Journal of Petroleum Science and Engineering 146 (2016) 129–133

Contents lists available at ScienceDirect

Journal of Petroleum Science and Engineering

journal homepage: www.elsevier.com/locate/petrol

Finite element method and bed test to torque analysis of kelly cock valve in gas drilling

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ARTICLE INFO

Article history:
Received 5 July 2015
Received in revised form
13 April 2016
Accepted 18 April 2016
Available online 20 April 2016

Keywords:
Finite element simulation
Bed test
Torque value
Kelly cock valves

ABSTRACT

This work studies the torque of kelly cock valve used in gas drilling through Finite Element (FE) simulation and experimental approach. The goal of this work is to use bed test to characterize failures of rotary switch and provide the valuable reference value for operating the kelly cock valve in oil field. During the FE simulation, the Eight-Node Brick Element is suitable for meshing, and it analyzes the stress distribution under different pressure drops of rotary switch. And torque values in different pressure drops had been tested in bed test. Also, in bed test, it can verify results of FE simulation of stress distribution. Parameters of 40CrMnMo used in the process of FE simulation based on STM E8/E8M-11 experiments. The comparison of the finite element analysis with the bed test results shows the torque values trends and the stress distribution of the rotary switch agree well with one another.

1. Introduction

A kelly cock valve, a manual control valve which used in drilling string cycle system. It is one of the effective tools for preventing blowout. It is well known that kelly cock valves find use in wide range of drilling sites such as under-balance gas drilling and mud drilling.

The existing kelly cock valves are spherical sealing, so the structure are relatively less, the main difference lies in the size and can withstand the maximum pressure value of bottom hole. The sizes are mainly from 2 $^3/_8$″ to 8″, and the commonly used sizes are 2″, 4″, 5″, 5 $^1/_2$″ and 8″. At present, the pressure classes are from 70 to 105 Mpa. As exploit to the ultra-deep drilling and tight sandstone reservoir, the 150 MPa pressure class is the trend of the future. Therefore, it needs higher requirements to the structure and sealing performance of kelly cock valves.

A kelly cock valve is fixed at the end of kelly bar, its operation is accomplished by rotating ball valve with a specific wrench. Turning the rotary switch going counterclockwise 90° with special wrench, and ball valve rotates 90° simultaneously, so the axis of ball valve and valve body are in the same direction. At the moment, kelly cock valve is opening. In the same way, turn the knob going clockwise 90° and the axial direction of ball valve and valve body is vertical. Under the present circumstances, the up seat, down seat and ball valve works closely to form sealing.

This study focus on kelly cock valves used in gas drilling, and gas drilling technology accounts for approximately 30% of the world's land oil and gas drilling operations (William et al., 2009) . Gas drilling belongs to underbalanced drilling (UBD), this type of drilling takes advantage of the low annulus bottom hole pressure characteristic of the technology (William et al., 2009). UBD operations attempt to avoid damage to the reservoir rock formation so that the reservoir will produce effectively through its life. UBD than conventional mud drilling has its advantages, but the bottom hole pressure is greater than the wellbore pressure will lead to solid particles and mud cakes into kelly cock valves through bit ports and make them failure. In addition, the challenge that it cannot be transfer torque effectively for the rotary switch has been worn is quite great.

Statistically analyzing 20 typical wells which had used kelly cock valves in Tarim oil field in 2014. Based on field investigation, when DX-1 of Tarim oil field drilled to 4689 m, the kelly cock valve (5″-105 MPa) could not be closed for the annulus was stuck by solid particles, which are shown in Fig. 1. What's more, when DB-101 well drilled to the high pressure formation (4811 m), the bottom hole pressure grown rapidly, so the differential pressure on both up and down ends of the ball valve intensified sharply and the kelly cock valve (4″–105 MPa) could not be opened by a specific wrench. Increasingly a large number of failures about kelly cock valves appear in drilling site, which delay the period of drilling and increase the cost of drilling to oil-gas field drilling. Next work is combined with the down-hole working condition to analyze reasons of failures.

Based on the existing literatures (Ahmad et al., 2013; Angadi

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http://dx.doi.org/10.1016/j.petrol.2016.04.020
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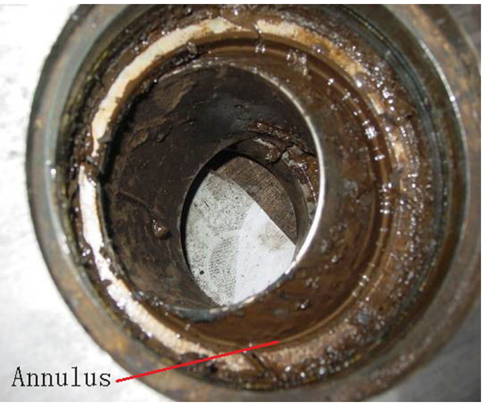

Fig. 1. Annulus of rotary switch.

et al., 2009; Park and Chung, 2006; Wallevik, 2014), it appears that the published literature on kelly cock valves' experiments is surprisingly scarce. Furthermore, the work of kelly cock valves are simulation experiments (Zheng et al., 2011) and hardly any field tests. However, litter of the research in by-pass valve (Zauner et al., 2013; Zhu et al., 2014) and butterfly valve (Naseradinmousavi, 2014; Park and Chung, 2006; Vakili-Tahami et al., 2012) in the last decade and extensive literatures (Mutschler et al., 2014; Park and Chung, 2006; Zhu et al., 2014) do provide guidance as to common problems seen in kelly cock valves and factors which affect them. Those information can then be used to design an experiment which can be used to map the failure and reliability of kelly cock valves researched in this research. The article is based on the finite element method and field bed test to study the torque value at various pressure drops.

As previously discussed, the failure analysis of kelly cock valve have not involved in gas drilling, less involved in analysis the relationship between different pressure drops and torque. This work focuses mostly on the influence of different pressure drops on torque failure, especially in gas drilling. It should also be combined the drilling condition. Apply finite element method and bed test to torque analysis of kelly cock valves under different pressure drops in gas drilling.

This paper is organized as follows: Section 2 gives a description of finite element method and related parameters settings of workbench, and then evaluate results. The test bed used to obtain the exact value of torque under the different pressure drops. Meanwhile, comparison of the results of FE simulation with that of the experiments are given in Section 3. Section 4 presents the results analysis and concluding remarks.

2. Finite element method

2.1. Initial condition

The research object used in this study is kelly cock valve with a diameter of 6 5/8" and the maximum pressure (the maximum bottom hole pressure) is 105 MPa. The material of the kelly cock valve is 40CrMnMo.

The specimens of tensile test that were machined according to ASTM E8/E8M-11. The purpose of it is to get the data for following FE simulation. The basic parameters of the specimens and test data as shown in Table 1. The force-displacement curve of three specimens is shown in Fig. 2. From Fig. 2, it can be noticed that the trend of force-displacement curve of three test specimens is very close, and the maximum Force is 64.80kN. Also, the $\boldsymbol{\delta} - \boldsymbol{\varepsilon}$ curve and mechanical properties of 40CrMnMo are shown in Fig. 3 and Table 2.

Utilizing Solidworks equivalent module (see Fig. 4) to fulfill FE simulation on rotary switch of kelly cock valve. From Fig. 4, the kelly cock valve is fully closed, and the blue circle domain is action face of equivalent pressure drop (see top-right). Table 3 shows the input parameters for the FE simulation.

The load matrix for three-dimensional problems in a concentrated-loading situation, the load matrix is formed by placing the components of the load at appropriate nodes in appropriate directions. For a distributed load, the load matrix is computed from the equation

$$\{F\}^{(e)} = \int_A [S]^T \{P\} dA \tag{1}$$

where

$$\{P\} = \begin{Bmatrix} p_x \\ p_y \\ p_z \end{Bmatrix}, \quad S^T = \begin{bmatrix} S_i & 0 \\ 0 & S_i \\ S_j & 0 \\ 0 & S_j \\ S_k & 0 \\ 0 & S_k \end{bmatrix}$$

and A represents the surface over which the distributed-load components are acting. p_x, p_y and p_z are distributed load. S_i, S_j and S_k represent the shape function. The surfaces of the tetrahedral element are triangular in shape. So the load matrix becomes

$$\{F\}^{(e)} = \frac{A}{3} \begin{Bmatrix} p_x \\ p_y \\ p_z \\ p_x \\ p_y \\ p_z \\ p_x \\ p_y \\ p_z \\ 0 \\ 0 \\ 0 \end{Bmatrix} \tag{2}$$

2.2. Results of finite element method

The Eight-Node Brick Element is suitable for meshing the rotary switch system to FE simulation (Baldwin et al., 2012; Bernard and Chenouard, 2014; Cacuci, 2014; Cacuci and Badea, 2014; Esteban et al., 2007). Fig. 5 shows the equivalent stress distribution during rotary switch at different positions.

During forming, the rotary switch, which is initially at a uniform moment 110 N m, comes in contact with shifting block and ball valve. As shown in Fig. 5, the region of the rotary switch which force acts on has higher contact stress compared with the initial state and the intermediate state. The initial pressure drop of both sides of ball is 1 MPa and the final is 70 MPa. A significant stress up was observed over the deformation time period (10 s), the results show that the crack and fracture of the department within the six-party of the rotary switch is caused by stress concentration on the acute angle effect. What is more, the stress concentration results from the transition surface section size of the six-party changes suddenly.