Journal of Engineering Physics and Thermophysics, Vol. 77, No. 1, 2004

CALCULATION OF CHAMBER-TYPE PULSERS

A. I. Nakorchevskii, M. P. Martynenko, and B. I. Basok

UDC 532.54

The computation al relations and experimental data for deflection of rubber membranes in chamber-type pulsers for the cases of independent and combined deformation of the membranes with account for initial residual deformation are presented. The results of the calculations and experiments are in satisfactory agreement.

Chamber-type pulsers are used in extraction processes in the food, pharmacological, and other branches of industry [1, 2]. The mathematical model of their operation is given in [3–5] in detail. The main element of the pulser is a chamber, one of the possible engineering solutions of which is shown in Fig. 1. Here 1 is the channel connecting the chamber 2 with the processed medium 6. The chamber has branch pipes 3 (section *A–A*) for connection through the two-way valve 4 with the working gas vessels of high (H) and low (L) pressure. Two rubber membranes 5, which move synchronously and symmetrically under the effect of the pressure difference of gas $p_{\rm m}$ and liquid $p_{\rm a}$ toward the central plane of the chamber (connection to the vessel H) or in an opposite direction (connection to the vessel L), are placed in the chamber. These motions initiate a corresponding motion of suspension in the channel 1. The main technological effect of the device is related to a sharp retardation of flow in the channel when the membranes are pressed to the internal side surfaces of the chamber and at a limiting position of them in the central plane of the chamber, which causes phenomena of the type of a hydraulic shock.

To calculate the operation of these devices and find extremum values of pressure in the chamber $p_{\rm a,ex}$, we must determine relations between $p_{\rm a}$ and flow rate in the connecting channel 1 for the periods of filling and emptying of the chamber and the "shock" period. In [3], the corresponding relations are presented for the latter case. However, the stage of contact between the membranes with "flattening" of them in the central zone, which is typical of the final stage of the second period (emptying), was not considered in detail; the authors restricted themselves to approximate relations. In the present work, we thoroughly consider this very case (Fig. 2). As the membranes move to the central plane of the chamber, they touch each other at the central point when the central deflection W_0 (deflection at $r = 0$) becomes equal to h with subsequent "flattening" of the contact zone, which is characterized by the radius r_h. The quantity h is constant and is determined by the designed size of the chamber. The conditions of force effect on the membrane are presented in Fig. 3, according to which the resultant pressure difference on the membrane Δp is determined by the relation

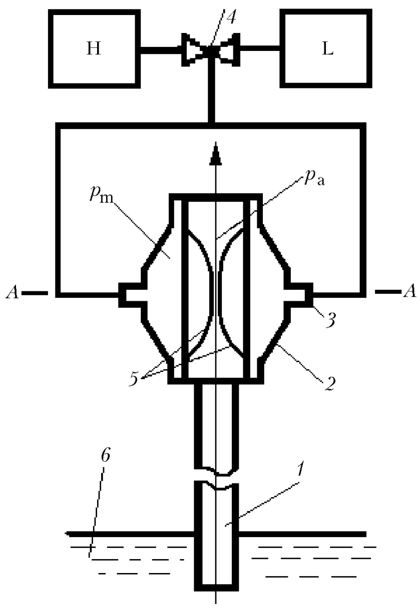
$$\Delta p = p_{\rm m} - p_{\rm a} = 2\sigma \frac{bR}{R^2 - r_h^2} \sin \alpha \, . \tag{1}$$

The sense of the notation is obvious from the consideration of Fig. 3. The rubber membranes fall into the class of highly flexible envelopes, and a free surface of them is a sphere of constant curvature, which is confirmed by experimental studies. In this case, it is not difficult to obtain the formula

$$\sin \alpha = \frac{R}{\sqrt{R^2 + \dfrac{(R^2 - r_h^2 - h^2)^2}{4h^2}}} \, , \tag{2}$$

Institute of Technical Thermophysics, National Academy of Sciences of Ukraine, 2a Zhelyabov Str., Kiev-57, Ukraine; email: toet_ittf@fm.com.ua. Translated from Inzhenerno-Fizicheskii Zhurnal, Vol. 77, No. 1, pp. 129–132, January–February, 2004. Original article submitted March 4, 2003.

1062-0125/04/7701-0156 ©2004 Plenum Publishing Corporation



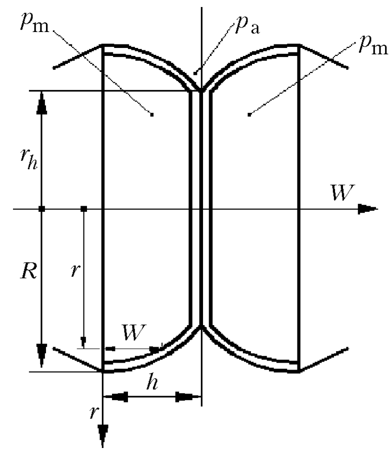


Fig. 1. Schematic of the pulsation unit of the chamber-type pulser.

Fig. 2. Combined deformation of the membranes.

Here the denominator is the radius of the envelope ρ relative to the center of a spherical surface.

For absolutely flexible plates in the region of elastic deformations the relation

$$\sigma = \frac{S - S_0}{S_0} E_r \tag{3}$$

holds, where

$$S = \pi \left(2 \sqrt{R^2 h^2 + 0.25\,(R^2 - r_h^2 - h^2)^2} + r_h^2 \right), \quad S_0 = \pi R^2 . \tag{4}$$

Substitution of expressions (2)–(4) into (1) allows one to obtain a final dependence for Δp.

During exploitation of the pulsers, rubber, as a rule, gains residual deformation, the value of which can be characterized by the central deflection in a nonstressed state W_{0d}. The residual deformation must be allowed for in computations which determine deformation loading of the membranes in both independent motion of each membrane and combined deformation of them. For the first case we have the classic relation

$$\Delta p = 4\sigma \frac{W_0 b}{R^2 + W_0^2} , \tag{5}$$

where in the absence of residual deformation

$$\sigma = \frac{S - S_0}{S_0} E_r = \frac{W_0^2}{R^2} E_r . \tag{6}$$

If at $\Delta p = 0$ we observe residual deformation characterized by central deflection W_{0d}, then

$$S - S_0 = \pi\,(W_0^2 - W_{0d}^2) , \quad S_0 = \pi\,(R^2 + W_{0d}^2) . \tag{7}$$

Assuming $W_{0d} << R$, by substitution of (7) into (5) we obtain

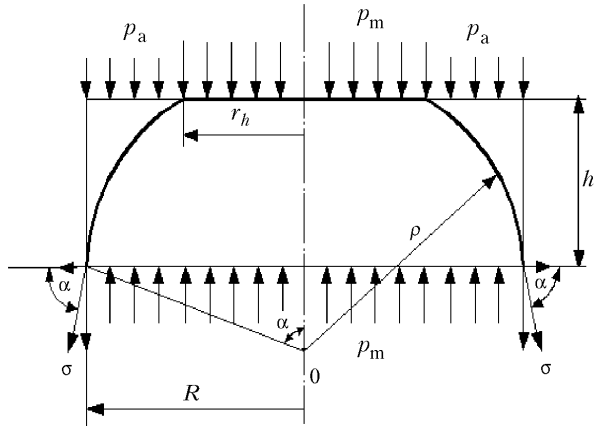


Fig. 3. Scheme of force action on the membrane.

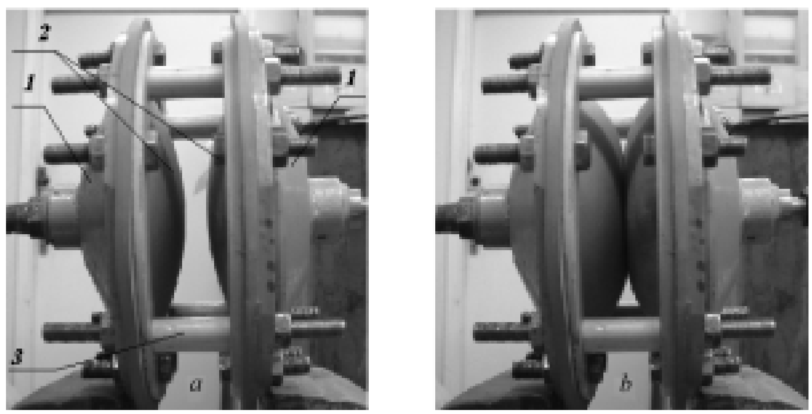


Fig. 4. Position of the membranes in independent (a) and combined (b) deformation.

$$\Delta p = 4\cdot\frac{W_0^2 - W_{0d}^2}{R^2}\,\frac{W_0 b}{R^2}\,E_r\,. \tag{8}$$

The same corrections we must introduce to the second formula of (4) for the case of combined deformation of the membranes using the second formula of (7) for calculation of S_0. Finally, relation (1) becomes as follows:

$$\Delta p = \left(\frac{2\sqrt{R^2h^2 + 0.25\,(R^2 - r_h^2 - h^2)^2} + r_h^2}{R^2 + W_{0d}^2} - 1\right)\frac{bRE_r}{(R^2 - r_h^2)\,(\sqrt{R^2h^2 + 0.25\,(R^2 - r_h^2 - h^2)^2}}\,. \tag{9}$$

In order to check the computations given above we performed studies of independent and combined deformation of the membranes in the working chamber of the pulser. To visualize the process, the central drum with the connecting pipe was removed from the chamber (Fig. 4a). The conical linings 1 of the chamber were positioned with the help of the inserts 3 at a distance corresponding to the width of the cylindrical drum. As a result, deflections of the membranes 2 became accessible for visualization and measurement. The working gas was supplied through the receiver H (see Fig. 1) and the rate of pressure variation was controlled by the valve on the gas duct. The pressure of the gas on the membrane p_m was measured by a standard pressure gauge. The pressure in the open chamber p_a was constant and equal to atmospheric pressure. The deflections of the membranes, whose values were determined by a computer, were photographed by a digital C-800 Fujifilm camera.

The technique of and the experiments was as follows. The two-way cock which connects the chamber and the receiver H was shut, and the receiver was filled by compressed air. Preliminarily, the initial position of the membrane

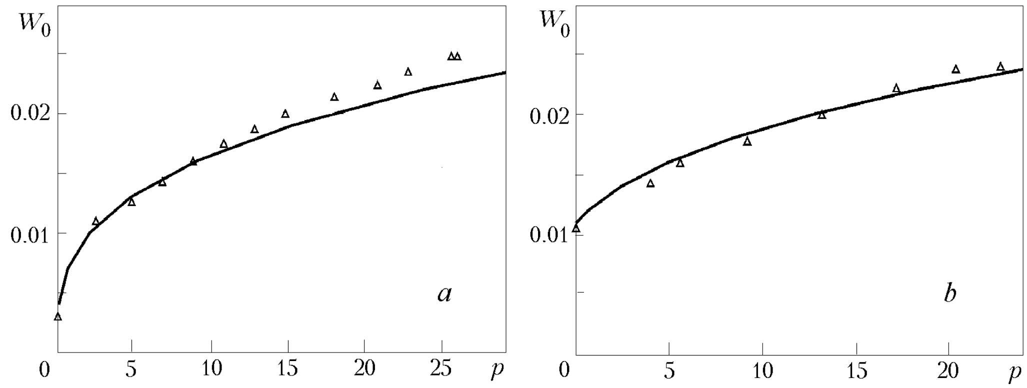


Fig. 5. Change of central deflection of the membranes before the contact at $W_{0d} = 3{\cdot}10^{-3}$ m (a) and $W_{0d} = 11{\cdot}10^{-3}$ m (b); symbols — experimental points. p, 10^3 Pa; W_0, m.

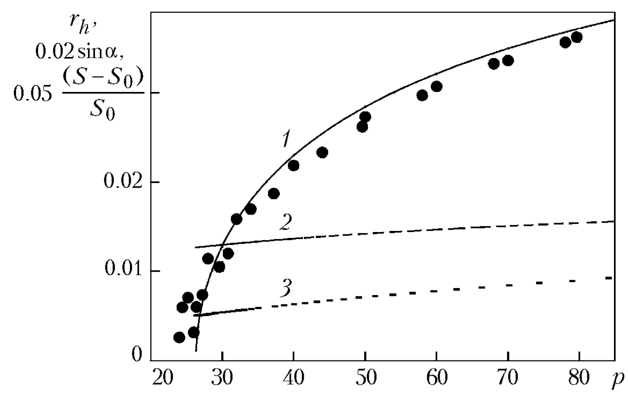


Fig. 6. Change of the radius of contact of the membranes r_h (1), function 0.02 sin α (2), and relative deformation $0.05(S - S_0)/S_0$ (3); points — experiment. p, 10^3 Pa.

was photographed. The two-way cock was adjusted to the position of a small flow rate of the air and the rate of pressure variation in the chamber did not exceed 30 Pa/sec. As pressure increases, photographing was done and values of the excess pressure $\Delta p = p_m - p_a$ were recorded. On reaching the maximum ($p_m = 80{\cdot}10^3$ Pa), the pressure in the chamber decreased and measurements were taken in inverse order. The membranes with the working radius $R = 0.07$ m were made of rubber of thickness $b = 6.9{\cdot}10^{-3}$ m. The elasticity modulus of the rubber $E_r = 2.1{\cdot}10^6$ Pa was found experimentally beforehand.

Figure 4 presents the photographs of the membranes before and after the contact. It is easy to verify the sphericity of the deformable surfaces in both cases. The main measurements were made on the right-hand side of the chamber; therefore, the objective of the photocamera was focused at the central point of the right flange; as a result the deflection of the membrane on the left-hand side is visually larger. The calculations by (8) were compared to the experimental data at $W_{0d} = 3{\cdot}10^{-3}$ m (Fig. 5a) and $W_{0d} = 11{\cdot}10^{-3}$ m (Fig. 5b). Figure 6 shows the results of the experiments on combined deformation of the membranes at $W_{0d} = 11{\cdot}10^{-3}$ m. The results of the comparison indicate the correctness of the analysis made.

If, during operation of the pulser, the membranes gain considerable residual deformations W_{0d}, a gas cavity, which impedes a tight fit of the membrane to the body, can be formed between the chamber body and the membrane. This cavity damps the shock action due to sudden stop of flow in the connecting channel and deteriorates the technological effect of medium processing. To avoid negative aftereffects, one must put the internal surface of the chamber into a spherical shape and make control calculations following the above-formulated technique with account for the predicted value of W_{0d}.

Thus, we have suggested a technique for calculation of deflections of the rubber membranes in chamber-type pulsers in independent and combined deformation of the membranes with account for possible initial residual deformation which manifests itself during exploitation of the equipment. The results of the calculations are confirmed by the experimental data.

NOTATION

b, thickness of the rubber membrane, m; E_r, elasticity modulus of rubber, Pa; h, half-distance between the linings of the chamber, m; p, pressure, Pa; R, radius of the membrane, m; r, current radius, m; S and S_0, area of the surface and its value in the nonstressed state, m^2; W, coordinate of the deflection line, m; α, angle of slope of the tangent to the membrane; σ, tensile stress of rubber, Pa. Subscripts: a, cross section; m, membrane; ex, extremum; d, deformation; 0, initial state; r, rubber.

REFERENCES

1. I. A. Chaika and M. P. Martynenko, Extraction of Organic Raw Materials in Oscillations of a Medium, in: *Proc. 1st Int. Sci.-Pract. Conf. "Modern Energy-Conservation Thermal Technologies*" [in Russian], Vol. 3, MGAU, Moscow (2002), pp. 242–246.
2. B. I. Basok, I. A. Chaika, and M. P. Martynenko, Pneumopulsational Extraction of Components from a Solid Body to Liquid, in: *Ext. Abstr. of Papers presented at Int. Sci.-Method. Conf. "Strategical Trends of Development of Enterprises of Food Industry and Trade"* [in Russian], Khar'kov State Academy of Technology and Organization of Trade, Khar'kov (2001), pp. 179–180.
3. A. I. Nakorchevskii, B. I. Basok, and I. A. Chaika, Pulsers with a Variable Geometry of the Working Volume and the Effect of Processed Composites on the Dynamic Characteristics of Pulsers, *Inzh.-Fiz. Zh.*, **71**, No. 5, 775–783 (1998).
4. A. I. Nakorchevskii, B. I. Basok, and I. A. Chaika, Dynamic Characteristics of Pulsers with a Variable Working Volume, *Teor. Osnovy Khim. Tekhnol.*, **33**, No. 3, 308–311 (1999).
5. A. I. Nakorchevskii and B. I. Basok, *Hydrodynamics and Heat and Mass Transfer in Heterogeneous Systems in Pulsating Flows* [in Russian], Naukova Dumka, Kiev (2001).