METHOD FOR DESIGNING EXPLOSION CHAMBERS

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An explosion chamber is a hermetically sealed volume of arbitrary shape. After an explosion in an evacuated chamber, the shell is bombarded with explosion products; after an explosion in a chamber containing some medium, the shell is subjected to a shock wave. In both cases, the shell is subjected to a pressure impulse. There are two steps involved in the design of the chamber shell: 1) determining the magnitude of the impulse per unit area of the chamber wall under the assumption that the chamber is absolutely rigid, and 2) determining the strain which results in the wall of a real chamber.

1. Dimensional approach to the problem. We assume that in an infinite cylinder, or in a spherical shell, with absolutely rigid walls, an infinitely long cylindrical charge or a spherical charge, respectively, is detonated. The charge is assumed to lie along the cylinder axis or at the center of the sphere. There is a functional relationship among the parameters describing the effect on the shell:

$$F(I,\ E_0,\ p_1,\ \rho_0,\ \rho_1,\ r_0,\ R,\ \gamma_0)=0. \tag{1.1}$$

We assume this relation can be solved for one of the parameters, and that we can rewrite it as

$$\frac{I}{r_0\rho_0\sqrt{kQ_0}}=\Phi\left(\frac{p_1}{k\rho_0Q_0},\ \frac{R}{r_0},\ \frac{\rho_1}{\rho_0},\ \gamma_0\right). \tag{1.2}$$

In (1.2), the explosion energy is

$$E_0=kr_0\rho_0Q_0.$$

For a compact charge, Eq. (1.2) can be rewritten in the form

$$\varphi=\varphi(\eta),\qquad \varphi=I/r_0\rho_0\sqrt{kQ_0}\qquad (\eta=R/r_0). \tag{1.3}$$

The natural dimensionless parameter for modeling the stress on the chamber wall is thus η.

2. Experimental results. Experiments were carried out only in cylindrical explosion chambers, both evacuated and not evacuated, with cylindrical chargers. Figure 1 shows values of the function $\varphi = \varphi(\eta)$ calculated from the experimental results according to (1.3). The impulse I is given by

$$I=\int_0^{t_0} p(t)\,dt. \tag{2.1}$$

The oscillograms in Fig. 2 show the time dependence of the pressure p, with a marker frequency of f = 500 kHz. Those on the left were obtained during explosions in vacuum, and those on the right were obtained with air in the chamber (p_1 = 1 atm). These oscillograms were obtained by means of piezoelectric transducers and an oscilloscope for

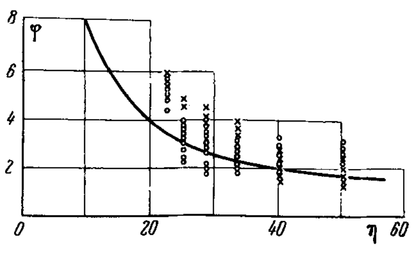

Fig. 1

the pressure at the inner surface of the chamber wall after the explosion of a charge of a given radius r_0. The area under the curve in each oscillogram was calculated numerically and multiplied by the scale factors α_p and α_t, yielding the impulse I. Integral (2.1) can be written

$$I=\alpha_p\alpha_t\int_0^{x_0} y(x)\,dx\qquad\left(\alpha_p=\frac{p(t)}{y(x)},\ \alpha_t=\frac{t}{x}\right). \tag{2.2}$$

Here the factor α_p, found during the calibration of the piezoelectric transducer, and α_t are dimensionless quantities. The average pressures and dimensionless impulses found during the explosion of RDX charges having a density ρ_0 = 1.21 g/cm^3, a length L = 105 cm, and various radii are as follows:

$r_0 =$	0.4	0.5	0.6	0.7	0.8	0.9
$P =$	$\frac{190}{170}$	$\frac{210}{260}$	$\frac{290}{420}$	$\frac{490}{650}$	$\frac{630}{780}$	$\frac{1050}{1150}$
$\varphi =$	$\frac{2.5}{1.7}$	$\frac{2.7}{2.2}$	$\frac{2.9}{3.5}$	$\frac{3.3}{4.1}$	$\frac{3.8}{4.7}$	$\frac{5.3}{6.0}$

The pressures and impulses in the numerators of the fractions are for explosions in vacuum, while those in the denominators are for explosions with air in the chamber.

3. Experimental. The pressures and impulses at the chamber walls were determined with the experimental apparatus shown schematically in Fig. 3: 1) oscilloscope; 2) tube; 3) camera; 4) marker-signal oscillator; 5) transducer for triggering the oscilloscope; 6) transducer for pressure measurements; 7) explosion chamber; 8) vacuum gauge valve; 9) vacuum line valve; 10) cathode follower; 11) power supply; 12) detonator leads; 13) electrical detonator; 14) explosive. The explosion chamber was a cylindrical vessel 1.6 m long and 2R = 200 mm in diameter; it had a wall thickness δ = 10 mm, and a hemispherical bottom covered with a hemispherical cover. The piezoelectric transducers were described in [1].

4. Semiempirical equation for the impulse. With Q_0 representing the specific energy of the explosive, a mass $M = \rho_0V_0$ of explosive contains an energy $E_0 = \rho_0V_0Q_0$, where V_0 is the explosive volume. After the explosion of a charge of mass M, the energy E_0 ultimately appears as kinetic energy of the escaping explosion products (for an explosion in an evacuated chamber), or as the kinetic energy per unit mass of the gas moving behind the shock wave front (for explosion in a chamber containing air), and as the heat carried by the explosion products. We can thus write

$$E_0=\int_0^M \frac{v^2}{2}\,dm+Q. \tag{4.1}$$

where we have assumed [2] that the mass of the gas moving behind the shock wave front is equal to the charge mass M.

From the law of the mean, we have

$$\int_0^M \frac{v^2}{2}\,dm=\frac{v_m^2}{2}M, \tag{4.2}$$

where v_m is the explosion-product velocity or the average gas velocity behind the shock wave front, averaged over the radius in either case.

Since most of the heat released during the reaction is converted into elastic-repulsion energy in the compressed explosion products [3], and is then converted into the kinetic energy of the escaping products or the kinetic energy of the gas moving behind the shock front, the temperature of the explosion products turns out to be low; i.e., the

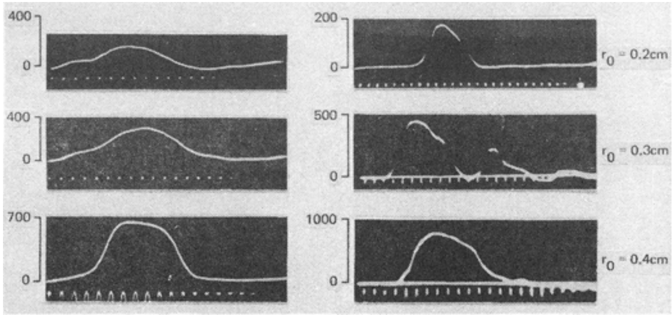

Fig. 2

second term on the right-hand side of (4.1) may be neglected. We are left with

$$E_0 = M\frac{v_m^2}{2}. \qquad (4.3)$$

The kinetic energy [3] is imparted to the chamber shell in the form of an impulse $I^* = \sqrt{2ME_0}$; the impulse per unit area of the shell is $I_0 = I^*/S$. The actual impulse received by unit area of the shell is $I = I_0\alpha$. The coefficient α shows the extent of gas reflection from the wall ($1 \le \alpha \le 2$), and is found empirically. The space charge is $V_0 = kr_0^\nu$, and the shell area is $S = \nu kR^{\nu-1}$. Substituting I_0, I^*, S, M, V_0, and E_0 into $I = \alpha I_0$, we find

$$I = (\alpha/\nu)\,\eta^\nu R\rho_0\sqrt{2Q_0}. \qquad (4.4)$$

An analogous equation for the impulse was found in [4]. We can convert impulse (4.4) into dimensionless form by dividing it by $r_0\rho_0\sqrt{kQ_0}$; i.e., we find the function

$$\varphi = \frac{\alpha}{\nu}\,\eta^{\nu-1}\left(\frac{2}{k}\right)^{1/2} \qquad \left(\eta = \frac{R}{r_0}\right). \qquad (4.5)$$

Figure 1 shows a $\varphi = \varphi(\eta)$ curve calculated for the cylindrical case with $\alpha = 2$. Equation (4.4) is seen to hold for the impulse I received by the wall in evacuated explosion chambers for $\eta \ge 25$, and in air-filled chambers for $\eta \ge 40$.

Comparing the time t_0 during which the pressure acts on the walls with the periods T of the eigenvibrations of typical chambers, we find that, generally, $t_0 \ll T$. Under this condition, the strain in the structure and in its individual elements is governed, not by the pressure magnitude, but by the corresponding impulse.

5. Basic equations for calculations. Axisymmetric vibrations an infinite thin cylindrical or spherical shell are described by

$$\ddot{u} + \omega^2 u = AP(t), \qquad A = \frac{1}{\rho\delta},$$
$$\omega^2 = \frac{E}{\rho R^2}, \quad \omega^2 = \frac{2E}{(1-\mu)\rho R^2}. \qquad (5.1)$$

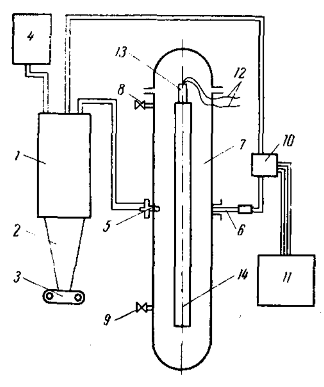

Fig. 3

The first equation in (5.1) for ω^2 corresponds to the cylindrical shell, and the second corresponds to the spherical shell; also, μ is the Poisson ratio, ρ is the density of the shell material, and u is the displacement.

A solution of this equation for the initial velocity $\dot{u} = AI$ and for zero initial displacement, which correspond to a stress which is effective only briefly in comparison with the period of the eigenvibrations, is

$$u = \frac{AI}{\omega}\sin\omega t, \qquad u_{max} = \frac{AI}{\omega}, \qquad (5.2)$$

where u_{max} is the maximum shell displacement.

Explosive charges of a variety of shapes are encountered in practice. A charge for which one dimension is several times as great as the other two may be treated as "cylindrical," where the long dimension is the length of the cylinder, and r_0, the reduced radius, is

$$r_0 = \left(\frac{ab}{\pi}\right)^{1/2},$$

where a and b are the other two (smaller) dimensions of the charge. A cylindrical explosion chamber is more convenient for such charges. A charge having three roughly equal dimensions may be treated as "spherical," the reduced radius r_0 of the sphere being found from

$$r_0 = \left(\frac{3abc}{4\pi}\right)^{1/3},$$

where a, b, and c are the dimensions of the actual charge.

Using Hook's law for $\alpha = 2$, we find equations useful for designing explosion chambers from (4.4) and (5.2):

$$\sigma_d = \frac{\rho_0 r_0^2\sqrt{2Q_0E}}{R\rho\delta a_0}, \qquad \sigma_d = \frac{2}{3}\left(\frac{1}{1-\mu}\right)^{1/2}\frac{\rho_0 r_0^3\sqrt{Q_0E}}{\rho R^2\delta a_0}. \qquad (5.3)$$

The first of these is for use in designing cylindrical chambers, and the second is for spherical ones. Here σ_d is the dynamic stress arising in the chamber shell during the explosion, and a_0 is the velocity of sound in the shell.

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