Finite element method analysis of preventer ram seals of different materials

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Abstract. The paper is dedicated to reducing risk of possible emergency in operation of blowout prevention equipment. It provides some general information on well blow out prevention equipment, describes materials of the principal elements of a ram-type blowout preventer and graphs reflecting deformation of rubber and polyurethane depending on static loads. It is suggested to replace a rubber seal IRP-1352 with a polyurethane-based seal SKU-7L as exemplified with a blind ram model. Ram strength calculations were performed with the ANSYS Workbench software and provided data on maximum deflection of the lower pipe ramp and equivalent stresses for rubber and polyurethane seals. Suggestions are given for selecting materials for ram blowout preventer seals.

1. Introduction
Statistics of emergencies in oil and gas industry shows that the main types of emergencies taking place at drilling sites (over 60%) are fires, explosions, gas and oil eruptions and blowouts. Blowout appearing during well drilling are complex emergencies in the oil and gas industry. Their manifestation breaks the process of well construction or overhaul and brings significant economic and environmental losses; human losses are also possible [1, 2].

In the last 5 years, according to Rostekhnadzor, there were 23 blowouts in Russia; during the last year alone there were over 70 drilling rig fires resulting from gas and oil show. Currently, there is much concern about reducing risks from possible emergencies in operation of blowout prevention equipment to an optimal level [3, 4].

The main elements of blowout prevention equipment include: preventers, adapter spool, wellhead cross, detachable trough, manifolds, manifold and BOP control station. There are three types of preventers: ram-type, annular and rotating preventers [5, 14].

During operation of a ram preventer, special attention shall be paid to diagnostics of its technical condition, service life evaluation, increasing life between overhauls, changing component material in order to increase equipment reliability and safety of operation for personnel and environment alike [6, 7, 13].
2. Materials and methods
The subject of this research is a hydraulically operated ram-type blowout preventer PPG-230x35 connected with a typical piping scheme OP no. 3. Materials of the main elements of the preventer are as follows:
- ram body is made with a Grade 40 steel with the following characteristics: Poisson’s ratio $\mu = 0.27$, density $\rho = 7810$ kg/m$^3$, Young’s module $E = 2.2 \cdot 10^{11}$ Pa, breaking strength $\sigma_b = 65 \cdot 10^7$ Pa, yield strength $\sigma_y = 36 \cdot 10^7$ Pa, shear elasticity $G = 8.28 \cdot 10^{10}$ Pa;
- pins are made of Grade 60 steel, with the following characteristics: $\mu = 0.27$, $\rho = 7800$ kg/m$^3$, $E = 2.04 \cdot 10^{11}$ Pa, $\sigma_b = 70 \cdot 10^7$ Pa, $\sigma_y = 51 \cdot 10^7$ Pa, $G = 8.28 \cdot 10^{10}$ Pa;
- ram seal is made of IPR-1352 rubber with the following characteristics: $\rho = 1000$ kg/m$^3$, $\mu = 0.498$, $E = 9 \cdot 10^6$ Pa, $G = 3 \cdot 10^6$ Pa and volumetric coefficient $V = 7.75 \cdot 10^{11}$ Pa and SKUL-7L polyurethane with the following characteristics: $\rho = 1200$ kg/m$^3$, $\mu = 0.498$, $E = 6 \cdot 10^7$ Pa, $G = 2 \cdot 10^7$ Pa, $V = 5 \cdot 10^{10}$ Pa.

Calculations used data from uniaxial compression tests of elastic materials. Below are graphs reflecting deformation of rubber (Figure 1) and polyurethane (Figure 2) as a function static load.

![Figure 1. Deformation of IPR-1352 rubber as a function of load](image-url)
3. **FEM analysis of preventer ram seals**

From analysis of patent and reference information on preventers, it has been determined that rams and body are the preventer components which undergo most design modifications. In case of rams, new designs are being developed for seals, shear blades, plates, as well as new methods for parts replacement. In case of body, general layout and kinematic part undergo most modifications. During the last 10 years, design of ram-type preventers underwent various changes, but as emergencies are unpredictable and blowout pressure is too high, there is a need to increase reliability of both rams and preventer body proceeding from their design features in order to prevent emergencies rather than mitigate damages [8, 9, 11].

Preventer installed at a wellhead shall be constantly in the mode of instantaneous availability. Most failures are related to ram elements, thus daily testing of rams and their seals is commonly adopted. Run of a seal is measured in the number of closing cycle of the preventer and a total length of pipes drawn through the closed preventer at a speed of 0.000139 m/s with a cylinder pressure and well pressure not exceeding 10 MPa. According to regulations, average time to failure of a seal shall be at least 300 preventer closings without pressure [10, 12].

In this paper, we suggest replacing a ram seal made of IRP-1352 rubber with a seal made of SKU-7L polyurethane, as exemplified by a blind ram model shown in Figure 3. Top and bottom seals are made of the same material. Currently, most companies use the following materials: standard (CO² and H₂S <0.03 %, t <150°C) – IRP-1352 rubber; gas proof (CO₂ и H₂S> 0.03 %) – IRP-1683 rubber; temperature-resistant (>150 °C) – IRP-1287 fluorinated rubber.

![Figure 2. Deformation of SKUL-7L polyurethane as a function of load](image-url)
Characteristics of polyurethane and rubber are compared in Table 1.

| Indicator                        | Rubber       | Polyurethane |
|----------------------------------|--------------|--------------|
| Shore A hardness                 | 65 - 95      | 70 - 100     |
| Tensile yield strength, MPa      | 12           | 32           |
| Relative elongation at failure, %| 300          | 500 - 600    |
| Compaction, %                    | 35 - 40      | 33           |
| Elasticity, %                    | 30           | 40           |
| Abrasion resistance (H22)        | 2            | 10           |
| Thermal brittle strength, °C     | minus 70     | minus 80     |
| Operating temperature range, °C  | minus 30…50  | minus 70…120 |

From the data, it is evident that rubber is inferior to polyurethane in strength and elasticity; rubber also has a narrower range of operating temperatures. Besides, rubber is less resistant to the effects of moisture and chemicals and has lower abrasion resistance. Due to that, many manufacturers are replacing rubber parts with polyurethane analogs. This trend is especially pronounced in machine manufacturing. There, use of polyurethane parts allows for a significant reduction in wear of the main parts of machinery, thus reducing costs of maintenance and repair.

Strength of the preventer ram was calculated with the ANSYS Workbench software. The strength under static loads considered a load of 1000,000 N at the ram channel and additionally a pressure of 35 MPa at the ram’s bottom surface. It has been established with mathematical calculations and regression analysis, that the value of the lower front seal bending ($W$) depends on a coefficient, which in its own turn depends on the size of packing part of the seal ($\beta$); tubing head pressure ($P_{скв}$); rigidity of the front seal section ($D_p$). Obtained experimental data shows that when $P_{скв} = 35$ MPa, $D_p = 2.86$ kN·m, $\beta = 1.61$, the bending may amount to $W = 1.69$ mm.

Calculations in ANSYS Workbench has shown that maximum bending of the lower front seal with a rubber seal is 0.21371 mm (Figure 4), while with a polyurethane seal it is 0.24811 mm (Figure 5).
When the tubing head pressure increases by 5-7 MPa, equivalent stress in the rubber seal increases by 3.5 MPa, while for the polyurethane seal there is an increase of 0.16 MPa. Maximum bending of the rubber seal is 0.21 mm, that of the polyurethane one is 0.22 mm. Marginal strength coefficient of the ram was calculated in the software and found equal to $n_{\text{ram}} = 2.8425$, which exceeds allowable $n_{st} = 1.32$.

The equivalent stress of the ram with the rubber seal was 540 MPa, the same with the polyurethane one was 600 MPa. Equivalent stress of the rubber seal is shown in Figure 6 and is equal to 22 MPa, while the same of the polyurethane seal is equal to 0.28 MPa and shown in Figure 7.
Thus, it may be concluded that under static loading of a ram, polyurethane bears less load than rubber, while they experience the same deformation.

4. Conclusion
In order to increase the no-failure lifetime of preventer rams, this work involved changing the material of ram seal from IRP-1352 rubber to SKU-7L polyurethane, which has better physical, chemical and performance indicators.

Calculations in ANSYS Workbench have shown that under static load of rams, polyurethane bears less load, namely, when tubing head pressure increases by 5-7 MPa, the equivalent stress in a rubber seal increases by 3.5 MPa, while the same in a polyurethane one increases only by 0.16 MPa. At that, both materials demonstrate the same bending of 0.21-0.24 mm, which is less than allowable value of 1.69 mm. Thus, use of polyurethane instead of rubber in seals may significantly increase the ram strength and reliability, as well as broaden the working temperature range, as follows from technical and performance indicators of both materials. Substituting the material may allow reducing the emergency risk in operation of blowout preventer severalfold.

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