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Design and Reliability Analysis of Integrated BOP

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Abstract: This article in view of existing BOP seal leakage point, low service life, large volume,high weight, height and installation of time-consuming to faults, the annular BOP and ram preventer, one-piece BOP design scheme is put forward, and seal the mouth of the well on the whole, 21 mpa pressure blowout limit design conditions for structural reliability analysis of one-piece BOP.The analysis results show that because the integrated BOP uses the integrated shell, does not need to use the flange connection, less leakage points, can greatly improve the traditional BOP short life, easy to leak and other shortcomings, and the maximum stress and maximum deformation displacement meet the design requirements.

Keywords: Annular BOP, Ram BOP, Reliability analysis.

1. Introduction

In the process of exploitation of oil and natural gas, since most of the oil Wells proved in our country are deep and ultra-deep Wells, the well pressure of this kind of oil well is much higher than that of the conventional deep oil well. This puts forward higher requirements for well control technology and well control equipment. The BOP serves as the core well control device. During drilling operations, the well can be quickly shut in in case of emergency such as overflow, kick or blowout. If the BOP fails, it will lead to blowout and other malignant accidents.

According to the principle of the capping element of the BOP, the BOP can be divided into ram preventer, ring preventer and rotary preventer. The ram preventer provides good well sealing and corrosion resistance under high load conditions, but it seals too many leaks and fails to seal the well when a blowout has occurred. The annular preventer is designed to fully seal the well in the event of an empty well; It can seal the annular space between the string and the wellhead when there is a string in the well, but it does not last long enough to be used in long-term shut-in conditions. Rotary BOP are primarily used in underbalanced drilling to deliver torque while capping the well.

In 1992,Hydril designed and manufactured a new generation of BOP for Saga's Snore field in Norway [1], with the topmost ram of shear ram, capable of shearing drill pipe, equipped with over-sized control cylinders, allowing rapid shearing of thick wall and large diameter tubing. In 2001, S. angesland, A. ivertsen et al designed an electric valve spool downhole BOP [2], which achieves bottom-hole blowout prevention by controlling the opening and closing of the internal conduits of the drill pipe as well as the fluid inlet channels of the rubber cylinder compression chamber through the electric spool. In 2011, Gao Xinjun, Zheng Junhui et al. [3] designed a full-diameter BOP in the drilling tool. The preventer is equipped with four guiding centralizing blocks in the inner cavity. In 2014, Dong Yan, Liu Jiangtao et al. [4] designed an active sealed rotary BOP. When sealing is needed, the hydraulic oil enters the rubber core, and the rubber core closes towards the center of the circle under the action of pressure until it is tightly held with the drill tool to produce interference fit, forming a sealing effect. In addition, the rubber core can rotate synchronously with the assembly along with the rotary drill tool, realizing the function of the rotating BOP.In 2017, Zhang Leicheng, Zhang Haiyang et al. [5] designed a BOP with pressure relief function. Based on the conventional BOP, this device is equipped with automatic pressure relief device, alarm device and collection device. In 2017, Norwegian company Electrical Subsea& Drilling developed an all-electric BOP [6] that uses an all-electric BOP control system as an alternative to electro-hydraulic BOP control technology.

At present, most of the research on the BOP at home and abroad focuses on the separate structural optimization of the ram BOP and the annular BOP. At present, the ram BOP is unable to seal the well in case of a blowout because of the large number of sealing leakage points. Annular BOP can not be used for long-term well sealing, and its life is not long; Combined BOP packs are large, heavy, tall, time-consuming and laborious to install, and seal many leaks. Aiming at the disadvantages of each type of BOP, this paper puts forward a new design scheme of integrated BOP and analyzes the reliability of its key structure.

2. Structural Design and Reliability Analysis

2.1. Structural design

According to the field feedback, the most commonly used BOP is the combination of annular BOP and ram BOP connected through flange. However, the combination BOP has some disadvantages such as large volume, heavy weight, high height, time-consuming and laborious installation, and many sealing leakage points. To solve the above problems, the structure of the combined BOP is optimized in this paper. The annular, single gate and drilling four-way are designed in one piece, and flange connection is no longer required. The structure is shown in Figure 1. Compared with the combined BOP group, the integrated BOP has fewer sealing leakage points, less time and labor before and after drilling installation, shorter drilling cycle, lower production cost, lower overall quality and lower overall height. When there is drill, tubing or casing in the well, a variety of annular Spaces of different sizes can be closed; When there is no drilling tool in the well, the wellhead can be completely closed; In the process of drilling, coring, logging and other operations in the blowout, can be closed kelly pipe, coring tools, cable and steel wire and shaft formed annular space;In the use of pressure relief valve and buffer energy storage, through 18° no fine buckle butt welding drill pipe joint, forced down the drill tool.

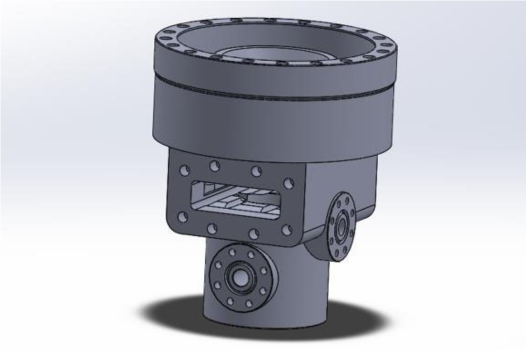


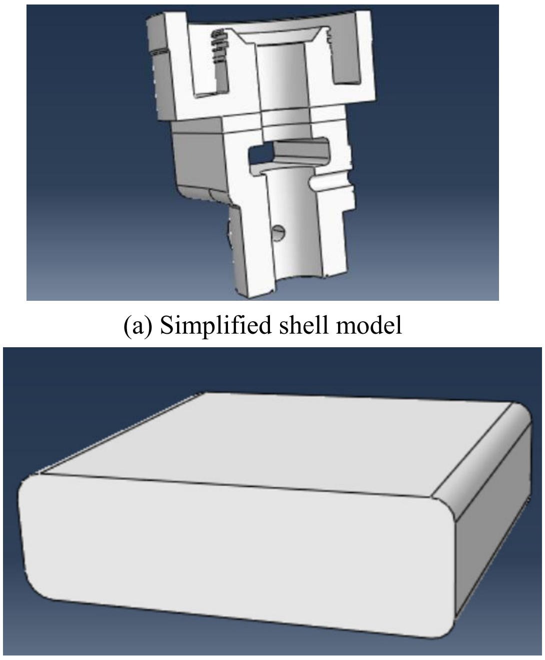
Figure 1. Schematic diagram of the integrated BOP housing structure

2.2. Reliability Analysis

In this paper, the design maximum bearing pressure of the integrated BOP, that is, the maximum blowout pressure of 21MPa when the wellhead is fully sealed, is taken as the working condition. Abaqus simulation analysis software is used to verify the rationality and reliability of the structural design of the BOP.

2.2.1. Geometric model

This paper takes the integrated BOP as the research object and uses Solidworks to build a three-dimensional model of the integrated BOP shell and ram.In order to reduce the calculation and analysis time, simplify the structure of the BOP shell, such as chamfer, fillet and ram track;Simplify the BOP deck seal groove and other structures.Since the all-in-one BOP structure is symmetrical about the Y-axis, take half of the 3D model of the BOP housing and import it into Abaqus;The simplified BOP housing and ram model are shown in Figure 2.Both the BOP housing and ram are modulated alloy steel with an elastic modulus of 2.06×10^5MPa and Poisson's ratio of 0.3.



(a) Simplified shell model

(b)Ram simulation model

Figure 2. Simplified model of BOP housing and ram

2.2.2. 2.2.2 Mesh division

Divide the BOP housing, lay out the global seeds, set the approximate global size to 20 and the maximum offset factor to 0.1, and seed the BOP housing as a whole.When the blowout head is fully sealed, due to the influence of the bottom hole pressure, the contact surface between the ram chamber and the ram of the BOP will be subjected to enormous pressure. This area is the weak area of the BOP.Therefore, a local seed is used in the area where the ram cavity and the ram contact, and the mesh is encrypted in this area. The minimum size of the local seed is set as 5 and the maximum size as 10.The bottom surface of the BOP shell connected to the wellhead and the upper surface of the BOP shell connected to the upper drilling tool will be subject to great pressure due to the influence of the bottom hole pressure. The local seeds are arranged with fine seeds of minimum size 5 and maximum size 10, and the mesh is encrypted.Similarly, a local seed arrangement with a minimum size of 5 and a maximum size of 10 is used for mesh encryption where the size of the BOP housing changes and stresses are concentrated.The rest of the BOP housing is laid out in accordance with the initial global seed size.A tetrahedral grid was used for meshing, with a total of 292,248 meshes.The partitioning results are shown in Figure 3.

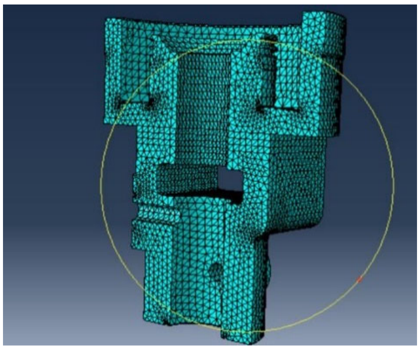


Figure 3. BOP housing grid model

The BOP ram is divided, the global seed is laid out, the approximate global size is set to 10, the maximum offset factor is 0.1, and the overall seed is laid out for the BOP ram. A tetrahedral grid was used for grid partitioning, and a total of 44,330 grids were divided. The partitioning results are shown in Figure 4.

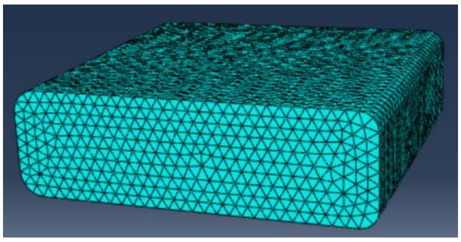


Figure 4. BOP ram grid model

2.2.3. Boundary condition setting

Under the condition of blowout and fully sealed wellhead, the ram is pushed up by a positive force along the Y-axis under the bottom hole pressure, and the interaction between the shell and the ram is simplified as 'surface-surface' contact between the upper surface of the ram and the chamber of the shell. When in contact, there is no slip between the ram and the shell. The friction formula of tangential behavior is rough and that of normal behavior is hard contact. There is no contact between the lower surface of the ram and the chamber of the shell under pressure. The interaction between the ram and the housing is shown in Figure 5:

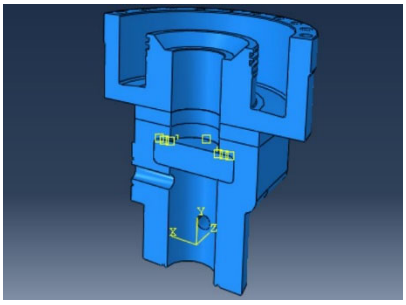


Figure 5. Schematic diagram of the interaction between the shell and the ram

The integrated BOP is installed at the wellhead, and other drilling tools are installed on the upper part, which cannot generate any displacement in the actual working process. The BOP housing is regarded as a part with zero freedom, and articulated constraints are imposed on the bottom and top of the BOP housing. When simplifying the BOP housing, the shell shape is symmetric about the y axis. The shell cross-section is set as the symmetry plane about the symmetry of the y axis.The boundary condition distribution is shown in Figure 6:

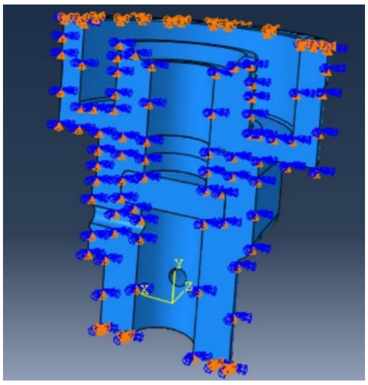


Figure 6. Schematic diagram of model boundary conditions

The designed maximum bearing pressure of the integrated BOP is 21MPa blowout pressure. When setting the load boundary conditions, the rated working pressure of the integrated BOP with a size of 21MPa is evenly distributed on the lower surface of the ram, the lower surface of the BOP shell and the surface of the four way outlet in the form of load pressure. The load distribution is shown in Figure 7.

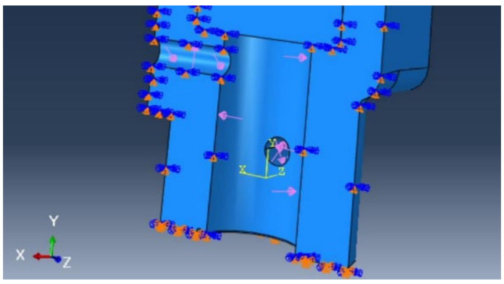


Figure 7. Schematic diagram of load boundary conditions of the model

The side doors of the BOP are bolted to the BOP housing and are used to hold the ram and seal it.When the blowout is fully sealed, the side door will also be subject to the bottom hole pressure due to the sealing. The pressure is transferred to the plane of the side door of the blowout preventer shell through the bolt. Therefore, the working pressure of 5.6MPa along the positive direction of the Z axis is applied to this plane.The load distribution is shown in Figure 8.

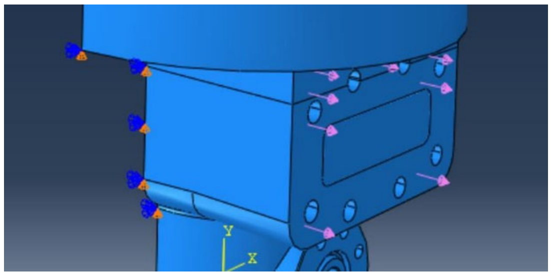


Figure 8. Schematic diagram of model load boundary conditions

3. Analysis of Calculation Results

Through calculation, it can be concluded that the stress and strain distribution of the integrated BOP under 21MPa blowout pressure when the wellhead is fully sealed, Figure 9 shows the Mises stress nephograph of the integrated BOP shell and ram.As shown in the figure, stress concentration exists in the integrated BOP shell at the four-way outlet and where the annular BOP seal groove is installed.The upper surface of the ram and the upper surface of the ram cavity of the BOP housing, that is, the contact surface between the ram and the ram cavity, is near the annulus where the stress is the greatest, up to 459MPa. This is the weakest position of the entire structure of the BOP.Referring to the mechanical engineering manual, it is known that the yield limit of the modulated synthetic steel is 517MPa, so the shell design meets the design requirements and can meet the working conditions.

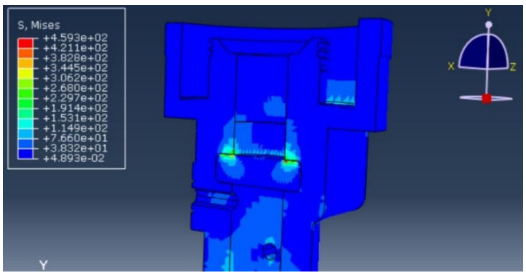
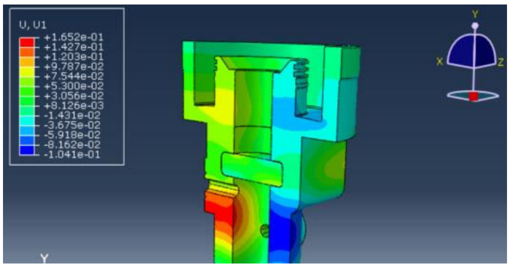


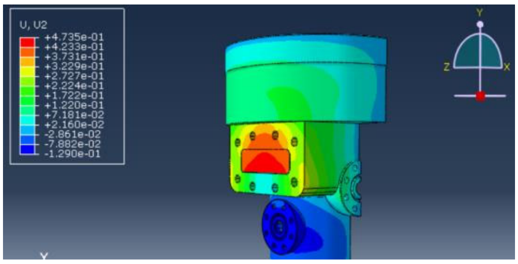
Figure 9. Mises strain cloud map

Figure 10 shows the deformation and displacement nephogram of the integrated BOP shell and ram in X, Y and Z directions and the total deformation and displacement nephogram.As shown in the figure, under the condition of fully sealed wellhead and blowout pressure of 21MPa, the structural strength of the four-way exit decreases due to structural mutation and wall thickness thinning. Here, the deformation displacement in X direction and Z direction is the largest, with the deformation displacement in X direction up to 0.17mm and the deformation displacement in Z direction up to 0.10mm.Because the ram mainly bears the stress in the Y direction in the work project, and the ram cavity is relatively low, the maximum deformation displacement in the

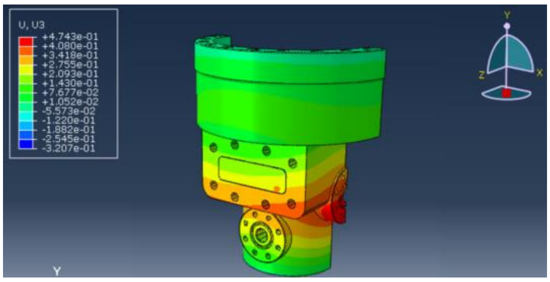
Y direction occurs at the ram, up to 0.10mm.The total deformation and displacement nephogram of the BOP was obtained by the sum of the deformation and displacement in the X, Y and Z directions. The maximum deformation and displacement of the BOP was 0.12mm at the gate and four outlet.To sum up: under the fully sealed wellhead and 21MPa working pressure, the deformation displacement and total deformation displacement of the integrated BOP in the X, Y and Z directions all meet the design requirements and can meet the working conditions.



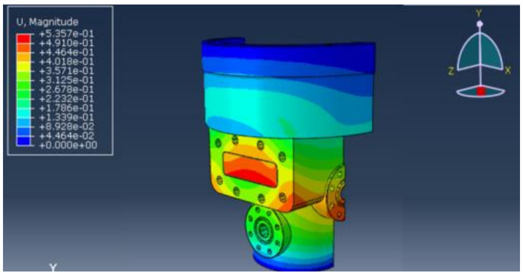
(a) X-direction deformation



(b) Y-direction deformation



(c) Z-direction deformation



(d) Total deformation

Figure 10. Deformation and displacement nephogram

4. Summary

In view of the shortcomings of the existing BOP, such as many sealing leakage points, low life, large volume, large weight, high height, timeconsuming and labor-intensive installation, this paper combines the annular BOP and the ram BOP, puts forward the design scheme of the integrated BOP, and analyzes the structural reliability of the integrated BOP for the limit design condition of the fully sealed wellhead and 21MPa blowout pressure.The analysis results show that, because the integrated BOP uses the integrated shell, does not need to use the flange connection, less leakage points, can greatly improve the traditional BOP short life, easy to leak and other shortcomings, and the maximum stress and maximum deformation displacement meet the design requirements.Based on the reliability analysis results, the following suggestions are put forward for the design of the integrated BOP:

(1) The four outlet of the integrated BOP shell is connected with the four flange, and the structural strength here is relatively low, easy to appear relatively large deformation and displacement, which has a great impact on the sealing performance, so there is a potential leak, it is necessary to strengthen the sealing performance here;

(2) The integrated BOP shell has stress concentration at the four-way outlet, the installation of the annular BOP sealing groove, and the contact surface between the ram and the ram cavity.It is suggested that in the design stage, structural optimization should be carried out according to the above positions to alleviate the stress concentration, and surface strengthening process should be carried out to improve the structural strength.

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