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HERMETIZATION ABILITY ANALYSIS OF RUBBER SEALS OF TEST PACKERS IN THE FRAMEWORK OF CAE-SYSTEMS

The problems of test process of wellhead and preventer equipment during the construction and underground repair of wells are considered. The effects of extrusion of seal material into the gap to hermetization ability of self-sealing packer and quality test of wellhead and preventer equipment as a whole was analyzed and the need for serious research of self-sealing rubber cuffs was justified. The conditions of application of the model physics of themooney-rivlin material behavior in the implementation of computer simulation of stress-strain state of a rubber self-sealing cuff are analyzed. The major operational factors influencing the ability hermetization of self-sealing cuff during the test are described. The stages and results of computer simulation of stress-strain state of self-sealing rubber cuffs taking into account operational factors were determined. Comparison of the research results of hermetization ability cuff in the quantitative simulation and experimental study was done.

Keywords: *wellhead test packer, self-sealing cuffs; computer simulation, stress-strained state.*

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АНАЛІЗ ГЕРМЕТИЗАЦІЙНОЇ ЗДАТНОСТІ ГУМОВИХ УЩІЛЬНЕНЬ ВИПРОБУВАЛЬНИХ ПАКЕРІВ У РАМКАХ САЕ-СИСТЕМ

Розглянуто проблематику процесу випробування устєвого та противикидного обладнання під час спорудження та підземного ремонту свердловин. Виділено наявність множини конструкцій пакерів для проведення випробування та їх недоліки. Виявлено важливість вузла ущільнення пакера в розрізі герметизаційної здатності устєвого випробувального пакера та якості проведення процесу випробування в цілому. Проведено аналіз літературних джерел і публікацій у сфері дослідження герметизаційної здатності свердловинних пакерів. Висвітлено етапи та результати комп'ютерного моделювання напружено-деформованого стану гумової самоущільнювальної манжети з урахуванням експлуатаційних факторів.

Ключові слова: *устєвий випробувальний пакер, самоущільнювальна манжета, комп'ютерне моделювання, напружено-деформований стан.*

Introduction. During the construction and repair of underground oil and gas wells wellhead and preventer equipment must to be a subject to hydraulic test for checking the hermetization ability:

– To establish at the well;
– After each mounting at the well;
– After repairs (replacing preventer rams, replacing cylinder rod seal of ram preventer, etc.);
– Before opening productive horizon;
– Periodically in accordance with the requirements of drilling company or the company (in accordance with the requirements of API R 53 at intervals of not more than three weeks) [1].

When drilling it is often necessary to test the preventers in the case of open borehole. Creating an excess pressure in the well during test may lead to fluid absorption by the wells, and sometimes even to hydraulic fracturing. In this case it is not possible to comply with regulated requirements totest of mounted preventers.

Today to separate the borehole from the wellhead and preventer equipment during their test down hole packers are used. To test it should be used packer, with ease of operation and high hermetization ability. Such requirements today are corresponded to packer on the basis of self-sealing cuffs. To achieve hermetizationit isn't necessary for external forces because the rubber seal of packers in the basis of self-sealing cuffs automatically trigger when the appearance of excess pressure of the test fluid in packer space.

The modern market of equipment for the construction or operation of oil and gas wells is characterized by a variety of packer design on the basis cuffs. The most successful design is the UHF test packer type manufactured by special rescue service «LIKVO» of PJSC «Ukrgasvydobuvannya» (Fig. 1) [2].

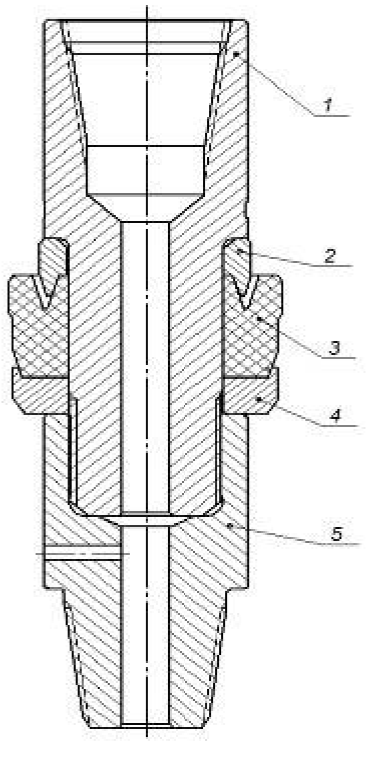

Figure 1 – Wellhead packer UHF 168×50:
1 – case; 2 – bearing sleeve; 3 – self-sealing cuff; 4 – retainer; 5 – selector

The main element of test packer construction is seal assembly on the basis of self-sealing cuff. This structural element determines hermetization of the borehole separation, and therefore the quality of the whole process of test wellhead and preventer equipment.

Given the importance of seal assembly in the system of the entire packer, a special place is development of its rational design. Today, there is no scientific and methodological basis for designing self-sealing cuffs. Some recommendations make it impossible to implement the system design principle, not take into account a number of factors that occur during operation of packers.

In connection with the above, a number of outstanding scientific and technical problems that require mandatory solution through additional research are appeared.

Analysis of recent publications. Currently, there are a large number of scientific papers about research of packer hermetization ability based on cylindrical cuffs [3]. The principle of this type of seal packers consists in application of additional axial external force for packer removal and imposes appropriate restrictions on the use of analytical dependences in developing self-sealing cuffs of wellhead test packers.

In the works [4, 5] the constructive design of test packer on the basis of self-sealing cuff with some practical recommendations to improve hermetization during the test wellhead and preventer equipment is highlighted. In [4] short information about rational cuff tension is given. In [5] recommendations on the radial clearance between the seal assembly retainer and casing pipe wall are given. In [4, 5] there are no experimental or theoretical confirmation of these recommendations.

Given the absence of clearly defined criteria to ensure the hermetization of rubber self-sealing cuffs of down hole packers, a critical analysis of scientific papers on research of self-sealing cuffs structures was conducted in the field of general engineering. The principle of the operation of self-sealing cuffs of down hole packers are absolutely the same principle of the cuffs used for locking the working fluid in movable and immovable joints of various hydraulic and pneumatic systems units or devices.

In the scientific work [6] the dependence of previous contact pressures of self-sealing cuffs on the value of pretension is highlighted. Work [7] presents a scheme of distribution of specific contact pressures on the conjugate cuff surface "outer lip - cylinder". Analytical equation for determining the contact pressures that occur in the process of hydraulic device work on contact sealing surfaces is derived. The authors of [8] classified the factors that determine hermetization of hydraulic cylinders.

Revealing still unsolved aspects of the problem. The results of the works [4 – 8] in theoretical and experimental studies of rubber self-sealing cuffs in the field of general machinery can't fully be used for research of hermetization ability and design of wellhead cuffs for test packers because of a completely different configuration of the latter. Proof of this is relevant study [9], indicating that the performance and value of stresses that occur during operation essentially primarily depend on the size, shape, material and operating temperature of the seal. Comparing the above configuration components of self-sealing cuffs of wellhead test packers and cuffs of general machinery, it can be argued that, apart from the principle of work, they have nothing in common.

In these scientific works there are no studies on the effect of deformation and strength characteristics of self-sealing cuffs such as pressure modulus or shear modulus on the seal. Practice has shown that soft and pliable material with a lower shear modulus, faster, easier and with less energy fills irregularities and hollows of seal surface. Seal surface of well can be represented as corrosive caverns, mud, clay crust of varying thickness and so on. This dramatically increases the extrusion of the material, which also has significant disadvantages (Fig. 2).

Rubber extrusion in irrational radial gap between the seal retainer and casing pipe leads first to a significant extrusion of the material as a result of tensile strength and of redistribution of operate contact pressures on the conjugate surface in the direction of reducing to zero, and then to depressurization due to violation of hermetization conditions. A solid material with greater shear modulus leads to reduce of cuff flexibility. Lack of cuff flexibility has a negative impact during the initial test pressure when installing a packer into casing pipe with significant out-of-roundness on fit completeness of the operation cuff surface to seal surface of casing pipe. This greatly affects the sea land should be taken into account.

The analysis of research in this area shows that today there is no information on research of rubber self-sealing cuffs of wellhead test packers in terms of comprehensive action of power, geometrical parameters and material properties on the latest. There is no systematic distribution base of unit contact pressures under conditions of different levels of the stress state of the seal element at different values of the test pressure, radial clearance and tension.

Summarizing the above information, the authors decided to conduct hermetization ability of seal assemblies of self-sealing packers, taking into account a number of the most influential factors.

The aim of the work. The research was aimed to: identify the stress-strain state of seal assembly cuff in the test conditions for evaluating hermetization ability with the purpose of fundamentalization of development-constructing works with self-sealing cuffs of wellhead test packers.

Basic material and results. The priority is the study of experimental researches on specimens of cuffs of well-head test packers in conditions close to real.

Given the relatively high cost of experimental researches taking into account all factors and possible technical and design parameters of the cuff, search for alternative methods was conducted. An alternative method was analytical and numerical methods.

a)

b)

Figure 2 – Results of seal material extrusion:
a – deformation of the cuff support after raising packer from the well;
b – destruction of the packer cuff support due to rubber extrusion

For more complex structures and boundary conditions many numerical (computer) methods of solving problems are used that allow approximately describe nonlinear geometric forms and methods of application of an external load. A system with a large number of equations, whose solution requires significant computational power, is created for obtaining results with small precision. However, the development of modern computers is not an obstacle.

One method of computer simulation is the finite element method. It is based on replacing the freeform studying area by finite elements with simpler configuration and known properties that are interconnected in the assemblies. Parameters in any internal point are found with the known values of the field at the model borders (boundary conditions) point. Today this method is the most common because of the universality of approach [10].

The problem of the strain and stress patterns with different geometric dimensions and material properties, contact interactions of diverse bodies depending on the applied loads and conditions of interaction with contacting bodies are well solved using the finite element method in CAE-system.

Finite element method was selected to study stress-strain state of the cuffs and according of hermetization ability.

Computer simulation was performed as follows:

– Building a geometric model of seal assemblies;
– Choice of behavior for seal material;
– Splitting cuffs on finite elements;
– Definition of boundary conditions and loads during operation of wellhead test packer;
– Research to obtain relevant diagrams of strain and stress state.

In terms of the first and most critical stages for proper construction of finite-element model is the choice of seal material behavior model. That is necessary to determine the physical model of deformation and a number of physical parameters inherent in the existing model. The physical characteristics and the relationship between stress and deformation of rubber are set by hyperelastic models.

To represent the physics behavior of the material was selected Mooney – Rivlin model used to describe the behavior of low-compressible rubber during stretching and compression and is based on the expression of strain energy density for functions, which allows accounting up to nine parameters in the form of combinations of strain tensor invariants, whose values were established experimentally.

Finite element mesh was created after building geometric models (Fig. 3 a) and the appropriate boundary conditions on the kinematics of seal assemblies during the action of the test pressure were set (Fig. 3, B).

To simulate the cuff was following dimensions: inner diameter d is 81 mm; outside diameter D_M – 149.1 mm; height h - 70 mm. The inner diameter of 168-millimeter test casing pipe is 147,1mm.

The task of simulation within the CAE-system was to obtain the maximum equivalent stress (von Mises) and analysis of their distribution through the cuff body under load. Knowing the distribution of the maximum equivalent stress is very important in terms of research of extrusion process of cuffs in the test of wellhead equipment in radial clearance between the cuff support and the inner wall of the casing pipe d.

Practical experience shows that extrusion is the cause of destruction of the cuff support and packer depressurization during operation.

Simulation was performed on the basis of the most influential factors: the shear modulus of the material σ_{sh} (obtained experimentally), the value of the test pressure P, the value of the radial clearance δ between seal assembly support and the inner wall of the casing pipe and cuff tension Δ.

Fig. 4 shows an intermediate result of simulation in the form of diagrams of stress-strain state of the cuff indicating the restrictions.

The research result is related graphic dependences. One of them is shown in Figure 5.

Obtained dependencies were compared with experimental results. The discrepancy between the results of computer simulation and experimental study was 8%.

Identified simulation results made it possible to rationalize them in improving wellhead test packer and implement it into production.

a b

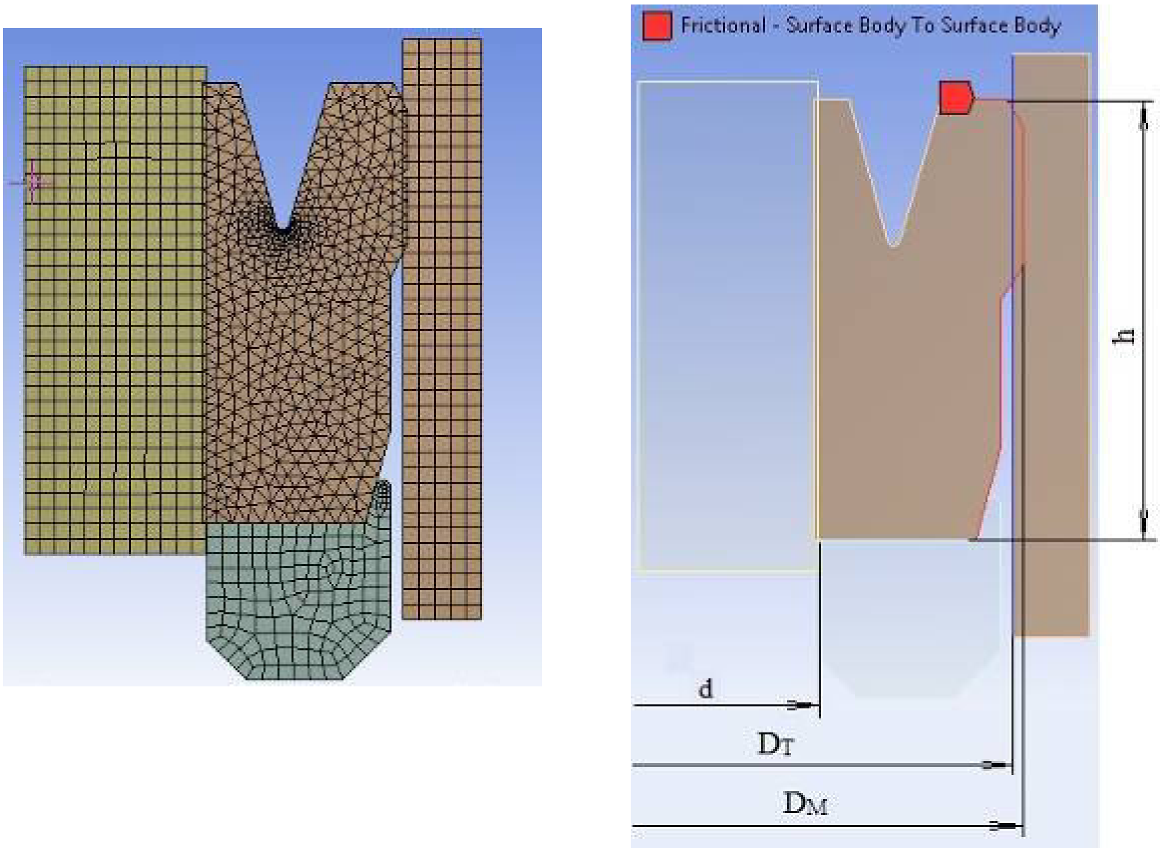

Figure 3 – Preparatory stages of finite element simulation:
a – creating finite element mesh; b – setting the boundary conditions
(d – inner cuff diameter; D_T – inner pipe diameter;
D_M – outer cuff diameter; h – cuff height)

Research of advanced cuffs has been conducted considering similar impacts. Fig. 6 shows intermediate simulation results in the form of diagrams of stress-strain state of the cuff indicating the restrictions.

Improvement of stress-strain state is obvious after comparing the results of the study. Fig. 6 shows that the area of the radial clearance is no longer the stress raiser. This was achieved due to the increasing the height of the cuff support and the angle of inclination in contact point with packer support.

Research make it possible to argue that numerical simulation is an effective research tool and creates rational design of seal assemblies of down hole test packers.

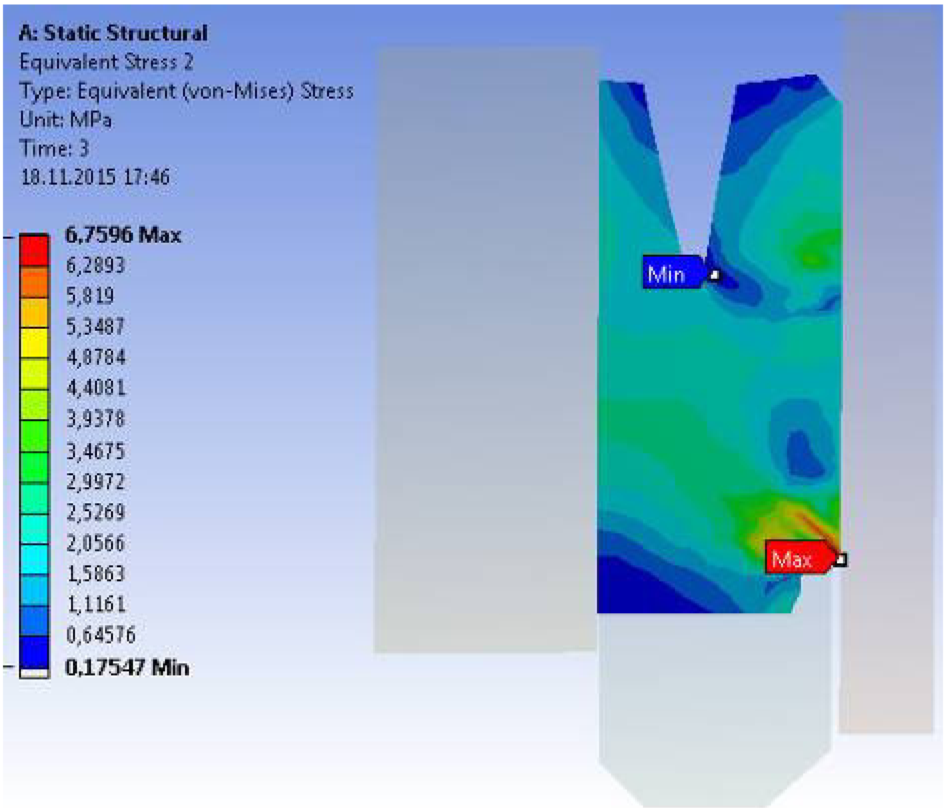

Figure 4 – Distribution of equivalent stress
(von Mises) under the following conditions:
Δ = 2 mm; δ = 1 mm; σ_{sh} = 2.47 MPa; P = 30 MPa

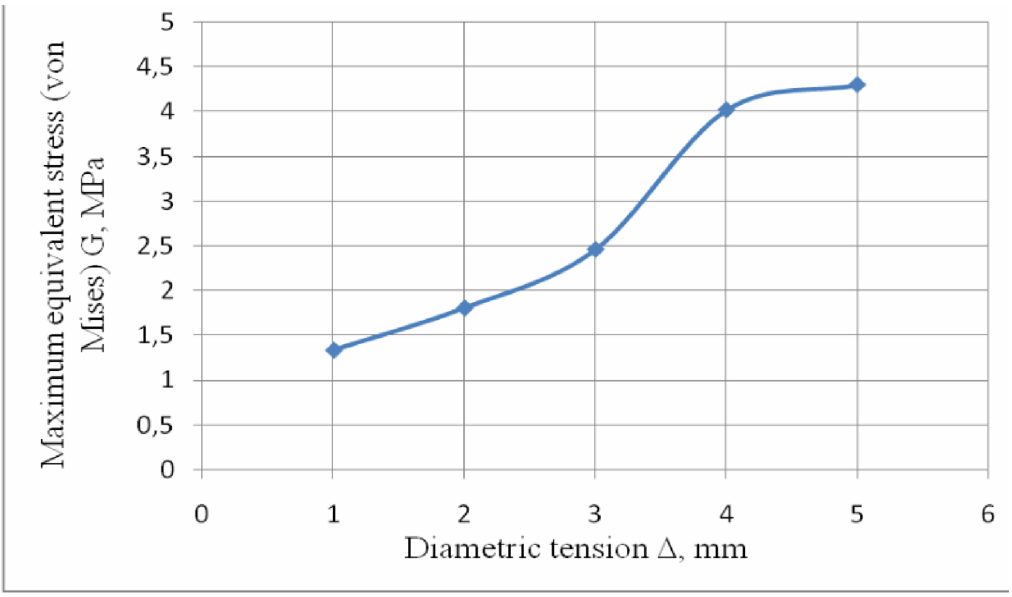

Figure 5 – Dependence of maximum equivalent stress G
on the tension Δ of self-sealing cuff

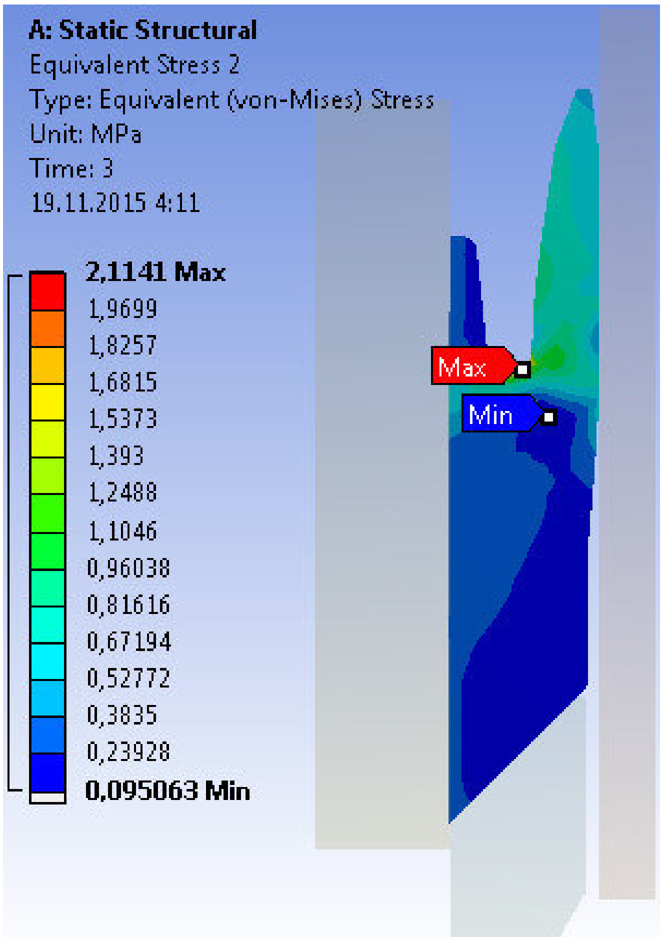

Figure 6 – Distribution of equivalent stress (von Mises) under the following conditions:
Δ = 2 mm; δ = 1 mm; σ_{sh} = 2.47 MPa; P = 30 MPa

Conclusions. Computer simulation of the stress-strain state of self-sealing cuffs of wellhead test packer has allowed concluding the next.

The most dangerous zone of stress concentration is lower zone of the cuff support at the border with radial clearance.

The intensity of increasing maximum equivalent stress increases with radial gap of 4 mm and above.

The angle of inclination of the support cuff and the angle of inclination in contact point with packer support are essential.

Material elasticity and the value of material extrusion material in the gap increase with decreasing shear modulus. The simulation showed that rational shear modulus can be considered value σ_{sh} = 2.47 MPa.

Significant influence on stress distribution is the value of the cuff tension. Rational tension with minimum required values of contact pressures is the range of 3 - 4 mm.

The research results of improved form of self-sealing cuff showed a significant decreasing stress in the area of stress raiser - radial gap.

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