Metal explosion chambers: designing, manufacturing, application

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Abstract. Designing of explosion chambers is based on research investigations of the chamber body stress-strain state, which is determined by numerical computation and experimentally by the strain gage technique. Studies show that chamber bottoms are the most loaded elements, and maximal stresses arise in chamber poles. Increasing the shell thickness around poles by welding-in an insert is a simple and saving way to solve this problem. There are structural solutions, enabling reliable hermetic closure and preventing leakage of detonation products from the chamber. Explosion chambers are employed in scientific research and in different industrial applications: explosive welding and hardening, synthesis of new materials, disposal of expired ammunition, and etc.

1. Introduction
Explosion chambers are the special facilities for containment of explosion effects, such as shock waves, fragments, toxic detonation products, and seismic waves. Metal explosion chambers can localize all the listed effects and can be mounted in ordinary industrial or laboratory premises. The review of published works on the concerned subject can be found in [1]. The nominal explosive charge mass for which chamber is designed is usually specified in trotyl (TNT) equivalent. The main part of explosion chamber is its body in a form of metal shell, which mostly consist of main cylindrical part and two bottoms (generally spherical or elliptical) attached to the said cylinder by welding or via the bayonet lock. Dynamic stresses in such composed shell were considered in [1], but for the case of their uniform distribution. In reality stress distribution in the shell is not uniform, and shell poles (bottom centres) are the mostly loaded places. The present studies are focused on the methods permitting to reduce the stresses in shell poles and to obtain close to uniform stress distribution. Besides, examples of explosion chambers and their application are given.

2. Theoretical considerations and stress metering
Hermetic shell is a main structural element of explosion chamber. Among the shells of different types, non-spherical ones are most common; as a rule they consist of a cylindrical part and two spherical or non-spherical, generally elliptical, bottoms. These shells have a number of technological advantages as compared to spherical ones, but at the same time have an increased weight resulting from the not uniform stress distribution due to the “swinging” effect arising at shell vibrations, even in case of uniform loading. Theoretical and experimental studies show that bottoms are the most loaded elements, and the maximal stresses determining the chamber lifetime emerge in bottom poles [2-4]. To
make bottoms of not even thickness is a way to reduce stresses in poles and to obtain the more uniform distribution of stresses in the chamber shell. For this, there is the simplest and most saving method – to weld-in inserts of increased thickness into bottom poles. In this connection, the important problem is to find the radius of insert with the known thickness which would provide the most uniform stress distribution in the shell elements. Numerical analysis of the problem relating to the determination of the insert optimal radius has been carried out on the base of equations [5] with the use finite-element method [6].

Figure 1 presents the dependence of the maximal values of equivalent stresses $\sigma_{\text{eff}}$ in the shell pole with embedded strengthening insert (curve 1) and in the insert – bottom conjugation point (curve 2) on the insert radius $r$. Calculations were made for the case when insert thickness is 1.6 times greater than the shell thickness. This dependence evidently has a periodical character (curve 1) and the amplitude of equivalent stress deviation from the equilibrium position decreases as the insert radius rises. As $r$ decreases, the maximal and minimal values of the amplitude of stress oscillations practically do not change. Periodical dependence of the maximal effective stresses on the insert radius is caused by the vibrations of the insert as additional mass. The minimal and maximal values of the equivalent stress amplitudes correspond to the cases when the vibration phases of the bottom and insert are the same.

![Figure 1](image_url)

**Figure 1.** Maximal values of equivalent stresses versus the insert radius: in the insert center (1) and in the insert – bottom conjugation point (2).

The abscissa of curves 1 and 2 cross point in figure 1 corresponds to the optimal value of the insert radius which is about 30% of the bottom radius. As the insert radius is less than its optimal value, the effective stresses in the conjugation point are higher than those in the insert center (shell pole). And when the insert radius is greater than optimal one, effective stresses in the conjugation point are less than those in the insert center. Thus, the numerical simulation shows that there is the only one cross point of curves 1 and 2 (see Figure 1). It also follows from the calculations that insert of the optimal radius reduces maximal equivalent stresses proportionally to insert thickness/shell thickness ratio.

Measurements of dynamic stresses provided by the strain gauge technique confirm that there is really the stress concentration in shell poles. Maximal stresses in shell poles can be $1.5 - 2.0$ times
greater than those in the middle of cylindrical part. The method of insert embedding was verified experimentally. The strengthening insert in a form of disc was weld into one of the poles of cylindrical explosive chamber with two elliptical bottoms designed for 200 g TNT. Insert thickness was 1.7 times as much as the thickness of the rest part of shell. Measurements have shown that stress distribution becomes practically uniform, as maximal stresses in the strengthened pole (150 MPa) and in the middle of shell (137 MPa) differ only by 9.5%.

There is the other way to decrease stresses in poles, consisting in placing of cylindrical shield into the chamber body concentrically with the shell cylindrical part. The shield reduces stresses in the middle of the shell, in result stresses in poles go down because they depend on the amplitude of bending vibrations of shell cylindrical part. The shielding method was used in manufacturing of certain KV-2 and KV-5 chambers. Stress metering of KV-2 chamber equipped with the shield and without shield was performed. The shield thickness was 3 times less than that of the chamber body. Measurements have shown that without shield stresses in chamber pole reach the value of 233 MPa, whereas with installed shield they are equal to 181 MPa [7].

It should be noted that approaches, suggested in early investigations [8, 9] and in a sequel developed to the level of engineering practice [10] give rather good description of a chamber stress-strain state when the shell shape is close to spherical. But these approaches leave out of account bending waves travelling along the shell, and therefore omit stress concentration in a composed shell which is under study here. Thus, only numerical calculations can give reliable information on stress-strain state of composed shell under effect of explosion.

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There is the useful formula for calculation the circumferential stress $\sigma$ in a spherical shell at explosion of high-explosive (HE) spherical charge [10, 12]

$$\sigma = \frac{2}{3} \frac{\rho r^3 \sqrt{Q_r}}{R^2 \delta} \sqrt{\frac{E}{\rho}} = \frac{2}{3} \frac{\rho r^3 c \sqrt{Q_e}}{R^2 \delta}$$

(1)

where $\mu$ is the Poisson coefficient, $E$ – the Young modulus, $\rho$ – the density, $c$ – the sound velocity of the shell material, $\delta$ – the shell thickness, $R$ – the shell radius, $\rho_e$ – the density of HE, $r_e$ – the radius of HE charge, $Q_e$ – the specific heat of HE explosion. This formula can also be used in crude estimation of stresses in any composed non-spherical shell. Nevertheless, taking into account the stress concentrations, for chamber poles the value calculated by (1) must be multiplied by two.

3. Explosion chamber designs and applications

Explosion chambers are used both in scientific research and in industry. For example, the chamber DVK-0.2 for 200 g TNT is designed for investigation of detonation products behind the detonation front with the use of synchrotron emission [1]. The chamber KV-0.2 (Figure 2) is made of stainless steel and is intended for explosive synthesis of new materials. Chamber shell has outward diameter of 860 mm and the length of 1100 mm. Stainless steel body enables production of pure materials without undesirable contaminants. This chamber can be used for explosive synthesis of nanodiamonds. The other chamber KVG-2 for 2 kg TNT is designed in 2016 for pulsed X-ray registration of explosion processes in vacuum (Figure 3). Its outward diameter and length are 1290 and 2550 mm, respectively. Special design of output valve and labyrinth sealing of chamber bayonet lock [11] permit to keep a vacuum and prevent leakage of detonation products from the chamber to laboratory or industrial premises. The output valve contains a destructible membrane with a thickness depending on an explosive charge value.

There are industrial chambers designed for explosive charge mass varying from 2 to 8 kg TNT and intended for explosive working of materials, including disposal of ammunition elements. Examples of such plants are given in [1], where explosion chambers KV-2, KV-5 and KVG-8 and their applications are described.
It should be noted that uniform distribution of stresses in chamber shell can be also achieved by the proper choice of chamber structure. The task is to prevent a propagation of bending waves from chamber cylindrical part to its bottoms, and hereby to avoid stress concentration in the chamber poles. For relatively small explosion chambers the design was developed, in which main body and chamber coverage are bound together by means of the special device. Such explosive chamber KIP-0.2 for 200 g TNT is shown on Figure 4. Overall dimensions of this chamber are 1030 x 850 x 1400 mm, weight 850 kg.

![Figure 2. Explosion chamber KV-0.2.](image1)

![Figure 3. Explosion chamber KVG-2.](image2)

![Figure 4. Explosion chamber KIP-0.2.](image3)

The mentioned examples of explosion chambers does not present all modifications of equipment produced in Lavrentyev Institute of Hydrodynamics. Additional information can be found for example in [12]. There are the other companies, producing explosion chambers, e.g. DYNASAFE, Special Materials Corporation and a number of institutions in different countries. However, most of produced chambers are not designed for multiple explosions, but for one unauthorized blast. That’s why they are lightweight and more cheap compared to metal chambers described above. Laboratory and industrial
explosion chambers presented here are high-cycle, as they carry thousands and tens of thousands of explosions. About 100 explosion chambers of different modifications were made in Lavrentyev Institute of Hydrodynamics from 1976 to present time.

4. Conclusion
Numerical calculations and stress metering help to find construction solutions enabling to produce metal explosion chambers with uniform stress distribution in the chamber shell. Welded-in inserts, inner shields, and special joining devices between shell elements permit to reduce stresses in chamber poles. Metal explosion chambers enable the reliable containment of the effects caused by explosions, therefore they are successfully used in scientific research and in industry for explosive working of materials.

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