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Tomography of the flow field of detonation product using SR

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ABSTRACT

The method of extracting the parameters of gas steady-state flow (velocity field and pressure) from the spatial distribution of density known from experiment is described. The method is based on solving the equations of continuity and motion and does not require any information about the state equation. Using the data of high-speed X-ray density tomography, the spatial distributions of the velocity vector and pressure for the steady-state detonation of cylindrical charges of the pressed mixture of TNT with RDX were obtained.

1. Introduction

The procedure of high-speed X-ray tomography of density developed by us [1,2], based on raying the sample under investigation with the synchrotron radiation, allows one to record the distribution of the density $\rho(r,z)$ of detonation products of the cylindrical charges of condensed explosive. Here ρ is density, r, z are the radial and longitudinal coordinates. Using these data one may formulate the problem of extracting other flow parameters, that is, the fields of the mass velocity vector and pressure. To solve this problem, we may use a system of the equations of steady-state gas dynamics:

$$\mathrm{div}(\rho\vec{v}) = 0 \tag{1}$$

$$\mathrm{div}(\rho v\vec{v}) + \nabla p = 0. \tag{2}$$

The equation of energy conservation is not used; it is not necessary to know the equation of state of detonation products. Such a formulation is non-conventional for solving the problems of gas dynamics; generally, it is necessary to analyze the possible correct formulation of the problem. In the case under consideration, the problem becomes simpler because the flow is potential in the steady-state case. So, system (1), (2) is broken into two independent equations which are to be solved consecutively.

2. Scheme of experiment

To determine the spatial distribution of density in the products of detonation of a cylindrical charge of condensed explosive, we used the X-ray tomography procedure described in Refs. [1,2]. In experiment, an X-ray shade of the detonating charge was captured consecutively in the specific section at a 0.5 μs step between the frames (Fig. 1). The characteristics of the X-ray radiation detector used in the investigation were described in detail in Ref. [3].

The amount of rayed mass along the ray was determined on the basis of weakening of the X-ray radiation flow using the corresponding calibration.

3. Density imaging

Detonation of pressed charges made of a mixture of TNT with RDX at a ratio of 50:50% with the initial density of 1.7 g/cm^3 was used in the work; detonation velocity was $D = 7.6$ km/s. The diameter of charges was 15 mm, the distance from the initiated end to the measurement section was 60 mm. Initiation was carried out with a plane wave generator.

Since the process is steady-state, the data are represented using a connection between time t and the spatial coordinate $Dt = z$.

The data obtained in the experiment are presented as a surface ρd in Fig. 2.

The methods of density tomography of static objects have been successfully developed by present. For dynamically changing objects, they are used with a smaller success in gas dynamics and plasma physics to determine temperature and density [4], and also in the pulse X-ray examination of density [5]. Almost in all

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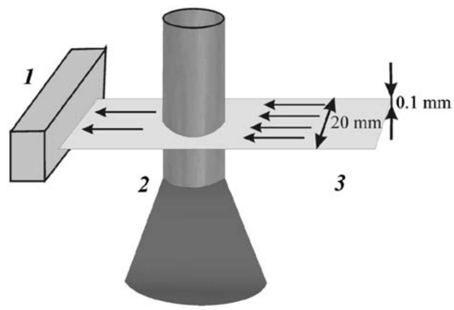

Fig. 1. A scheme of the X-ray experiment: 1—one-dimensional detector Dimex, 2—the charge of explosive under investigation, 3—synchrotron radiation ray.

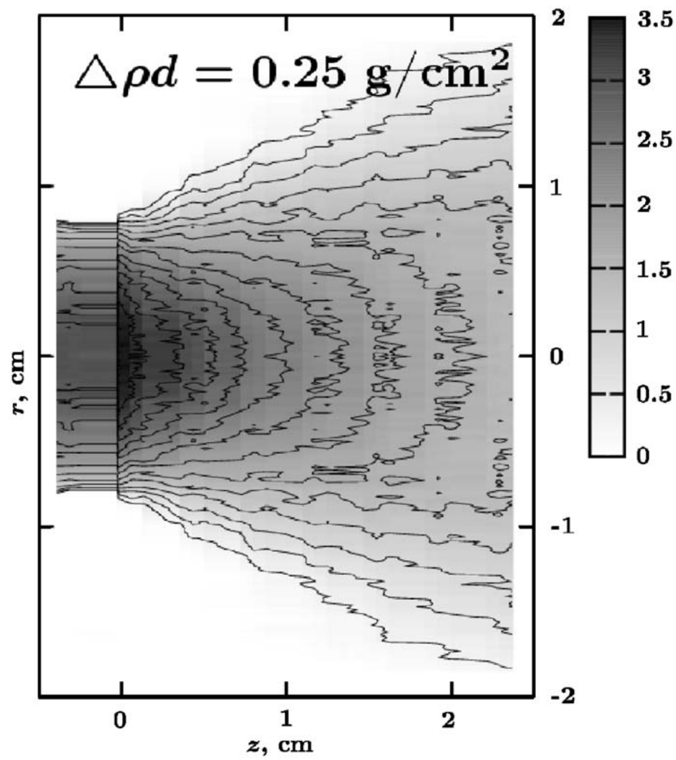

Fig. 2. Spatial distribution of the rayed matter (ρd, g/cm^2).

the cases, it is impossible to obtain the experimental data taken from several positions and with good accuracy. Because of this, the choice of an algorithm of recovery which would be stable against errors and allow efficient use of the a priori information about the object under investigation is principally important for the high-quality recovery of density.

A method of density recovery on the basis of a shade from the object under investigation proposed in Refs. [1,2] is based on regularization and uses the a priori information about the kind of the target function. This method allows one to achieve a good accuracy of the recovery of density, $\rho(r,z)$, which is necessary to recover velocity and pressure. Using this method, we have recovered the density $\rho(r,z)$ of the spreading explosion products (Fig. 3).

The distribution of density over the charge axis is shown in Fig. 4. Here $z=0$ corresponds to the position of the front of detonation wave; the density at negative z corresponds to the initial density of the charge; positive z values relate to explosion products. Insufficient accuracy of the temporal and spatial resolutions of the procedure does not allow one to carry out

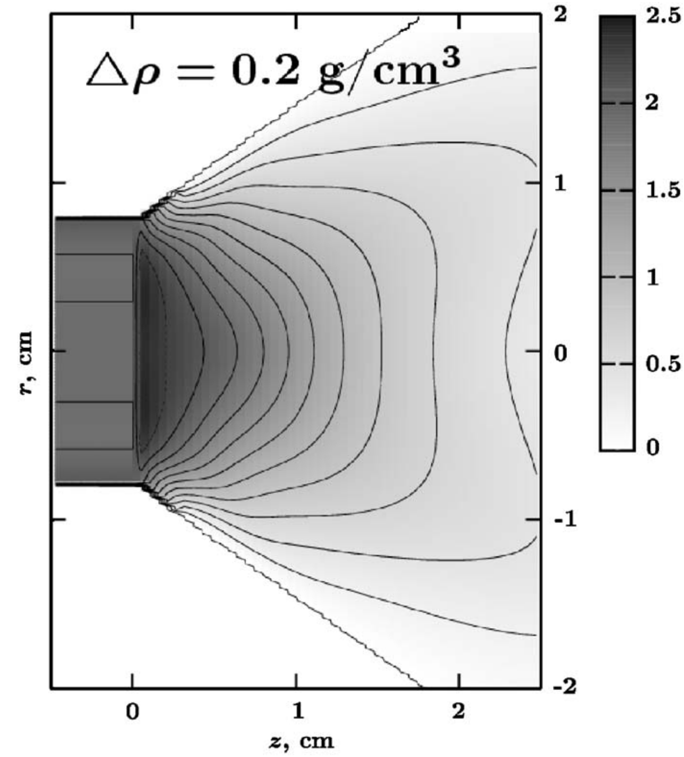

Fig. 3. Spatial distribution of density (ρ, g/cm^3).

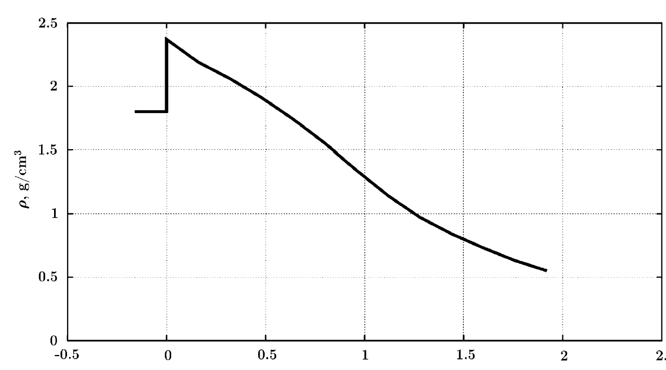

Fig. 4. Density at the axis of charge.

measurements in the energy evolution zone, and a density jump at the front corresponds to Chapman–Jouguet detonation parameters.

Estimations show that the density is measured with the accuracy of 0.1 g/cm^3.

4. Recovery of the velocity distribution

Now, using the obtained density distribution $\rho(r,z)$, it is necessary to recover the field of the mass velocity vector. Eq. (1) will be used for this purpose. Let us introduce the scalar potential of velocity $\varphi(r,z)$, $\vec{v} = \nabla\varphi$, then Eq. (1) leads to the following Laplace equation:

$$\mathrm{div}(\rho\nabla\varphi) = 0. \tag{3}$$

Then, it is necessary to solve Eq. (3) in the axisymmetric region occupied by the flow under investigation, with the corresponding boundary conditions.