Study on acoustic transmission characteristics of BHA in directional well

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Abstract: Acoustic telemetry technology while drilling may effectively solve the practical and speed bottleneck of downhole information transmission, but its channel characteristics are subject to the influence of drill string structure in the channel. According to the requirements of reservoir exploitation and drilling technology, the directional well technology is becoming more complex, and the changeable bottom hole assembly (BHA) in the well causes the aperiodicity of acoustic channel. Through the modeling and analysis of BHA under different drilling technology, the characteristics of various aperiodic channels are obtained, and compared with the characteristics of ideal periodic channels, the acoustic transmission characteristics of drill string in directional well are obtained. The aperiodicity brought by BHA makes the high frequency section of the channel seriously attenuated, so the number of aperiodic drilling tools used in the acoustic remote transmission channel needs to be strictly controlled. It can be excluded from the channel if necessary.

1. Introduction
The telemetry while drilling technology is used to transmit downhole instruments and surface data, which is one of the key technologies of intelligent drilling. At present, the most widely used measurements while drilling (MWD) technology is based on mud medium, and data transmission based on electromagnetic wave is also used in oil fields, but both technologies have limitations, and the data transmission rate is difficult to meet the transmission requirements of a large number of data while drilling[1]. The high-speed remote transmission of data while drilling has become a bottleneck to limit the intellectualization of downhole drilling instruments.

In theory, the data transmission speed of acoustic wave in drill string is 1-2 orders of magnitude higher than that of mud pulse and electromagnetic wave. In 1948, sun oil company of the United States began to study the technology of acoustic wave transmission in drill string. In 1983, Drumheller used the one-dimensional sound propagation theory to establish the sound propagation characteristics of an ideal drill string system[2-3]. As of 2011, Xact has served more than 400 wells, of which the maximum well depth is 4000m under the use of two transponders[4]. In 1991, relevant research began in China, and Liu Qingyou established the mechanical model of drill string vibration[5]. At present, the channel characteristics of the periodic drill string and the attenuation of the acoustic signal by the environment have been fully studied in China, and the influence of different drill string structures on the channel has also been studied.

In thin reservoir, fault block reservoir, marginal reservoir, remaining reservoir and other hard to develop reserves, the difficulty and cost of oil and gas production continue to increase[6]. To further improve oil recovery and minimize formation damage, directional drilling techniques such as
horizontal wells and extended reach wells are needed [7-9].

The structure of complex bottom hole assembly (BHA) and drill string used in directional well is not consistent, which will lead to the aperiodicity of the acoustic channel of drill string. The analysis of the channel characteristics of drill string in directional well can improve the design method of MWD when complex BHA is used.

2. Channel analysis of BHA in directional drilling

In the process of directional drilling, according to the design requirements of different drilling technology, the BHA with bent joint and downhole screw power are often used. With the use of stabilizers, non-magnetic drill collars, weighted drill string, flexible short joints, conversion joints and other drilling tools, the bottom drilling tool generates guiding force by using the bending angle of the bending joint itself with the aid of the fulcrum of the well wall, and the lateral cutting of the formation causes the deviation of the newly drilled well axis, so as to achieve the purpose of directional drilling [10,11]. However, the structural change brings about the non periodic change of the drill string channel.

The structure of drill collars in the BHA is a cylindrical pipe with constant cross-section, and there is no abrupt change of cross-section. According to the analysis of the transmissive film model, the transmission coefficient is 1 and the reflection coefficient is 0. Therefore, the influence of stabilizer on the transmission characteristics of drill string is mainly considered in the BHA of directional drilling. It is assumed that the number of drill strings to be analyzed is 100 and the transmission distance is 948m. The structural parameters of different drilling tools in the drill string channel are shown in Table 1 [12].

| Type               | ID(mm) | OD(mm) | Cross-sectional area(m²) | Length(m) |
|--------------------|--------|--------|--------------------------|-----------|
| Drill string body  | 121.3  | 139.7  | 0.0038                   | 8.6848    |
| Drill string joint | 88.9   | 177.8  | 0.0186                   | 0.4572    |
| Stabilizer joint   | 71.4   | 177.8  | 0.0208                   | 1.50      |
| Stabilizer working face | 71.4 | 215.9  | 0.0326                   | 0.5       |

1) Channel analysis of BHA with single stabilizer

Only by changing the position of a single stabilizer in the BHA and fully considering the well parameters, drilling parameters and formation factors, can the well deviation of the well trajectory be adjusted [13]. As shown in Fig. 1, sound waves are emitted from the left side of the string. A stabilizer is used next to the acoustic generator, and the rest are periodic drill string structures composed of pipe body and joint. The stabilizer is used to calculate the propagation characteristics of the acoustic wave in the drill string structure, which is equivalent to the drill string periodic sequence by using the penetrating anti boundary mask model. Through the equivalent reflection film model, the stabilizer is included in the combination of drill string period, and the propagation characteristics of acoustic wave in drill string structure are analyzed as a whole.

Figure 1 the equivalent structure of acoustic transmission of BHA with single stabilizer
In Figure 2, the bottom figure shows the ideal acoustic transmission characteristics of 100 periodic drill strings without stabilizer, and the top figure shows the acoustic transmission characteristics of the BHA with stabilizer.

It is found that a single stabilizer has a certain influence on the acoustic wave transmission, and the overall transmission characteristics have little influence.

2) Channel analysis of BHA with double stabilizers

The single stabilizer can only reduce and increase the deviation of the well trajectory. When directional drilling, the double stabilizer is often used in different positions of the drill string combination to achieve the operation requirements of stabilizing, reducing and increasing the deviation. The transmission characteristics of the double stabilizers are analyzed here.

Figure 3 the equivalent structure of acoustic transmission of BHA with double stabilizers

Figure 4 Comparison of influence of double stabilizers on acoustic transmission characteristics

The figure below in Figure 4 shows the acoustic transmission characteristics of 100 periodic drill
strings without stabilizer. The figure above shows the acoustic transmission characteristics of the BHA when the second stabilizer is 50m away from the acoustic generator. The figure in the middle shows the transmission characteristics of the second stabilizer 20m away from the acoustic generator.

It can be seen from the comparison that the different positions of the stabilizers lead to the great fading of the acoustic transmission characteristics of the drill string channel, especially for the passband with the frequency above 1300hz. However, the position of the second stabilizer in the double stabilizer BHA has little influence on the acoustic transmission characteristics.

3) Channel analysis of BHA with multiple stabilizers

Under the influence of formation dip angle and geological structure, it is difficult to achieve directional drilling with stable well deviation. In order to achieve better results, three or more stabilizers are often used in the actual drilling process to increase the rigidity of downhole BHA and achieve the purpose of better stable well deviation, as shown in Figure 5. Generally, the distance between two stabilizers in the BHA is between 10-20m. According to different process requirements, specific matching parameters are shown in Table 2.

| BHA          | L1(m) | L2(m) | L3(m) | L4(m) | L5(m) |
|--------------|-------|-------|-------|-------|-------|
| Strong       | 0.8–1.2 | 4.5–6.0 | 9.0   | 9.0   | 9.0   |
| Medium       | 1.0–1.8 | 3.0–6.0 | 9.0–18.0 | 9.0–27.0 | —     |
| Weak         | 1.0–1.8 | 4.5   | 9.0   | —     | —     |

Table 2 matching dimensions of BHA with stable inclination

![Strong stability BHA](image1)

![Medium stability BHA](image2)

![Weak stability BHA](image3)

Figure 5 the structural of BHA with multiple stabilizers
Figure 6 Comparison of influence of multiple stabilizers on acoustic transmission characteristics

In Figure 6, the acoustic transmission characteristics of drill string channel with 5, 4 and 3 stabilizers are respectively shown from top to bottom. The bottom figure shows the ideal acoustic transmission characteristics of 100 periodic drill strings without stabilizers. It can be seen that the use of multiple stabilizers in the channel seriously attenuates the acoustic transmission signal, and has relatively small impact on the passband below 500Hz, but the passband attenuation above 1400Hz is almost zero. In the combination of multiple stabilizers, the distance between the second connected stabilizers is equal, so the number of multiple stabilizers has little effect on the acoustic transmission.

3. Conclusion
The structure of stabilizer in BHA destroys the periodicity of the drill string channel and affects the channel characteristics of the periodic drill string. Three stabilizers attenuate the frequency band above 500Hz seriously, and the number of stabilizers has a great influence on the acoustic transmission characteristics. If multiple stabilizers appear in the BHA aperiodically, the situation will be more serious.

Therefore, the aperiodic drill string structure in the drill string channel has a significant impact on the channel characteristics. Although the directional requirements are considered in the actual drilling process, it is necessary to avoid the occurrence of similar structure drilling tools in the transmission channel as much as possible to avoid the occurrence of various abnormal structures in the channel. If not, the position of the transducer must be moved up.

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