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Design and study of gas-tight premium threads for tubing and casing

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ABSTRACT

Two premium threaded connections with buttress threads and torque shoulders are established in this paper. One premium threaded connection uses the taper difference fit model and the other uses the arc and straight line fit model for the sealing surfaces of the pipe body and the collar body. 3D models are established to consider the frictional shear stress during the make-up process. The finite element analyses of the two connection models are performed to obtain the stress distribution and deformation-induced space variation on the connection models. In addition, the characteristics of the designed structures are analyzed and the tubing and casing make-up curves are deduced based on these characteristics. Finally, an experimental test with the arc and straight line fit model is carried out. As a result, the arc and straight line fit model shows good gas seal performance in the make-up and break-out operation tests. This study is expected to provide a theoretical guide to practical operations in China, thereby reducing the damage probability of tubing and casing during make-up.

1. Introduction

Easily accessible oil and natural gas resources have been decreasing dramatically due to the continuous exploitation in recent years. Many oilfields have entered a production stage involving the exploitation of deep and ultra-deep wells. The operating conditions in the deep and ultra-deep wells are extremely complex and present great challenges for tubing and casing operations. The API standard threads used for shallow well operations cannot meet the requirements because of their defects in sealing property and connection strength. Therefore, premium threaded tubing and casing connections with better connection strength and sealing property are in urgent need to ensure the safety operations of downhole tubing and casing strings.

2. Defects of API standard threads

Tubing and casing are thread-connected as a string of several hundred meters in length, and the thread connection is the weakest link in the whole string. API standard threads are generally adopted in shallow wells; however, they have apparent defects in sealing property and connection strength (Xu and Guo, 2012). Firstly, due to the thread profile and thread angle tolerances in manufacturing, a clearance occurs not only between the tooth top and tooth bottom but also between the internal and external guide surfaces and the bearing surfaces after thread engagement (Fig. 1), leading to the formation of a spiral leakage channel; therefore, API threads have no sealing ability (Xiaolei, 1997). The clearance can be filled with thread sealing grease to ensure sealing (Jiaoqi et al., 1997). In addition, the profile angle of API round threads is 60° and the bearing surface angle of the tooth side is 30°. When threads are stressed, such a large bearing angle will generate a large radial component force and cause external expansion of collar threads and internal shrinkage of tube threads. As a result, the connection strength of the threads is only 60–75% of that of the pipe body (Zhanghua et al., 2004). According to a survey by American oil industry, failure in tubing or casing strings connected with API threads is closely related to the connection threads, and 86% of casing string failure and 55% of tubing string failure occur at threaded connections (Weiner and True, 1969).

In recent years, petroleum companies have focused on how to make a profit from petroleum development and on the subsequent oil production. However, continuous merger and structural changes of large petroleum companies give rise to fierce competition in the world petroleum industry (My and Kunishige, 2002). Large oilfields all over the world are continuously producing oil and natural gases and oil and gas resources are decreasing dramatically; therefore, many oil and gas fields have entered a production stage involving exploitation of deep and ultra-deep wells. These wells are over 6000 m in depth (approximately 2000 m deeper

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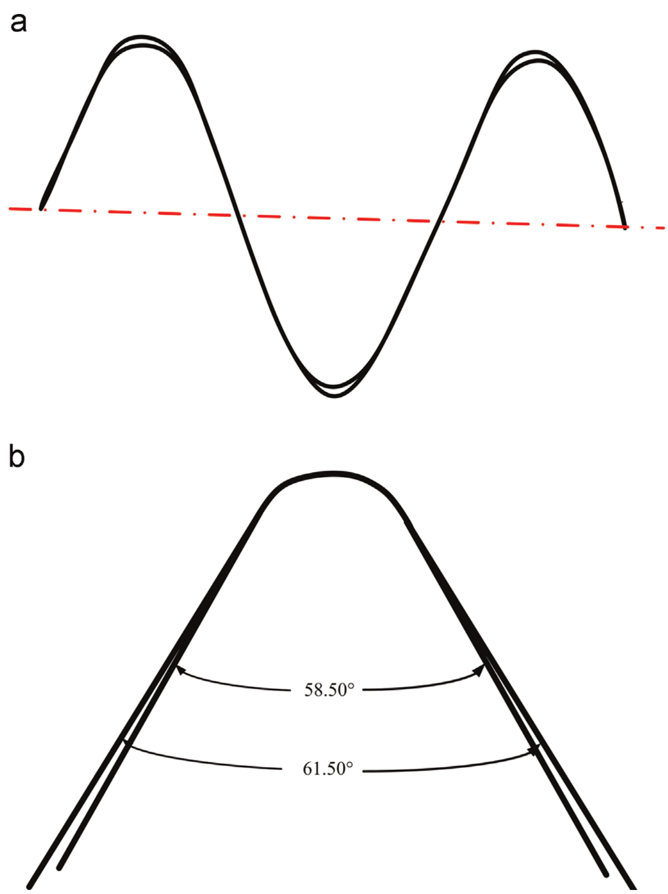

Fig. 1. Clearance in API threads. (a) Tooth top and bottom clearance caused by thread profile tolerance. (b) Maximum clearance caused by thread angle tolerance.

than conventional oil wells), with an operation pressure over 60 MPa (nearly twice as high as that in conventional wells) and a bottom hole temperature is 20–40 °C higher than that in conventional wells. Under high pressures, sealing grease will be squeezed out and round threads will lose its sealing property; at high temperatures, sealing grease will be ablated and cause seal failures. Therefore, this sort of grease sealing for API threads is no longer applicable to operations in deep and ultra-deep wells. In addition, the connection strength of standard API threads cannot reach requirements for such complex operating conditions. To realize effective sealing and prevent thread-off accidents, non-API thread connections, i.e. premium threaded connections, have been studied and adopted widely. Premium threaded connections are high-end products for tubing and casing, mostly manufactured in such countries as the United States, Germany and Japan. Only a few types of premium threaded connections are produced independently in China and these connections have some problems with reliability (Lianxin and Jiaoq, 2008), such as sealing surface scuffing. For this reason, this paper is aimed to put forward some design ideas for premium threads.

3. Existing premium connections on Chinese market

Currently, some common premium threaded connections on Chinese market (Bai et al., 2011; Guan and Yang, 1999; Piao and Zhang, 2006) are listed in Table 1, and their structure diagrams of premium threaded connections are shown in Fig. 2.

As shown above, the common premium connections on Chinese market are divided into two types according to the metal sealing form, one sealing structure is by taper/taper, and the other is by sphere/cylinder. Under the load of make-up process, the contact area is smaller in sphere/cylinder than that in taper/taper. Although the gas-tight performance is well in sphere/cylinder, the machining precision of cylinder surface is high and the maintenance is not convenient in the actual field.

Table 1
The premium connections on Chinese market.

Connector	Main sealing surface	Torque shoulder (deg)	Threads	Manufacturers
TP-CQ	Taper/taper	– 15	Improved buttress	TPCO
HSM-1	Taper/taper	– 15	Improved buttress	HYST
BGC	Sphere/cylinder	– 15	Improved buttress	BAOSTEEL
WSP-1 T	Sphere/cylinder	– 15	Improved buttress	WSP

In traditional premium connections, the sealing structure with taper/taper is widely used in API standard threads, and improved taper difference threads are used in premium threaded connections. The taper is usually 1:10 in taper/taper structure, the contact area is large and the contact stress is uniform and small, however, the contact stress changes violently under the load of make-up process.

4. Design ideas for premium threads

Generally, a premium threaded connection consists of threaded connection, metal seal and torque shoulder, as shown in Fig. 3. The threaded connection is used for fixing, connection, and pre-tightening of the sealing surface and torque shoulder. The threaded connection uses buttress threads, with a bearing angle about 3° and a radial component force far smaller than that of standard API round threads, which can effectively prevent thread-off accidents. The metal seal is the primary sealing part, which is composed of the same taper fit model along with a small transition arc in tube body and a large transition arc in collar; however it often represents a weak link in practical operations because of the local plastic deformation. Fig. 4 shows the real pictures with local plastic deformation which happened between the small transition arc in tube body and the large transition arc in collar. In this paper, two metal sealing structures are used for pipe body sealing surface and collar sealing surface: (1) the taper difference fit model and (2) the arc and straight line fit model, as shown in Figs. 5 and 6, respectively. Comparative analysis is conducted between the two models, with an aim to provide a theoretical guide to practical operations in oilfields and to reduce the damage probability of tubing and casing during make-up.

The taper difference fit model has a conical sealing surface at the end of the pipe body on the external thread and one at the end of the collar body on the internal thread. The two sealing surfaces have a geometric taper difference of about 1.5° to help realize the interference fit along the taper direction during make-up. The interference fit with such a small taper difference can improve the stress distribution on the conical sealing surfaces. Most importantly, there is a transitional arc connection between the conical sealing surface and the torque shoulder in both the tube body and the collar body, and the diameter of the large arc in the tube body is about 2–3 times larger than that of the small arc in the collar body (Fig. 5). Due to the existence of the two transitional arc connections, a deformation release space is formed between the two arc areas to protect the conical sealing surfaces and ensure effective sealing in the event of conical sealing surface