Simulation of Conditions for Detonation Initiation in Unconfined Space with Use of Accelerated Jet Stream

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1 Introduction

The compact device of a periodic detonation initiation in unconfined volume that does not use solid explosives has been elaborated to solve the initiation problem at the method of an explosive minefield clearance. This device was designed and manufactured to generate a detonation into the mixture which is formed into the exhaust gases of the tank engine. A detonation tube equipped with a pulse accelerator of a gas stream behind the detonation wave front in the moment when the wave is going out in unconfined volume is a basis of technical decision.

The conditions of plane wave conversion into spherical one have been considered, for example, in [1]. It is well-known that there is a critical diameter of the detonation tube providing of the further detonation propagation in unrestrictedly large volume. The diameter depends upon detonation cell size λ and it equals $(12\div13)\lambda$. The diameter can differ for mixtures. The process of deflagration to detonation transition takes place at the distance about several tube diameters into the tube. Application of detonation tubes having lengths about several meters is needed to initiate a detonation in unrestricted space by detonation cell size more than 50 mm. Such tube size leads to restriction of the tube using in elaborated method of the minefield clearance.

The conditions of jet detonation initiation in unconfined volume have been studied, for example, in [2]. The mechanism of stream detonation initiation still remains as an issue. Nevertheless it has been determined that the vortexes intensification promotes a detonation formation. It is well known that under expanded stream during the outcome process forms the regions of "back-streams" that leads to the large-scale vortex of the gas stream. Thus the formation of extra-compressing detonation wave in the edge of the tube is assumed in the elaborated device. The additional pulse compression of the wave is created due to effect of "plasma piston".

The results of mathematical simulation of shock wave formation and evaluation into unrestricted volume near the tube edge by different regimes of pulse acceleration of the stream behind the wave are presented. The goal of this simulation was determination of conditions by which the shock wave intensity is keeping during the time interval when the spherical shock wave passed through several detonation cells.

2 The ground state principle of spherical detonation initiation by the accelerated stream

It is supposing that collapse of spherical detonation in conditions of detonation initiation with use of detonation tubes could be explained by following reason. The plane shock wave is transforming into spherical one at the end of tube. At the same time the law of shock wave fading is changing in dependence on passed distance. I.e. the intensity of wave does not decrease proportionally the distance but proportionally to the square of distance. These circumstances lead to following. The indispensable intensity of shock wave does not remain stable during the period of wave passing the distance equal to the length of detonation cell. This is main factor of detonation collapse. In a similar manner of detonation appearing in detonation tube where the detonation appears as the result of intensity increasing of series of blast waves, in elaborated device the detonation is exciting due to following procedure. In our facility in the moment of detonation wave outcome from the tube (1, see Fig. 1) the plasma piston (2) is forming in detonation materials, this piston is accelerated by means of electro dynamical forces and compress the detonation exhaust materials to the spherical wave front . Obviously in this case the piston velocity U_1 has to be more then velocity of shock wave expansion U_2. The compensation of pressure decreasing after the wave front is occurring in this situation during the wave expansion.

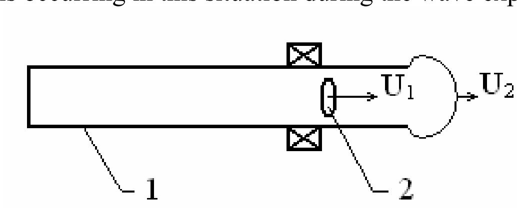

Fig.1. The scheme of the device for spherical detonation initiation by the accelerated stream

The spatial and temporal features of energy deposition influence on the process of detonation initiation. According to work [3], initiation energy E of multifront detonation is proportional to energy E_0 of detonation initiation into the elementary detonation cell:

$$E = n^* E_0, \tag{1}$$

where n^* is a coefficient of proportion characterizing the minimum number of micro explosions which are able jointly to generate a multifront wave.

Thus, it is possible to define minimum energy which must be deposited by electrodynamic acceleration of shock wave to initiate a spherical detonation via calculation of the difference between the initiation energy of multifront detonation and total energy of micro explosions generated by shock wave which goes out of the detonation tube having smaller diameter than the critical one. It is necessary to provide the high values of parameter characterizing of a volume power of energy input too.

3 Mathematical Model

Basic equations. The following assumption concerning the fact that the convective mass exchange has the main influence on the considered gas dynamical process has been accepted as the result of structure fluid stream analysis and compete mathematical model decomposition. It is enough to use the truncated Navier-Stokes equations by means of neglecting of viscous terms (Eulerian approximation with source terms) for description of two-component gas mixing process [4, 5].The turbulent diffusion coefficient in the equation for admixture concentration changing was defined in accordance with algebraic model proposed by M.E. Berlyand.

Simulation region is the parallelepiped with rectilineal generators and replaced in right Cartesian system. The simulation region is divided onto space cells with planes sizes are fitted in agreement with ones of distinctive peculiarities of the above simulation region (roughness of the streamlined surface, dimension of streamlined objects). The study object is performed in the nozzle shape. The gas outcome is occurring from the nozzle outlet with given consumption.

Boundary and initial conditions, algorithm of numerical simulation. The boundary conditions on the income zone have been assigned on the surface planes of simulation cells, that are in contact with boundaries of simulation regions and through which the atmospheric air is coming. The approach stream on the inlet has been determined by the following values: total enthalpy, entropy function, the direction of stream velocity vector, relative specific mass density of admixture Q ($Q \leq 1$ if the gas admixture is incoming). The law of admixture outcome consumption changes was assigned on the permeable boundaries. In outcome regions the atmospheric pressure was assigned as well. The environment parameters were assigned in all “gaseous” cells of simulation region in the initial moment. The algorithm of numerical simulation of main equations has been elaborated on the base of conservation laws with use of scheme of collapse of arbitrary break. The aggregate of gas dynamical parameters in all cells in any moment was determined in the frameworks of integral-interpolation approach proposed by S.K. Godunov. The stability of finite-difference scheme was provided by the corresponding time step choice.

4 Results of simulation.

The simulation results of jet outcome phenomena are performed on Fig. 2-4 by accepting of laws for increasing and decreasing consumptions. For these cases the laws of velocity changes on the detonation tube exit have been assigned in the form:

$$U_{11}(t) = U_0(50U_0t+1)^{\frac{3}{5}} \text{ if } 0 \le t \le 40 \text{ µs and } U_{11} = U_{11}(40\cdot10^{-6}) \text{ if } t > 40 \text{ µs}, \quad (2)$$

$$U_{12}(t) = U_0(50U_0t+1)^{\frac{-3}{5}}, \quad 3)$$

where U_0 = 800 m/s.

Expression (2) models a condition of the electrodynamic acceleration of shock wave via acceleration of gas stream into the exhaust tube. Expression (3) shows a condition without the acceleration.

At the same time it has been assumed that the values of specific gas density at the tube exit are keeping constant. The diameter of outcome nozzle was equal to 100 mm.

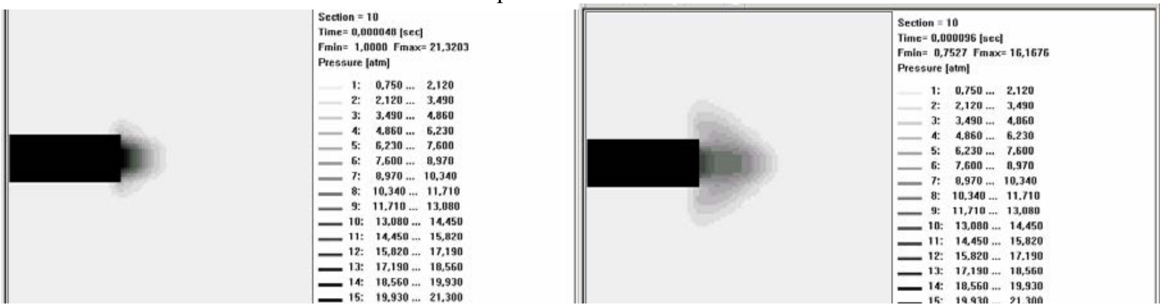

Fig.2.The field of pressure distribution in the stream if the exit stream velocity is $U_{11}(t)$.

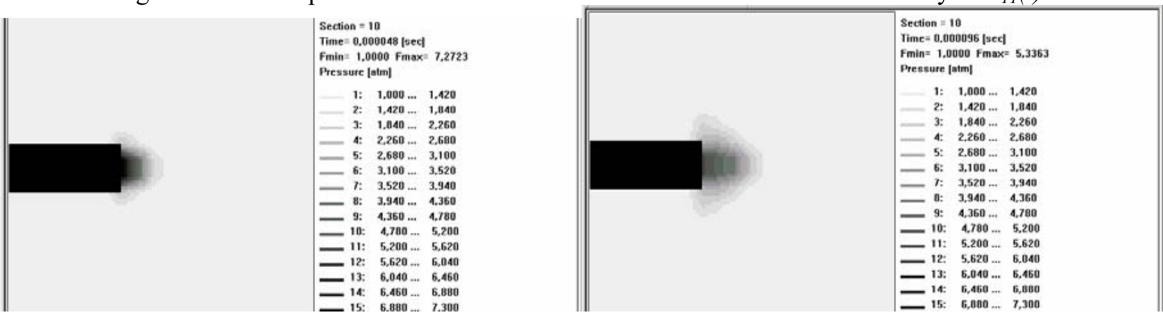

Fig.3.The field of pressure distribution in the stream if the exit stream velocity is $U_{12}(t)$.

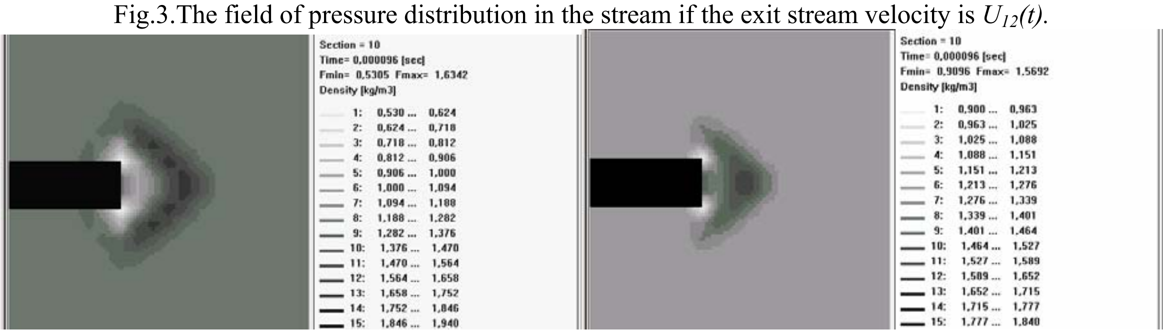

Fig.4. Comparison of density fields with different dynamics of stream outcome (left - $U_{11}(t)$, right - $U_{12}(t)$).

It has been determined that the surface shapes of perturbed gas volumes are practically concurred one with another in the same moment and this is the result of gas parameters comparison that were obtained during the process of evaluation of accelerated and not-accelerated streams But there are quality differences and peculiarities within the perturbed volumes. The intensive pulse head of gas right after the stream front provides the short-duration "retention" of thermo-dynamical gas properties in the conditions of spherical front of disturbances propagation. The velocity of perturbed volume expansion is increasing slightly in the case of stream acceleration. This effect leads to increasing of gas thermo-dynamical properties in the region behind the spherical front of the shock wave (fig 5).

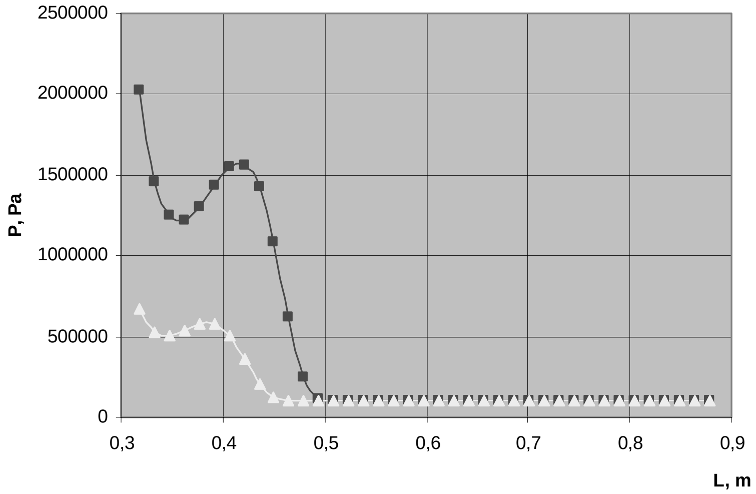

Fig. 5. Pressure distribution along axis by the steam acceleration according to expression (2) is shown on overhead line and without one (lower line). Estimated time is 91 µs

5 Experimental stydy.

The experimental investigations have been conducted for studying of dynamical processes of stream outcome with diameter of nozzle exit equal to 2 mm. Intensive pulse stream acceleration in this case has been provided by the Joule heating of gas with use of pulse electric arc. The specific gas density in the discharge cavity was more then the one in stream region. The volume of cavity has been selected with requirement to provide the density decreasing not more then 10 percent during the gas pulse acceleration. The dynamic of stream evolution is performed on Fig. 6.

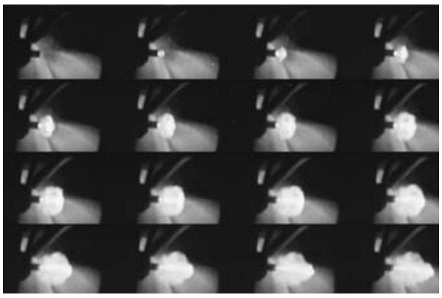

Fig.6. Outcome evaluation of pulse accelerated plasma stream into environment. Duration between shots is 8 micro seconds

The experimental data verify the supposition that the intensive pulse head of stream leads to stream shape changes and this is the quality verification. The self-spherical perturbed region expansion is observing.

6 Conclusions

1. The realization of flow acceleration behind the shock wave front allows initiating a detonation in unconfined volume by using of the detonation tube having the tube diameter which is smaller than the critical one.
2. The elaborated mathematical model can calculate a necessary regime of the stream acceleration in dependence on the detonation tube diameter.

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