РАСЧЕТ МАШИНОСТРОИТЕЛЬНЫХ КОНСТРУКЦИЙ

УДК 539.3
DOI: 10.22363/1815-5235-2018-14-2-112-119

ANALYSIS OF PRESSURE STABILIZER ELLIPTIC CHAMBERS ON THE DEFORMED STATE BY NUMERICAL METHOD

F.V. REKACH*, G.L. GBAGUIDI AISSE**

* Peoples' Friendship University of Russia (RUDN University)
6 Miklukho-Maklaya St., Moscow, 117198, Russian Federation
** University of Abomey-Calavi (UAC)
02 BP 244 Cotonou, Republic of Benin

(*received:* December 12, 2017; *accepted:* March 04, 2018)

The question of pressure and flow rate stabilization is particularly relevant to short pipelines systems, which have high requirements for flow rate consistency of the working fluid. At medium and high pressures (up to 100 atmospheres and higher) the pressure stabilizer with elliptical elastic chambers provides conditions for normal operation of the corresponding equipment. For proper design of the stabilizer, especially deciding question of the liquid volume which the stabilizer can accommodate, it is necessary to carry out the calculation of the elliptical shell in the deformed state. The article provides the calculation of the elliptical shell in the deformed state by step by step loading method and checking the strength conditions at each step of loading. One of the main questions of the study is the question of what maximum load can withstand elliptical chambers. In this paper, we investigate the dependence of the maximum pressure at which the unit operates in the elastic area of deformation on the of the elliptical pipe wall thickness. If harmful oscillating discharge is known we should know the liquid volume which the camera can take. The dependence of the cross-sectional area increase coefficient on the thickness of the pipe wall is built. The article discusses some questions of pressure stabilizer designing.

Keywords: the pressure stabilizer, harmful pressure fluctuations, elastic camera

Introduction. Pipeline system, transporting fluid under pressure, generated by pumping units or creating conditions for gravity flow of the liquid, is an elastic construction. It consists of various elements, organizing and controlling the flow and fluid pressure. Among them are the straight pipe sections, devices controlling pressure and fluid discharge, turning of fluid flows, branching of liquid flows, means to protect the most vulnerable units and pipeline parts and so on. An important factor in ensuring the safety of the pipeline is the correct installation of fastening systems, both overground and underground pats of pipe line. Owing to the irregular operation of pumping units, changes in physical and (or) geometric conditions of the fluid motion unsteady movement occurs. It is often accompanied by a sudden increase of pressure (water hammer phenomenon) or harmful pressure fluctuations. The above phenomena can lead to the failure of certain devices, as well as pipe breaks with probable fatal accident.

In aircraft and rocket engines non-uniformity of flow and pressure in liquid fuel delivery systems are especially dangerous. The occurrence of discharge and pressure fluctuations in these systems is possible due to the complexity of the organization of working process of the pumping equipment, the inability to create fluid motion without centripetal accelerations (flow turns, slope changes of motion). There is also the danger of vortex formation in a production environment, the occurrence of self-excited vibration and resonance condition. The amplitude of pressure and discharge in pipelines pump units can reach considerable values, especially for units of high pressure, powerful circulating pumps, turbines with high discharges of non-stationary streams. The mechanism of pressure fluctuations formation of liquid and gas is described in detail in the book by I. A. Czarnye [2].

Periodic fluctuations of liquid or gas pressure and discharge, resulting from the interaction between the flow and the pipe, may cause mechanical vibrations of the pipeline and its equipment and supporting structures. In the event of resonance of the pumping fluid or gas can be likely created longitudinal waves causing resonant vibrations of the entire pipeline system.

One the piping system protective means from the above-listed factors is the pressure stabilizer. For hydraulic systems supplying fuel at high pressure (above 60 atmospheres) and relatively small discharge amplitude oscillations for small pipe length there is an effective means to reduce harmful flow pressure and discharge pulsations. It is the pressure stabilizer with elastic elliptical chambers. This device is capable to work under pressures above 200 atmospheres. Similar calculations were considered in works [4–6].

Fig. 1 shows a diagram of the stabilizer with elastic elliptical chambers. It consists of a Central tube 1 of circular cross-section. Due to the uniformly distributed perforations 2, the fluid flows into the coaxial elastic chamber 3 of elliptical cross section 4 made of spring steel. The Central tube is connected to the main pipeline by means of flanges 6. The length of coaxial elliptical segment is designed depending on the desired range of dynamic processes of a hydraulic system correction.

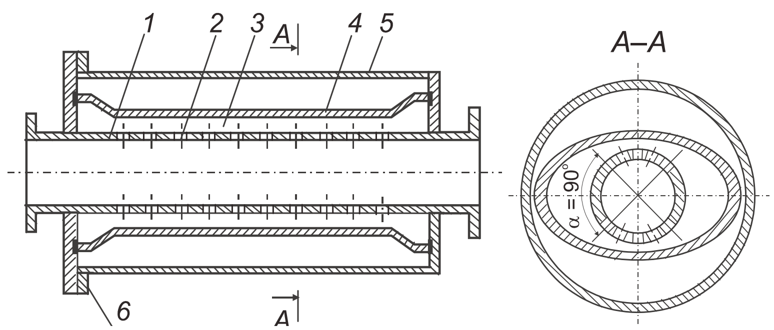

Fig. 1. Design of the stabilizer with elastic chambers

In the event of fluctuations in the pipeline due to elastic deformation of a coaxial camera and distributed perforation the dissipation of energy of oscillations pressure of working environment takes place. By selection of appropriate parameters of a coaxial camera and distributed perforations tone can achieve the necessary degree of reduction of pressure fluctuations and changes in the natural frequencies of the system.

The main part. Calculation of the elliptical chamber on the strength and compliance is necessary to perform on the deformed state, as the difference in the results compared to linear analysis can reach a considerable value.

From the elliptical pipe is cut out a part of the pipe 1 meter length. Consider a quarter of an ellipse with smilaxes a_0 and b_0. On the edges are two reactions of the supports: in point B – horizontal reaction and moment; in the point A – vertical reaction and moment (Fig. 2). The arc $\breve{AB}$ is divided into rectilinear segments $l_1, l_2, ..., l_n$. The pressure in the ellipse is added step by step, with a step Δp. It is considered as a distributed load perpendicular to the counter $\breve{AB}$ and transferred to nodes 2,..., n (forces F) and to nodes 1 and n+1 (forces $F/2$).

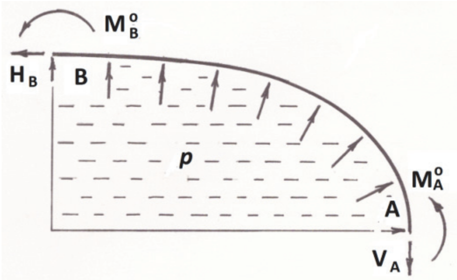

Fig. 2. Calculation diagram

Fig. 3 shows a moment diagram from the internal pressure Δp in the basic statically determinate system. As an unknown support reaction Z is assumed moment in the point A.

Fig. 4 shows a diagram of the moments from the unit unknown reactions $\overline{Z}=1$.

Displacements in the direction of the reaction Z from the unit reaction $\overline{Z}=1$ and from the load Δp in the basic system are calculated by the formulas (1):

$$\delta_{11}=\int_0^l \frac{\overline{M}_1\overline{M}_1}{EI}ds, \qquad \Delta_{1P}=\int_0^l \frac{\overline{M}_1 M_F}{EI}ds. \tag{1}$$

The unknown Z is found from the equation:

$$\delta_{11}Z+\Delta_{1F}=0. \tag{2}$$

After Z is found, the moment diagram in statically indeterminate system is built by the formula: $M=M_F+Z\overline{M}_1$. Then vertical and horizontal unit forces are put at all nodes of the basic system in turn and horizontal and vertical displacements of all nodes are found.

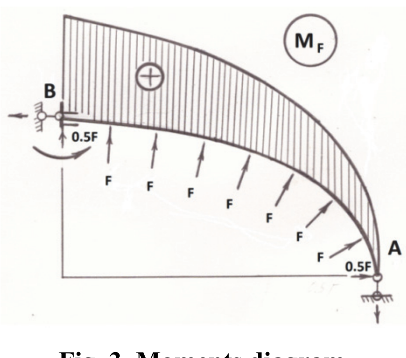

Fig. 3. Moments diagram from pressure Δp in basic system

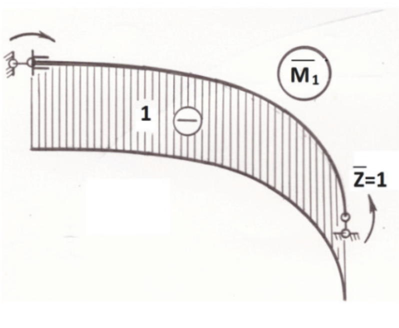

Fig. 4. Diagram from unit unknown $\overline{Z}$

Horizontal and vertical displacements of the nodes are calculated by the formulas:

$$\Delta^H_{j\Delta p}=\int_0^l \frac{\overline{M}^H_j M}{EI}ds \quad \text{and} \quad \Delta^V_{j\Delta p}=\int_0^l \frac{\overline{M}^V_j M}{EI}ds, \tag{3}$$

where $\Delta^H_{j\,\Delta p}$ *and* $\Delta^V_{j\,\Delta p}$ – horizontal and vertical displacements in the node j from moment M in statically indeterminate system from load Δp; $\bar{M}^H_j$ and $\bar{M}^V_j$ – moments from unit horizontal and vertical force applied in the node j.

At each load step the coordinates of the nodes are corrected, i.e. the geometry of the pipe cross section is changing. Since adding the load ellipse will tend to "transform" into a circle, the expected limit load will be more. Check of the ellipse contour strength is calculated as follows:

$$\sigma_{\max} \le [\sigma_{adm}],$$

where $\sigma_{\max}$ is calculated by the formula: $\sigma_{\max} = \dfrac{M_{\max}}{I} z_{\max}$; $M_{\max} = \left(\dfrac{1}{R_1} - \dfrac{1}{R_0}\right) \cdot \dfrac{EI}{2(1-\nu^2)}$;

$1/R_0$ – the initial curvature of the ellipse point; $1/R_1$ – the curvature of an ellipse points after load application [3].

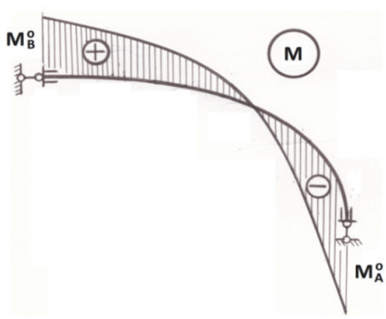

Fig. 5. Moments diagram in statically indeterminate system from load Δp

Moments diagram in statically indeterminate system is shown in fig. 5

Calculations and main results. ***The analysis of numerical calculation convergence.*** The calculation program was compiled in C++.

Phase 1. Convergence of the solution on the number of segments *n*, when cutting an arc $\breve{AB}$ by parts $l_1, l_2, ..., l_n$.

Numerical experiments showed that the difference in the solution with n_1 = 50 and n_2 = 100 is less than 0.7%. Is assumed n = 100.

Phase 2. Convergence of the solution on the number of load steps.

Numerical experiments showed that the difference in the solution when the number of steps on load ns_1 = 50 and ns_2 = 100 is less than 0.8%. Is assumed ns = 100.

Problem 1. *Data*: Elliptical section of the pipe with big and small semiaxis $a_0 = 0.03$ м and $b_0 = 0.012$ м, pipe wall thickness $h_0 = 0.001$ м. The material is steel with modulus of elasticity $E = 2.1 \cdot 10^5 MPa$, permissible stress $[\sigma_{adm}] = 2.57 \cdot 10^2 MPa$, the Poisson's ratio $\nu = 0.3$.

Fig. 6 shows a quarter of the pipe cross section before and after deformation.

Figures 7 and 8 show the moments diagram and the normal stress diagram at the counter of the ellipse from point B to point A relative to the axis oX.

Calculations show that the maximum internal pressure p_0 which the pipe can resist on $[\sigma_{adm}]$ is $0.353 MPa$. It is obvious that by increasing the wall thickness of the pipe h_0, the pipe will resist greater pressure. However, this will reduce the points displacements of the pipe, and thus to the reduction of the cross-sectional area increase ratio $k_A = \frac{A_1}{A_0}$, where A_0 is the cross-sectional area before deformation, A_1 is the cross – sectional area after deformation.

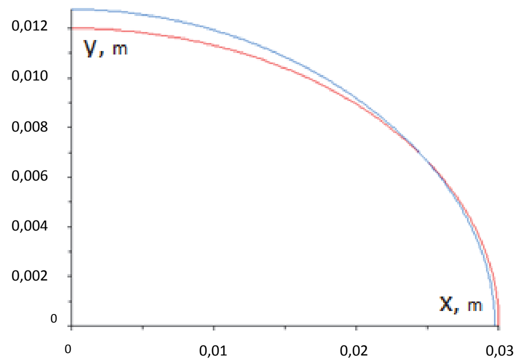

Fig. 6. A quarter of the elliptical cross-section before and after deformation

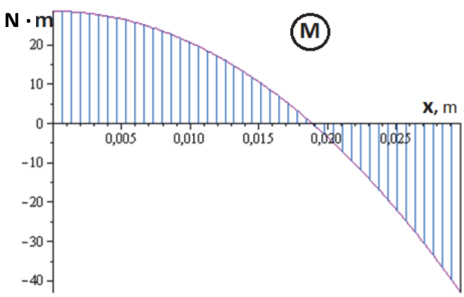

Fig. 7. Moments diagram for the quarter of the ellipse

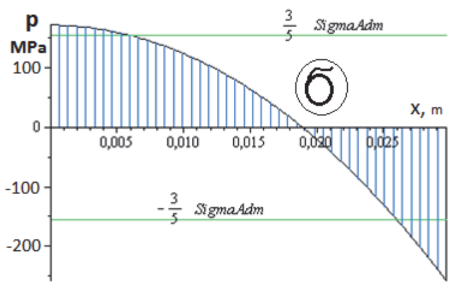

Fig. 8. Normal stresses diagram for the quarter of the ellipse

Problem 2. The research of the maximum internal pipe pressure p_{max} dependence on its thickness was carried out (Fig. 9). All entrance data were taken same as in problem 1.

The calculations showed that pipe thickness should be taken depending on the given maximum pressure in the pipe p_{max}.

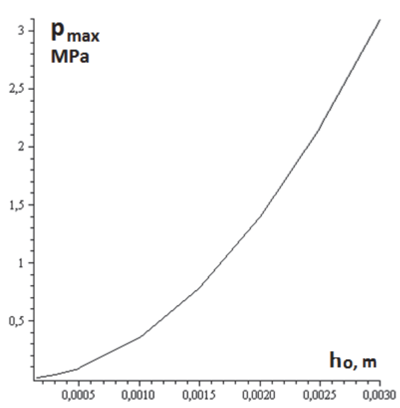

Fig. 9. Dependence of maximum pressure on the pipe thickness

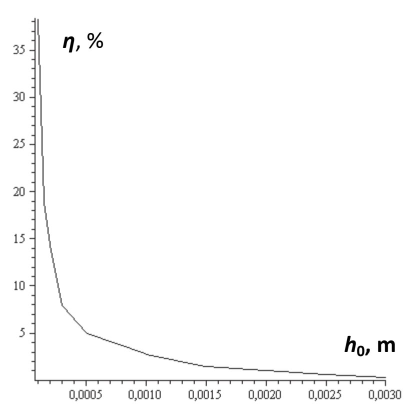

Fig. 10. Dependence of the relative increase ratio of the cross-sectional area of the pipe η on its thickness

Problem 3. These researches confirmed necessity for the calculation on the deformed state (Fig. 10). All data were taken the same as in problem 1.

Numerical analysis shows that relative error $\eta\%$ of calculations on the deformed and undeformed state may exceed 35%. When calculating on deformed state the limit load increases, since each step changes the geometry of the cross section towards "transformation" of the ellipse into a circle.

Problem 4. The research of cross sectional increase ratio area k_A of the pipe on the thickness of the pipe was carried out (Fig. 11). All entrance data were taken the same as in problem 1.

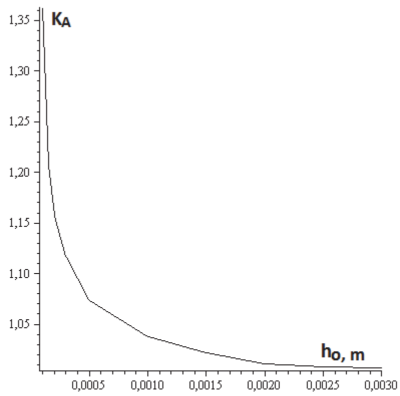

Fig. 11. Dependence of the cross-sectional increase ratio area k_A of the pipe on the thickness of the pipe

This parameter (k_A) effects on the projected length of the elliptical pipe when oscillation amplitude of the fluid flow is given.

Conclusions. 1. For the correct calculation of bending moment at each load step, we need to use a formula that takes into account the change of curvature of the cross section.

2. The choice of the elliptical pipe thickness (at the accepted cross section) should be performed depending on the maximum pressure which can resist the pipeline.

3. When calculating on the deformed state the maximum load that can resist the pipeline increases comparing with the undeformed analysis. The difference of results can reach 35%.

4. The thinner is the pipe wall, the greater is the additional volume of liquid (when pressure increases) which the pipe section of elliptical cross-section can hold. Depending on h_0 the total length is designed.

5. For better design of the pipeline it is also necessary to consider the various ratios b_0/a_0.

R e f e r e n c e s

1. Chucherov, A.I., Galyuk,V.X., Nizamov, H.N. (1991). Pul'satsii davleniya v truboprovodakh i sposoby ikh ustraneniya [The pulsations of pressure in the pipes and their solutions] // *VNIIOENG Overview. Series "Transport and storage of oil".* Moscow: VNIIOENG, 1991, 88. (In Russ.)

2. Charnye I. A. (1975). Neustanovivsheesya dvizhenie real'noi zhidkosti v trubakh [Unsteady motion of a real fluid in pipes. 2nd ed.]. 2-e izd. Moscow: Nedra Publ., 296.

3. Fedos'ev V.I. (1940). Raschet tonkostennykh trubok Burdona ellipticheskogo secheniya energeticheskim metodom [Analyses of thin Bourdon elliptic tubes by energy method]. Moscow: Oborongiz Publ., 94.

4. Shambina S.L., Kazarian A.A. (2015). Application of bionic forms and approaches of analytical geometry to modern architectural design. *Structural mechanics of engineering constructions and buildings and facilities engineer*. No 1, 3–11. (In Russ.)

5. Vanin V.V., Shambina S.L., Virchenko G.I. (2015). Variant computer shell prototyping based on polyparameterization of middle surfaces. *Structural mechanics of engineering constructions and buildings and facilities engineer.* No 6, 3–8. (In Russ.)

6. Siyanov, A.I., Rynkovskaya, M.I., Abu Mahadi, M. I., Mathieu, G. O. (2017). Improving the performance parameters of metal cylindrical grid shell structures. *J. Fundam. Appl. Sci.,* 9 (7), 365–376.

About the author:

Fedor V. Rekach – Candidate of Technical Science, Associate Professor, Department of Architecture and Construction, Peoples' Friendship University of Russia (RUDN University). *Research Interests*: application of mathematics to mechanics (structural mechanics, dynamics of pipelines, numerical solutions), differential equations with small parameter, design of board and computer games. *Contact information:* e-mail – rekfedor@yandex.ru

Gbaguidi Aisse Gérard Léopold – Senior Lecturer, Department of Civil Engineering, University of Abomey-Calavi (UAC). Director of the Graduate School of Civil Engineering VERECHAGUINE A.K. Director of Laboratory of Materials and Structures (LAMS), Republic of Benin. *Research Interests:* vegetal fibers, materials engineering, reinforced concrete structures. *Contact information:* e-mail – gbaguidi.gerard@yahoo.fr

For citation:

Rekach, F.V., Gbaguidi Aisse, G.L. (2018). Analysis of pressure stabilizer elliptic chambers on the deformed state by numerical method. *Structural Mechanics of Engineering Constructions and Buildings.* 14 (2), 112–119. DOI: 10.22363/1815-5235-2018-14-2-112-119.

РАСЧЕТ ЭЛЛИПТИЧЕСКИХ УПРУГИХ КАМЕР СТАБИЛИЗАТОРА ДАВЛЕНИЯ ПО ДЕФОРМИРОВАННОМУ СОСТОЯНИЮ ЧИСЛЕННЫМ МЕТОДОМ

Ф.В. РЕКАЧ*, Ж.Л. ГБАГУИДИ АЙССЕ**

* Российский университет дружбы народов (РУДН)
ул. Миклухо-Маклая, 6, Москва, Россия, 117198

** Университет Абомей-Калави
02 BP 244 Котону, Республика Бенин

(*поступила в редакцию:* 12 декабря 2017 г.; *принята к публикации:* 04 марта 2018 г.)

Вопрос стабилизации давления и расхода жидкости особенно актуален в системах коротких трубопроводов, где предъявляются повышенные требования к равномерности подачи рабочей жидкости. В условиях средних и высоких давлений (до 100 атмосфер и выше) стабилизатор давления с эллиптическими упругими камерами создает условия для нормальной работы соответствующего оборудования. Для грамотного проектирования стабилизатора, особенно при решении вопроса об объеме жидкости, который способен вместить стабилизатор, необходимо проводить расчет эллиптической оболочки по деформированному состоянию. В статье приводится расчет эллиптической оболочки по деформированному состоянию методом пошагового нагружения и проверки условий прочности на каждом шаге нагружения. Одним из основных вопросов исследования является вопрос о том, какую максимальную нагрузку могут выдерживать эллиптические камеры. В работе исследуется зависимость максимального давления при котором конструкция работает в упругой области деформирования от толщины стенки эллиптической трубы. Если в ходе гидравлических расчетов становится известен расход жидкости, который необходимо погасить, то необходимо знать, какой объем жидкости способна «принять» камера. В работе приведена зависимость коэффициента увеличения площади поперечного сечения от толщины стенки трубы. Рассмотрены некоторые вопросы проектирования стабилизатора давления.

Ключевые слова: стабилизатор давления, вредные колебания давления, упругие камеры

Список литературы

1. *Чучеров А.И., Галюк В.Х., Низамов Х.Н.* и др. Пульсации давления в трубопроводах и способы их устранения // Обзорная информация ВНИИОЭНГ. Серия: Транспорт и хранение нефти. М.: ВНИИОЭНГ, 1991.

2. *Чарный И.А.* Неустановившееся движение реальной жидкости в трубах. 2-е изд. М.: Недра, 1975. 296 с.

3. *Федосьев В.И.* Расчет тонкостенных трубок Бурдона эллиптического сечения энергетическим методом. М.: Оборонгиз, 1940. 96 с.

4. *Шамбина С.Л., Казарян А.А.* Применение бионических форм и аппарата аналитической геометрии в современном архитектурном дизайне // Строительная механика инженерных конструкций и сооружений. 2015. № 1. С. 3–11.

5. *Ванин В.В., Шамбина С.Л., Вирченко Г.И.* Вариантное компьютерное моделирование оболочек на основе полипараметризации средних поверхностей // Строительная механика инженерных конструкций и сооружений. 2015. № 6. С. 3–8.

6. *Siyanov A.I., Rynkovskaya, M.I., Abu Mahadi M. I., Mathieu G. O.* Improving the performance parameters of metal cylindrical grid shell structures // J. Fundam. Appl. Sci., 2017. 9 (7S), 365–376.

Об авторе:

Рекач Федор Владимирович – кандидат технических наук, доцент департамента архитектуры и строительства, Российский университет дружбы народов (РУДН). *Область научных интересов:* приложения математики к механике (строительная механика, динамика трубопроводных систем, численные решения), дифференциальные уравнения с малым параметром, создание настольных и компьютерных игр. *Контактная информация:* e-mail – rekfedor@yandex.ru

Гбагуиди Айссе Жерар Леопольд – доктор наук, профессор факультета гражданского строительства, Университет Абомей-Калави (ОАК). Директор Высшей школы гражданского строительства им. А.К. Верещагина, заведующий лабораторией материалов и конструкций, Республика Бенин. *Область научных интересов:* растительные волокна, материаловедение, железобетонные конструкции. *Контактная информация:* e-mail – gbaguidi.gerard@yahoo.fr

Для цитирования:

Rekach F.V., Gbaguidi Aisse G.L. Analysis of pressure stabilizer elliptic chambers on the deformed state by numerical method // Строительная механика инженерных конструкций и сооружений. 2018. Т. 14. № 2. С. 112–119. DOI: 10.22363/1815-5235-2018-14-2-112-119.