The study of the stress-strain state of trunk gas pipeline sections with defects in the shape of the cross-section of the pipe

[1]*Ya.V. Doroshenko*[*], [1]*L.D. Pylypiv*, [2]*K.A. Poliarush*, [1]*Yu.I. Doroshenko*

[1]*Ivano-Frankivsk National Technical University of Oil and Gas;*
15, Karpatska str., Ivano-Frankivsk, 76019, Ukraine

[2]*PJSC "Kyivenergo" SSS "Kyiv Thermal Network" HTN "Pechersk";*
1, Tovarna str., Kyiv, 01103, Ukraine

Received: 13.10.2017 Accepted: 01.12.2017

Abstract

There is carried out 3D modeling of the trunk gas pipeline sections with defects in the cross section shape of the pipe - dents and ovalities. The ANSYS Fluent R18.0 Academic software packge simulates gas flow through these sections of the gas pipeline. The mathematical model of the gas motion is based on the solution of the Navier–Stokes equations and the energy transfer, closed by a two-parametric model of the Launder–Sharma turbulence, using a wall function with corresponding initial and boundary conditions. The structure of the gas flow in the sections of the gas pipeline with defects of the cross section shape of the pipe is investigated. The simulation results were visualized by designing flow lines, the fields of velocity and pressure modules on the contours, in longitudinal and cross-sectional sections. The exact values of velocity and pressure at different points of the inner cavity of gas pipeline sections with defects in the cross-section shape were determined. The places of slowdown and acceleration of gas flow, increase and decrease of pressure were found.

Such results opened the possibilities for studying the stress-strain state of gas pipeline sections with defects in the shape of the cross-section of the pipe. The results of the gas-dynamic calculation were imported into the mechanical module of ANSYS Static Structural for this purpose, where the stress-strain state was modeled by the finite element method. The simulated results were visualized by designing the fields of von Mises stresses and total deformations. There were revealed areas of maximum and minimum equivalent von Mises stresses and general deformations from these fields in the sections of the gas pipeline with dents and ovality of the pipe of different dimensions. Based on these results there were built the dependences of the maximum equivalent von Mises stresses on the depth of the dent, the parameter of ovality, and determined the permissible defect dimensions of the cross section shape of the pipe.

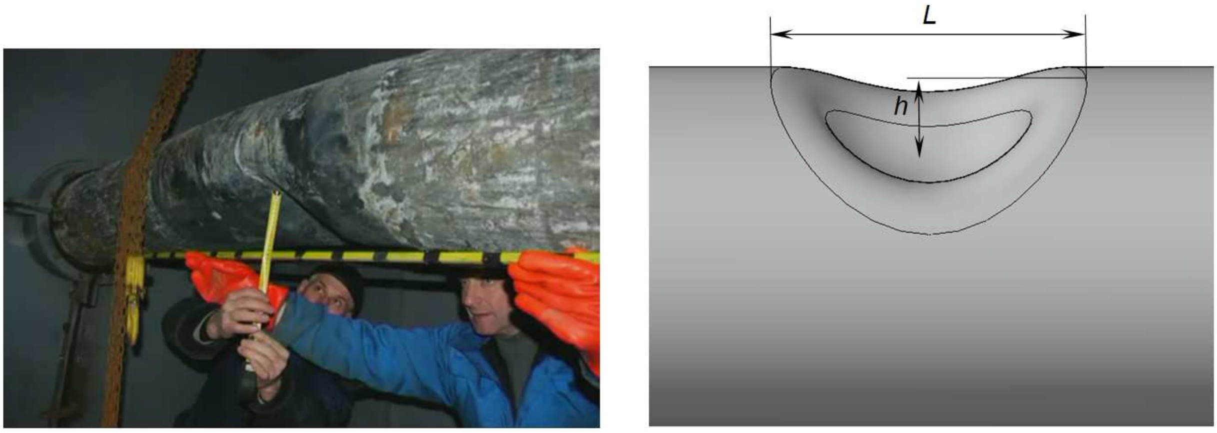
Keywords: *dent, equivalent stresses, finite element method, ovality, permissible parameters, pressure fields.*

Defects in the cross-section shape of the pipe of the gas pipelines (dents, ovalities) are local stress concentrators, which make such places dangerous, requiring special attention and increase of the assessment accuracy of the hazard level of the gas pipeline sections with such defects. Therefore, having detected such defects and calculated their size, the strength of the gas pipeline must be assessed. The existing norms for repelling defects in the shape of cross-sectional pipelines differ in various regulatory documents, and the normative methods of such a calculation do not allow to fully take into account all the factors that affect the strength of the pipeline in the place of defects in the shape of the cross-section of the gas pipelines. In particular, they do not allow us to estimate the three-dimensional distribution of stresses in the area of a defect, which is extremely important for such defects, since they take a complex three-dimensional geometric curvilinear form. Therefore, a comprehensive study of the stress-strain state of the main gas pipeline sections with defects in the cross-section shape of the pipe is relevant.

It is difficult to accurately estimate the strength of the trunk gas pipeline sections with defects in the shape of the cross-section and to determine their permissible parameters due to the need to solve the problem in three-dimensional formulation, and also take into account a wide range of parameters that affect the stress-strain state of the pipe wall in place of dents, ovality, in particular gas-dynamic processes in the inner cavity of the gas pipeline, as there is a decrease in the cross-sectional area of the pipe in these places.

Today, such problems can be solved in the shortest time by means of modern ANSYS simulation software, which provides the ability to perform multidisciplinary computations. The strength and hydrodynamic modules are combined in one interface by means of the new integration computing environment ANSYS Workbench. In addition, the current ANSYS Workbench platform allows you to simulate physical processes using 3D models built in CAD packages.

* Corresponding author:
srgg@nung.edu.ua



a) ***b)***

a) measurement of the size of the dent; b) scheme of the dent in the pipeline

Figure 1 – Characteristics of the dent

Defects in the shape of the cross-section of the pipe may occur in pipelines for different purposes. Finley D. [1] used computer modelling to investigate the stress-strain state of DN 400 mm gas pipeline under pressure with a dent 156 mm long and 28 mm deep, detected by in-pipe diagnosis. The sheets of equivalent stresses were obtained at the place of the dent. Sutomo J. and Wardhana W. [2] modeled the flow of fluid through the pipeline with a dent. As a result, they received pouring of speed and pressure in the inner cavity of the pipeline. The simulation results were imported into the mechanical module of the ANSYS program complex, where the stresses in the pipe wall at the dent were calculated, taking into account the uneven distribution of pressure in the inner cavity of the gas pipeline. The geometric three-dimensional dent model in this paper does not correspond to the real geometry of such defects because it is not smoothly rounded in the upper part.

Budylov I., Kulyasov G. et al. [3] performed a study of the stress-strain state and estimated the strength of the pipes of technological pipelines of oil pipelines with an external diameter of 550 mm in place of dents using computer simulation methods in DEFORM-3D and ANSYS. There have been estimated the values of deformations and strength conditions that ensure the reliability of technological pipelines with such defects. It is shown that the greatest damage to the pipeline occurs when the defect is located transversely. In this case, the area of the maximum damage does not always coincide with the boundary and middle points of the symmetry axis of dents, which confirms the expediency of three-dimensional design models of dents that would correspond to the real geometry of defects.

The strength of the oval part of the pipeline can be estimated by the method shown in P 51-31323949-42 [4]. This technique takes into account the mechanical and geometric characteristics of the pipe. By this method, the actual parameter of the ovality of the pipe is calculated and compared with the permissible one.

Existing methods of calculating the stress-strain state of gas mains areas with defects of cross-sectional shape of the pipe do not include the complex three-dimensional geometric curvilinear form of such defects and uneven distribution of pressure in the inner cavity of the pipeline, which is present in the following locations.

The objective of the study is numerical 3D modeling of the stress-strain state of the trunk gas pipelines sections with defects in shape of the pipe cross-section (dents, ovality) on the basis of gas-dynamic processes that occur in places of such defects. Determination of the acceptable parameters of such defects.

Defects in the cross-section shape of the pipe of the gas pipelines are dents and ovalities. The most common causes of such defects are mechanical damage to gas pipelines, non-compliance with rules and regulations for their construction. Most often, the causes of mechanical damage to underground gas pipelines are construction works near the pipeline. They may appear due to incompliance of pipeline location with the location, specified in the project documentation, negligence or errors of builders that are random. Mechanical damages associated with external influences are up to 10 % of the total number of defects and damages to gas pipelines.

A dent is characterized by the length L and the depth h (Fig. 1). As a rule, the larger the depth of the dent, the greater is its length.

Ovality of the pipeline is characterized by the actual parameter

$$\beta = \frac{D_{\max} - D_{\min}}{D_{out}}, \qquad (1)$$

where $D_{\max}$, $D_{\min}$ are, respectively, the largest and smallest external diameters of the pipeline in a cross-section in the place of its ovality; D_{out} is the outer diameter of the pipeline.

The problem of evaluating the strength of gas pipeline sections in the place of defects of the cross-sectional shape is to be solved in a three-dimensional formulation. In addition, a complicated physical picture of the gas flow occurs in the place of defects of the cross-sectional shape. There is an uneven distribution of pressure, which affects the tensile state of the pipe wall. Therefore, it is necessary to perform a multidisciplinary calculation combining gas-dynamic calculation with mechanical one.

This problem can be solved by ANSYS software. The simulation is performed in the ANSYS R18.2 Academic Finite Element Analysis software.

The complex procedure of numerical simulation of the considered problem consists of four stages:

designing a geometric model of the sections walls of the gas pipeline with defects in the shape of the cross-section and geometric flow pattern in these areas in AutoCad and their import into the Ansys Fluent geometric module;

modeling a gas flow in the section of a gas pipeline with a defect in the shape of a cross section in ANSYS Fluent module;

importing 3D wall geometry and obtained results from the ANSYS Fluent hydrogases module into the mechanical module of the ANSYS Static Structural software;

modeling the stress-strain state of the gas pipeline section with a defect in the shape of the cross section in the mechanical module ANSYS Static Structural.

To do this, the calculation scheme shown in Fig. 2 was set in the calculation environment ANSYS Workbench.

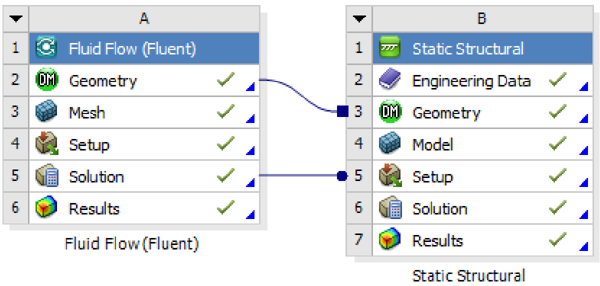
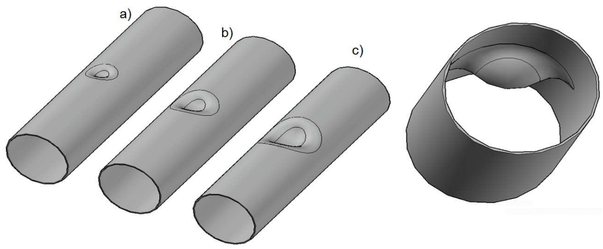


Figure 2 – The computation scheme specified in the ANSYS Workbench environment

Geometric modeling

Three-dimensional geometric models of the gas pipeline section with a defect in cross-sectional shape were designed in computer-aided design (CAD) program AutoCad. There was modeled the section of the trunk gas pipeline 3.5 m long with an external diameter of 1420 mm, a nominal wall thickness of 18.7 mm with defects of the cross-sectional shape of a complex three-dimensional geometric curvilinear shape – dents and ovalities. Three dents and four ovalities of different sizes were modeled. Geometrical models of gas pipeline sections and dents sizes are shown in Fig. 3, and the areas of the gas pipeline with the ovality of the pipe – in Fig. 4. Parameters of ovality of modeled sections of the gas pipeline were 0.028, 0.042, 0.056, 0.113. The length of the oval section of the gas pipeline was 1 m, transitional sections (from round to oval) – 0.5 m and sections with a circular cross section – 2 m (Fig. 4).

Three-dimensional models of the gas pipeline section with defects of cross-sectional shape were imported into the geometric module of Ansys Fluent-Design Modeler (Fig. 5). The models contained three-dimensional geometry of the wall and three-dimensional flow geometry. The geometry of the wall was removed since there were performed only gas-dynamic calculations in Ansys Fluent.



a) $h = 173$ mm, $L = 607$ mm*; b)* $h = 277$ mm, $L = 896$ mm*; c)* $h = 424$ mm, $L = 1195$ mm

Figure 3 – Geometric models of the gas pipeline sections with dents

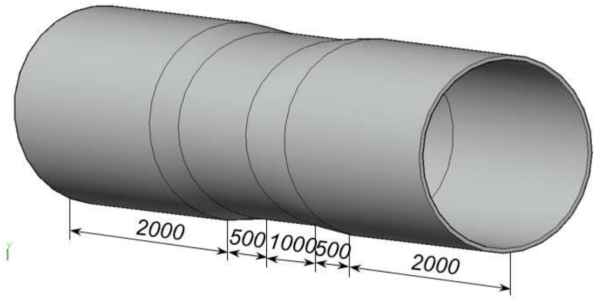
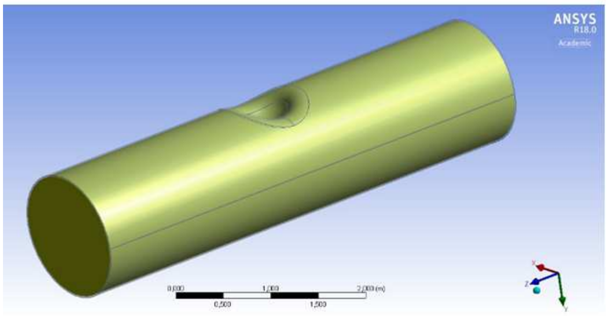
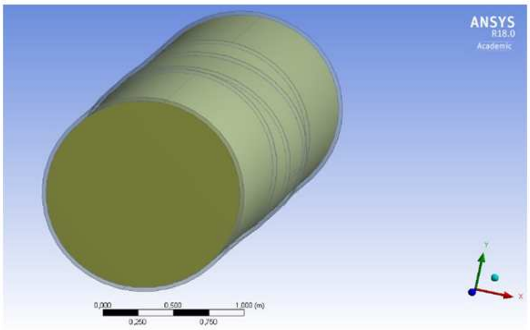


Figure 4 – Geometric model of the gas pipeline section with pipe ovality



a)



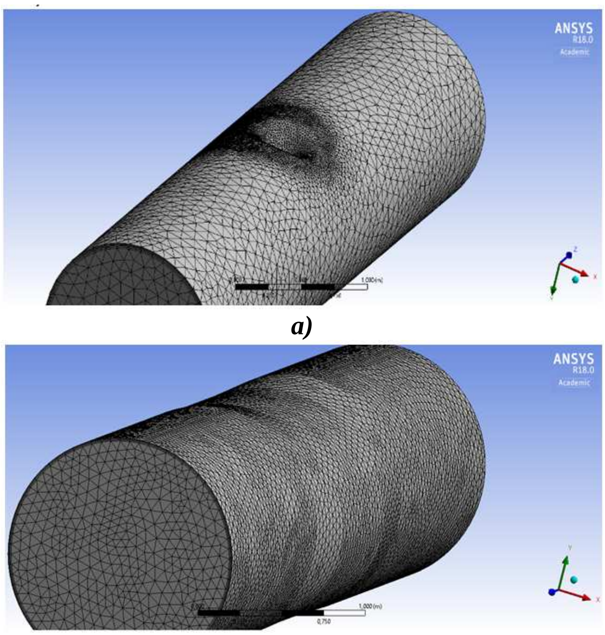
b)

a) a dent; b) ovality

Figure 5 – Geometric models of the flow in the gas pipeline section with defects of the cross section shape in DesignModeler

Modeling of gas dynamics

A volumetric computational mesh Automatic was generated in the Fluent Meshing – the volume was filled with triangular prisms, and if it was not possible, then parallelepipeds were applied. The size of the mesh elements was set as 0.1 *m* (Fig. 6). There was also created a wall layer of Inflation lattices with a lattice height of 0.1 *m* and a number of their layers – 5 for a better description of the boundary layer, and the mesh was ground to the size of the mesh elements – 0.03 *m* for better modeling the flow in the location of the dent (Fig. 6, *a*). For this size of mesh elements, the results of the calculation were qualitatively visualized, and the calculation time was about an hour. After generating the mesh, the boundaries of the input and output of the flow were set.



a)

b)

a) a dent; b) ovality

Figure 6 – Computational volumetric mesh of the flow

A standard two-parameter Realizable $k-\varepsilon$ model of Turbulence Modification has been chosen in ANSYS Fluent. The Turbulence model $k-\varepsilon$ does not allow to fully simulate the effects that occur near the walls. Therefore, there were used the near wall functions for the qualitative modeling of near wall flows. There was chosen near wall function Enhanced Wall Treatment – extended near wall modeling.

Natural gas was chosen from the ANSYS Fluent materials database and assigned to the computational mesh. To solve problems of gas dynamics there should be taken into account the compressibility of gas. The point of Real-gas was chosen for this purpose. Besides, Energy equation is automatically added to the equations to be solved and when setting the boundary conditions, it is necessary to set the temperature of the gas. Steel was selected as a wall material from the ANSYS Fluent material database.

The following boundary conditions were specified in Boundary Condition menu (Fig. 8, *a*), (Fig. 13, *a*). Mass flow inlet $M_{in} = 697.9\ kg/\mathrm{s}$ was set at the inlet, and Pressure outlet $P_{out} = 6.2\ MPa$ – at the outlet. In addition to setting the mass flow rate at the inlet, the Turbulence Intensity was set 5 % in the Mass flow inlet window, the Hydraulic Diameter and the gas temperature $T_{in} = 293\ K$ were set at the inlet. When setting the pressure at the outlet, the Turbulence Intensity 5 %, the Hydraulic Diameter and the gas temperature $T_{out} = 293\ K$ were also specified in the Pressure Outlet window. As a rule, the intensity of turbulence does not exceed 20 %, but in most cases it is in the range of 1 to 10 %. For a turbulence intensity of 5 %, the flow is considered to be completely turbulent.

Also, the boundary condition of the Wall with the coefficient of equivalent roughness of pipes was chosen.

The movement of the continuous phase natural gas is modeled by computational solving of the systems of equations that describe the most general case of motion of a gaseous medium. Such are the Navier-Stokes equation (2), which expresses the law of conservation of momentum, (or Reynolds (3), if the flow is turbulent) and indissolubility (4), which is the law of conservation of mass

$$\frac{\partial}{\partial t}(\rho u_i) + \frac{\partial}{\partial x_j}(\rho u_i u_j) = -\frac{\partial p}{\partial x_i} + \frac{\partial}{\partial x_j}\left(\mu\left(\frac{\partial u_i}{\partial x_j} + \frac{\partial u_j}{\partial x_i}\right)\right) + f_i\ , \quad (2)$$

$$\frac{\partial}{\partial t}(\rho u_i) + \frac{\partial}{\partial x_j}(\rho u_i u_j) + \frac{\partial}{\partial x_j}(\rho u_i' u_j') = -\frac{\partial p}{\partial x_i} + \frac{\partial}{\partial x_j}\left(\mu\left(\frac{\partial u_i}{\partial x_j} + \frac{\partial u_j}{\partial x_i}\right)\right) + f\ , \quad (3)$$

$$\frac{\partial \rho}{\partial t} + \frac{\partial}{\partial x_j}(\rho u_j) = 0\ , \quad (4)$$

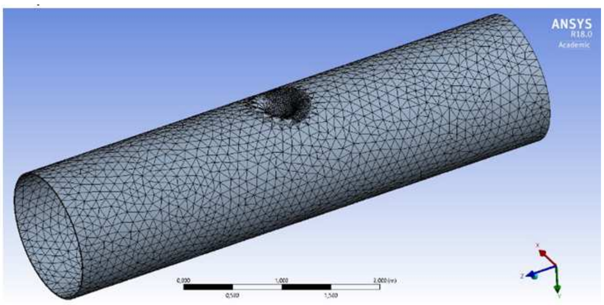
where x_j, x_i are the coordinates; t is time; u_i, u_j are velocity components; ρ is the density of gas; μ is the molecular dynamic viscosity of gas; f_i is a term that takes into account the effect of mass forces; p is the pressure; u_i are time-averaged velocity values; u_i' are the constituents of velocities pulsation. [5]

The results of gas flow simulation in sections of the gas pipeline with defects of cross-sectional shape were visualized in ANSYS Fluent post-processors, ANSYS CFDs (Fig. 8, Fig. 9, Fig. 13).

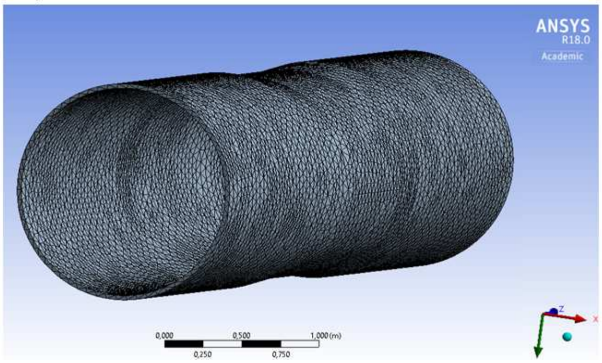
Modeling of the stress-strain state

Three-dimensional wall geometry and the results obtained from the ANSYS Fluent hydro-gas dynamic module were imported into the mechanical module ANSYS Static Structural for modeling the stress-strain state of the gas pipeline section with defects of cross-sectional shape.

Then there was set the material – 13G1S-U steel. A volumetric computational mesh Automatic was generated in the Static Structural – Meshing preprocessor. The size of the mesh elements was set at 0.07 *m* (Fig. 7). In place of the dent, the mesh was crushed to the size of the mesh elements – 0.03 *m* (Fig. 7, *a*).



a)



b)

a) a dent; b) ovality

Figure 7 – Computational volumetric mesh of the pipe wall

Then, the results of computing the pressure distribution on the inner wall of the pipe were imported from the hydro-gas dynamic module of ANSYS Fluent to the mechanical module of ANSYS Static Structural (Fig. 10, Fig. 14). The ends of the sections of gas pipelines with defects of the cross-sectional shape were fixed on the ends. The load of the influence of soil was applied on the outside of the pipeline by the Elastic Support function, where loam was taken as soil.

The simulation of the stress-strain state in the ANSYS Static Structural module is performed by the finite element method. The basic idea of this method is that any continuous quantity such as temperature, pressure and displacement can be approximated by a discrete model based on the set of finite-continuous functions. In the general case, the continuous value is not known in advance, and it is necessary to determine the value in some interior points of the area. A discrete model is very easy to design if we first assume that the numerical values of this value are known in each inner area. Then we can study the general case. Consequently, when designing a discrete model of continuous value, proceed as follows:

a finite number of points is fixed in this domain. These points are called nodal points or nodes;

the value of a continuous quantity at each point is considered as a variable to be determined;

the domain of definition of a continuous value is divided into a finite number of domains called elements. These elements have common nodal points and approximate the shape of the domain;

the continuous value is approximated to each element by a polynomial, which is determined by the nodal values of this quantity. There is determined its polynomial for each element, but the polynomials are chosen so that the continuity of the quantity along the element boundaries (which is called the function of the element) is preserved. The choice of the form of elements and their functions for specific tasks determines the accuracy of an approximate solution and depends on the ingenuity and skill of the engineer.

The deformation function or the deformation vector is expressed through the displacement function.

In the case of tension, the relative elongation of the rod as follows

$$\{\varepsilon\} = \left\{\frac{\partial f}{\partial z}\right\} = \frac{1}{l}\left|-1;1\right|\begin{Bmatrix} u_i \\ u_j \end{Bmatrix}. \tag{5}$$

Expression $\frac{1}{l}\left|-1;1\right|$ is considered a matrix, then

$$\{\varepsilon\} = |B|\{\delta\}, \tag{6}$$

where $\{\delta\} = \begin{Bmatrix} u_i \\ u_j \end{Bmatrix}$ is the movement of the element nodes.

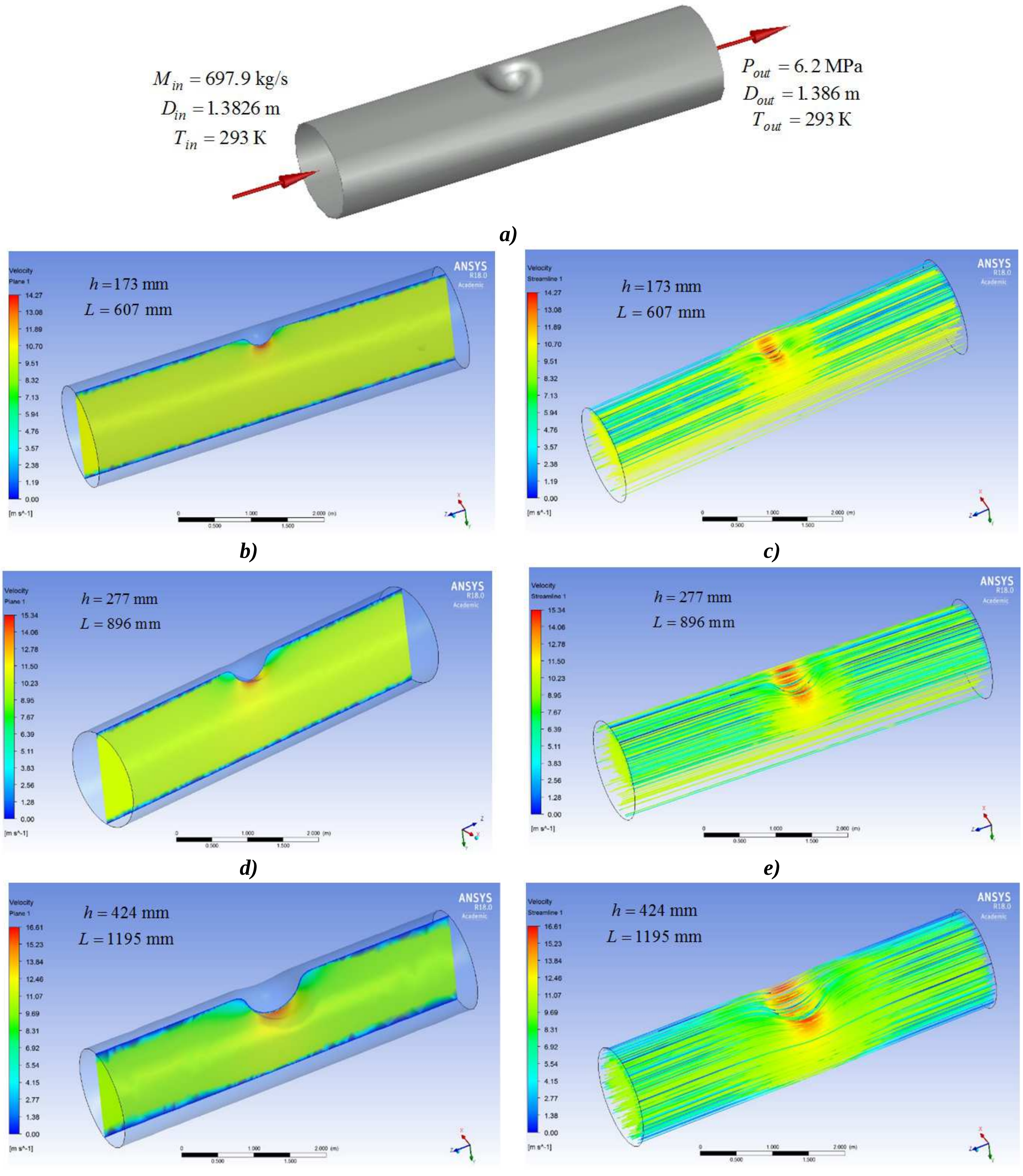
The stress function (stress vector) is expressed through the deformation vector

$$\{\sigma\} = |D|\left(\{\varepsilon\} - \{\varepsilon_o\}\right) + \{\sigma_o\}, \tag{7}$$

where $|D|$ is the matrix of elasticity (binds stress and deformation with each other); $\{\varepsilon_o\}$ are initial deformations; $\{\sigma_o\}$ are initial stresses [6].

The results of the gas-dynamic modelling were visualized in the ANSYS Fluent and ANSYS CFD post-processors, which allowed seeing the structure of the gas flow in the areas of gas pipelines with dents. There were designed the fields of velocities in longitudinal sections (Fig. 8, *b*, *d*, *f*), lines of the flow (Fig. 8, *c*, *e*, *g*), pressure fields in longitudinal sections (Figs 9, *a*, *c*, *e*) and on contours (Fig. 9, *b*, *d*, *f*). By selecting the Probe button on the ANSYS CFX software toolbar, the exact velocity and pressure values were determined at any point in the field of velocity or pressure module.

Based on the velocity fields in longitudinal planes (Fig. 8, *b*, *d*, *f*) and streamlines (Fig. 8, *c*, *e*, *g*) it was determined that the flow velocity along the axis of the gas pipeline was $\upsilon_{in} = 10,3\,m/\mathrm{s}$ at the inlet of the section of the gas pipeline with a dent. There is a slight decrease in the flow rate from the axis in the direction of the wall, and the speed of the gas streamline decreases sharply near the wall. There is a slowdown of the gas streamline to 4 m/s in the beginning and the end of the dent (in the course of the product movement), in the place of its bend, and the greater the dent, the slowdown area is greater. There is a significant acceleration of the flow near the middle of the dent (in the place where its depth is maximal). Moreover, the

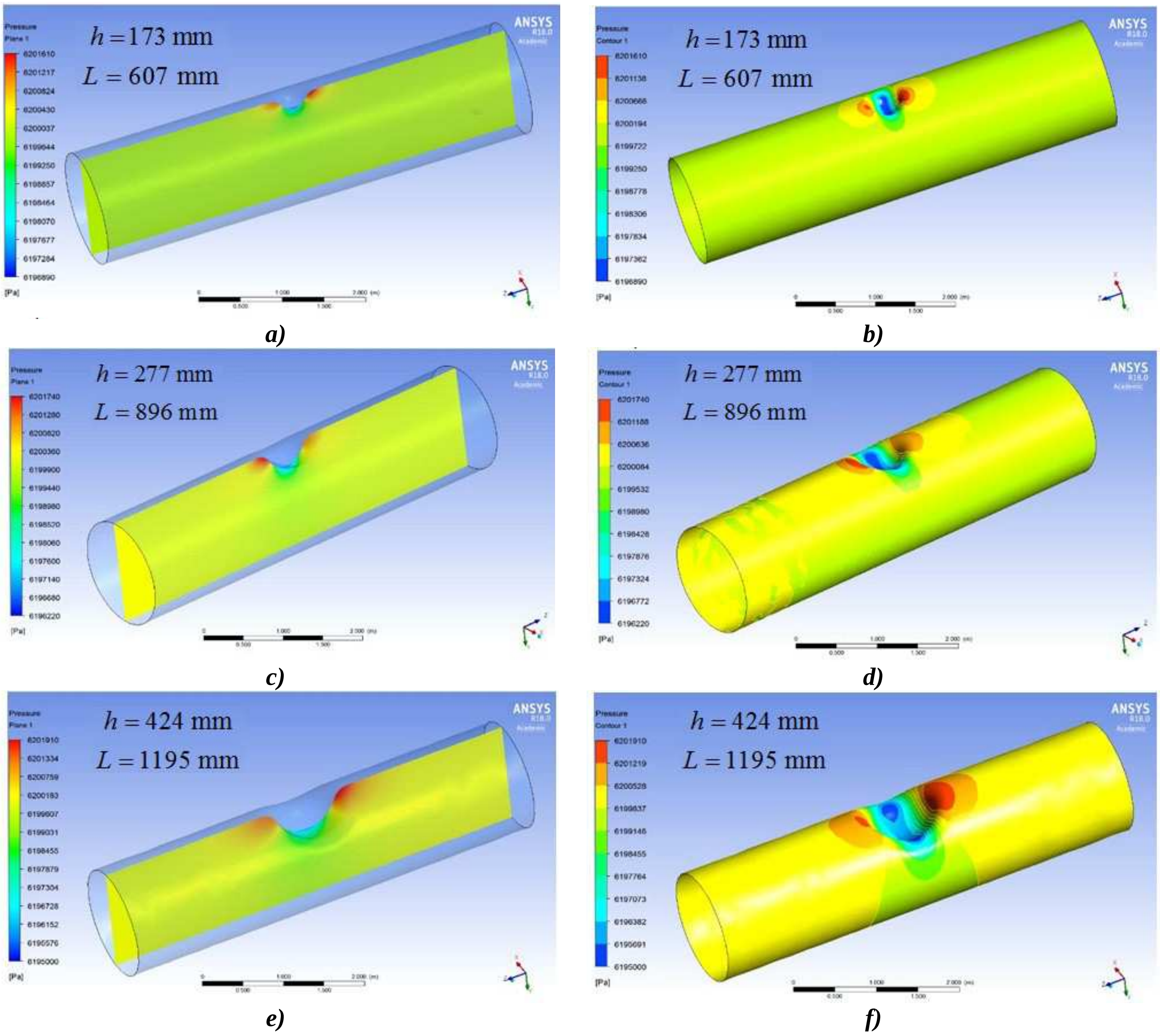


a) computational scheme; b), d), f) velocity fields in the longitudinal plane; c), e), g) lines of the flow

Figure 8 – Results of modeling the flow rate of gas flow by the gas pipeline with a dent

greater the depth of the dent, the faster is the flow and the larger is the area of acceleration. Thus, at the depth of the dent 173 mm the maximum flow rate is 14.27 m/s (Fig. 8, *b*, *c*), at a depth of 277 mm – 15.34 m/s (Fig. 8, *d*, *e*), and at a depth of 424 mm – 16.61 m/s (Fig. 8, *f*, *g*).

As can be seen from the pressure fields (Fig. 9), the pressure is distributed unevenly in the place of the dent. Since the length of the gas pipeline area is small, the pressure at the inlet is approximately equal to the pressure set at the outlet and equals to 6.2 MPa. Based on the pressure fields it was noticed that there was a slight increase in pressure at the beginning and at the end of the dent (in the course of the product movement), in the place where the gas streamline was detected, and the greater the dent, the area of increase and the magnitude of the pressure increase is greater. There is a drop in pressure near the middle of the dent (in the place where its depth is maximal). Moreover, the greater the depth of the dent, the greater is the pressure drop area.



a), c), e) pressure fields in longitudinal plane; b), d), f) pressure fields on the contours

Figure 9 – Results of modeling the pressure distribution in the inner cavity of the gas pipeline with a dent

The uneven distribution of pressure in the inner cavity of the gas pipeline in the dent (Fig. 9) affects the stress state of the pipe wall. To account for this effect, the computational results of pressure on the inner wall of the pipe were imported from the ANSYS Fluent hydrogases module into the mechanical module ANSYS Static Structural (Fig. 10).

The results of the modelling the stress-strain state of the gas pipeline plane with dent were visualized by the finite element method in ANSYS Static Structural by designing the fields of equivalent von Mises stresses (Fig. 11, *a, c, e, g*) and the fields of total deformations (Fig. 11, *b, d, f*).

It is evident from the fields of equivalent von Mises stresses and total deformations, that the area of maximum equivalent von Mises stresses and the area of the maximum total deformations was formed on the outer wall at the beginning and the end of the dent (in the course of the flow movement) at the point of its bend, where the pressure increase was detected (Fig. 11). Moreover, the larger the dent, the greater is the magnitude of the maximum equivalent stresses and maximum total deformations. Thus, at the depth of denture 173 mm and the length of 607 mm the maximum equivalent von Mises stresses are 352.2 MPa in this area, and the maximum total deformations are 3.3 mm (Fig. 11, *a, b*), the maximum equivalent stresses and the maximum total deformations are 6.7 mm at the depth of the dent 277 mm and the length of 896 mm (Fig. 11, *c, d*), the maximum equivalent stresses are 802 MPa and the maximum deformations are 11 mm at the depth of the dent 424 mm and the length of 1195 mm (Fig. 11, *e, f*).

Based on the modeling results, the graphical dependence of the maximum equivalent stresses $\sigma^{\max}$ on the depth h of the dent was designed (Fig. 12). From the graphic dependence it was found out that the values of the maximum equivalent stresses were larger than the boundaries of 13G1S-U steel flux, which was set to the wall of the pipe, at the depth of the dent more than 212 mm. In the case of exploitation of the gas pipeline in the mode, given in the input data, and the depth of the dent more than 212 mm there can begin the

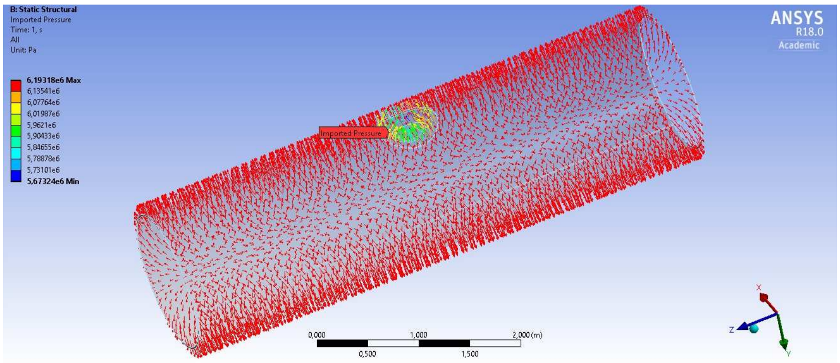
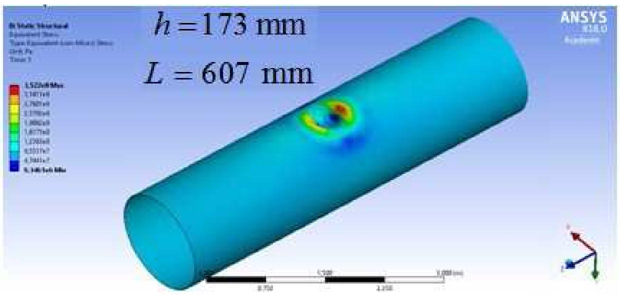
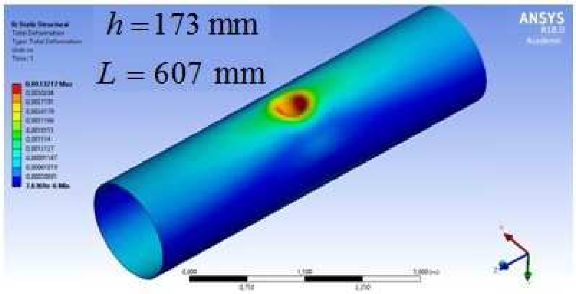


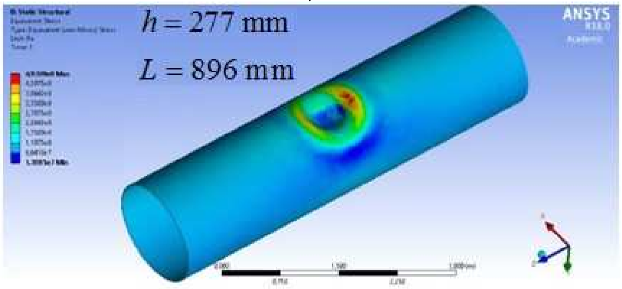
Figure 10 – Results of computing the pressure distribution on the inner wall of the pipe in the place of the dent, imported from ANSYS Fluent in ANSYS Static Structural



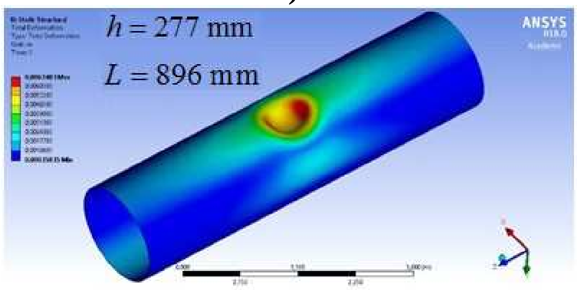
a)



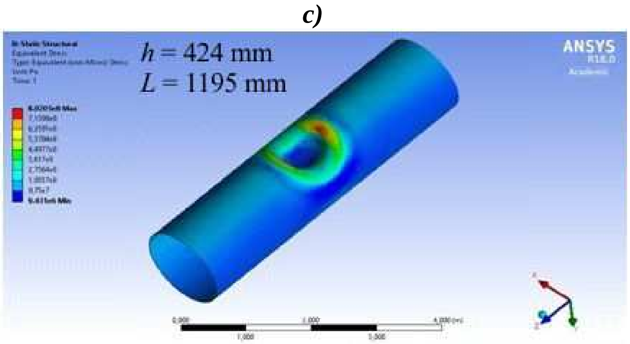
b)



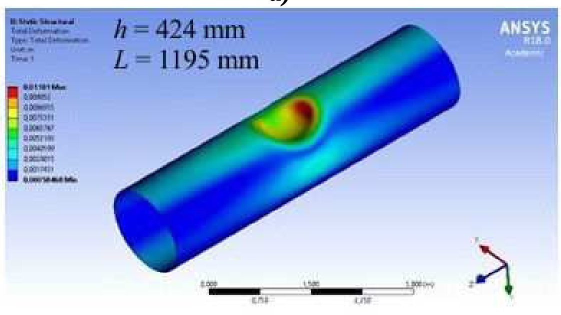
c)



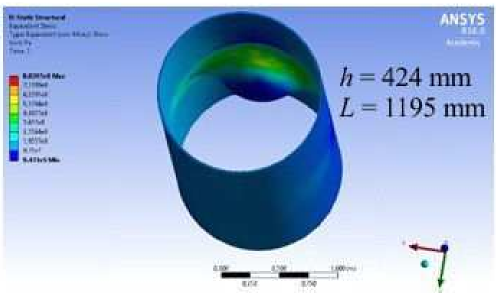
d)



e)



f)



g)

a), c), e), g) equivalent von Mises stresses; b), d), f) total deformations

Figure 11 – Results of modelling the stressed state and deformations of the gas pipeline section with a dent

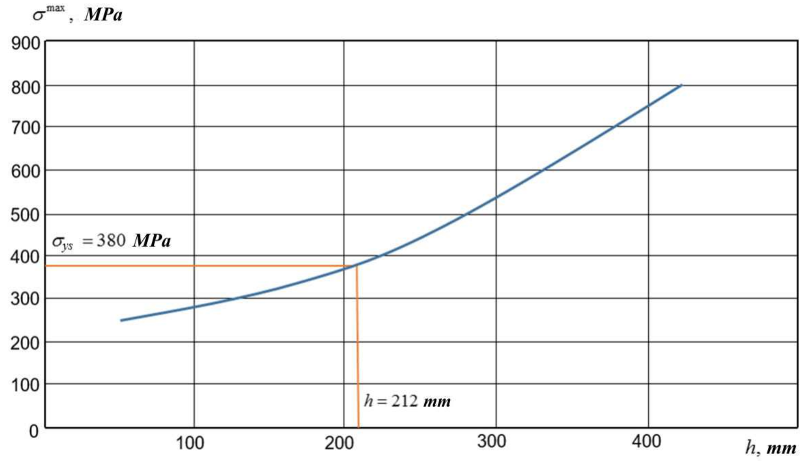


Figure 12 – Dependence of maximum equivalent stresses $\sigma^{\max}$ on the depth h of the dent

development of the plastic deformation of the metal and loss of the bearing capacity of the pipe wall. Therefore, exploitation of this gas pipeline is permitted if the depth of the dents, detected during the examination, does not exceed 212 mm.

As can be seen from the fields of equivalent von Mises stresses (Fig. 11, *g*), these stresses are much smaller at the inner wall at the beginning and the end of the dent (in the course of the flow movement), in the place of its bend, than at the outer wall. There is a significant decrease in equivalent von Mises stresses and total deformations near the middle of the dent (in the place where its depth is maximal) (Fig. 11).

The results of the gas-dynamic modeling were visualized in the ANSYS CFD post-processor, which allowed to see the structure of the gas flow in the oval section of the gas pipeline. Based on the results of the gas-dynamic modeling, it has been established that the velocity of the gas flow in the oval part does not change as the cross-sectional area of the gas pipeline does not change. The pressure fields were designed in longitudinal and transverse sections (Fig. 13, *b*) and on contours (Fig. 13, *c*).

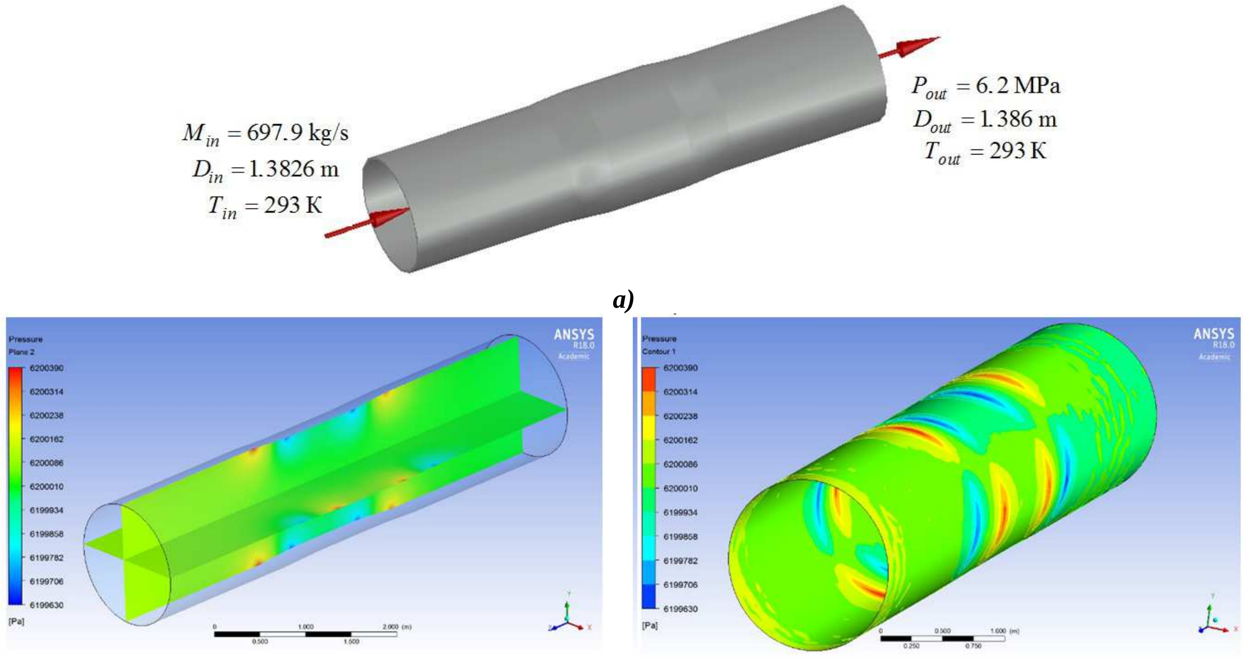
Based on the values of the pressure fields in the longitudinal and transverse sections (Fig. 13, *b*) and on the contours (Fig. 13, *c*), it was determined that the pressure is unevenly distributed in the place of the gas supply. Since the length of the gas pipeline is small, the pressure at the inlet is approximately equal to the pressure set at the outlet and it is 6.2 MPa. Based on the values of the pressure fields it was observed that there is a slight increase in pressure in places where the diameter of the pipeline begins to decline at the beginning of the transition from round to oval shape of cross-section (in the direction of the flow motion) and vice versa – there is a slight reduction of pressure in places where the diameter of the pipeline begins to increase. The same uneven pressure distribution is observed at the end of transition from the oval cross section to the round (in the direction of the flow movement). At the end of transition from a circular to an oval cross-sectional shape (in the direction of flow movement), uneven redistribution of pressure also occurs. There is a slight decrease in pressure in places where the diameter of the pipeline finishes decreasing and, conversely, there is a slight increase in pressure in sites where the pipeline diameter is increasing. The same uneven distribution of pressure is observed at the beginning of transition from the oval cross section to the circular (in the direction of the flow movement).

The uneven distribution of pressure in the inner cavity of the gas pipeline with the ovality (Fig. 13) affects the stress state of the pipe wall. To take into account this effect, the computational results of pressure on the inner wall of the pipe were imported from the ANSYS Fluent hydro-gas dynamic module into the mechanical module ANSYS Static Structural (Fig. 14).

The results of modeling the stress-strain state of the gas pipeline section with the ovality of the pipe by the finite element method in ANSYS Static Structural were visualized by designing the fields of equivalent von Mises stresses (Figs. 15, *a, c, e, g*) and fields of total deformations (Figs. 15, *b, d , f, h*).

Based on the values of the fields of equivalent von Mises stresses, it can be seen that the maximum equivalent stresses are concentrated in the place of the ovality of the pipeline and are not evenly distributed. They are concentrated on the outer wall in the place of the smaller diameter of the pipeline and on the inner wall in the place of the increased diameter of the pipeline. The minimum equivalent stresses, on the contrary, are concentrated on the inner wall in the place where the diameter of the pipeline decreases and on the outer wall at the point where the diameter of the pipeline increases (Fig. 15, *a, c, e, g*). The largest deformations of the pipeline are observed in the place of the reduced diameter of the pipeline. They are also large in the place where the diameter of the pipeline increases, but somewhat smaller than in the place of their reduction (Fig. 15, *b, d, f, h*).

With the increase of the ovality parameter, the magnitude of the maximum equivalent stresses and deformations increases. Thus, when the magnitude of the ovality parameter equals $\beta = 0.028$, the maximum equivalent von Mises stresse are 225.5 MPa in the place of ovality, and the maximum total deformations are 5.5 mm (Fig. 15, *a, b*), when the magnitude of the ovality parameter is $\beta = 0.042$, the maximum



a)

b) *c)*

a) the computational scheme; b) the pressure fields in the longitudinal and transverse sections; c) the pressure fields on the contours

Figure 13 – Results of modeling the pressure distribution in the inner cavity of the gas pipeline with the ovality of the pipe ($\beta = 0.112$)

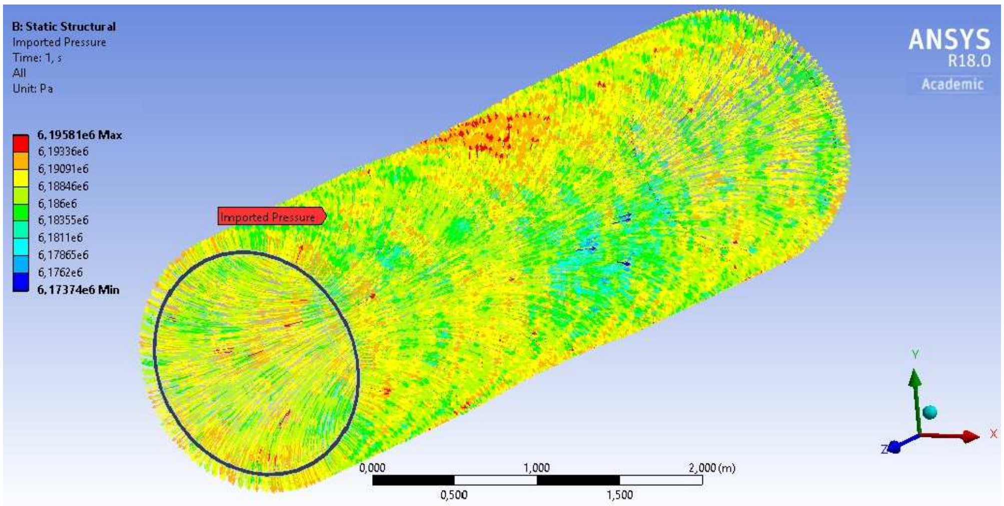
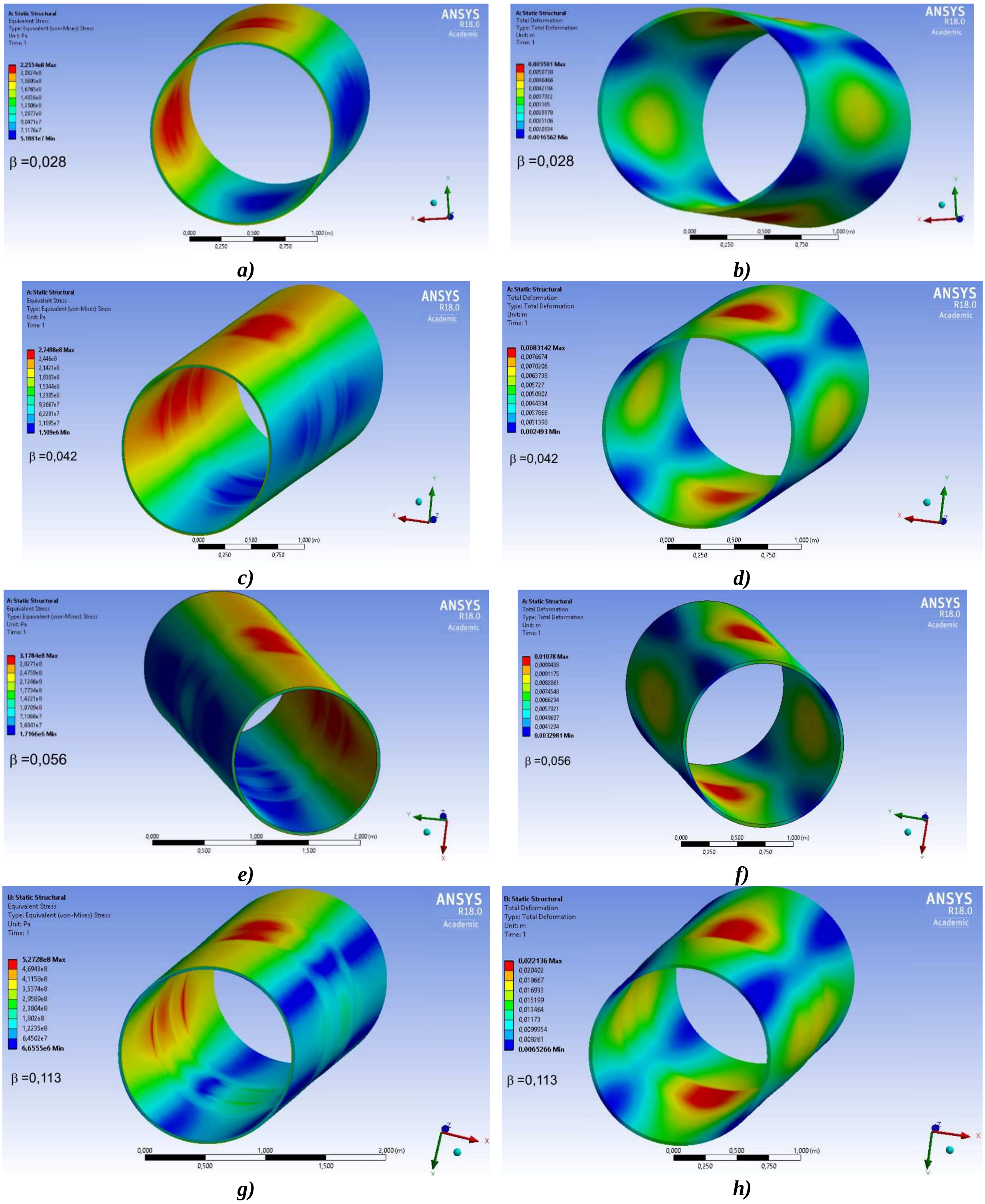


Figure 14 – Results of calculating the pressure distribution on the inner wall of the pipe in the area of ovality imported from ANSYS Fluent in ANSYS Static Structural

equivalent stresses are 275 MPa, and the maximum total deformations 8.3 mm (Fig. 15, *c*, *d*), when the magnitude of the ovality parameter is $\beta = 0.056$ the maximum equivalent stresses are 317.8 MPa, and the total maximum deformations are 10.7 mm (Fig. 15, *e*, *f*), and when the magnitude of the ovality parameter is $\beta = 0.113$, the maximum equivalent stresses are 527.3 MPa, and the total maximum deformations are 22.1 mm (Fig. 15, *g*, *h*).

According to the simulation results, there is designed a graphical dependence of the maximum equivalent stresses $\sigma^{\max}$ on the ovality parameter β (Fig. 16). Based on the graphic dependence it is established that if the ovality parameter is more than 212 mm, the maximum equivalent stresses are larger than the boundaries of 13G1S-U steel flux, which was set to the wall of the pipe. In the case of exploitation of the gas pipeline in the mode specified by the initial data and with the ovality parameter more than 0.074, there may occur the development of the plastic deformation of the metal and the loss of the bearing capacity of the pipe wall. Therefore, exploitation of this gas pipeline is allowed if the ovality parameter detected during the examination of such defects does not exceed 0.074.



a), c), e), g) – equivalent von Mises stresses; b), d), f), h) – total deformations

Figure 15 – Results of modeling the stress state and deformations of the oval section of the gas pipeline

Conclusions

The method of three-dimensional modeling the stress-strain state of main gas pipelines sections with defects of the cross-section shape of the pipe (dents, ovality) is developed taking into account the gas-dynamic processes occurring in the places of these defects in the inner cavity of the gas pipeline. It is established that the dents with the depth more than 212 mm and oval areas with an ovality parameter more than 0.074 are dangerous and can lead to an accident for a modeled gas pipeline. It was found that the areas of maximum equivalent von Mises stresses occur at the beginning and the end of the dent (in the course of the flow movement) in the place of its bend. If the pipeline section is oval, then the maximum equivalent stresses are concentrated on the outer wall in the place of the smaller diameter of the pipeline and on the inner wall in the place of the increased diameter of the pipeline.

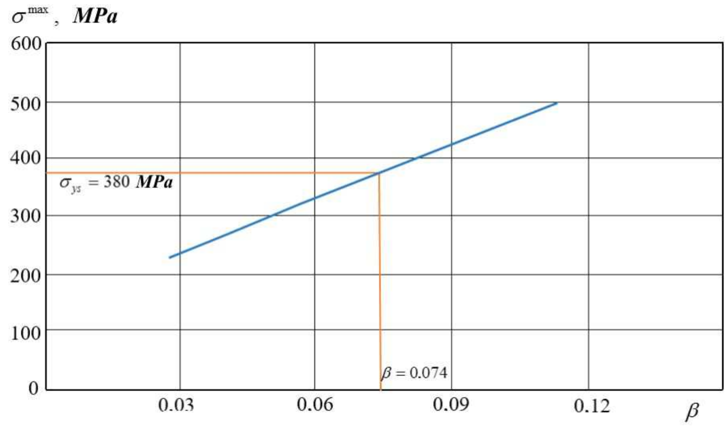


Figure 16 – Dependence of the maximum equivalent stresses q_{eq}^{mqx} on the parameter of ovality β

The developed method makes it possible to determine the influence of defects in the shape of the pipe cross section of the gas pipelines on its bearing capacity, to perform the ranking of such defects by the degree of danger, and to determine which of them are critical.

References

[1] Finley, D 2015, *Summary of Dent Assessment Methodologies and use of ILI Calliper Data.* MACAW Engineering Ltd, Newcastle, UK, 21 p.

[2] Sutomo, J & Wardhana, W 2010, *Analisa fatigue akibat tekanan internal siklis pada dented pipe,* TUGAS AKHIR – MO 091336, Institut Teknologi Sepuluh Nopembe, Indonesia, 22 p.

[3] Budilov, IN, Kuljasov, GV, Lukashhuk, JuV & Shevela, VV 2013, 'Evaluation of the strength of technological pipelines with defects of mechanical origin', *Bulletin of UGATU*, vol. 17, no.1 (54), pp. 57–62. [in Russian]

[4] Recommendations 1998, *Recommendations for assessing the performance of defective parts of gas pipelines*, GD 51-31323949-42–99, JSC Gazprom. [in Russian]

[5] Squires, K & Eaton, J 1990, 'Particle response and turbulence modification in isotropic turbulence', *Phys. Fluid*, vol. 2, no. 7, pp. 1191–1203.

[6] Ovcharenko, VA, Podlyesny`j, SV & Zinchenko, SM 2008, *Fundamentals of the finite elements method and its application in engineering calculations*, DDMA, Kramators`k, p. 380. [in Ukrainian]

УДК 622.691.4

Дослідження напружено-деформованого стану ділянок магістральних газопроводів з дефектами форми поперечного перерізу труби

[1]Я.В. Дорошенко, [1]Л.Д. Пилипів, [2]К.А. Поляруш, [1]Ю.І. Дорошенко

[1] Івано-Франківський національний технічний університет нафти і газу; вул. Карпатська, 15, м. Івано-Франківськ, 76019, Україна

[2]ПАТ "Київенерго" СВП "Київські Теплові Мережі" РТМ "Печерськ"; вул. Товарна, 1, м. Київ, 01103, Україна

Здійснено 3D моделювання ділянок магістрального газопроводу з дефектами форми поперечного перерізу труби – вм'ятинами та овальністю. У програмному комплексі ANSYS Fluent R18.0 Academic виконано моделювання руху газу цими ділянками газопроводу. Математична модель руху газу базується на розв'язанні рівнянь Нав'є–Стокса і перенесення енергії, замкнених двопараметричною моделлю турбулентності Лаундера–Шарма з застосуванням пристінної функції з відповідними початковими і граничними умовами. Досліджено структуру потоку газу у ділянках газопроводу з дефектами форми поперечного перерізу труби. Результати моделювання візуалізовано побудовою ліній течії, полів модуля швидкості та тиску на контурах, в повздовжніх і поперечних перерізах. Визначались точні значення швидкості, тиску в різних точках внутрішньої порожнини ділянок газопроводу з дефектами форми поперечного перерізу. Виявлено місця сповільнення та пришвидшення газового потоку, підвищення та падіння тиску.

Результати моделювання відкрили можливості для дослідження напружено-деформованого стану ділянок газопроводу з дефектами форми поперечного перерізу труби. Для цього результати газодинамічного розрахунку імпортувались в механічний модуль ANSYS Static Structural для моделювання напружено-деформованого стану. Результати моделювання візуалізовано побудовою полів еквівалентних напружень за Мізесом та полів загальних деформацій, з яких виявлено зони максимальних та мінімальних еквівалентних напружень за Мізесом і загальних деформацій в ділянках газопроводу з вм'ятинами та овальністю труби різної величини. За результатами побудовано залежності максимальних еквівалентних напружень від глибини вм'ятини і параметра овальності, з яких визначено допустимі розміри дефектів.

Ключові слова: *вм'ятина, допустимі параметри, еквівалентні напруження, метод скінчених елементів, овальність, поле тиску.*