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COMPLEMENTARY PRODUCTS AND DEVICES

DESIGN OF PACKERS FOR SEALING OF THE INTER-TUBE SPACE IN EQUIPMENT USED FOR RECOVERY OF OIL AND GAS

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The working conditions of rubber seals of packers for sealing of individual zones of a well are considered. Means of improving the reliability of existing packer designs are offered. A new packer design is developed for casing pipes.
***Keywords**: design, seal, packer, extrusion, rubber, casing pipe.*

Ecological and production safety of equipment for recovery of oil and gas is determined, including the reliability of the seal. Seals – packers, which in the initial transient (inactive) state easily pass into the well being sealed, are frequently employed when equipment is being lowered into the well shaft; their installation is therefore possible in the most difficult-to-access areas of the well.

The packer must be activated prior to the start of work – compress the elastic element in the axial direction. Normally, the elastic element is fabricated from rubber, making it possible to compensate for surface defects in the casing pipe (roughness and abrasions). Under axial compression, the rubber element is expanded in the radial direction, completely filling the gap between the lift and casing strings. After completion of work, the seal is deactivated (axial compression is removed), and the packer is extracted from the hole. Frequently, the packer is not only called a rubber sealing element, but also the entire coupling, including the activation mechanism and metallic equipment around the rubber element [1].

In traditional seal designs, the magnitude of the compression of the rubber element is constant and is determined by the geometry of the metallic parts (usually by the depth of the seat). When a packer is employed, the magnitude of the compressive force can be changed by varying the magnitude of the activation force. For example, as a packer encompassing a cable functions when lowered into a well. Such a seal is more frequently called a gland; in essence, however, this is the same as a packer. The packer under consideration functions in three modes: without activation; weak activation (a sealing effect is created, but movement of the cable is not blocked); and vigorous activation (employed for retention of the cable). The most widespread form of packer is a cylinder with beveled edges (Fig. 1).

The outside diameter of the packer D_0 normally does not exceed the assigned value in the non-activated state, and is structurally limited for both the rubber part, and also all metallic parts of the coupling. The packer is installed in a hole with an internal diameter D_a. The packer is activated by external force F_a.

The following requirements must be fulfilled to ensure serviceability of the packer:

1. Upon activation, to create a pressure on the inner surface of hole D_a and on the inner surface of the packer (with a diameter D_i), which is sufficient for assurance of a sealing effect.

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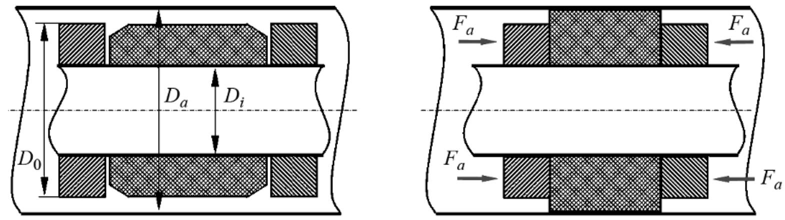

a *b*

Fig. 1. Design of black-cat type of packer: *a*) packer not activated; *b*) activated packer.

2. To prevent failure of the rubber during activation. The basic cause of failure is extrusion (pressing) of the rubber into the gap formed by the cylindrical surfaces with diameters D_a and D_0.

3. To return of the packer to its original state during its deactivation.

The average pressure on the end surface of the deformed rubber element p_a is defined by the ratio of the force F_a to the area of the ring with dimensions D_a and D_i:

$$p_a = \frac{4F_a}{\pi(D_a^2 - D_i^2)}.$$

Here, the contact pressure (contact stress) on the outside diameter of the packer D_a will be somewhat lower than p_a, but somewhat higher than p_a on the inside diameter. If the external pressure p_{ext} satisfies the condition $p_{ext} + \Delta < p_a$, therefore, the packer will fulfill its sealing functions (the value of Δ will depend on the pressure, and the design and properties of the rubber). Under modern conditions of oil and gas extraction, the pressure in the well p_{ext} may attain 700–1000 bar; it is therefore practically impossible to create a force F_a of the required value. Since in packers such as “black-cat,” the contact pressures on the metal–rubber surface being sealed do not increase with increasing external pressure (i.e., there is no self-sealing effect), and the question arises – are the packers functioning under these conditions? If the external pressure p_{ext} exceeds the contact pressure p_a, the appearance of leakage is inevitable.

A self-sealing effect can be created if, for example, the shape of the rubber elements is not cylindrical, but conical. In that case, an annular gap in the form of a wedge is formed where the rubber is forced outward during activation. The rubber is forced into the wedge-shape gap more vigorously with increasing external pressure, contributing to an increase in local contact stresses – the effect of self-sealing develops (Fig. 2).

A similar effect may be achieved when different anti-extrusion adaptors are used, for example, a ring formed from a coil bracelet spring (Fig. 3). This solution does not, however, always ensure the required reliability.

The problem was stated thusly: to ensure the serviceability of a modified packer of cylindrical form (see Fig. 3). The modified packer is distinguished from the previously employed serviceable design by a reduced axial dimension.

. The cause of unstable operation of such a packer is observed experimentally during analysis of the position of the so-called sealing line – a closed line bounding the region of influence exerted by the external pressure. A special paper, the color of which changed during pressure variation, was used to determine the position of the sealing line. The sealing line was found to reside near the metallic springs, and serviceability of the packer was achieved by a wedging effect. Instability of this effect created instability in the performance of the entire packer.

The condition whereby the packer functions reliably is fulfilled by preventing the rubber from extruding into the gap between the metallic parts (between diameters D_a and D_0). In a number of cases, the gap reaches 5–10 mm, and cannot be reduced, since it is determined by the clearance dimensions of the overall structure. A sufficiently rigid rubber must be created in order that it not be pressed into this gap under an external pressure p_{ext} = 700–1000 bar, which is virtually impossible. Coil bracelet springs are some of the anti-extrusion devices that are often used in packers (see Figs. 2, 3). The metallic springs are installed in a mold as is done in S-seals (see Fig. 2, circumferences). Here, the rubber in the gap is not pushed outward, and is not a problem during deactivation of the seal. The disadvantages are: high cost; difficulty in fabricating the rubber-metallic

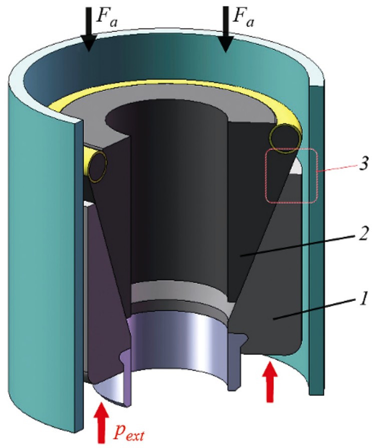

Fig. 2. Design of packer with effective self-sealing: *1*) soft rubber; *2*) stiff rubber; *3*) sealing region.

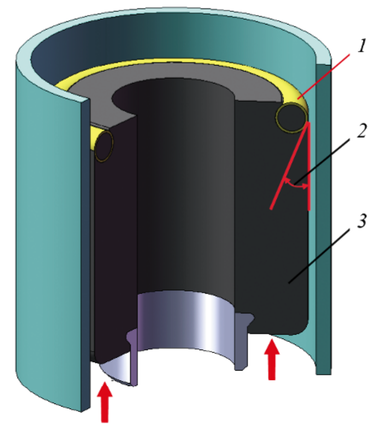

Fig. 3. Cylindrical packer with spring anti-extrusion ring creating self-sealing effect: *1*) spring ring; *2*) wedge; *3*) rubber.

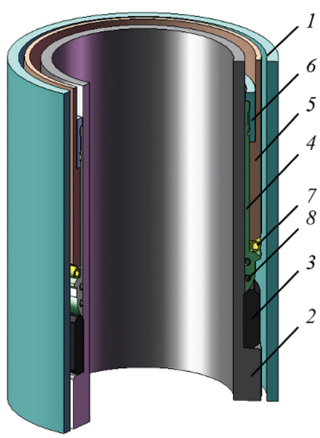

Fig. 4. Packer design: *1*) surface to be sealed; *2*) packer housing; *3*) elastic rubber element; *4*) molded sleeve; *5*) pusher; *6*) slotted nut; *7*) dual coil sting; *8*) rubber sealing ring.

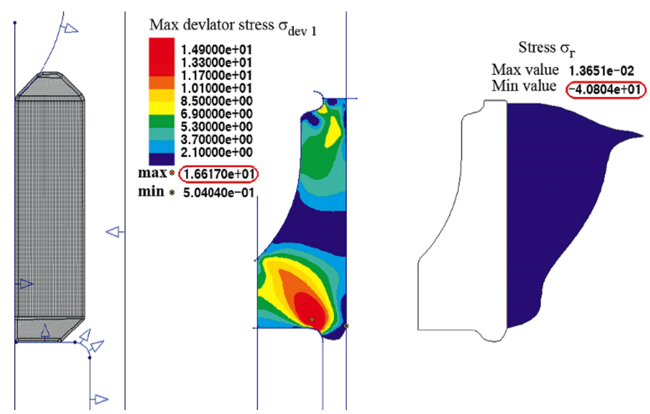

Fig. 5. Finite-element model of elastic element of packer. Field of principle stress deviator, and contact stresses reside on outer cylindrical surface of elastic element.

parts; and, during activation, the spring is appreciably deformed (much more vigorously than in S-seals), whereupon the adhesive bond between the rubber mass and metal of the spring is broken, diminishing the reliability and longevity of the packer.

For packers seldom extracted (once), Γ-shape all-metal rings are used in lieu of the springs. During activation, the ring is straightened and prevents the rubber from pressing outward into the gap. The rings that are not bonded to the rubber can be replaced; during activation of the packer, however, they deform plastically, rendering extraction of the packer from the hole difficult. For this reason, it is desirable to use metallic parts that are deformed only elastically.

Not all packers are serviceable at depth (under water) due to the additional pressure of the water, and the friction generated between the metal and rubber may cause sticking in the activated packer. This can be avoided by the use of rubbers with a reduced coefficient of friction. Normally, however, the sealing properties of stationary seals are degraded when the frictional properties of the rubber are reduced. Another means for solution of this problem is the reduced effect of stretching forces on the rubber during deactivation.

An example of one possible packer design for sealing of a casing string is shown in Fig. 4.

Rubber element *3* assumes a cylindrical form with beveled ends. The activation force is applied from the top downward. During activation of the packer, molded sleeve *4* (in the form of a cone) presses against rubber element *3* and deforms it (Fig. 5). Here, the rubber element is thrust into the surface being sealed *1* (the inner surface of the casing pipe). The developing contact stresses are independent of the force of activation, but depend on the external pressure, also ensuring development of a sealing effect. The force of activation should be sufficient to deform the rubber. The dependence of the activation force on the external pressure (acting downward) is insignificant (see Fig. 4). If the external pressure acts at the moment of activation, it will only contribute to displacement of the rubber element in the required direction.

Coil bracelet spring *7* (see Fig. 4), which is set in a conical seat of variable section, is an anti-extrusion device. When the packer is activated as a result of displacement of pusher *5* relative to molded sleeve *4*, spring *7* is pressed against surface *1* being sealed. This design allows for separation of the spring from the rubber, and when deforming, the spring does not destroy the rubber element. A double spring, i.e., another spring of smaller diameter is inserted inside a larger spring, is fabricated to prevent extrusion of the rubber. Two rubber rings *8* are additionally installed to prevent leakage around the inside circumference (see Fig. 4).

Deactivation occurs under the action of a force acting from above onto molded sleeve *4*. This force should overcome the force of friction between rubber element *3* and molded sleeve *4*.

A characteristic of this design is its appreciable axial dimensions. The required activation fo5rce is relatively small, and is virtually independent of the external pressure. This is a primary attribute of the design. During activation, the path of motion of the sleeve is longer than that for traditional packers. The activation may proceed under an n external pressure. When the packer is deactivated, there should be no external pressure, and the activation force should be large.

We have developed a procedure for design of packers intended for various purposes, which is based on finite-element analyses with use of an original software package [2], and also results of bench and full-scale tests.

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