Study of efficiency of application of locally reinforced fitting units with stiffening ribs

A M Fairushin, A S Tokarev, D V Karetnikov and M Z Zaripov

Department "Equipment and technologies for welding and control", Ufa State Petroleum Technological University, Kosmonavtov Str.,1, Ufa, 450062, Republic of Bashkortostan, Russia

E-mail: otsk@rusoil.net

Abstract. In this work, one of the main methods of strengthening the hole in the apparatus is considered - strengthening with overhead rings, the advantages and disadvantages of using reinforcing rings are indicated. An analysis of the main methods of strengthening the openings of pressure vessels and devices shows that the difficulties in designing and installing the reinforcing rings are in the technology of assembly, detection of weld defects and detection of the local location of this defect. The work shows the possibilities of using locally rib-reinforced nozzle assemblies, which in some cases can serve as an alternative to reinforcing rings, and are also more technological in manufacture, repair and control. Calculations show that the use of two stiffening ribs oriented along the generatrix of the shell to strengthen the hole allows reducing stresses in the area of welding of the nozzle to the body of the apparatus under static load. Practical experiments carried out at the same time showed that in conditions of dynamic loading, it is categorically not recommended to use the strengthening of the nozzle with local stiffening ribs oriented along the generatrix of the shell.

1. Introduction

Today, most vessels and devices are designed with nipple assemblies in two versions: this is a tie-in of the nozzle passing and not passing without reinforcement with an overhead ring, if the design diameter, which does not require strengthening, is more than necessary, or if, in accordance with the requirements of the calculations, the hole strengthening, the nozzle is designed, fixed with the overhead ring. The diameter of the hole is one of the main parameters affecting the requirement to strengthen the nozzle assembly with a ring. For a device loaded with medium and operating under pressure, any tightness violation is a risk of an even greater state of tension. With an increase in voltage, which at different design temperatures for different grades of steel has its own value, the diameter that does not require strengthening also changes.

With all its advantages, the design with an overhead ring has a number of significant drawbacks:

- The complexity of the assembly in accordance with the requirements of GOST R 52630-2006, since the technologies used at present for their manufacture do not allow for a tight fit of the ring to the housing, which leads to an increase in the clearance, especially with large thicknesses of the reinforcing rings, as well as when installing them on the bottoms [1,2].
• Difficulty of detection of internal defects during non-destructive inspection of weld quality [3–5]. The existing technique for monitoring this node during the diagnosis and determination of the residual resource involves a leak detection test, and does not provide for the determination of internal defects that can negatively affect its performance. So, for example, due to the lack of sufficient control, the strengthening of holes in the shells and bottoms of vessels, apparatuses and units of technological installations for the preparation and processing of oil and gas containing hydrogen sulfide and causing corrosion cracking is carried out only with the help of excessive thickness of reinforced elements and nozzles (allowed in some cases with thicknesses above 35 mm). At the same time, the thickness of the walls of the nozzle nozzles should, as a rule, not exceed the thickness of the walls of the reinforced elements (shells, bottoms).

• If a leak is detected due to the design features of the assembly, it is not possible to accurately determine the location of the defect. If the medium passes, the entire weld joint is cut out instead of correcting the local defect [6].

Thus, there is a need to improve the structure of the assembly, the use of other, more technological and easy from the point of view of manufacture and control methods for strengthening the hole.

The purpose of the study is to consider the possibility of strengthening the hole in an alternative way, to find the optimal way to strengthen.

The use of reinforcing rings is most widely used today, but the manufacture of the reinforcing ring is low-tech and difficult under repair conditions.

In this work, it is proposed to consider the use of a stiffening rib to strengthen the hole in the areas of localization of the greatest stresses. Currently, the works of P.G. Pimstein, V.N. Skopinsky, S.I. Ponikarov and other researchers [7–10], which analyzed the stress-strain state of the nipple assemblies, are known, but there is no work on the study and comparison of the stress-strain state of the nipple assemblies using stiffening ribs.

2. Results and Discussion
During the study, the use of stiffening ribs and reinforcing rings was compared (figure 1).

Figure 1. Methods to strengthen the hole are as follows: (a) reinforcing ring; (b) stiffening ribs.

Geometric models are various versions of the nozzle-body assembly: with a reinforcing ring and with stiffening ribs. The shell diameter is 1000 mm, the thickness is 10 mm, the width of the shell section under consideration is 500 mm. Nozzle diameter 200 mm, thickness 10 mm, length 250 mm, departure 200 mm. The diameter of the reinforcing ring is 172 mm, the thickness is 10 mm. The geometric model includes a housing consisting of a shell and a bottom, with a union consisting of a branch pipe, a flange and a reinforcing element. The width of the reinforcing ring is equal to the side of the slash and is 130 mm.

The bottom and flange are included in the design model in order to take into account the possible effect of edge effects, axial tensile force (from pressure applied to the bottoms) and flange stiffness on the stressed-deformed state of the assembly.
The nozzle-housing assembly is symmetrical with respect to the plane passing through the axes of the shell and nozzle, therefore, to reduce the calculation time and the required computational resources, half of the studied design was used as a model (figure 2).

![Figure 2. Geometric models of nozzle-housing assembly with various reinforcement options.](image)

The locally adapted finite element grid is designed so that the size of the elements in the stress concentration zone does not exceed 1-2 mm, and in remote areas is 25 mm.

Material properties were specified within the elastic zone: elastic modulus $E = 2 \times 10^{11}$ Pa, Poisson coefficient $\nu = 0.3$.

The following boundary conditions are attached to the model:

- constrain the movement along the X axis: surface located in the YZ plane - symmetry condition;
- restricting movements along the Z axis (coinciding with the shell axis) of the circumferential section at the junction of the shell and the bottom on one side and restricting movements along the Y axis of the nodes lying on the shell axis, which avoids large movements in the model nodes arising from computational errors in case of absence of fixation in any direction.

Two types of load are applied to the design model:

- distributed load - pressure $p = 1$ MPa - is applied to all units of the inner surface of the shell, bottom and nozzle;
- concentrated force - axial load $F_z = 1000$ N acting on the connector.

The performance assessment of the existing and proposed structure of the hole strengthening was carried out according to two parameters: displacement (displacement) of the structural units and stress.

As a result of the calculation, movements, stresses and strains were determined. The diagram shown in figure 3 shows the maximum equivalent Mises stresses that occur in nodes of various designs.

![Figure 3. Maximum equivalent stresses occurring in the apparatus housing in the nozzle welding unit: 1 - without strengthening; 2 - with reinforcing ring without clearance; 3 - with a reinforcing ring with a gap of 3 mm; 4 - with stiffening rib and backing plate.](image)
The calculation results show that in the fixed joint welding unit under the action of internal pressure of 1 MPa, the maximum stresses are localized at the point of connection of the joint with the shell in meridional section, while the highest equivalent stresses are 192 MPa. In an assembly secured by a ring without a gap, the largest value of equivalent voltages 162 MPa is 30 MPa (15%) lower, the nature of the stress distribution does not practically change.

If the hole is reinforced with stiffeners located in the meridional section, the maximum equivalent stresses are reduced by 14 MPa and amount to 178 MPa (lower by 7.5%). At the same time, the stress distribution is more compressed in the axial direction, i.e., as the stress is removed from the nozzle, it decreases faster.

Thus, the calculation shows that the use of two stiffening ribs oriented along the generatrix of the shell to strengthen the hole with a diameter of up to 150 mm with a shell diameter of 1000 mm allows, under static load, to reduce stresses in the area of the union welding to the apparatus body. At the same time, such a structure is easier to manufacture and install compared to a reinforcing ring.

As a rule, during the operation of the device, the axial load acts on the nozzle, therefore, in this work an analysis of the stress state of the nozzle assembly of various versions was carried out when it is affected by an axial load of 1 kN.

Figure 5 shows changes in equivalent stresses along the generatrix of the shell in meridional section taking into account the action of axial load on the nozzle of 1 kN.

As the results of the numerical analysis show, the maximum equivalent stresses in the node without strengthening are 255 MPa, in the node reinforced by the ring - 178 MPa (30% lower), in the node reinforced by the stiffeners - 210 MPa (15% lower).
3. Conclusion
Calculations carried out using finite element methods made it possible to establish that the use of two stiffeners oriented along the generatrix of the shell to strengthen the hole with a diameter of up to 150 mm with a shell diameter of 1000 mm allows reducing stresses in the area of welding the nozzle to the body of the apparatus under static load. At the same time, such a design is simpler to manufacture and install compared to the reinforcing ring and is permissible if the nozzle does not have a dynamic load. The results of the numerical analysis with additional axial load applied to the nozzle show that the maximum equivalent stresses in the unit without strengthening are 255 MPa, in the unit reinforced by the ring - 178 MPa (30% lower), in the unit reinforced by the stiffeners - 210 MPa (15% lower).

References
[1] Apisov I V 2014 Analysis of the stress state of the choke assembly reinforced with a patch ring, taking into account assembly defects Oil Gas Bus. Electron. Sci. J. 5 223-37
[2] Apisov I V 2014 Development of a methodology for monitoring the adhesion of the reinforcing ring to the surface of the apparatus body Oil Gas Bus. 12 148-56
[3] Sapun A A, Kravtsov A V, Pavlov O A and Gurevich D V 2015 Assessment of the reliability of the results of ultrasonic testing of welded joints of choke units Autom Telemehch Commun oil Ind. 11 17-9
[4] Tokarev A S, Karetnikov D V, Rizvanov R G, Fayrushin A M and Zaripov M Z 2020 Assessment of the Stress-Strain State of a Tube Sheet of the Heat Exchanger at Rotary Friction Welding Application Mater. Sci. Forum 991 70-6
[5] Lukyanov V F, Sobol B V, Panov Y V and Petrenkova S B 2015 Investigation of the regularities of initiation and development of fracture of welded choke joints based on fatigue tests Integr. Vib. wave Technol. Mech. Eng. Metalwork. 1 342-5
[6] Yakhin A V, Karetnikov D V, Rizvanov R G, Abutalipova E M, Gareev A G and Tokarev A S 2019 Improving the Technology Used in Fabrication of Tube Bundles of Heat Exchangers Produced from 12Cr18Ni10Ti Steel by Means of Friction Welding Chem. Pet. Eng. 54 801-5
[7] Pimshtein P G, Mordina G M and Barabanova L P 2003 Stress state of choke assemblies in the cylindrical wall of pressure vessels Chem. Oil Gas Eng. 4 3-5
[8] Skopinsky V N and Berkov N A 2010 Elastoplastic analysis of stresses in intersecting cylindrical shells reinforced with an overhead ring Chem.Oil Gas Eng. 4 14
[9] Rizvanov R G, Mulikov D S, Karetnikov D V, Fayrushin A M and Tokarev A S 2018 Evaluation of the Possibility of Obtaining Tube-to-Tube Sheet Welded Joints of 15Cr5Mo Steel by Alternative Technological Process IOP Conf. Ser. Mater. Sci. Eng. 317 12077
[10] Sabitov M K and Ponikarov S I 2011 Analysis of the stress-strain state of choke units based on the low-cycle strength of pressure vessels Bull. Kazan Technol.Univ. 20 208-12