Research of Tension and Deformations in the Elastic Element of the Universal Spherical Preventer Seal

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Abstract. The reliability of the preventer operation to the greatest extent depends on the rubber-metal seal, which is a powerful elastic rubber-metal ring. In the work, different options of the design of sealing elements with different forms of reinforcing elements are considered. In this work, the influence of the shape of the elements, reinforcing the elastic spherical ring seal, on the functionality of the universal preventer was investigated. The study was conducted by numerical simulation methods for two seals with the same physical and mechanical properties and geometric dimensions, under the same loading conditions, but with different reinforcing elements. Based on the results of the study, the deformation parameters of the seal and the contact loads on the casing were obtained.

Keywords: Universal preventer · Blowout preventer (BOP) · Spherical O-ring · Elastic element · Reinforcing element · Deformation · Contact force · Contact pressure

1 Introduction

One of the most important components for efficient and safe operation of a drilling rig is the blowout preventer (BOP). The universal spherical blowout preventer is used when drilling wells and is designed to seal the wellhead during drilling operations, both with and without drill pipe and drilling tools. The reliability of preventer operation to the greatest extent depends on the rubber-metal liner, which is a powerful ring elastic seal that allows the drill pipe string to pass when the preventer is open, and compresses when closed, crimping the pipe (lead pipe, lock) and seals the annular space between the drill pipe and the casing string. Elasticity of the rubber seal allows the preventer to be closed on pipes of different diameter, on tool joints and drill collars. Application of universal preventers gives an opportunity to rotate and loosen the string with sealed O-ring gap [1, 2]. The compression of the annular seal is ensured either by the direct effect of the hydraulic force on the sealing element, or due to the effect of this force on the seal through a special annular piston [3].

When constructing wells with deep layers, it is necessary to use preventers with large casing diameter from 114 to 508 mm and more according to Russian GOST R 13862 [4] and API 5CT [5]. Naturally with such diameters of the packer the size of the

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packer reaches considerable values, that leads to unstable behavior of the hyperelastic material under the volume deformation. Metal reinforcement systems are used to ensure directional deformation of the seal and uniform transfer of hydraulic control load from the piston to the seal. Knowing the nature of deformation, the magnitude of excessive sealing properties of the main working element allows predicting the safe operation of the preventer and the entire blowout preventing equipment of the well.

2 Problem Statement

Let us consider the most known methods of reinforcing seals for spherical ring preventers. In the practice of application of blowout preventers the most widespread are constructions of the seal with steel segments representing concentric spherical surfaces interacting with the spherical surfaces on the upper and lower bodies. The upper part of the segment repeats the surface of the cover and the lower part the surface of the piston, the upper and lower parts of the segment are connected by flat ribs of lamellar shape, located radially relative to the passage opening. This design is the most common and is described in papers [6–8]; let us call it a T-bar reinforced design. Typically uses a circular array of curved metal reinforcing segments that slide in a hemispherical cavity and are pushed upward by a hydraulic piston into a spherical cavity to reduce the diameter of the passage through which drill-string components are inserted. The metal segments are held in a circumferential ratio, being molded into an elastic rubber matrix, and forming a single element with it. When the sealing element containing the curved metal segments and the rubber matrix is moved upward, a forced deformation of the inner cylindrical rubber surface towards the outer circumferential surface of the drill string occurs, thus sealing and preventing the leakage of pressurized fluids under the preventer. In the universal preventer, sufficient inward movement of rubber is ensured to completely seal the preventer borehole, even in the complete absence of a drilling tool. Different variants of constructions and materials for the reinforcing segments are suggested, so the authors of [9] describe the sealing element for blowout preventer, where the flexible non-metal composite bodies on general circular base are suggested to apply as a reinforcing component. Replacement of metal inserts with a non-metallic composite elastic element, according to the authors, improves the parameters of the stress-strain state of the compactor as a whole, which increases its service life. Other options of reinforcing devices are incompressible sealing element segments, consisting of parts moving relative to each other [10], such design of segments, limits the impact force between reinforcing metal elements and drill string, which reduces the wear.

The present work studies a design of reinforcing segments of flat shape additionally provided with a flexible metal cable, connecting the metal elements. It is supposed that metal segments of flat form simultaneously provide sliding of the sealant along the metal cover, but due to their flat form they do not create additional friction. Moreover, they create a mode of volume stress state: compression – extrusion, providing deformation of elastic base (matrix) in the direction of the sealed through hole. The proposed design is less metal-intensive and reduces the weight of the gasket, which is a replaceable part, which facilitates the operation of its replacement.

The main problem, of all the designs under consideration is that in the closed position the pressure in the wellbore may exert pressure on the elastomeric body, which leads to further stress inside the elastic element, which is in a stretched and deformed state. At certain areas of the elastomeric body, significant stresses occur, acting on the sealing assembly in two directions: radially inward and axially upward. At significant reservoir pressures, the stresses can be significant and lead to seal failure.

The 21 ¼" (540 mm) diameter borehole is the maximum borehole diameter of a universal blowout preventer. According to Russian GOST R 51365-2009 [11], preventers with 540 mm passage opening is PUG-540, according to API Spec 16A, it is a 21 ¼" preventer [12]. The overall dimensions, weight and cost of the sealing element for the preventer of the considered size are considerable, whereas the normative service life of standard designs of sealing elements for ring preventers is relatively low, which does not satisfy drilling contractors. That is why the specialists of leading organizations have become more and more active in order to improve and optimize the main operational parameters of sealing elements. The aim of the present investigation is to make a comparative analysis of the stress-strain state while performing the main function, namely sealing of the annular space when executing a technological operation of the gasket with T-shaped segments. These gaskets are the most widely used in preventers of various manufacturers and a newly suggested design with flat reinforcing segments for the preventer with a maximum bore hole.

3 Results and Discussion

Numerical methods with the use of computational digital models approximated to the real ones with setting the properties of the real material with maximum approximation to the operating conditions allow preliminary evaluating the consistency of the set problem and, if the result is positive, significantly reduce the cost of a natural full-scale study [13]. The results obtained narrow the range of problems, solved in full-scale experiments.

The study of hyperelastic models of rubber materials mainly includes molecular network models and phenomenological theoretical models. Based on the above two models, various constitutive models are derived by simplifying the model parameters. These are mainly Arrude-Boyce, Mooney-Rivlin, Yoch, Ogden and other models [14]. Compared to other models, the Yoch model is more suitable for describing large deformations of rubber materials [15, 16].

A nonlinear static solver (Advanced Nonlinear Static NXSTRAT 601) was used as a tool for the numerical method. Numerical simulations were performed using a software package that has a free license for 45 days [17]. To solve the problem, elastic and plastic boundary value problems under maximum loading and contact analysis were used.

A numerical study of two spherical O-ring sealing elements with 540 mm bore diameter (according to the diameter of the socket pipe) has been performed under the condition of casing compression 508.0 mm according to API 5CT. Maximum load of hydraulic control system of 35 MPa has been applied to steel reinforcement elements of sealing through the rod.

Design scheme of the first option of the seal with lamellar reinforcing elements is shown in Fig. 1.

The structural scheme of the second option of the seal with T-shaped reinforcing elements is shown in Fig. 2.

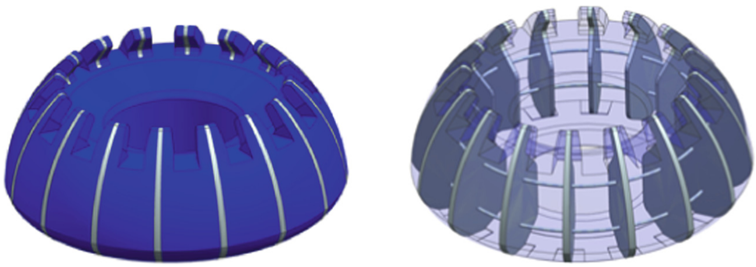

Fig. 1 Seal with lamellar reinforcement

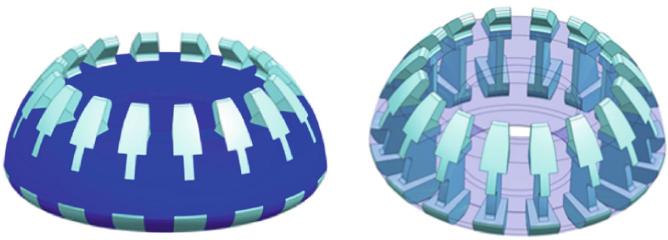

Fig. 2 Seal with T-bar reinforcement

The results of numerical analysis are shown in Figs. 3, 4, 5 and 6 in comparison for two designs:

(a) seal with lamellar reinforcement, (b) seal with T-shape reinforcement. The stress-strain state of sealing elements was considered, nonlinear equivalent stresses were calculated according to the hypothesis of forming energy.

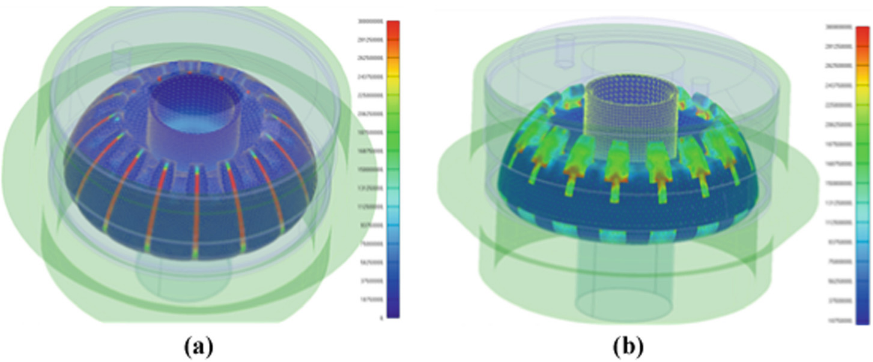

Fig. 3 Nonlinear equivalent stresses, Pa

According to the calculated total displacements, the corresponding values of contact force and pressure in the pipe sealing zone were obtained.

The results of numerical studies are present in Figs. 3, 4, 5 and 6 as a comparison of the analyzed parameters of elastic element behavior. The analyzed parameters were:

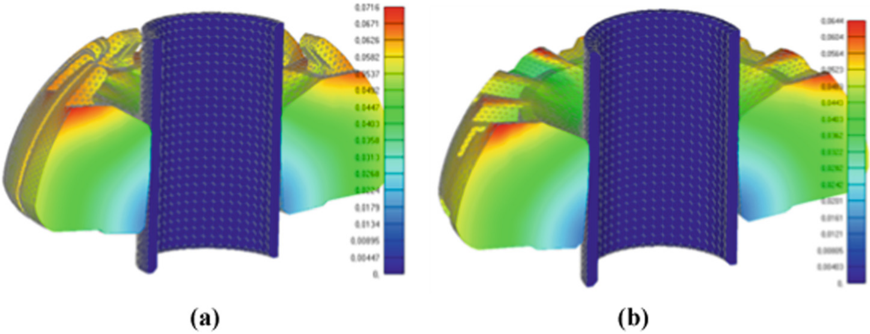

Fig. 4 Total displacements for the structures were, m: (a) $x = 0.0252$, $y = 0.03$, $z = 0.0265$; (b) $x = 0.0061$, $y = 0.0217$, $z = 0.0241$

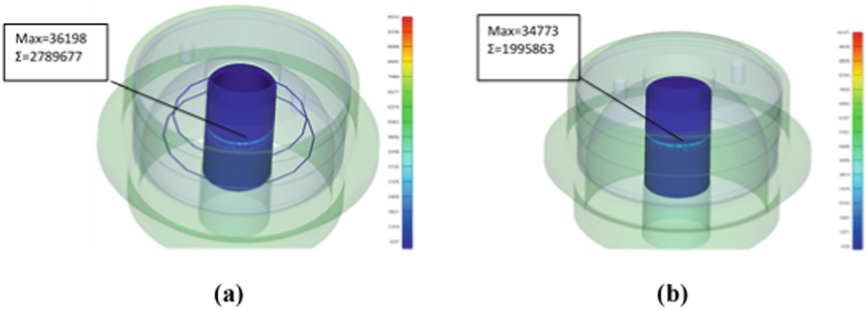

Fig. 5 Total contact force, N

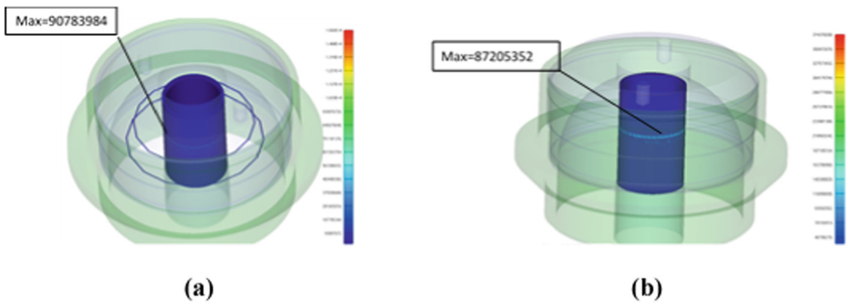

Fig. 6 Total contact pressure, Pa

(i) maximum displacements in the contact zone with the casing;
(ii) total contact force on the casing;
(iii) the maximum contact pressure on the casing.

The research has shown that more technological (obviously cheaper) sealing with lamellar reinforcement has advantages over sealing with T-shaped reinforcing elements by the compared parameters. The ratio of measured and calculated parameters of the option (a) with lamellar reinforcement to the option (b) with T-shaped reinforcing elements is obtained:

(i) in the maximum displacement direction of elastic element in contact with casing: $\Delta d = \left(x^2 + y^2 + z^2\right)^{1/2} = 1.43$;
(ii) total contact force on casing surface: $\Delta f = 1.4$;
(iii) maximum casing contact pressure: $\Delta p = 1.04$.

Data on critical values of stresses arising in places of contact of rubber core with metal segment, protruding zones of stress concentration and being possible causes of delaminations and ruptures of rubber matrix correspond in this part to the results of calculations, presented in work [18].

4 Conclusions

The safety of operations at oil and gas wells cannot be excessive; the consequences of blowout control equipment failures, as history shows, can lead to environmental disasters and loss of life. However, today, in difficult economic conditions, the problem of inexpensive and reliable equipment is very urgent. Thus, the proposed sealing element with less weight and simple shape of metal segments provides the necessary function of the overlapping of the preventer flow-through hole, when performing technological operations (casing wells were considered).

The obtained results require further verification in the nonlinear dynamic solver, to get a more accurate picture of the elastic element in such extremely important equipment as blowout preventer. Similar studies were conducted in [18], where based on the theory of large deformation of rubber and sealing mechanism of the rubber core, it was studied the dynamic finite element model of the rubber core connection to the oil pipe. The model correctness was verified by comparing the destruction of rubber samples. The studies of stress-strain state are of great interest at significant degrees of deformation, corresponding to complete overlapping of the well in the absence of a tool.

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