Fatigue detection and analysis of drilling tools based on metal magnetic memory method

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Abstract. With the vigorous development of offshore oil and gas resources in the world, underwater extended reach horizontal wells have been widely used. However, due to the complicated stress and serious corrosion of drill pipes in horizontal wells, drill pipes are vulnerable to damage. After a period of service at sea, some drill tools will be placed in coastal areas for a long time. The cumulative fatigue of drilling tools is not easy to master. In the past year or two, drilling tool failure has become more and more frequent. In order to evaluate the fatigue of drilling tools in different periods and master the quantitative fatigue of drilling tools, the metal magnetic memory method has its unique advantages in detecting the stress concentration and early damage of ferromagnetic materials. The self-developed metal magnetic memory detection device is used to detect the drilling tools in the drilling tool base. The results show that the gradient peak value and ladder are used to detect the drilling tools in the drilling tool base. The average degree can be used to classify the fatigue of drilling tools, and the metal magnetic memory method is more than sensitive to various defects of drilling tools, such as penetration, internal corrosion, external corrosion, wall thickness thinning, etc.

1. Introduction

The onshore Oil-gas exploitation technique has been very mature, while the exploitation of offshore oil and gas resources is still in its infancy. The exploitation of offshore oil and gas resources has a lot of important strategic significance [1-3]. Therefore, offshore oil and gas resources are the goal that the whole world is striving to exploit. Extended reach horizontal well has its unique advantages in oil and gas production, so it is widely used in the development of offshore oil and gas resources [4-5]. Nevertheless, the drill pipe of the horizontal well is subject to damage due to its complex stress status and serious corrosion on the sea [6-7]. Like the artery of the whole drilling system, the damaged drill pipe will produce serious consequences and cause certain unnecessary economic losses.

At present, the existing nondestructive testing technology includes magnetic flux leakage testing, ultrasonic testing and so on. However, it has some disadvantages, such as material limitation, inability to detect early defects, and need to magnetize the object to be tested. Compared with other nondestructive testing technologies, metal magnetic memory testing technology has the advantages of being more sensitive to stress concentration, early diagnosis of fatigue damage, and no pretreatment of samples. Its principle can be expressed as follows: in the presence of an external magnetic field or a geomagnetic field, ferromagnetic material components will reorientate the magnetostrictive domain structure in the stress concentration and deformation concentration region, and irreversible magnetic field distortion will occur. In this region, the permeability decreases and the surface leakage magnetic field is maximum. This kind of magnetic state can be maintained after the working load is eliminated and is related to the...
maximum stress. This phenomenon is called the magnetic memory effect of metal [8-9]. In this paper, the metal magnetic memory testing is used to detect and analyze the drilling tool fatigue, and the endoscope and ultrasonic measurement are used to verify. Among them, the purpose of using endoscope is to observe the internal defects of drill pipe and verify the detection effect; Ultrasonic measurement is to verify the effect of metal magnetic memory testing.

Therefore, in order to evaluate the drill tool fatigue in different periods in the drill tool base and grasp the quantified fatigue degree of the drill tool based on the preliminary research in the laboratory [10], the drill tool portable magnetic memory detection system was completed for the field application requirements through the self-developed drill string damage state intelligent diagnosis and early warning software system, the drill pipes placed in the Tanggu Drilling Tool Base in Tianjin were tested. The results are helpful to the fatigue of the drill pipes placed in the coastal area for a long time.

2. Field test
The methodology must be clearly stated and described in sufficient detail or with sufficient references.

2.1. Experimental Subject
The self-made drill pipe magnetic memory testing tool is required for this inspection. There are 70 5 1/2" drill pipes, 70 5" drill pipes, 62 3.5" drill pipes and 20 drill pipes with typical defects, of which 185 are marked as Grade I drill pipes, 23 are Grade II drill pipes and 14 are discarded. The actual drill pipe to be inspected is shown in Table 1.

| Drill pipe specification | 3.5" | 5" | 5.5" | Subtotal |
|--------------------------|------|----|------|---------|
| Grade I                  | 62   | 70 | 53   | 185     |
| Grade II                 | 6    | 0  | 17   | 23      |
| Scrap                    | 0    | 9  | 5    | 14      |
| total                    | 68   | 79 | 75   | 222     |

2.2. Evaluation parameters of magnetic memory testing
Peak value is a principle evaluation parameter of magnetic memory testing for drill pipes, that is, the maximum amplitude of magnetic memory signal in the evaluation area.

\[ V_p = \max |H_p(x)| \] (1)

Where \( H_p(x) \) is the magnetic memory detection signal amplitude along the detection length direction.

2.3. Detection System
2.3.1 Equipment composition and working principle. The portable magnetic memory testing device developed by China University of Petroleum (Beijing) is used in this test, which consists of a testing controller, a crawling rapid scanning mechanism and a notebook computer. Among them, the controller mainly includes DC motor driver, governor and remote control switch. The tube crawling type fast scanning mechanism includes the magnetic memory detection ring which can be opened and closed, the position adjustment mechanism of the detection ring, the data collector, the wireless router, the crawling roller, the DC motor and the fixed support, etc., as shown in figure 1; The notebook computer realizes wireless data communication through wireless router and data collector, which is used for data acquisition process control, real-time detection signal waveform observation, detection data recording and field data analysis. Before testing, firstly, a magnetic memory testing ring of
corresponding specifications is assembled according to the specifications of the drill pipe to be inspected, and the detection efficiency and detection resolution is comprehensively considered to set the crawling speed of the scanning mechanism through the governor and set the data acquisition control parameters through the detection software.

During testing, the remote control is used to start the crawling of the scanning mechanism, and the data acquisition process is controlled at the same time. When the scanning mechanism completes the stroke of the drill pipe body at a constant speed on the drill pipe, the scanning mechanism is controlled to stop crawling through the remote control. In the meanwhile, the data collection is terminated and the current drill pipe detection data is saved.

In fact, the results of magnetic memory testing in the thickened zone are much more complex than the results of theoretical analysis. The typical distribution of the drill pipe gradient peak is shown in figure 3. This complexity mainly comes from three aspects:

1. Due to the influence of slip extrusion, the thickened zone of drill pipe is also the area of frequent contact with slip. The extrusion effect of slip on the outer surface of the thickened zone
during making up and breaking out and the magnetism brought by slip during frequent friction and extrusion can complicate the magnetic field distribution on the outer surface of the thickened belt;

(2) During the working process, the thickened area in the drill pipe is easy to be eroded and damaged by fluid erosion, resulting in structural changes and damage, which will also affect the magnetic field change of the thickening zone;

(3) The actual bearing condition of the drill pipe is more complicated than that of theoretical analysis.

Based on the above reasons, when the gradient value of the magnetic memory signal detected by the thickened band is high and there is no obvious damage on the outer surface, the inner surface of the thickened band should be explored with an endoscope.

Figure 3. Distribution of drill pipe gradient peak value.

In the process of analyzing the stress concentration distribution of the drill pipe body, the following three situations should be considered:

(1) When the drill pipe mainly works in the vertical section, the change of magnetic memory signal of pipe body is relatively stable and at a low peak level. Except for the mechanical damage caused by corrosion and other reasons, there is no obvious magnetic field distortion.

(2) When the drill pipe works in the horizontal section, the pipe body may contact with the good wall in the deflecting section or horizontal well section and lead to strong friction effect or deformation, which will cause local stress concentration, resulting in obvious magnetic field distortion. Even if there is no obvious defect, the magnetic memory signal will have a significant peak level.

(3) The influence of the grab hook of the pipe grabber when the drill pipe is transferred on site. In the process of pipe grabbing, some drill pipes will roll and slide along the grapple. Due to frequent contact and friction between the pipe grabber and the drill pipe, there will be a strong magnetic field on the surface of the grapple. Therefore, the magnetic field changes obviously at the position where the pipe body of some drill pipes contacts with the pipe grabber. When it happens, the mutation position of the magnetic memory signal at the two parts of the drill pipe contacting with the pipe grabbing machine is relatively fixed, and the distance between the two parts is consistent with that of the pipe grabber, as shown in figure 4. In order to effectively identify this kind of signal in data analysis, it is necessary to record and mark the contact position between the pipe grabber and the drill pipe, so as to eliminate the interference signals in these positions during data processing.


3. Parameter statistics of drill pipe detection

3.1. Statistics of gradient peak value in the transition zone of thickened drill pipe male

The peak values of the male gradient of drill pipe are counted, as shown in Figure 5. It can be clearly seen that the gradient range gradually increases with the increase of rating. There are some cases in the first-stage drill pipe where the instrument cannot pass due to excessive signal and deformation of the drill pipe. The gradient peaks of the remaining drill pipes are in a low range, and the gradient peaks of the second-stage drill pipe are higher than those of the first-stage drill pipe. In the scrapped drill pipe, one female head transition area is seriously bent and deformed, but the peak value of the male head transition area and pipe body is not high, and the gradient peak value of the rest scrapped drill pipes is much higher than that of the first and second stage drill pipes.

3.2. Statistics of the gradient peak value of middle pipe body of drill pipe

Statistics of the gradient peak value of the drill pipe body is shown in Figure 6. Nearly 99% of the gradient peak value of the first-stage drill pipe is below 4. With the improvement of the rating, more and more areas with a larger gradient peak range are distributed. Especially for scrapped drill pipes, except for the severe bending deformation in the transition zone of a female head. However, the peaks of the transition zone of the male head and the pipe body are not high, and the gradient peaks of other scrapped drill pipes are much higher than those of the first-stage and second-stage drill pipes.

3.3. Statistics of gradient peak value in the transition zone of thickened drill pipe head

Statistics of the gradient peak value of the drill pipe body is shown in Figure 7. The difference of the proportion of the gradient peak values indicated by the first-stage drill pipe is obvious, where the peak value less than 4 makes up 82% while the peak value between 4 and 7 constitutes 14.5%. The
instrument cannot pass through the transition area of an individual female head. As for the second-stage drill pipe, the value of the gradient peak less than 4 accounts for 65%, while the value between 4 and 8 takes the proportion of 20%. Meanwhile, the proportion for the discarded drill pipe whose peak values of the female head within a range of 4 and 8 approximately reaches 79%, and the gradient peak value of 14% discarded drill pipes exceeds 8, one of which has a serious deformation in the transition area of the female head.

(a) Statistics on the thickened transition zone of the first grade drill pipe male head
(b) Statistics on the thickened transition zone of the secondary drill pipe male head
(c) Statistics on the thickened transition zone of scrap drill pipe male head

Figure 5. Gradient peak grading statistics in the transition zone of the male head.
4. Defect Detection Evaluation

4.1. Puncture and leakage detection
The number of 5-inch scrapped drill pipe is completely rusted and invisible. The inspection results are shown in figure 8 and figure 9.
The number of 5-inch scrapped drill pipe is completely rusted and invisible. The inspection results are shown in figure 10 and figure 11 respectively.

4.2. Detection of internal corrosion defects
Drilling tool No. c130036, grade I 3.5 "drill pipe. The inspection drawing and endoscopic photos are shown in figure 12 and figure 13 respectively.
4.3. External corrosion pit and scratch detection
Drill tool No. 110231, grade I 5.5 "drill pipe. Figure 14 is the inspection diagram, and figure 15 is the defect photo.

**Figure 14.** Magnetic signal diagram of external corrosion pit.  
**Figure 15.** External corrosion pit.

Drill pipe No. z77131, grade I 5.5 "drill pipe. The inspection diagrams are shown in figure 16 and figure 17, and the defect diagrams are shown in figure 18 and figure 19.

**Figure 16.** Magnetic signal diagram of external corrosion pit.  
**Figure 17.** External corrosion pit.

**Figure 18.** Magnetic signal of external scratch.  
**Figure 19.** External scuffing.

Drill tool No. 31-227, grade II 5.5 "drill pipe, as shown in figure 20 and figure 21.
4.4. Verification of ultrasonic thickness measurement for wall thickness reduction
There are some drill pipes whose outer surface looks flawless, yet there are still abnormal magnetic signals in it, which cannot be observed by the endoscope. Ultrasonic instruments are used to detect the wall thickness. The drill tool number is e18368. The magnetic signal detection figure is shown in figure 22 and the ultrasonic wall thickness measurement is shown in figure 23.

4.5. External corrosion spot detection
Drilling tool No. c130006, Grade I 3.5 "drill pipe, external corrosion spots are shown in figure 26 and figure 27.
5. Conclusion
According to the statistics of the gradient peaks of 222 Grade I, II and scrapped drill pipes in Tianjin Binhai Tanggu drilling base, it can be found that with the increase of drill pipe rating, the gradient peak values of transition zone and pipe body of drill pipe male and female thickening zone gradually increase, and the drill pipe can be rated by the gradient peaks.

The typical defects identified on the external and internal parts of the scrapped drill pipe can be detected accurately, and the accuracy rate of defect location evaluation reaches 100%. The external corrosion pit, scratch and scratch of the drill pipe with no marked defects can also be effectively detected. In some places with abnormal magnetic signals, ultrasonic wall thickness measurement is used to verify the wall thickness thinning.

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