsilon-1)}{\varepsilon}}{V}\cdot P_0, \qquad (2)$$

where P – the overpressure of the explosion; ε – the degree of expansion of the explosion products; U – the apparent speed of the flame; P_0 – atmospheric pressure ($P_0 = 101.3$ kPa); γ – air adiabatic index ($\gamma = 1.4$); V - the volume of the chamber; R – the radius of the spherical flame front.



1 2

Fig. 1. Instant photos of the process of explosive combustion of a propane-air mixture in a volume equipped with a hinged safety structure (SS). 1 - the moment of the beginning of the opening of the SS; 2 - photograph of the explosion process 30 ms after the beginning of the opening of the SS.

Excess pressure at the initial stage of the explosion can be determined by the relation, which is an integral of equation (2):

$$P=\gamma\cdot\frac{4\pi\cdot(U\cdot t)^3\cdot\frac{(\varepsilon-1)}{\varepsilon}}{3\cdot V}\cdot P_0=\gamma\cdot\frac{4\pi\cdot R^3\cdot\frac{(\varepsilon-1)}{\varepsilon}}{3\cdot V}\cdot P_0. \qquad (3)$$

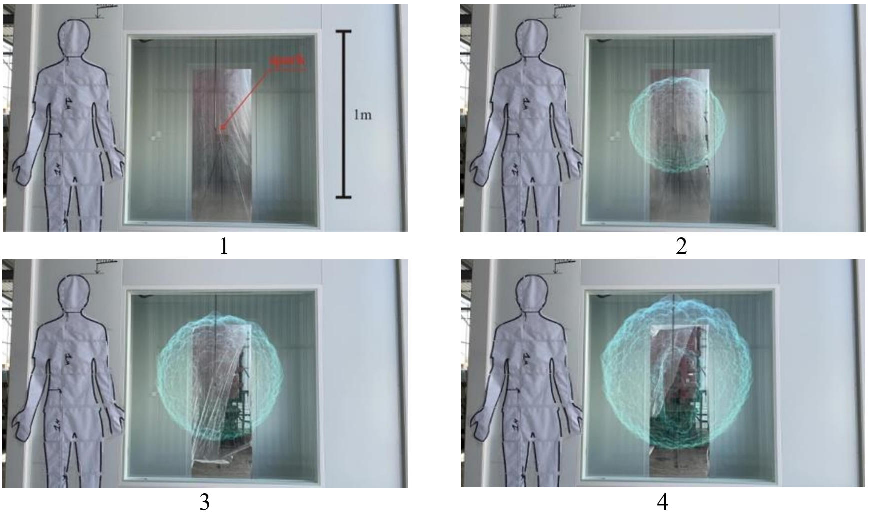
Therefore, the pressure growth rate is determined, following (2), by the flame front radius and the apparent flame velocity, and the explosive pressure, following (3), is determined by the current value of the flame front radius. Therefore, the apparent flame velocity can be determined by having a sufficiently detailed time dependence of the explosive pressure in the experimental chamber.

As shown above, the apparent flame velocity can be determined by having a sufficiently detailed time dependence of the explosive pressure in the experimental chamber. This method of experimental determination of any parameter is called the indirect method. In this case, the apparent flame speed can be determined by direct measurements, the essence of which is reduced to detailed video filming of the explosion process through the transparent edge of the explosion chamber. After that, using the available frames, it is necessary to directly measure the dimensions of the flame front and determine the speed of flame propagation by dividing the path traveled by the flame by the time interval between film frames.

For a detailed study of the explosive pressure-formed as a result of an internal deflagration explosion, it is necessary, using the available experimental data that describe the dependence of the explosive pressure on time - $P(t)$, to obtain a spectral characteristic of the overpressure - $P(\omega)$. For this, the well-known Fourier transform is used, which transfers the function from the time domain to the spectral domain. The spectral composition of the excess pressure created by the emergency explosion makes it possible to judge its destructive ability with building structures and the possibility of its perception by a person.

3 Discussion

Let us consider the process of explosive combustion of a propane-air mixture of stoichiometric composition in a cubic room [5-8] a photograph of which at the moment of ignition of the mixture is shown in the first photograph of Figure 2.



1 2 3 4

Fig. 2. Photos of several moments of explosive combustion in the room. 1 - the moment of ignition of the mixture (1 frame); 2 - frame 40; 3 - frame 50; 4 - frame 60.

The photographs shown in Figure 2 were obtained using high-speed filming at 239 frames per second, the time interval between frames was 4.18 ms. The room where the explosion was carried out is equipped with a window through which filming was made and an open doorway, which during the explosion served as a discharge opening and was closed with a film before the explosion to avoid leakage of an explosive mixture during the filling of the room with gas.

Figure 2 shows photographs of several points in time. The first photograph of Figure 2 shows the moment of ignition of the mixture; the second photograph of Figure 2 corresponds to the time 163.2 ms; the third photo corresponds to the time 205.0 ms; the fourth photo corresponds to the time 246.9 ms; the fifth photo corresponds to the moment of time 288.7 ms; the sixth photograph in Figure 2 corresponds to the time 305.4 ms.

The presence of a transparent window opening and high-speed filming of the explosion process made it possible to determine the apparent speed of the flame during the explosion. In this case, direct fixation of the apparent flame velocity was performed. To do this, the size of the explosion area was determined from the photographs obtained during high-speed filming for each moment [9-12].

As noted earlier, the flame front is an expanding sphere at the initial stage of explosive combustion. Figure 3 shows the dependence of the flame front radius on time. The dots mark the experimental values of the flame front size, determined from photographs obtained from high-speed filming. The interpolation curve obtained based on the obtained experimental points is also shown there. The interpolation was carried out by a third degree polynomial, which is sufficient for the available monotonic dependence of the flame front dimensions on time.

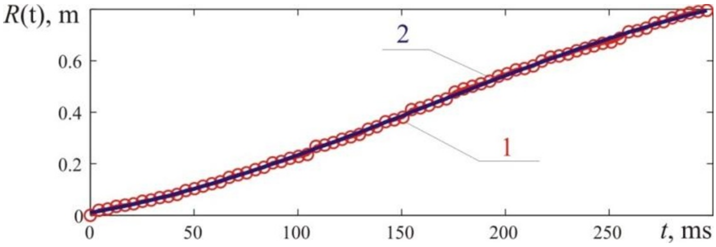


Fig. 3. Dependence of the flame front radius on time during a deflagration explosion in a room. 1 – experimental points; 2 - interpolation curve.

Figure 4 shows the apparent flame speed (curve 2 in Figure 4) obtained by differentiating the interpolation curve shown in Figure 3. The points in Figure 4 show the values of the apparent flame speed, which were obtained by differentiating the experimental values of the flame front radius shown by the dots in Figure 4. It can be seen that the formal differentiation of the coordinates of the flame front does not allow for obtaining reasonable values of the apparent flame velocity.

It follows from Figure 4 that the maximum apparent flame speed is realized approximately halfway between the ignition point (in this case, the center of the room) and the building envelope (walls, ceiling, floor). The numerical value of the maximum speed was 3.15m/s.

No significant acceleration of the apparent flame velocity associated with autoturbulization was found for such relatively small rooms.

Taking into account that the dimensions of the test room correspond to many real rooms with explosive technologies and closely correspond to the dimensions of typical kitchens (this is especially true for old projects that are mainly equipped with gas stoves), we can assume that the autoturbulization of explosive combustion in them plays an insignificant role, which can be neglected [13-17].

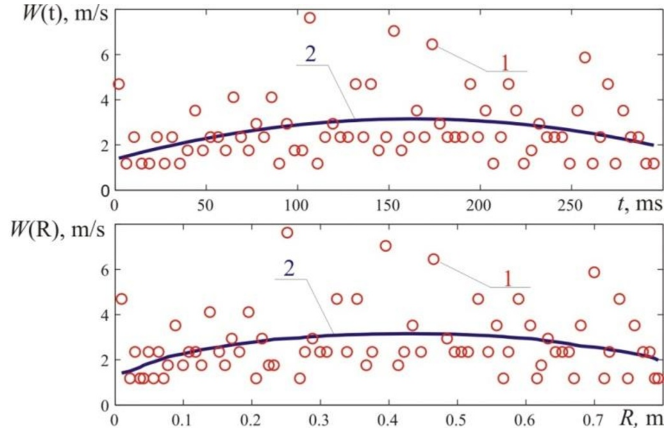


Fig. 4. The dependence of the apparent flame speed during a deflagration explosion in a room: from time (upper figure); distance (bottom figure). 1 – flame speed obtained from experimental points; 2 – flame speed obtained from the interpolation curve.

Figure 5 shows an oscillogram of the explosive pressure in the room.

Figure 6 shows a narrowband explosive pressure spectrum (bandwidth 1.25 Hz), from which it follows that the main wave energy is concentrated at low frequencies (below 100 Hz). Therefore, the actual explosive pressure is poorly perceived by a person who perceives sound vibrations starting only from 20 Hz and above.

Figure 5 (curve 2) shows the explosive pressure, cleared of high-frequency components, the frequency of which is above 250 Hz. The cutoff frequency of the high-frequency components is marked with a dot in Figure 6. It can be seen that the filtered signal practically does not differ from the initial explosive pressure oscillogram (curve 1 in Figure 5). This indicates that the measuring path is protected from extraneous noise, and, as mentioned above, the main explosive energy is concentrated at low frequencies [18-20].

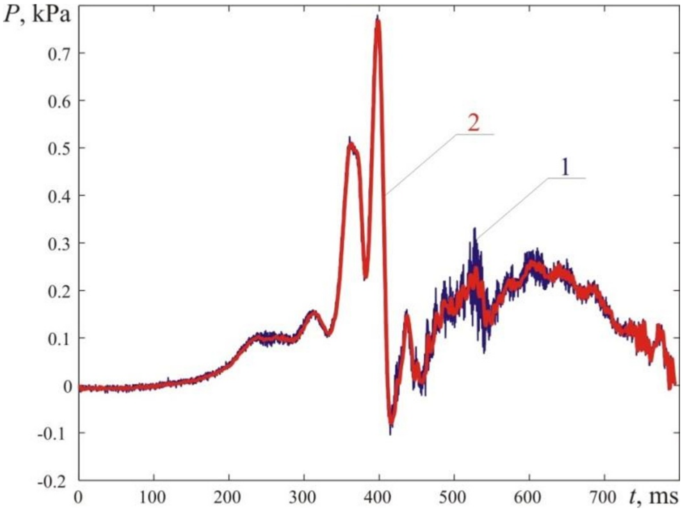


Fig. 5. Explosive pressure in the room. 1 - oscillogram of the explosive pressure in the room; 2 - explosive pressure in the room, cleared of high-frequency components, the frequency of which is above 250 Hz.

Let us consider the results of experimental studies of an internal deflagration explosion in a chamber that does not have a transparent edge, which does not allow filming of the flame front inside the chamber. The chamber is equipped with a rotary explosion venting structure (EVS), the opening of which occurs under the action of the internal pressure of the explosion. The numerical value of the pressure at which the EVS opens is not known in advance.

The main purpose of the experiment was to determine the effectiveness of EVS. The criterion for the effectiveness of EVS is the necessary release of the discharge opening from the safety structure at a certain explosion pressure. In this case, the required degree of release of the discharge opening from the safety structure is determined by the release level of the explosion's excess pressure. In turn, the release level of excess explosion pressure is determined by the allowable level of maximum pressure in a particular room.

The effectiveness of EVS was determined in a cubic chamber with an internal size of 2.15 m volume of 10 m3. A propane-air mixture of stoichiometric composition was used as a fuel. The discharge opening with an area of 1.550x1.250 m was closed with the tested EVS, the mass of which (including the frame) was 64 kg (without the frame, the mass of the sash was 50 kg). The mixture was ignited by a spark in the chamber's center. Explosive pressure was recorded by two sensors with an analog-to-digital converter polling rate of 5000 polls per second (5000 Hz), and the time step was 0.2 ms. Two cameras recorded the EVS opening process: the first camera at a speed of 500 frames per second or 2.0 ms between frames and the second camera at 130 frames per second.

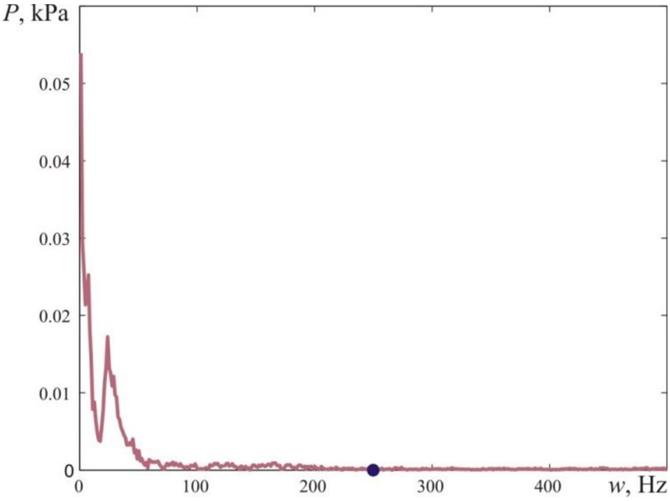


Fig. 6. Narrowband spectrum of explosive pressure in the room.

Figure 7 shows photographs taken from the second camera of four moments of testing to determine the effectiveness of EVS.

An analysis of high-speed filming photographs showed that the opening of the EVS occurs at 252 ms at an explosive pressure of 0.89 kPa.

Figure 8 shows the explosive pressure recorded in the chamber and cleaned of high-frequency components, the frequency of which is above 250 Hz.

1 2 3 4

Fig. 7. Photographs of some moments of the opening of the EVS in determining its effectiveness. 1 – 252 ms (the beginning of a noticeable shift of the EVS); 2 – 270 ms (minor EVS shift); 3 – 292 ms moment of maximum pressure (EVS displacement by about 25 mm); 4 – 338 ms.

Similarly to the previous case, it was found that the filtered signal practically does not differ from the original explosive pressure oscillogram, so the original pressure oscillogram is not presented here.

Let us analyze the experimental data on the explosive pressure shown in Figure 8.

When opening an explosion venting structure (EVS), the area of the discharge opening increases. At a certain point in time, the rate of pressure release through the opening begins to prevail over the rate of pressure increase created by the explosion. In this case, an inflection occurs in the pressure oscillogram, i.e. the derivative of the explosive pressure passing through the extremum begins to decrease. The inflection point can be determined by analyzing the pressure waveform. For this procedure, a specific section of the explosive pressure waveform was selected (between 100 ms and 300 ms), highlighted in red in Figure 8.

Figure 9 shows the results of processing this part of the oscillogram. The upper graph of Figure 9 shows a fragment of the analyzed explosive pressure oscillogram, and the lower graph of Figure 9 shows the derivative of this fragment. At the point corresponding to the time moment T = 237 ms, the derivative has a maximum, which means the fact that the pressure release rate through the opening discharge opening exceeds the pressure increase rate due to explosive combustion. It follows from Figure 9 that the maximum value of the explosive pressure derivative is realized at T = 237 ms. This instant of time corresponds to an explosive pressure of 0.74 kPa.

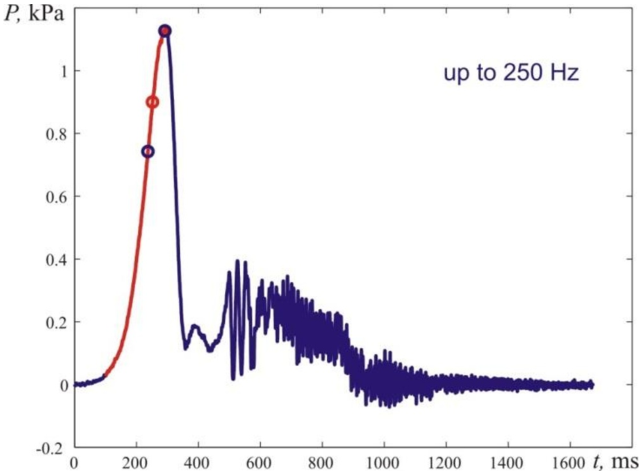


Fig. 8. Explosive pressure cleared of noise. Time: 1 – 237 ms, 2 – 252 ms, 3 – 292 ms. Pressure: 1 - 0.74 kPa, 2 - 0.89 kPa, 3 - 1.13 kPa.

Previously, by analyzing photos of high-speed filming, we found that the opening of the EVS occurs at 252 ms at an explosive pressure of 0.89 kPa. An analysis of the explosive pressure oscillogram shows that at a pressure of 0.74 kPa, pressure relief begins to occur, i.e., the discharge opening has already been opened because the rate of increase in pressure begins to fall (decrease).

Thus, the analysis of the explosive oscillogram, based on determining its inflection point, showed that the opening of the EVS occurred at 237 ms at an explosive pressure of 0.74 kPa. In other words, we can say that a significant release of pressure has begun due to the opening, which is released from the safety structure.

Figure 10 shows the results of calculating the apparent flame velocity. The upper graph of Figure 10 shows the processed section of the pressure oscillogram, the middle graph shows the apparent flame speed, and the lower graph shows the flame front radius corresponding to the current value of the flame front radius.

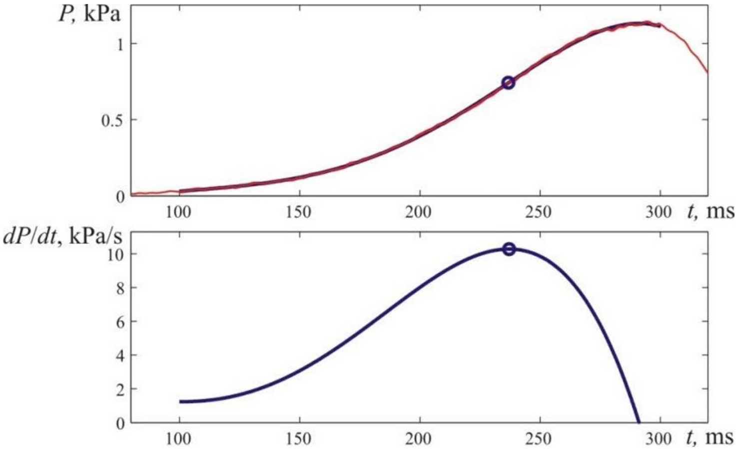


Fig. 9. The results of processing the oscillogram of the explosive pressure in the test chamber. The upper graph is a fragment of the processed waveform. The lower graph is the derivative of the waveform fragment.

The radius of the flame front (in the lower graph of Figure 10 - R_S) is found by formula (3), based on the explosive pressure function shown in the upper graph of Figure 10. Having differentiated the explosive pressure function and knowing the values of the flame front radius by formula (2) we determine the apparent flame speed, shown in the middle graph of Figure 10.

The above figure shows that the maximum value of the apparent flame speed is 4.03m/s. From 200 ms, the explosive pressure growth rate begins to decrease, which leads to a formal (according to calculations for a closed volume) decrease in the apparent flame speed, but in reality this indicates that the volume has been depressurized. With a decrease in the calculated speed by 10% (in Figure 10, the maximum level and a decrease in speed by 10% are marked with red lines) can be taken as a guaranteed opening of the EVS. This moment of time corresponds to the moment of inflection in the pressure oscillogram, i.e., approximately this happens at 237 ms at an explosive pressure of 0.74 kPa.

Thus, the analysis of the explosive pressure oscillogram, based on the determination of the apparent flame velocity in a closed volume, showed that the opening of the EVS occurred approximately at 237 ms at an explosive pressure of 0.74 kPa.

It follows from the analysis of the filming materials that the EVS has opened at 252 ms. Based on the numerical processing of the explosive pressure oscillogram, the EVS is opened at 237 ms, which differs by 15 ms from the visual analysis. It should be noted that 15 ms, by which the data of visual analysis and calculation methods differ, exactly correspond to the time interval required for the visible displacement of the EVS under the action of pressure force.

Below is an estimated calculation of the time delay due to the inertia of the EVS, which does not allow one to reliably determine the moment the structure began to move by the visual method, which is based on the analysis of the filming results [21-23].

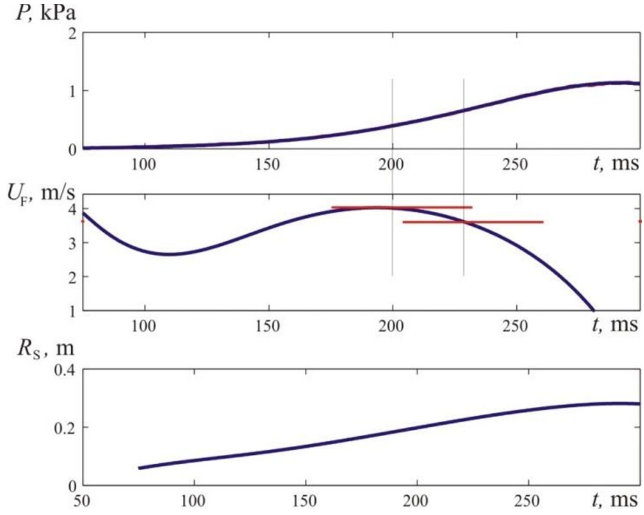


Fig. 10. Results of processing a fragment of the explosive pressure oscillogram. The upper graph is a fragment of the processed waveform. The middle plot is the apparent speed of the flame. The lower graph is the radius of the flame front.

The equation describing the rotary motion of the EVS has the form: $J\frac{d^2\omega}{dt^2}=M$ where $J=m\cdot\frac{h^2}{3}$ is the moment of inertia of the EVS; *m* – the mass of the EVS; *h* – the size of the

EVS shoulder; $M = P \cdot h \cdot \frac{L \cdot h}{2} = P \cdot h \cdot \frac{S}{2}$ - the moment of pressure force; $\omega = \frac{V}{h} = \frac{d\varphi}{dt}$ the circular speed of rotation of EVS; φ – the angle of rotation of the EVS; V – the speed of movement of the outer face of the EVS; $X = \varphi \cdot h$ - displacement of the outer face of the EVS.

Having integrated the EVS 's motion equation under zero initial conditions, we obtain the circular velocity and displacement of the EVS 's outer face $X = \varphi \cdot h = 0.75 \cdot \frac{P \cdot S}{m} \cdot t^2$. Then, assuming P = 0.9 kPa, S = 1.3 m^2, m = 50 kg, we get that to shift the outer face of the EVS by a distance visible in the photographs of X = 5 mm, a time equal to t = 17 ms is required.

4 Conclusions

The general methodology for processing experimental data on the study of deflagration explosions inside buildings and premises is given.

Examples of processing materials from experiments performed in chambers equipped with a transparent edge allow high-speed filming of the explosive combustion process inside the chamber.

The possibility is demonstrated by processing detailed data on the overpressure in the explosion chamber to obtain complete characteristics of the loads formed in the chamber during an internal deflagration explosion. The proposed technique makes it possible to abandon the explosion chamber's transparent edge and obtain data on the explosion process based on the numerical processing of the excess pressure created in the explosion chamber.

An example of processing a full-scale experiment to determine the effectiveness of a real explosion venting structure (EVS) is given. As a result of processing the experimental materials, the following data were obtained:

An analysis of photographs taken with the help of high-speed filming showed that a noticeable movement of the EVS begins at 252 ms of the explosion process. This moment corresponds to a pressure of 0.89 kPa.

An analysis of the explosive oscillogram, based on determining its inflection point, showed that the opening of the EVS occurred at 237 ms, 15 ms earlier than the visual analysis of the video materials. Numerical data processing on excess pressure in the explosion chamber showed that the discharge opening occurred at an explosive pressure of 0.74 kPa.

When processing the experimental materials, the parameters of explosive combustion inside the chamber were obtained without visual control tools. The maximum value of the apparent flame velocity was found to be 4.03 m/s.

An analysis of the explosive oscillogram, based on the determination of the apparent flame velocity in a closed volume, showed that the opening of the EVS occurred approximately at 237 ms at an explosive pressure of 0.74 kPa.

It is shown that 15 ms, by which the data of visual analysis and calculation methods differ, exactly correspond to the time interval required for the apparent displacement of the EVS under the action of the pressure force.

This work was financially supported by the Ministry of Science and Higher Education of Russian Federation (grant # 075-15-2021-686). Tests were carried out using research equipment of The Head Regional Shared Research Facilities of the Moscow State University of Civil Engineering

References

1. Bradly D. Evolution of flame propagation in large diameter explosions. In: Molkov V.V. (ed.). Proceedings of 2nd International Seminar on Fire-and-Explosion Hazard of Substances and Venting Deflagrations. Moscow, All-Russian Research Institute for Fire Protection, pp.51–59, (1997)
2. Moen I. O., Donato M. Flame acceleration due to turbulent produced by obstacles. Combustion and Flame, 31:21-30, (1980)
3. Solberg D. M. Observations of flame instabilities in large scale vented gas explosions. 18-th Symposium (International) the combustion institute, 1607-1614, (1980)
4. Molkov V. V., Grigorash A. V., Eber R. M. Vented gaseous deflagrations: Modelling of springloaded inertial vent covers. Fire Safety Journal, vol. **40**, issue 4, pp. 307–319, (2005) DOI:10.1016/j.firesaf.2005.01.004
5. C. Regis Bauwens, Jeff Chaffee, Sergey Dorofeev. Effect of Instabilities and Acoustics on Pressure Generated in Vented Propane-Air Explosions. 22nd ICDERS July 27-31, Minsk, Belarus, (2009)
6. V A Gorev. Scale model operation of formation of pressure at internal explosion. IOP Conf.Series: Journal of Physics: Conf. Series 1425, (2020) 012177 doi:10.1088/1742-6596/1425/1/012177.
7. Komarov A.A., Korolchenko D.A., Gromov N.V., Korolchenko A.D. Specifics of explosion-venting structures providing acceptable indoor explosion loads. Applied Sciences (Switzerland), **12,** № 1, (2022) DOI: 10.3390/app12010025
8. Polandov Yu.Kh., Babankov V.A. Influence of the location of the ignition source in the room on the development of a gas explosion. Pozharovzryvobezopasnost/Fire and Explosion Safety, 23(3):68-76, (2014)
9. Komarov A.A. Forecasting loads from emergency deflagration explosions and assessing the consequences of their impact on buildings and structures. Dissertation for the degree of Doctor of Technical Sciences. M. MGSU, 460 p., (2001)
10. Pilyugin L. P. Obespecheniye vzryvoustoychivosti zdaniy s pomoshchyu predokhranitelnykh konstruktsiy [Maintenance explosion proof buildings with relief designs]. Moscow, Pozhnauka Publ., 224 p, (in Russian) (2000)
11. Gorev V. A., Korolchenko A. D. The effect of venting structures on overpressure caused by an indoor explosion. Pozharovzryvobezopasnost/Fire and Explosion Safety, 31(3):12-23, (In Russian) (2022) DOI: 10.22227/0869–7493.2022.31.03.12-23
12. Korolchenko O.N., Korolchenko A.D. Determining the burst pressure of vent structures with account taken of wind loads. Vestnik MGSU [Monthly Journal on Construction and Architecture]. 17(7):914-921, (In Russian) (2022) DOI: 10.22227/1997-0935.2022.7.914-921
13. Konstantinov A.P., Korolchenko A.D. Features of the use of easily dumped window structures in gasified residential buildings. Stroitel'nye Materialy [Construction Materials]. No. 5, pp. 37–43, (In Russian) (2021) DOI: https://doi.org/10.31659/0585-430X-2021-791-5-37-43
14. Orlov G.G., Korolchenko A.D. Loadings which destroy building structures in consiquence of emergency explosions. Pozharovzryvobezopasnost/Fire and Explosion Safety, 25(3):45-56, (In Russ.) (2016) https://doi.org/10.18322/PVB.2016.25.03.45-56
15. Shleg A.M. Determination of the parameters of easily dropped structures. Dissertation for the degree of candidate of technical sciences.–M.: MGSU, 2002.–201p, (2002)

16. Komarov, A, Gromov, N. Experimental observation of visible flame propagation rate in accidental deflagration explosions and explosive load reduction. (IPICSE-2018) MATEC Web of Conferences 251, 02024, (2018) DOI: 10.1051/matecconf/201825102024
17. Komarov, A., Gromov, N., Sokolova, Y. Assessing destructive capacity of impulse loads. (IPICSE-2016) MATEC Web of Conferences 86, 01023, (2016) DOI: 10.1051/matecconf/20168601023
18. Polandov Yu.K., Korolchenko D.A., Evich A.A. Conditions of occurrence of fire in the room with a gas explosion. Experimental data. Pozharovzryvobezopasnost/Fire and Explosion Safety, 29(1):9-21, (In Russ.) (2020) DOI: 10.18322/PVB.2020.29.01.9-21
19. Korolchenko D., Polandov Iu.K., Evich A. On ignition of combustible material in a gas explosion in the premise. (FORM 2020) IOP Conf. Ser.: Mater. Sci. Eng. 869 052056, (2020) DOI: 10.1088/1757-899X/869/5/052056
20. Polandov Yu.K., Korolchenko A.D. On conditions enabling resonant combustion in gas explosion in non-enclosed volume. Pozharovzryvobezopasnost/Fire and Explosion Safety. 27(7-8):9-23, (2018) DOI: 10.18322/pvb.2018.27.7-8.9-23
21. Korolchenko D., Polandov Iu.K., Evich A. Dynamic Effects at Internal Deflagration Explosions. (WMCAUS 2019) IOP Conf. Ser.: Mater. Sci. Eng. 603 052008, (2019) DOI: 10.1088/1757-899X/603/5/052008
22. Komarov A. A., Korolchenko D. A., Phan Tuan Anh. Features of determination of the dynamic amplification factor under impulse loads. Pozharovzryvobezopasnost/Fire and Explosion Safety, vol. **27**, no. 2-3, pp. 37–43 (in Russian) (2018) DOI: 10.18322/PVB.2018.27.02-03.37-43
23. Polandov Iu., Korolchenko D. The consideration of the turbulence influence on the gas explosion expansion in non-closed areas. MATEC Web of Conferences, vol. **106**, art. 01040, 8 p., (2019) DOI:10.1051/matecconf/201710601040