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ABSTRACT

With the demand for oil and gas increased, and the development of oil and gas drilling technology so fast, the development of global oil and gas exploration has entered a deep well, ultra deep well and offshore deep water exploration and development era. Land and shallow sea oil and gas exploration degree now is high, oil and gas production has been close to the peak, therefore many country and big oil and gas multinational companies have turned to deep water search for oil and gas resources, and have got a series of major discovery and development.

Due to the restriction and impact of the ocean drilling platform arrangement and cost, Offshore drilling widely used cluster well, directional well, horizontal well and large displacement technology, all these lead to drill stem under cyclic loading, and the working condition of drill stem become more and more bad. Due to the high cost of offshore drilling industry, the failure accident of drill stem will cause huge economic losses.

Oil drill stems is the main tool for exploration and development of oil and gas, the failure accident of drill stem in oil and gas exploration will not only hindered the drilling speed and production, but also caused huge economic loss.

The failure type of drill stem is given priority to fatigue failure, according to the research of the drilling contractor, there are about 50~60% fatigue failure in the total failure of drill stem. Therefore, the research of tool fatigue prediction will bring great significance for enhance drill stem management standards, establish a whole life cycle of drill stem, monitoring, evaluation and query, ensure the safety of drill stem quality and drill string, and reduce drilling cost.

ACKNOWLEDGEMENTS

My thesis is developed from November, 2015 to May, 2016. During the process of preparation, I have learned a lot from the internet, research, magazine and some Chinese books related to drill stem failure analysis.

After left Norway, I went back China and got promoted to be a operation supervisor of operation and QHSE department of COSL Drilling. The main work for my job is in charge of more than 40 rig's operation of COSL Drilling, during this time I worked overtime almost every day. The drill stem management and coordination is part of everyday work. A lot of thoughts in my thesis are from my work and colleagues. Therefore I would like to express my great appreciation to the people who help me a lot in my work and the process of writing this thesis.

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I would like to thank my wife and daughter. They pay for a lot of things and give me a strong support in studying abroad and writing the thesis. When I was ill in hospital, my wife give me patient care and encouragement. I would like to thank my parents and relatives for their unconditional love and support throughout my life. They have been accompanied us to go through the toughest moments.

Finally, I would like to express thanks from my deep heart to COSL, thank my company for providing me such a great opportunity of studying in University of Stavanger, learning different culture, and learn from the best professor. Thank you for all of your trust, and I will do my utmost to dedicate myself to the development of COSL.

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Section 1 Introduction

In recent years, with the increase of drilling depth and the drilling technology development of high angle wells and large displacement horizontal wells, the performance requirement for drill stem is more and more higher. Oil drill stems is the main tool for exploration and development of oil and gas, the failure accident of drill stem in oil and gas exploration will not only hindered the drilling speed and production, but also caused huge economic loss. The research of tool fatigue prediction will bring great significance for enhance drill stem management standards, establish a whole life cycle of drill stem, monitoring, evaluation and query, ensure the safety of drill stem quality and drill string, and reduce drilling cost.

1.1Background

With the demand for oil and gas increased, and the development of oil and gas drilling technology so fast, the development of global oil and gas exploration has entered a deep well, ultra deep well and offshore deep water exploration and development era. Land and shallow sea oil and gas exploration degree now is high, oil and gas production has been close to the peak, therefore many country and big oil and gas multinational companies have turned to deep water search for oil and gas resources, and have got a series of major discovery and development.

Due to the restriction and impact of the ocean drilling platform arrangement and cost, Offshore drilling widely used cluster well, directional well, horizontal well and large displacement technology, all these lead to drill stem under cyclic loading, and the working condition of drill stem become more and more bad. Due to the high cost of offshore drilling industry, the failure accident of drill stem will cause huge economic losses. The studies have shown that, the fee of fixed drilling ship is about $100,000, floating drilling ship takes one day even 2 times than fixed drilling ship, and the fee of deep-water drilling ship (water depth > 1524 m) is about 400,000 dollars per one day (Jenkins R W,1999). Therefore, drill stem failure will bring huge economic losses for oil field, the failure problem of drill stem is been pay much attention for each oil field company. The failure type of drill stem is given priority to fatigue failure, according to the research of the drilling contractor, there are about 50~60% fatigue failure in the total failure of drill stem. Therefore, the research of tool fatigue prediction will bring great significance for enhance drill stem management standards, establish a whole life cycle of drill stem, monitoring, evaluation and query, ensure the safety of drill stem quality and drill string, and reduce drilling cost.

1.2 Scope and objective

The main scope of this thesis is to study and propose the failure problem of drill stem in China and abroad of China, and to study the inspection and class analysis of drill stem. Also the project scope contain the reliability and utility of condition monitoring and inspection maintenance during whole life cycle of drill stem.

The objective of this project mainly include the following several aspects:

a) Through the investigation analysis of drill stem failure situation in China and abroad of China and the typical failure reason analysis of offshore drill stem, to reveal the failure mechanism and failure reason of drill stem.
b) Research and identify the cause types and forms of failure, and its regularity for drill stem.
c) Research drill tool use, inspection and testing requirements of domestic and foreign oil companies, this include testing frequency, range, content. Research the field and factory implementation and testing procedures of oilfield services company.
d) Research the new detect technology of drill stem in China and abroad of China, analysis the advantages and disadvantages of various technique;
e) Research the inspection cycle, classification of drill stem in China and abroad of China, and study the mandatory scrapping system of drill stem in China and abroad of China.
f) Research and study the configuration of drill stem for deepwater drilling platform and the special inspection requirements in China and abroad of China.

1.3 limitation of the project

The research of this thesis focuses on the drill stem failure situation in China and abroad of China and the typical failure reason analysis of offshore drill stem, analysis the failure reason of drill stem. Also, research the inspection and grade for drill stem. But due to limitation of founding out information and integrity of collection data, some of the research does not contain all the condition of drill stem failure problem.

Additionally, although this paper propose some advantageous strategies regarding drill stem management for the condition monitoring and inspection maintenance, but does not deeply research and study the management strategies in system.

1.4 Thesis structure

This thesis is divided in to eight sections in total with the following outlines:

Section 1 – This section covers the introduction and scopes of the thesis. It also describes the background information and its limitations for preparing the thesis.

Section 2 – This section is written based on general situation of failure problem of drill stem in China and abroad of China which include offshore drill stem failure aspect.

Section 3 – In this section, it is written about the failure cause type and its regularity of drill stem.

Section 4 – In this section, it is written about the detection and classification research of drill stem which include the China oil company and international oil company aspects.

Section 5 – In this section, it will introduce the new technology for drill stem inspection.

Section 6 – These sections draws the discussion and conclusion from the findings of thesis.

Section 7 – It provides the list of references and sources that had been used for preparing the thesis.

Section 2 General situation of failure problem of drill stem

2.1The general statistics of failure situation of drill stem

The growing demand of the world for oil and gas resources is become more and more huge, as the oil and gas exploration and development is increasingly thorough, the deep well drilling scale is more and more big, the offshore oil exploration now is from shallow sea to the deep sea. Oil drill stems is the main tool for exploration and development of oil and gas, the failure accident of drill stem in oil and gas exploration will not only hindered the drilling speed and production, but also caused huge economic loss.

2.1.1 Failure problem of drill stem in onshore drilling main oilfield of China

(1) Tarim oilfield

The failure percentage of drill stem from 1995 to 2000: 35% of drill collar, 21% of drill pipe, 16% of joint, 11% of centralizer, 8% of high weight drill pipe, 5% of shock absorber 5%, and 4% of others. In all of the drill stem failure types, there are about 66% of fatigue fracture, 16% of brittle fracture, 6% of stress corrosion fracture, 6% of ductile fracture, and 6% of other types.

There has about 157 times of drill stem failure accidents happened from 2001 to 2003, of which 121 drill pipe failure accidents occurred (Lin Yuanhua, 2007), and the most failure problem was happened in thickening transition zone. 21 times of drill collar failure accidents which all the problem occurred for box rupture or leakage failure.

There has total 93 times of frilling tool failure accidents happened in 2005 in Tarim oilfield which 60 times of drill pipe leak and fracture, 14 times of drilling jar and shock absorbers fracture, 9 times of drill collar fracture, 7 times of downhole stabilizer fracture, and 3 times of high weight drill pipe fracture (Wang Xiyong, 2006). Drill pipe leaks happened about 57 which the leak area failure was mainly for thickening transition zone disappeared area.

There has total 87 times of frilling tool failure accidents happened in 2006 which include 48 times of fracture accidents and 49 times of leak accidents. The fracture of drill collar was highest in all the drill stem fracture accidents which accounting for 72.0% of the total number of fracture accidents. The drill stem leak location was mainly for drill pipe thickening transition zone area, just a few for joint thread leakage.

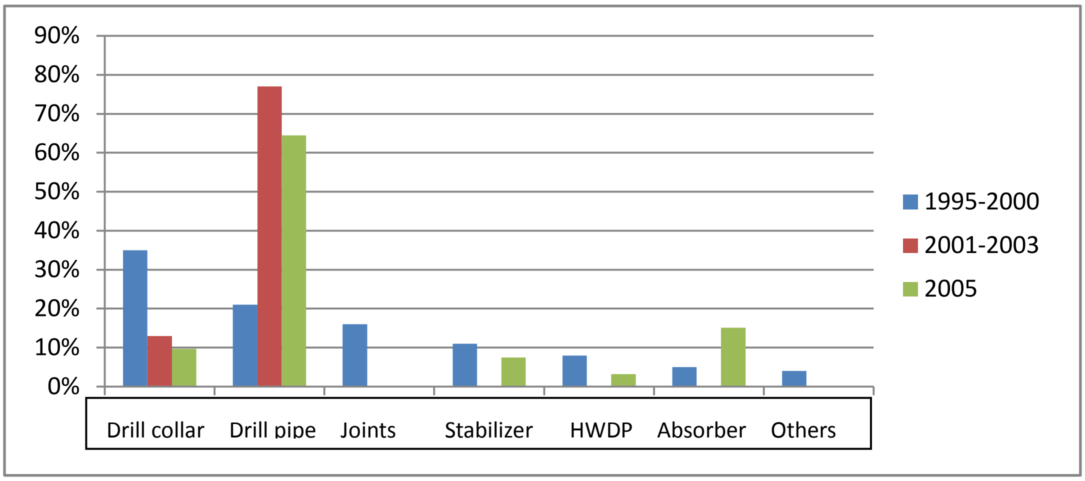


Figure 2-1 Drill stem failure statistics of Tarim oilfield in 1995-2005

As we can see from the statistics of drill stem failure in Tarim oil field, the failure quantity of drill pipe is the most in all the failure accidents which followed by the drill collar failure. And the failure types of drill pipe is mainly for thicken and transitional area leakage.

(2) East of Sichuan drilling company

According to the statistics of the drill stem failure accident from 2011 to 2012 in east of Sichuan drilling company, the drill stem failure accident can be roughly divided into two kinds: (1) drill stem failure, accounts for about 62% of the total number of drill stem failure, failure to drill collar connection thread root and compound pipe butt welding thickening in a circumferential fracture is given priority to, it is show metal brittle fatigue fracture. (2) the drill leakage failure, accounts for about 38% of the total number of drill stem failure, mainly from the drill pipe thickening transition zone of 0.15 ~ 1.13 m in a circumferential pipe body pierced the failure (Chen Shaoan, 2014).

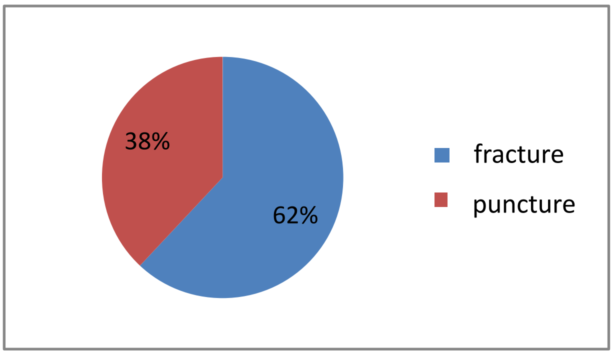


Figure 2-2 Proportion of drill stem failure in East of Sichuan drilling company

① Rule of failure position: Basic the puncture if from the drill pipe joints and pipe butt welding thickening transition zone of 0.15~1.13 m of the tube body, it is account for 64.8% of the total number of drill pipe failure; For the drill collar, it is generally in the 2 ~ 3 buttons in a circumferential of female thread, account for 91.1% of the total number of drill collar failure.

② Location features of failure depth：Drill collar failure is basic at the dynamic zero stress points of weight on bit, joint rigidity transition zone of bit and drill collar, this is nearly account for about 95.6% of the total number of drill collar failure; Drill pipe failure in basic at the rigidity abrupt transition zone and well track changed area, it is account for about 91.9% of the total number of drill pipe failure.

③ Formation features of failure: The failure in at the shallow hole of Shaxi temple, artesian well, Liangao mountain, Xujia river strata, it is about account for 44% of total failure.

④ Relationship of working condition and drill stem failure：In 2011, there has 3 wells of well track mutation section, it is account for 3.3% of the total failure; In 2012, there has 29 wells of well track mutation section, account for 53.7% of the total failure. It can been see that the influence of the well track mutation for drill stem failure is on the rise.

⑤ Relationship of drill collar and bottom hole assembly for φ311.5mm Hole in table.

Table 2-1 Relationship of drill collar and BHA for φ311.5mm Hole

Year	Bottom Hole Assembly			
	φ229mm+φ203mm+φ165mm		φ229mm+φ203mm+φ178mm	
	φ165 Drill collar failure	Ratio	φ178 Drill collar failure	Ratio
2011	8 wells	36.4%	4 wells	18.2%
2012	10 wells	62.5%	2 wells	12.5%

As we can see, the failure ratio of use φ165mm drill collar is 2 ~ 5 times than use φ178mm for the bottom hole assembly of φ 311.15 mm hole, that is to say theφ165 mm drill collar is unfavorable use.

(3) Drill pipe failure statistics of Jidong oilfield

Jidong oilfield is located in the Bohai bay area which the surface is for shrimp ponds, fish ponds and rice fields, the cost of the platform construction is high; The structure position is located in the north basin of Huanghua depression of Bohai bay, it is a typical complex fault block oil and gas fields.

The failure statistics of the drill pipe in 62 wells of Jidong oilfield which serviced by Zhongyuan drilling company in 2013 show that the drill stem failure pattern is mainly includes pipe body piercing, thread fastening, thorn leakage and pipe body fracture, and so on and so forth (Hu Yulei, 2014).

Table 2-2 Failure statistics of Zhongyuan drilling in Jidong oilfield in 2013

Name and specifications	Grade	Quantity	Position and reason
5" drill pipe	I	51	Body puncture
5" drill pipe	New	1	Body puncture
5" drill pipe	New	26	Threaded fastening
5" drill pipe	I	5	Body fracture
5" drill pipe	I	2	Male and female puncture
5.5" drill pipe	I	22	Body puncture

It can be seen from the table, the drill stem failure is mainly concentrated in the 5" and 5-1/2" drill pipe, and most of the failure is for pipe body fracture and threaded fastening. From the result of well conditions for verification of Jidong oilfield well design, it is basically deflect at about of 500 m, the drill string is by the larger bending stress, therefore the drill pipe is easy to fatigue at deflection area.

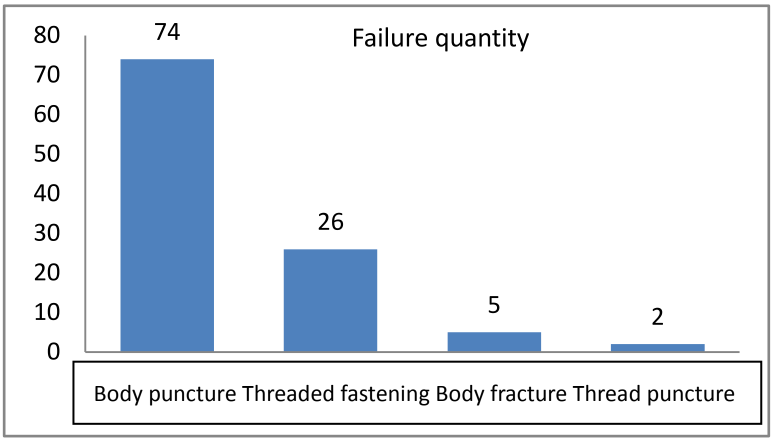


Figure 2-3 Ratio of drill stem failure in Jidong oilfield

(4) Statistics of drill stem failure in Sugeli area

As the Chinese biggest gas field, there are total 22 drill stem failure accidents occurred in Sugeli gas field area during July 3-2010 (Hua Jianjun, 2012). These include 7 times fatigue fracture failure accidents of drill collar thread root, 6 times fatigue fracture failure accidents of drill pipe joint thread root, 4 times fatigue fracture failure accidents of drill pipe thickening transition zone, 2 times overload fracture failure of drill pipe body, 1 thread tripping accident of drill collar joint, and 2 times of other failure accidents. Among these failure accidents, the highest percentage of 3 kinds are the fatigue failure of drill pipe, thread joint fatigue invalidation of drill collar and overload failure of drill pipe body, which are respectively for 45%, 32% and 9% of the total drill stem failure. From the figure 2-4, we can see that the failure accidents is mainly by fatigue failure of drill pipe and drill collar thread in Sugeli area.

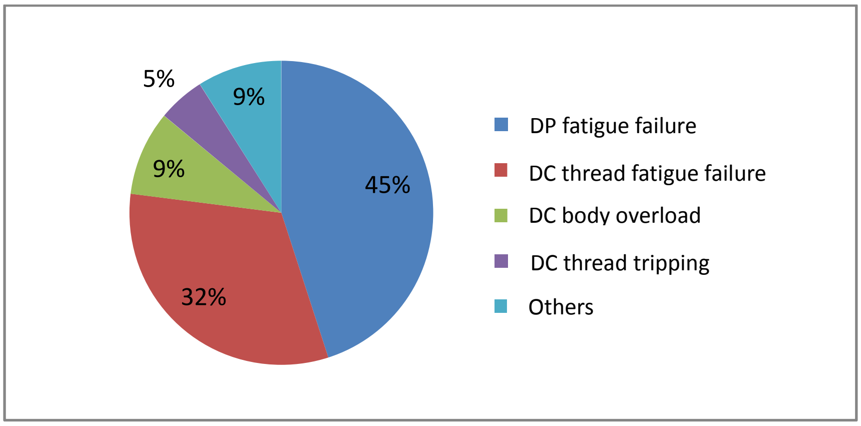


Figure 2-4 Failure statistics of drill stem in Sugeli area

Summary: The main drill stem failure types of land drilling is the fatigue fracture or the fatigue leakage, which the main location are drill pipe joint, drill collar joint thread and drill pipe thickening transition zone. The well section is given priority to dog leg serious interval.

2.1.2 General situation of drill stem failure in offshore drilling

(1) Incomplete statistics for the year 1999 ~2013

Compared with onshore drilling, offshore drilling has higher risk and higher cost. The phenomenon of leakage from 1999 to 2013 in the part of the east China Sea and Bohai oil field drilling can be seen in the statistics table 2-3 (Jiang Yuanwen, 2007) (Zhou Aqi, 2014). The drill stem leakage characteristics can been show as occurred in the female joint side of drill pipe body which about 0.5~0.7m from the mother buckle end and located in the transition zone of drill pipe thickening. According to the above statistics, it can be seen that the failure of drill stem in the offshore drilling is mainly caused by the failure of drill pipe thickening transition zone in the past 10 years.

Table 2-3 Leaking statistics of drill stem for the east China Sea and Bohai in the past 10 years

Oil-Gas field	Well number	Occurrence time	Leaking quantity	Specification and grade
PH	B6	1999.2~1999.3	4	φ127mm, S135 drill pipe
PH	B1	1999.6~1999.7	24	φ127mm, 1 joint for G105, others for S135
PH	A6	1999.8~1999.9	19	φ127mm,G105
PH	BA6	2001.3~2001.4	14	φ127mm, 11joints for G105, others for S135
PH	Aa5	2002.11~2003.2	3	φ127mm, S135
LD	LD5-2	2006.2	2	φ127mm, G135
CFD	XFD11-1A	2006.5	2	φ127mm, height weight drill pipe
BZ	BZ25-1C	2006.6	1	φ127mm, S135
BZ	BZ25-1C	2006.26-29	3	φ127mm, S135
PL	PL19-3A	2007.5.28	1	φ127mm, S135
PH	BA6s	2012.11~2013.2	18	φ127mm, S135

(2) Failure statistics of drill stem for COSL (China Oilfield Services Limited) 2012~2014

According to the drill stem failure statistics of COSL 2012 ~ 2014, the drill sting leakage failure occurred about 42 cases. Among them, as shown in Figure 2-5, there are 38 times of drill pipe leaking which accounted for the total failure of 90.5% and 4 times of drill stem fracture failure which accounting for only 9.5%.

In the total number of puncture failure, there are about 26.3% for the male connector end thickening transition zone, about 47.7% the female connector end thickening transition zone, about 13.2% for the body leakage and about 13.2% for the joint puncture leakage. It can be seen from figure 2-6 that the drill stem puncture is mainly at the disappear area of thicken transition zone and slip bite area which accounting for about 73.7% of the total leakage failure accidents.

Drill pipe leakage accident is mainly located near the KOP (Kick Off Point) of the well, and the dogleg neat the KOP is larger, even some reach to 3 degrees /30m. In addition, some of the leakage failure happened in rotary table area, which may be related to the rock or bumps of drilling rig. When the drilling rig is swinging or pitching, some of the derrick is inclined, the upper end of the drill string is not vertical, and the drill pipe under some distance from the rotary table is still vertical, therefore the drill string is bent. Because the stiffness of drill pipe is much smaller than kelly, so most of the bending occurs on the first drill pipe the side of the kelly. In the vicinity of the rotary table, the drill pipe is easy to leak due to bending fatigue.

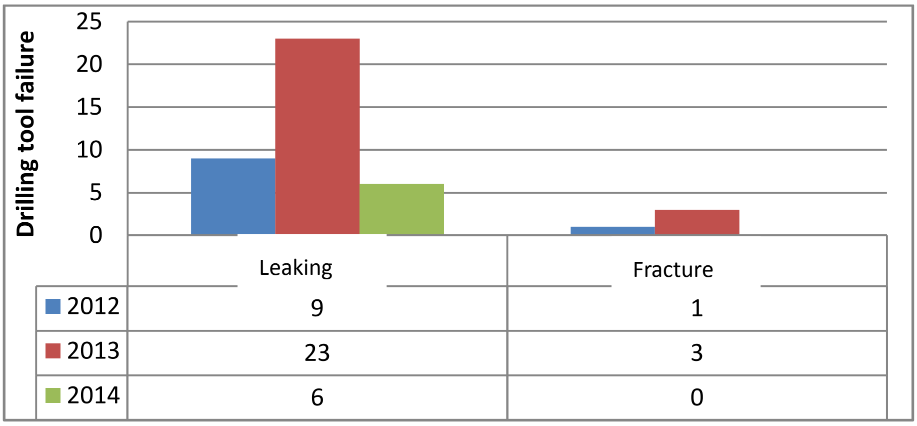


Figure 2-5 Failure statistics of drill stem for COSL of 2012~2014

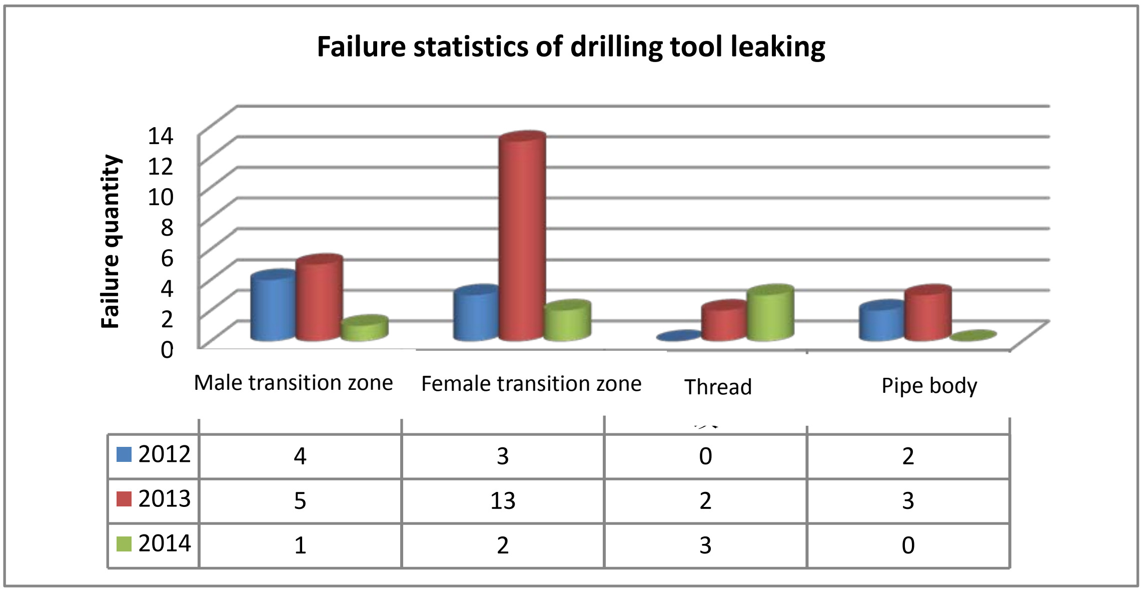


Figure 2-6 Type statistics of frilling tool leaking

2.1.3 Drill stem failure in foreign countries

(1) Failure analysis and research results of the International Association of Drilling Contractors

According to the IADC (International Association of Drilling Contractors) and failure analysis of drill pipe survey results, the failure occurred at thicken transitional zone of drill pipe body is accounted for 70% of drill pipe failure accidents, the drill pipe thicken transitional zone is the "weak link" of drill pipe.

(2) Failure of drill stem in North oilfield of Norway

J.V.Bjune of University of Stavanger and K.A.Macdonald of Norway DNV (DET Norske Veritas) done the drill stem failure research of the North Sea for nearly 10 years (1996-2006) (K A Macdonald, 2007), it was found that most of the drill stem failure occurred mainly in the thicken transition zone area and the threaded connection area, rarely occur in the body of the drill pipe. They also listed the three typical cases to represents the drill tool leakage failure trends and types of cause:

① Slip bite caused. In the course of tripping, the area of slip clamp holding larger tension load, stress concentration caused by slip bite marks, this can lead fatigue crack initiation, finally cause fatigue leaking. The fatigue crack can been usually observed at the bottom of the slip bite area.

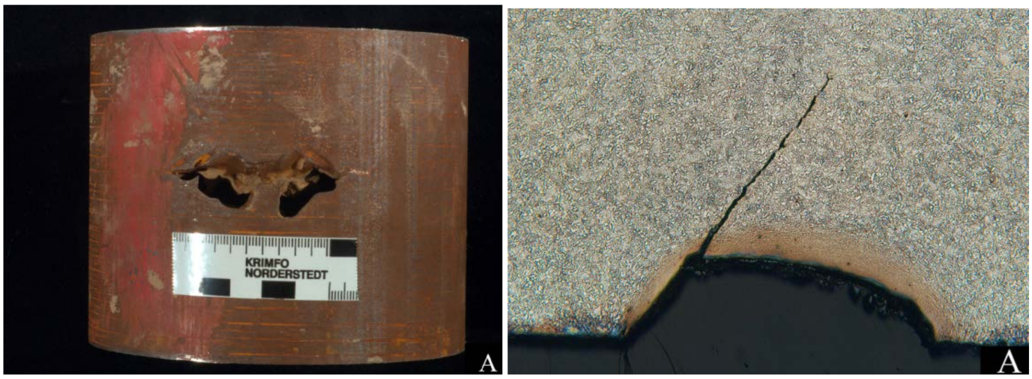


Figure 2-7 The leaking caused by slip clamp

② Drill pipe internal coating peeling off. Internal coating not only reduce the friction of drilling fluid, but also play a role in corrosion protection. After the internal coating is partially detached, corrosion fatigue is easy to occur, which causes the initiation of fatigue cracks at the bottom of the corrosion pits. Internal coating peeling is usually due to the combination decline of the coating and the body which caused by the poor construction quality and placed too long time of the drill stem. When split the leaking hole, the blistering and shedding phenomenon can be seen in the internal coating, sometimes also observed the morphology of thorn crack which expansion from the inside to outward of the hole.

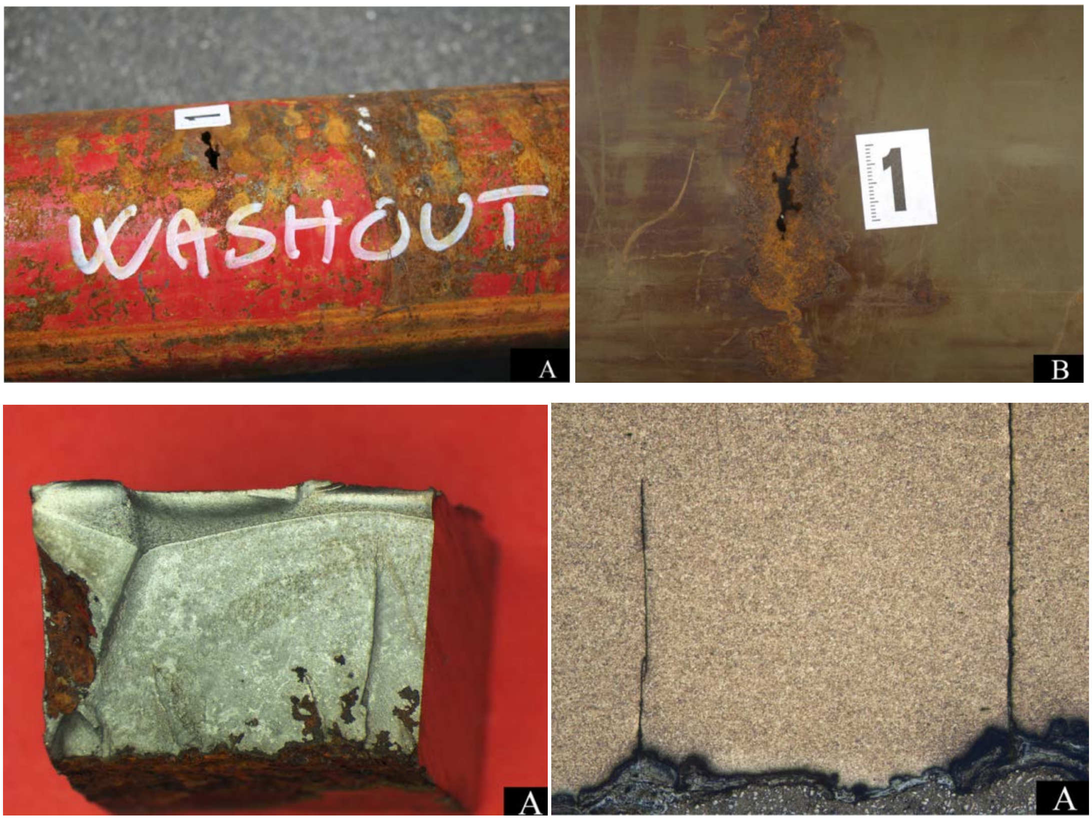


Figure 2-8 Washout due to the internal coating peeling off

③ Drill pipe manufacturing defects. The small original quenching crack and folding defects existed in the drill pipe, and does not detected, this will become a source of fatigue crack during the drill pipe service process, and finally washout or fracture due to the crack extension in the drill pipe.

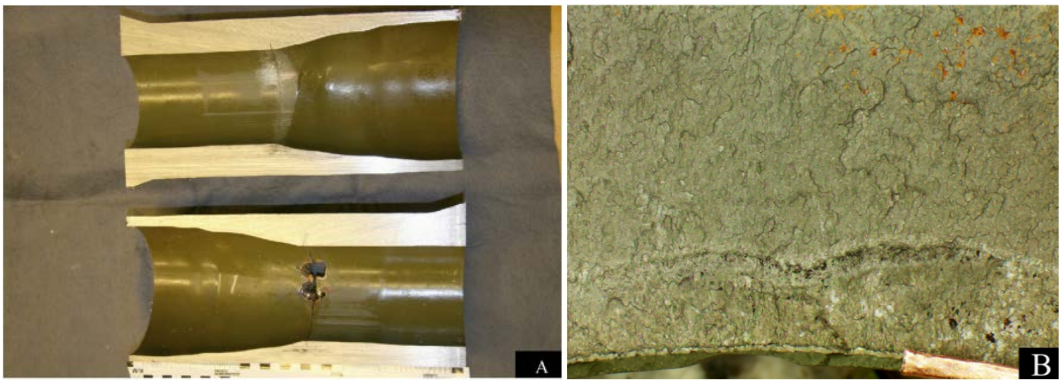


Figure 2-9 Washout due to the original defect

(3) General situation of drill stem failure in Iran national South Oil Company

S.Moradi and K.Ranjbar researched drill stem failure analysis to statistics 30 years of the National Iranian South Oil Company (S Moradi, 2009) , it established database which contains 92 wells of drill stem failure. The statistics show that more than 750 cases of drill stem failure types are thorn leakage and overload fracture, and the thorn leakage is the most common form of failure. Although the overload fracture appear less frequently, but usually cause huge losses. Based on the failure database, they also studied the discipline of well depth, casing for drill stem failure. According to the data analysis, the following conclusions are obtained:

1) About 93% of the failure occurred at the top of the well (casing diameter 466.78mm, 444.5mm of the hole), only 6% occurred in the 311.2mm of well diameter section. As the figure shown below, the failure occurred in 18-5/8" casing section is more, when access to 13" casing, the failure number of failure is reduced to 0. It is to say that the probability of buckling and vibration of drill stem can be reduced due to reduce the diameter of the borehole.

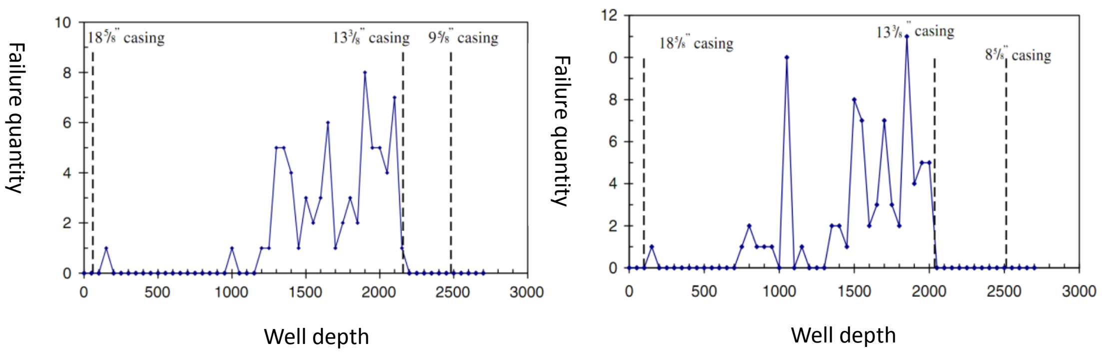


Figure 2-10 Relationship between failure quantity and well depth

2) 95% of the failure is the puncture and leakage of tube, and the rest is reverse fracture.

3) 65% failure accident occurred for drill pipe, and most of them located in slip holding area. About 22% failure accident occurred for drill collar, and most of the failure pipe is near the bottom hole assembly.

4) The failure drill pipe comprises new drill pipe and old drill pipe.

5) The most failure accident occurred when use three cone bit to drill the well.

Summary: The results of typical oil field research in foreign countries show that the main failure modes of drill stems are puncture and overload, and the puncture is more common.

2.1.4 Summary

It is found that the drill stem failure situation of China and foreign onshore and offshore drilling are as below:

(1) In all types of drill stem failure, the fatigue failure is the main form which include drill pipe thicken transitional belt and slip clamp area of the thorn leakage failure, joint thread fatigue thorn leakage and fracture failure.

(2) The drill pipe thicken transitional belt and slip clamp area of the thorn leakage failure is more prominent for offshore drilling, thorn leakage wells occurred in the well section with high dogleg.

2.2 Failure analysis of typical drill stem cases

In order to further understand the cause of the failure of offshore drilling, a well drill stem in the east China sea thorn leakage situation are analyzed.

2.2.1 Accident background

The well type was been designed for directional well in the east China sea which the well depth is 4788 m, the water depth is 88.88 m, the rotary table height is 46.62 m, and the side tracking window is located in the well depth of 855 m ~ 860.7 m. The drilling fluid performance as follows: 1.70 ~ 2.53 g/cm3 density, fluid loss 14.0 ml ~ 18.0 ml, 47.0 ~ 51.0 s viscosity, pH value of 10. The ROP (rate of penetration) is average about 77-81 RPM.

The total drill pipe thorn leakage of the well is 20 joints, these including 18 joints of 5 " S-135 drill pipe and 2 joints of 5" height weight drill pipe. The drill pipe thorn leakage of well depth and quantity statistics are shown in table 2-4. From the statistics we can see that the quantity of drill pipe thorn leakage in 600 ~ 1000 m hole are 14 joints (include 2 joints height weight drill pipe) and in 1000 ~ 1500 m hole are 6 joints even most are old pipe.

Analysis the two samples of S-135 drill pipe leakage, thorn leakage location are the thickening transition zone disappear area of female joint. Sample number are 8-1 and 8-4 which the corresponding pipe number are SZAR258 and S0398 respectively. The specifications of drill pipe is for Φ 127 mm x 9.19 mm which thick form for internal thicken and drill pipe manufacturers for Grant Drill stems Limited Company.

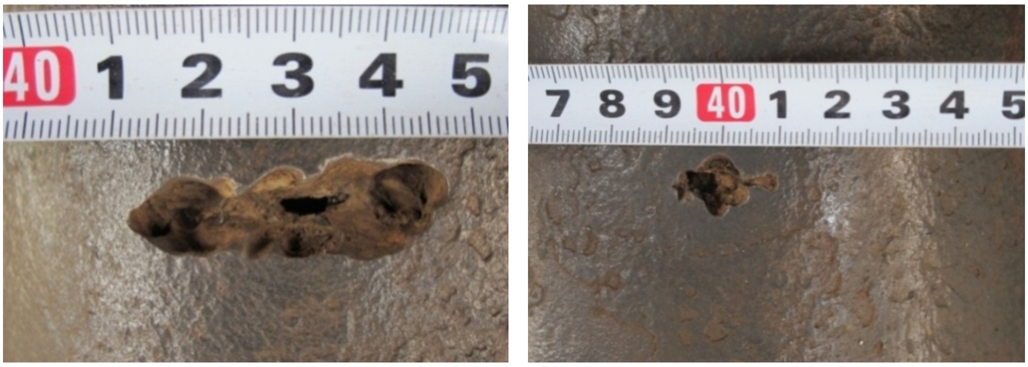
Table 2-4 Statistics of leakage well depth and quantity

Thorn of well depth/mm	Drill pipe number/root
600-1000	14
1000-1500	6
Note: 2 joints of height weight drill pipe in 14 joints	

2.2.2 Macroscopic observation and size measurement

The macroscopic sample analysis is shown in figure 2-11 which the outer wall of 2 samples is corrosion serious. Sample 8-1 piercings as shown in figure 2-12 (a) which the piercings hole bigger and present oval shaped. Sample 8-4 piercings as shown in figure 2-12 (b) which present circular. The specific size parameter of measurement results are shown in table 2-5.

Figure 2-11 Macroscopic feature of sample



（a）Sample 8-1 （b）Sample 8-4

Figure 2-12 piercing feature

Table 2-5 sample size measurement results

Sample number	Distance between piercings and internal thread joint sealing surface /mm	Distance between piercings hole and weld line/mm	Piercing size/mm		Welding neck diameter/mm	Tube diameter of piercing position /mm
			Lateral length	lengthways length		
8-1	550	152	38	12	129.2,129.1	127.8
8-4	530	143	12	11	128.8,129.0	127.1

After open the sample 8-1, it is found that the internal wall coating has been damaged which as shown in figure 2-13 (a), and the internal coating of thickening transition zone was serious peeling off, the tube coating spraying of thickening transition zone and its near position of the tube was uneven and presented ring shaped distribution. After observation, there are sparkling falls off phenomenon around the piercings coating as shown in figure (b) 2-13, the coating spraying uneven phenomenon also exist in other parts of this sample, and the junction between the coating and coating has been sparkling fall off as shown in figure (c) 2-13. Sample 8-4 cut open after wall The morphology of sample 8-4 as shown in figure 4 when cut open the sample, we can see that almost all internal coating was corrode and felled off.

When measure the internal thickening area size of the two samples, the results are shown in table 2-6. From the results, we can say that the internal upset parallel length of Liu and internal thickening transition zone length of Miu are all conform to API Spec 5 DP - 2009 standard.

Table 2-6 Measurement results of thorn leakage sample size

Sample number	Internal upset parallel length of Liu / mm	Internal thickening transition zone length of Miu / mm
8-1	96.5	91.5
8-4	96.5	100.5
API Spec 5 DP standard	95.25~146.05	≥76.20

The macroscopic morphology observation results show that the leakage hole of two samples are located in a thickening transition zone disappeared area, and the crack is originated in inner wall, also the internal coating spraying of drill pipe is uneven, foaming, falls off.

2.2.3 Physical and chemical properties test

(1) Chemical composition analysis

Respectively sampling around piercings of sample of 8-1 and 8-4, using direct reading spectrometer to analysis the chemical composition in accordance with the standard of ASTM E415-08, results show that the chemical composition of the two failure samples are in accordance with API Spec 5 DP - 2009 standard's requirement for drill pipe body.

(2) Tensile and impact properties

According to ASTM A370 standard, respectively take samples in sample 8-1 and 8-4 by plate tensile and 7.5 mm x 10 mm x 55 mm impact test at room temperature which the results as shown in table 2-7. It is showed that the yield strength, tensile strength, elongation and impact energy of failure samples are in accordance with API Spec 5 DP - 2009 standard's requirement.

Table 2-7 Tensile and impact performance results of failure sample

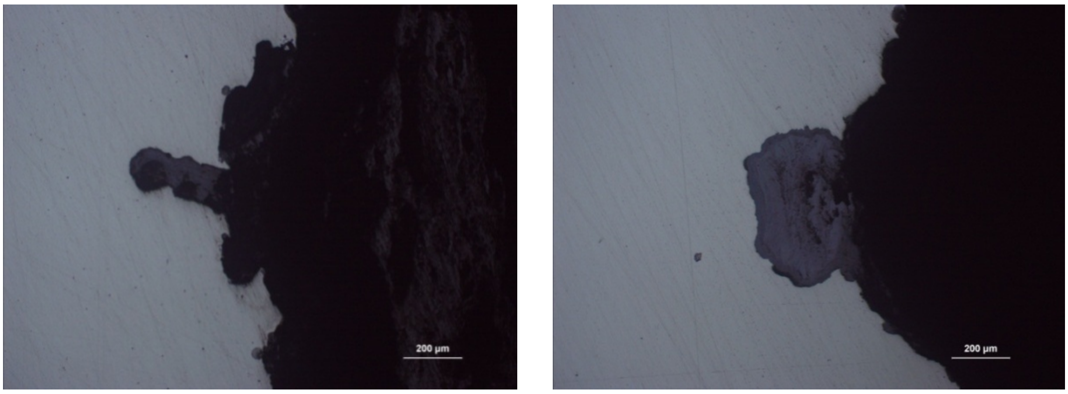
Performance / Smple	Tension property			Impact property	
	Tension strength Rm / MPa	Yield strength Rt 0.7/MPa	Elongation /A%	Single	Average
8-1	1064.5	1001.6	20.0	80,80,76	79
8-4	1017.9	966.4	20.8	76,74,76	75
API Spec 5DP-2009	≥1000	931~1138	≥13	≥38	≥43

(3) Rockwell hardness

Take annular specimen near the piercings and carry out Rockwell hardness test in accordance with the ASTM A370, the results showed that the Rockwell hardness of failure samples piercings near to relatively homogeneous.

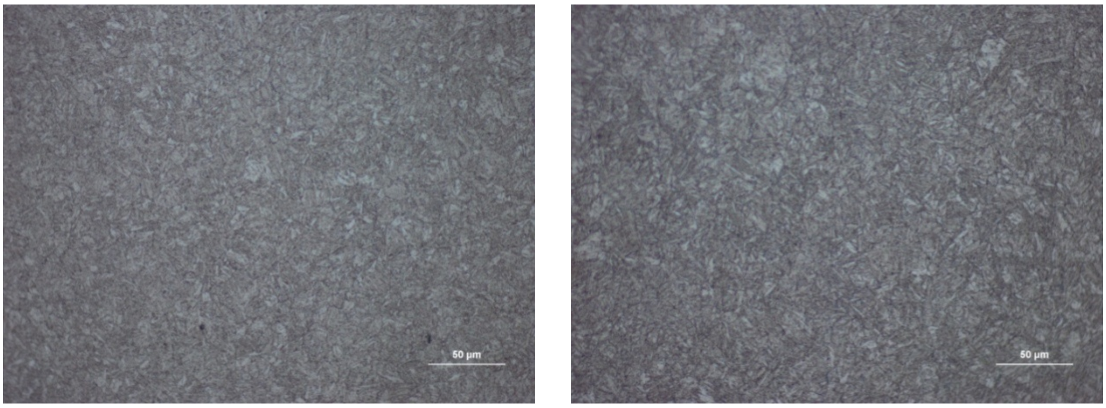
(4) Metallographic structure analysis

Respectively take samples of 8-1, 8-4 on the blistering place of sample coating to test the metallographic specimen, corrosion pit can been observed at the bottom of coating which as shown in figure 2-13. Along the lateral to take metallographic specimen for microstructure observation, the metallographic structure of the samples are tempered sorbite which the results as shown in figure 2-14. Along the longitudinal to take metallographic specimen for non-metallic inclusion rating analysis, the inclusion content of the organization are within the normal range.



(a) Sample 8-1 **(b) Sample 8-4**

Figure 2-13 Corrosion pit morphology of the coating at the bottom of the foam



(a) Sample 8-1 **(b) Sample 8-4**

Figure 2-14 Metallographic structure morphology

(5) Internal coating rating of drill pipe

Due to the coating of sample 8-4 has already erosion fall off and cannot evaluate coating. Take longitudinal metallographic specimen in tube coating uneven area of sample 8-1 to observe the coating section which the results are shown in figure 2-15. From the figure, we can seen that the coating within a small amount of bubbles and the thickness of coating spraying is not uniform, That is to say the internal coating thickness of the sample does not conform to SY/T 0544-2010 oil drill pipe internal coating technology conditions.

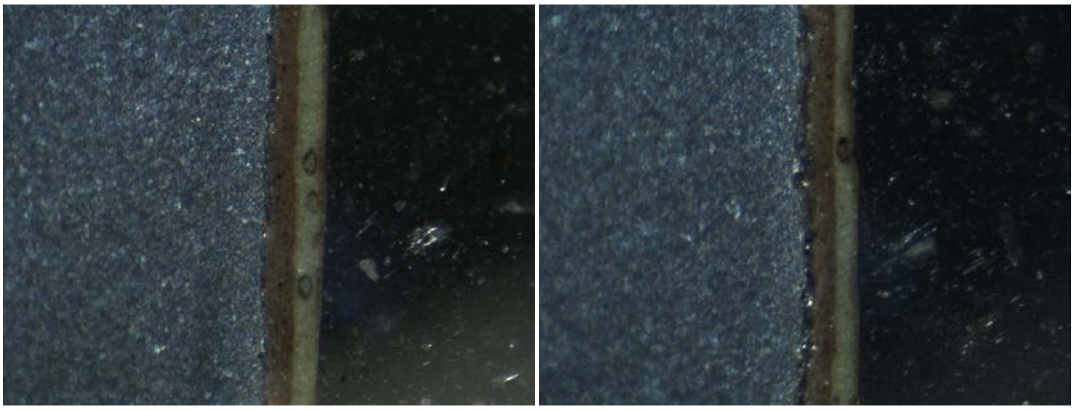


Figure 2-15 Internal coating profile morphology of drill pipe

(5) Micro analysis

The piercings fracture of sample 8-1 is mud flushing traces, the original crack surface have been damaged. When observed the original crack surface morphology of sample 8-4 by scanning electron microscope piercings, the result as shown in figure 2-16. From the result we can say that it is mainly for the mud corrosion morphology, after the original crack formation, mud seeping into the crack.

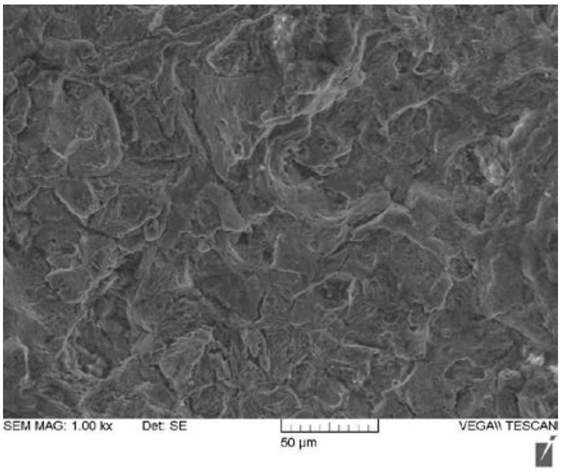


Figure2-16 Sample 4 Crack surface morphology around hole

2.2.4 Thickening transition zone structure analysis

Drill pipe upset end thickening transition zone is the transition region of drill pipe and tube body, is the area of section size changed. There is an obvious stress concentration in use process for drill pipe thickening transition disappeared zone, this is mainly related to transition zone length Miu and transition radius R. There are no relevant provisions in API Spec 5 DP standard for pipe body and the transition zone at the junction of the transition radius, but the related data show that the longer the Miu and

R, the smaller the stress concentration factor of the tube body and the transition zone.

Thorn leakage of sample 8-1, 8-4 internal thicken of Miu is 91.5 mm and 100.5 mm respectively, and the good internal thicken sample of other manufacturers of Miu is 135 mm, which compares as shown in figure 2-17. From the figure we can see that the failure samples internal thicken straight section and the transition angle of transition zone is bigger, the transition is not flat.

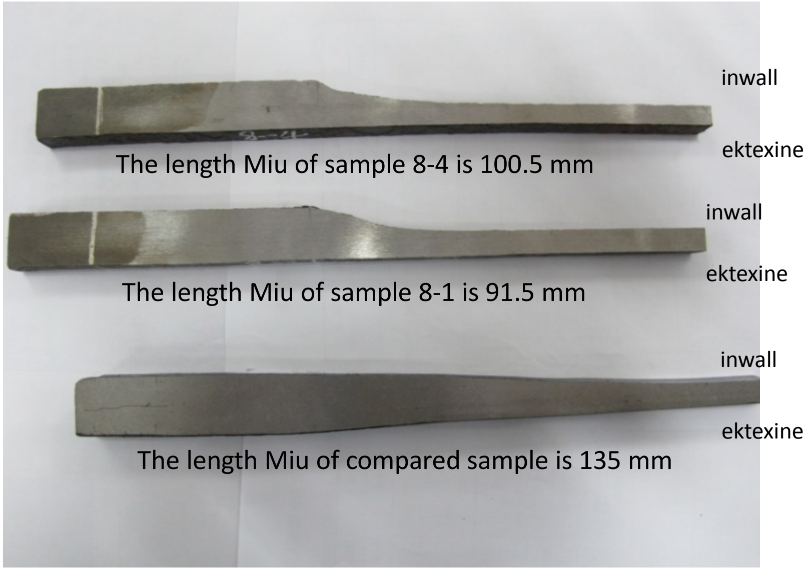


Figure 2-17 Open morphology of thicken end

2.2.5 Comprehensive analysis

The well for directional well, and total of 20 root thorn leakage happened. The analyzed of sample thorn leakage location are internal thickening transition disappear zone. According to the well conditions, accumulative total drilling time of piercing pipe is about 127 h ~ 400 h. The essence of the drill rod thorn leakage failure is the result of fatigue crack propagation through, the physical and chemical test results show that the chemical composition, mechanical properties of the failure drill pipe are in accordance with API Spec 5 DP - 2009 standards. The main reason of thorn leakage of the failure drill pipe are the quality of drill pipe internal coating, the structure of thickening transition zone, the rate of borehole whole angle and other factors. The following will one by one to analysis.

(1) The quality effect of drill pipe internal coating

Drill pipe internal coating not only can improve hydraulic conditions, but also can effectively prevent the pipe inside corrosion. Part foam peeling of drill pipe internal coating is a main cause of corrosion fatigue. According to the observation, coating samples of 8-4 inside coating almost completely washed off, and the sample 8-1 inwall spray coating quality is poorer, uneven thickness, the thickness of the local area is only 100 um, it does not conform to the stipulations of the ST/T0544-2010 standard. In addition, the part of coating section also found that there are air bubbles, it may cause foaming coating fall off, this is also a reason why it cause corrosion fatigue of the drill pipe.

When drill pipe has been used, the uneven coating of stress concentration area foam and fall off firstly, then the exposed body of drill pipe and the electrochemical corrosion of drilling fluid will generate pitting corrosion pit, and then form the fatigue initiation fatigue crack source. And the formation of pitting corrosion pit is further exacerbated the partly stress concentration, also accelerate the process of the whole pipe corrosion fatigue. When the fatigue crack penetrates the whole wall thickness eventually, the drill pipe thorn leakage failure will happen.

(2) The structure effect of drill pipe internal thickening transition zone

In the thickening transition zone as the section size change area of the drill rod, the stress concentration is more obvious. Drill pipe failure in thickening transition disappear area of the hole formed position as the severe stress concentration area. Finite element simulation results show that under the effect of composite load, the longer of length Miu of the internal thicken transition zone, the more relax of the stress distribution, and the low level of the stress.

Relevant data show that drill pipe thickening transition area within a thorn leakage is most occurred inside the nipple end, and rarely occurred in the male connection end of the drill pipe. From the perspective of the structure size of drill pipe joints, drill pipe external thread for fluid contraction joint end, and drill pipe internal joint thread end for fluid diffusion section. The spread of the fluid is much more complicated than fluid contraction, it have some impact in the process of diffusion vortex on the wall erosion and initiation of crack. From the result of flow field analysis of the failure samples, the total pressure of internal flow field for thickening transition zone is bigger than inner and outer thickening type, due to the thickening transition zone of the failure sample is not flat, the vortex reflux formed near the transition zone, this cause certain impact to the lining, and have further denudation for initiation of corrosion pit, fatigue crack, and so on.

(3) The effect of borehole whole angle rate

Drill string on borehole angle rate all overweight or too big section will bear the additional bending load, drill pipe puncture caused by fatigue. According to drilling data, the drill pipe thorn leakage failure of the Well are mainly distributed near the wellhead of 600 m ~ 1500 m sections which the borehole whole angle change rate is too high section, but the borehole whole angle rate of other hole section is low which without pipe thorn leakage failures occur.

Generally, if it is more close to the wellhead, the requirements of the borehole whole angle rate of change is smaller. Therefore, if drill pipe is near the wellhead, it will under bigger tensile load, fatigue damage will more occure. If the drill pipe wiht better quality of coating and internal thickening transition zone at borehole whole angle rate changed larger section, it can reduce the probability of thorn leakage failure of drill pipe in certain degree.

To sum up based on the analysis, drill pipe thorn leakage failure of the well is mainly caused by three reasons: (1) internal coating quality of thickening transition zone area is not well, bubbles off of the coating on uneven areas cause drill pipe corrosion fatigue; (2) internal thickening transition disappear zone is high form fatigue crack. (3) the borehole whole angular rate in 600 m - 1000 - m sections is changed bigger, drill pipe under rotating bending load will cause fatigue crack in stress concentration area.

2.2.6 Conclusion

(1) The physical and chemical properties of drill pipe failure samples are comply with the requirement of API Spec 5 DP - 2009 standard.

(2) The internal coating of drill pipe failure samples spraying uneven, and local thickness does not conform to the stipulations of the SY/T0544-2010 standard.

(3) The spraying quality of the drill pipe internal coating is unevenly, internal thicken transition region is not smooth, overall smooth of surface roughness is poor, all these are the reasons of drill pipe leakage failure. Also the "dog leg" of the well in 600 m ~ 1000 m section is too large, it is the main reason which lead to the drill pipe thorn leakage.

Section 3 Cause type and regularity of drill stem failure

Drill stem service environment is poor, and the stress state is very complex which include torsion, bend, tension and compression load, and also impact by the environmental media, such as drilling fluid, H2S, CO2, temperature, pressure, etc.. For a long time, the failure statistics and analysis results show that the main forms of drill stem failure include: fracture failure, failure of puncture and leakage, corrosion failure, wear and deformation. The reason and regularity of drill stem failure are as follows (Li Helin, 1990).

3.1 Fracture failure of drill stem and its expression form

Fracture failure mainly include fatigue and corrosion fatigue fracture, overload fracture, low stress brittle fracture, hydrogen embrittlement failure etc..

3.1.1 Fatigue and corrosion fatigue fracture

Fatigue fracture failure of drill stems is the sudden brittle fracture under the alternating stress of the fatigue limit of the metal. Drill stem in the hole to produce buckling or in the well section of "dogleg" will produce serious alternating bending, these will occur fatigue because the drill string is under alternating stress (Lin Yuanhua, 2004). During the rotation, the side of the curved drill string is subjected to cyclic tension / compression alternating stress in the axial direction. When the stress at the root of the crack reaches a certain value, the crack will continue to expand at a certain rate until the rest of the section is not enough to bear the fracture.

Fatigue fracture generally occurs in drill pipe joint, drill collar and adapter threaded part or section mutation region, or surface damage caused by the stress concentration zone.

The form of fatigue fracture: drill joint thread fatigue fracture, crack source area is relatively flat, the fatigue crack can be observed in the vicinity of the bottom. If the fracture surface is relatively intact, the fatigue zone can be observed in the fatigue fracture zone by scanning electron microscope.

(a) Fatigue fracture of drill collar thread (b) Fatigue fracture of drill pipe body

Figure 3-1 Fatigue fracture morphology

In fact, because of the special drilling environment, the drill stem has less failure due to fatigue, usually failure in the presence of corrosion and fatigue. Drill pipe corrosion fatigue fracture failure is caused by the corrosive medium (mud and formation of harmful gases and other media) and bending alternating stress.

Drill string corrosion fatigue mechanism: under the action of alternating stress, the slip occur between the metal lattice, this destroy the protective film of metal surface. Due to the electrochemical corrosion, micro corrosion occurs at the sliding point, micro corrosion forms a corrosion pit under the alternating stress. Under the common action of the alternating stress and the anodic dissolution process of the crack tip, the crack continuously develops and the leakage or fracture occurs finally.

Expression form: The fracture surface of corrosion fatigue is similar to the fatigue fracture surface, the area of the crack is fan shaped and the fracture surface is relatively flat.

3.1.1 Overload fracture

According to the types of loads, overload fracture can be divided into tensile overload fracture and torsional overload fracture. Tensile overload is the drill string tensile load greater than the yield load, and torsional overload is caused by the torque of the drill string in the bottom of the well greater than the yield torque.

Overload fracture is generally by sticking, free stick, milling and other un normal operation which generates a larger drill yield torque or tensile load, fracture occur in weak link of the drill stem.

Expression form: There will be a large number of plastic deformation and "thin neck" phenomenon in the vicinity of the tensile overload fracture. This is due to the plastic deformation exist which is often accompanied by the tensile overload. There is a certain fracture flanging. Due to the good toughness of drill pipe material, the fracture surface of the over twist area usually presents a cup cone shape.

Figure 3-2 Fracture failure morphology due to over twist and overload

3.1.2 Low stress brittle fracture

Low stress brittle fracture is refers to drill stem which in bear is much lower than the nominal yield force load and suddenly brittle fracture.

Expression form: low stress brittle fracture is flush, no obvious plastic deformation, section exist herringbone extended lines (Gong Danmei, 2014).

Low stress brittle fracture caused by (1) heat treatment of drill pipe material is improper, toughness is low, these resulted in the brittle fracture of the thread; (2) cracking because welds exist in large gray spots area; (3) quenching crack exist because of tubes heat treatment etc..

Figure 3-3 Morphology of low stress brittle fracture

3.1.3 Hydrogen embrittlement

Hydrogen embrittlement is mainly due to hydrogen atoms into the steel organization, brittle fracture occurred under the tensile stress. Hydrogen sulfide stress corrosion cracking is caused by hydrogen in oil and gas well which contain hydrogen sulfide, hydrogen sulfide stress corrosion cracking is a kind of hydrogen embrittlement.

The mechanism of hydrogen sulfide stress corrosion cracking (SSC) is mainly considered as the mechanism of hydrogen induced cracking stress corrosion. H2S soluble in water and ionization and acidic gradual occur, which describe by the following corrosion process:

- $H_2S \rightarrow HS^- + H^+$ (2-1)
- $HS^- \rightarrow S^{2-} + H^+$ (2-2)

The electrochemical reaction occurred on the surface of the steel:

Anodic reaction:

- $Fe \rightarrow Fe^{2+} + 2e$ (2-3)

Cathodic reaction:

- $2H^+ + 2e \rightarrow [H] + [H]$ (2-4)

Hydrogen atoms adsorbed on the surface of the steel, partially formed for hydrogen and diffusion in the solution, and some of the hydrogen atoms will diffuse into the steel, forming lattice hydrogen.

Corrosion products formed by anode:

$Fe^{2+} + S^{2-} \rightarrow FeS$（2-4）

Hydrogen atom diffusion into the internal steel and then aggregate in steel defect, such as surface defects, dislocations and the three dimensional stress area. The binding strength of these defects and hydrogen is strong, the hydrogen has been captured by these defects and cannot spread. The hydrogen atoms in a trap combined for hydrogen molecules, when the accumulation of hydrogen is in very high pressure, plus stress or residual stress will urged to make steel crack formation in the defect site.

Expression form: The fracture is brittle fracture in macroscopic and intergranular morphology in microscopic.

Figure 3-4 Hydrogen sulfide stress corrosion cracking of drill pipe (SSC)

3.2 Puncture failure and forms of drill stem

According to the puncture position of drill pipe, the puncture failure can be divided into drill pipe body thickening transition zone, drill pipe weld puncture, drill pipe joint puncture. The failure mechanism, the form of expression and the rule of the puncture are as follows.

3.2.1 Puncture of drill pipe thickening transition zone

(1) Mechanism and process of drill pipe puncture

The leakage position of drill pipe internal thicken transition zone is the most common form of puncture. According to statistics, it accounts for about 70% of the failure of drill stems. Puncture mechanism and process (Lv Shuanlu, 2006): Corrosion occur and pit corrosion develop after drill pipe inner wall coating damaged. Due to stress concentrated, corrosion fatigue crack initiate and crack propagate and penetrate the thick wall, then drill mud pierced erosion from internal to outside, and finally formed puncture. Most fatigue crack of thorn leakage position of drill pipe internal thickening transition zone originated from the inner surface, a handful of fatigue crack of thorn leakage position of drill pipe internal thickening transition zone originated from the defect area of outer surface (such as slip bite marks, corrosion, wear, etc.).

(2) Expression form

The leakage position of drill pipe internal thicken transition zone is generally from female joint sealing surface about 0.5~0.7m, the circular or elliptical distribution along the circumferential direction is shown in figure 1. When opened the fracture, there is no more than half circle around the fatigue crack growth in the hole, and the origin of the crack can be judged according to the plane of the original crack. The circular arc faces to outer wall, the crack plane is in wide and narrow shape, it can be considered that the crack originated from the inner wall. If the original fatigue crack plane is not completely destroyed, fatigue can be observed at the front of the crack growth sector.

(a) Puncture macroscopic morphology (b) Fatigue crack extend from inner wall
(c) Puncture macroscopic of pipe body (d) Crack extend from out wall to inner wall

Figure 3-5 Puncture morphology of drill pipe internal thicken transition zone

(3) Regularity of puncture

1) Structure of drill pipe thicken transition zone

The puncture of drill pipe thicken transition zone is mainly occurred in the transition with female connector end, little occurred in male joint end. The thicken transition zone is the area of the section size changed, the stress concentration is more obvious, therefore the fatigue crack initiation is more easily. From the structure size aspect of the drill pipe joint, the joint end of the drill pipe male connection is a fluid contraction section, and the joint end of the drill pipe female adapter is a fluid diffusion section. The diffusion of fluid is much more complicated than contraction of the fluid, and some impact vortices generated during the diffusion process can be used to the wall erosion and promote the initiation of fatigue crack.

2) Well section regularity of drill pipe puncture

According to the statistics of drill stem leakage in the Tarim Oilfield, the drill pipe puncture and leakage in the 0~1500m well section is accounted for 68.8%. This is mainly related to the force of the drill pipe. The tension of the drill pipe is mainly from the weight of the drill pipe during the normal use. The drill pipe which near the wellhead will get greater pull stress. In addition, borehole has certain whole angle rate, the more the drill pipe near the wellhead of the well, the worst of the whole angle rate damaged on drill pipe.

3) Well depth regularity of drill pipe puncture

Statistics show that there are 92.5% of the puncture occurred in the depth of 2001~5000 m section, which indicates that the stress condition is harsh in the well (Lv Shuanlu, 2006). The size of 311.2 mm and 215.9 mm drill bit had been used in the 2001~5000 m depth range of the field, that is to say the force conditions of drill pipe is quite seriously within the size of the hole and the well body structure and the assembly conditions.

4) The influence of rotary speed on the puncture of drill pipe

The statistical results show that with the increase of rotary speed, the number of drill pipe puncture is increased. High speed will increase the centrifugal force and additional bending stress for the drill string, and high speed will produce violent vibration load which damaged the drill string seriously; high speed will increase the composite stress for the drill string which leading to fatigue crack initiated and propagation speed increased and piercing the drill pipe finally.

5) Whole angle change rate influenced on drill pipe puncture

The whole angle change rate is too big to make the drill string bear additional bending load, and prone to accidents of drill pipe piercing. Pinghu 6As well which located in China East Sea had 20 joints of drill pipe thorn leakage which are located close to the large section of wellhead whole angle changed rate. There are three points of whole angle changed rate in the vicinity of 4°~ /30m, maximum up to 4.81°/30m. Thus, the change rate of whole angel has great influence on the life of drill pipe.

6) Effect of drill pipe aging

The grade II of drill pipe is not allowed to be used in parts of harsh onshore drilling and offshore drilling. The fatigue cumulative damage of the drill pipe aging should be paid attention. According to the statistics of the Tarim Oilfield, the grade II drill pipe is in the drill pipe piercing for 65.3%. Drill pipe piercing through corrosion, fatigue crack initiation and propagation stages, drill pipe piercing is the result of fatigue accumulation. The deeper the well is, the more severe the drilling condition is, the shorter the fatigue life of the drill pipe is. The grade II drill pipe is generally used for a long time, and the fatigue accumulation is relatively serious. The proportion of grade II drill pipe piercing is mainly related to the aging of the drill pipe. This requires to develop a reasonable lift testing period. If we can predict the time of drill pipe to generate fatigue crack, we can determine the reasonable flaw detection period, and finally reduce and prevent drill pipe puncture and fracture accident effectively.

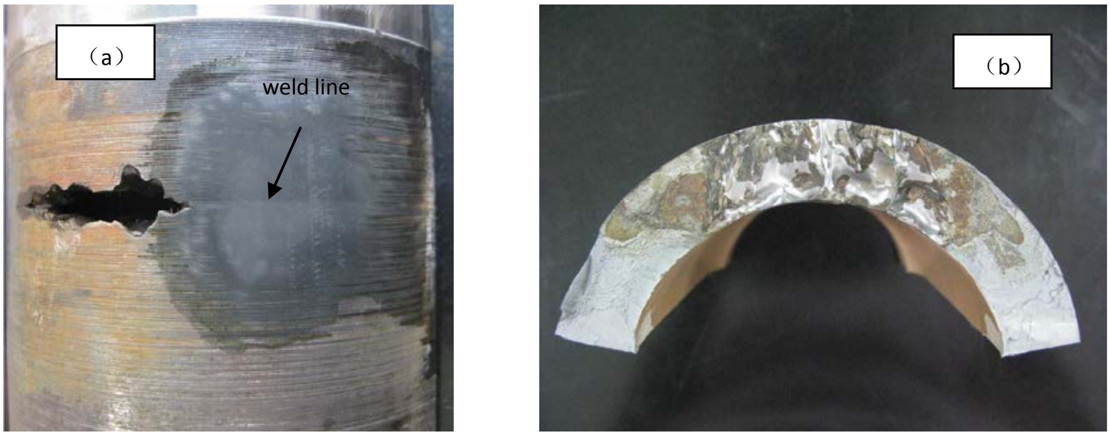
3.2.2 Puncture on drill pipe weld area

(1) Drill pipe weld puncture mechanism

The thickness of drill pipe weld zone is about 2 times than the pipe wall thickness, weld leakage is mainly caused for welding of gray leaf spot (Yu Shijie, 2011). Drill pipe friction welding does not produce large areas of gray leaf spot generally, but because the surface quality control is lax before welding and weldment shortening is insufficient which may cause welding gray spots flaw.

(2) Expression form

Drill pipe washout puncture occurred in friction welding, open the thorn hole will found the cross section around the hole is flat and thorn.



(a) Weld line of puncture area (b) Fracture appearance of puncture

Figure 3-6 Puncture morphology of weld line

3.2.3 Drill pipe joint thread puncture

Joint thorn leakage often occurs in the thread and sealing surface, the rate of joint thorn leakage occurred in the drill pipe joint is bigger than occurred in the drill collar thread (Gong Danmei, 2014). The joint thread leakage may be due to: (1) joint torque is insufficient which resulting in seal shoulder surface contact pressure drop, and the sealing performance failure; (2) joint thread is for the stress concentration region. Under the effect of alternating load condition, it will prone to fatigue crack, when the crack penetrate the wall thickness, joint thorn leakage; (3) when the original flaw or the original crack exist in the thread parts, it also can lead to joint puncture early.

3.3 Drill stem wear failure

The wear failure of drill stem is mainly includes: joint thread sticking and pipe body friction and wear.

3.3.1 Thread sticking and wear of joint

(1) Reason of sticking

Drill stem joint sticking and wear is due to the internal and external thread with metal friction interference which make the surface temperature rise sharply, so that the internal and external thread surface bonding (Lv Shuanlu, 2011). Because, internal and external thread surface circumferential displace even often accompanied by gluing metal migration in the process of make-up and break out. Sticking is usually adhesive wear, but if there are gravel, iron and other hard particles sandwiched between inner and outer thread, it also can form sticking wear.

(2) Influence factors and performance of sticking

① Quality of design and processing

1) Thread surface roughness. Inner and outer thread easy sticking when the rotate if the machining thread with rough surface. The surface roughness of the screw thread is related to the precision and performance of the lathe.

2) Taper mismatch. In the case of big taper of inner thread but small taper of external thread, with the internal and external thread joint, the small end will get big contact force which makes it easy to stick. In the case of small taper of inner thread but big taper of external thread, with the internal and external thread joint, the bid end will get big contact force which makes it easy to stick.

3) Thread pitch mismatch. When the inner joint thread pitch is greater than the external thread joint pitch, the contact pressure on the guide surface of joint big thread and bearing surface of joint small thread is high which can prone to stick. when the inner joint thread pitch is less than external thread joint pitch, the contact pressure on the guide surface of joint big thread and bearing surface of joint small thread is high which can prone to stick.

4) Tight pitch of thread. In the case of the other single parameter with small deviation, the thread tight pitch is mainly reflects the diameter of the thread. If the external and internal thread tight pitch is both too large, the thread will exposed if make up with normal torque; but if increase torque of making up to no exposed thread, it will easy to gluing.

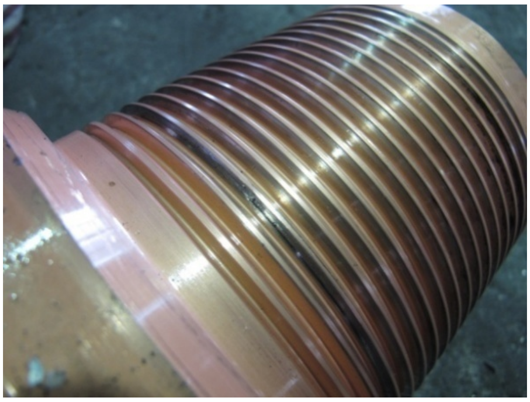


Figure 3-7 Thread gluing morphology due to poor accuracy control

② Influence of thread surface treatment quality

Influence of surface treatment quality. The surface treatment of drill stem joint thread are copper plating and phosphating. Surface treatment failure can easily lead to thread gluing, such as : a, surface treatment is not thick enough which can easy to wear off in use; b, the strength and toughness of surface treatment layer is insufficient which can easy to broken off in use; c, the surface treatment layer is not dense, with holes, defects such as trachoma which can easy to rust in placing and use; d, surface treatment layer off, the base metal will direct contact in the process of making up and break out which can easy lead to thread gluing.

③ Effect of thread grease

The main role of thread grease is to lubricate the surface of thread, reduce friction, prevent sticking and rust and so on. If the quality of thread grease is poor, mixed with debris (sand, bits of iron, etc.) , it will easy to make the oil casing thread joints rust, even gluing.

④ Improper fastening

In the process of connect drill string, too quickly making up speed can make the joint subjected to impact loads which can damage thread. If make-up thread with deflection which the drill string center shaft line and the into hole drill pipe axis ling are not properly aligned, large deviation will exist which produced a larger tilt angle when the thread in the screwing process. Therefore, easy to gluing.

Feature of thread gluing: It is very easy to cause serious thread gluing which the entire thread teeth have been worn out, and if the thread gluing is serious, the appearance of the "secondary hardening martensite" can be formed.

Figure 3-8 Thread gluing due to improper fastening

⑤ The fast make up speed lead to deviation of drill pipe joint

If make up speed fast, especially in the guide button process, the external thread haven't reached normal engagement, tooth of male and female thread will interfere with each other, this will result in extrusion wear in the thread surface, and caused plastic deformation, eventually led to wrong button and a stick (Yu Shijie, 2011). In addition, the high making up speed will cause the thread surface heat not easy to distribute, the friction surface temperature will rise sharply so that the friction surface of the metal to soften and flow, this will also easy lead to thread gluing.

⑥ Thread gluing caused by over torque

Over torque of making up is easy to cause thread gluing. To ensure that the internal and external threads to achieve the best fit, the making up torque of joint must be moderate. If the torque is too large, it will resulting in plastic deformation in the surface of the internal and external thread , and finally cause thread gluing.

3.4 Excessive deformation

The failure of excessive deformation of drill stem is mainly shown as the extension of drill pipe female joint and the part extension of drill pipe outer thread joint. The main common is the internal thread joint expansion. Within the expansion morphology of internal thread joint is for trumpet shaped, seal regional with serious deformation organizations. The process of deformation and swell of drill pipe joint generate a large amount of friction heat which makes the phase transition occurs in the surface microstructure, and finally the formation of white bright layer "secondary hardening martensite" can been see as below.

Figure 3-9 Thread joint expansion of female joint

The main reason for the joint expansion is (Lv Shuanlu, 2008):

(1) Bottom hole torque is too large. On the one hand, a large hole drilling make the drill string under large torque. Failure analysis data shows that, the drill string bear large torque if drilling in large hole. On the other hand, bouncing or sticking will increase torque for drill string. It will make the rotary torque increases instantaneous when bit bouncing or sticking, and the drill string will bear double of torsion load.

(2) The torque for drill pipe is insufficient. The insufficient of drill pipe connection torque make the shoulder sealing surface of drill pipe joint does not have enough contact surface pressure. In the drilling process, the drill pipe joint will self make up which caused by variety of over torsion and out of control of downhole factors. So that the contact surface pressure of shoulder sealing of tool joint increase and exceed the material yield strength, ultimate failure by plastic deformation and swelling damage.

(3) The size of external thread joint does not meet the standard requirements. For example, the chamfer diameter of outer thread joint shoulder surface is smaller than internal thread joint shoulder surface, even a larger extent beyond the tolerance range of the standard requirements. This will make the chamfer diameter of internal thread sealing shoulders small which will make the bearing stress shift to the inner wall.

3.5 Corrosion failure

The corrosion failure is most for the drill pipe internal coating destruction which environmental media and various factors that caused drill pipe inner wall corrode. The corrosion failure types are mainly as CO_2 corrosion, oxygen corrode, salt mud drilling corrosion, etc.

Section 4 Inspection and classification of drill stem

4.1 Inspection standards of drill stem

The international old drill stem inspection common standards is mainly used for: the "API RP 7G. Recommended practice for drill stem design and operating limits" the third chapter drill stem of "DS-1 (API, 1998). Standard DS-1 chapter 3 drill stem inspection", the "NS-2 (T H Hill, 2012). Drill string inspection standard NS-2" (Procter Group Fearnley, 2005). In China the old drill stem inspection is mainly according to the oil industry standard "SY/T5824-93 Drill grading and inspection method" and "GB/T 24956-24956 Oil and gas industry drilling string design and operational limits".

In fact, "GB/T 24956-2010 standard" is equivalent to translate the API RP 7 G, 16 edition, 1998, and the grading requirement in the SY/T5824-93 standard requirements is basically the same with the API standards. For the inspection of drill pipe, API 7 G inspection standard is basically the same as the test requirements of class 3 of "Standard DS-1"; the category 5 of "Standard DS-1" inspection is basically equivalent to "Drill string inspection standard NS-2". The following will introduce and compare the inspection grading requirements of the standard.

4.1.1 API inspection standards

API standard is mainly on the basis of residual wall thickness of pipe and corrosion pit depth which divided used drill pipe into 3 class: class Ⅰ, class Ⅱ and class Ⅲ. The sub class is based on minimum diameter of drill pipe joint, minimum shoulder thick of eccentric wear female joint which divided sub into Ⅰ and Ⅱ. The detail of classification data are as follow standard.

The minimum wall thickness of class Ⅰ drill pipe is about 80% of the nominal wall thickness, and the minimum wall thickness of class Ⅱ drill pipe is about 70% of the nominal wall thickness. The rules of classification are in the following table.

Table 4-1 Classification of used drill pipe (API RP 7G)

Pipe condition	Class Ⅰ (Premium class) Two White Bands	Class Ⅱ Yellow Bands	Class Ⅲ Orange Bands
1.Exterior condition			
A. OD wall wear			
Wall thickness	Remaining wall not less than 80%	Remaining wall not less than 70%	
B. Dents and mashes	Not over 3% of OD reduction	Not over 4% of OD reduction	
Crushing, necking	Not over 3% of OD reduction	Not over 4% of OD reduction	
C. Mechanical damage of slip area Bite mark, scratch	Bite mark not over the 10% of average wall thickness	Bite mark not over the 20% of average wall thickness	
D. Stress induced diameter variations			Over the dents and mashes of Class Ⅱ drill pipe
（1） Stretched	Not over 3% of OD reduction	Not over 4% of OD reduction	
（2） Shortened	Not over 3% of OD reduction	Not over 4% of OD reduction	
E. Corrosion, incision, bruise			
（1） Corrosion	Remaining wall not less than 80%	Remaining wall not less than 70%	
（2） Cuts and bruise			
Longitudinal	Remaining wall not less than 80%	Remaining wall not less than70%	
transverse	Remaining wall not less than 80%	Remaining wall not less than 70%	
F. Fatigue craxks	None	None	None
2.Interior conditions			
A. Corrosive pitting Wall thickness	Remaining wall not less than 80% measured from base of deepest pit	Remaining wall not less than 70% measured from base of deepest pit	
B. Erosion and wear Wall thickness	Remaining wall not less than 80%	Remaining wall not less than 70%	
C. Fatigue cracks	None	None	None

No matter which class of drill pipe, once found that fatigue crack or leak, it should not use. For drill pipe joint, we generally according to the standard table 4-1 to determine the minimum diameter of drill pipe joint to divided class Ⅰ and class Ⅱ.

4.1.2 Inspection requirement of DS-1 standards

(1) Inspection methods of drill pipe

The latest standard of DS-1 category (4th edition, 2012) stipulated 33 kinds of drill pipe inspection methods. These methods including 32 kinds which must be conducted by the inspection company and one kind may be done by the drilling crew or inspection company. There are total of 16 kinds of 33 kinds of testing method is suitable for drill pipe inspection.

(2) Inspection category

DS-1 standard make 6 kinds of service category according to the drilling risk and failure costs which the different service category corresponds to the different inspection requirements. The 6 categories are as below:

Category 1: suitable for shallow well and conventional well of developed area. When the drill string failure occurs the failure loss is very small, so that a large number of inspection fee is not economical.

Category 2: for conventional drilling conditions, the failure rate is low, the existing practice is a small amount of inspection.

Category 3: designed for moderate drilling conditions, the inspection standard outline the most reasonable. If failure occur, the fishing cost or loss well risk is lower. Category 3 is the minimum design requirements of category 2.

Category 4: this type can be used for more demanding drilling conditions than category 3. When drill string failure, it may have higher fishing costs or losses.

Category 5: this type is suitable for very demanding drilling conditions. Many factors lead to very high cost of possible failure, category 5 is the minimum design requirements of category 3.

Category HDLS：Due to the tensile load increase especially in deep water, adds category 6 in the third edition of service category. This type is design for HDLS (Heavy Duty Landing strings).

(3) Inspection frequency

According to the different use categories, DS - 1 standard make recommendations inspection frequency of drill pipe as table 4-2.

Table 4-2 Inspection frequency of different category

Component	Service category			
	1	2-3	4-5	HDLS
Drill pipe	Put out of hole	Put out of hole	Before trip in	（Note 2）

Note 2：If used before any other operations, such as drilling or jar, or the tensile load more than 90% of tensile strength, inspection should be done before every time operation, otherwise, inspect while operation 3 times.

(4) Inspection equipment

DS-1 standard has detailed regulations and requirements for inspection equipment, these regulations and requirements are not contained in API RP 7G.

(5) Drill pipe classification

Regulate classification of drill pipe is a shortcuts which most users used to formulate drill pipe and its sub receiving criterion. DS - 1 standard stipulated 4 classification of drill pipe.

① Class Ⅰ: This class code applies to new drill pipe and tool joint. It is equivalent to new drill pipe.

② Premium class：Drill pipe body and tool joint meet the requirements of table 3.5.1. Tool joint torsional strength is about 80% of new drill pipe body which with "standard" specification of tool joint.

③ The premium class of drill pipe which reduced torsional strength ratio: torsional strength ratio (TSR) refers to the tool joint and the ratio of the torsional strength of drill pipe body. The torsional strength ratio of new pipe and premium class drill pipe is about 80%. The torsional strength ratio of premium tool joint of drill pipe which still reduced the torsional strength ratio is about 60% while in keeping all the other properties of the DS-1 standards. In addition to the torsional strength, the bearing capacity for this pipe and premium class drill pipe is the same. The class of this drill pipe has not been recognized by API.

④ Class Ⅱ： Drill pipe body and tool joint meet the requirements of table 4-3. The tensile strength and torsion strength is about 70% of new drill pipe body which with "standard" specification of tool joint.

Table 4-3　Classification of used drill pipe and tool joint (DS-1)

Class Component	Condition	premium class	class Ⅱ
Pipe body	Remaining wall	≥80%	≥70%
	Slip bite mark and groove	≤3% of average border upon	≤20% of average border upon
	Outer diameter reduction	≤3%×stipulate OD	≤4%×stipulate OD
	Outer diameter increase	≤3%×stipulate OD	≤4%×stipulate OD
	Cracks	None	None
Tool joint	Torsional strength	≥80% of premium class pipe body	≥80% of class Ⅱ pipe body
	External thread elongation	≤0.006”（within in the scope of 2"）	≤0.006"（within in the scope of 2"）
	Other size	As the standard requirement of table 3.7.1-3.7.17	As the standard requirement of 3.7.1-3.7.17

(6) Recommended inspection outline

DS-1 category standards goal is to build the inspection standard procedure of old drill stem components. These inspection procedure aimed to ensure that every component has the appropriate bearing capacity, and to replace fatigue crack (or high risk) component.

In accordance with the standards of DS-1 category inspection, the inspection procedure should be consists of 4 parts: equipment table, use method, effective receiving criterion and inspection frequency. For ordinary drill pipe (that is, the ordinary drill pipe), its effective receiving criterion is usually stipulate service class to divide inspection class. DS-1 standard specified 6 classes in the different degree of risk for drilling service. The inspection procedure as show in table 4-4.

Table 4-4 Recommended inspection outline of drill pipe

Class / Component	Service classification					
	1	**2**	**3**	**4**	**5**	**6**
Tool joint	Tool joint visual	Tool joint visual Size 1	Tool joint visual Size 1	Tool joint visual Size 2	Tool joint visual Size 1 Black light	Tool joint visual Size 2 Black light Retroactivity
Drill pipe body	Pipe body visual	Pipe body visual OD calipers Wall thickness UT	Pipe body visual OD calipers Wall thickness UT EMI1	Pipe body visual OD calipers Wall thickness UT EMI1 Slips/Thicken MPI	Pipe body visual OD calipers EMI2 Slips/Thicken MPI Slips/Thicken UT	Pipe body visual OD calipers FLUT2 Slips/Thicken MPI Slips/Thicken UT Retroactivity
Receiving criterion	class Ⅱ	class Ⅱ	Premium class	Premium class	Premium class	Item standard

(7) Consideration factor while set out inspection frequency

When set out inspection plan for old drill pipe, the cumulative fatigue damage of drill pipe body shall be determined. But the difficulty is the fatigue damage may be in accumulation in different rate in different parts of drill stem. In addition, the change of bearing capacity which caused by tool joint and pipe body should be considered.

The standard recommended the method of the estimation cumulative fatigue damage. In order to simplify the problem, drill stem designer divided the drill stem into several parts, then apply the follow formula to estimate the cumulative fatigue damage of each part. By accumulating the "damage" of drill stem sections to estimate, the location of the components in the rearrangement of drill string can be used to try balance the damage, and according to the total cumulative damage to set out inspection plan.

$$\mathrm{DP} = \frac{60 \times \mathrm{CI} \times \mathrm{RPM} \times \mathrm{Footage}}{\mathrm{ROP} \times 10^6}$$

In the formula：

DP—the fatigue "damage" of accumulated;

CI—the average bent index;

RPM—the average rotary speed of drill stem (Revolution/minute)；

Footage—the consideration drilling footage (ft);

ROP—the average drilling speed of consideration (ft/h).

When totally cumulative damage point of certain section of drill stem reached certain degree, the fatigue crack inspection should be execute. According to the results of several failure analysis, the standard recommend that the inspection should be execute while the initial estimate total cumulative reached to 500.

Table 4-5 Cumulative damage point of different design scenario

Drilling condition (Design scenario)	Inspection trigger point (Cumulative damage point)
3	500
2	600
1	700

This artificial estimate is very rough, but is more useful for insure inspection frequency than any experience methods. This method takes into account the relative punitive of drilling condition, it is an improved method than only consider simple footage or rotate time, and better than traditional experience method which according to estimation of rotation time or penetration.

4.1.3 NS-2 inspection standards

NS-2 standards focuses on the North sea drill stem which belong to the European oil drill stem standard, also known as the standards of the Shell or the North Sea. The inspection scope of NS-2 standards covers all of the inspection and repair of drill stem components for North Sea drilling. NS-2 standards include some content what no included API, DS-1 standards, such as high twist joint connection, special drilling equipment, automatic thread detection, received new drill pipe inspection, fishing and milling tool; detailed inspection frequency guidance, inside coating, etc.

The standards has strict requirements for inspection equipment, inspection personnel and inspection method. For some non API thread tool joint, it also has detailed inspection requirements. Therefore, NS-2 standard is the most strict inspection standards for offshore drill stem.

(1) Classification of used drill pipe and tool joints

To the North Sea drilling, in addition to new drill pipe, only the premium class drill pipe is acceptable. The classification as show in follow table：

Table 4-6 Classification demand

Drill pipe body	Demand
Minimum remaining wall	80%
Slip bite mark and nick (maximum depth)	10% of average critical wall thickness
Diameter reduction	3% of stipulate OD
Diameter reduction	3% of stipulate OD
Fatigue crack	None
Tool joints	Demand
Torsional strength	80% of premium class pipe body
Male end elongation	Elongate 0.006 inch/every 2 inch
Other size	Note
Fatigue crack	None

Note：Other sizes include API tool joints diameter, shoulder width, WT joints, the relevant requirements size of DS tool joints.

(2) Basic requirements of drill pipe inspection procedure

For API drill pipe, the inspection method is as follow:

Table 4-7 Inspection method for different part of drill pipe

Tool joints and thread	1. Fluorescent magnetic particle flaw detection; 2. Macroscopic observation; 3. Dimension inspection; 4. ATI（ACFM）electromagnetic testing.
Slip area and upset area	1. Fluorescent magnetic particle flaw detection; 2. Macroscopic observation; 3. Dimension inspection; 4. Ultrasonic pipe body inspection; 5. MIU length and profile inspection.
Pipe body, slip area and upset area	1. OD inspection; 2.Ultrasonic inspect wall thickness; 3. Macroscopic observation; 4. Pipe body electromagnetic.

(3) Inspection frequency guidance of the North Sea drill stem

In order to minimize the possibility of drill stem failure, periodically inspection or replace in accordance with inspection stage should be comply. See figure 4-1.

Standard thinks that in the past drill stem inspection which based on drill stem rotating time or drilling footage to determine whether need to inspect is arbitrary. According to the experience of a region or the used time of a component is like guess. Whether or not to inspect drill stem should be depends on the harsh degree of drilling environment rather than used time.

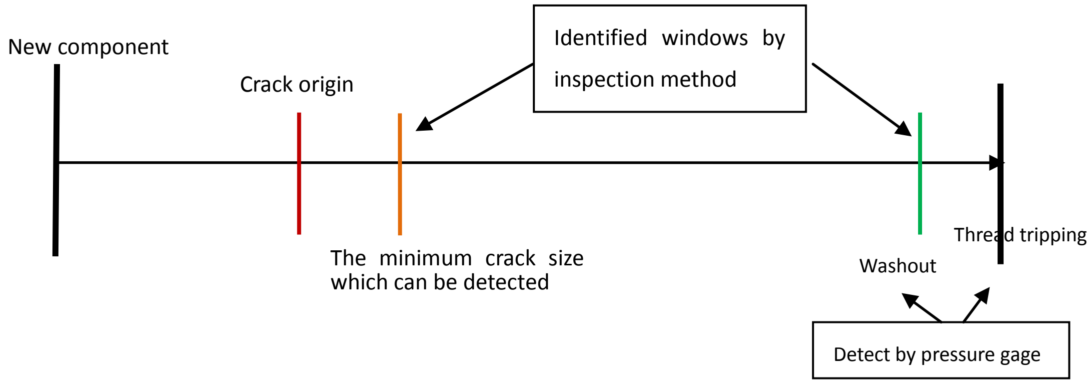


Figure 4-1 Identified windows by inspection

The inspection outline of the standards using WS-INSPECT computer program, this program is developed from the specific failure analysis date of Shell Expro (Shell) exploration wells. WS-INSPET assumes that each component of drill stem existed micro cracks, the micro cracks is very small and was not detected in the latest inspection. After drill stem service, the program follow up drill stem position and estimate the propagation rate of the crack. When the program calculated the component is close to the final failure curve, it will alert users to arrange inspection. For some strict Wells (larger slope angle), when harsh service environment beyond the scope of the following outline requirements, WS-INSPET can provide accurate crack propagation analysis and generate detailed drill stem inspection procedure. The inspection frequency requirement which the standards outline is as follows:

1) Vertical well

- According to contract to inspect before drilling the first well;
- Inspect after the accumulative drilling footage reach to 10668 m, (Every half year to inspect if there is no record footage);
- For single well, inspect after accumulative drilling footage more than 6096 m.

2) Directional well

- According to contract to inspect before drilling the first well
- Inspect after the accumulative drilling footage reach to 9144 m, (Every half year to inspect if there is no record footage);
- For single well, if the total well depth exceed to 4114.8 m, inspect the drill pipe which well depth exceed 4114.8 m or rotate at the build zone. That is, if the depth of directional well is more than 4114.8 m, the inspection should be done for the drill pipe which at the build zone (A) and the adjacent area (B) of the length is 4114.8 m to the total depth.

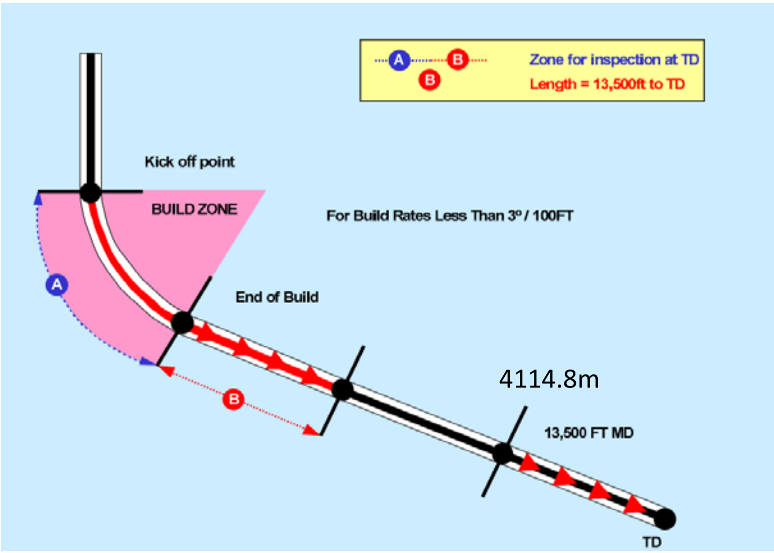


Figure 4-2 Drill stem inspection requirement for direction well

But, If the drilling plan or operation practice exceed any of the following circumstances, the WS - INSPECT should be used to generate the follow inspection frequency program in detail.

Table 4-8 Special requirement while exceed circumstance

Drilling rate	Average less than 3 m/h below 4114.8 m of well depth
Wellhead rotate speed	Average exceed 150 rpm below 4114.8m of measured depth
Rate of build	Average exceed 3°/30 m at upper build zone
Total vertical depth (TVD)	Exceed 3200m

3）Horizontal well

- According to contract to inspect before drilling the first well
- Inspect after the accumulative drilling footage reach to 9144 m, (Every half year to inspect if there is no record footage);

- For single well, if the total well depth exceed to 4114.8 m, inspect the drill pipe which well depth exceed 4114.8 m or rotate at the lower build zone. That is, if the depth of horizontal well is more than 4114.8 m, the inspection should be done for the drill pipe which at the lower build zone (A) and the adjacent area (B) of the length is 4114.8 m to the total depth.

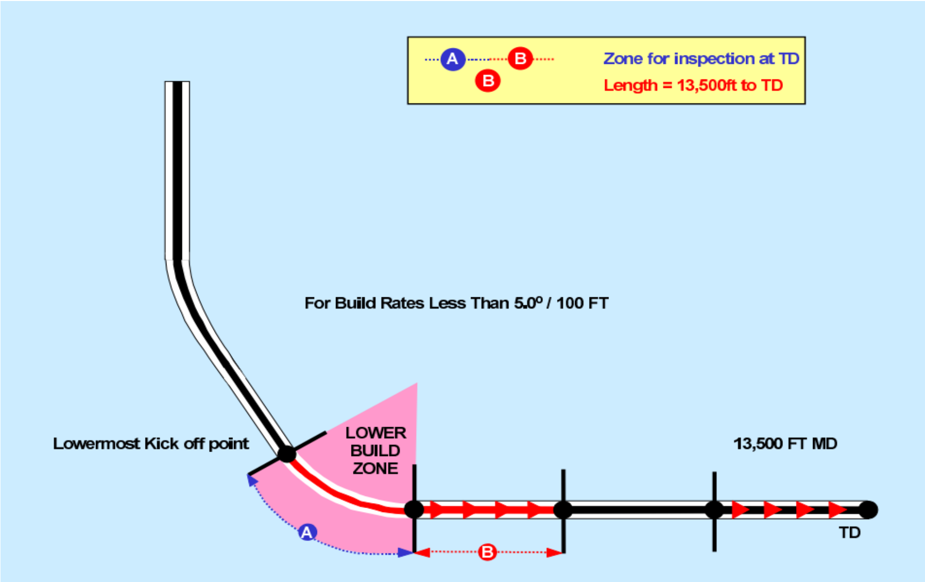


Figure 4-3 Drill stem inspection requirement for horizontal well

But, If the drilling plan or operation practice exceed any of the following circumstances, the WS - INSPECT should be used to generate the follow inspection frequency program in detail.

Table 4-9 Special conditions for horizontal well

Permeation rate	Average less than 6 m/h below 4114.8 m of well depth
Wellhead rotate speed	Average exceed 60 rpm below 4114.8m of measured depth
Rate of build	Average exceed 5°/30 m at upper build zone

It's worth noting that the guidance outline of the standards did not mention detailed requirements for upper build zone or kick off point of horizontal well, and did not set inspection frequency for remaining drill stem, also did not make up clear drill stem life-cycle management method.

4.1.4 Contrast of drill stem inspection requirements for the three standards

Based on the above explain, the main difference and relation of drill pipe inspection requirements of API 7G, DS-1 and NS-2 standards are as follows:

(1) The main difference

API RP 7G：(1) only as recommend; (2) drill stem design and operation limit; (3) the explain is more general and no specificity; (4) choose with limit.

DS-1 standards：(1) the accept and rejection standard of used drill pipe; (2) the drill stem inspection include many component; (3) the specific procedure and method； (4) flexible choose; (5) training and qualification; (6) calibration and compulsive requirement; (7) summarize of quality control and measure for equipment and procedure.

NS-2 drill stem inspection standards: (1) inspection personnel qualification; (2) requirement for inspection and repair equipment; (3) detailed inspection, testing and repair procedure; (4) defective evaluate; (5) detection and repair procedure; (6) accepted detection requirement for new drill stem; (7)service limitation; (8) other recommend, such as the drill stem inspection frequency outline。

(2) Comparison of drill pipe classification

From the table which contain drill pipe classification requirements of 3 standards we can see that the acceptable and criterion standard for premium class pipe is the same. But the acceptable standard of class Ⅱ is the same for API 7G and DS-1. The API 7G even retain the divide of class 3. Under the premium class circumstance of drill pipe body and tool joints, DS-1 standards added the premium class which reduce the torsional strength rate between the premium class and class Ⅱaccording to the decline degree of torsional strength rate, but this has not been accepted by API. NS-2 standards only class premium class pipe after inspect because the North Sea drilling only accept above quality of class Ⅱ drill pipe.

However, in quality control aspect, DS-1 standards and NS-2 standards both have clear and strict requirements for equipment, using and inspection procedures.

Table 4-10 Comparison of drill pipe classification

Classification (API RP 7G)	Class Ⅰ (New drill pipe)	Premium class	-	Class Ⅱ	Class Ⅲ
Classification (DS-1 standards)	Class Ⅰ (New drill pipe)	Premium class	Premium class which reduce the torsional strength rate	Class Ⅱ	-
NS-2 standards	-	Premium class	-	-	-

(3) Comparison inspection procedure

DS-1 standards divide 6 classes according to rigor drilling environment, each class has different inspection requirements. Under class 3 and below, the premium class and class Ⅱ drill pipe are essentially the same as API standards. But considering the harsher drilling problems in application, DS-1 standards increase the class 4, and class 5 inspection. For landing string applications, especially in deep water condition, DS-1 standards added HDLS class due to the tensile load increased.

4.2 Drill stem using and inspection for Chinese oil companies

According to research, the specific classification and inspection standards of Chinese domestic oil company such as Petro China Tarim Oilfield Company, Sinopec Northwest Branch Company, Petro China Great Wall drilling Company, Western Drilling Company, Sinopec Jianghan Drilling Oilfield and other drilling services company are in according with API RP7G and the "SY/T5824-93 Drill Classification Test Method". Each company set out inspection cycle for themselves which the cycle is roughly the same and generally inspect after the new drill pipe using for half year. The following will explain the using and inspection requirements of Chinese domestic oil companies such as Petro China Tarim Oilfield Company and Sinopec Northwest Branch Company.

4.2.1 Using and field inspection requirements of drill stem

4.2.1.1 Petro China Tarim Oilfield

(1) Field flaw detection of drill stem:

Drill stem field flaw detection items are shown in the following table:

Table 4-11 Field flaw detection item

Drill stem name	Drill pipe	Heavy weight drill pipe	Kelly	Stabilizer, crossover sub	Downhole tool
Flaw detection item	Welding line	Welding line, thread	Welding line, thread	Thread	Thread

Under normal operating conditions, perform field flaw detection in accordance with the following period:

① Drill pipe field flaw detection period:

A: The rotation time of the new drill rod is 250±100 hours;

B: The rotation time of the Class Ⅰ drill pipe is 600±100 hours;

C: The rotation time of the Class Ⅱ drill pipe is 500±100 hours.

② Drill collar, crossover sub and stabilizer field flaw detection period:

A: 8-1/2" and above the well hole rotation time is 475±25 hours;

B: 6" and the below well hole rotation time is 275±25 hours.

③ Heavy weight drill pipe field flaw detection period:

A: 8-1/2" and above the well hole rotation time is 475±25 hours;

B: 6" and the below well hole rotation time is 275±25 hours.

④ Kelly field flaw detection period:

Rotation time is 1000±100 hours.

After special operations (such as accident treatment, underground complex problem, etc.), the user can apply early detection for engineering and technical department.

(2) Plant inspection

After drill stem out of service more than 3 days, the engineering and technical department should be informed to recover the drill stem. The follow drill stem detection in the factory should be done:

① To further clean inner and outer surface of drill pipe and screw thread in time.

② In accordance with the requirements of SY/T5824-93, the "Drill pipe Classification Inspection Method", SY/T5369-94 the "Management and Using of Petroleum Drill Stem, Kelly, Drill Pipe, Drill Collar", and Q/CNPC-TZ 52 -2004 the "Drill Stem Maintenance and Screw Thread Repair Specification" to execute the inspection. After inspection, the drill pipe should be marking in accordance with drill pipe class mark.

③ The inspection results should be accurate and record, so that to provide single drill pipe inspection report to user.

After test finished, the drilling tool which need to repair should be done:

(1) Specific carry out the standard of Q/CNPC-TZ 52-2004 the "Drill Stem Maintenance and Screw Thread Repair Specification".

(2) The drill stem which has been repaired should mark code to ensure the traceability.

(3) Strictly carry out 3 classification inspection for repaired drill stem to ensure the repair quality reach to 100%.

4.2.1.2 Sinopec Northwest Branch Company

The recovery drill stem should be inspect according to the Sinopec Northwest Branch Company standard to carry out, below the Class Ⅱ drill pipe prohibit to use.

Under normal operating conditions, the drill stem inspection cycle is required to execute the normal standard. If the drill stem used for special operations such as drilling tool failure processing, downhole complex problem like percussion drilling, serious limp drilling, sticking, corrosion of hydrogen sulfide and carbon dioxide etc., the special detection should be established before the normal flaw detection.

According to the requirements of drill stem classification, nondestructive detection item and inspection period, the drill pipe should be sent to tube plant workshop for classification, detection if the using time reaching inspection period; other drill stem should be send to tube plant workshop or in the field for classification and detection.

(1) Field flaw detection requirements

- Detection requirements:

The field detection of drill stem include appearance inspection, dimensional measurement and nondestructive flaw detection (including ultrasonic testing, magnetic particle detection and liquid penetration testing), etc.. The detection process should pay more attention to the crack defect of drill stem threaded connection location, drill pipe upset transition disappear zone and drill collar operating groove area.

- Detection frequency:

The drill stem field nondestructive flaw detection period shall be determined according to drill stem working time, classification, used time, geological condition, drilling technology, drilling parameters and the area drill stem failure analysis condition. For BHA (bottom hole assembly), each trip should execute crack detection. In the process of gas drilling, the field detection period is about 20%~40% of common drilling.

If the drill stem used for special operations such as drilling tool failure processing, downhole complex problem like percussion drilling, serious limp drilling, sticking, corrosion of hydrogen sulfide and carbon dioxide etc., the suitable detection method should be choose for drill stem flaw detection.

After the failure of drill stem has be treated, the inspection of drill stem which near the fault position should be done.

(2) Inspect after drilling tool recovery

After the drilling is finished, the drill stem should be recovered inspection or field inspection in timely, the inner and outer surface thread and pipe body shall be cleaned. The inner and outer surface and the thread part of the recovery drill stem should be cleaned and checked in time. The inspection contents include: quantity, specification, steel grade, pipe body coating, joint type, thread, wear-resistant belt and other information.

The recovery drill stem should be determine class based on the detection data, classify place according to drill pipe classification, and classified record.

If the inspection is disqualified and does not meet the drill stem scrap standards, it should be repaired and recorded according to the requirements.

4.3 Inspection and classification of drill stem for international oil company

According to the research for drill stem inspection company, the results show that generally for deepwater drilling the NS-2 or DS-1 of the fifth class inspection should be conduct, and for shallow water drilling the DS-1 fourth class inspection should be conduct.

4.3.2 Shell (China) Exploration and Production Co., Ltd.

Shell Exploration Company in China unconventional gas projects is mainly for Sichuan Fushun shale gas project, Shaanxi Changbei tight gas project, Sichuan Jinqiu and Zitong tight gas project. In these projects, Yulin Changbei tight gas project require inspection in accordance with the NS-2 standards which can be equivalent to the class 5 of DS-1 standards. But in the shale gas projects of Sichuan, Shall also in accordance with the requirements of the class 5 of DS-1 standards when lease Shenzhen Far East drill pipe for operation.

4.3.2 Drill stem inspection requirements for deep water drilling

The research of Texaco drilling company and oil and gas leasing service corporation as early as 1999 in offshore drilling with 5.5" drill pipe operation show that it is respectively using the DS-1 4 and 5 class for drill stem inspection.

The Ocean star rig of Texaco drilling operations in Mexico Green Valley. The water depth is about 1219m, and the depth of the well is about 8387m. The drilling duration of this project was about 18 months, after successful drilled 2 wells, the drill pipe was divided into two stages to inspect.

(1) Initial detection procedure

The half of the drill pipe had been transported to plant to carry out the strict inspection. Set out a detailed inspection procedure before inspect, and in accordance with the 5 class of DS-1 standards to inspect which including:

① Macroscopic, outside diameter measurement ; ultrasonic thickness measurement, electromagnetism detector pipe body.

② Macroscopic and size measurement for external thread.

③ Ultrasonic detection in thickened area.

④ Magnetic particle inspection and size measurement for external threads.

⑤ Magnetic particle inspection for thickened area and thread.

Test results: rejected or scraped for 70 internal thread joints, 70 external threaded joints and 7 whole length of joints.

(2) Final detection procedure

According to the initial detection results, using class 1 of oil leasing services company's standard to inspect the rest of the drill pipe, the results are as shown in below.

① Macroscopic ; outside diameter measurement ; ultrasonic thickness measurement, electromagnetism detector pipe body.
② Macroscopic and size measurement for external thread.
③ Ultrasonic detection in thickened area.
④ Magnetic particle inspection and size measurement for external threads.
⑤ Magnetic particle inspection for thickened area and thread.

After completed the inspection of remaining half drill pipe, the rejection of the joint for 8 internal threaded joints, 17 external threaded joints and 1 full length of the joint. It can be seen that deepwater drilling at least use the 4 and 5 class of DS-1standars to inspect drill stem.

The Chinese domestic oil companies have not yet been strictly implement the inspection in accordance with the NS-2 standards. But in case of key exploration projects, they will inspect old drill pipe based on NS-2 standards, such as Shell in the South China Sea project and Sichuan unconventional gas projects. Most European companies, such as the Norway National Petroleum Corporation, British National Oil Company are implement the NS-2 standards to inspect drill pipe. Due to the special risks and expensive costs of offshore drilling, the inspection of drill stem is in accordance with the NS-2 and fourth or fifth categories of DS-1 standards to implement. But in fact the inspection of slip clip area and thicken zone of category fifth of DS-1 standards is less than of NS-2 standards, for most internal upset transition area of drill stem failure, this is particularly important. Therefore, as can be seen from the above analysis, the advanced experience and commonly method of international oil company for drill stem inspection of offshore drilling is based on NS-2 standards, and only using new drill pipe and the high quality grade drill pipe.

Section 5 New inspection technology of drill stem

After long time using, it is necessary to carry out nondestructive testing for drill stem. The choice of nondestructive testing methods of drilling tools is usually selected according to the standard of inspection, the inspection methods and equipment requirements for different parts of the drill pipe, DS-1 standards and NS-2 standards are described in detail. The commonly NDT inspection methods include: ray detection, ultrasonic testing methods, eddy current testing, magnetic particle testing, penetration testing and other methods. These commonly used inspection methods has some common characteristics: ① the requirements of inspection space and environmental are not very strict; ② the body harm for test people is less, without using special protection measures; ③ the required devices are easy to carry which is conducive to carry out on-site inspection work; ④ using the rechargeable battery, without requiring using industrial power supply.

With the requirement of drill stem system management in oil field, several inspection methods have emerging in recent years, such as acoustic emission testing, magnetic memory testing, ultrasonic phased array testing and so on.

5.1 Common detection methods

The five conventional detection of nondestructive detection include: ultrasonic testing, radiographic testing, magnetic particle testing, eddy current testing. And the additional detection methods are ultrasonic testing, electromagnetic testing (magnetic particle testing, magnetic flux leakage testing) and penetration testing.

5.1.3 Ultrasonic testing

Ultrasonic flaw detection is a method that using ultrasound to penetrate the depths of the metal material, and using the interface occurs reflection characteristic at the edge of the interface while ultrasound from one cross section to enter another section.

The advantages of ultrasonic flaw detection include thickness detection, high sensitivity, fast, low cost, harmless to the human body, localization and quantification of defects characters. However, the technology for ultrasonic testing technology is difficult, it can be influenced by the subjective and objective factors, also the testing results is difficult to be preserved. This detection method is commonly used for drill pipe inside and outside body upset transitional belt, tube body and joint weld, pipe body thickness and drill collar thread damage detection.

5.1.3 Electromagnetic testing

The electromagnetic testing method is using the characteristics which generated at defect area or no defect area of the magnetic field generated by the current, or the current generated by the changed magnetic field to detect the internal state of drill stem (Lu Mingjong, 2004). The electromagnetic testing include magnetic particle testing method magnetic flux leakage testing method.

For Magnetic particle testing, it is commonly used for Chinese domestic, the detection result of this method is intuitive, the testing operation is simple, the testing cost is low and the detection efficiency for surface and near surface defect is high. But it is unable to know the depth of defect and it is only suitable for test the surface and near surface of ferromagnetic material, the degree of testing automation is low, it is easy affected by human factors.

For magnetic flux leakage testing, it is mainly for detection of drill pipe body, this method have the advantages of simple structure, convenience in signal processing, detection capability, high sensitivity, it is especially with positioning, objectivity and recording advantages which is not only suitable for detection of oil drill pipe, also suitable for the rough surface of tubes. Meanwhile, this detection method has higher requirements for magnetic flux leakage testing equipment, detecting probe and magnetization technology.

5.1.3 Penetration testing

Penetration testing is not limited by magnetic, shape, size, structure, chemical composition and defects of the workpiece, and a single operation can check the defects in each direction. Penetration testing operation is simple, and does not require complex equipments, the testing cost is low, the defect is easy display and has very high sensitivity. Due to the penetration detection has the unique advantage, it is throughout application in various fields of modern industry. The international research shows that the detection probability of penetration testing for surface and linear defect is higher than magnetic particle testing, and it is one of the most effective surface detection methods.

But penetration testing also has its own limitations as show in the following three aspects:

(1) It can only detect the open surface defects;.

(2) It does not apply to test for porous material made of the workpiece and rough surface materials.

(3) The penetration testing can only detect the distribution of surface defects, it is

difficult to determine the depth of defect and to make quantitative evaluation for defects. The detection result is affected by the operator. For drill stem damage detection, it is mainly applicable to detect the internal and external threads none magnetic drill collar.

5.2 New technology of drill stem inspection

At present, the new technology of drill stem nondestructive testing is mainly include magnetic memory testing, acoustic emission technology and ultrasonic phased array testing technology. For this research, due to the limitation of material collection and ability of myself, this paper will not research and discuss so much.

Section 6 Discussion and conclusion

With the increase of drilling depth and the drilling technology development of high angle wells and large displacement horizontal wells, the performance requirement for drill stem is more and more higher. Oil drill stems is the main tool for exploration and development of oil and gas, the failure accident of drill stem in oil and gas exploration will not only hindered the drilling speed and production, but also caused huge economic loss.

The failure type of drill stem is given priority to fatigue failure. It is found that for all types of drill stem failure, the fatigue failure is the main form which include drill pipe thicken transitional belt and slip clamp area of the pricking leakage e failure, joint thread fatigue thorn leakage and fracture failure. Also the drill pipe thicken transitional belt and slip clamp area of the thorn leakage failure is more prominent for offshore drilling, thorn leakage wells occurred in the well section with high dogleg.

The physical and chemical properties of drill pipe failure samples are comply with the requirement of API Spec 5 DP-2009 standard. The internal coating of drill pipe failure samples spraying uneven, and local thickness does not conform to the stipulations. The spraying quality of the drill pipe internal coating is unevenly, internal thicken transition region is not smooth, overall smooth of surface roughness is poor, all these are the reasons of drill pipe pricking leakage failure.

Drill stem service environment is poor, and the stress state is very complex which include torsion, bend, tension and compression load, and also impact by the environmental media, such as drilling fluid, H_2S, CO_2, temperature, pressure, etc.. The failure statistics and analysis results show that the main forms of drill stem failure include fracture failure, pricking leakage failure, corrosion failure, wear and deformation. And the fatigue and corrosion are the frequently-occurring failure.

Using the general failure analysis methods to analysis the drill stem failure, it can not only beneficial to find the failure reason, mechanism, but also can out forward the prevention measures for the failure forms and behavior characteristics of drill stem. The general failure analysis methods is difficult to find out he failure reason when analysis the individual failure problem, this need special analysis for special environment and special problems.

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