Numerical study of drill string uncertainty in acoustic information transmission

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Abstract. Acoustic data transmission in drill string is one of the effective methods to solve the bottleneck of downhole information transmission speed, but its channel characteristics are mainly affected by the structural changes of string. In the process of drilling, the downhole BHA changes constantly according to the well condition, and the shape of drill string changes indefinitely under the condition of wear and force, which leads to the uncertainty of acoustic channel. Through the numerical simulation analysis, we can get the channel changes of drill string in different shapes, and analyze the main factors that affect the information transmission. The size inconsistency of multiple drill strings will lead to the deterioration of the channel characteristics to a certain extent, but the aperiodic drilling tool structure in the channel will cause a significant change in the transmission characteristics.

1. Introduction
At present, the high-speed information transmission while drilling is one of the bottlenecks of intelligent drilling technology[1-2]. The mud pulse measurement while drilling (MWD) technology which has been widely used commercially, and electromagnetic wave measurement while drilling (EMWD) technology have great limitations, especially the data transmission rate is difficult to meet the transmission demand of a large amount of data while drilling [3]. The high speed transmission of data while drilling has become the key technology to improve downhole drilling technology. Compared with the above technologies, the acoustic information transmission technology in drill string has advantages in reliability and applicability. Theoretically, the transmission speed in drill string is 1-2 orders of magnitude higher than that of mud pulse or electromagnetic wave data transmission technology.

Since 1948, the Sun Oil Company of the United States began to study the technology of sound wave transmission in drill string [4]. Drumheller began to study the sound propagation theory in the string in 1983, and obtained the sound propagation characteristics of the drill string system [5-8]. Up to 2011, XACT’s related products have been used in more than 400 wells, of which the maximum well depth of 4000 meters can be achieved by using two transponders [9-13]. In 1991, Liu Qingyou analyzed and explored the mechanical model of drill string based on vibration model [14]. At present, the channel characteristics of periodic drill string and the attenuation of acoustic signal by environment have been fully studied in China, and the influence of different drill string structures on the channel has also been studied [15-20].

In the process of drilling, the loss state of drill string is constantly changing, and a complex BHA also may be used in directional drilling to control the well trajectory [31-33]. The inconsistency of the
dimensions between unconventional drill string and conventional drill string will lead to the non periodicity and unpredictability of drill string acoustic channel.

2. Influence of inconsistent length loss of drill string joint on acoustic transmission characteristics

In the field operation, the old and new drill string are used together, and the length and other dimensions of the repaired old drill string will change. At the same time, the inner and outer diameters of the drill string will also change when it is washed and worn by drilling fluid and borehole wall. The random change of the size parameters of each drill string in the channel will lead to the uncertainty of the acoustic transmission channel while drilling.

During drilling, the rotary torque and WOB required by the bit to break rock are transmitted through the drill string. The joint thread of the drill string is invalid after a certain period of work, which needs to be repaired and new threads are machined, resulting in the reduction of the length of the joint of the drill string. Referring to the classification standard of drill string, assuming that the length reduction of drill string threaded joint used in acoustic transmission while drilling channel is less than 10%, but the reduction changes randomly, the acoustic transmission characteristics are analyzed.

![Figure 1](image)

**Figure 1** Influence of drill string joint length loss on acoustic transmission characteristics

The basic parameters of each drill string in the simulation model refer to the data of 4-inch class I drill string standard, and the number of drill strings is 10. Figure1 shows the acoustic transmission characteristics in the frequency range of 0-1400hz. The above figure shows the influence of random variation of drill string joint length on the acoustic transmission characteristics, and the following figure shows the ideal drill string acoustic transmission characteristics for comparison.

It can be seen from the figure that the random variation of the drill string joint length within the error produces a small amplitude of high-frequency superposition on the acoustic wave transmission waveform of the drill string. In the channel characteristics, the high-frequency passband bandwidth above 2500Hz decreases slightly, while the low-frequency passband characteristics below 2500Hz change slightly.

3. Influence of wear change of drill string joint on acoustic transmission characteristics

In the process of rotary drilling and lifting and lowering of drilling tools, the diameter of drill string joint is much larger than the diameter of drill string pipe body, which leads to the contact between drill string joint and borehole wall. The friction between drill string joint and borehole wall rock causes the outer diameter of joint to decrease, and the inner diameter of joint to increase due to the corrosion and erosion of mud.

According to the grading standard of the drill string, the wear of the outer diameter of the excellent drill string is not more than 3%, and the wall thickness is more than 80%. The wear of the outer diameter of the II drill string is not more than 4%, and the wall thickness is more than 70%. Otherwise, it needs
to be scrapped. According to this standard, the variation range of outer diameter of drill string joint is 152.4mm to 137.7mm, the variation range of inner diameter is 82.6mm to 86.82mm, and the variation range of cross-sectional area is 129cm$^2$ to 89.72cm$^2$. The simulation model is used to calculate the variation of sound wave transmission in drill string.

The wear of drill string joint and the change of inner diameter make the change of cross-sectional area up to 30%. The consistency of change in actual drilling process should be better. The decrease of cross-sectional area caused by joint wear can reduce the reflection of sound wave when the cross-section changes, which can play a powerful role in improving the transmission channel.

![Figure 2: Influence of drill string joint wear on acoustic transmission characteristics](image)

As shown in Figure 2, the figure above shows the acoustic transmission characteristic curve when the wear amount of the joint changes randomly within the standard range, and the figure below is the ideal drill string acoustic transmission characteristic curve for comparison. The results are as follows:

- The envelope of the acoustic transmission passband curve remains unchanged.
- The low frequency band of each stop band of sound wave transmission is superimposed with the pass and stop frequency points with small interval.
- If the drill string is worn uniformly, the superposition effect of random variation can be effectively reduced, and the transmission bandwidth can be broadened.

4. **Influence of composite wear loss on acoustic transmission characteristics**

In the process of drilling, all kinds of wear loss and random change of drill string length will appear at the same time. Assuming that the joint length loss is less than 10%, the cross-sectional area loss is less than 30%, the tube length loss is less than 1% (8.7mm), and the cross-sectional area loss is less than 18.5%, then the channel characteristics are calculated. As shown in Figure 3, it is a comparison diagram in the frequency range of 0-1400Hz. The figure above shows the influence of composite loss on acoustic transmission characteristics, and the figure below shows the acoustic transmission characteristics of ideal drill string.
The acoustic transmission characteristics caused by the composite wear loss of drill string can be regarded as the superposition of the effects of various parameters. Therefore, the influence of the wear state of drill string on the acoustic transmission characteristics in the actual drilling process can be obtained as follows:

- If the length and cross-sectional area of the drill string joint are within the scope of the drill string classification standard, the impact on the transmission characteristics is small, and if the consistency of the loss can be controlled, the transmission characteristics can be optimized to a certain extent.

- The random length loss of drill string has a great influence on the acoustic transmission characteristics. The random length variation of more than 10% can make the available passband disappear. The consistency of drill string length directly determines the feasibility of acoustic transmission channel and the number and bandwidth of available passbands. The consistency range of the length of drill string pipe body should be less than 5%.

- The change of 18.5% of the cross-sectional area of the drill string in the standard wear range of drill string classification reduces the passband bandwidth by 20%.

5. Conclusion
The transmission of acoustic wave carrier information in drill string is greatly affected by the size of drill string. However, in drilling engineering operation, due to the wear and repair of drill string, there is uncertainty in various dimensions. Research shows that the better the consistency of drill string, the better the channel characteristics. When the loss of drill string is inevitable, it is necessary to determine the consistency parameters of different size data of drill string according to the number of drill string or drilling depth to ensure the feasibility of drill string channel. If the drill string is not optimized, the channel will deteriorate until there is no available channel. This technical requirement puts forward higher requirements for conventional drilling operation, but it is necessary for channel transmission.

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